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Prospects of biotechnology for crop cultivation in low-lying coastal areas

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Abstract

During severe weather events rice and other crops in nations inhabiting low-lying coastal areas can be submerged under salty sea water long enough to eventually kill them. In fact, many farmers already suffer from these events in the coastal areas of Bangladesh, Mauritius, and Grenada. To survive such natural calamities, the development of salt and submergence resistant-crops could be an effective option. Recent progress in the field of molecular biotechnology has shown that rice plants with tolerance to salt and submergence can be developed in near future.

Key words: Transgenic rice plant, *Oryza sativa,* Salt-tolerance, Submergence tolerance, Climate change and sea level rise, Pokkali rice, *Tecticornia pergranulata*

Agriculture began about 10,000 years ago after the last ice age (Hamilton, 2009); during that period people collected seeds and plants with useful traits and started using breeding practices for improving livestock. In contrast, modern biotechnology started just about 60 years ago when the double helical structure of DNA was reported by Watson and Crick; the research at the molecular level has expanded greatly since then, creating a revolution in the field of agriculture, pharmaceuticals, diagnostics, etc. Genome sequencing of many viruses, bacteria, fungi, plants, drosophila, mouse, insects, human and many more have been completed (http://genomics.energy.gov/). Exploitation of the sequences can help our ability to confront emerging crop diseases and changing environment of the world. Agricultural field is now challenged to develop crops with enhanced yields, stress-tolerance, disease-resistance, improved nutritional content of foods, etc. In agriculture, biotechnology has huge applications as have been seen already in generating some pest-resistant crops, frost-resistant crops, and delaying ripening of fruits like tomato, etc. (Oeller et al., 1991). In the future, biotechnology also has the potential to produce food crops which have elevated essential amino acids or contain vitamins as in ‘golden rice’ (Zimmermann and Hurrell, 2002; Tang et al., 2009).

A popular mechanism of generating transgenic plants employs the bacteria *Agrobacterium tumefaciens.* This type of bacteria contains the Ti plasmid that helps them integrate into the plant genome. A genetically modified Ti plasmid has the capacity to introduce a ‘gene of interest’ to many types of plant cells. Successful transformation of rice has been reported (Rashid et al., 1996). The most challenging part of this process is identification of the gene(s) responsible for conferring the trait. The usual protocol for this kind of work is to (a) clone gene / cDNA, (b) transform into target plant, (c) obtain optimum level of expression, (d) modify location of expression, and (e) proper function of the gene product. An *Arabidopsis thaliana* plant gene *SOS1 (Salt Overly Sensitive 1)*, which is up-regulated in response to NaCl stress, has been cloned and characterized to be Na^+/H^+ antiporter (Shi et al., 2000). They have reported expression of SOS1 complemented the salt-hypersensitive phenotype of *sos1-1* mutant plants. Identification of R genes from plants showed to provide resistance to a relatively wide range of pathogens (McDowell and Woffenden, 2003). Similarly, disease-resistance genes like *LR17* and *LR26* were identified that provides resistance to leaf rust (Abdul, 2011). Constitutive

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expression of GASA4 in *Arabidopsis* led to elevated heat tolerance in transgenic lines (Ko et al., 2007; Dias and Lidon, 2010). Transgenic rice plants expressing *cry1Ia5* gene (*Bacillus thuringiensis* toxin) has been reported to be resistant to stem borer (Moghaieb, 2010). Identification of drought response genes and their expression is currently under way in plants (Iskandar et al., 2011).

Over 600 million people live in coastal areas that are less than 10 meters above sea level, and two-thirds of the world's cities that have populations over five million are located in these at-risk areas (http://www.npr.org/templates/story/story.php?storyId=9162438). The countries with the largest share of their populations living in low-elevation areas are Bahamas, Suriname, the Netherlands, Vietnam, Guyana, Bangladesh, Djibouti, Belize, Egypt, and Gambia. About 1/3 of world's irrigated land has been estimated to be contaminated with high salt levels every year (Shereen et al., 2011). In November 2007, Bangladesh faced one of the most devastating cyclones in its history, causing enormous damage in terms of human loss, crop loss, animal loss, etc. In the foreseeable future, the country is likely to be affected by the larger, long lasting and global scale human induced disaster - climate change and sea level rise (CCSLR). Bangladesh is thought to be one of the most vulnerable countries of the world to CCSLR. For low lying coastal areas like Bangladesh, biotechnology can provide the best possible solution for better crop yields, as it faces floods and cyclones in the coastal areas every year.

Some plants synthesize "osmo-protectants", low molecular weight non-toxic compounds that protect and stabilize cellular macromolecules from damage by high salt levels, but these may not be enough to sustain extreme conditions (Apse and Blumwald, 2002). The demand for rice is constantly rising in Bangladesh and an increase in rice production must be achieved at a faster rate than in most other countries (http://www.worldbank.org/html/cgiar/newsletter/june97/ 9bang.html). Recently, the identification of the *Oryza sativa* ssp. *indica* cultivar FR13A has given hope among the crop cultivators. This rice species can survive up to 2 weeks of complete submergence under water. The gene that has been implicated in the resistance is named the *Submergence 1 (Sub1)* locus in chromosome 9 of *Oryza sativa* (Xu and Mackill, 1996; Perata and Voesenek, 2007). Structurally this is a cluster of 3 genes (encoding putative ethylene response factors), and recently it has been reported that overexpression of Sub1A-1 conferred enhanced tolerance in other rice species (Xu et al., 2006).

In addition, salt stress is a major problem in the coastal areas, because the water submerging crops here is saline. *Oryza sativa* is not salt-resistant and genetic improvement for salt tolerance is needed. Studies of naturally salt-tolerant rice have given great hope in this regard. The *Pokkali* system of rice cultivation in the acid saline soils of Kerala, India is a unique method of rice production (Shylaraj and Sasidharan, 2005). The VTL5 rice variety of the Pokkali in land of Kerala is a high yielding salt-tolerant rice strain (Figure 1). The *Saltol*-loci has been identified in chromosome 1 in Pokkali strain (Xu et al., 2006; Walia et al., 2005; Kim et al., 2009; Kumari et al., 2009).

Figure 1. Pokkali Rice in natural habitat.
Source: USDA-Agricultural Research Service

A recent article from Islam's laboratory in the University of Dhaka, Bangladesh, has reported another *Oryza sativa* rice strain, Horkuch, obtained from the southwest coast of Bangladesh, also expressing salt-sensitive genes (Lisa et al., 2011). This could be a potential alternative to Pokkali rice for the future. However, salt-resistance by these plants was tested at up to 15 dS/m NaCl which is well below salinity level (50 to 60 dS/m NaCl) in sea water. Therefore, a rice strain that is tolerant to salt-stress similar to sea water as well as tolerant to submergence is needed; this could be the best solution to maintain or improve rice crop yields in low lying coastal areas. Theoretically, this may be possible to achieve; we just need to identify the gene(s) from naturally more salt tolerant plants. A recent report on the halophytic stem-succulent *Tecticornia pergranulata* (Blackseed Samphire), naturally found in salt marshes of Western Australia (Figure 2), is greatly encouraging (Colmer et al., 2009). These plants were reported to have tolerance to both submergence and high salt exposure. These plants can maintain underwater photosynthesis at up to 40 dS/m NaCl and, most promising; retain 70% of activity at 80 dS/m NaCl which is substantially above sea water salinity.

Figure 2. *Tecticornia pergranulata* (Blackseed Samphire) in marsh lands.
Source: Sikder B. Ullah

Moreover, *T. pergranulata* displays conservation of substrates under submergence for 28-56 days helping plants quickly recover after floodwaters recede; this phenomenon is called 'quiescence response' (Bailey-Serres and Voesenek, 2008). This could provide the breakthrough we are waiting for. This work, however, would need the identification of the gene(s) giving those particular traits shown by *T. pergranulata*. Then the genes could be engineered into the rice plants like *Oryza sativa* that would also have the overexpressed sub1 gene. The engineered *Oryza sativa* rice expressing higher Sub1A-1 and *Saltol*-like gene obtained from *T. pergranulata* may offer the possibility of resistance to both submergence and high salt levels.

So, farmers from the coastal areas can hope for a useful solution in near future to save their rice crops during adverse climatic conditions.

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