Chapter 13

Climate resilient rice cultivars adapted to excess water

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The resilience of many ecosystems is likely to be exceeded this century by an unprecedented combination of climate change, associated disturbances (e.g. flooding, drought) and other global change drivers like land use change and over exploitation of resources (IPCC, 2007). By 2030, the average temperatures in India will rise by 1.7-2.2°C and extreme temperatures by 1-4°C in comparison to the 1970s. The hotter summers and warmer winters will lead to substantial changes in agricultural production, water flows, and could cause dramatic changes in the country's weather; as reported by the Indian Network for Climate Change Assessment (INCCA, 2010). Rising temperatures will accelerate the rate of melting of snow and glacier ice, increasing seasonal peak flows of the Himalayan headwaters. This in turn may lead to an increased frequency of flooding particularly along the rivers whose channel capacity has been reduced by sedimentation (Aggarwal et al., 2004).

Coasts are projected to be exposed to increasing risks, including coastal erosion, due to climate change and sea level rise and many millions more people than today are projected to experience floods every year due to sea level rise (IPCC, 2007). Excessive flooding poses risks to human life and is a major contributor to the poverty and vulnerability of marginalized communities. It is estimated that the flood-affected area has more than doubled in size from about 5% (19 m ha) to about 12% (40 m ha) of India's geographic area in the past five decades. Adding to these already high risks, the climate projections suggest that temperatures, precipitation and flooding are likely to increase, with adverse impacts on crop yields and farm incomes. Among the more substantial effects is a spatial shift in the pattern of rainfall towards the already flood-prone coastal areas. As an example of the implied magnitudes, the probability that the discharge might exceed 25,000 cubic meters per second (at the measuring station at Naraj on the Mahanadi River in Odisha), is currently low-about 2%. But under climate change, this is projected to rise dramatically to over 10% (World Bank Report, 2008). Productive deltaic agricultural land would become more vulnerable to floods, to the impacts of possibly more severe tropical cyclones and to rising sea levels. A possible sea-level rise of 15 to 38 cm by the 2050s (Douglas, 2009) would cause saline water to penetrate further inland and ultimately displace some 35 million people around the Bay of Bengal, and change the conditions in other deltas and coastal plains on a similar scale (Wassmann et al., 2009). Climate changes appear to be influencing the monsoon and tropical cyclones, the two prime drivers of flood events in South Asia (Unnikrishnan et al., 2006). Average annual precipitation of Odisha is around 1500 mm and 75 % of it is received through South-west monsoon during June to September (Fig. 1). If we look at the rainfall pattern of the last decade, we find that there is a huge deviation from the normal, and 300-400 mm rainfall is received within a span of 1-2 days, causing severe flood and drought in subsequent days (Singh et al., 2011). The rainfall has become irregular and unpredictable. Therefore, a number of interacting problems threaten future and present sustainability and food security.

In developing countries especially, in Asia, food security means the availability of the principal staple food rice. Worldwide, rice provides 27% of the dietary energy supply, and 20% of the

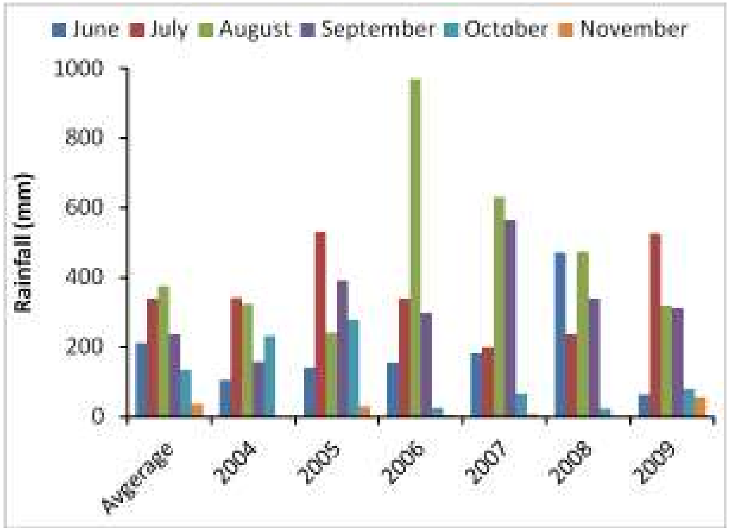

FIGURE 1. *Variability in rainfall during the main rice growing season of Odisha*

dietary protein intake. In Asia alone, more than 2 billion people obtain 60–70 % of their energy intake from rice and its derived products. Rice is currently the most rapidly growing food source in Africa (FAO, 2004). Adaptation to the adverse impacts of climate change has been recognized as a priority area for national and international policy. The findings of the Fourth Assessment Report of the IPCC have reemphasized the urgency of action and the scale of response needed to cope with climate change outcomes. The scientific community has an important role to play in advancing the information and knowledge base that would help in identifying, developing and implementing effective responses to enhance adaptive capacity and reduce vulnerability. Geographically rice is being grown in lands as far as 50°N latitude (Aiwei, China) to 30°S latitude (New South Wales, Australia). It is grown in lands situated below sea level in Kerela to 2761 m above sea level (Jumulla valley, Nepal) thus making its presence in all the environments and all continents of World (Chang, 2000). In India the area under rice cultivation is 43.7 m ha with an annual production of 91.1 m t and an average productivity of 2.09 t ha^{-1} (2006-07) (Anonymous, 2007). In India rice is grown in various ecologies ranging from irrigated to uplands, rainfed lowland, deep water and tidal wetlands. So rice is a versatile crop and it can be grown in different land situations. It is further emphasized that rice is a hope to encounter the adverse effect of climate change to secure food and livelihood.

Production constraints in changing climate due to excess water

Rice areas encompass a great diversity of growing conditions that vary based on the amount and duration of rainfall, depth and extent of standing water, flooding frequency, time of flooding within the growing season, soil type and topography. Besides biological constraint, the physical constraint influences the rice productivity which is more paramount in a changing climate. Crucial for survival and yield of the rice crop are the age of plants at the start of inundation, the rate of water rise, and the duration of the floods. Many parts of the tidal, deepwater and rainfed lowland rice areas are faced with abrupt increases in water level that completely inundate the crop, commonly called flash floods. These floods occur after local or remote heavy rains and may completely submerge the crop for several days with the consequent delays in development and reduced stand.

India has almost all the ecology of flood prone rice ranging from flash floods to semi-deep and deepwater, where submergence occurs during early or late vegetative stages for about one to two weeks (in flash floods) and 3-6 weeks in semi-deep conditions (Sarkar et al., 2009a). Stagnant flooding also occurs in several parts of Bihar, Odisha, West Bengal and Assam, inundating rice crops to different depths and durations and adversely affecting the growth and yield. In flash flood areas, the water is invariably laden with silt which is deposited on leaf surfaces causing mechanical damage and diminishes underwater photosynthesis by rice plants. In deep water areas where dry direct seeding is practiced in the month of May and June, crop suffers from drought if rain is delayed after initial showers, while submergence occurs at early growth stages due to heavy rains in the month of July. In flash flood areas too, submergence and or drought could occur either alone or in combination depending upon the timing and intensity of rains causing yield penalty in both lowland and irrigated rice. Impacts are very likely to increase due to increased frequencies and intensities of some extreme weather events.

Cultivation strategies to overcome excess water effects

Flooding may occur any time during the crop growing period, results accumulation of water on field. Through genetic enhancement and proper management practices, the tolerance of plant to excess water situation can be enhanced.

Cultivar with greater plasticity for rainfed lowland- Photoperiod sensitivity

Traditional varieties adapted to the lowland and deepwater ecosystems are generally not high yielding types, but photo-sensitive in nature. Due to the photo-sensitivity these cultivars avoid the submergence stress at the time of flowering. The possession of photo-sensitivity is significant because complete submergence during flowering even for a few days affects grain formation and spikelets become completely sterile. Besides, photoperiod-sensitive cultivars possess high plasticity and can be planted at different ages without much loss in grain yield (Reddy et al., 2009). The farmers of eastern India sometimes plant more than two months old seedlings to avoid complete inundation especially in deepwater and water stagnant areas. *Bolan* or double transplanting is a traditional practice of farmers in submergence prone areas in North-eastern part of West Bengal, India. Use of photoperiod-sensitive cultivars has helped in adopting this technology.

Anaerobic seeding tolerance

Direct seeding under the surface of flooded soil is known as anaerobic seeding, which requires less labour, and less energy than transplanting. Anaerobic seeding not only reduces the cost of cultivation but is also environment friendly due to reduction in the application of herbicide compared to the other method of direct sowing. In rainfed lowland, direct dry seeding is the common practice. If flood and or heavy rainfall occurs, due to low lying topographical condition of rainfed lowland, water stagnates, establishment of rice may not be proper and sometimes total area becomes barren. If rice varieties which can germinate and grow under flooded soil surface are available, the constraints of both direct wet and dry sowing would be solved.

Screening technique for anaerobic germination

Small tray (minimum height of the tray is 12 cm) is filled up with fine clay-loam farm soil. Dry seeds are sown just below soil surface. Immediately after sowing, the tray is filled up with 10 cm depth of standing water, which is kept in ambient environmental conditions under the temperature range of 25-32°C. Crop establishment or survival are counted after 15 days of sowing. Emergence of leaf tips above the water surface is considered as establishment or survival. Germination under non-stressed condition is taken as 100 % and accordingly the survival % is calculated for each cultivar under stressed condition. Some rice genotypes that are tolerant to anaerobic seeding are AC917, AC1160, AC1571, AC1631, AC39416, AC40413, AC40561, AC40598, AC41625, AC41644 and EC516602.

Seed invigoration to improve under water plant establishment

Soak the seeds with simple tap water or 2% Jamun (*Syzygium cumini)* leaves extract for 14-16 hoursand dry the seeds under the sun till the moisture percentage of seeds come down to 10-12%. This process of treatment to rice seeds is called "Priming". The primed seed can be stored up to three months without any germination deterioration (Table 1).

TABLE 1. *Effect of seed priming on yield and yield attributes in two rice cultivars under non-stressed and stressed conditions (anaerobic germination)*

Yield and its attributes	Swarna			Swarna *Sub1*			LSD
	CNP	PNW	PLE	CNP	PNW	PLE	($p<0.05$)
A. Non-stressed conditions							
Panicle number (m^{-2})	295	339	344	292	342	349	28
Single panicle weight (g)	2.46	2.52	2.78	2.23	2.49	2.78	0.23
Fertile spikelet (%)	73.0	72.5	71.5	66.7	72.2	71.5	4.2
Harvest Index	0.44	0.41	0.44	0.38	0.41	0.41	0.04
Grain yield (t ha^{-1})	5.31	5.68	5.68	4.84	5.35	5.08	0.41
B. Under anaerobic germination							
Panicle number (m^{-2})	166	218	257	208	295	275	28
Single panicle weight (g)	2.28	3.11	2.93	2.41	2.68	3.16	0.23
Fertile spikelet (%)	64.1	68.4	74.2	65.9	71.9	69.7	4.2
Harvest Index	0.39	0.41	0.42	0.39	0.40	0.44	0.04
Grain yield (t ha^{-1})	3.52	3.98	4.02	3.28	5.22	4.89	0.41

CNP: Controlled no priming; PNW: Priming with normal tap water; PLE: Priming with 2% leaf extracts of *Syzygium cumini*

Offset the adverse effects of complete submergence

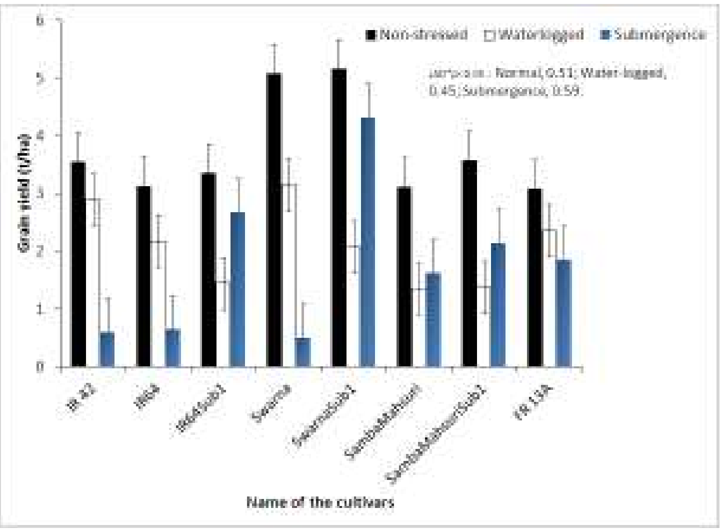

FIGURE. 2. *Performance of rice cultivars with and without Sub1 at different water regimes*

Submergence tolerant cultivars

Rice genotypes with *Sub1* have great potential for improving the productivity of rainfed lowland or areas prone to flash-flooding (Sarkar et al., 2009b). Introgression of *Sub1* has been made to many popular rice varieties including Swarna. Under flash-flooding, genotypes with *Sub1* survived complete submergence stress with turbid water for up to 12 days, whereas genotypes without *Sub1* did not survive (Fig. 2). It has been observed that even under mild excess water stress (submergence period 5-6 days) in natural farmers' fields conditions, Swarna*Sub1* produced higher grain yield than Swarna at all sites with a yield advantage of up to 1.65 t ha^{-1} (an average of 0.81 t ha^{-1} over five sites).

Nutrient status

Nutrient status of seedling before submergence affects the survival of rice during submergence. Therefore, besides genetic improvement, manipulation of some of the traits associated with submergence tolerance through certain management practices, could substantially enhance survival and productivity of rice in flood prone area, particularly when both are combined (Das et al., 2009; Sarkar & Panda, 2009; Das et al., 2005; Das et al., 2001; Sarkar, 1998). Survival of both FR13A (with *Sub1*) and IR42 decreased substantially in seedlings with high nitrogen dose. The fact that there is a negative relationship between nitrogen and starch content and therefore, a low nitrogen level in a plant contributed to an accumulation of starch in the shoot (Sarkar, 1998). It was observed that application of N: P: K @ 15:40:20 kg ha^{-1} at the seed bed helped in the formation of robust seedlings which could withstand complete submergence stress to a greater extent. A significant positive correlation was also noticed between application of phosphorous and submergence tolerance. Apart from better survival, plants receiving phosphorous showed greater accumulation of carbohydrate before submergence and had less elongation during submergence compared to the plants without additional phosphorous application. Robust seedlings can be produced through nursery management by sowing good quality seeds @ 30 g m^{-2} and application of N, P, and K @ 15, 40 and 20 kg ha^{-1} on seed bed. For raising robust seedlings under field conditions, the seed rate would be 60-70 kg ha^{-1} and the doses of N: P: K would be 15: 60: 40 kg ha^{-1}, respectively. Later on nitrogen management is to be done depending on the stagnation of water on rice field. Nitrogen application up to meiosis stage (15 days before flowering) improves grain yield production; therefore depending upon the water regime nitrogen should be applied @ 40 kg N ha^{-1} in two split doses.

Adaptation strategies under stagnant water flooding

Rice plants that exhibit only limited elongation during submergence often show tolerance to complete flooding. The ideal response to stagnant water flooding is submergence tolerance (survival under water) together with some elongating ability. This ideotype is suitable when water level increases and then (i) stays at that level, (ii) recedes only partly or (iii) recedes but then rises again and stays for longer duration. "KHODA" as submergence tolerant line possesses submergence tolerant gene '*Sub1*', has limited elongation capacity with greater regeneration ability is better than Swarna*Sub1* and is suitable for highly fluctuating water level.

Avoiding common pitfalls in submergence screening

The quality of floodwater influences the survival of plants, hence for screening the cultivars, greater attention should be given to the susceptible ones. Depending on the quality of floodwater, duration could be decided so that mortality of the susceptible check is nearer to 100%. Extreme yellowing of leaves and softening of base is a harbinger of plant death and on that basis a decision about the total days of submergence can also be taken. Under clear water submergence, stress can be applied for 10-15 days depending upon the state of susceptible check.

Flash flood

A. Under field tanks

The mechanisms of survival under flash flooding and stagnant water conditions are different. Plants are raised under direct seeded condition. Generally, 18-21 days old seedlings are completely submerged under 70-80 cm of water. Plant height is taken before and after submergence to know the elongation ability which may give an idea about the suitability of plants for flash flood or stagnant water conditions. Care should be taken so that no leaf tips come above the water surface. Finally number of

FIGURE 3 (A & B). *Screening of submergence tolerance of rice in tank*

survivors is counted after 10 days of de-submergence (Fig. 3A & 3B). Survival (%) = (Number of plants after 10 days of de-submergence/number of plants before submergence) x 100.

B. Under net house conditions

Seeds are direct seeded in small trays. After 10 days of sowing, the trays along with seedlings are submerged in small concrete tanks under 80 cm depth of water for 10 days. Plant survival count is taken after 10 days of drainage of water. Plant height is taken immediately after drainage (Fig. 4). This technique is highly useful for transgenic plant as well as for other genetical studies. This saves time and needs limited resources and can be used to distinguish between tolerant and susceptible types. Some rice genotypes that are tolerant to complete submergence are Swarna*Sub1*, IR64*Sub1*, Savitri*Sub1*, Khoda, Kalaputia, Atiranga, Gangasiuli, Kusuma, AC42088, AC38575, AC37887 and AC39968.

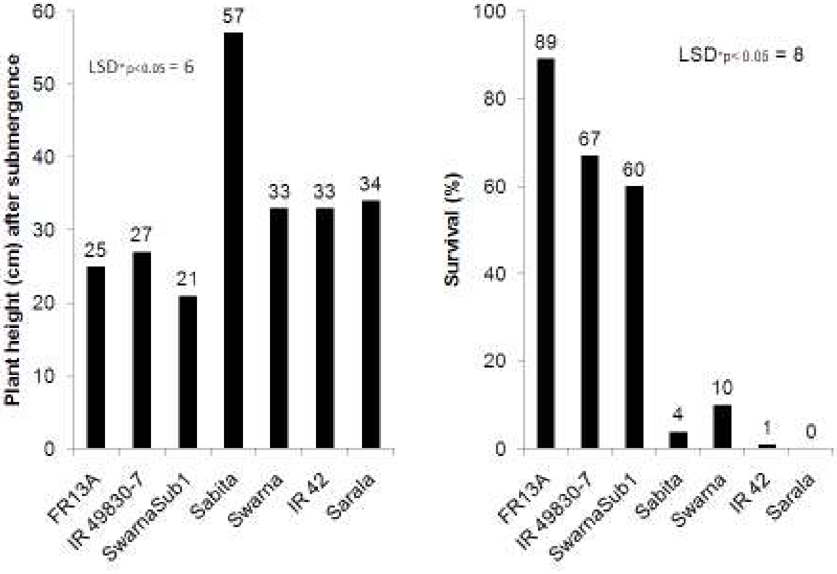

FIGURE 4. *Survival percentage and changes in plant height after 10 days of submergence under net-house tray sown condition*

Screening for stagnant water flooding

Screening plants for semi-deep to deep water conditions is some what different, where elongation ability is also an important parameter. However, extensive elongation which occurs in floating rice is not desirable for deep water conditions (up to a water depth of 100 cm). Plants with straight, erect leaves that come up above the water are suitable for the condition, but the cultivars would be termed as best where elongation stop once the leaves emerge out of water.

Plants are raised under direct seeded condition with basal fertilizers (N: P: K @ 20: 30: 30 kg ha^{-1}). Thirty to thirty-five-days old seedlings are submerged under 70-80 cm of water depth. The depth of water is maintained at least for one month. Plant height and survival percentage are taken before and after one month of inundation. Some rice genotypes that are tolerant to stagnant water flooding are Atiranga, Gangasiuli, Kusuma, Khoda, AC39416, AC42084, AC42102, AC42220, AC42243, AC42254, and AC42271.

Conclusions

The most cost effective ways to help the poor farmers is to breed climate resilient cultivars, which can adapt the changes, can save resources and drudgery to some extent. Of course it is a daunting task because of uncertainty about the magnitude of possible climate changes, their geographic distribution, and the long lead times needed to implement adaptation efforts. Rice crop with multiple abiotic stress tolerance are needed. The present knowledge though inadequate, can serve an incredible role in mitigating the excess water stress.

References

Aggarwal, P.K., Joshi, P.K., Ingram, J.S.I., & Gupta, R.K. (2004). Adapting food systems of the Indo-Gangetic plains to global environmental change: Key information needs to improve policy formulation. *Environment Science and Policy,* 7, 487-498.

Anonymous. (2007). *Agricultural statistics at a glance*, 2007. Directorate of Economics and Statistics, Ministry of Agriculture, Govt. of India.

Chang, Te-Tzu. (2000). Rice. In K.F. Kiple, K.C. Ornelas (Eds.), *The Cambridge world history of food*. Chapter II (A. 7). UK: Cambridge university Press.

Das, K.K., Panda, D., Sarkar, R.K., Reddy, J.N., & Ismail, A.M. (2009). Submergence tolerance in relation to variable floodwater conditions in rice. *Environmental and Experimental Botany,* 66, 425-434.

Das, K.K., Sarkar, R.K., & Ismail, A.M. (2005). Elongation ability and non-structural carbohydrate levels in relation to submergence tolerance in rice. *Plant Science,* 168, 131-136.

Das, K.K., & Sarkar, R.K. (2001). Post flood changes on the status of chlorophyll, carbohydrate and nitrogen content and its association with submergence tolerance in rice. *Plant Achieves,* 1, 15-19.

Douglas, I. (2009). Climate change, flooding and food security in South Asia. *Food Security,* 1, 127-136.

Food and Agriculture Organization Statistics (FAOSTAT). (2004). Statistical Databases. Italy: Food and Agricultural Organization of the United Nations.

INCCA (Indian Network for Climate Change Assessment). (2010). Climate change and India: A 4x4 assessment, A sartorial and regional analysis for 2030s: Ministry of Environment and Forests, Government of India.

Intergovernmental Panel on Climate Change (IPCC). (2007). *Climate change - The scientific basis*. Cambridge Univ., UK: Cambridge Press.

Reddy, J.N., Sarkar, R.K., Patnaik, S.S.C., Singh, D.P., Singh, U.S., Ismail, A.M., & Mackill, D.J. (2009). Improvement of rice germplasm for rainfed lowland of eastern India. *SABRAO Journal of Breeding and Genetics*, 41, Special Supplement, August 2009. ISSN 102907073.

Sarkar, R.K. (1998). Saccharide content and growth parameters in relation with flooding tolerance in rice. *Biologia Plantarum*, 40, 597-603.

Sarkar, R.K., & Panda, D. (2009). Distinction and characterisation of submergence tolerant and sensitive rice cultivars, probed by the fluorescence OJIP rise kinetics. *Functional Plant Physiology*, 36, 1-12.

Sarkar, R.K., Reddy, J.N., Das, K.K., Ram, P.C., Singh, P.N., Mazid, M.A., Sommut, W., Pane, H., Sharma, S.G., & Ismail, A.M. (2009a). Biophysical constraints in flood-prone ecosystems: Impacts and prospects for enhancing and sustaining productivity. In S.M. Haefele, A.M. Ismail (Eds.), *Natural resource management for poverty reduction and environmental sustainability in fragile rice-based systems*. Limited Proceedings No. 15. (pp. 67-81). Los Banos, Philippines: International Rice Research Institute.

Sarkar, R.K., Panda, D., Reddy, J.N., Patnaik, S.S.C., Mackil, D.J., & Ismail, A.M. (2009b). Performance of submergence tolerant rice (*Oryza sativa*) genotypes carrying the Sub1 quantitative trait locus under stressed and non-stressed natural field conditions. *Indian Journal of Agricultural Sciences*, 79, 876-883.

Singh, D.P., Mahata, K.R., & Ismail, A.M. (2011). Increasing rice productivity in coastal saline areas of the Mahanadi delta, India through salt tolerant varieties and improved crop management. In *Deltas under climate change: The challenges of adaptation*. International Conference Delta 2011, 2nd - 4th March, Hanoi, Vietnam.

Unnikrishnan, A.S., Rupa Kumar, K., Fernandes, S.E., Michael, G.S., & Patwardhan, S.K. (2006). Sea level changes along the Indian coast: Observations and projections. *Current Science,* 90, 362-363.

Wassmann, R., Jagadish, S.V.K., Heuer, S., Ismail, A.M., Redona, E., Serraj, R., Singh, R.K., Howell, G., Pathak, H., & Sumfleth, K. (2009). Climate change affecting rice production: The physiological and agronomic basis for possible adaptation strategies. *Advances in Agronomy,* 101, 60-122.

World Bank (2008). Climate change impacts in drought and flood affected areas: Case studies in India. *Report No. 43946-IN*, 1-162.

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