

Better Crop Management Practices to Overcome Submergence Stress in Rice under Eastern Indian Condition : An Overview and Recommendations

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ABSTRACT

Importance of rice is well-known and well-accepted in every strata of society. Nearly half of the world's population depends on rice for their dietary intake. But when this important crop faces the abiotic stress like flooding (or complete submergence) in short-term and prolonged time, its performance cannot reach up to its potential. With this backdrop rice needs to cope up the stress following some alteration in agronomic management, so that the non-tolerant varieties can perform with its best potential. Despite the tolerant varieties (varieties with Sub1 QTL) can re-emerge after stress with good recovery potential, that does not always solve the problem especially where these varieties remain unavailable. For this, agronomic management worked well and showed a good promise after the years of experimentation in the rice-dominated areas. This article highlights some technological interventions which has been recommended specially under flood affected rice-growing Eastern Indian condition.

Key words : Rice, Genotypes for submergence, Different stages, Physiological adaptations, Agronomic management.

Introduction

India is often reported to be highly vulnerable to floods, where more than 40 mha area is flood prone, out of the total geographical area of 329 mha. Floods are recurrent natural calamity, causing a huge loss to life and livelihood systems of that particular area as well as spreading in the surrounding areas. This can be attributed to many factors like rising population, rapid urbanization, growing developmental and economic activities in flood plains coupled with global warming. As per the

estimate, every year 75 lakh hectares of land is affected, 1600 lives are lost and a huge damage caused to crops, houses and public utilities is estimated around Rs.1805 crores due to floods (NDMA, Govt. of India).

In India, submergence is a major constraint for agriculture, and significantly hampers rice production in lowland areas. In West Bengal, nearly 30% rice growing areas are vulnerable for flash flooding (Bhowmick *et al.*, 2014). In Assam state, rice is cultivated in 2.6 million ha lands,

of which nearly 1 million ha land is affected by flash-flooding (Chetia *et al.*, 2018). In general, flooding severely hampers the O₂ and CO₂ exchange processes between plant and environment. This condition appears by a slower diffusion of gases in water compared to air (Armstrong, 1980; Mommer and Visser, 2005), and further intensified by turbid water. Thus, flash flooding in rice fields was associated with substantial yield losses, aggravating poverty and food insecurity, worldwide (Ismail, 2018).

Rice (*Oryza sativa* L.) is a water-loving crop, comfortably grows in the lowland semi-aquatic and flood-prone ecosystems (Kuroha and Ashikari, 2020). But, excess water can be harmful for normal rice plant germination, growth and development process (Nishiuchi *et al.*, 2012; Kuroha and Ashikari, 2020). In general, cultivated mega rice varieties have low germination under anaerobic condition, but, few rice landraces (e.g. AC41620, Kalarata) has the ability to germinate even in anaerobic condition (Vijayan *et al.*, 2018; Ghosal *et al.*, 2019). Molecular study associated with anaerobic germination identifies qAG-9-2 is a major QTL for tolerance to germination stage oxygen deficiency, abbreviated as GSOD (Kretschmar *et al.*, 2015). Similarly, cultivated mega rice cultivars cannot tolerate consequences of excess water stress during early vegetative stages and die within one week of complete submergence (Xu *et al.*, 2006; Ghosal *et al.*, 2019). The most common response of complete submergence at an early vegetative stage was associated with internodal elongation, and leaf senescence (yellowing of leaves) in submerged parts (Sarkar and Bhattacharjee, 2011, Singh *et*

al., 2014; Chakraborty *et al.*, 2021). This process of elongation initiates in plant to get plant parts out from water surface. But, this elongation process has a major caveat, and aggravates breakdown of stored starch compounds of plants and in a condition when photosynthesis is reduced due to lower availability of CO₂ and O₂. Fortunately, not all rice genotypes showed a high rate of elongation under submergence, and maintain low to moderate growth under excess water stress (Xu and Mackill, 1996). Reports suggests, Flood resistant 13A (FR13A) rice genotypes showed a lower growth up to two weeks of complete submergence (Xu *et al.*, 2006). This mechanism of underwater survival is known as 'low oxygen quiescence strategy'.

Underwater quiescence strategy assures low degradation of reserved food compounds (starch) in plants, and secure rejuvenation of growth and quick recovery after de-submergence. Molecular study associated to complete submergence stress tolerance identifies quiescence was maintained in FR13A rice genotypes through the function of Submergence-1 (SUB1) QTL gene, which is located on chromosome 9 (Xu *et al.*, 2006). SUB1 QTL mainly contains three ethylene responsive genes- SUB1A, SUB1B and SUB1C (Xu *et al.*, 2006). Among, SUB1A is an *Apetala2*/Ethylene response factor (AP2/ERF) transcription factor, and responsible for flash flood tolerance. Activity of Sub1A gene restricts the gene activities associated with starch breakdown process (α amylase and sucrose synthase), ethylene and gibberellin biosynthesis pathways. Fukao and Bailey-Serres (2008) showed, SUB1A function can facilitate the expression of two

repressors SLR1 and SLRL1 of gibberellin synthesis. Thus, SUB1A action can associate with underwater tissue portions growth and elongation (Perata and Voesenek, 2007). Furthermore, studies with flooding tolerance identify expression of a wax biosynthesis gene leaf gas film 1 (LGF1) might be crucial for maintaining rice hydrophobicity and gas films (Zhang *et al.*, 2016; Kurokawa *et al.*, 2018). Thus, allows more gaseous exchange with the environment.

To improve the complete submergence tolerance of cultivated mega rice varieties, SUB1 QTL is now incorporated into the cultivated varieties to attain improved submergence tolerance in cultivated rice. Till now, this program generates different rice varieties having SUB1 QTL such as Swarna Sub1, IR64 Sub1, Samba Masuri Sub1, Savitri Sub1, Ranjit Sub1 (Bailey-Serres *et al.*, 2010; Sarkar and Bhattacharjee, 2011; Chetia *et al.*, 2018). Competent functioning of this Sub1 QTL into cultivated plant significantly secures underwater quiescence and thereby, improved complete submergence tolerance. Alternatively, different agronomic practices (high seed rate for sowing, aged seedling, spacing alteration, seed priming and nutrient management) help to minimize complete submergence associated damage in both intolerant and tolerant plant, and help in optimization of crop-stress performance under stress (Bhowmik *et al.*, 2014; Ella *et al.*, 2010; Bhaduri *et al.*, 2020; Hussain *et al.*, 2016; Gautam *et al.*, 2014; Gautam *et al.*, 2015). In this compilation, we reviewed different crop management practices associated with complete submergence during germination and early vegetative stage of rice plant, which

effectively improved plant survival in excess water condition.

Complete submergence stress

According to Catling (1992), a submerged plant is defined by “a plant standing in water with at least part of terminal above the water or completely covered in water”. The major difference between these two conditions of excess water can be separated by keyword ‘complete’; which suggests the entire plant remain in underwater (Jackson and Ram, 2003). Complete submergence stress can come at germination and early vegetative growth phases (Vijayan *et al.*, 2018; Oladosu *et al.*, 2020) of rice. Depending upon the depth and stagnation period of water in the rice field, submergence stress can be divided into two different types known ‘flash flooding’ and ‘deep water flooding’. Flash flooding in general lasts for few weeks, while, deep water flooding lasts for several months in rice field.

Germination stage complete submergence

In general, intolerant rice plants showed a distinct difference in internodal elongation under complete submergence stress at germination stage. In rice field, if water stagnation presents just after seed sowing, due to a sudden heavy rainfall, can lower germination and seedling emergence. Elite rice cultivars are in general intolerant to germination stage complete submergence. These rice cultivars are unable to secure germination in this condition due to low availability of oxygen. Fortunately, few rice plants, those are tolerant to germination stage complete submergence, have ability to germinate in low oxygen environments and extend its

coleoptile portions rapidly in under water conditions by compromising growth of coleorhizae (Chakraborty *et al.* 2022). Kretzschmar *et al.* 2015 reported Khan Hlan On rice genotype can germinate and survived in low oxygen conditions. Vijayan *et al.* (2018) reported a rice landrace AC41620 also secured germination and seedling emergence under excess water conditions. Similarly, a rice landrace Kalarata has high anaerobic germination potential (Ghosh *et al.*, 2019).

Early vegetative stage complete submergence

In general, intolerant rice plants showed three types of visible symptoms of injury under complete submergence stress (Jackson and Ram, 2003). These includes– (i) a faster rate of elongation of internodal or shoot tissue portion (Sarkar and Bhattacharjee, 2011; Singh *et al.*, 2014; Chakraborty *et al.*, 2021), (ii) Faster degradation of chlorophyll or yellowing of leaves and (iii) Faster degradation of plant biomass. Literature report showed mega rice varieties like IR42, Swarna, and IR64 are intolerant / susceptible for complete submergence stress (Singh *et al.*, 2014) and showed faster elongation of shoot tissue portion, which was 114.6% for IR42, 104.0% for Swarna, 75.3% for IR64 and 97.5% for Samba Masuri. Further studies of Chakraborty *et al.*, (2021) also showed same for intolerant rice genotypes IC450292 and Swarna. Contrastingly, in case of tolerant rice plants showed a low to moderate elongation of shoot or internodal tissue portions under submergence. A study of Sarkar and Bhattacharjee, 2011 reported that complete submergence tolerant rice landrace FR13A can restrict its underwater

shoot tissue growth. Similarly, Singh *et al.* (2014) reported that tolerant rice genotypes, FR13A, IC49830-7, Swarna Sub1, IR64 Sub1, Samba Masuri Sub1 have abilities to restrict underwater growth. Further studies of Chakraborty *et al.* (2021) reported that FR13A and Swarna Sub1 can restrict the underwater tissue growth in complete submergence stress. Along with variation of internodal elongation, a distinct variation of chlorophyll was observed in tolerant and intolerant rice plants. Plants those are tolerant against complete submergence stress showed slower rate of chlorophyll breakdown compared to intolerant rice genotypes (Singh *et al.*, 2014; Sarkar and Bhattacharjee, 2011; Chakraborty *et al.*, 2021).

Physiological adaptations to flash flooding at early vegetative stage

Plant may experience low light, low carbon-di-oxide (CO₂) and low oxygen (O₂) conditions, at complete submergence stress (Vosenek and Sasidharan, 2013; Vosenek and Bailey-Serres, 2014). This was due to turbidity of stagnant water, and slow diffusion rate of gases in water as compared to air (Armstrong, 1980). To cope with complete submergence, plants may maintain a super-hydrophobic leaf surface that retain gas film and showed lysigenous aerenchyma formation (Voesenek *et al.*, 2006; Pedersen *et al.*, 2009; Parlanti *et al.*, 2011) in submerged plant portion. Leaf gas film is a micro-layer of air trapped portion present between submerged leaves and surrounding water. Along with, a thick layer of cuticle may serve as a physical barrier between inner tissue and outer environment. Presence of leaf gas film and thick layer of cuticle on

rice leaf surface may protect submerged parts from direct contact of water. Thus, allow a better flow of electrons from PS-II, thereby, improved PS-II activity and minimizes chlorophyll destruction process (Ella *et al.*, 2003; Panda *et al.*, 2006, 2008; Barik *et al.*, 2019). Better chlorophyll function and improved gaseous exchange process CO₂ and O₂ mediated by LGF, may improves underwater photosynthesis (Winkel *et al.*, 2014) in FR13A. Underwater photosynthesis can also enhance the O₂ concentrations of submerged plant portions, which improved root aeration in anoxic or hypoxic soil (Winkel *et al.*, 2013). In general, submergence stress may facilitate the formation of lysigenous aerenchyma in leaf sheath portions, thereby, improves the tissue aeration in O₂ deprived condition. Parlanti *et al.* (2011) showed submerged intolerant (Arborio Precoce) and tolerant (FR13A) rice plants increases the aerenchymatous portions in submerged leaf sheath tissue. Along with these, submergence stress can effectively limit the gaseous exchange of endogenously produced gas ethylene, causing physical entrapment of ethylene. Vreeburg *et al.* (2005) showed ethylene concentration may increase in submerged plants within minutes after submergence and this process may aid in internodal elongation. Reports suggest presence of a thick leaf gas film in FR13A may lower tissue ethylene concentration by facilitating gaseous exchange, thereby, lowers internodal elongation of submerged plant parts. Conversely, a thin layer of leaf gas film and its early depletion may causes entrapment of ethylene in intolerant rice genotype IR42, thus, facilitates intermodal elongation (Chakraborty *et al.*, 2021).

Agronomic management practices for submergence tolerance in rice

Different agronomic management practices including using of healthy seeds or seedling, seed rate, spacing, seed priming, nutrient management etc. in nursery beds as well in main fields for both transplanting and direct sown are indispensable to provide tolerance or uplift the survivability of crop under submergence whether using tolerant or non-tolerant variety (Table 1). During submergence for longer period or shorter period, plants undergo drastic interchange of environment, from aerobic to anaerobic and vice-versa, which severely affects their physiological and metabolic processes. In this regard, better agronomic management plays a crucial role in improving tolerance capacity by activates or resuscitate the physiological and metabolic processes to cope up with this changing environment. Several experiments have proven the importance of improved management practices regarding increasing the survivability, tolerance capacity and productivity of the rice under submergence.

Seed rate

Several findings reported that alternation of seed rate could possibly be a way to obtain greater survivability of rice plant under submerged condition (Sharma and Ghosh, 1998; Sharma and Ghosh, 1999; Bhawmick *et al.*, 2014; Illangakoon *et al.*, 2018, Lal *et al.* 2018). According to Sharma, 1995a directed seeded rice crop prior to monsoon exhibit better submergence tolerance than transplanted seedling. Lal *et al.* (2018) illustrated that increased seed rate (60 kg ha⁻¹) in directed seeded rice enhanced the growth

attributes; yield attributes and yield than seed rate of 40 kg ha⁻¹ in both submergence tolerant and intolerant varieties as higher plant population at 60 kg ha⁻¹ seed rate compensated lower germination under flooded condition. Same line of work by other scientists (Sharma and Ghosh, 1998, Abou Khalifa *et al.*, 2014, Illangakoon *et al.*, 2018, Lal *et al.*, 2018) reported similar finding evincing higher seedling emergence under submergence was attributed with higher seed rate as a result higher of higher tiller number, panicle number and grain yield. According to Chae and Lee, 1996 high density of seeds exhibit greater germination, seedling vigour and plant population. Although, interplant competition due to higher plant population than optimum due higher seed rate affects biomass production or yield of crops. But with increased nitrogen fertilization this loss can be compensated (Reddy *et al.*, 1986). However, growing of healthy seedlings by maintaining optimum seed rate can also be another submergence tolerance option. Maintaining optimum seed rate at nursery bed induce robust root system and better nutrient storage in shoot by reducing interplant competition (Bhowmik *et al.*, 2014, Banayo *et al.*, 2018).

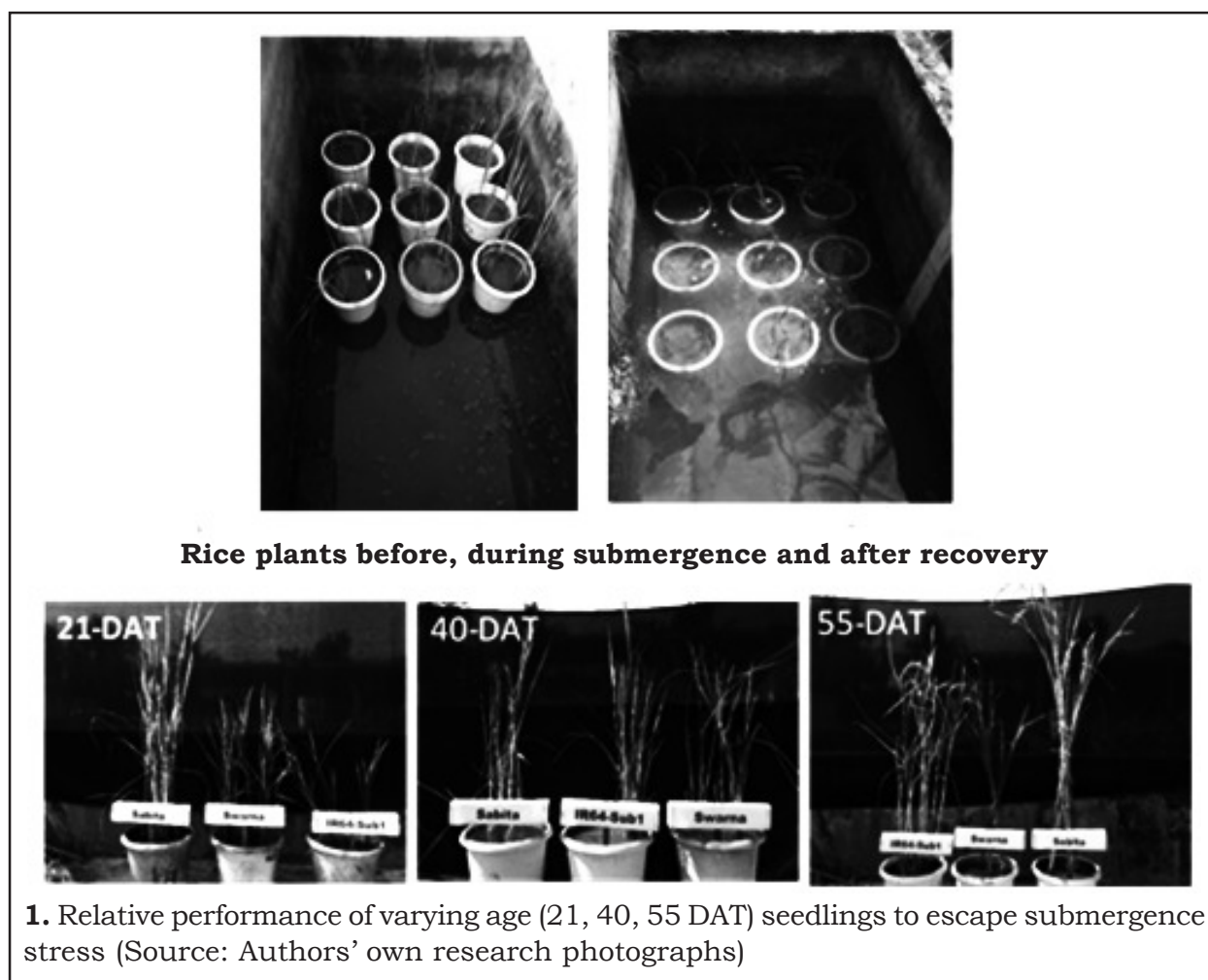
Seed or Seedling age

Age of seed or seedling to be transplanted appear to be a critical factor to survive against submergence condition. As viability of stored food materials or vigorous root and shoot system solely depends on the age of the seeds or seedlings age. Bhowmick *et al.* (2014) depicted from the experiment that performance of older seedlings (44 days) under natural submergence was greater

than 30 days old seedlings in terms of survivability, growth, yield attributes and found 6% more yield than 30 days old seedlings. Survivability of older seedlings are better might be due to higher vigour, mature tissue, carbohydrate content and lower underwater shoot elongation (Singh *et al.*, 2005). Similar findings also were reported by Chapagain and Yamaji (2010), where 21 days old seedlings recorded higher 3% higher yield than 14 days old seedlings under 5-7 cm continuous flooding. Bhaduri *et al.* (2021) tested the survivability of seedling of three different transplanting dates (21, 40 and 55 days) in three different varieties (Sabita, Swarna and IR64-Sub1) under flash flood condition and reported that late transplanting dates (40 d, 55 d) exhibited better submergence tolerance as compared to normal date of transplanting (21 d) in terms of elongation ability, leaf regeneration, tillering ability, underwater radiation, chlorophyll fluorescence, antioxidant enzymes malondialdehyde and non-structural carbohydrates (Figure 1). On other hand, fresh and viable seeds performed better than older seed as under submergence situation oxidation degradation of lipid and decline in antioxidant metabolites was found in older seeds (Ella *et al.*, 2010).

Crop Spacing and Geometry

Configuration of crops is one of the key factor that determine the light penetration and interception by the crop canopy, which reflects on the production of photosynthates and accumulation of dry matter production. Under submerged condition, wider spacing among the rice plant (row-row: 20 cm and plant-plant: 15 cm and more) showed greater tolerance,



greater underwater radiation, less leaf senescence, initial non-structural carbohydrate, higher antioxidant activities than closer spacing rice plants (Bhaduri *et al.*, 2020) (Figure 2). Alteration in row-row and plant to plant spacing modify the plant population per unit land area which can affect seedling vigour and plant biomass at the time crop establishment (Chapagain and Yamaji, 2010). Thus, wide spacing in rice field can be an effective strategy for underwater plant survival. Experiment of various crop geometry *i.e.* circle, square and hexagon in rice under

submergence for 13 days at ICAR-NRRI, Odisha, India showed that hexagonal distribution of planting geometry had less depletion rate of starch and chlorophyll, delayed leaf senescence, and less oxidative damage under submergence, followed by better recovery leading to better stress tolerance, as compared to circle and square geometries. Also, the plants situated in the periphery across the three geometries showed better submergence tolerance ability, over the plants situated in the core (Annual report, 2021, ICAR-NRRI) (Figure 3).

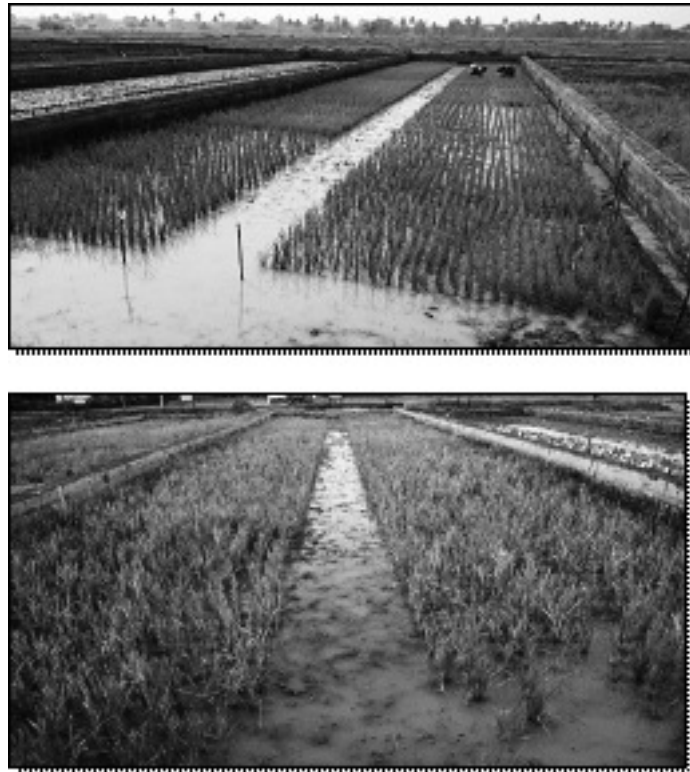


Figure 2. Submergence experiment (1. before treatment and 2. post-submergence recovery situation) (Source: Authors' own research photographs)



Figure 3. Condition of treatment tank (submerged, in left) and control tank (in right) after withdrawal of submergence treatment with layout of crop geometry (square, hexagon, circle) replicated in the experiment (Source: Authors' own research photographs)

Seed Priming

The preliminary criteria to sustain under submerged condition are higher germination rate of seeds coupled with healthy seedling growth (Miro and Ismail, 2013). Though rice crop well adapted to germinate under anaerobic environment, still vigour seedlings became a limiting factor for better crop establishment under submerged situation. Under this circumstances, priming with water or chemicals, found be one of good agronomic practices to overcome the stress effect to some extent. Treatment of seeds using water or chemicals accelerates the desirable metabolic processes and activates the biomolecules (enzymes, proteins etc.) regarding germination, which helps the 'upcoming' seedlings to survive under adverse situation (Ella *et al.*, 2010; Ismail *et al.*, 2012; Javed *et al.*, 2021; Mei *et al.*, 2017). About 40 % greater survivability of seedling was observed in hydro primed (H_2O) seed than non-primed seed as a result of increased activity of α -amylase, synthesis of soluble sugars and break down of starch under flooded condition (Illangakoon *et al.*, 2016; Mulbah and Adjetej, 2017).

Breakdown of starch in presence of α -amylase into readily fermentable carbohydrates supply the require energy for the coleoptile growth and further stand of the seedling (Magneschi and Perata, 2009; Park *et al.*, 2010). Hussain *et al.* (2016) described through his experiment under controlled system that seed priming using selenium ($60 \mu M$ selenium) and salicylic acid ($100 mg L^{-1}$ salicylic acid) increased the germination by 44% and 46% respectively, than without priming of seeds

in rice. Besides that, shoot and root length, shoot and root fresh weight of the seedlings were significantly improved in primed seed and seedling vigour index was approximately three times; and α -amylase activity and total soluble sugar contents in rice seedlings were approximately two times higher than non-primed seed under submergence condition.

Authors' own group have also studied some priming effect towards managing AG (anaerobic germination) stress. Submergence at germination stage (standing water depth of 8 cm till 28 days) was experimented with two contrasting cultivars (IR 64 and IR 64-AG) in combination of treatments for seed priming (Pr0: control, Pr1: 1% $CaCl_2$, Pr2: 1.5% KH_2PO_4) and nutrient management (N0: RDF and N1: RDF+Ca). It was found that priming with 1.5% KH_2PO_4 and RDF+Ca was the best combination that improved AG potential under prolonged submergence stress at germination stage, and it was reflected in enhanced germination percentage, germination rate and hypocotyl elongation and reduced mean germination time, particularly in non-AG genotype. Priming improved periodic availability of non-structural carbohydrates as a result of increased α -amylase activity in both AG and non-AG cultivars (Annual Report, ICAR-NRRI, 2019).

Using of 2% of Jamun (*Syzygium cumini*) leaf extract as a priming agent has improved establishment of seedling as well as yield attributes and yield of rice under flooded condition (Sarkar, 2012). Under anaerobic condition, primary way of producing energy in plant is alcoholic fermentation and increased activity of alcohol dehydrogenase

in primed seed is one of reason for better survivability than non-primed seed under flooded condition (Sarkar, 2012).

Nutrient management

Inundation of water for a certain period in both nursery bed or in main field causes flashed out of nutrients from the upper surface of the soil through runoff and percolation, causing severe nutrient deficiency in plant. As a result, rice plant under submerged cause poor seedlings or poor crop stands in main field after transplanting. Farmers faced heavy economic losses due to not adopting appropriate pre and post flood nutrient management. Several experiments over the years have demonstrated proper nutrient management practices during pre- and post-flood situation to activate the important physiological and biochemical processes to recover from stress and enhances the growth and productivity of the crop.

Optimum nutrient application through fertilizers in nursery bed produced healthy seedlings, which became well equip to survive against submergence (Sarangi *et al.*, 2015, Singh *et al.*, 2018). Singh *et al.* (2018) reported that application nitrogen, phosphorus and potassium at 20:40:60 kg ha⁻¹ at nursery bed recorded significantly higher yield attributes and yield than other lower doses of fertilization. Integrated application of organic manure and fertilizers found to be increased the vigour of seedlings and subsequently recorded higher grain yield (Sarangi *et al.*, 2015, Banayo *et al.*, 2018).

Nitrogen and Phosphorus

Several experiments (Ella and Ismail, 2006, Gautam *et al.*, 2014a and b, Gautam

et al., 2015) have reported that post flood nitrogen along with basal phosphorus application helps to faster recovery, maintaining important metabolic processes, regeneration of chlorophyll and production of non-structural carbohydrates also enhanced growth and productivity of the crop. It was also reported that foliar application of urea instead of broadcasting much more beneficial (Gautam *et al.*, 2014b). On the other hand, pre submergence nitrogen application with no basal phosphorus enhances the shoot elongation (Gautam *et al.*, 2014a). It was found that ethylene production in shoots was significantly reduced due to basal phosphorus application and hence increased the survival and photosynthesis after receding of water (Gautam *et al.*, 2015; Ramakrishnayya *et al.*, 1999). Gautam *et al.*, 2015 reported that ethylene production in plants with basal application of phosphorus was 22.1 % lowered than the plants with no phosphorus application. Before submergence application of nitrogen accelerates the succulency in the shoot and elongation, which causes more plant mortality (Gautam *et al.*, 2014a) and poor root growth due to greater accumulation of soluble carbohydrates in shoot part (Ella and Ismail, 2006). However, integrated application of organic manures including FYM and *Sesbania* and nitrogen and phosphorus fertilizers also reported better survivability, biomass production and yield in direct sown rice under submergence (Ghosh, 2007).

Potassium

Under flooded condition loss of potassium from roots creates deficiency in plant body (Marschner 1995). Therefore,

an additional application of potassium after receding the water can help to improve the tolerance capacity during submergence and recovery period after submergence. Dwivedi *et al.* (2018) revealed through their experiment that additional application of 10 kg nitrogen and potassium each in rice improved 1000 grain weight, grain yield and harvest index in Swarna-Sub1 in Indo-Gangetic plain of Bihar, where plants were completely submerged for 16 days. They also reported 1.5-10-fold higher antioxidant activities after submergence than before as potassium played a significant role in to overcome the submergence stress through involvement in several physiological and biochemical processes, activation of enzymes and enhancing antioxidants activities (Gautam *et al.*, 2016; Cakmak, 2005).

Silicon

Besides combination application of major nutrients, silicon (Si) application as basal found to be beneficial for in submergence tolerance (Chu *et al.*, 2018; Ella *et al.* 2011; Gautam *et al.*, 2016). Silicon helps to maintain the erectness of the leaf which facilitates higher light transmission and photosynthesis (Tamai and Ma, 2008). Under lowland rice cultivation, basal application of silicon with post flood nitrogen application showed a synergist effect and improves production of the crop (Lal *et al.*, 2015; Chu *et al.*, 2018; Mohanty *et al.*, 2020).

Conclusion

Rice being a semi-aquatic plant, it can tolerate this excess water stresses better than other cereals. Most rice genotypes can tolerate 2-3 days of complete submergence without any physiological or metabolic

damage, but more often the period of stress exceeds a longer time in the field condition. In this article, the physiological adaptations under both germination stage and early vegetative submergence stress were discussed followed by the effective interventions of crop management practices which have important to impart tolerance to a significant extent. Agronomic management practices like higher seed rates, changing date of transplanting, alteration in crop geometry, seed priming, along with nutrient management at pre- and post-submergence stages may enhance both survival and yield by improving crop germination, elongation, biomass, photosynthetic efficiency at an early crop growth stage and optimum partitioning of carbohydrates to vegetative and reproductive parts at later crop growth stage. Realizing the importance, this compilation was attempted to project the research findings from authors and other groups and paved the future research avenues in the similar or related aspects.

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Table 1: Modified nutrient management practices for better rice crop establishment facing submergence stress

Management strategies	Nutrient applied	Crop	Genotype/ Cultivar	Observation	Reference
Nursery management	Nitrogen (N), phosphate (P) and potassium (K)	Rice	Swarna and Swarna Sub1	N:P:K- 20:40:60 kg ha ⁻¹ treatment ensures a better yield in Swarna Sub1 rice genotype.	Singh et al. 2018
	N, P, and K		Swarna Sub1 and Amal- Mana	Forty day old seedling and seed density 25 g m ⁻² , with N: P: K- 50:30:15 kg ha ⁻¹ and 5 ton field yard manure per hecter.	Sarang et al. 2015
	N, P, and Zinc (Zn)		IR64 Sub1 and IR42	N:P:K:Zn- 40:17:33:39 kg ha ⁻¹ with organic manure (5000 kg ha ⁻¹ , having N:P:K 20:9:17 kg ha ⁻¹), low seedling rate (400 kg ha ⁻¹), transplanting of older plants (30 days) and higher planting density (20 cm x 15 cm) may ensures a higher yield.	Banayo et al. 2018
	N, P, and K		Swarna Sub1	N:P:K-80:40:40 kg ha ⁻¹ of nursery treatment ensures higher survival and straw yield, seedling density 40 gm ⁻² and transplanting 40 days old seedling.	Bishoyi et al. 2022
	N, P, and K		Swarna Sub1	N:P:K-80:40:40 kg ha ⁻¹ , seedling density 25 gm ⁻² and transplanting of 44 days old seedling ensures higher yield under submergence.	Bhowmick et al. 2014
Seed priming	100 µM of Melatonin	Rice	XZX45	Application of 100µM melatonin aids to minimize the damage of submergence and facilitates germination.	Zeng et al. 2022
	H ₂ O and Polyethylene glycol (PEG)		Gangyou 527, Yangdao 6, Nongken 57, Zhonghan 3	PEG priming with a proper concentration had a better effect for securing germination, it was 20% for Gangyou 527 and 10-15% for Nongken 57.	Yuan-Yuan et al. 2010
	H ₂ O and Jamun leaf extract		Swarna and Swarna Sub1	Seed priming with H ₂ O and 2% Jamun extract facilitates to ensure an underwater growth.	Sarkar, 2012
	Selenium and salicylic acid		Huanghuazhan	60µM selenium and 100mg L ⁻¹ salicylic acid was most effective for submergence treatment.	Hussain et al. 2016
	H ₂ O, 1% KCl and 5% PEG		243 lowland rice genotypes were screened	Hydropriming and 1%KCl priming could be best for ensuring underwater germination.	Doley et al. 2018
Nutritional management	Phosphorus at 40, 80 and 120 kg ha ⁻¹ before seedling	Rice	IR42, Mahsuri, FR13A and TCA 48	High phosphorus fertilization 120 kg ha ⁻¹ was beneficial for survival, biomass accumulation and dry matter production	Singh et al. 2006
	Phosphorus at 60 kg ha ⁻¹		IR64, IR64 Sub1, Swarna and Swarna Sub1	Shoot elongation, leaf senescence and lodging was lowest with high phosphorus	Gautam et al. 2019
	Nitrogen and phosphorus		FR13A and IR42	Survival was negatively associated with leaf N concentration, Addition of P can enhance tolerance of plants grown P- deficient soils.	Ella and Ismail, 2006
	Nitrogen and phosphorus		IR64 Sub1, Swarna Sub1 and IR20	Basal phosphorus (114 mg SSP) reduced elongation, senescence and ethylene production, Post- flood foliar spray of urea (2% w/v) beneficial for rejuvenate growth after de-submergence	Gautam et al. 2014a

Nitrogen and phosphorus	Nitrogen and phosphorus	IR64 and IR64 Sub1	Post submergence N application and basal P application increased survival, pre submergence N application can leads to reduced survival.	Gautam et al. 2014b
			Post submergence N application and basal P application increased survival and photosynthesis, pre submergence N application can leads to reduced survival.	Gautam et al. 2015
			Post submergence N application [urea 2.0%(w/v)] and basal P application increased survival.	Gautam et al. 2017
	Potassium	IR64, IR64 Sub1, Swarna and Swarna Sub1	Application of 0.47 g MOP ha ⁻¹ can be an effective nutritional strategy to combat the adversities of submergence stress.	Gautam et al. 2016a
	Potassium	Swarna Sub1	40 kg ha ⁻¹ of potassium in basal and one foliar spray of 0.5% K at panicle initiation stage secures maximum grain yield.	Dwivedi et al. 2017
	Nitrogen, Potassium	Swarna Sub1	Post flood application of K ₂ O and N at 5-6 days after de-submergence effectively improved photosynthetic parameters and yield.	Dwivedi et al. 2018
	Silicon (600 kg ha ⁻¹)	IR49830-7-1-2-3, Swarna Sub1, IR42 and Swarna	Addition of 10 kg N and 10 kg K ₂ O after de-submergence showed maximum yield.	Ella et al. 2011
	Nitrogen and silicon	IR64, IR64 Sub1, Swarna and Swarna Sub1	Application of excessive silica in soil before 1 day of sowing negatively affects growth and survival.	
	Nitrogen and silicon	Ningjing 3 (Japonica rice cultivar)	Basal Si when combined with post-flood N spray is most promising method for nutritional management.	Gautam et al. 2016b
	Nitrogen, phosphorus and silicon	IR64 Sub1, Swarna Sub1, Savitri Sub1 and IR20	Foliar spraying of N had more advantages than silicon.	Chu et al. 2018
	Nitrogen, phosphate and potassium	Hnan Gar, Swarna Sub1, Bio 6 and Bio 8	Combined application of N, P and Si showed highest survival and biomass.	Lal et al. 2015
	Nitrogen	IR64, IR64 Sub1, Swarna and Swarna Sub1	N:P:K 110: 50:110 Kg ha ⁻¹ ensures a high grain filling and improves 1000 grain weight.	Htwe et al. 2019
			Forty days old seedlings showed significantly higher submergence tolerance, Post flood application of N resulted in better survival.	Gautam et al. 2017