Climate Resilient Production Technologies for Rainfed Upland Rice Systems

D Maiti, NP Mandal, CV Singh, SM Prasad, S Bhagat, S Roy, A Banerjee and BC Verma

SUMMARY

Upland rice accounts for about 13% and 13.5% respectively of world and Indian rice growing areas. It is grown under diverse topography, climatic and soil conditions, mostly as direct seeded, rainfed crop. Due to adverse topography (sloppy), poor soil conditions and absolute rain dependence, it often suffers from drought at several growth phases. Besides, poor soil nutrient conditions, biotic stresses like weeds, diseases and insects, which also are accentuated by drought, are major challenges for improving upland rice productivity. This chapter discusses progress of research to address these constraints and suggests way forward based on knowledge gap analysis.

1. INTRODUCTION

Upland rice is grown in around 15 Mha globally. Major upland rice areas are in Asia (8.9 Mha) followed by Africa (3 Mha) and Latin America (3.1 Mha). Nearly 100 million people, globally, depend on it as their daily staple food (Arraudeau 1995). In India it covers about 6.0 Mha under rainfed ecology. Major portion of upland rice areas in India are in eastern and northeastern states.

Agricultural production system of upland ecology in India is mainly monsoon dependent where rice is the major crop. However, rice productivity of the target ecology is very poor owing to several constraints including moisture stress as the most important followed by weeds, poor soil nutrient status and diseases (blast and brown spot). The upland rice ecosystem is extremely diverse as it is grown on leveled to gently rolling land (0-8% slope) and also on lands where slopes are greater than 30%. Soils vary from highly fertile volcanic and alluvial soils to highly weathered, infertile and acidic type. Upland rice is grown at altitudes of up to 2000 m above MSL and in areas with annual rainfall ranging from 1000 to 4500 mm. But erratic rainfall frequently causes drought during growth periods and results in low and unstable yields of upland rice (1–2 t ha^{-1}), compared to irrigated lowland rice (>5 t ha^{-1}). Improving productivity of rice in the upland ecosystem is essential to meet food security needs of impoverished upland communities leading to address the set national targets of (i) Bringing Green Revolution to Eastern India (BGREI) and (ii) doubling farmers' income. In this context, the roadmap for improving rice production system of this ecology has been set through: (i) breeding for drought-tolerant, high yielding rice variety; (ii) developing climate resilient crop production technology including crop establishment, nutrient management and (ii) establishing suitable crop protection schedule (Integrated

Pest Management; IPM) including weeds, diseases and insects. All these components under compatible integration would promote improvement of rice production system of rainfed uplands. Thus, the objective of this chapter is to introduce the problems, assesses present status of research and suggest way forward for improving upland rice production system.

2. GENETIC ENHANCEMENT OF UPLAND RICE

Varietal improvement for upland rice at the international level has progressed independently in tropical Asia, Africa and Latin America in collaboration with different international agricultural research centers (Gupta and O'Toole 1986). Varietal improvement in Africa is mainly through international programs as there were very few national programs existed. Among the national programs, National Cereals Research Institute, Ibadan in Nigeria is the pioneer in upland rice breeding in Africa and developed many varieties, among them OS6 (FARO 11) became very popular because of its drought tolerance. The Institute has specifically developed 63 rice varieties that are low N and water use efficient, pest and diseases resistant for various rice ecologies, with the recently released upland varieties FARO 58 and 59. In the Ivory Coast the Ministry of Agricultural Research has released several useful varieties including Moroberekan, before 1966. International Agricultural Research Centers (IARCs) such as International Institute of Tropical Agriculture (IITA), IRAT (now CIRAD; the French Agricultural Research and International Cooperation Organization), WARDA (now Africa Rice) and International Rice Research Institute (IRRI) began large scale testing of new varieties in 1976. These IARCs extensively collaborated among themselves and kept developing and providing superior breeding lines to the national programs to enhance their rice production. The varietal development program in Africa revolutionized with the first NERICA (New Rice for Africa) rice variety (Jones et al. 1997) developed by the Africa Rice Center (WARDA) from a cross between the local African rice *Oryza glabberima* and the Asian type *Oryza sativa*. Total 18 NERICA varieties were released with doubled average yield in sub-Saharan Africa. Development of NERICA rice opened up new gene pools and increased rice biodiversity to scientific community.

In Latin America, upland rice improvement program was initiated in Brazil at the Instituto Agronomico Campinas (IAC), São Paulo during 1937. Since then, several important cultivars have been released. Upland rice breeding program at the National Rice and Beans Research Center (EMBRAPA/CNPAF) began in 1976 combining IAC developed varieties with African germplasm 63-83, OS6, and LAC23 to broaden genetic base and new varieties Cuiabana, Araguaia and Guarani were released between 1985-1986.

In south and south-east Asia, IRRI collaborated with national programs of different countries (Bangladesh, Cambodia, Indonesia, India, Thailand, Philippines etc.) to help in identifying more productive cultivars. In the early part, upland rice breeding in most of the countries was limited to collecting farmers' varieties, purification, and evaluation with limited hybridization. During this period many improved varieties from tall parents were released. Upland rice breeding in the Philippines began early than any other countries and released varieties developed through hybridization. Later in the 1970s, the University of the Philippines at Los Baños developed C22, UPL Ri-3, UPL Ri-5, and UPL Ri-7 which have intermediate height, moderate tillering ability, and good grain quality. Some of these varieties were introduced in other countries though INGER program of IRRI and utilized by the breeders for varietal development under national program. Upland rice improvement program at IRRI progressed in collaboration with national programs and international institutes such as IITA, WARDA, IRAT and CIAT (Gupta and O'Toole 1986). Larger numbers of crosses were made at IRRI involving improved germplasm and traditional varieties and the lines were distributed to partners for location specific selection.

Drought tolerance breeding started with use of secondary traits for the improvement of drought tolerance in terms of grain yield under stress which met with limited success because of several limitations. From the first decade of this century the strategy changed towards direct selection for grain yield under stress for the improvement of drought tolerance. It was demonstrated at IRRI that if the stress is applied uniformly and consistently, yield under stress can be as heritable as yield under control condition and resulted in significant gain in upland rice drought tolerance (Bernier et al. 2007; Venuprasad et al. 2007; Kumar et al. 2008). For a more intensive high input upland system, a new set of cultivars were developed for Asian tropics with improved lodging resistance, harvest index and input responsiveness (Atlin et al. 2006). These cultivars combined yield potential of high yielding lowland rice with aerobic adaptation of upland rice and proved promise for water limited environment. With the standardization of screening protocol for yield under drought, large-scale conventional breeding and QTL identification programmes were started, using yield as a selection criterion. This approach has led to the successful development and release of 17 high-yielding drought-tolerant rice varieties in south Asia, south-east Asia, and Africa.

In India, systematic rice improvement program began when ICAR-National Rice Research Institute (ICAR-NRRI; formerly Central Rice Research Institute, CRRI) was established at Cuttack, Orissa in 1946. Attempts to develop drought tolerant varieties through hybridization began in Tamil Nadu and Kerala in 1955. The drought resistant variety Co31 was released from Coimbatore, Tamil Nadu but this variety has long growth duration and is photoperiod-sensitive. Initially selection from land races were made to develop drought tolerant variety in India e.g., N22 from Rajbhog in Uttar Pradesh, BR19 from Brown gora in Bihar and PTB10 from Thavala Kannan in Kerala. The All India Coordinated Rice Improvement Project (AICRIP) initiated in 1965 organized a coordinated rice improvement program involving state agricultural university/department with those of CRRI and other ICAR institutes and ushered into a new era of rice breeding. This effort resulted in identification of drought tolerant, long duration varieties like Lalnakanda41, CH45 etc. Subsequently, the focus shifted to development of shorter duration (90-110 days), drought tolerant varieties to fit in the southwest monsoon season of uplands. During next phase (1965-1970), short duration, drought tolerant varieties like Bala, Annada (Orissa), Annapurna (Kerala), Cauvery (Tamil Nadu), Parijat (Orissa), Pusa2-21 (IARI), Rasi, Kanchan (Bihar) were developed using the semi-dwarf gene. Later on, it was realized that tall varieties are more appropriate to challenge the high weed pressure and first semi-tall variety Kalinga III was released in 1983 from CRRI.. The momentum of upland rice varietal improvement programme was intensified with the establishment of Central Rainfed Upland Rice Research Station (CRURRS) of Central Rice Research Institute at Hazaribag during early 1980's. The first drought tolerant, early duration (90-95 days) variety Vandana was developed in 1992 from this station, using drought tolerant *aus* and high yielding *indica* genotypes (Sinha et al. 1994). Further efforts led to the development of varieties like Anjali (2002), Virendra (2006), CR Dhan 40 (2008) and Sahbhagidhan (2011). Simultaneous efforts at IGKV, Raipur and NDUA&T, Faizabad led to the development and release of lndira Barani dhan-1 and Shushk Samrat, respectively. The collaboration of DFID (Department of International Collaboration) with Birsa Agricultural University at Ranchi developed two popular upland varieties BVD109 and BVD110 in 2005. Subsequently, through Upland Rice Shuttle Breeding Network, linking centers in eastern and western India working on upland rice, under the aegis of ICAR-IRRI collaborative program, development of location specific upland rice varieties were initiated in 2002 leading to development of variety Sahabhagidhan (Mandal et al. 2010). The success of Sahbhagidhan due to its resilience and higher productivity under stress motivated the research group to identify QTLs that perform well under stress. Several QTLs (*DTY12.1, 2.2, 3.1, 4.1, 6.1* and *9.1*) were identified at IRRI. Breeding programmes at NRRI-CRURRS, Hazaribag focused on the transfer of these QTLs to productive background, in collaboration with IRRI. The first drought tolerant variety, developed through marker assisted selection (IR64 Drt1), where 2 major QTLs (*qDTY2.2* and *qDTY4.1*) for grain yield under drought stress have been introgressed into popular variety 'IR 64' was released in 2014. Several institutions including CRRl, lRRl, BAU and DRR were involved in phenotyping and advancement of the material through multilocation testing. The Hazaribag centre has now moved on to combining drought tolerance and blast resistance genes in productive backgrounds. Vandana has been improved for drought and blast resistance with drought QTLs (12.1) and blast *R* gene (*Pi2*). The developed lines are currently under multilocation testing.

3. MANAGEMENT OPTIONS FOR SUSTAINABLE RICE PRODUCTION UNDER DIRECT SEEDED RAINFED ECOLOGY

Direct seeding of rice refers to the process of establishing the crop from seeds sown in the field rather than by transplanting seedlings from the nursery (Farooq et al. 2011). Upland rice is grown in rainfed unbunded fields that are prepared and seeded under dry conditions as other upland crops like maize and wheat. The upland rice ecosystem differs from other rice production systems because the plants grow in well-drained soils that are not flooded. Soils do not impound rainwater even for short period of 2-3 days because of high porosity (soil) and sloppy topography. Rice is more susceptible to drought than other crops owing to its shallow root system.

Beside direct effects, drought also declines yield through poor nitrogen (N) acquisition. Upland rice is typically a subsistence crop in India where farmers apply few or no purchased inputs (Arraudeau 1995), and do most of the work using family laborers. Joshi et al. (2013) reported that direct seeded rice (DSR) may be planted using any of the three major methods viz., dry seeding (sowing dry seeds into dry soil), wet seeding (sowing pre-germinated seeds on wet puddle soils) and water seeding (seeds sown into standing water). Dry-DSR system is traditionally practiced under rainfed uplands in most of the Asian countries.

Almost all the upland soils are low in nitrogen (N) and phosphorus (P) and have high P fixation capacity. The soils are characteristically of high porosity and of low fertility. In these soils, the productivity of the crop is not only low but also inconsistent. Next to inadequate water and nutrient supply, weeds are the major constraint in upland rice production system. Direct-seeded upland rice ecosystems are most vulnerable to weed competition. Weeds reduce upland rice grain yield and quality. Estimates of yield losses caused by weeds in upland rice range from 30 to 100%. Hence, the production technology of rainfed upland rice revolves around crop establishment, nutrient and weed management and likely shifts in weed flora due to adoption of direct-seeded rice and crop diversification.

3.1. Crop establishment

To maintain good soil moisture and to maximize soil to seed contact, field should be pulverized well under conventional tillage. For zero tilled direct seeded rice (ZT-DSR), existing weeds should be burned down by using herbicides such as paraquat @ 0.5 kg a.i. ha^{-1} or glyphosate @ 1.0 kg a.i. ha^{-1} (Gopal et al. 2010). Soil structure is improved due to reduced compaction under zero tillage. Zero tillage beds also provide the opportunity for mechanical weed control and improved fertilizer placement.

Uneven crop stand provides less competition to weeds compared to good crop stand. Thus, ensuring good population through better land preparation and employing seed invigoration approaches may help minimizing weed population. Seed priming tools have the potential to improve emergence and stand establishment under a wide range of field condition including DSR. Recent research on a range of crop species showed faster germination, early emergence, and vigorous seedlings achieved by soaking seeds in water for some time, followed by surface drying before sowing, which may result in higher crop yield (Harris et al. 2000). In drought-prone areas, seed priming reduced the need for a high seeding rate, although it (low seed rate) can be detrimental if seeding takes place in soil that is at or near saturation (Du and Tuong 2002). Reviewed literature showed use of seed rates of up to 200 kg ha^{-1} to grow a DSR crop. High seed rates are used mostly in areas where seed is broadcast with an aim to suppress weeds (Moody 1977). High seed rates can, on the other hand, result in large yield losses due to excessive vegetative growth before anthesis followed by a reduced rate of dry matter production after anthesis and lower foliage N concentration at heading leading to higher spikelet sterility. Moreover, dense plant populations at high seed rates can create favorable conditions for diseases and insects and make plants more prone to lodging. Under good management, optimum seed rates for row seeding 20 cm apart and broadcast were 300 and 400 seeds/m^2 (67.5 and 90 kg ha^{-1} for cv. Kalinga III), respectively (Singh et al. 2017).

Seeding depth is also critical for uniform germination. Therefore, rice should not be drilled deeper than 2.5 cm to maximize uniform crop establishment (Gopal et al. 2010; Kamboj et al. 2012). Further, optimum time of planting results in improved rainwater use efficiency by 40-50% and enhances the total productivity. To optimize the use of monsoon rain, the optimum time for sowing DSR is about 10-15 days prior to onset of monsoon (Gopal et al. 2010; Kamboj et al. 2012). Singh et al. (2017) reported that an average increase of 25% grain yield when seeding date was advanced to first fortnight of June in the red sandy loam soils of uplands. They further suggested that varieties of 85-95 days would perform consistently better under advance seeding though performance of 100-105 days varieties could be subject to even distribution of rainfall during the cropping season.

3.2. Nutrient management

Applying a full dose of phosphorus (P), potash (K) and one-third nitrogen (N) as basal at the time of sowing is the general recommendation for dry-DSR. Split applications of N are recommended to maximize grain yield and to reduce N losses. The remaining two-third dose of N should be applied in splits and top-dressed in equal parts at active tillering and panicle initiation stages (Kamboj et al. 2012). In addition, N application can be managed using a leaf color chart (LCC) (Kamboj et al. 2012).

Fertilizer management in direct seeded rice should aim at benefiting crop only, or if not possible, benefiting crop more than weeds. Nitrogen fertilizer is usually applied three times, at seeding, tillering, and panicle initiation stages, respectively, with a total amount from 40 (Singh and Singh 2005) up to 200 kg N ha$^{"1}$ (Yang et al. 2002) split as 1/3, 1/3, 1/3 or 1/2, 1/4, 1/4 to synchronize with the demand of rice growth. Weeds must be removed before N application, otherwise a greater weed growth and competition would be created and rice yield would be even lower than when there is no N application. However, timing of N application must accurately meet demand by the rice plant, and that is often not feasible because of unpredictable rainfall. In upland conditions, N recovery can also be affected by N loss from leaching. Singh and Singh (2005) concluded that application of 1/4th N as basal in addition to two splits (1/2 at 20 and 1/4 at 40 DAS) produced more grain and straw yield of upland rice than the split application alone. When stale bed technique was adopted, application of N at the time of sowing helped in increasing the early crop vigor and rapid coverage of the field by the rice foliage with a consequent reduction in weed population (Murty et al. 1986). Mishra et al. (1995) reported that growth and vigor of both rice and weeds were less under Mussoorie Rock Phosphate at the early stage, but the growth of rice increased at the late vegetative stage compared with the single superphosphate application, without loss in grain yield. N application significantly influenced P uptake in grain and straw. Shorter duration (100–110 days) upland rice varieties were found to respond up to 18 kg applied P ha^{-1} in lateritic soils of eastern India.

Poor phosphorus (P) availability continues to be another major constraint for agricultural productivity in drought prone rainfed uplands. On the other hand, it has been reported that the well-drained, aerobic soil conditions of this ecology support native arbuscular mycorrhiza (AM) activities which is known to promote higher P acquisition by the associated plants. AM is symbiotic association between plant roots and a special group of fungi (arbuscular mycorrhiza fungi; AMF). Sound association of upland rice with AM-fungi forming mycorrhizal symbiosis was confirmed long back by Brown et al. (1988). Partial dependence of upland rice on AMF for P acquisition was also demonstrated (Saha et al. 2005). Exploitation of natural association (AM) for improving P acquisition in upland rice was extensively attempted in upland rice at CRURRS (Hazaribag) of ICAR-NRRI and has been reviewed (Maiti 2011). Several native AM-supportive crop culture components for upland rice based cropping systems (RBCS) were identified and judicious integration of the components improved P nutrition of upland rice substantially with concomitant yield increase (Maiti et al. 2011)

3.3 Weed management

Upland rice is directly sown in non-puddled, non-flooded soil, where weeds and rice germinate simultaneously. The lack of ‘head start’ to rice over weeds and the absence of floodwater make upland rice more weed infested than irrigated lowland rice leading to yield loss ranging between 30-98% (De Datta and Llagas, 1984). There is a diversity of floristic composition of weeds in different agro-climatic and *edaphic* conditions. A mixture of annuals and perennials, grasses and broadleaf weeds, intensifies the competitive effects of weeds in upland rice.

Mishra et al. (1995) reported from NRRI-CRURRS, Hazaribag that out of 30 weed species observed, only 14 were important based on their abundance. Among the important weeds, *Echinochloa colonum* was predominant in both coverage and number. The major weeds in upland, however, are *Echinochloa colonum*, *Eleusine indica*, *Ageratum conyzoides*, *Cyperus rotundus*, *and Cynodon dactylon* spp., *Commelina benghalensis*, *Richardia brassilensis* and *Setaria glauca* (Rafey and Prasad 1995). Several methods are used to control weeds in the upland rice. While direct methods are used to remove weeds completely from the upland fields; the substitutive, preventive and complimentary measures generally minimize weed populations to a manageable level. Preventive methods aiming at preventing weed dispersal and build up of seed reserves in the soil include: (1) using weed-free seeds; (2) maintaining clean fields, borders, levees and irrigation canals, and (3) cleaning farm equipment to prevent weed transfer from one field to another (De Datta and Baltazar, 1996). Good tillage and land leveling can remove weed vegetation at sowing and suppress perennial weeds; provide fine soil to allow uniform and early rice establishment; and permit uniform and easy irrigation and drainage (De Datta and Baltazar 1996).

Direct physical control methods include removal of weeds by hand, with weeding tools (hoe, scythe and spade), or with mechanical implements. Hand weeding, though effective, is expensive, labor intensive and time consuming. Besides there are difficulties in procuring sufficient labor force for weeding operation in uplands as land preparation and transplanting operations of medium and lowland rice coincide. Mechanical weeding could be an alternative supplement to hand weeding. Hoe weedings plus hand weeding at 14 and 28 days after rice emergence respectively in upland rice has been observed to be the most suitable and economical weed-control practice.

Herbicides have the potential to offer an alternative to physical method of weed control as they are less time-consuming and cheaper. However, relative efficiency of such herbicides under upland situation is dependent upon the weed species, pattern of weed emergence, soil moisture fluctuations and correctness of land preparation. Singh et al. (2008) reported that application of pre-emergence butachlor @ 1.5 kg a.i. ha^{-1} followed by a hand-weeding 30 DAS coupled with modified N and P application schedule proved the best strategy for integrated weed management in rainfed upland rice. Early post emergence spray of anilophos, pendimethalin, pretilachlor, pyrazosulfuron etc. has also been found effective in controlling upland weeds. However, one supplementary hand-weeding was found necessary in areas of heavy weed infestation and especially where flushes of weed emerge at intervals (Pandey and Singh 1982). Similarly, butachlor performed better when it was combined with post-emergence application of the herbicide-propanil (Carson 1975).

Herbicides have been increasingly and broadly applied in agriculture since the 1940s. However, intensive and repeated use of herbicide causes problems of environment pollution and resistant weed biotypes, which have aroused increasing concerns. Weed resistant biotypes have appeared in the major rice producing nations including China, India, Thailand and the Philippines. Reduced dependence on herbicides may bring down the costs of crop production and retard the development of herbicide resistance in weeds.

Differences in ability of rice cultivar to compete with weeds were initially reported several decades ago. Tall, droopy-leafed and vigorous traditional cultivars were reported to be more weed-competitive but lower in yield potential than short-statured, erect modern ones (De Datta 1980). Early vigor is important for the direct-seeded systems that increases stand establishment and weed competitiveness, both of which are important components for high yields in direct seeded systems (Zhao et al. 2006). Early vigor becomes more important when both rice as well as weeds emerges simultaneously. Pre-sowing seed treatments have sown good promise for promoting germination and early growth in several crops. Singh et al. (2017) reported that integration of hormonal priming by GA_3 @100 ppm with thermal hardening using alternate temperatures of 43/28 ^{o}C improved rice productivity by influencing growth and yield attributes of rice and reducing the weed pressure by increasing crop-competitive ability. Intercrop systems are reported to use resources more efficiently and are able to remove more resources than mono-crop systems, thus decreasing the amount available for weed growth. Rice equivalent yield and economics indicated overall advantages accrued from intercropping of pigeon pea and cowpea with rice in 4:1 and 4:2 row ratios, respectively (Singh et al. 2017).

4. RICE BASED FARMING SYSTEMS FOR DROUGHT PRONE RAINFED ECOLOGY

Integrated Farming System (IFS) approach is judicious mix of two or more components while minimizing competition and maximizing complementariness with advanced agronomic management tools aimed at sustainable and environment friendly improvement of farm income and family nutrition. Integrated farming system involves preservation of bio-diversity, diversification of cropping or farming system and maximum recycling of residues. In general, farming system approach is based on several objectives that include sustainable improvement of farm house hold systems involving rural communities, enhanced input efficiency in farm production. It satisfies the basic needs of farm families, improve their nutrition and raise family income through optimum use of resources and proper recycling of residues within the system.

This approach is considered important and relevant especially for the small and marginal farmers in rainfed areas. Due to erratic monsoons and climatic variability, rainfed agriculture is becoming highly risk prone, particularly for resource poor farmers. Therefore, development and adoption of location specific IFS module would minimize risk beside other advantages. In IFS approach several components like crops, livestocks, horticultural crops, poultry, mushroom, duckery, vermin-composting, apiary, fisheries and other many enterprises get effectively integrated at the household level with a view to optimize income and resource use.

The ICAR-NRRI, Cuttack has developed modules for rainfed lowland and irrigated ecologies with rice- fish farming/ rice based farming systems. Inclusion of poultry, duckery, goatery, etc. in those IFS modules has been done. Rice based farming system including different enterprises to enhance the per unit area production of farming community is the focus of the institute.

5. BIOTIC STRESS MANAGEMENT STRATEGIES FOR RAINFED UPLAND

Upland rice suffers from several biotic stresses including diseases, insects and weeds. Losses due to pest (diseases and insects) range between 10-30%. Negligence of endemic areas can result in complete crop failures. Among the upland rice pests, major diseases are: rice blast (*Pyricularia oryzae*), brown spot (*Helminthosporium oryzae/ Bipolaris oryzae*), sheath rot (*Sarocladium oryzae*) and major insects are: yellow stem borer (*Scirpophaga incertulas*), leaf folder (*Cnaphalocrocis medinalis*), gundhi bug (*Leptocorisa acuta*) and termite (*Odontotermes obesus*) (Chauhan et al. 1991). Among important pests, this section has dealt with disease stresses which account for major loss in upland rice. The weed component has been discussed in section 3.3 of this chapter.

Rice blast caused by *Magnaporthe oryzae* is the most serious threat in uplands. Occurrences of new races of the pathogen have resulted in frequent breakdown of resistance causing 20–100% of crop losses despite utilization of many blast resistance genes in land races (Khus and Jena 2009). Despite more than 10 decades of dedicated efforts, rice blast continues to be the most destructive disease of rice. Researchers have been successfully tapping available wild sources for many genes in rice breeding for useful traits such as blast resistance genes *Pi9* from *Oryza minuta*, *Pi-40(t)* from *Oryza australiensis* and *Pirf2-1(t)* from *O. rufipogon*. The introgression of broad-spectrum blast resistance gene(s) from *Oryza rufipogon* into *indica* rice cultivar has also been reported (Ram et al. 2007). Identification of QTLs for rice blast resistance was initiated in cv. Moroberekan, a *japonica* rice cultivar cultivated in Africa. 373 QTLs for blast resistance have, so far, been identified (Sharma et al. 2012). Brown spot of rice caused by *Bipolaris oryzae (*teleomorph – *Cochliobolus miyabeanus*) is another serious disease for upland rice, causing significant crop yield loss, reported to occur in all the rice growing countries. The disease has been reported to cause enormous losses in grain yield (up to 90%) particularly under epiphytotic condition as observed in Great Bengal Famine during 1942 (Ghose et al. 1960). In Indian uplands, the disease is more severe in dry/direct seeded rice in the states of Bihar, Chhatisgarh, Madhya Pradesh, Orissa, Assam, Jharkhand and West Bengal. The disease especially occurs under moisture stress combined with nutritional imbalance, particularly lack of nitrogen. The pathogen attacks the crop from seedling to milk stage. The fungus may penetrate the glumes and leave blackish spots on the endosperm.

5.1. Management strategies for rice leaf blast

Among several management strategies, use of host plant resistance (HPR) is most effective. However, along with use of resistant variety, several cultural and chemical methods need to be integrated to reduce challenge of the fungus in order to decrease chances of resistance breakdown. Recently, marker assisted backcrossing (MAB) method has been extensively used for developing blast resistant variety. Several researchers (Miah et al. 2017) developed blast resistant rice varieties using MAB. Development of blast resistant upland rice varieties through conventional and molecular breeding has been discussed in the section 2 of this chapter.

Beside conventional cultural methods like burning of diseased straw and residual stubble, collection of disease free seeds, application of optimum N dose in splits, use of multilines of mixtures of several near-isogenic lines (NILs) with uniform phenotypic agricultural traits but different resistance levels can be used to control rice blast (Han et al. 2015).

The efficacy of various fungicides has been reported by researchers around the world. Variar et al. (1993b) identified suitable fungicide formulations (seed dressing with tricyclazole followed by need based spraying of ediphenphos) for controlling blast (both leaf and neck blast) in upland rice.

Recently, some botanicals were used for their antifungal activity against *M. oryzae*. Aqueous extracts of *Aloe vera, Allium sativum, Annona muricata, Azadirachta indica, Bidens pilosa, Camellia sinensis, Chrysanthemum coccineum*, processed *Coffee arabica, Datura stramonium, Nicotiana tabacum* and *Zingiber officinalis* were used by Hubert et al. (2015) for controlling rice blast disease *in-vitro* and *in-vivo*, without any phytotoxicity.

Chaetomium cochliodes, a biological agent, was found effective as seed dresser in the control of *M. oryzae.* Strains of *Bacillus subtillis* and *Streptomyces sindenius* have good antagonistic activity against *M. oryzae* (Yang et al. 2008).

5.2. Management strategies for brown leaf spot of rice

In the past, resistance breeding efforts have been more emphasized on diseases such as blast and bacterial blight with little focus on brown spot of rice. However, efforts have been made towards searching for resistance to brown spot. Screening of upland rice germplasm revealed partial and complete resistance to the pathogen expressed in several genotypes under field conditions (Shukla et al. 1995). Bala and Goel (2006) identified resistance sources from 15 wild rice accessions with diverse origin. Subsequently, Katara et al. (2010) identified 10 QTLs, associated with brown spot resistance. Resistance breeding using conventional and molecular methods is now underway in different institutions including that of NRRI-CRURRS, Hazaribag.

Among several fungicides evaluated, seed treatment with tricyclazole (0.4%) followed by spraying with formulation of mancozeb + tricyclazole and seed treatment with thiram followed by spraying fungicide formulation of mancozeb + metalaxyl proved highly effective against brown spot. Spraying the crop with mancozeb and edifenphos also reduced disease considerably (Lore et al. 2007). Commercially available antagonistic *Pseudomonas* and *Trichoderma* species can suppress diseases by direct effect on the pathogen through mycoparasitism, antibiosis, and competition for nutrients or by improving plant immunity. Plant extracts and botanicals have also been found to be effective against brown spot disease. Aqueous leaf extract of *Thuja orientalis* proved better for minimizing the incidence of *B. oryzae* and enhancing seed germination and seeding growth (Krishnamurthy et al. 2001).

5.3. Management of sheath rot of rice

Sheath rot is an important disease next to blast and brown spot for upland rice. Research on this disease under upland ecology was initiated in NRRI-CRURRS, Hazaribag during early nineties. Based on information generated on perpetuation mode and other ecological aspects of the pathogen in upland ecology, a low-cost method of managing the disease below threshold level, in short duration varieties under subsistence farming system, through mechanical separation of diseased seeds using 20% common salt solution was developed (Maiti et al. 1995). Once the infection from primary inoculums (from infected seeds) is managed the short duration varieties (90-100 days) of uplands escape the secondary infection.

5.4. Integrated pest management for upland rice

Degree of pest(s) infestation, in upland rice, varies as drought occurs every year during different phenological stages of crop growth (Variar et al. 1993a). Such interactive effects necessitate modifications in the pest management schedules, depending on the intensity of drought. Considering this, a suitable IPM package with flexible options, to be implemented based on need based *ad hoc* decisions, for drought-prone upland rice was developed after validation in farmers' field (Maiti et al. 1996) and time to time up-gradation was made based on farmers' feedback. Under favorable uplands with wet DSR, same schedule with additional component for weed management of using both early post emergence and need based post emergence (betweed 20-30 DAS) is necessary (Maiti et al. unpublished).

6. KNOWLEDGE GAP AND WAY FORWARD

The complex rainfed upland ecology necessitates more focus on rice varietal improvement with incorporation of multiple traits, governed by a combination of minor and major genes, into elite high yielding varieties. This can be achieved using diverse parents with desired traits following conventional pedigree breeding which is very slow process. In the current climate change scenario it is necessary to reduce the time of breeding cycle because the farmers who use varieties bred very recently are at least risk with respect to climate change. So, there is need to modernize the upland breeding program with rapid generation advancement technology, genomic prediction and recycling of new parents on the basis of field testing to increase the genetic gain. The major limitation of drought stress breeding is the lack of suitable screening methods for large volume of breeding population along with its environment specific nature. Earlier studies tried to link secondary traits with drought tolerance. However, recently direct selection for yield under drought and well-watered condition has been accepted for drought tolerance in rice (Kumar et al. 2008).

Implementation and adoption of technology related to microbial support system of nutrient management in crops is very poor owing to quality control issues. Such support system, on the other hand, is very much required for upland rice farmers which are poor and not capable of applying required amount of fertilizers in uplands. Quality control is mainly policy issue and beyond purview of research. So, exploitation of native beneficial micro-flora is an alternative to address this problem. Among microbes, fungi are most effective in acidic soils of uplands. Native AM fungi have been demonstrated to be exploited by manipulating crop culture components in favor of these fungi for improving P nutrition of upland rice (Maiti et al. 2011). Another innovative approach of exploiting native AMF flora could be through taking advantage of potential of plant species (host) to harness ecosystem services rendered by native AMF. This could be achieved by genetic manipulation of crop varieties for enhanced AM response. The agronomic and genetic manipulations for enhanced mycorrhizal nutrient acquisition and response are mutually inclusive and in combination could exploit, to the full extent, AMF biodiversity in soil. The AM-responsiveness trait, in rice, was demonstrated by the team working at NRRI-CRURRS, Hazaribag, to be linked to QTLs (Toppo et al. 2013). Identification of such QTLs would promote development of highly AM-responsive rice varieties.

By following the principles of integrated weed management system, herbicide(s) use can be reduced beside economic returns. Integrated weed management systems have the potential to reduce herbicide use (and associated costs) and to provide more robust weed management over the long term. Successful weed management is concerned with minimizing the impacts of weeds in the short term and simultaneously ensuring yield losses under an acceptable limit in the long term because of practices being implemented. Hence, the most useful practices of weed control would provide favorable stand establishment and growth for the crop, and that are simultaneously unfavorable to the weeds through manipulation of agronomic practices like fertilizer management, cropping system and seed treatment. Due to complimentary nature of such agronomic practices, need is still felt to combine these practices to the most direct methods of weed control, including hand weeding, mechanical weeding, and herbicides. Research on rice based cropping systems has been done, so far, with the perspective of improving productivity but there has been limited research on impact of intercropping configuration on weed suppression as component of integrated weed management.

Blast and brown spot are the major diseases in uplands. These biotic stresses get accentuated under moisture stress (Variar et al. 1993a). So, genetic improvement of upland rice for blast and brown spot diseases is imperative to stabilize the production. The efficacy of blast resistance is increased when genes for partial resistance is incorporated along with major genes. Two major genes for blast resistance, Pi2 and Pi9 have been incorporated through MAS and haplotypes of Pi9 also have been identified from Indian landraces (Imam et al. 2016). It is necessary to develop and validate functional molecular markers for these two genes to facilitate their use in MAB. Genetics of brown spot is poorly understood. QTLs have been reported for resistance against brown spot disease but none of them explained large phenotypic variation for this trait. Three QTLs for brown spot resistance have also been identified at NRRI-CRURRS in Kalinga III/Moroberekan populations which need to be validated for future use.

The new knowledge and technologies are not reaching most of the farmers due to poor extension efforts in this area. The extension services in many countries is very poorly trained and not equipped to handle delivery of new knowledge from researchers to farmers. This lacuna should be urgently addressed. The technology delivery system should be re-oriented to handle changing circumstances and to deliver complex, knowledge-intensive technologies to farmers. There is a need to explore private sector extension agencies in commercial farming areas and other service-oriented agencies (NGOs) in food crop areas to extend new knowledge and technologies to farmers. The effectiveness of different combinations of public, private, cooperative and NGO extension agencies need to be further strengthened.

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