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Weedy rice: problems and its management

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ABSTRACT

Weedy rice belongs to the same genus and species as cultivated rice but with different forms. It appears as hybrid swarms due to introgression of genes between wild and cultivated species in nature. In Asian rice, it is known as *Oryza sativa* var. *spontanea* whereas in African context it is said as *O. sativa* var. *stapfii*. It grows faster; produces more tillers, panicles and biomass; makes better use of available N; shatters earlier; has better resistance to adverse conditions; and possesses longer dormancy in soil. Because of its high competitive ability, it becomes a serious threat to rice growers worldwide. Great morphological variability, similar growth behavior and high biological affinity with cultivated varieties make its control difficult. No single management technique can effectively control weedy rice. An appropriate combination of preventive, cultural, mechanical and chemical control measures is essential.

Key words: Distribution, Origin, Traits, Weedy rice, Weedy rice management, Weedy rice problem

Weedy rice, an introgressed form of wild and of cultivated rice (*Oryza sativa* L.), is native of Asia (Londo *et al.* 2006) but was first documented in North Carolina, USA in 1846 (Smith 1981). A century after, it was considered a noxious weed in Arkansas, USA (Vincenheller 1906). Weedy rice infests rice fields in most of the rice growing areas in the tropics, and is particularly a problem in the direct-seeded rice systems of the Americas, the Caribbean and South and South-East Asia (Mortimer *et al.* 2000). The spread of weedy rice infestations have been reported to 40-75% of the total rice area in Europe (Ferrero 2003), 40% in Brazil **(**De Souza 1989), 55% in Senegal (Diallo 1999), 80% in Cuba (Garcia de la Osa and Rivero 1999) and 60% in Costa Rica (Fletes 1999). The extent of infestation was found 5-60% in different states of India, whereas it was observed in the range of 11.32 to 44.28% in cultivators' field and 0.78 to 2.40% at research farm of DWSR. Ten types of weedy rice (known as Sada or Sadwan) found in the farmers' field and other two types found in water ponds/tanks (called as Pasai Dhan in Madhya Pradesh) were identified and characterized (Varshney and Tiwari 2008). Different hypotheses were proposed to explain its origin (Kane and Baack 2007). It evolved from wild forms of *Oryza* or it may have originated through natural hybridization of cultivated and wild species **(**Azmi and Karim 2008) or from escaped domesticated rice seeds, which then evolved weedy traits.

In the United States, weedy rice (called red rice) has been a persistent problem for many decades (Goss and Brown 1939). In Asia, however, weedy rice is an emerging problem in Malaysia, Thailand, India, Republic of Korea, Philippines, Vietnam and Srilanka (Delouche *et al.* 2007). Its infestation was first reported in Malaysia in 1988, in the Philippines in 1990, and in Vietnam in 1994 (Mortimer *et al.* 1999, Mortimer *et al.* 2000, Wahab and Faimi 1991). Weedy rice aggressively competes with rice crop, increases production cost and reduces farmers' income quantitatively through yield reduction and qualitatively through lowering the value of cultivated rice in markets as grains of cultivated rice at harvest get contaminated with weedy rice grains having coloured pericarps (Mortimer *et al.* 2000**,** Chauhan 2013). The growth and competitive ability of weedy rice may vary considerably due to differences in plant height, tiller and leaf area producing capacity (Estorninos *et al.* 2002). Labrada (2003) stated two major weeds of particular concern to rice production; one is *Echinochloa* species, and the other is weedy rice. In Asia, rice yield losses due to weedy rice infestation were reported to be from 16-74% (Azmi *et al.* 1994 Chin, 2001). Smith (1988) reported that 5 to 10 plants/m^2 of barnyard grass, *Echinochloa crusgalli* (L.) P. Beauv. were threshold infestation to prevent yield losses of rice, whereas the corresponding density for weedy rice was only 1 to 3 plants/m^2. Serious infestation of weedy rice in Malaysia caused a maximum yield loss of 74% in direct-seeded rice (Azmi *et al.* 1994). In a later study, it was estimated that infestations represented by about 35 weedy rice panicles/m^2 would cause a yield loss of about 1 tonne rice grains/ha (Azmi *et*

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al. 2005). In the United States, low weedy rice infestations (5 plants/m^2) caused severe yield and quality losses in dry seeded rice, and also contaminated field with shattered grains of weedy rice (Diarra *et al.* 1985a). The threshold infestation of weedy rice to prevent yield losses of rice was 1-3 plants/m^2 (Smith 1988). Weedy rice at densities of 35 to 40 plants/m^2 can reduce yields of tall rice cultivars by 60% and short cultivars by 90%, which are much greater yield losses than with other grassy weeds such as bearded sprangletop [*Leptochloa fascicularis* (Lam.) Gray] (Smith 1983, Kwon *et al.* 1991). In India, infesaton was ranged from 5-60% in different states, therefore, considering mean of 10% infestation, the average loss in rice production in India was assessed to the extent of 9.15 million tones (Varshney and Tiwari 2008)

The spread of weedy rice became significant over the last 30 years due to large scale cultivation of semi-dwarf indica-type rice varieties. The spread has further aggravated due to use of commercial seeds that contain seeds of the weedy rice and through the machines used in rice cultivation specially the tillage implements and mechanical harvesters. The increase in weedy rice infestation in South-east Asia is closely associated with the increase in area under direct seeded rice (Delouche *et al.* 2007) and is a growing problem as this establishment method spreads in entire tropical Asia (Rao *et al.* 2007). Infestation of weedy rice is also reported to be higher in the no-till fields compared to the cultivated fields (Pyon *et al.* 2000).

The physical and physiological similarities of weedy rice to cultivated rice, adoption of direct seeded rice systems and the absence of standing water at the time of crop emergence in direct-sown rice fields, makes weedy rice infestation one of the most serious problems that farmers encounter during recent times (Azmi and Karim 2008, Chauhan and Johnson 2010, Chauhan 2012). Due to that reason, in some countries where direct seeding is already a common practice, farmers are reverting to mechanized transplanting to manage weedy rice. Selective herbicides to control weedy rice in conventional rice cultivation are not available and therefore, managing weedy rice is a challenging problem for farmers in Asia (Chauhan 2013). For farmers, it becomes a difficult-to-control, aggressive weed that increases the costs of production, reduces yield, lowers the market value of their crop and, where not controlled properly, can render the infested land unfit for rice production. Due to difficulties in controlling, it has been posing cancerous threat to the rice farmers of many South-east Asian countries (Karim *et al.* 2010).

Origin, sources and distribution of weedy rice

The phylogenetic origin of the weedy forms is closely related to that of cultivated rice. Many weedy plants share most of the features of the two cultivated species *i.e.*, Asian rice (*Oryza sativa)* and African rice (*O. glaberrima)*. Wild species like *O. nivara*, *O. rufipogon* and *O. longistaminata* share the same genome 'AA' as cultivated rice and can easily be crossed with the cultivated *O. sativa* and *O. glaberrima* species. The wild *O. barthii* species (*O. breviligulata*) is considered to be the progenitor of African rice. In the distant past, different types of weedy rice were generated primarily through natural crossing between wild and cultivated rice species in areas where they grew (or still grow) sympatrically (Vaughan and Morishima 2003). While this type of crossing is still important in a few areas in Africa and Asia, most types of weedy rice elsewhere now arise from much closer crosses between the plants of cultivated varieties and those of the weedy rice that infest the crop. *Oryza rufipogon*, a wild perennial rice with a red pericarp, is endemic to South and Southeast Asia and both the weedy and cultivated rice are believed to have evolved from this wild species (Khush 1997, Londo *et al.* 2006). It is considered to be an ancestor of the *sativa* (AA) group of cultivated rice, *i.e. indica, japonica* and *javanica* types, and the likely donor of the red pericarp that is the common characteristic of the weedy red rice as well as selected red-pericarp lines of rice that have been and still are cultivated. In fact, some red rice accessions in the southern USA belong to the same genotypic cluster as its progenitor *O. rufipogon* (Vaughan *et al.* 2001).

The main sources of weedy rice are the contaminated seed stocks. However**,** several "delivery systems" other than seed stocks have been implicated in the spread of weedy rice. Harvesting equipment is a significant source of contamination of rice seed lots and rice fields with seeds of weedy rice (De Souza 1989, Smith 1992). Weedy rice seeds are also spread within fields and to other fields with mud adhering to the hooves and legs of animals, the wheels of carts, trucks and similar vehicles and in the movement of rice straw (Garcia de la Osa and Rivero 1999). Because the spikelets (grains) of many of the weedy rice phenotypes are pubescent and some have long, hispid awns, the seeds can be spread by adhering to the fur of domestic and wild animals and even the clothing of field workers.

In the United States of America, weedy rice (also known as red rice) infestations were reported as early as 1846 (Allston 1846). It is generally believed that red rice was introduced into the United States of America at a much earlier date as contaminants in imported seed rice in the states of North and South Carolina in 1698 from the India subcontinent (Cragmiles 1978). As rice cultivation expanded, seeds were imported from several other countries including Japan in a search for better varieties. Indeed, weedy rice strains from Brazil, China (upper Yangtze River area), Japan and the United States of America belong to the same group called crop "mimics" with *indica* characteristics (Tang and Morishima 1996). The majority of present-day red rice accessions in the United States of America fall into the mimics' category (Vaughan *et al.* 2001). While in Latin America and the Caribbean region, the original sources of weedy rice are believed to be rice seeds imported from the United States of America (Dominguez 1999, Garcia de la Osa and Rivero 1999), Spain or through The Netherlands, France and Portugal from Asian suppliers for cultivation in their "New World" colonies. It was apparently introduced into Venezuela from the United States of America in the mid-1940s in imported rice seed stocks (Dominguez 1999).

In Cuba, it was probably introduced in rice seeds from the United States of America during the intensification of rice cultivation beginning in 1927, or perhaps even earlier from Spain during the colonial period (Garcia de la Osa and Rivero 1999). Southern European and other Mediterranean countries have not escaped the weedy rice problem. According to Vidotto and Ferrero (2005), shattering types of weedy rices were reported in Italian paddy fields early in the nineteenth century. Since the beginning of the twentieth century, weedy rices in Europe have been classified as *O. sativa* var. *sylvatica*. According to Ferrero and Vidotto (1999), red grain weedy rices began to be considered a significant problem when direct seeding replaced transplanting about 30 years ago. In Asia and West Africa, the origin of weedy rices were different from that in the Americas or Europe because they are the sites of the evolution and domestication of the two cultivated rice species, *O. sativa* in Asia and *O. glaberrima* in Africa, where there are other wild rice species, many of which are troublesome weeds, and where rice has been cultivated for thousands of years. In Egypt, the types of weedy rice (including red rices) appear to be more similar to those in the Americas and Asia than to those in West Africa and south of the Sahel.

Important traits of weedy rice

Weedy rice plants show a wide variability of anatomical, biological and physiological features (Tang and Morishima 1997, Vaughan *et al.* 2001). One group includes plants with a black hull, purple apex and long awns, showing evidence of wild traits while the other group has straw hull and apex, and no awn, mimicking cultivated varieties (Federici *et al.* 2001). The important traits of weedy rice that distinguish it from cultivated rice are rapid early growth; taller canopy; high tillering capacity; spreading growth habit with long, drooping leaves; tendency to lodge because of weak culm; voracious consumption of fertilizer; tolerance to shade, asynchronous maturation of grains; seed dehiscence; seed dormancy and a red pericarp (Burgos *et al.* 2006, Delouche *et al.* 2007). Identification of weedy rice is possible only after tillering when several morphological differences such as numerous, longer and more slender tillers, leaves often hispid on both surfaces, tall plants, pigmentation of several plant parts, easy seed dispersal after their formation in the panicle, are visible with respect to cultivated rice.

Weedy rice seems to have inherited the high reproductive capacity from modern rice varieties, and seed shattering and dormancy from wild rice, which contribute towards build up and persistence of its seed bank in the soil. The seeds of most weedy biotypes of *O. sativa* and *O. glaberrima* have pigmented pericarps due to the presence of varying levels of anthocyanin, cathekin, and catheolic tannins. Because of this reason, the term 'red rice' is commonly adopted in international literature to identify these wild plants. This term, however, does not seem very appropriate as red-coat grains are also present in some cultivated varieties, but also absent in various weedy forms. Milled japonica red rice showed greater variations in physicochemical properties than white kernel cultivars: their protein, amylose, and cooked rice hardness trended higher, while their paste and breakdown viscosities, and cooked rice stickiness were lower (Goto *et al.* 1996, Matsue *et al.* 1997). Total carbohydrates and starch contents of milled red rice from India, however, were lower than those of un-pigmented rice (Srinivas 1976).

During flowering, the florets opening of weedy rice begin between 08: 00 and 09: 00 am and continue at least one hour longer than that of the cultivated varieties. For this reason, cross-pollination is higher in weedy rice than in cultivated varieties. The flowering period in weedy rice (8-93 days) is usually longer than that of cultivated rice (7-22 days) biotypes (Longevin *et al.* 1990, Mongkolbunjong *et al.* 1999). Due to heterosis, hybrids were generally taller and more vigorous and began flowering 20-30 days later than the parent weedy plants. The seeds of weedy rice show a variable degree of dormancy (Gu *et al.* 2005). Viable weedy rice seeds with red pericarp may remain dormant up to two years or more. The longevity of the weedy rice seeds can last up to 12 years; however, it is largely influenced by burial depth (Thanh *et al.* 1999). Early seed shattering is another specific characteristic of weedy rice (Azmi and Karim 2008). It starts 9 days after flowering and increases gradually up to 30 days until complete development of the panicle. In general, the shattered grains show a lower germinability up to 24 days after flowering, in comparison to that of non-shattered seeds of cultivated rice. The seeds that shattered after 15 days from flowering contained nearly filled and physiologically mature grains (Do Lago 1982). The shattered seeds required at least 70 days in favourable temperature and moisture conditions before germination starts.

Recent threats to rice cultivation in India

In India, *O. sativa f. spontanea* is considered a weedy species in cultivated rice fields. The country has been identified as the centre of origin of rice (Vavilov 1926), and many wild and weedy relatives are present in major rice-growing areas of the country. The Western Ghats region of South India is rich in biodiversity of wild *Oryza* species including *O. rufipogon, O. nivara, O. granulata, O. malampuzhaensis* and *O. officinalis* (Thomas *et al.* 2001). Similarly in Eastern India (e.g. eastern Uttar Pradesh, Madhya Pradesh, Bihar, Odisha, Manipur, Assam and West Bengal) where wild and weedy relatives are common, two wild species, *viz.O. nivara* and *O. rufipogon* are found abundantly in lowlands, swamps and marshes, in open ditches as well as in swampy grasslands. The world weedy rice types are classified into two distinct groups corresponding to *indica* and *japonica* cultivars (Suh *et al.* 1997) and the Indian weedy rice belongs to the *indica* group similar to the wild type which indicates that these weedy rice strains may have originated from hybridization between wild and cultivated rice.

Among the different wild species present in India, *O. nivara* and *O. rufipogon* share the same genome AA as cultivated rice and can easily be crossed with cultivated *O sativa*. (Olofsdotter *et al*. 2000). Due to this reason, weedy rice is now spreading rapidly in all the traditional rice growing regions of the country including South, West and western India, either through natural hybridization or through seed stocks admixing with weedy rice seeds. However, in North-western states of India (*e.g*. Haryana and Punjab), wild and weedy relatives are not present, thus, there are very low risks of development of weedy rice naturally. However, it may spread in this region through seed stocks from other contaminated regions as it happened earlier in many countries of the United States. Thomas (2009) reported that the rice production in India might fall drastically (by over 40%) in the next few years if the weedy rice infestation was not contained. About 24–32% infestation of weedy rice was reported from Ranchi, Khunti and East Singhbhum areas of Jharkhand with an estimated yield loss of 10–45% (Sharma and Upasani 2012). Recently, it was reported that weedy rice is prevalent in the areas where direct-sown rice has been practiced for a long time in the rainfed uplands as well as lowland rice ecosystems of eastern Uttar Pradesh, Bihar, Odisha, West Bengal, Assam, Manipur, and other hilly tracts of the North East. But, the threat will be much greater in irrigated rice systems, where direct-sown rice is being adopted by farmers on a large scale in view of the current challenges (Singh *et al.* 2013). Therefore, effective management strategies are needed to counter the weedy rice threat in the direct-sown rainfed lowlands as well as irrigated ecosystems of India.

Problems caused by weedy rice

Weedy rice disperses in rice fields, and grows alongside cultivated rice, making its identification and control very difficult because of its similarity with cultivated rice at early vegetative stage. Growth and competitive ability of weedy rice may vary considerably due to differences in plant height, tiller and leaf area producing capacity (Estorninos *et al.* 2002). Blackhull weedy rice biotypes in the United States, for example, tillered 27% more and produced 18% more straw than straw-hull biotypes (Diarra *et al.* 1985b). Short varieties are usually more susceptible to weedy rice competition than tall ones. Interference between cultivated varieties and weedy rice begins three weeks after rice emergence. Compared to cultivated rice, weedy rice has a greater response to higher N rates, takes up more N, and higher N use efficiency for biomass production than cultivated rice (Burgos *et al.* 2006, Chauhan and Johnson 2011).

Tall weedy rice plants, besides shading cultivated rice, may lodge over the crop; (Caton *et al.* 1997) make crop harvesting more difficult and reduce rice yields. With heavy infestations, complete lodging of weedy rice may result in total yield loss of the rice crop (Azmi *et al.* 2000). In addition, weedy rice responded more strongly than cultivated rice to rising CO_2 level, with greater competitive ability, and subsequent negative effects on cultivated rice (Ziska *et al.* 2010). This suggests that with rising CO_2 level in future due to climate change, weedy rice may become a more serious problem than now. Another important characteristic of weedy rice is early shattering of the grain and ability to remain dormant in the soil for several years, thus assuring future infestations (Azmi and Karim 2008, Chauhan 2013). The early and heavy shattering of seeds as they mature in the inflorescence, is an important mechanism for its quick dispersal and distribution. These seeds can be transferred from heavily infested field to neighboring fields by the combined harvester or other machines used in rice cultivation. It may also transmit by the commercial seeds contaminated with weedy rice.

Management of weedy rice

Control of weedy rice is much more difficult because of its greater morphological variability, similar growth behavior, and high biological affinity with cultivated varieties. Due to this reason, control of weedy rice is expensive, time-consuming and usually does not lead to total eradication of the infestation. Incomplete control of the weed for a given year could lead to eliminating the results of several years of good control. An appropriate combination of different methods including preventative, cultural, mechanical, chemical and/or genetic practices can reduce the chances of weedy rice infestation.

Preventive management

The first and most important step in reducing weedy rice infestation is the use of certified seeds or clean seeds from a known source that is free from weedy rice grains (Chauhan 2013). Farmers should inspect their fields regularly and must rogue weedy rice plants whenever these appear. Removal of weedy rice panicles by hand at heading/flowering stage helps to reduce weedy rice seed bank in soil. There is a need to increase awareness of weedy rice among farmers so that they are able to distinguish off type and weedy rice accessions from cultivated rice (Delouche *et al.* 2007). Closer watch on the species in new areas is needed to avoid its invasion, and such plants should be rogued out upon their initial appearance in the field. Use of clean machinery is another important aspect. The machine used for land preparation, sowing, harvesting and threshing should be cleaned if it is coming from infested fields. The canals, irrigation channels etc. should be cleared from infestations of wild/ weedy rice.

Cultural management

Emergence of weedy rice could be suppressed by deep tillage that buries seed below 8.0 cm (Chauhan 2012b). However, shallow tillage operations should be done subsequently in the next few seasons to avoid bringing back the buried seeds on the soil surface. Adoption of 'Stale seed bed' technique has been reported to reduce weedy rice infestations (Delouche *et al.* 2007). In heavily infested areas, it should be repeated to incrementally deplete the soil seed bank of weedy rice. In the Mekong Delta, farmers broadcast pre-germinated rice seeds in 10-15 cm deep water (Luat 2000). This practice of 'water seeding' or 'wet seeding' buries weedy rice seeds in the soil and is not able to emerge. In heavily infested areas, puddling the field combined with the presence of a thin layer of water over the well-leveled soil maintains the anaerobic conditions in the top soil and prevents weedy plants from becoming established (Diarra *et al.* 1985a, Vidotto and Ferrero 2000). Thus, 'manual or mechanical transplanting' could be a suitable alternative method of crop establishment to prevent weedy rice infestation. Transplanted seedlings will be more competitive against newly emerged weeds and weedy rice seedlings and it will be easy to distinguish cultivated rice seedlings from weedy rice seedlings. In addition, standing water/flooding in well-leveled soils at the time of transplanting limits weedy rice germination (Chin 2001, Azmi and Karim 2008, Chauhan 2012a, b). In a study in Italy, winter flooding between rice crops resulted in greater reduction of weedy rice seeds on the soil surface as compared to fields left dry between rice crops (Fogliatto *et al.* 2010).

Use of high seeding rates not only suppress weedy rice in highly infested fields but also ensure against uncertainty in crop establishment (Chauhan 2013). Seeding rate greater than 150 kg/ha was adopted in some weedy rice infested areas in Malaysia to reduce the problem of weedy rice (Azmi and Karim 2008). Again, row crops will have an advantage over broadcast crops as weedy rice emerging between the rows can easily be distinguished and pulled out (Chauhan, 2012a). Sowing of rice in rows also helps to remove the weedy rice seedlings grown between the rows by using mechanical tools like finger weeder or cono weeder. There is a strong-felt need by the farmers in eastern India for growing purple base rice cultivars in weedy rice infested areas (Tewari 2008). High yielding purple stemmed (base) cultivars with green foliage can also be used to get rid of weedy rice infestations. Green manuring by *Sesbania* sp. in rainfed lowlands helps in successfully smothering weedy rice (Labrada 1997). Proper crop rotation by growing soybean, groundnut, maize, wheat, sunflower, sorghum, mungbean etc. would help to suppress weedy rice as cultivation practices of these crops act like an alternative herbicide treatment (Watanabe *et al.* 1998).

Chemical control

The close anatomical and physiological similarity to cultivated varieties makes the control of weedy rice plants with selective post-emergence herbicides very difficult. The most successful management technique is based on application of pre-emergence herbicides before crop sowing/planting. In continued flooded monocultures, an effective management of weedy rice can achieve by adoption of stale seed bed technique followed by spraying of the graminicides, *viz.* dalapon (12 kg/ha), clethodim (0.2 kg/ha) and cycloxydim (0.6-0.8 kg/ha) or non-selective herbicides, *viz.* glyphosate (1-1.5 kg/ha), glufosinate ammonium (0.5-0.7 kg/ha), paraquat (0.8 kg/ha) and oxyfluorfen (0.8 kg/ha) once the weeds have reached 2-3-leaf stage (Vidotto *et al.* 1998). In rice field, it was observed that pre-sowing application of anti-germinative herbicides, *viz.* molinate at 7.2 kg/ha or butylate at 4.2 kg/ha are found effective to prevent germination of weedy rice seeds (Vidotto *et al.* 1998). However, these herbicides need to immediately be incorporated into the soil to avoid volatilization. In Malaysia, it was found that application of pretilachlor (1.5-2.0 kg/ha) just before or after tillage in standing water reduced weedy rice seed bank (Azmi *et al.* 2004). In Thailand too, application of pretilachlor by dripping the concentrate or slightly diluted product directly into the water during last leveling offered an effective control of weedy rice (Allard *et al.* 2005). Herbicides like oxadiazon and metolachlor may also provide effective control of weedy rice, but to avoid any phytotoxic effect on rice, these herbicides should be applied at least 15 days before rice sowing (Eleftherohorinos and Dhima 2002). Spraying of Maleic hydrazide on weedy rice plants at the heading stage helps in reducing seed viability. However, it should be done before milky-stage of cultivated rice to avoid its negative effects on the yield and seed viability (Noldin and Cobucci 1999).

Genetic and biotechnological approach

Dilday *et al.* 1995 suggested that the problem of weedy rice can be tackled by the introduction of herbicide-resistant varieties which allow the selective post-emergence control of weedy rice infestation. The introduction of herbicide-resistant Clearfield rice (IMI rice), a mutant developed by radioactive bombardment of a conventional rice plant, made selective control of weedy rice possible with the use of imazethapyr and imazamox (Webster and Masson 2001). This herbicide has proved to be effective against weedy rice and other rice weeds when applied twice at 70 kg/habefore flooding and oneapplication of imazamox (45 g/ha) during mid season to control weedy rice and other weeds(Avila *et al.* 2005, Levy *et al.* 2006, Ottis *et al.* 2004, Steele 2002). But there is great concern about its sustainability because of the potential evolution of herbicide-resistant weedy rice populations either via gene flow from IMI rice to weedy rice (Shivrain *et al.* 2007, 2008) or increased herbicide selection pressure on the weed. An out-crossing between IMI herbicide-resistant rice and weedy rice has been discovered in Arkansas (Schultz 2004). Therefore, IMI rice should not be planted in two growing seasons in a row to ensure the longevity of this technology. Additional reduction of the weed can be achieved using herbicides with different action mechanisms or with cultural and mechanical weed control means. Crop or rice cultivar rotation has an important role in preserving the usefulness of IMI.

Herbicide tolerance has been the predominant trait of genetically modified (GM) crops since their commercialization. The genetically modified herbicide tolerant (GMHT) rice could be an effective means for weed control, especially for the management of rapid emergence of weedy rice. Many have concerns that GMHT rice would bring reduction of biodiversity, and then affect the balance of agro-ecosystem; that exogenous gene of GMHT rice would escape to cultivated rice, weedy rice and its wild relatives through gene flow; and also that GHMT rice would become a weed or invasive natural habitats. To meet people's demand of food and ensure safety to people and environment, the research about the possible effects of GHMT rice on biodiversity is urgent and important (Jiang *et al.* 2010).

With current crop management practices, including direct seeding of rice, weedy rice infestations are likely to increase and will threaten sustainability of production systems in the country. Due to their high competitive ability, these weeds can remarkably affect rice yields. No selective herbicide is available to manage weedy rice in rice fields (Chauhan 2012). Multiple approaches need to be integrated to reduce weedy rice infestations in fields as farmers usually fail to reduce weedy rice populations using a single method of control (Saha *et al.* 2013). Further research is, therefore, urgently needed to determine the impact of different tillage systems, appropriate time and duration of flooding, the use of rice cultivars capable of emerging in anaerobic conditions, and herbicide practices on weedy rice growth and control. Integrated crop management practices with varietal aspects, such as crop plant density (seeding rate), narrow row spacing, weed competitive cultivars with good initial vigour and purple base rice varieties for easy identification of weedy rice in crop fields need to be evaluated for effective weedy rice management (Chauhan 2012).

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