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A short review of the impact and management of weedy rice

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Summary

Weedy rice consists of the early shattering biotypes of cultivated rice (*Oryza sativa* L.) and the natural hybrids of *Oryza* spp. and the cultivated rice varieties. Some important characteristics of weedy rice include comparatively early maturation, easy shattering, short shattering periods, red pericarp (in some strains), short grain, long awns and tall plant habit. Continuous direct seeding over the seasons and poor water management are the main factors enhancing infestation with weedy rice biotypes. Under moderate infestation (15–20 panicles m^{-2}) there occurs about 50–60% yield loss and with high infestations (20–30 panicles m^{-2}) up to 70–80% yield loss. Weedy rice seeds are an important contaminant of rice seeds, as they diminish farmers' income qualitatively and quantitatively. On an average there is 17–28% indirect cost through land preparation and 3–5% direct cost through manual weeding or roguing, incurred for controlling the weed. The farmers may get a return of US$105–374 ha^{-1} if the weed is controlled properly. An integrated approach including the use of clean certified seeds, sequential tillage for land preparation, burning of rice straw on the field, spraying of herbicides as a pre-planting procedure, manual weeding at the mid stage of rice growth and the use of transgenic herbicide-resistant rice cultivars, are suggested options to control weedy rice populations. The practice of water seeding and transplanting of rice seedlings instead of dry seeding and the rotation of rice crop with other upland crops like soybean and maize are recommended practices to effectively manage the weedy rice problem.

Introduction

Weedy rice is characterized by undesirable early shattering biotypes that are morphologically very similar to cultivated rice varieties and can cause severe yield reduction in rice crops (Azmi *et al*. 1994). Weedy rice is known by different names such as, 'padi angin' in Malaysia, 'lua lon' in Vietnam, 'lutao' in China, 'akamai' in Japan, 'sharei' in Korea, 'khao pa' in Laos, 'khao nok' in Thailand, 'jhora dhan' in Bangladesh and 'red rice' in USA and Canada (Watanabe *et al*. 1996, Watanabe *et al*. 2000). Weedy rice consists of a range of biotypes belonging to numerous species. The wild relatives of rice with the AA genome can hybridize with cultivated rice (*O. sativa* var. *sylvatica*) and can evolve into weedy types (Catling 1992).

The wild species *O. barthii* and *O. longistaminata* or weedy biotypes from the cultivated *O. glaberima* are among the most noxious weeds in West Africa and the Sahel region of Africa (Ferrero 2003a). In Vietnam and the South-East Asian countries, the species *O. granulata, O. officinalis, O. rufipogon* and *O. nivara* are sometimes classified as weedy rice (Ferrero 2003a). Red rice (*O. sativa* f. *spontanea*) is the most common weedy biotype of cultivated rice in all rice growing areas in temperate regions (Ferrero 2003a). This weedy rice has red pericarp and dark coloured grains. In temperate areas, red rice is observed as late maturing, tall plants with pubescent leaves and hulls, a longer seed dormancy period and easy seed shattering. *O. latifolia* (locally called 'Arroz pato') is a taller (2 m height) weedy rice species that is widespread in Central America (Castro-Espitia 1999). Both the weedy rice and cultivated rice have the same number of chromosomes (2n = 24, genome = AA). However, some *Oryza* species e.g. *O. minuta* and *O. ridleyi* are tetraploid, having 48 chromosomes, they are less weedy in nature, and some have a different genome e.g. *O. officinalis* (2n = 24, genome = CC). (Table 1) (Oka 1990, Gressel 1999). Ten different genome types of *Oryza* species are AA, BB, CC, BBCC, CCDD, EE, FF, GG, JJHH, and JJKK. The wild relatives of rice with different genome types have significant reproductive isolation and usually do not hybridize under natural conditions. The wild species with AA genome are of most concern because they are responsible for gene flow to cultivated rice (Lu 2004). The species *O. sativa* hybridizes and produces viable offspring close to the wild relatives, notably *O. rufipogon* (Lu *et al.* 2003). *O. rufipogon* is thought to be the ancestor of cultivated rice and is an endangered species in China (Lu *et al.* 2003).

Weedy rice poses a great threat to rice cultivation in Asia, Africa, Europe and America (Labrada 2002, Ferrero 2003b, Azmi *et al.* 2003, Azmi *et al.* 2005a,b). In European countries the spread of weedy rice started in the late seventies after the cultivation of weak, semi-dwarf *indica* type rice varieties (Tarditi and Vercesi 1993). The infestation with weedy rice has been reported in 40–75% of the rice growing area in the European countries, 40% in Brazil, 55% in Senegal, 80% in Cuba and 60% in Costa Rica (Ferrero 2003b). This review will focus on the present status of the weedy rice problem in rice culture worldwide and suggest possible control measures.

Origin of weedy rice

Weedy rice in Malaysia could have evolved from cultivated rice by two possible ways: i) either by spontaneous mutation of genes controlling shattering or ii) by hybridization among cultivars and subsequent selection in favour of the shattering phenotypes (Abdullah *et al*. 1996). Abdullah *et al*. (1996) confirmed that Malaysian weedy rice originated from cultivated rice, since the DNA analysis using RAPD (random amplified polymorphic DNA) markers showed that the genetic structure of weedy rice was close to that of cultivated rice. In Surinam, two types of weedy rice were recognized; one type resulted from dropped seeds from previous harvests and the other was red rice (Watanabe *et al*. 2000). Uruguayan scientists are of the opinion that weedy rice has adapted to cultivation and/or the natural environment and are continually evolving in Uruguayan rice fields. Since weedy rice are compatible with and mimic cultivated rice, subsequent intercrossing and differentiation have resulted in various intermediate types (Federici *et al.* 2001). Ghesquiere (1999) noted that the weedy rice biotypes of the Mediterranean rice fields belonged to the *japonica* type and those from Brazil were close to the *indica* type. Vaughan *et al.* (2001) remarked that the samples of weedy rice collected from the United States belonged not only to the *indica* and *japonica* subspecies, but also to *O. rufipogon* and *O. nivara* species.

Table 1. Different *Oryza* species with their chromosome number, polyploidy, genome symbol, and weediness.

Species	Number of chromosome	Polyploidy	Genome[A] symbols	Weediness
O. sativa L.	24	Diploid	AA	Cultivated
O. glaberima Steud.	24	Diploid	AA	Cultivated
O. sativa var. *sylvatica*	24	Diploid	AA	Cultivated
O. sativa f. *spontanea*	24	Diploid	AA	Major weed
O. latifolia	24	Diploid	AA	Major weed
O. rufipogon Griff.	24	Diploid	AA	Major weed
O. glumaepatula	24	Diploid	AA	Major weed
O. officinalis Wall ex Watt.	24	Diploid	CC	Major weed
O. longistaminata	24	Diploid	AA	Major weed
O. barthii	24	Diploid	AA	Major weed
O. granulata	24	Diploid	AA	Minor weed
O. perennis	24	Diploid	AA	Minor weed
O. nivara Sharma & Shastry	24	Diploid	AA	Minor weed
O. minuta Presl. et Presl.	48	Tetraploid	BBCC	Minor weed
O. ridleyi Hook. f.	48	Tetraploid	HHJJ	Minor weed

[A] Taxa with the same genome symbols show no significant disturbance in chromosome pairing in their hybrids. Source: Oka 1990, Gressel 1999, modified.

Table 2. Agronomic characteristics and morphology of weedy and cultivated rice.

Characteristics	In Vietnam		In China	
	Weedy rice	Cultivated rice	Weedy rice	Cultivated rice
1. Plant height (cm)	112.5	74.3	126.0	95.0
2. Number of panicles per hill	2.4	2.1	5.0	3.0
3. Number of tillers per plant	–	–	4.0	2.0
4. Panicle length (cm)	20.1	17.2	21.0	18.0
5. Number of grains per panicle	53.1	34.3	117.0	84.0
6. Length of grain (mm)	8.2	8.4	8.6	8.4
7. Width of grain (mm)	2.9	2.8	–	–
8. Weight of 1000 grain (g)	22.6	22.6	19.5	20.4
9. Awn length (mm)	25.7	0.0	–	–
10. Length of flag leaf (cm)	30.8	21.9	–	–
11. Colour of grain	Red	Brown	Light green	Light green

Source: Chin 1997, Liuqing *et al*. 2000, modified.

Characteristic features of weedy rice

Morphological features

In general weedy rice plants are taller, produce more tillers and panicles per hill, with greater panicle length and more grains per panicle, longer flag leaf and have an earlier flowering habit than cultivated rice (Table 2) (Chin 1997, Liuqing *et al.* 2000, Azmi *et al*. 2000). Although they show close similarities to modern cultivars, they differ from the latter in terms of plant height, pericarp pigmentation, possession of an awn and longer panicles. From a survey in the Muda area of Malaysia it was observed that 93% of weedy rice plants were taller than the modern cultivars (e.g. MR84, MR123), 34% had pigmented grain, and 39% had grains with long awns (Tada and Morooka 1995).

Red rice biotypes cannot be distinguished easily from the cultivated varieties at the early stages, but at the tillering stage they are distinguished by greater height, more numerous, longer and more slender tillers, leaves that are often hispid on both surfaces, pigmentation of the pericarp and easy seed dispersal after formation in the panicles (Ferrero 2003a). In a study in Uruguay with 26 weedy rice accessions it was observed that one group of plants possessed black hull, purple apex and long awn indicating wild traits; while the other group contained straw hull and apex, with no awn, similar to cultivated species (Federici *et al.* 2001). Mongkolbunjong *et al*. (1999) noted that the flowering period of wild rice varied from 8 to 93 days whereas the cultivated varieties needed only 7 to 22 days to complete flowering. Weedy rice usually matures one week earlier than cultivated rice. The most important characteristic of weedy rice is the early shattering of the grains, before the harvest of the rice crop. At maturity weedy rice plants can easily be identified by the handgrip test. A slight handgrip can easily cause grain shattering from the panicle and accumulation in the palm of the hand (Azmi *et al*. 2000).

Grain shattering ability

Grain shattering of weedy rice varies for the different biotypes. In an investigation in Malaysia, it was observed that three variants showed the following different shattering traits. Variant A (awned and pigmented grain) shed their seeds continuously for 20 days between 10 to 30 days after heading (early shattering type), variant B (awnless and pigmented grain) and variant C (awnless and non-pigmented grain) shed their seeds more rapidly; with shattering beginning earlier and ending within 10–12 days (spontaneous shattering type) (Azmi *et al*. 2003). The seed shattering behaviour of weedy rice is controlled by the gene 'Sh' in the conditions of homozygous (Sh Sh) or heterozygous (sh Sh) (Sastry and Seetharaman 1973). The seed dropping occurs due to the formation of abscission tissue developed by three layers of cells between the spikelets and the pedicel (Nagao and Takahashi 1963). Most of the weedy rice start shedding their seeds usually after 13 to 14 days of initial heading regardless of heading time, and usually 10 to 20 days earlier than the rice crop (e.g. MR84) (Azmi *et al*. 2003).

Seed dormancy

Weedy rice has variable seed dormancy unlike cultivated rice. Seed dormancy of weedy rice usually disappears three months after shedding, and this leads to severe problems in the next season of double rice cropping in Malaysia and neighbouring countries (Tada and Morooka 1995). The degree of seed dormancy of the spontaneous shattering type is higher than that of the intermediate shattering type (Tada and Morooka 1995). The seed longevity of weedy rice may be up to 12 years (Diarra *et al.* 1985). In a study at the United States, some samples of the weed seed remained 90% viable after two years of burial in the soil (Ferrero 2003b), however the viability of the weed seed was found to decrease by 5% after two years of burial in Italy (Ferrero and Vidotto 1998). Under the direct seeded conditions, weedy rice emerges earlier than the seeded cultivated rice, thereby gaining a competitive advantage over the cultivated rice (Watanabe 1996). Some Korean weedy rice strains were found to have a high degree of germinability at low temperatures and a high degree of shoot emergence in deep water (Suit *et al.* 2002). Weedy rice seeds survive longer than cultivated rice (MR84 and MR123) seeds in the soil and a high percentage of seeds could germinate after one year of storage at room temperature (Anon 1999).

Impact of weedy rice on rice production

Rice yield loss

Since weedy rice biotypes have a similar morphology to cultivated rice varieties, they are more difficult to control as compared to other weeds. Weedy rice reduces the yield of the rice crop, as the grain is lost because of their early and easy shattering characteristics. Weedy rice plants have been reported to have dispersed about 970 kg ha^{-1} seeds in rice fields in one season, which is a great harvest loss, besides increasing the weed seed bank. One of the weedy rice variants was found to shatter as much as 57% of its grains at 95% ripening as compared to the cultivated rice varieties MR84 and MR123, which shattered only <0.05% of seeds (Azmi *et al*. 1994).

Under moderate infestation of weedy rice (15–20 panicles m^{-2}) there is approximately 50 to 60% yield loss, under high infestation (20 to 30 panicles m^{-2}) 70 to 80% yield loss and under heavy infestation (more than 40 panicles m^{-2}) lodging of weedy rice may cause total yield loss under tropical climatic conditions (Watanabe *et al.* 1996, Azmi and Abdullah 1998, Azmi *et al*. 2000, Azmi *et al.* 2004). In the United States, a yield loss of 60% in cultivar '*oryzica*' was observed when the weed competed at a density of 20 weeds m^{-2} for first 40 days (Fischer and Ramirez 1993). A 75% yield loss was noted when the weed competed for the whole season at a density of 24 weeds m^{-2}. In Vietnam, a weedy rice density of 10 plants m^{-2} caused a significant yield loss (Chin *et al*. 2000).

Quality deterioration of the rice grain

Weedy rice seed is an important contaminant in rice seeds and this ultimately contributes to the introduction of weedy rice plants into the fields and finally diminishes the farmers' income both quantitatively and qualitatively (Mortimer *et al.* 2000, Ferrero 2003b, Azmi *et al.* 2005a). In a study in Malaysia it was observed that the direct-seeded crop, raised from certified seeds produced by licensed seed growers, contained about three weedy rice panicles per m^2 (Azmi *et al.* 2005a). A similar situation was also noted in Vietnam, where weedy rice was found to be the major seed contaminant (Mai *et al.* 2000). Weedy rice reduces the quality of rice grains due to the presence of coloured grains. Sometimes unripe weed grains are mixed with the cultivated rice grains during early harvesting, which is done to avoid heavy shattering causing a reduction in the market value (Azmi *et al.* 2003). The red layers of weedy rice grains need to be removed by extra milling, which sometimes results in broken grains thus eventually reducing the commercial grade (Smith 1981, Diarra *et al.* 1985).

Increase in the cost of production

Azmi *et al.* (2005b) has estimated that the cost of weedy rice control as an indirect cost through land preparation is 17–28% and direct cost through manual weeding or roguing of weedy rice plants is 3–5% of the total cost (US$636–850 ha^{-1}). The farmers may get the return of US$105–374 ha^{-1} if the weeds are controlled adequately (Azmi *et al.* 2005b).

The undesirable characteristics of weedy rice that interfere with rice cultivation are given in Table 3.

Factors favouring weedy rice infestation

Crop establishment techniques

In European rice growing countries (e.g. Italy, France, Portugal and Greece) the spread of weedy rice (red rice) became significant as direct seeding is preferred to

Table 3. Undesirable characteristics of weedy rice that interfere in rice cultivation.

Characteristics	Mode of interference to rice production
Plants mimic cultivated rice	Difficult to identify during manual weeding
Long culm and slender internodes	Cause lodging, competitive edge over rice
Early and spontaneous shattering	Reduce rice yield and increase weed seed bank in soil
Longer seed viability in soil	Makes it difficult to reduce the size of the weed seed bank
Persistent and long seed dormancy	Makes weed control difficult
Short, pigmented grain and coloured pericarp	Reduces rice quality and commercial grade
Tolerant to most of the normally used rice herbicides	Makes post-planting chemical control less effective

Source: Azmi and Abdullah 1998, modified.

transplanting (Ferrero 2003a). The weed problem in Central America is the result of permanent monocropping of rice and adoption of the direct seeding practice in rice cultivation (Labrada 2002). Similarly, in Malaysia and nearby countries, dry-seeding associated with the retaining of volunteer seedlings are considered to be the most important contributory factors to infestation by weedy rice (Azmi *et al.* 2000). Poor establishment can often result in dry seeded fields, which are subjected to the vagaries of uncertain rainfall, and this can favour weedy rice forms. At present, weedy rice infestation is severe and increasing with the spread of the direct-seeding rice culture in Tropical Asia (Moody 1994). Infestation of the weed is reduced to a great extent if pre-germinated rice seeds are sown in puddled soil with 5–10 cm water, a technique called the water seeding (Armenta and Coulombe 1993, Vidotto and Ferrero 2000, Azmi and Muhammad 2003).

Seed purity
Rice seed contaminated with weedy rice seeds is an important factor which causes weedy rice infestation in the rice fields. The spread of weedy rice to un-infested fields has occurred in Europe and South Asian countries by the distribution to the farmers of rice seeds contaminated with weedy rice seeds (Johnson 1996, Ferrero 2003b, Azmi *et al.* 2005a). Noldin (2002) stated that in Brazil, planting fields free of weedy rice (red rice) with rice seeds containing only two seeds kg^{-1} contamination may result in a soil infestation of 100 kg weedy rice seeds ha^{-1} after three seasons only.

Characteristics of rice cultivars
Short varieties of rice are usually more affected by weedy rice than the tall varieties (Kwon *et al*. 1991). In Tanzania, Johnson *et al*. (1999) noted that the growth of weedy rice species *O. barthi* was sufficiently suppressed by the cultivation of the tall rice variety, 'Kilombero'; whereas the cultivation of the short stature 'Katrin' resulted in the overgrowth of the weed.

Method of land preparation
The method of land preparation also has an important bearing on the emergence of weedy rice in rice fields. Increased soil rotovation can reduce the emergence of weedy rice seedlings (Azmi *et al.* 1999). The degree of weedy rice infestation is also directly dependent on the size of the weed seed bank (Azmi *et al.* 1999). From a study in Italy, Ferrero and Vidotto (1999) compared the effects of harrowing and ploughing on the emergence of weedy rice (red rice) seeds. They found 7.2% emergence in harrowed plots and 2.5% emergence in ploughed plots. The reduced emergence in ploughed plots was due to deeper placement of the weedy rice seeds in the soil during soil inversion.

Table 4. Field operations and their relative contribution in controlling weedy rice.

Field operations	Effectiveness[A]	After effect[B]
1. Adoption of the transplanting method of cultivation	5	AB
2. Land preparation with sequential tillage	5	AB
3. Application of foliage herbicide at land preparation	4	A
4. Intensive manual weeding and rouging	4	A
5. Use of competitive cultivars	4	BD
6. Burning of rice straw in dry rice fields	3	GA
7. Use of certified, pure rice seeds	3	C
8. Irrigation 3–5 days after sowing	3	AB
9. Sowing of pre-germinated seeds in standing water	3	AD
10. Sowing of seeds in lines/rows	3	BE
11. Using of vigorous rice seeds	2	C
12. Use of higher seed rates	2	D
13. Correct timing of fertilizer application	1	D
14. Soil-incorporation of pre-plant herbicides	1	A
15. Timely harvesting	1	CF

Source: Watanabe *et al*. 1996, modified.
[A] Effectiveness: 1 = less effective, 5 = very effective.
[B] After effects: A = reduce weedy rice and volunteer seedling population, B = uniform crop establishment, C = prevents weedy rice contamination, D = better crop establishment and gives competitive advantage over weedy rice, E = facilitates manual weeding, F = prevents grain shattering, G = destroys weedy rice seeds on the soil surface.

Soil depth
The depth of soil influences the germination of weedy rice seeds and thereby affects the weedy rice infestation in the fields. In a study when the seeds were buried at a depth of 4–5 cm, a delay in germination by 15 days was observed as compared to when the seeds were placed near the soil surface (Ferrero and Finassi 1995). No emergence took place from the depth below of 10 cm.

Water management
Management of water in rice fields influences the infestation with weedy rice. Poor water management i.e. insufficient water during flooding in the early stages encourages weedy rice infestation (Azmi *et al*. 1999). Minimum tillage, performed to no more than 10 cm in depth and good soil moisture are the best conditions for weedy rice emergence, whilst ploughing with a mouldboard plough and soil flooding after land preparation are the worst conditions for weedy rice seed germination (Ferrero and Vidotto 1999).

Roguing
Failure to rogue the infested rice fields may aggravate the problem of weed seed contamination of the grain retained for planting the following season (Watanabe 1996) and also increase the weed seed bank in the soil (Rao and Harger 1981). An escape of 5% or less weedy rice in the field can produce enough seeds to restore the original seed bank in soil (Rao and Harger 1981).

Control of weedy rice
Cultural management practices
The relative contribution of different field operations in controlling weedy rice is given in Table 4. The use of clean certified seed, proper land preparation following sequential tillage with a 10 day gap, selection of competitive cultivars, use of foliage herbicides before crop planting, irrigation 3–5 days after sowing and intensive weeding and roguing are the best options that help to reduce the weedy rice population (Nakayama *et al.* 1996, Azmi *et al*. 2000, 2003, Watanabe *et al*. 2000). Burning rice straw in dry rice fields can help to destroy weedy rice seeds on the soil surface (Azmi *et al.* 2000). The germination of weedy rice at a soil depth of 5 cm was 30% less when it was covered with water to a depth of 6–8 cm than in moist conditions under Mediterranean climatic conditions (Vidotto and Ferrero 2000). Sowing of pre-germinated seeds on to the soil, which was flooded for 20 days after puddling, resulted in good suppression of weedy rice in Central America (Armenta and Coulombe 1993). Azmi and Muhammad (2003) practiced water seeding in Malaysia

(seeding of pre-germinated seeds under 5–10 cm water after seedbed preparation) and found that the weedy rice population declined from 30% (in the previous season, 1999) to 10% (the following season, 2000) and the seed return to soil seed bank was reduced to 24–30%. Stale seed bed (false seeding) technique of rice cultivation can aid in reducing the weedy rice problem to a great extent (Ferrero 2003b). In this technique, after seedbed preparation, the area is left idle, to allow weedy rice to grow, the seedlings are then destroyed either mechanically or chemically before sowing of the rice crop. A new technique of seedling broadcasting with 5–10 cm water in the field has been introduced to replace wet seeding in order to suppress weedy rice (Chin *et al*. 2000).

In addition, manual weeding at the early stages and roguing of weedy rice plants after the mid stage of the rice plant growth are the most effective operations for controlling weedy rice. In Vietnam, roguing during the tillering, booting and flowering stages is an important method of control (Mai *et al*. 2000). In Colombia, the panicles are cut by a machete, while in Europe this operation is usually done with a combine harvester-cutting device. About 94% panicles can be cut in two phases by using this equipment (Ferrero and Vidotto 1999).

By rotating rice with other upland crops such as soybean, maize and mungbean and by using clean combine harvesters in non-infested fields, weedy rice problems could be reduced (Azmi *et al*. 2003; Chin 2001). The practice of mungbean cropping after rice in Vietnam resulted in a huge reduction of weedy rice infestation (Watanabe *et al.* 1998). In Italy, cultivation of soybean after rice for one year led to a reduction of the weedy rice seed bank by about 97% (Ferrero and Vidotto 1997). Similar results with rotation cropping were also found in the United States, where one or two-year rotation with soybean usually served to control severe infestations of weedy rice (Griffin and Harger 1990, Noldin *et al.* 1998).

A life cycle model of weedy rice along with various strategies of management, as proposed by Pandey *et al*. (2000) and Azmi *et al*. (2003), can be followed in order to reduce weedy rice population in the rice ecosystem.

Chemical control

Incorporating molinate at 4.5 kg a.i. ha^{-1} in the soil just before seeding is a good chemical method to control the germination of the weedy rice seeds from the soil seed bank (Azmi and Abdullah 1998). The combination of a pre-sowing treatment of pretilachlor at 0.6 kg a.i. ha^{-1} in flooded fields, drainage before sowing and seed treatment with fenclorim (as safener) are also effective control methods (Nakayama *et al.* 1996, Anon 1999, Azmi *et al*. 2003). Under European conditions good control (more than 75%) can be obtained with pretilachlor and dimethenamid used alone or in combination at 1.5 kg ai ha^{-1} and 0.48 kg ha^{-1}, respectively (Ferrero and Vidotto 1999).

Use of herbicide-resistant cultivars

Development of herbicide-resistant rice cultivars (HRC) may serve as an effective alternative when adopting chemical control. Oard *et al*. (1996) and Zhang *et al*. (1999) observed effective control of weedy rice by glufosinate when glufosinate-resistant transgenic rice bearing the 'bar' genes were mixed with weedy rice and then sprayed with glufosinate. Glufosinate applied at the 3–4 leaf stage of weedy rice resulted in better control (91%) than at the panicle initiation (74%) or booting stage (77%) (Sankula *et al.* 1997). Rice cultivars tolerant to glufosinate, imadozolinones and glyphosate have already been developed in USA (Valverde *et al*. 2000). However, continuous use of HRCs combined with inappropriate use of herbicides may lead to the development of herbicide-resistant weedy rice. The possibility of gene transfer from the transgenic herbicide-resistant rice to the weedy rice has been studied in Spain. It was observed that the average gene flow from the transgenic 'Senia' (tolerant to glufosinate) to red weedy rice was only 0.082% (Messequer 2002). Chen *et al.* (2004) noted in China that the detectable rate of the herbicide resistance gene flow from the transgenic rice to the weedy rice plants varied between 0.011~0.046%. As per assessment report of the Advisory Committee on Releases to the Environment (ACRE), UK, the consequences of gene flow from the genetically modified herbicide-tolerant rice, LLRICE62 to the weedy rice is not an important issue for UK (Anon. 2004).

Introgression of uniform ripening and anti-shattering genes into weedy rice could help in harvesting the non-shattering weedy rice seeds with the cultivated rice (Gressel 1999).

Conclusions

An infestation of weedy rice in areas where direct-seeding is practiced poses a serious threat to the rice industry. Neglecting weed control for merely one season may create a severe problem in the future. All possible control measures should be integrated, adopted and monitored to check the spread and size of the weedy rice population in rice fields. Destroying the weedy rice plants near the cultivated rice fields in addition to other control methods should be undertaken in order to prevent possible hybridization between the wild and cultivated rice. Song *et al.* (2004) suggested that an isolation distance of 100 m between genetically engineered (GE) rice and non-GE rice or close wild relatives should be maintained and sugar cane may be planted as a buffer to reduce GE pollen dispersal. Farmers should be made aware of the weedy rice problems and advised on their control methods through appropriate training programs, like the multimedia strategic extension campaign (SEC) on Integrated Weed Management (IWM) carried out in Malaysia. The campaign was launched in the Muda area in 1989 to inform, motivate and persuade the farmers to adopt the holistic approach of IWM in order to overcome the weed problem. After one year of adoption of the IWM program by the farmers a substantial impact was noticed; reduction of weed infestation was reduced by 66%, yield was increased by 27%, and use of herbicides was reduced to a great extent. The economic benefit per farm family that adopted the SEC recommendation was about US$195 per season (Ho *et al.* 1990, Ramli and Khor 1990).

No single weed control method can effectively manage the weedy rice problem since both weedy and cultivated rice plants have similar morphological and physiological characteristics. An integrated approach based on ecological methods and involving indirect and direct control methods especially at the pre-planting stage should be adopted.

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