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Weedy Rice (*Oryza sativa f. spontanea*) Complexes on Direct Seeded Rice (DSR) and its Management Strategy: A Review

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ABSTRACT

Weedy rice (*Oryza sativa f. spontanea*) is one of the most notorious weeds occurring in rice growing areas especially in direct-seeded rice (DSR) system, worldwide and the problem is pervasive. It is a complex of *Oryza* morphotypes widely distributed in the commercial rice fields in more than 50 countries of Asia, Africa, Latin America and Southeast Asia. Weedy rice is progenies of crosses between wild rice and cultivated. The major characteristic of weedy rice is easy shattering. Other characteristics observed are taller plants, fewer tillers, grains having awns and high percentage of red rice in milled rice. It is difficult to manage the infestation of weedy rice because of its morphological similarities with cultivated rice. Recently, biotechnology approach using genetically modified herbicide tolerant rice varieties may be an efficient strategy. A non-transgenic rice variety Clearfield' is tolerant to Imidazolinone herbicides. It aims at determining whether the integration of Imidazolinone herbicides and tolerant trait in the genotypes can be used for controlling weedy rice in rice field. Satisfactory control of weedy rice requires an integrated approach based on the combination of preventive, cultural, mechanical, chemical and biotechnological means rather than using only a single method for its control.

Key words: Direct seeded rice, Infestation, Management strategy, Weedy rice.

Rice is the staple food for more than half of the world population. Asia accounts for 90% of the world's total rice area and production. In India, rice is grown on approximately 45 million ha annually with a production of 104 million tonnes. India's rice demand is estimated to rise to 122 million tonnes in 2025, which is equivalent to an overall increase of 22% in the next 10 years. But, the current evidence shows declining factor productivity and a plateau in rice yields due to fatigued natural resources, declining water table, increasing labour scarcity and energy shortage, escalating fuel prices and changing climatic conditions. Therefore, yield of gains have to be achieved by using less water, labour, land and energy.

In India, rice is most commonly grown by transplanting rice seedlings into puddled soil (wet-tillage). Both transplanting and puddling, however, require a large amount of water, labour and energy. All these resources are becoming increasingly scarce, making rice production more expensive and less profitable. Therefore, interest has increased in shifting from puddled transplanted rice to direct seeded rice (DSR). DSR is more rapidly and easily planted, less labour intensive, consumes less water, matures 7 to 10 days earlier and has less methane emissions. Despite these benefits, one of the major threats associated with the introduction of DSR is the evolution of weedy rice, one of the most difficult-to-control weed species of rice in the world (Azmi *et al*., 2000).

Weedy rice

Weedy rice is one of the most persistent and noxious weeds found in rice-growing ecosystems worldwide (Cao *et al*., 2007). It can be defined as a weedy population of genus *Oryza*.

(1) It is similar to cultivated rice but has greater seed dormancy and longevity, high susceptibility to seed shattering, red pigmentation of pericarp.
(2) Grows unintentionally and vigorously in and around cultivated rice.
(3) Very diverse phenotypically and genotypically.
(4) Highly competitive and difficult to control.
(5) Reduces farmers' income by reducing grain yield, quality and profit.

Weedy rice known as *O. sativa f.spontanea* is the result of mutation or natural crosses between cultivated species of *O.sativa* with the annual *O. nivara/O. rufipogon* (Gupta and Upadhyay, 2000). Weedy rice is known by different names in different countries. Examples are "Padi Angin" in Malaysia, "Lua Lon" in Vietnam, "Lutao" in China, "Akamai" in Japan, "Sharei" in Korea, "Khao Pa" in Laos, "Khao Nok"

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in Thailand and "Jhora Dhan" in Bangladesh (David Johnson, 2011).

Origin and distribution

It is widely hypothesized, that weedy rice may have a variety of origins (Vongsaroj, 2000). Weedy rice is a complex of *Oryza* morphotypes widely distributed in the commercial rice fields in more than 50 countries of Asia, Africa, Latin America and South east Asia, epecially in areas where farmers have switched to direct seeding. The Indian weedy rice belongs to indica group. In India *Oryza sativa f. spontanea* is considered as weedy species in cultivated rice. Its problem in Eastern India (Eastern U.P., Bihar, Orissa, Manipur and West Bengal) and Southern India (Kerala, Karnataka and AP) (Abraham *et al*., 2012).

Botany of weedy rice

Common name : Weedy rice
Scientific name : *Oryza sp*
Family : Poaceae

Weedy rice has variable, erect, stout or slender annual rice with varying height and form.

Stem

Tufted, erect, hollow and slender or stout, smooth and hairless, 80-120-cm tall.

Leaf

Blade flat with parallel veins, 15-30 cm long. Ligule and auricle present; Ligule usually 10-20 mm long.

Inflorescence

An erect or nodding loose panicle, spikelet about 7-mm-long, flat, one-flowered, with or without awns of varying length.

Weedy rice characters

Weedy rice is variable in height, panicle form, grain size, awn length, flag leaf and growth duration. Weedy rice can be a serious problem because it is very competitive with cultivated rice, its seeds have dormancy and its grains shatter easily. Weedy rice tends to have vigorous vegetative growth, comparatively early maturity, easy shattering and, in some variants, the grains have long awns and the grain (preicarps) color after milling is red (David Johnson, 2011).

Weedy rice has variable seed dormancy, but commonly a large proportion of the seeds will germinate within 3 months of shedding. This can lead to severe problems in a subsequent crop where rice is double-cropped (David Johnson, 2011). They come to flowering much earlier than cultivated rice and produce grains having awns, with varying coloration of ear head. The seeds mature within a short period and shatter immediately facilitating the buildup of weed seed bank before the farmer gets a chance to remove the seeds along with the harvest of rice crop (Abraham *et al*., 2012). Weedy rice is taller than common rice, grain has awns, grain shatters early, grain has a dark pericarp color, plants flower early and grains are smaller (Mai *et al*., 2000).

Weedy rice grows taller than cultivated rice and it has longer and wider leaves. Weedy rice reached a height of 140-150 cm, whereas cultivated rice grew to 115-120 cm. Because it is tall, weedy rice lodged and its panicles drooped and it germinated and emerged at the same time as cultivated rice, but it flowered earlier and its seeds matured 4–5 days earlier than did those of cultivated rice. The grains shattered at or even before maturity. Weedy rice also produced fewer leaves, tillers, panicles per plant and grains per panicle than cultivated rice. The grains were smaller and the pericarp shorter than those of cultivated rice (Ramachandiran and Balasubramanian, 2012). Currently the wide spread incidence of weedy rice in the rice wing tracts of Kerala has become a major threat to the rice cultivation in the state. A survey conducted by AICRP on weed control in the rice growing tracts of Kole lands, Thrissur and Kuttanad of Alleppy and Kottayam districts revealed the presence of different biotypes of weedy rice variation in height from (70 cm to 130 cm), tiller number (1 to 32), panicle number (1 to 12), awn length (1.8 to 6.6) and seed colour varied from golden yellow, brown and black. The initial germination (just after harvest) ranged from 8-12%. Above 50% of the seed germinated after 5 months of storage, 5-10% seeds germinated during the intervening period (Girija *et al*., 2010). Chin (2001) reported that one major feature of weedy rice is its shattering trait. This would result in higher population densities in the soil seed bank, thus rendering control more difficult. The other major characteristics of weedy rice are tallness, low tillering ability and a high percentage of red rice (weedy rice) and unfilled grains.

Dispersal of weedy rice

Weedy rice spreads rapidly from infested fields to new non-infested areas. Knowledge of the sources responsible for the dispersal of weedy rice can help in preventing its spread to non-infested areas. The use of contaminated weedy rice seeds is the most important source of its spread to new areas. The use of weedy rice-contaminated agricultural equipment/machinery also plays a vital role in its dispersal (Olguin *et al*., 2009). It is therefore important to use weedy rice-free certified seeds and machinery should be cleaned before moving it to new areas to prevent weedy rice spread. In addition, weedy rice can be dispersed from one field to another through irrigation channels or irrigation water, heavy winds or storms and flooding.

Extent of infestation

Weedy rice was first documented in USA as early as 1846 and has continued to affect the rice production areas. Weedy rice is a superior competitor to crop cultivars due to its early vigour, greater tillering and height of plants. Yield losses largely depend on season, weed species, weed density, rice cultivar, growth rate and density of weeds and rice. Weedy rice at 35% infestation caused about a 60% yield loss and, under serious infestation, yield loss of 74% was recorded in direct seeded rice (Mispan and Baki, 2008). Yield of weedy rice infested plots at the rate of 10, 100 and 1,000 weedy

seeds per square meter were 4.05, 2.75 and 0.43 t ha^{-1}, respectively, compared to the check yield of 4.53 t ha^{-1} (Chin and Mortimer, 2002). Short varieties are usually more susceptible to weedy rice competition than tall ones and interference duration is also a yield deciding factor (Shivrain *et al.,* 2009). Weedy rice usually coexisted with cultivated rice and was highly competitive in rice fields of China (Xia *et al*., 2011). According to Chauhan (2012), the important weedy traits of weedy rice are early shattering of seeds, variable seed dormancy, high seed persistence in soil and high nitrogen use efficiency.

Weedy rice infestation across the world

The infestation has spread across the globe and is now a problem particularly to America, the Carribean, South Asia and South east Asia. There are many reports on weedy rice infestation although per cent area infested varies. Infestation of weedy rice has also been reported in China, Thailand, Sri Lanka, Vietnam, the Philippines and in many states of India. An yield loss of 74% in direct seeded rice has been reported in Malaysia. Weedy rice densities of 35-40 plants/m^2 can reduce yields of tall rice cultivars by 60% and short cultivars by 90%, indicating losses greater than grass weeds (Rathore *et al*., 2013)

Weedy rice infestation across the India

The problem has now invaded India with an infestation of 5-60% across different states. A paddy field in *Kharif* 2012 of Jabalpur district, Madhya Pradesh infested with weedy rice where labours are engaged in hand weeding to remove the same. In 2009, agronomists from West Bengal also detected and revealed their concerns regarding weedy rice to the State authorities. Rice agricultural fields in Kerala were found to have weedy rice as a major problem (Abraham *et al*., 2012). Heavy infestation in the fields of Kerala during recent years has caused a reduction in yield by 30-60% depending on severity of infestation (3-10 mature plants of weedy rice/m^2).

Recently, Jharkhand recorded 24-32% infestation of weedy rice across Ranchi, Khunti and East Singhbhum areas with as estimated yield loss of 10-45%. Heavy infestation of weedy rice is seen in eastern and southern India where direct seeding of rice is common, though it is yet not a problem in Haryana and Punjab where paddy is cultivated through transplanting method (Rathore *et al*., 2013).

Management strategy of weedy rice

Weedy rice is very difficult to control with a single method and an integrated weed management (IWM) strategy is needed for its effective control in DSR systems (Singh *et al*., 2013). IWM consists of preventive, cultural, chemical, mechanical and biotechnological approaches.

Preventive methods

Prevention is one of the most important steps that can be implemented immediately to minimize the infestation of weedy rice in DSR fields.

Use of weedy rice-free seeds

It is one of the best preventive measures to control weedy rice. The use of self-saved rice seeds is considered one of the major causes of the spread of weedy rice to new areas (Abraham, 2012). Seed replacement and the selection of pure, good-quality certified seed is the best method to prevent the introduction or dissemination of weedy rice in new areas (Kathiresan and Vishnudevi, 2021).

Use of clean agricultural implements

Agricultural implements can disperse weedy rice seeds from one area to another and proper cleaning of harvesting/ sowing equipment prior to its use in new areas can prevent the spread of weedy rice seeds (Chauhan, 2013).

Increasing awareness for farmers

There is a need to increase awareness for farmers about the risk imposed by weedy rice (Nadir *et al*., 2017). 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 (Svizzero, 2021).

Cultural methods

Cultural strategy of weedy rice control includes the use of weed suppressing varieties and submergence tolerant varieties. Tall and long cycle varieties usually have shown a greater competitiveness than modern early and semi dwarf varieties (Marambe, 2009). Non chemical means of weed control in rice should be centered on land preparation, varietal selection of crop, water management and fertilizer management (Svizzero, 2021). California Department of Food and Agriculture (2001) reported that in the absence of effective selective post emergence chemical control, techniques to minimize weedy rice infestations necessarily focused on

(1) Lowering the chance of emergence of weedy rice seedlings at crop establishment.
(2) Preventing subsequent seed return to the soil from surviving plants at maturity.

Stale seedbed technique

The field is irrigated and left unsown for two to three weeks to allow weedy rice seeds to germinate and then emerged weedy rice seedlings are killed by either a non-selective herbicide (paraquat or glyphosate) or by shallow tillage prior to rice sowing (Nadir *et al*., 2017). The duration of the stale seedbed must be long enough to allow the weedy rice seedlings to grow up to 2 to 3 leaf stage and must not delay the sowing of the main crop. This technique not only reduces the weedy rice population in the crop but also decreases the weedy rice seed bank in the soil (Marambe, 2009). The rice seed should be sown with minimum disturbance to avoid bringing new seeds buried at deeper depth to the upper germination zone of the soil and also to avoid exposure of weedy rice seeds to light and other stimuli that encourage germination and emergence of weedy rice (Kathiresan and Vishnudevi, 2021).

According to Azmi and Johnson, (2001) the success of the stale seed bed method depended on the way the soil

is prepared, the water management and its duration. Wet tillage after weed germination destroyed weedy rice seedlings and promoted new emergence. Sindhu *et al.* (2011) pointed out that soil flooding during the application of the stale seed bed reduced emergence from the soil in comparison to dry or moist soil, but favoured the evenness of the germination that in turn made the control easier. The duration of this technique in temperate climate conditions should be about 25-30 days.

Soil solarisation

Soil solarisation was reported as an advanced non chemical field technology for weed management (Marambe, 2009). The process significantly increased the soil temperature to 10-15°C above the normal temperature. This technique was practiced in the warmest months for a duration of 4-6 weeks using thin transparent polyethylene films of 19-25 micro meter. The efficiency of soil solarisation on the control of weed seed bank was reported by Abraham and Jose (2014).

Tillage

Tillage plays an important role in controlling weedy rice populations in DSR. Weedy rice seeds emerge from shallow soil depths; weed seeds present in the upper soil layer can be buried deep by deep ploughing (Mansor *et al*., 2012). Under zero-till conditions, weedy rice seeds present in upper soil layers can be depleted before rice crop sowing by employing the stale seedbed technique. Residue should be retained on the soil surface as mulch under zero-till conditions can help in reducing weedy rice recruitment (Nadir *et al*., 2017). In different direct seeding systems, tillage is performed in dry or wet soil conditions. In dry-seeded rice systems, soil is cultivated in dry conditions, whereas, in wet-seeded rice, soil is cultivated in wet conditions (Kathiresan and Vishnudevi, 2021). Through land preparation has been well known to control weeds (Marambe, 2009). Repeated tillage operations may help reduce the seed bank and seedlings of weedy rice in rice fields. Weedy rice seedlings that emerge after cultivation can be killed by subsequent cultivation operations (Svizzero, 2021).

Different tillage operations could be used to bury weedy rice seeds deep so that they cannot emerge from that depth. Most weedy rice seedlings emerge from the top 6-8 cm of soil burial depths. Such information indicates that weedy rice emergence could be suppressed by deep tillage that buries seed below 8 cm (Saha *et al.,* 2014). In such situations, however, subsequent tillage operations should be shallow in the next few seasons to avoid bringing back the buried and viable seed to the soil surface. Seed brought to the soil surface may reinvest the field.

Selection of rice cultivars

In any crop or seeding system, weed-competitive cultivars should be involved as a tool in integrated weed management strategies (Mansor *et al*., 2012). Tall cultivars are usually more competitive against weeds, but they have lower yield potential than short-statured modern cultivars. In addition, tall cultivars may not be used widely in the future (Svizzero, 2021). Because of the ever-increasing population, there will be more pressure in future farming to produce more rice on less land. In such situations, growers may need to increase nitrogen fertilizer rates and high nitrogen is known to cause crop lodging (Wongtamee *et al*., 2017). Overall, information on the effect of weed-competitive cultivars on weedy rice is very limited in Asia. In the absence of such information, the use of cultivars with the traits of early vigor and quick canopy closure may help suppress weedy rice growth (Saha *et al.,* 2014). Short-duration cultivars that mature earlier than weedy rice may also help in reducing the weedy rice seed bank. Selecting cultivars with vigorous initial growth plays an important role in suppressing weedy rice (Marambe, 2009). In Malaysia, cultivars having tall stature, more tillering capacity, more vegetative growth in the initial crop growth phase and early maturity reduced the weedy rice population. Coloured-stem cultivars are effective in identifying weedy rice at an early stage and thus in its management. In eastern and southern India, coloured-leaf (purple) rice cultivars help in differentiating cultivated rice from weedy rice (Kathiresan and Vishnudevi, 2021). Similarly, farmers in Himachal Pradesh adopted purple-leaf rice cultivars in weedy rice- infested fields.

High crop density and row-seeded crops

A dense crop may help to suppress weeds in rice. Growers in many regions in Asia use high seeding rates to reduce weeds and to compensate for poor seed quality and crop establishment. Growers also increase seeding rates to compensate for losses due to birds, rodents, insects, nematodes and snails (Saha *et al.,* 2014). In Asia, growers use high seeding rates (up to 150 kg seed ha^{-1}) mainly in a broadcast rice crop but, in other parts of the world (e.g., South America), high seeding rates are also used in a mechanized row-seeded rice crop. The use of high seeding rates in weedy rice-infested areas, for example, in Malaysia, helped to reduce the problem of weedy rice (Chauhan, 2013). High seeding rates may not increase rice yield in weed-free environments, but may help to reduce yield losses due to weed infestation in weedy or partially weedy environments. Recent studies in the Philippines suggested that increasing rice crop interference could substantially reduce tiller and leaf numbers, leaf area and shoot biomass of different weedy rice biotypes (Marambe, 2009). Nonetheless, the surviving weedy rice plants may produce enough seed to cause infestation in subsequent cropping seasons. Therefore, there is a need to combine other weed management approaches with the use of high seeding rates (Chauhan, 2013).

Water management

Water management can play an important role in weedy rice control. Early flooding 20-30 days before land preparation would help to control red rice (Espinoza *et al*., 2005). After seeding of pre germinated seeds, water management was critical to successfully suppress weedy

rice. There were two management strategies for irrigation after seeding:

(1) Water was maintained at a depth of 5-10 cm until drainage at harvest (continuous flooding).
(2) Water was drained, soil is kept saturated for 3-5 days and flooding is returned gradually. Excessive drainage exposed the soil to air and increased oxygen concentration in the soil, thus stimulating weedy rice germination.

Azmi *et al*. (2000) reported that farmers resorting to transplanting rice culture in weedy rice infested areas had minimal or no recurrent problems with weeds. Puddling combined with the presence of a thin layer of water over the well levelled soil maintained the anaerobic conditions in the top soil and prevented weedy plants from becoming established. Ferrero (2001) have also found that flooding in well levelled soils limited weedy rice germination. He reported that combination of water seeding and the use of weedy rice free seeds had led to the virtual disappearance of the weed in California.

Water seeding

Rice plants require oxygen, moisture and optimum temperature for germination and one of these missing may cause a reduction in rice germination (Chauhan, 2013). In the water-seeding technique, pre-germinated rice seeds are shown on well-levelled flat soils having minimum residue with clear standing water by the broadcasting method to decrease the weedy rice population (Ajaykumar and Sharmili, 2020). Seedling broadcasting is also an innovative technology adopted in some DSR-growing countries, such as Vietnam, China and Sri Lanka, for controlling weedy rice where 12-15-day-old seedlings are broadcast on 5-7 cm of standing water and this layer of water controls the emergence of weedy rice (de Avila *et al*., 2021).

Shifting from direct seeding to transplanted culture

Transplanting is an established and efficient method for controlling weedy rice. Alternating transplanting (preferably, mechanical transplanting) with DSR after 3-4 years of DSR can minimize the problem of weedy rice and help in reducing the weedy rice seed bank in the soil (de Avila *et al*., 2021). Transplanting also helps to improve competitiveness against weedy rice germination, establishment and growth.

In transplanted systems, rice seedlings are more competitive against the newly emerged weedy rice seedlings and it is easy to distinguish weedy rice seedlings from cultivated rice seedlings (Saha *et al.,* 2014). Standing water present in the field at the time of transplanting also helps to suppress the emergence and growth of weedy rice seedlings. Growers in many countries, such as Korea, Malaysia and Vietnam, have been successful in reducing weedy rice infestation by introducing transplanted rice. In many Asian countries, however, there is a need to develop "custom-hiring" systems as many growers cannot afford to buy transplanters (de Avila *et al*., 2021). In Sri Lanka and Vietnam, seedling broadcasting is practiced in the absence of availability of effective transplanters (Mansor *et al*., 2012). In this method, seedlings are grown in a nursery and thrown / broadcasted randomly into puddled soil. Standing water in the field at the time of seedling broadcast helps to suppress weedy rice. In Malaysia, too, seedling broadcasting was found effective in reducing weedy rice infestation.

Hand weeding/roguing

The control of weedy rice plants is sometimes carried out manually, but this practice is costly and time consuming (Mansor *et al*., 2012). Hand weeding is quite impractical up to 30-40 days after crop emergence as it is very difficult to distinguish the cultivated varieties from the weedy rice in the early stages (Chauhan, 2013). Hand weeding of weedy rice plants can sometimes carried out for light infestations and frequently it is used together with other means of control (chemical) when the latter has given poor results, so as to avoid grain dispersal and also in seed production plots.

Crop rotation

Continuous growing of rice with similar management practices allows weedy rice to become dominant in the cropping system (Saha *et al.,* 2014). Crops with different management practices, however, may help in disrupting the growth cycle of weedy rice. Therefore, a crop rotation is considered as the most effective control measure for weedy rice and other problematic weed species (Ajaykumar and Sharmili, 2020). The cropping system was also considered to be a very important factor influencing weedy rice infestation Based on the interviews, cultivation of upland crops seemed to contribute to control of weedy rice infestation. Farmers who introduced mungbean cropping in the dry season found that weedy rice decreased a few years after serious infestation. Multiple cropping systems were found to be effective in reducing the weedy rice population in this region (Watanabe, 2000).

Mechanical methods

Inter-cultivation using mechanical weeders

Mechanical weeding is possible in row-seeded rice (Singh *et al*., 2013). Mechanical weeders, such as the cono-weeder and inter-cultivation implements (tractor-drawn, bullock-drawn, or manual) remove weeds from between the rows (Saha *et al.,* 2014). Line sowing also reduces seed cost as a lower seed rate is used when seeds are drilled than when seeds are broadcasted.

Chopping

Chopping is applicable for controlling weedy rice plants, which are taller than cultivated rice (Chauhan, 2013). The panicles are chopped from the weedy rice plants before seed setting takes place (Ajaykumar and Sharmili, 2020). In many countries, weedy rice panicles are cut with the help of a machete or a special knife attached to a stick (Singh *et al*., 2013). In developed countries, a combine harvester cutting device is mounted on the front of the tractor and used to cut the weedy rice panicles (de Avila *et al*., 2021).

Chemical control of weedy rice

Herbicide based weed management is generally the most popular method for weed control in the direct seeded rice fields (Braun *et al*., 2019). However, it is very difficult to control weedy rice by the use of selective herbicides because weedy rice was essentially the same biological species as cultivated rice (Mansor *et al*., 2012). Close anatomical and physiological similarity of weedy rice to the crop made selective post emergence herbicidal control of weedy rice plants very difficult (Chen *et al*., 2004).

Use of herbicides before sowing

Use of antigerminative herbicides, such as metolachlor at 3.5 kg ai ha^{-1}, alachlor at 3.5 kg ai ha^{-1}, applied in soybean as pre emergence resulted in weedy rice control of about 90 percent (Espinoza *et al*., 2005). Ferrero (2001) could obtain good control of weedy rice (often higher than 75 per cent) in European rice conditions with pretilachlor and dimethenamid used alone or in combination at 1.5 kg ai ha^{-1} and 0.48 kg ha^{-1}, respectively. To avoid any phytotoxicity risks, both herbicides need to be applied at least 25 days before rice planting. Pre-plant incorporation of thiocarbamate herbicides like molinate and butylatealso controlled weedy plants (Rao *et al*., 2007).

Jose *et al.* (2012) found that weedy rice was completely controlled by thiobencarb at 2.1 kg ha^{-1} and oxadiazon at 0.24 kg ha^{-1}. Molinate (6.5 kg ha^{-1}), however, gave 26-67% control when applied 6 days before rice seeding. Thiobencarb application as a preplant surface treatment at the rate of 4.4 kg ha^{-1} in combination with reflooding within 3 to 5 d after drainage is recommended to control red rice in the United States (Yamaguchi *et al*., 2008).

Use of seed protectants

Coating of dry seeds with 20% calcium peroxide using 4% PVA solution and broadcasting them in field with 10-15 cm standing water for 10 days can control weedy rice (Abraham and Jose, 2014). Later, this technology was found not practicable due to increased water fowl attack on coated seeds and lankiness of the crop plants due to continued submergence (de Avila *et al*., 2021).

According to the experiments carried out in Central and South America, the best weedy rice control could be achieved by applying molinate at 7.2 kg ha^{-1} and butylate at 4.2 kg ha^{-1} with seed protectants such as oxabetrinil at 1.5 g kg^{-1} and flurazole at 2.5 g kg^{-1} (Ziska *et al*., 2015).

Use of herbicides during the crop season

Chemical control in crop post planting should only be considered as a salvage operation and it mainly relies on difference in size or growth stage between weedy rice and commercial rice (Singh *et al*., 2013). Weedy rice that had grown taller than rice could be treated with foliar systemic herbicides such as glyphosate or cycloxydim, at 20 and 5 per cent concentrations, respectively, by using wick/wiper applicators (de Avila *et al*., 2021).

The equipment can be mounted on self moving machines, the front of a tractor or handheld equipment. A plant growth regulator, maleic hydrazide, had been used in Brazil to control seed production of red rice (Abraham *et al*., 2012). Rice cultivars must be earlier and head at least 10-15 days before red rice. Maleic hydrazide sprayed at the rice milk stage and prior to or during red rice heading stage reduces the production of red rice seed. It was noticed that maleic hydrazide reduced seed viability and so it should not be used on rice seed production fields (Abraham and Jose, 2014). The application of maleic hydrazide complements other methods for reducing seed production of red rice and, consequently, minimized this problem.

Biotechnological approach: Herbicide-resistant rice

The use of herbicide-resistant rice cultivars is another strategy advocated by researchers for selective control of weedy rice in cultivated rice. One of the main reasons for the development of herbicide-resistant rice was to obtain effective and selective control of weedy rice in the rice crop (Olofsdotter *et al*., 2000). Three major herbicide-resistant rice systems developed are imidazolinone (IMI)-resistant rice (IMI-rice), glyphosate-resistant rice and glufosinate-resistant rice, which conveys resistance to the imidazolinone group of herbicides (imazethapyr, imazomox, imazapyr, *etc*.), glyphosate and glufosinate, respectively (Abraham *et al*., 2012).

Out of these three herbicide-resistant rice systems, IMI-rice is nontransgenic, whereas both glyphosate- and glufosinate-resistant rice are transgenic and are known as genetically modified crops. Glyphosate and glufosinate are non-selective, broad-spectrum and post-emergence herbicides with no soil or residual activity. The imidazolinone group of herbicides is also broad-spectrum, effective at low doses, can be applied pre- and post-emergence, has soil or residual activity and has a favourable environmental profile (Singh *et al*., 2013). IMI-rice is the only herbicide resistant rice that has been commercialized. In Asia, IMI-rice cultivars have been released only in Malaysia. Although herbicide-resistant rice technology offers opportunities for selective control of weedy rice, the risk of gene flow from herbicide resistant rice to weedy rice poses a serious threat for the long-term utility of this technology (Abraham and Jose, 2014). Therefore, it is important to assess the potential risks imposed by this technology before its introduction in the region.

The risk of gene flow from herbicide-resistant rice to weedy rice will be minimal in the northwestern Indian states of Punjab and Haryana as wild and weedy rice are not present in this region (de Avila *et al*., 2021), but continuous direct seeding of rice could potentially lead to the evolution of weedy rice in this region, too. The risks of gene escape are higher in the eastern and southern Indian states where many wild and weedy relatives are present (Olofsdotter *et al*., 2000). In summary, these methods can target many phases of the weedy rice life cycle as an integrated weed management strategy for weedy rice control.

CONCLUSION

Weedy rice will likely emerge as a major problem in rice with increases in the adoption of DSR in India owing to the rising scarcity of labour and water. Weedy rice belongs to t same genus (*Oryza*) as cultivated rice and is an important weed in DSR production areas. Its unique characteristics, such as early and heavy seed shattering, prolonged dormancy and longevity and high competitiveness, make it a difficult-to-control, troublesome and economically damaging weed problem. Satisfactory control of weedy rice requires an integrated approach based on the combination of preventive, cultural, mechanical, chemical and biotechnological means rather than using only a single method for its control.

Conflict of interest

All authors declared that there is no conflict of interest.

REFERENCES

Abraham, C.T. (2012). Weedy rice-Threat to rice ecosystems. Sustainable Weed Management Options-Approaches and Applications. pp. 280-285.

Abraham, C.T., Jose. N. (2014). Weedy rice invasion in rice fields of India and management options. Journal of Crop and Weed. 10(2): 365-374.

Abraham, C.T., Jose, N., Rathore, M. (2012). Current Status of Weedy Rice in India and Strategies for its Management. In: Biennial Conference of ISWS on Weed Threat to Agriculture, Biodiversity and Environment. pp. 19-20.

Ajaykumar, R. and Sharmili, K. (2020). Chapter-7 Weedy Rice: An Emerging Threat to Rice Cultivation. Chief Editor Dr. Vishuddha Nand. 107.

Azmi, B.M., Johnson, D. (2001). Beware of Weedy Rice in Asia. Leaflet on Weedy Rice, IRRI, Manila, Philippines.

Azmi, M., Abdullah, M.Z., Mislamah, B., Baki, B.B., Chin, D.V., Mortimer, M., (2000). Management of weedy rice (*Oryza sativa* L.): The Malaysian experience. Wild and Weedy Rice in Rice Ecosystems in Asia- A review. pp 91-96.

Braun, G., Braun, M., Kruse, J., Amelung, W., Renaud, F.G., Khoi, C.M., Sebesvari, Z. (2019). Pesticides and antibiotics in permanent rice, alternating rice-shrimp and permanent shrimp systems of the coastal Mekong Delta, Vietnam. Environment international. 127: 442-451.

California Department of Food and Agriculture, Encycloweedia. (2001). Notes on Identification, Biology and Management of Plants Defined as Noxious Weeds by California Law.

Cao, Q.J., Li, B.O., Zhi, P.S., Xing, X.C. and Bao Rong, L. (2007). Impact of weedy rice populations on the growth and yield of direct seeded and transplanted rice. Weed Biology and Management 7(2): 97-104.

Chauhan, B.S. (2012). Weed ecology and weed management strategies for dry-seeded rice in Asia. Weed Technology. 26(1): 1-13.

Chauhan, B.S. (2013). Strategies to manage weedy rice in Asia. Crop Protection. 48: 51-56.

Chen, L.J., Lee, D.S., Song, Z.P., Suh, H.S. and LU, B.R. (2004). Gene flow from cultivated rice (*Oryza sativa*) to its weedy and wild relatives. Annals of Botany 93(1): 67-73.

Chin, D.V., Mortimer, M. (2002). Weed management in direct-seeded rice in South Vietnam. Direct seeding: Research strategies and opportunities. Los Banos, Philippines: International Rice Research Institute. pp. 349-356.

Chin, D.V. (2001). Biology and management of barnyardgrass, red sprangletop and weedy rice. Weed Biology and Management. 1(1): 37-41.

David, J. (2011). Be Aware of Weedy Rice in Asia. The International Rice Research Institute, Philippines.

De Avila, L.A., Noldin, J.A., Mariot, C.H., Massoni, P.F., Fipke, M.V., Gehrke, V.R. and Roma-Burgos, N. (2021). Status of weedy rice (*Oryza* spp.) infestation and management practices in southern Brazil. Weed Science. 69(5): 536-546.

Espinoza, G.A., Sanchez, E., Vargas, S., Lobo, J., Queseda, T. and Espinoza, A.M. (2005). The weedy rice complex in Costa Rica. Gen. Resour. Crop Evoln. 52: 575-587.

Ferrero, A. (2001). Red rice control in rice. Cah. Options Méditerr. 28: 1-8.

Girija, T., Rajeev, V.E., Abraham, C.T. (2010). Variability in the morphologic characters of weedy rice of Kerala, DWSRC, KAU, Thrissur, Kerala. Recent Advances in weed Science Research. 79: 90-92.

Gupta, S.R., Upadhyay, M.P. (2000). Wild and weedy rice in the Nepalese ecosystem. Rungsit Suwanketnikon. 41: 55-58.

Jose, N., Abraham, C.T., Leenkumary, S. (2012). "c. Alternate strategies for management of weedy rice complex in rice fields of Kerala." In Abst. Bien. Conf. Indian Soc. Weed Sci. on Weed threat to Agric., Biodiversity and Env. pp. 19-20.

Kathiresan, R. and Vishnudevi, S. (2021). Rice farming components for biological weed control in transplanted rice: Perspective on weedy rice management. Weed Science. 69(5): 609-614.

Mai, V., Chien, H.V., Van, V., Thi, V., Suong, T. and Thiet, L.V. (2000). Rice Seed contamination in Vietnam. In: Proceedings of the International Symposium on Wild and Weedy Rices in Rice Ecosystems in Asia: A Review. [B.B. Baki, Chin, D.V. and Mortimer, M. (Eds.)]. pp. 17-19.

Marambe, B. (2009). Weedy rice-evolution, threats and management. Tropical Agriculturist. 157: 43-64.

Mansor, M., Karim, S.R. and Abidin, Z. (2012). Effects of farmers cultural practices on the weedy rice infestation and rice production. Scientific Research and Essays. 7(5): 609-615.

Mispan, M., Baki, B.B. (2008). They stand among equals: Descriptive analysis on the new biotypes of weedy rice (*Oryza sativa* L.) in Malaysia. In Abstracts V International Weed Science Congress. Vancouver, Canada, Abstract. 724.

Nadir, S., Xiong, H.B., Zhu, Q., Zhang, X.L., Xu, H.Y., Li, J. and Chen, L.J. (2017). Weedy rice in sustainable rice production. A review. Agronomy for Sustainable Development. 37(5): 1-14.

Olguin, E.R.S., Arrieta-Espinoza, G., Lobo, J.A. and Espinoza-Esquivel, A.M. (2009). Assessment of gene flow from a herbicide-resistant indica rice (*Oryza sativa* L.) to the Costa Rican weedy rice (*Oryza sativa*) in Tropical America: factors affecting hybridization rates and characterization of F 1 hybrids. Transgenic Research. 18(4): 633-647.

Olofsdotter, M., Valverde, B.E. and Madsen, K.H. (2000). Herbicide resistant rice (*Oryza sativa* L.): Global implications for weedy rice and weed management. Annals of Applied Biology. 137(3): 279-295.

Ramachandiran, K., Balasubramanian, R. (2012). Weedy rice and its management-A review. Agricultural Reviews. 33(2): 175-178.

Rao, A.N., Johnson, D.E., Sivaprasad, B., Ladha, J.K., Mortimer, A.M. (2007). Weed management in direct seeded rice. Advances in Agronomy. 93: 153-255.

Rathore, M., Singh, R. and Kumar, B. (2013). Weedy rice: An emerging threat to rice cultivation and options for its management. Current Science. pp. 1067-1072.

Saha, S., Patra, B.C., Munda, S. and Mohapatra, T. (2014). Weedy rice: problems and its management. Indian Journal of Weed Science. 46(1): 14-22.

Shivrain, V.K., Burgos, N.R., Gealy, D.R., Smith, K.L., Scott, R.C., Mauromoustakos, A. and Black, H. (2009). Red rice (*Oryza sativa*) emergence characteristics and influence on rice yield at different planting dates. Weed Science. 57(1): 94-102.

Sindhu, P.V., George Thomas, C., Abraham, C.T. (2011). Stale seedbed and green manuring as an effective weed management strategy in dry-seeded rice (*Oryza sativa*). Indian Journal of Agronomy. 56(2): 109.

Singh, K., Kumar, V., Saharawat, Y.S., Gathala, M.K., Ladha, J.K. and Chauhan, B.S. (2013). Weedy rice: An emerging threat for direct-seeded rice production systems in India.

Svizzero, S. (2021). Agronomic practices and biotechnological methods dealing with the occurrence, dispersion, proliferation and adaptation of weedy rice (*Oryza sativa* f. spontanea). International Journal of Pest Management. 1-14.

Vongsaroj, P. (2000). Wild and weedy rice in Thailand. Proceedings of Wild and Weedy Rice in Rice Ecosystems in Asia (Eds., Baki, B.B., Chin, D.V., Mortimer, M.) IRRI, Los Banos, Philippines. pp 55-57.

Watanabe, H. (2000). Weedy Rice Complexes: Case Studies from Malaysia, Vietnam and Surinam. Proceedings of Wild and Weedy Rice in Rice Ecosystems in Asia-A Review (Ho Chi Minh City, Vietnam, 10-11 August 1998). pp 25-34.

Wongtamee, A., Maneechote, C., Pusadee, T., Rerkasem, B. and Jamjod, S. (2017). The dynamics of spatial and temporal population genetic structure of weedy rice (*Oryza sativa* f. spontanea Baker). Genetic Resources and Crop Evolution. 64(1): 23-39.

Xia, H., Xia, H., Ellstrand, N.C., Yang, C., Lu, B.R. (2011). Rapid evolutionary divergence and ecotypic diversification of germination behavior in weedy rice populations. New Phytol. 191: 1119-1127.

Yamaguchi, K., Ishihara, K. and Fukai, S. (2008). Wild and Weed Rice in Rice Ecosystems in Asia: A review. Limited Proceeding in IRRI, China. pp 87-99.

Ziska, L.H., Gealy, D.R., Burgos, N., Caicedo, A.L., Gressel, J., Lawton-Rauh, A.L. and Merotto, Jr, A. (2015). Weedy (red) rice: An emerging constraint to global rice production. Advances in Agronomy. 129: 181-228.