Weedy Rice Problems in Southeast Asia and Control Strategy

Hiroaki Watanabe

Abstract

Weedy rice with undesirable traits can inflict crop loss by reducing the yield and quality of commercial rice. Weedy rice rarely grows in the case of transplanted rice, but with the spread of direct seeding culture in Southeast Asia, its infestation is increasing. Difficulties in controlling volunteer rice have allowed the fields to be infested with weedy rice. In this region, weedy rice originated from cultivated rice (*Oryza sativa* L.) or wild rice (other *Oryza* species), and could have developed its ecological weedy characteristics such as easy grain shattering and moderate seed dormancy. It is known as "*Padi angin*" in Malaysia and "Weedy wild rice" in Thailand. It is likely that weedy rice will continue to evolve morphologically and metabolically as the rice crop by inter-crossing with modern cultivars, making it difficult to control it by using available herbicides. Therefore, integrated control measures based on ecological methods should be applied to overcome the problems. Genetic and ecological studies would give useful information for developing a control strategy.

Key words: weedy rice, wild rice, volunteer rice, easy shattering, seed dormancy

Introduction

In a region where a crop shows a high genetic diversity, the crop is often associated with its companion weed such as weed sorghum, weed oat, and weed rice (Oka, 1988). In rice fields where rice and its weedy form grow together, detection of weedy rice is rather difficult since it often shows continuous variations in its morphology that is closely similar (mimicry) to that of rice crop. Weed is defined biologically as a plant adapted to unstable and frequently irregularly disturbed habitats including agricultural fields (Kawano, 1969). Weed has also been defined by its undesirable behavior to the activities of man (Mortimer, 1990), even though weeds include some useful plants for man based on a recent definition (Kusanagi, 1994). In this paper, "weedy rice" is the term used to describe the rice plant adapted to rice fields and not wanted by farmers because of its interfering with rice production.

Weedy rice in rice fields has been reported in many countries, and designated under various local names such as "Red rice" in the USA, "*Akamai*" in Japan, "*Lutao*" in China, "*Sharei*" and "*Salpeh*" in Korea, "*Khao pa*" in Laos and "*Kbao nok*" in Thailand (Smith, 1981 ; Hyakutake *et al*., 1983 ; Oka, 1988 ; Kim, 1993 ; Vaughan, 1994 a). In tropical Asia, weedy rice problems have also been observed in India, Philippines, Vietnam and Myanmar (Oka, 1988 ; Moody, 1994 ; Vaughan, 1994 b). Infestation of "*padi angin*", Malaysian weedy rice affecting rice production due to its easy grain shattering, was observed in Projek Barat Laut Selangor in 1988 (Wahab and Suhaimi, 1990), and the problem was detected in 1990 in the Muda rice area (Md. Zuki and Kamarudin, 1994). Weedy rice infestation is serious in direct-seeded rice fields, and is supposed to be increasing with the spread of direct seeding rice culture in tropical Asia. Objective of this paper is to present information on some important characteristics of weedy rice with respect to its problems in rice production, morphological variation and adaptability in rice fields with special reference to Malaysian weedy rice. Future development of its control strategy will also be discussed.

Japan International Research Center for Agricultural Sciences, Tsukuba, Ibaraki, 305 Japan.

Origin of weedy rice

In the temperate region where wild rice does not grow, weedy rice has evolved from rice (*Oryza sativa* L.), although the origin of "*Lutao*" in China and "*Sharei*" in Korea is unknown. The origin of weedy rice in areas where rice and wild rice are sympatric may be more complicated. Rice in Asian countries is thought to be derived from common wild rice (*Oryza rufipogon* Griff.=Asian form of *O. perennis* Moench), and progenies of hybridization between cultivated rice and its wild relative are often weeds in lowland rice (Morishima, 1987). Common wild rice itself exhibits wide variations in life-history traits, and its annual type (sometimes designated as *O. nivara* or *O. sativa* f. *spontanea*) is adapted to disturbed habitats characterized by a prolonged dry season (Oka, 1988). These species have the same number of chromosomes (2 n=24, genome AA), and their F_1 hybrids do not show any disturbance in meiotic chromosome pairing (Chu *et al*., 1969). Therefore, not only cultivated rice but also annual or intermediate types of common wild rice and their natural hybrids are a possible origin of weedy rice in tropical Asia, although differentiation of the annual or intermediate type depends on environmental conditions.

Asia can be divided into two areas based on the distribution of annual and intermediate types of wild rice compared to perennial wild rice. India, Nepal, Sri Lanka, Bangladesh, Thailand, Cambodia, Laos, Myanmar and parts of southern Vietnam have a long dry season. In these countries annual and intermediate types of common wild rice can commonly be observed (Morishima *et al*., 1961; Morishima and Oka, 1975; Oka, 1988; Vaughan, 1994 a). The life-history traits of the annual, intermediate and perennial types have been compared (Barbier, 1989 a; 1989 b). Sano (1980) concluded that the intermediate type has a high evolutionary potential, and therefore is more likely to be the wild progenitor of rice (*O. sativa*) than the typical perennial type. Common wild rice which grows in rice fields and is considered to be a serious weed was identified as annual or intermediate type in Thailand (Hyakutake *et al*., 1983 a; 1983 b; 1984). Wild rice population found in a stream running through glutinous rice field in Chiangmai, Thailand, contained many heterozygotes for the glutinous gene (Oka and Chang, 1961), and population found in India was also shown to be a hybrid swarm between wild and cultivated rice. Therefore, common wild rice and resultant hybrids with rice cultivars might be an important progenitor of weedy rice in Thailand and India.

On the other hand, in the tropical rain forest area of Malaysia and Indonesia, differentiation of annual or intermediate types of common wild rice has rarely occurred. Thirty-two samples of common wild rice from Peninsular Malaysia all belonged to the perennial type (Abdullah *et al*., 1991). It grows along irrigation canals, roadside ditches, swamps in secondary drains adjacent to rice fields, banks of old canals, and corners of rice fields (Itoh *et al*., 1990). Perennial common wild rice itself is supposed to have little potential to be a serious weed in well managed rice fields. A population of weedy rice growing in a dry-seeded rice field in Malaysia showed wide variations in its morphology (Watanabe *et al*., 1994). DNA analysis using randomly amplified polymorphic DNA (RAPD) markers revealed that the genetic structure of these rice plants showed a close similarity to that of cultivated rice (Abdullah *et al*., 1994), indicating that the Malaysian weedy rice could have originated from cultivated rice, although gene transfer from common wild rice can occur.

In early August of 1994, common wild rice was observed flowering on the roadside adjacent to a rice field in the Muda area, Peninsular Malaysia. It was assumed to be an intermediate form of wild rice because it exhibited weak photoperiodism and higher seed fertility compared to typical perennial type which flowers from late September to late January (Itoh *et al*., 1990). The Muda area is characterized by a short dry season for two months. Its habitat is more disturbed than that of most perennial populations due to regular cleaning of roadside ditches. Relationship between the intermediate type of common wild rice and weedy rice is unknown in Malaysia.

Serious infestation and problems in Malaysia

The initiation of double cropping in 1970 followed by direct seeding culture in the 1980s had caused a weed shift and serious weed infestation in the Muda area (Ho, 1991; Itoh, 1991; Morooka and Yasunobu, 1993). At the beginning, wet seeding was mainly practiced. Dry seeding was practiced in the fields where the water supply was insufficient in off-season. Seedling establishment in dry-seeded fields is more unstable compared to wet seeding because it depends on erratic rainfall. Poor establishment of dry-seeded rice was sometimes compensated by the emergence of volunteer seedlings from shed seeds in the previous season. In the first season (off-season) of 1987 when irrigation water was not supplied in the Muda area, volunteer seedling culture was practiced in nearly 40% of all the rice fields, where farmers depended on volunteer rice seedlings for the season crop. Volunteer seedling culture has decreased in off-seasons from 1988 to early 1990s, when dry seeding culture was promoted to save irrigation water because of the continuous shortage of water supply from irrigation dams (Fujii and Cho, 1993). According to the field survey conducted in 1988 and 1989, rice crops in dry-seeded fields included a large number of volunteer seedlings (Hiraoka *et al.*, 1991). Weedy rice with easy grain shattering trait emerged with volunteer seedlings. The problem was detected in 1990, and became obvious in 1993 in the Muda area, where a total of 168 ha were infested with weedy rice (Md. Zuki and Kamarudin, 1994).

An interview survey was carried out in the Muda and Tanjung Karang rice areas to investigate the relationship between the cultivation method and weedy rice infestation. Eighty three farmers were selected for the survey whose fields were infested with weedy rice in 1994. According to the farmers' responses about cultivation from I/1993 to I/1994, infestation with weedy rice was more serious in dry-seeded fields (Fig. 1). Practice of dry seeding culture associated with volunteer rice seedlings is supposed to be the most important factor causing infestation with weedy rice in Malaysia. Weedy rice infestation, however, was also observed in wet-seeded rice fields. This fact suggested that weedy rice had adapted to puddled soil conditions, and that broadcasted seeds had been contaminated with weedy rice seeds. Crop Production Center (CPC) is providing seeds of several modern rice cultivars. However, its capacity of seed production is not sufficient for rice cultivation in the whole Muda area. In more than two-thirds of the planted area, it is assumed that the farmers use their own seeds from the previous crop. Therefore, seed contamination is considered to be a factor that enhances the weedy rice problem in the area.

Undesirable traits of weedy rice in rice production are listed in Table 1. Weedy rice reduces rice yield and causes lodging problems when its grows at a high density. In a seriously infested field where weedy rice plants accounted for 35% of the total rice plants, the rice grain yield was 3.2 ton/ha, which was 50% to 60% of the rice yield without weedy rice infestation (Watanabe *et al.*, 1994). In the dry-seeded fields, weedy rice emerged earlier than seeded cultivated rice from incorporated seeds in the soil, resulting in its competitive advantage over cultivated rice with poor seedling establishment.

Some rice farmers in Malaysia seemed to be less concerned with the quality of their harvested rice according to the survey. However, the grade of grains will be lower when they are contaminated with the

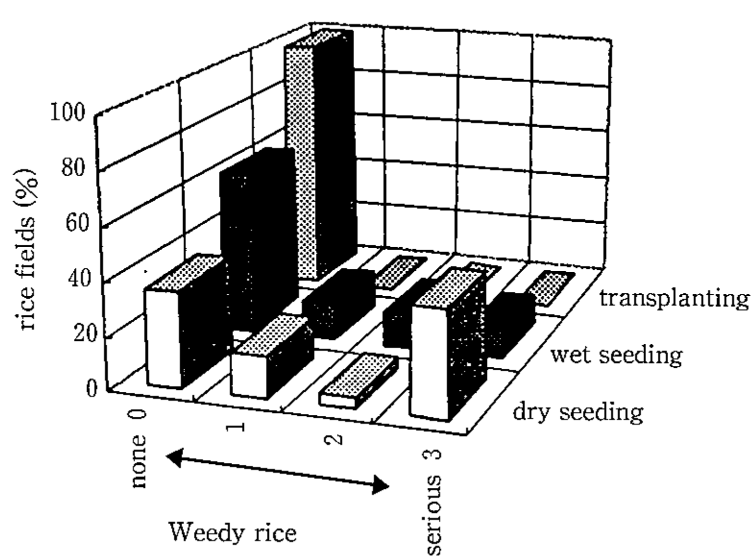

Fig. 1 Weedy rice infestation depending on cultivation methods

Table 1 Undesirable traits of weedy rice including evolutional characteristics in rice production in Malaysia

	Undesirable traits	Interference with rice production
Morphological characteristics	long culm	causing lodging, high competive advantage over rice
	short grain	
	pigmented grain	reducing rice quality
	pigmented pericarp awn	
	mimicry to rice	difficulty in identification
Ecological characteristics	easy grain shattering	reducing rice yield, increasing seed population in soil
	seed dormancy	difficulty in controlling after shedding
	seed viability in soil	difficulty in reducing seed population in rice fields
	variability in germination traits	adaptability to wet seeded fields
Physiological characteristics	tolerance to rice herbicides	lower effectiveness of chemical control

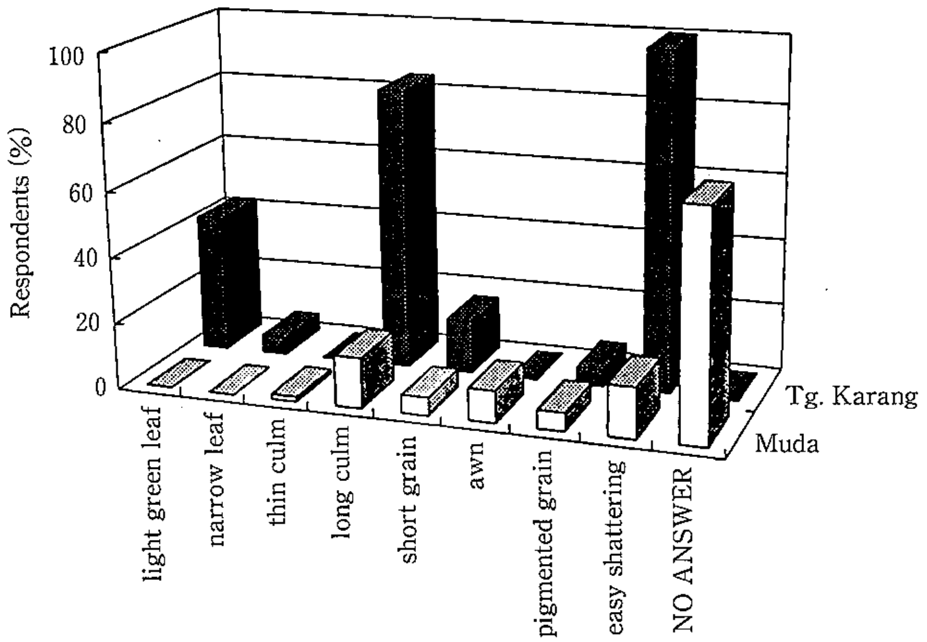

Fig. 2 Results of interview survey on characteristics for farmer's identification of weedy rice in the Muda and Tg. Karang areas, Peninsular Malaysia

short grains of weedy rice. Pigmented and/or awned grain and colored pericarp will also reduce the quality of rice grains. Farmers, who cultivate short maturation cultivars to avoid yield loss caused by early shattering of weedy rice, will harvest a large number of weedy rice grains. Mimicry to cultivated rice, seed dormancy and tolerance to rice herbicides are also undesirable characteristics. They hamper the control of weedy rice, which is costly to the farmer for eliminating it and reduces his net income.

Variation in morphology

Weedy rice plants showed differences in culm length, leaf color, grain size, grain and pericarp pigmentation, awn, panicle type and panicle length in Malaysia (Wahab and Suhaimi, 1991; Azmi *et al*., 1994). Some of the morphological characteristics resembled those of "*Mahsuri*", a rice cultivar with long culm and moderate to easy grain shattering traits, which farmers used to grow before the introduction of direct-seeded rice culture. Detailed survey on the morphology in a dry-seeded rice field showed that the majority (93%) of weedy rice plants had longer culms than cultivated rice (modern cultivars), 34% had pigmented grains, and 39% had grains with long awn, while the population included some easy shattering plants with short culms and non-pigmented awnless grains (Watanabe *et al*., 1994). These morphological characteristics were considered to be distributed independently from each other in the population.

According to the survey on identification methods of weedy rice, more than half of the Muda farmers did not have any identification method (Fig. 2) due to the limited experience of weedy rice infestation compared to the farmers in Tg. Karang area where the weedy rice problem occurred earlier. Long culm, short grain and its pigmentation were the criteria for identification after heading in both areas. Light green color of the leaf sheath was a useful character for farmers who controlled weedy rice at early stage of rice cultivation in Tg. Karang area. However, no farmers could identify weedy rice with the same morphological characteristics as those of cultivated rice. Several plants with easy grain shattering traits which resembled modern rice cultivar (MR-84) were found in direct-seeded rice fields in Malaysia (Vaughan 1994, personal communication).

Easy grain shattering and seed dormancy

Seventeen variants of Malaysian weedy rice showed a wide variation in their seed shedding behavior (Watanabe *et al*., 1994). Grain shattering started at eight days after heading in the earliest shattering type, and earlier shattering resulted in a higher shattering rate. Some variants showed less grain shattering as modern cultivars, MR-84 and MR-123. Vaughan (1994 b) classified their shedding performance into several grades as hard threshing, easy threshing, very easy threshing, easy shattering, very easy shattering, and spontaneous shattering.

According to the germination test using seeds of twenty weedy rice plants growing in a rice field in Malaysia, seed dormancy was absent at three months after shedding, although their germination was not

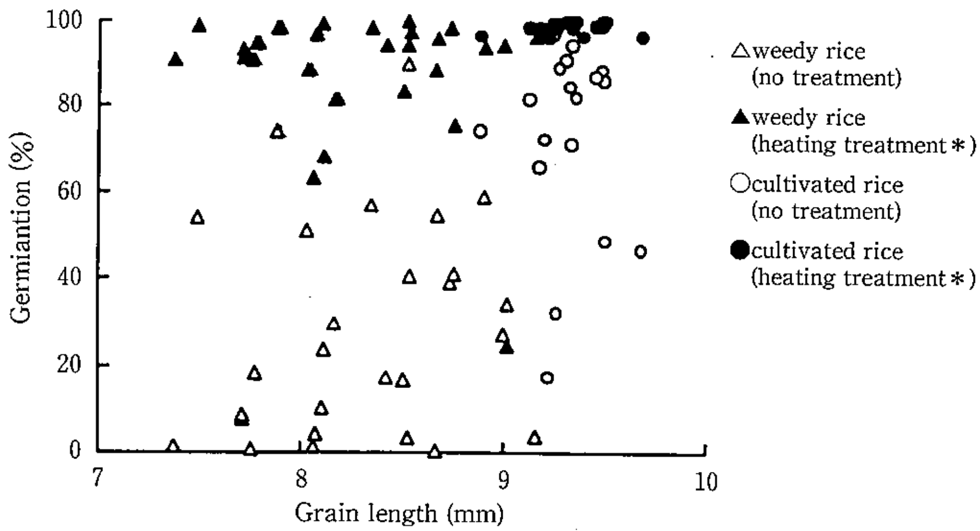

Fig. 3 Seed germination of weedy rice and cultivated rice collected from twenty six rice fields in Malaysia
(*heating treatment: 50°C for seven days before germination test)

uniform compared to MR-84 (Watanabe *et al.*, 1994). However, germination test using fresh dry seeds immediately after seed shedding showed wide variations in seed dormancy (Fig. 3), suggesting that Malaysian weedy rice required less than three months to overcome its seed dormancy. This trait may be desirable for weedy rice to emerge in the next season of rice double cropping in Malaysia.

The two ecological characteristics, seed shattering and its dormancy, are related to adaptability in rice fields. Weedy rice strains from Thailand, India, Korea and Nepal showed variations in the seed shedding rate and in the number of days required to overcome dormancy, while so-called "red rice" from Japan, Korea and Brazil had a low shedding rate and low degree of seed dormancy (Oka, 1988). The differences in the seed shattering pattern and dormancy in progenies of three variants growing in a rice field in Malaysia were estimated (Fig. 4). Variant 1 seemed to belong to the easy shattering type as intermediate between hard shattering and spontaneous shattering, while variant 2 and variant 3 seemed to belong to the spontaneous shattering type which started to shed seeds earlier and in which seed shedding was completed in several days. Seed germination percentage was higher in the progenies of variant 1 than of variant 2 and variant 3, indicating that the degree of seed dormancy of the spontaneous shattering type was higher than that of the intermediate shattering type. These findings clearly demonstrated that there was a genetic variation in ecological characteristics in the population, because the different types grew together in the rice field.

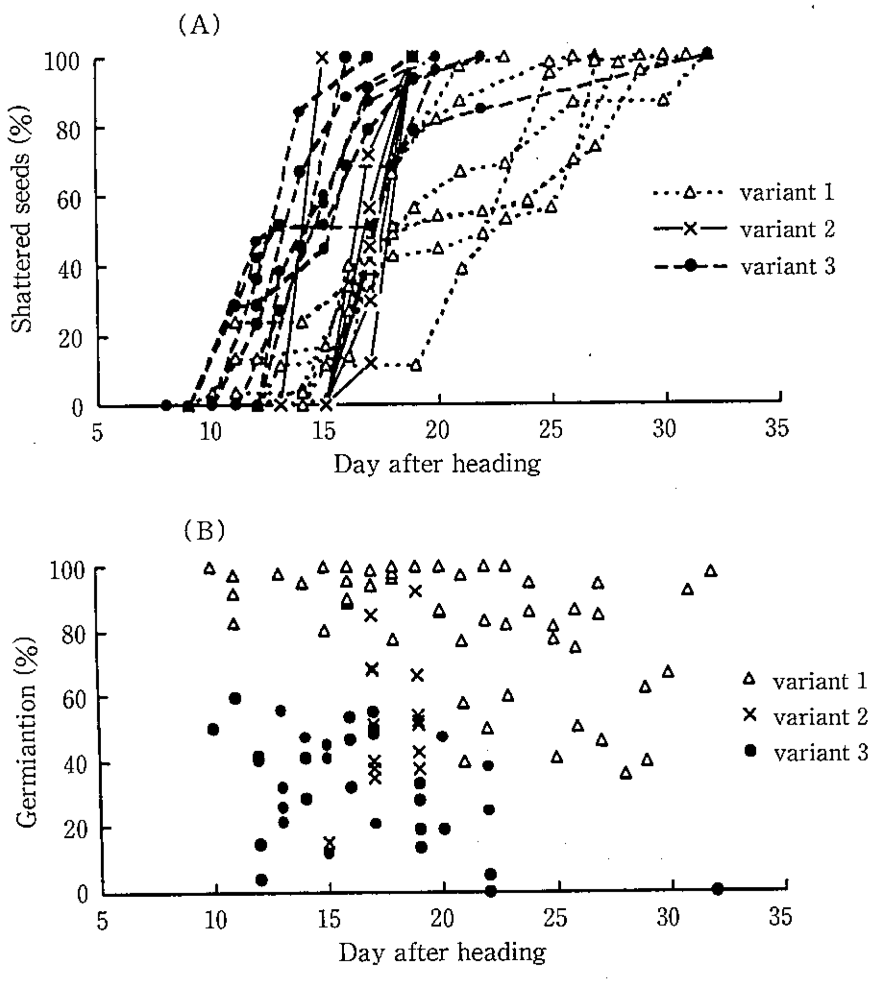

Fig. 4 Seed shattering of weedy rice sampled from the Muda area (A) and germination percentage of shattered seeds (B)

Control of weedy rice

Manual transplanting had protected rice fields from weedy rice infestation. Zainal and Azmi (1994) reported that farmers in the infested areas who reverted back to transplanting culture had completely avoided regeneration of weedy rice. In direct seeding culture, however, no single technique shows a superior effectiveness in controlling it. Interview survey indicates that many farmers were puzzled over the difficulty in controlling weedy rice in Malaysia (Fig. 5). Several control measures should be integrated to eliminate it (Table 2).

1. Land preparation

Weedy rice which become adapted to rice fields displays seed dormancy, to some extent, even when it evolved from cultivated rice. However, repeated rotovation is effective to reduce weedy rice population in rice fields. Weedy rice seedlings for which emergence is promoted by the first or the second rotovation will be buried in soil by the second or the third rotovation. In dry seeding rice culture, intensive land preparation is effective in getting uniform seedling establishment of broadcasted rice as well as reducing weedy rice population. The use of drive harrow was recommended to reduce the size of the soil lumps (Fujii and Cho, 1993). In wet seeding culture, intensive puddling is effective in reducing weedy rice emergence and also in reducing the occurrence of other aerobic germinating weeds and some perennial weeds.

2. Seed purity and vigor

Pure seeds could be harvested in pure field. Intensive rice cultivation is necessary for seed production. Selection of seeds with a high vigor is related to good seedling establishment and desirable rice growth competitive to weedy rice.

3. Seedling establishment

Uniform and rapid seedling establishment of cultivated rice is necessary to prevent serious weed infestation including weedy rice. In dry seeding culture under severe drought conditions, seedling establish-

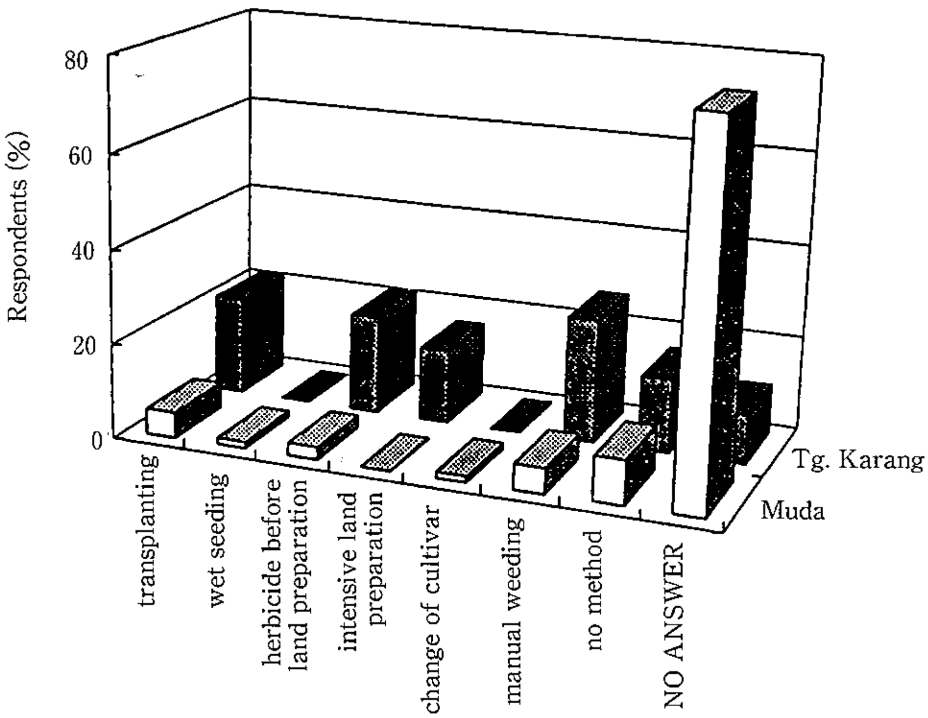

Fig. 5 Result of interview survey on effective methods of control of weedy rice in the Muda and Tg. Karang areas, Peninsular Malaysia

Table 2 Effectiveness of cultural practices on reducing weedy rice population in tropical rice fields

Cultural practice	Negative effect ←——→ Positive effect	Effectiveness (1)	Note (2)
herbicide before land preparation (3)	not applied ←——→ applied	* * * *	A
land preparation (3)	poor ←——→ intensive	* * * * *	A, B
seed purity	contaminated ←——→ pure	* * *	C
seed vigor	weak ←——→ strong	* *	B, D
cultivation method	dry seeding wet seeding transplanting	* * * * *	A, B, D
seeding method (wet)	broadcasting ←——→ row seeding	* * *	B, E
seeding method (dry)	broadcasting row seeding drill seeding	* * *	B, E
seed rate	low density ←——→ high density	* *	D
water management at seeding establishment (wet seeding)	no standing water ←——→ well drainage	* *	B
water management after seeding establishment	no standing water ←——→ flooded	*	A, D
herbicide usage in rice (4)	foliage soil treatment soil incorporation	*	A
manual weeding	none ←——→ intensive	* * * * *	A
fertilizer usage (3)	before weed control ←——→ after weed control	*	D
harvesting (3)	early or late ←——→ right timing	*	C, F

(1) Less effectiveness* to superior effectiveness*****
(2) Effective on ; A : reduction of volunteer rice seedlings including weedy rice
B : uniform seedling establishment
C : prevention of contamination of weedy rice
D : desirable rice growth and high competitive advantages over weedy rice
E : minimizing of difficulties in manual weeding
F : prevention of shattering of weedy rice seeds
(3) Timing of practices is important
(4) Few registered herbicides are available for tropical rice fields

ment depends on the attachment of the seed surface to soil. Tillage for mixing seeds with soil and pressing the soil with roller after sowing were recommended based on the results of field experiments under MADA/JIRCAS joint research program (Fujii and Cho, 1993). In wet seeding culture, remaining water in the fields after drainage causes the formation of vacant spots where weeds will emerge later. Therefore, adequate water drainage is necessary in the seedling establishment period. After seedling establishment, field should be submerged with water and fertilizer should be applied for suitable rice growth. Timing of fertilizer application will be important for competitive advantages over weedy rice.

4. Manual weeding

Many farmers noticed that manual weeding is the most effective practice for controlling weedy rice. However, this practice is laborious and costly. Moreover, there are difficulties in walking in broadcasted rice fields and identification of weedy rice. Making narrow ditches to walk in the field, row seeding or drill seeding will help farmers to practice manual weeding. Farmers who succeeded in eliminating weedy rice by manual weeding, had attempted to reduce the emergence of weedy rice by other methods.

5. Chemical control

Herbicide usage before land preparation is effective to reduce seed population of weedy rice in the field. Paraquat, glufosinate and glyphosate are suitable, and rotovation after herbicide usage will increase their effectiveness.

Few herbicides, however, are able to control the weed after seeding in direct-seeded rice fields in tropical Asia, although butachlor and oxadiazon were effective in controlling volunteer rice in transplanted rice in Japan (Nemoto *et al*., 1982). Several field experiments were carried out to control red rice in the USA. Treatment of pre-plant soil-incorporated molinate at 4.5 and 6.7 kg/ha in a continuously flooded culture or 6.7 kg/ha in an alternately drained-flooded culture controlled 87 to 93% of red rice, resulting in high grain yield and high grain quality while water culture treatments without molinate did not control red rice (Smith, 1981). Baker *et al*. (1986) concluded that pre-plant incorporated molinate at 4.5 kg/ha with brief post-seeding drainage gives the optimum red rice control. Effectiveness of molinate was also evaluated in *padi angin*, Malaysian weedy rice (Lo, 1994). Based on field experiments, incorporation of molinate at 4.5 kg/ha immediately before seeding was the most effective method of control of *padi angin*. Lo suggested that cultivated rice could have advantages over *padi angin* in stronger seedling vigor from broadcasted fresh seeds, resulting in the differential effect of molinate between cultivar and *padi angin*.

6. Control strategy in future

Breeding of rice varieties highly tolerant to herbicide may contribute to the chemical control of weedy rice. Rechard and Baker (1979) evaluated the response of seventy-three rice cultivars to molinate. They were divided into five grades from highly susceptible to highly tolerant, showing the possibility of developing cultivars which have a high tolerance to molinate. Tissue culture and other biotechnological procedures enable to develop rice plants resistant to AHAS-inhibiting herbicides from the mutant cells in the Rice Research Station in Crowley (Croughan, 1994). Transgenic rice lines resistant to glufosinate, a broad spectrum herbicide, were developed by Agracetus, Inc. from two rice cultivars, and their response to the herbicide was evaluated in RRSC (Braverman, 1994). Transgenic lines from Gulumont showed no apparent injury by glufosinate. Koshihikari lines displayed some initial yellowing shortly after herbicide treatment, but these symptoms had disappeared after 14 days of treatment.

Weedy rice will continue to evolve physiologically and metabolically in the same way as rice cultivars. Continuous usage of herbicide-resistant cultivars could lead to the formation of herbicide-resistant weedy rice through crossing and natural selection in rice fields. Segregation in heading time and culm length in progenies of weedy rice plants indicated that the rice field was infested with heterogeneous rice plants (Watanabe *et al*., 1994). Genetic structure of common wild rice was influenced by its mating system in natural population (Morishima and Barbier, 1990). Information on mating performance of weedy rice, gene transfer between weedy rice and cultivated rice and genetic structure in rice fields is necessary for further discussions on the evolution of weedy rice.

Acknowledgment

Presented information on Malaysian weedy rice was provided by the collaborative research program between Malaysian Research and Development Institute, Muda Agriculture Development Authority and Japan International Research Center for Agricultural Sciences with the kind cooperation of the National Institute of Agrobiological Resources. The author wishes to express his gratitude to Dr. Sharif Ahmad, Director General of MARDI, Dato' Syed Azizan Syed Mohamad Al-Idrus, General Manager of MADA and Dr. Keiji Kainuma, Director General of JIRCAS, and special thanks to Dr. Azmi Man and Mr. Abdullah Zain (MARDI), Mr. Ho Nai Kin and Mr. Md. Zuki Ismail (MADA), and Dr. Kazutoshi Okuno and Dr. Duncan A. Vaughan (NIAR), and all their staff members.

References

1) Abdullah, M. Z., Vaughan, D. A. and Mohammad, O. (1991): Wild relatives of rice in Malaysia: Their characteristics, distribution, ecology and potential in rice breeding. MARDI Report No. 145, 28 pp.

2) Abdullah, M. Z., Watanabe, H., Vaughan, D. A. and Okuno, K. (1994): Padi Angin: Its probable origin and diversity revealed through DNA polymorphism. Proc. of the 1st National Congress on Genetics, Kuala Lumpur, Malaysia: 164-167.

3) Azmi, M., Watanabe, H. and Abdullah, M. Z. (1994): Morphological characteristics of Padi Angin. Paper presented at MARDI Workshop on Padi Angin, 18 May 1994, Kepala Batas, Seberang Perai, Malaysia. 17 pp.

4) Baker, J. B., Sonnier, E. A. and Shrefler, J. M. (1986): Integration of molinate use with water management for red rice (*Oryza sativa*). Weed Sci. 34: 916-922.

5) Barbier, P. (1989 a): Genetic variation and ecotypic differentiation in the wild rice species *Oryza rufipogon*. I. population differentiation in life-history traits and isozymic loci. Jpn. J. Genet. 64: 259-271.

6) Barbier, P. (1989 b): Genetic variation and ecotypic differentiation in the wild rice species *Oryza rufipogon*. II. Influence of the mating system and life-history on the genetic structure of population. Jpn. J. Genet. 64: 273-285.

7) Braverman, M. P. (1994): Field evaluation of genetically engineered glufosinate resistant rice lines. Louisiana Agriculture 37 (3), 29 p.

8) Chu, Y-E., Morishima, H. and Oka, H. (1969): Reproductive barriers distributed in cultivated rice species and their wild relatives. Jpn. J. Genet. 44: 207-223.

9) Croughan, T. P. (1994): Application of tissue culture techniques to the development of herbicide resistant rice. Louisiana Agriculture 37 (3): 25-26.

10) Fujii, H. and Cho, M-C. (1993): Studies on water management under direct seeding in the Muda area, Malaysia. MADA/JIRCAS Final Report, 217 pp.

11) Hiraoka, H., Ho, N-K. and Wada, G. (1991): The establishment of direct seeding rice cultivation in the Muda irrigation scheme of Malaysia. MADA/TARC Final Report, 142 pp.

12) Ho, N-K. (1991): Comparative ecological studies of weed flora in irrigated rice fields in the Muda area. MADA Monograph No. 44, 97 pp.

13) Hyakutake, H., Prasarn, V., Chaiyot, S. and Siriporn, Z. (1983 a): Distribution and habitat of wild rice in deep-water rice and other areas in Thailand. Weed Research, Japan 28 (suppl. I): 181-182.

14) Hyakutake, H., Siriporn, Z. and Chaiyot, S. (1983 b): Some ecological characters of wild rice (*Oryza rufipogon*) in deep-water rice areas in Thailand. Weed Research, Japan 28: 183-184.

15) Hyakutake, H., Siriporn, Z., Prasarn, V. and Chaiyot, S. (1984): Ecological characteristics of weedy wild rice in Thailand (in Japanese). Weed Research, Japan 29 (suppl. I): 89-90.

16) Itoh, K., Abdullah, M. Z. and Azmi, M. (1990): Habitats of four species of wild rice in Malaysia. Proceedings of the 3 rd Tropical Weed Science Conference, Kuala Lumpur, Malaysia: 377-384.

17) Itoh, K. (1991): Integrated weed management of direct seeded wet rice fields in south-east Asia and Pacific regions, with special reference to Malaysia. Proceedings I of the 13 th Asian Weed Science Society Conference, Jakarta, Indonesia: 77-94.

18) Kim, S-C. (1993): Effective weed control technology for dry seeded rice in Korea. Proceedings I of the 10 th Australian and 14 th Asian Pacific Weed Science Society Conference, Brisbane, Australia: 144-148.

19) Kusanagi, T. (1994): A concept of weed and weed science (in Japanese). "Weed Management Handbook (First edition)", Asakura press: 2-6.

20) Lo, N-P. (1994): Chemical control of 'Padi Angin' (*Oryza sativa*). Paper presented at MARDI Workshop on Padi Angin, 18 May 1994, Kepala Batas, Seberang Perai, Malaysia. 10 pp.

21) Md. Zuki, I. and Kamarudin, D. (1994): Status dan kawalan 'Padi Angin' di kawasan MADA (in Malay). Paper presented at MARDI Workshop on Padi Angin, 18 May 1994, Kepala Batas, Seberang Perai, Malaysia. 20 pp.

22) Moody, K. (1994): Weedy forms of rice in Southeast Asia. Paper prsented at MARDI Workshop on Padi Angin, 18 May 1994, Kepala Batas, Seberang Perai, Malaysia. 5 pp.

23) Morishima, H., Oka, H. and Chang, W-T. (1961): Directions of differentiation in population of wild rice, *Oryza perennis* and *O. satva* f. *spontanea*. Evolution 15: 326-339.

24) Morishima, H. and Oka, H. (1975): Comparison of growth pattern and phenotypic plasticity between wild and cultivated rice strains Jpn J. Genet. 50 (1): 53-65.

25) Morishima, H. (1987): Wild rice in southeast Asia-Its variation and ecology- (in Japanese) Gakujutsu Geppou 40: 719-723.

26) Morishima, H. and Barbier, P. (1990): Mating system and genetic structure of natural populations in wild rice *Oryza rufipogon*. Plant Species Biol. 5: 31-39.

27) Morooka, Y. and Yasunobu K. (1993): Direct seeding culture and weed problems under double cropping in the Muda plain (in Japanse), Malaysia. Technical Document of TARC No. 19, 159 pp.

28) Mortimer, A. M. (1990): 1/The biology of weeds. "Weed control hand book (Eighth edition)", Blackwell Scientific Publications, Oxford: 1-42.

29) Nemoto, H., Nakagawa, E. and Hanawa, H. (1982): Control of volunteer rice in rice cultivation for seed production (in Japanese). Nogyo oyobi Engei 57 (3): 465-467.

30) Oka, H. and Chang, W-P. (1961): Hybrid swarms between wild and cultivated rice species, *Oryza perennis* and *O. sativa*. Evolution 15: 418-430.

31) Oka, H. (1988): Origin of cultivated rice. Japan Scientific Societies Press.

32) Rechard, E. P, Jr. and Baker J. B. (1979): Response of selected rice (*Oryza sativa*) lines to molinate. Weed Sci. 27: 217-223.

33) Sano, Y., Morishima, H. and Oka, H. (1980): Intermediate perennial-annual populations of *Oryza perennis* found in Thailand and their evolutionary significance. Bot. Mag, Tokyo 93: 291-305.

34) Smith, R. J. Jr. (1981): Control of red rice (*Oryza sativa*) in water-seeded rice (*O. sativa*). Weed Sci. 29: 663-666.

35) Vaughan, D. A. (1994 a): The wild relatives of rice, A genetic resources handbook. International Rice Research Institute, Los Banos, Philippines, 137 pp.

36) Vaughan, D. A. (1994 b): Preliminary report on field trip to Malaysia to study *Padi angin* (mimeograph). Paper presented to MARDI, JIRCAS and NIAR, August 1994.

37) Wahab, A. H. and Suhaimi, O. (1991): Padi angin-characteristics, adverse effects and methods of its eradication (in Malay with English abstract). Teknol. Padi. 7: 21-31.

38) Watanabe, H., Azmi, M. and Md. Zuki, I. (1994): Morphological and ecological variation of weedy rice in the Muda area. MADA/MARDI/JIRCAS Quarterly Meeting Report, No. 27, 41 pp.

39) Zainal, A. H. and Azmi, M. (1994): Kawalan kultura padi angin (in Malay). Paper presented at MARDI Workshop on Padi Angin, 18 May 1994, Kepala Batas, Seberang Perai, Malaysia. 7 pp.

Discussion

Hossain, Md. Amzad (Bangladesh): Since cultivated rice and weedy rice can be crossed, weedy rice could possibly be utilized.

De Datta, S.K. (USA): Mechanical transplanting should be promoted in Malaysia, since resources are available. We are going against nature as we try to grow rice where there is no water. In the case of dry seeding, instead of drilling seeds, we are broadcasting them. Where water is not available at the early stage of rice growth, drill-seeding should be practiced using a machine along with mechanical and chemical weeding.