J.Univ.Ruhuna 2015 1:2-13
Volume 3, December 2015
ISSN2345-9387

RESEARCH ARTICLE

Weedy rice: A threat to rice production in Sri Lanka

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Abstract: Weedy rice (*Oryza sativa* L. *f. spontanea*), one of the four most significant weeds, is globally well known as a problem in the rice industry. The economic and environmental problems they pose include those related to rice crop production, milling for commerce, quarantine regulations and seed trade. Weedy rice possesses a number of common features with other weeds and distinctive characteristics such as phylogenetic and morphological resemblance to cultivated rice. Weedy rice is a difficult-to-manage weed when coexists in rice ecosystems causing economic losses to rice. Currently, weedy rice has been found in nearly all the rice growing regions in Sri Lanka. The estimated rice yield losses caused by the infestation of weedy rice varied largely from 40% to 90%, depending on its density and degree of shattering in rice fields. Effective control of weedy rice must be taken into immediate consideration to secure rice production in the country. The promotion of the use of certified seed paddy without weedy rice contamination should be the immediate and key step in the implementation of efficient control mechanism followed by other integrated weed control measures to reduce the proliferation and limiting its distribution to non-contaminated areas. However, the outcome will be limited except all parties in the rice industry are unified and committed to control weedy rice. In contrary to all unfavorable impacts of weedy rice on rice production, high heritability values coupled with high genetic variability of its favorable characteristics could be considered in rice improvement programs and in broadening the rice gene pool.

Keywords: *Weedy rice, rice production in Sri Lanka, rice weeds, integrated weed control, Oryza sativa* L, *f. spontanea*

Introduction

Rice *(Oryza sative* L.*)* is one of the major staple food crops in the world and is particularly important in Asia where approximately 90 % of world's rice is produced and consumed (Khush, 2004; Zeigler & Barclay, 2008). Improving the productivity, qualitatively and quantitatively of rice has become immense importance to feed nearly half of the world's population. Weedy rice (*Oryza sativa* L. *f. spontanea*), botanically classified as the same species as cultivated rice of the family Poaceae is a feral plant accompanying cultivated rice and is widely distributed in rice growing areas all over the world (Ferrero et al., 1999; Mortimer et al., 2000). In regions of rice cultivation such as Asia and Latin America where native *Oryza* species occur, weedy rice may have arisen through a continual process of gene flow between the cultivated crop and neighboring wild populations. Weedy rice, being genetically close and having a similar physiological and life history to that of cultivated rice, has made a vast challenge to rice farmers. This paper provides an overview to the origin and distribution, morpho-physiological nature, genetic relationships and management of weedy rice as a weed in rice fields with special reference to Sri Lanka.

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Origin and distribution of Weedy Rice

Weedy rice is rated as one of the four most noxious weeds infesting rice fields worldwide (Gealy et al., 2002; Delouche et al., 2007). Weedy rice is an annual and self-pollinating plant that is conspecific to cultivated rice (Xia et al., 2011), and can spread rapidly through long-distance exchange seeds of cultivated rice, in which weedy rice seeds are mixed (He et al., 2014). Weedy rice appears to possess a wide variation in the characteristics. These different morphologies have lead to much speculation about the source of these weeds. There are three main hypotheses on origin of weedy rice; (i) weedy rice may have evolved from wild rice and adapted to take advantage of cultivated rice habitats (ii) weedy rice may have originated from escaped domesticated rice seeds and then evolved weedy traits (iii) inter-breeding between cultivated and wild rice may have lead to viable hybrids, having combined traits from both and then form weedy forms (Londo & Schaal, 2007). Although the weedy varieties differ in some traits, the multiple independent origins share some common phenotypic characteristics, including rapid growth, aggressive tillering, prolonged reproduction, seed dispersal at maturity and seed dormancy.

The continued presence of weedy rice in a rice field is attributed, in part, to its ability of strong seed shattering at maturity and seed dormancy, which can promote the persistence of weedy rice seeds in soil seed-banks (Delouche et al., 2007), although some non-dormant weedy rice populations have evolved a new mechanism to respond to a critical habitat temperature for seed germination (Xia et al., 2011). Hypothetically, weedy rice is evolved either from the natural hybridization between rice cultivars and wild rice relatives (exo-ferality) (Londo and Schaal 2007; Reagon et al., 2010), or from cultivated progenitors directly through the de-domestication process (endo-ferality) (Xia et al., 2011). Consequently, feral species can acquire and incorporate new alleles via hybridization and introgression from coexisting crop populations under human management (Ellstrand et al., 1999). Introgression may result in genetic differentiation among feral populations as they accumulate varietal-specific alleles acquired from crops over time (Xia et al., 2011), possibly explaining why introgression from crops increases adaptability and invasiveness of weedy or wild relatives in ago-ecosystems (Ellstrand and Schierenbeck 2000; Ellstrand, 2003; Song et al., 2004), altering the genetic structure of these species (Song et al., 2006; Xia et al., 2011).

In Sri Lankan context, evolutionary process of weedy rice is believed to have two origins; weedy rice in southern and eastern coastal areas was found to have similarities with wild rice species with respect to presence of awn (>80 %), red pericarp (>80%), long slender grain type (>60%), light seeds (>90%), higher seed shattering (>90%) and long seed dormancy (>75%). Weedy rice that are present in inland areas of the country showed similarities to traditional rice cultivars with characteristic features such as low degree of seed shattering (40-70%), different grain shapes; (long 20%, intermediate 30%, bold 50%), red/white pericarp color and absence of awns (70%) and comparatively less tillers (80%) and panicles/plant (Abeysekara, et al., 2013). In addition, Marambe (2005) indicated that rice grown in abandoned paddies in Sri Lanka have led to the development of feral forms of rice leading to evolution of such forms inferring possibility of introgression of genes by de-domestication of cultivated rice (Fig.1). However, genetic basis of weedy rice together with its relationship to wild, cultivated or feral forms in abandoned paddies yet to be understood to confirm the origin of weedy rice in the country as above findings are only based on the morphological characteristics.

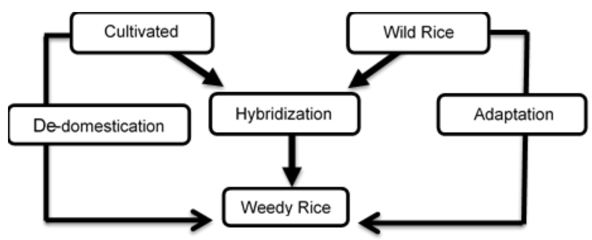


Fig. 1: Hypothetical evolutionary processes leading to the origin of weedy rice in Sri Lanka.

No matter which evolutionary process (exo- or endo-ferality) is involved, re-acquiring of seed shattering characteristics is the key for the origin of weedy rice. Currently weedy rice problem is pervasive and becoming a major problem throughout the world mostly where rice crops are direct seeded. In recent times, weedy rice has been increasingly reported as a major weed problem in Asian countries, such as Malaysia, Sri Lanka, Thailand, India, Republic of Korea, Philippines and Vietnam (Delouche, et al., 2007). The extent of the areas affected by weedy rice varies among the countries.

Weedy Rice status in Sri Lanka

Weedy rices are becoming common in most rice growing areas in Sri Lanka. In mid1990’s, weedy rice was first identified as a threat in Vavunia, Ampara, and Batticaloa, districts (Marambe and Amarasinghe, 2000) and since then it has spread in varying population densities, over all agro-ecological zones of the country. At present, weedy rice infestation is widely distributed in Puttlam, Ampara, Anuradhapura, Polonnaruwa, Kurunegala and Matara districts (Ratnasekera et al., 2014). This raises production costs and diminishes crop quality. Lack of a selective herbicide for the control of weedy rice, or other effective measures, has made its control a subject of national significance.

The superior competitive ability of weedy rice over cultivated rice has contributed to its rapid spread in the country. In addition, the high levels of seed shattering and seed dormancy have enriched the soil seed bank of weedy rice in infested fields. Seeds in the soil seed bank may germinate as soon as conditions are favorable, while seeds not germinated initially will germinate at later dates or when other factors change. The variable and prolonged periods during which seeds remain dormant are major factors that contribute to the success of weedy rice as a "weed." Weedy rice seed banks therefore play an important role in determining the severity of infestation in rice fields.
Currently, 90% of the rice farmers in Sri Lanka establish rice fields by broadcasting of pre-germinated seeds on saturated puddled soil. Rapid expansion of this practice over the last two to three decades, coupled with reliance on post emergence herbicide applications due to the lack of an affordable wage labor, has resulted in weeds becoming major problems in rice cultivation in the country. Further, crop management practices have contributed to the rapid spread of weedy rice in the major rice production areas.

Weedy Rice; Morpho-Physiological characteristics

Weedy rice is taxonomically classified as the same species as cultivated rice (*O. sativa*), but is strongly characterized by its seed shattering and dormancy, which apparently increase the distribution of this species. Weedy rice plant cannot be identified easily at seedling stage, as they are closer in appearance to cultivated rice. It generally grows faster with better use of the available N; produces comparatively more tillers, panicles and biomass, shatters early, has comparatively better resistance to adverse dry conditions, and possesses long and varied seed dormancy in soil. Morphologically seed and panicle characteristics of weedy rice are highly diverse (Fig. 2) and weedy rice plant is generally taller, profusely tillered, more open or spreading, have weaker culms, more susceptible to lodging, and exhibit more rapid seedling growth when compared to the cultivated rice to which they infest (Delouche et al., 2007).
A remarkable feature observed among weedy rice populations in Sri Lanka was the variability of the plant architecture and more than 4849 morpho-types have been recorded (Abeysekara et al., 2013).

High degrees of variations were observed among grain characteristics such as; presence / absence of awn, length and colour of the awn, hull and pericarp, grain size and shape, etc (Fig. 2). and among plant characteristics, such as number of panicles per hill, spikelets per panicle, percentage filled grains, grain weight etc. (Ratnasekera et al., 2014; Abeysekara et al., 2013).

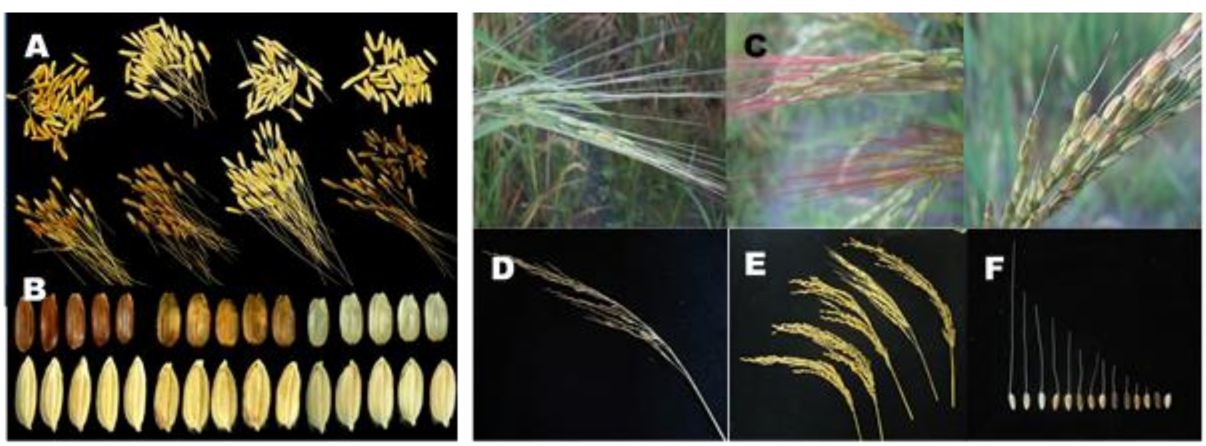


Fig. 2: Morphological characteristics of weedy rice. A- B: Diversity of seeds, C: Diversity of awns at immature panicles, D: High degree of shattering, E: Diversity of mature panicles, F: Variation of awn lengths in mature seeds (Source: Unpublished information)

In a study conducted in Ampara district, Perera et al., (2010) observed shortest plants (144.3cm) at Thottama weedy rice populations (Fig. 3) compared to other locations in the same district. The plants observed at Akkaraipattu and Lahugala (147.132) were comparatively taller (147.1 - 149.3) and no significant difference was observed among them. At Lahugala, tiller number/plant (3.22) and number of panicles/plant (2.54) were comparatively less than that of other locations. The highest number of tillers/plant (4.5) and panicles/plant (3.8) were observed at Akkaraipattu (Fig. 3).

Recent study conducted in Matara and Kurunegala districts revealed that the limited number of salient agro-morphological characteristics are found within the weedy rice eco-types that are supposed to be derived from mixing of germplasm either of cultivated or wild rice varieties. Further, the traits of long-fully awned and the absence of the awn are identified as pleisomorphic (primitive) characteristics, while short-fully and long-partly awned characteristics are apomorphic (derived) in weedy rice populations in Sri Lanka (Somaratne et al., 2014).

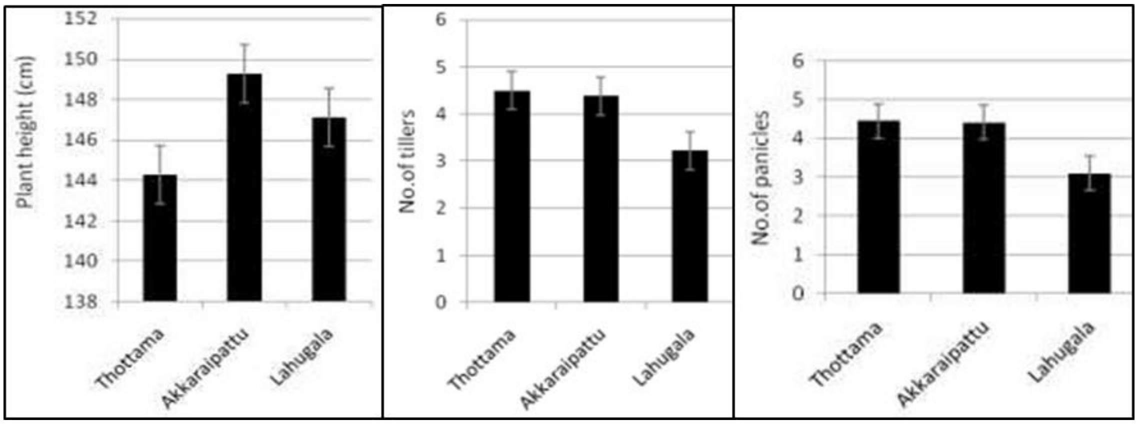


Fig. 3: Variation of plant characteristics (plant height, no. of tillers/plant and no. of panicles/plant) in three different locations (Lahugala, Thottama Akkareipattu) in Ampara district (Source: Perera et al., 2010).

Perera et al., (2010) also reported that higher variation in weedy rice seeds among and within locations of Amapara district, and four categories of awn types, which was supported by the observations made by Marambe and Amarasinghe (2000). The plants observed from the study showed seeds with and without awns. Also the size and the color of the awn were highly variable. The observed weedy rice seeds with awns were classified according to the color (white, purple and bicolor) and the length of awn (short, medium and long) (Fig. 4). The average number of seeds with awn observed was 60% of the total panicles in Ampara district but varied slightly among locations. Moreover, four different types of weedy rice were previously detected in the direct-seeded rice fields in Ampara on the basis of awn length *viz.* 0-2, 2-4, 4-6 and 6-8cm (Marambe and Amarasinghe, 2000).

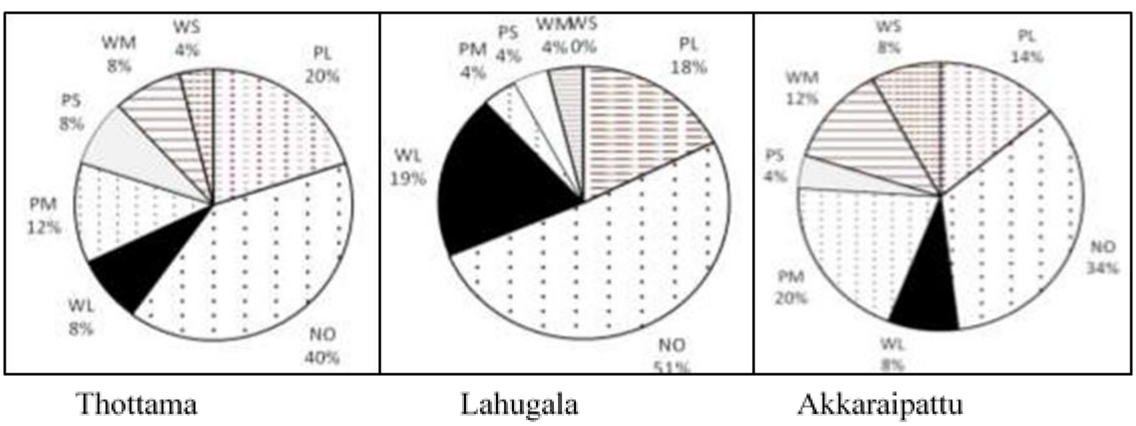


Fig. 4: Variation of the awn color and length of Sri Lankan weedy rice within locations. PL-Purple colored long awn, PM-Purple colored medium sized awn, PS-Purple colored short awn, WL-White colored long awn, WM-White colored medium sized awn, WS- White colored short awn, NO-Awnless (Perera et al., 2010).

Variability in seed dormancy is one of the major factors that contribute to the success of weedy rice to adapt and survive in rice ecosystems. However, Marambe (2005) reported lower germination and survival percentages in weedy rice than that of cultivated variety, Bg 300. In contrast, Rupasinghe & Ratnasekera (2013) observed that germination percentages of improved rice (Bg 359) buried at 15cm and 30cm depths were 45% and 50%, respectively at 4 weeks after burring (WAB) and it declined sharply to zero at 16WAB (Fig. 5). Germination percentages of weedy rice buried at 15cm and 30cm depths were 60% and 70%, respectively at 4WAB and it declined gradually to 32% and 35%, respectively at 24WAB. Viability percentages also followed similar pattern (Fig. 5) for improved and weedy rice seeds buried at 15 cm and 30 cm depths. This revealed that weedy rice seeds could remain viable under soil for more than 24 weeks compared to the improved rice varieties, which did not remain viable beyond 16 WAB (Fig. 6). Viability and germination ability of seeds always higher in deep soil (30cm) compared with surface soil (15cm depth) for both weedy and improved rice. These results support the observations of the persistent nature of weedy rice. Further, the findings highlight the importance of management measures to reduce the size of the weedy rice soil seed bank of infested fields and of long-term strategies to deprive the soil seed bank of weedy rice.

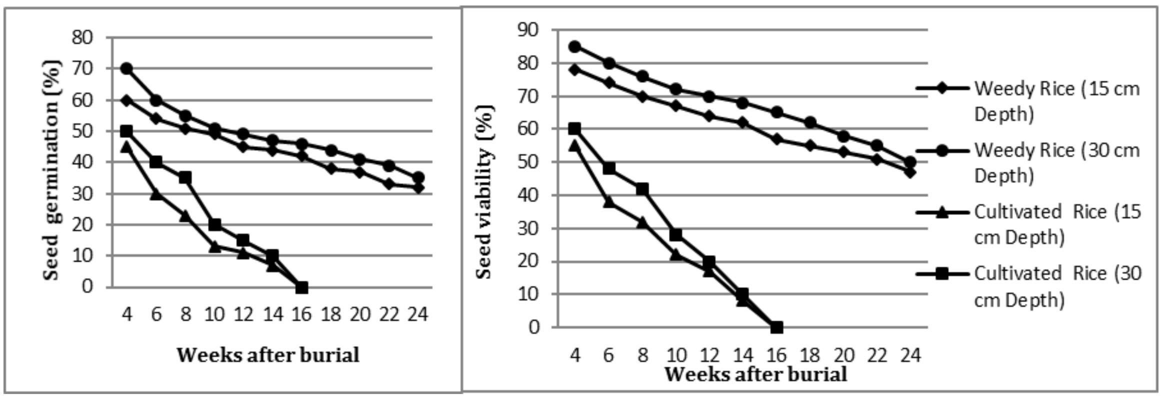
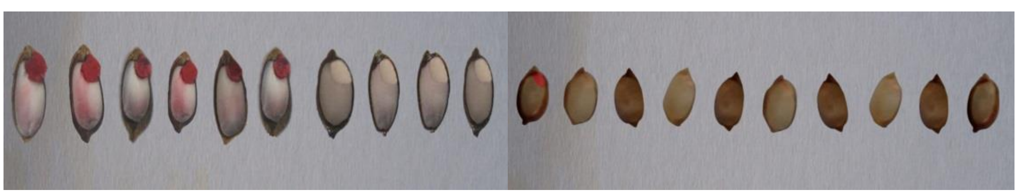


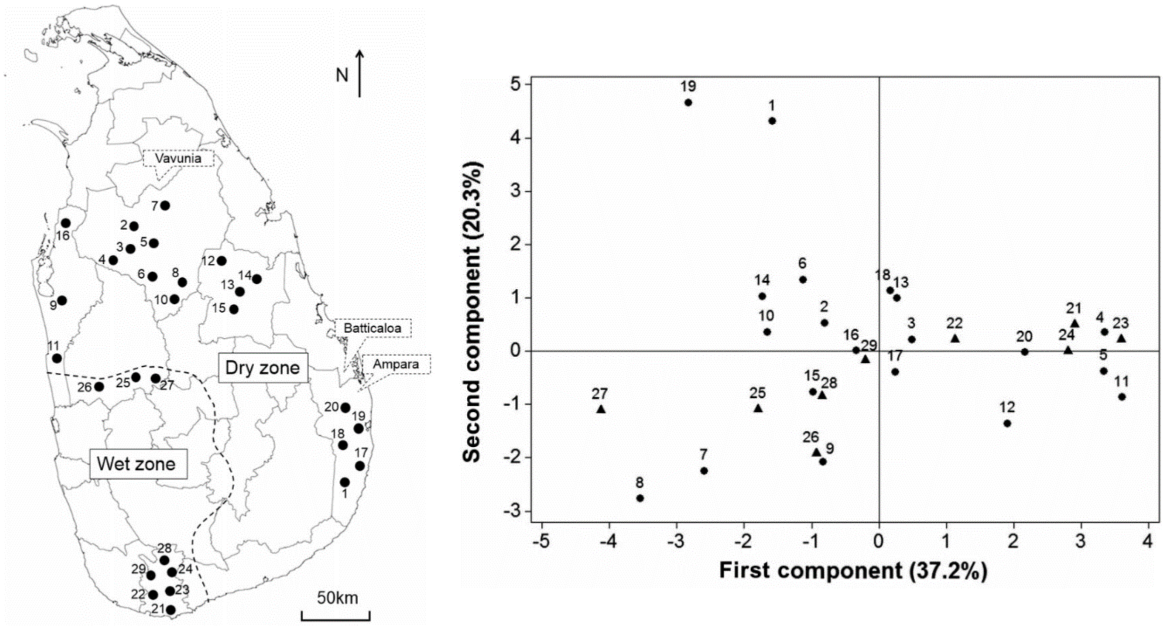
Fig. 5: Germination and viability percentages of improved cultivated rice (Bg 359) and weedy rice seeds from 4 to 24weeks after burying in rice soil (Source: Rupasinghe & Ratnasekera, 2013).



Seeds of weedy rice Seeds of variety Bg 359

Fig. 6: Comparison of seed viability between weedy and improved rice when seeds were buried at 30 cm depth for 12 weeks using TTC (Triphenyl tetrazolium chloride) test (Source: Rupasinghe & Ratnasekera, 2013).

Interestingly weedy rice biotypes in Sri Lanka have no correlation with their geographical locality (Ratnasekera et al., 2014). Seed shattering and the number of spikelets (grains) per plant are the most variable traits of weedy rice in Sri Lanka, which might explain the extent of the yield losses of cultivated rice, estimated to be >40% in Sri Lanka (Marambe & Amarasinghe, 2000). However, according to our recent unpublished data, weedy rice can cause even >90% of rice yield losses in some farmers' fields. Also the work conducted using 29 weedy rice populations collected island wide, indicated the existence of relatively high level of morphological diversity within and among weedy rice populations in Sri Lanka (Ratnasekera et al., 2014). However, such diversity appeared not the same among regions. Even within the same region, some populations showed a relatively higher diversity than that of others. Thus, the morphological variation of the weedy rice populations was appeared not associated with the agro-ecological conditions (Fig.7).



Collected Locations **Scatter Plot**

Fig.7: Collected locations and scatter plot of 29 weedy rice populations based on the first two principal components (representing 57.5% of the total variation) of the PCA, showing a largely divergent pattern of the selected populations that were not closely associated with their geographical locality (Ratnasekera et al., 2014).

Genetic diversity and Genetic relationship of Sri Lankan weedy rice

The weedy rice populations in Sri Lanka show high morphological and genetic diversity. Understanding genetic diversity and the possible mechanisms that contributed to the accumulation and spread of such diversity within and among weedy rice populations is essential for designing strategies for the effective control of this weed. Our recent study showed a high level of genetic diversity in Sri Lankan weedy rice populations (He et al., 2014), as estimated by 23 SSR (Simple Sequence Repeat) loci and is comparable with that estimated based on the morphological characterization in our previous study (Ratnasekera et al., 2014). The overall genetic diversity, as indicated by the *He* value (0.62), was unexpectedly high for this self-pollinated weed in this study, compared to that in previous studies of weedy rice populations from other regions of the world. The reported genetic diversity (*He*) of weedy rice populations based on SSR fingerprinting from northeast China (Cao et al., 2006), USA (Pritchard et al., 2000), and northern Italy (Jiang et al., 2012) varied between 0.31-0.48. We assume that the abundant genetic diversity of weedy rice in Sri Lanka may contribute to its adaptation and rapid spread across various rice growing regions. It is widely recognized that abundant genetic diversity allows weedy rice to adapt to a broad range of environmental conditions, including varying farming methods and weed management practices (Falush et al., 2003; Evanno et al., 2005; Cao et al., 2006). In addition, as reported by Dai et al. (2014), rich genetic diversity of weedy rice can significantly enhance its competitive ability with cultivated rice causing high yield losses. The current situation of enhanced damage to rice yield by weedy rice as reported by Marambe & Amarasinghe (2000) in Sri Lanka may also be attributed to high genetic diversity of weedy rice.

AMOVA test revealed much greater genetic variation within Sri Lankan weedy rice populations (83%) than that of among populations (15%) and populations between the two major zones (2%) (He et al., 2014). Thus, the genetic diversity of Sri Lankan weedy rice mainly exists within populations with limited genetic differentiation among populations. The relatively low *Fst* value (0.17) supports the observation of inadequate genetic differentiation among Sri Lankan weedy rice populations. The low average value (~0.04) of observed heterozygosity of different weedy rice populations confirms the self-pollination feature of Sri Lankan weedy rice.

The variation pattern of Sri Lankan weedy rice having abundant within population genetic diversity and limited genetic differentiation among populations, suggests considerable level of gene flow among populations, which is an important driving force to homogenize differences among populations (Londo and Schaal, 2007; Reed and Frankham, 2003). In other words, a considerable amount of gene flow conveying diverse genotypes of weedy rice from different sources has increased the genetic diversity of weedy rice occurring in the same field, and reduced genetic differentiation of weedy rice populations among fields and/or regions. Considering the traditional practice where farmers frequently exchange uncertified rice seeds between fields and regions in Sri Lanka, the long-distance movement of weedy rice seeds mixed with cultivated rice seeds may have played an important role in promoting the within-population genetic diversity and reducing among-population genetic differentiation.

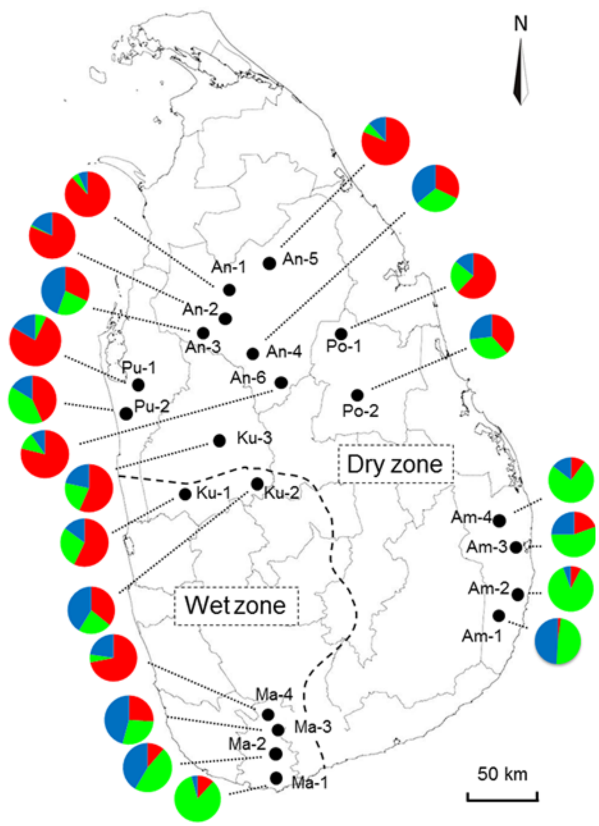


Fig. 8: Geographical locations of the 21 weedy rice populations collected from Sri Lanka. (He et al., 2014). (The colors in pies correspond to the genetic combinations explained in the STRUCTURE analysis for weedy rice populations).

The STRUCTURE (Pritchard et al., 2000) analysis generally indicates a relatively distinct genetic structure of weedy rice populations when compared to that of cultivated rice that is used as a reference, although the major component (indicates by the blue color assignment) of cultivated rice is also found in most of the weedy rice populations (Fig. 8). Weedy rice populations were represented by three major genetic components (indicated by the red, green and blue color assignments in Fig. 8). Weedy rice populations from Ampara (Am-1,Am-4) and Matara (Ma-1,Ma-3) Districts shared a similar genetic component, whereas populations from Polonnaruwa (Po-1, Po-2), Anuradhapura (An-1,An-6), Kurunegala (Ku-1,Ku-3), Matara (Ma-4), and Puttalam (Pu-1, Pu-2) Districts shared another similar genetic component. Noticeably, some weedy rice populations such as Am-1, An-2, An-3, Ma-2, and Ma-3 shared relatively a high proportion of genetic cluster assignment with the cultivated rice (Fig. 8), probably indicating the frequent gene flow from cultivated rice to those weedy rice populations or their origin from cultivated rice. Similarly, some weedy rice populations, such as Am-3, Po-2, Ku-3, and Pu-2 also shared a relatively high proportion of genetic cluster assignment with each other, suggesting the frequent gene flow between these weedy rice populations. In addition, when genetic structure of each of the weedy rice populations was plotted to the geographical locations, the proportion of genetic components of different weedy rice populations showed a pattern of somewhat gradual change from south to north in Sri Lanka, i.e., red in northern populations and green in southern populations. This indicated south-to-north genetic differentiation of weedy rice populations. Cluster analysis of He et al., (2014) showed a clear two-group pattern where all the weedy rice populations included in the analysis, were clustered as one group. This group was evidently separated from the cultivated and wild rice group at the similarity coefficient value of 0.42. However, all the Sri Lankan weedy rice populations showed a relatively close but variable genetic relationship at the similarity coefficient values of 0.72-0.98. The cultivated and wild rice sub-groups were somehow distantly related, showing separation at the similarity coefficient value of 0.52 (Fig. 9).

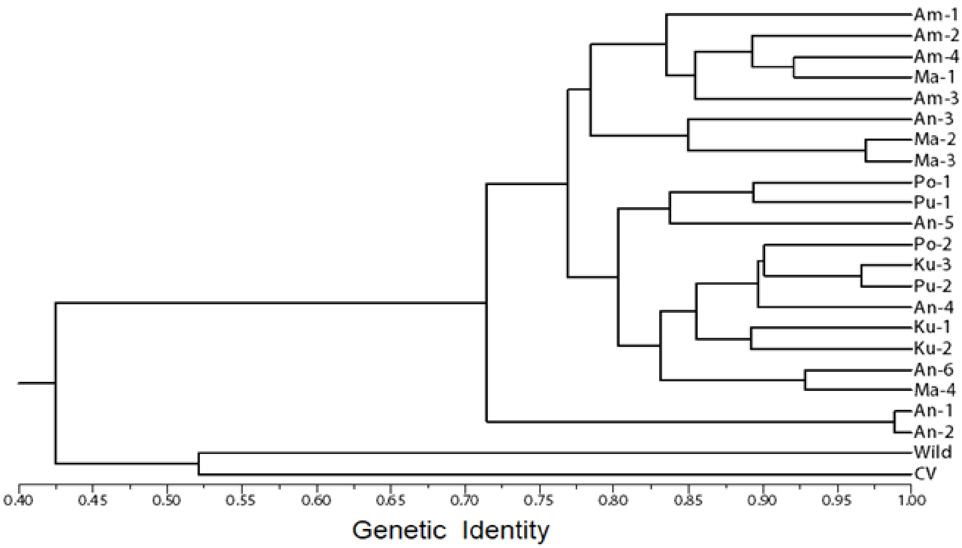


Fig. 9: UPGMA (Unweighted Pair Group Method with Arithmetic Mean) dendrogram constructed based on the genetic similarity of 21 weedy rice populations in Sri Lanka. Similarity was estimated by 23 SSR loci using cultivated (CV) and wild rice (Wild) as two reference groups (Source: He et al., 2014).

Noticeably, the clustering of weedy rice populations did not follow the rule of "isolating-by-distance". In other words, many weedy rice populations from the same geographical locations were not grouped together. For example, population An-1 and An-2 (from Anuradhapura District) were separated distinctly from all other four An-populations that were further scattered among different subgroups with weedy rice samples collected from different districts. Similarly, the Ma-populations from southern Sri Lanka (Matara District) were separated in different subgroups representing populations from different districts (Fig. 8, 9). In contrast, some populations from different geographical locations were grouped together. For example, population Po-2, Ku-3, Pu-2, and An-4 (from Polonnaruwa, Kurunegala, Puttalam, and Anuradhapura Districts) were clustered in a closely related group (Fig. 8, 9). This indicated the possible long-distance and frequent gene flow among the weedy rice populations collected from different geographical locations. The Mantel test did not show significant correlation ($r2$ = 0.0105, P =0.001) between genetic distance and spatial distance of the weedy rice populations, supporting the finding that there was no obvious genetic structure or pattern of isolation-by-distance (IBD) among the weedy rice populations across the country.

A previous report using DNA fingerprinting has shown clear taxonomic differentiation of wild rice from weedy rice in Sri Lanka, but was closely related to the prevailing cultivars Bg 300 and *Kaluheenati* (a traditional variety), (Subasinghe, 2007). The morphological characterization of the same study inferred that weedy rice possess intermediate characteristics to those of cultivated and annual wild rice, *O. nivara* indicating the potential of the occurrence of a hybrid between wild and cultivated rice (Subasinghe, 2007).

Strategies for Weedy Rice Management in Sri Lanka

Given the situation of weedy rice infestation in Sri Lanka and all the reported findings, it is evident that the current seed paddy distribution pattern is largely responsible for the rapid spread of weedy rice across the country, causing serious infestation. Therefore, efforts should be made to maintain clean seed sources, without contamination of weedy rice seeds and to break the long-distance movement and spread of weedy rice by only using certified clean seed paddy provided by either the government agencies or licensed seed production companies. This measure will be very effective for the weedy rice control in rice cultivation in Sri Lanka at present. Clean seed sources without contamination of weedy rice can significantly minimize the spread and infestation of this weed.

Currently in Sri Lanka, 90% of seed paddy supplies are provided by farmers' self-saved seeds and the distribution of rice seeds is essentially on a farmer-to-farmer basis. In the entire country, only, 10% of the certified seeds are provided and distributed by government-based seed production agencies, e.g. Department of Agriculture (4%), and private seed production companies (6%) (Weerasena and Madawanarachchi, 2000).

Public and private sector seed production institutions in Sri Lanka need to take immediate action to increase the production of certified seed paddy to a substantial level. However, due to various reasons, this goal has not been reached so far. Therefore, it is strongly recommended that the use and distribution of certified seed paddy should gradually

replace the current model of self-saved seed use and farmer-to-farmer seed distribution, to significantly minimize the rice yield losses caused by the infestation of weedy rice. The use of certified seed paddy is safe in sustaining rice production and making comparatively more economic benefit for farmers in the long run as the potential threats of rice yield losses (up to 90%) by weedy rice infestation can be minimized. Probably farmers to grow rice by purchasing certified seed is more expensive than the use of saved seeds that are essentially free, but the substantial yield losses that may be caused by weedy rice infestation through the weedy rice contaminated seed sources will result in poor incomes for farmers. In addition, fields used for producing certified rice seeds that are distributed to farmers for cultivation should be closely monitored to ensure that they are free from weedy rice infestation. Integrated weed control measures can significantly ensure the safe and sustainable production of rice in Sri Lanka by minimizing rice yield damages caused by weedy rice infestation.

Integrated weed control measures currently practiced include cultural, mechanical and chemical means. Because of the absence of selective herbicides, cultural weed management approaches, including tillage and flooding, may help reduce the weedy rice density. Emergence of weedy rice could be suppressed by deep tillage that buries seeds below their maximum depth of emergence (8 cm) and by flooding fields as early as possible (Chauhan, 2012). In addition, hand removing and application of contact chemicals at flowering stage by rope method are some other practices popular among Sri Lankan farmers. Herbicide resistant rice cultivars are used to manage weedy rice in some countries (Eg. United States). However, this opportunity is not available in Sri Lanka. Recently, it was found that the herbicide pretilachlor (a selective systemic herbicide absorbed by the germinated shoots and roots) has the potential to reduce weedy rice infestation in wet-seeded rice systems (Shen et al., 2013) indicating some novel practices yet to be incorporated to enhance the efficacy of integrated weed control measures in weedy rice management in Sri Lanka.

Desirable characteristics of weedy rice that can be transferred to cultivated rice and their heretabilities

In contrary weedy rice though imposes significant negative influence on quantity and quality of rice production as a weed, its diversity could be utilized to improve cultivated varieties by incorporating favorable characteristics of weedy rice into cultivated rice. Weedy rice was found to have a greater response to higher nitrogen rates than that of cultivated rice (Burgos et al., 2006) and some weedy rice accessions have been found to have a greater nitrogen-use efficiency in shoot biomass than that of cultivated rice (Chauhan and Johnson, 2011). In addition, weedy rice responded more strongly to rising CO_2 level with greater competitive ability, in comparison with cultivated rice, suggesting better adaptation of weedy rice in climate change scenario (Ziska et al., 2010).

Recent study highlighted that adequate genetic variability exists in the weedy rice populations in Sri Lanka and shattering percentage, total number of spikelets per plant and the number of filled seeds per panicle exhibited high genotypic and phenotypic coefficients of variation (Perera et al., 2014). They also observed that very high heritability values coupled with very high genetic advance for the shattering percentage, total number of spikelets per plant and the number of filled grains per panicle and high heritability values coupled with high genetic advance for plant height at the booting stage, number of panicles per plant and tiller number at seedling and booting stages suggesting the prevalence of additive gene action in the expression of these characteristics and the possible selection for effective improvement based on their phenotypic performance. They indicated that simply selecting comparatively taller plants with long seeds would identify high yielding weedy rice plants, which may be used in rice improvement programs.

Acknowledgement

The author wish to thank funding agencies; Bioversity International United Nations Environment Programme/Global Environment Facility project's "In-situ Conservation of Crop Wild Relatives through Information Management and Field Application - 2010"and project grant "Transforming University of Ruhuna to International Status" (TURIS)-2011 for financial support for author's studies include in this review paper.

References

1. Abeysekera, ASK, Wickramarathne, MS, Nugaliyadde L and Johnson DE (2013). Agro-morphological variations of weedy rice populations (*Oryza sativa* spontanea) in Sri Lanka. 24th APWSS Conference, (Ed.Baki hj. Bakar, Denny Kurniadie and Soekisman tjitrosoedirdjo). pp206-213. Bandung, Indonesia.

2. Abeysekara ASK, Nugaliyadda L, Herath HMS, Wickrame UB and Iqbal YB (2010). Weedy rice: A threat to direct seeded rice cultivation in Sri Lanka. Rice Congress 2010, PGRC, Gannoruwa, pp 17-18.

3. Abeysekara ASK, Herath HMS, Wickrame UB, Nugaliyadde L and Johnson DE (2010). Germinability, viability, and longevity of weedy and cultivated rice in Sri Lanka. International Rice Research Conference, OP09.

4. Burgos NR., Norman RJ., Gealy DR. and Black HL., (2006). Competitive N uptake between rice and weedy rice. Field Crop Res,99:96–105.

5. Cao QJ, Lu B-R, Xia H, Rong J, Sala F, et al. (2006). Genetic diversity and origin of weedy rice (*Oryza sativa f. spontanea*) populations found in north-eastern China revealed by simple sequence repeat (SSR) makers. Ann Bot 98: 1241– 1252.

6. Chauhan, BS (2012). Weedy rice (Oryza sativa) II. Response of Weedy Rice to Seed Burial and Flooding Depth Weed Science,60:385–388.

7. Chauhan BS. and Johnson DE., (2011). Competitive interactions between weedy rice and cultivated rice as a function of added nitrogen and the level of competition, Weed Biology and Management, vol:11, pp.202-209.

8. Dai L, Dai W, Song X, Lu B-R, Qiang S (2014). A comparative study of competitiveness between different genotypes of weedy rice (Oryza sativa) and cultivated rice. Pest Manag Sci 70(1): 113–122.

9. Delouche JC, Burgos NR, Gealy DR, Zorilla-San MG, Labrada R, Larinde MandRosell C (2007). Weedy Rices: Origin, Biology, Ecology and Control. FAO Plant Production and Protection Paper, FAO, Rome, Italy.

10. Ellstrand NC (2003). Dangerous liaisons? When cultivated plants mate with their wild relatives. The Johns Hopkins University Press, Baltimore, London.

11. Ellstrand NC and Schierenbeck KA (2000). Hybridization as a stimulus for the evolution of invasiveness in plants? Proc Natl Acad Sci USA 97:7043–7050.

12. Ellstrand NC, Prentice HC and Hancock JF (1999). Gene flow and introgression from domesticated plants into their wild relatives. Ann RevEcolSyst30: 539-563.

13. Evanno G, Regnaut S and Goudet J (2005). Detecting the number of clusters of individuals using the software STRUCTURE: a simulation study. MolEcol 14:2611–2620.

14. Falush D, Stephens M and Pritchard JK (2003). Inference of population structure: Extensions to linked loci and correlated allele frequencies. Genetics 164: 1567– 1587.

15. Ferrero A, Vidotto F, Balsari P, Airoldi G (1999). Mechanical and chemical control of red rice (*Oryza sativa* L. var. sylvatica) in rice (*Oryza sativa* L.) per-planting. Crop Protect 18: 245–251.

16. Gealy DR, Tai TH, Sneller CH (2002). Identification of red rice, rice, and hybrid populations using microsatellite markers. Weed Sci 50:333–339
17. He Z, Jiang X, Ratnasekera D, Grassi F, Perera U & Lu B-R. (2014). Seed mediated gene flow promotes within- population genetic variation of weedy rice: implication for weed management. PLOS One 9(12): e112778.

18. Jiang Z, Xia H, Basso B and Lu B-R. (2012). Introgression from cultivated rice influences genetic differentiation of weedy rice populations at a local spatial scale.TheorAppl Genet124(2):309-322.

19. Karunarathna KDK, Weerakoon SR, Somaratne S. Weerasena OVDSJ and Abeysekera ASK (2013): Autecology of invasive species Cyperus rotundus L. in

forest phenotypic and genotypic variations among weedy rice (*Oryza sativa f. spontanea*) populations in matara and Kurunagala districts of Sri Lanka. (Ed. Baki hj. Bakar, Denny Kurniadie and Soekisman tjitrosoedirdjo). pp 200-205. Bandung, Indonesia.

20. Khush GS (2004). Harnessing Science and Technology for Sustainable Rice Based Production System. FAO Rice Conference, Rome Italy.

21. Londo JP and Schaal BA (2007). Origins and population genetics of weedy red rice in the USA. Mol Ecol 16: 4523–4535.

22. Marambe B, (2005). Properties of rice growing in abandoned paddies in Sri Lanka. Chapter 18. I n Crop Ferality and Volunteerism (Ed. J Gressel). pp 295-303. Boca Raton, USA, CRC Press.

23. Marambe B and Amarasinghe L (2000). Weedy rice in Sri Lanka. In: Baki B.B., Chin D.V. and Mortimer M., editors. Proceedings of Wild and Weedy Rice in Rice Ecosystems in Asia. A Review. Los Banos, Philippines: International Rice Research Institute. pp. 79–82.

24. Mortimer MS, Pandey and Piggin C (2000). Weedy rice: approaches to ecological appraisal and implications for research priorities. In: Wild and weedy rice in rice ecosystems in Asia – A Review (Eds. Baki B.B. Chin D.V. Mortimer A.M.) pp 97-105. Limited Proceedings No 2, International Rice Research Institute, Philippines.

25. Perera UIP, Disna Ratnasekera, Senanayake SGJN, Abeysiriwardena DS de Z. (2014). Genetic Parameters and Correlations of Yield Attributing Characteristics of Weedy Rice in Sri Lanka. JNSF, Sri Lanka 42 (4): 299-306.

26. Perera UIP, Ratnasekera WADPR, Senanayake SGJN (2010). Morphological diversity of weedy rice accessions collected in Ampara district. Proceedings of the 15th International Forestry and Environmental Symposium, University of Sri Jayawardhanapura, Sri Lanka. pp. 190–194.

27. Pritchard JK, Stephens M, Donnelly P (2000). Inference of population structure using multi locus genotype data. Genetics 155: 945–959.

28. Ratnasekera D, Perera UIP, He Z, Senanayake SGJN, Wijesekara GAW, Yang X & Lu B-R. (2014). High level of variation among Sri Lankan weedy rice populations, as estimated by morphological characterization. Weed Biology and Management 14(1): 68-75.

29. Reagon M, Thurber CS, Gross BL, Olsen KM, Jia Y, Caicedo AL (2010). Genomic patterns of nucleotide diversity in divergent populations of US weedy rice. BMC Evol Biol 10:180.

30. Reed DH and Frankham R (2003). Correlation between fitness and genetic diversity. Conserv Biol 17(1): 230–237.

31. Rupasingha, KMASK and Disna Ratnasekera (2013). Germination behavior of weedy rice under field conditions at different sowing depths. International Symposium (ISAE 2013), Faculty of Agriculture, University of Ruhuna. pp 245-247.

32. Shen X, Gao X, Eneji AE, Chen Y (2013). Chemical control of weedy rice in precise hill-direct-seeded rice in South China. Weed Biol. Manag. 13: 39-43.

33. Somaratne, S, Karunarathna KDK, Weerakoon SR, Abeysekera ASK and Weeresena OVDSJ (2014). Salient characters of Weedy rice (*Oryza sativa f. spontanea*) populations in highly infested areas in Sri Lanka, Ruhuna Journal of Science, 5: 31-36.

34. Song ZP, Lu B-R, Wang B, Chen JK (2004). Fitness estimation through performance comparison of F1 hybrids with their parental species Oryza rufipogon and O. sativa. Ann Bot 93:311–316.

35. Song ZP, Zhu WY, Rong J, Lu B-R. (2006). Evidences of introgression from cultivated rice to Oryza rufipogon (Poaceae) populations based on SSR fingerprinting: implications for wild rice differentiation and conservation. Evol Ecol 20:501–522.

36. Subasinghe, SACC, Ranasinghe AM and Marambe B (2007). Molecular characterization of weedy rice in Sri Lanka. Proceedings of the 21st Asian Pacific Weed Science Society Conference (Eds: Marambe

B, Sangakkara UR, De Costa WAJM and Abeysekara ASK), 2-6 October 2007, Colombo, Sri Lanka. pp 469-476.

37. Weerasena SL and Madawanarachchi WP (2000). Improving quality seed supply in rice. In:, Department of Agriculture, , editors. Proceedings of the Annual Symposium of the Department of Agriculture (ASDA) in Kandy. Peradeniya, Sri Lanka.

38. Xia HB, Wang W., Xia H, Zhao W and Lu B-R. (2011). Conspecific crop-weed introgression influences evolution of weedy rice (*Oryza sativa f. spontanea*) across a geographical range. PLOS One 6(1): e16189.

39. Zeigler RS and Barclay A (2008). The relevance of rice. Rice 1: 3-10

40. Ziska LH.,Tomecek MB., Gealy DR., (2010). Competitive interactions between cultivated and red rice as a function of recent and projected increases in atmospheric carbon dioxide. Agronomy Journalvol: 102:118-123.