EFFECT OF WEEDY RICE (*Oryza sativa* L.) ON THE YIELD OF CULTIVATED RICE (*Oryza sativa* L.) IN GREENHOUSE AND FIELD ENVIRONMENT

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by

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ABBREVIATIONS

211	MR 211
220	MR 220
ANCOVA	Analysis Covariate
ANOVA	Analysis of Variance
B	Regression coefficient
CL1	MR 220 CL1
CL2	MR 220 CL2
cm	Centimeter
CR	Cultivated rice/ rice/ cultivar
d	Day
DAS	Day of sowing
et al.	Et alii/ et aliae/ et alia/ and others
e.g.	For example
f.	Forma
g	Gram
GRIN	Germplasm Resources Information Network
h	Hour
Ha	Hectare
i.e	In other words or that is
IRRI	International Rice Research Centre
IUCN	International Union for Conservation of Nature
Kg	Kilogram
LC	Least Concern
m	Meter
m^2	Meter square
m^{-2}	Per meter square
MARDI	Malaysian Agricultural Research and Development Institute
mm	Milimeter
MVSP	Multivariate Statistical Package
No.	Number
NPK	Nitrogen Phospate Potassium fertilizer
O.	*Oryza*
PC's	Principal Component

PCA	Principal Component Analysis
R^2	Sum of squares due to regression
RGR	Realtive Growth Rate
RY	Relative Yield
RY_{ch}	Relative Yield Culm Height
RY_{t}	Relative Yield Number of Tiller
RY_{fg}	Relative Yield Number of Filled Grain
RY_{1000g}	Relative Yield 1000 Grain Weight
RY_{yph}	Relative Yield per Hectare
S	Setanjung
Sect.	Section
Ser.	Series
Sig.	Significant
Sp.	Species
SPSS	Statistical Package for the Social Sciences
WR	Weedy rice
%	Percentage
>	Larger than
$\sum$	Sum
%	Percentage

KESAN PADI ANGIN (*Oryza sativa* L.) TERHADAP HASIL PADI SAWAH (*Oryza sativa* L.) DI PERSEKITARAN RUMAH HIJAU DAN LAPANGAN

ABSTRAK

Kajian ini bertujuan untuk mengkaji keupayaan persaingan padi sawah (CR) terhadap padi angin (WR). Kajian ini yang telah dijalankan selama dua belas bulan dari Januari 2012 hingga Disember 2012 di persekitaran rumah hijau dan lapangan. MR220, MR220 CL1, MR220 CL2, MR211, dan Setanjung adalah varieti yang telah dipilih bagi kajian rumah hijau. Kajian di lapangan dijalankan pada masa yang sama dengan menggunakan jenis variati CR yang sama dengan kajian rumah hijau. Walaubagaimanapun, hanya satu jenis variati CR yang ditanam dikawasan lapangan kerana kekurangan masa, tempat dan tenaga pekerja. MR220 CL2 dipilih kerana keupayaan hasil tuaian yang lebih baik dan tempoh kematangan lebih pendek berbanding varieti CR yang lain. WR dan CR telah ditanam mengikut nisbah tertentu di dalam pasu untuk kajian rumah hijau dan plot di lapangan dengan mengunakan kaedah rekabentuk tambah siri dan penggantian siri. Keupayaan persaingan varieti CR diukur berdasarkan Kadar Pertumbuhan Relatif (RGR), Hasil Relatif (RY) dan analisis regresi linear pada kepadatan serangan WR yang berlainan. Keputusan kaedah tambah siri dan penggantian siri telah menunjukkan bahawa varieti CR kurang kompetitif berbanding WR. Varieti CR yang berbeza menunjukkan kebolehan kompetitif yang berbeza. Kehadiran WR di CR menunjukkan penurunan hasil secara keseluruhan RGR, komponen hasil dan hasil tuaian. WR memberi kesan signifikan ($P<0.05$) kepada RGR, ketinggian batang, bilangan anak pokok, bilangan benih berisi, berat jerami, berat 1000 biji benih dan juga hasil tuaian varieti-varieti CR. Variati CR baru (MR220 CL2) memberikan hasil tuaian lebih tinggi, tetapi ia kurang kompetitif kepada WR berbanding dengan variati CR lain.

EFFECT OF WEEDY RICE (*Oryza sativa* L.) ON THE YIELD OF CULTIVATED RICE (*Oryza sativa* L.) IN GREENHOUSE AND FIELD ENVIRONMENT

ABSTRACT

This study aimed to investigate the competitive abilities of cultivated rice (CR) and weedy rice (WR). This study was performed over a period of twelve months from January 2012 to December 2012 in greenhouse and field environments. MR220, MR220 CL1, MR220 CL2, MR211, and Setanjung were the selected CR varieties used in the greenhouse study. The field study was simultaneously conducted using the same selected CR varieties as in the greenhouse study. However, only one type of CR variety was planted in the field study because of time, space and labour constraints. MR220 CL2 was selected because of its high yields and short maturity period among all the CR varieties. Specific proportions of WR and CR were planted in pots for the greenhouse study and plots for the field study based on additive series and replacement series designs. The competitive abilities of CR varieties were measured based on the Relative Growth Rate (RGR), Relative Yield, and linear regression analysis under different infestation densities of WR. Results of additive series and replacement series designs indicate that CR varieties were less competitive than WR. Different CR varieties demonstrated various competitive abilities. The presence of WR in CR decreased overall RGR, yield components, and yield. WR significantly ($P < 0.05$) affected RGR, culm height, number of tiller, number of filled grain, straw weight, 1000 grain weight, and yield of CR varieties. The new CR variety (MR220 CL2) demonstrated high yield, but it was less competitive than WR and other old rice varieties.

CHAPTER 1

INTRODUCTION

1.1 Brief History of Weedy Rice Infestation in Rice Cultivation

Weedy rice (WR) infestations were first reported from the Americas when red rice infestations were known to have occurred as early as 1846 (Allston, 1846). Delouche *et al.* (2007) stated that it is generally believed that the red rice was introduced into the United States of America at a much earlier date as contaminants in imported seed rice.

Problems related to WR infestations in rice fields were said to have been reported from European countries since the 1970s (Tarditi and Verseci, 1993). The WR phenomenon started when European farmers were cultivating the weak and semi-dwarf types of *Oryza sativa* var. *indica* (Tarditi and Verseci, 1993). In South-East Asian countries, Azmi *et al.* (1998) reported that WR infestation started after the adoption of direct seeding practices in rice cultivation. This is in contrast to the traditional practice of transplanting seedlings from seedbeds to the paddy fields where WR infestation was relatively unknown. In Malaysia, the phenomenon is said to have started in the 1980s (Vaughan *et al.*, 1993; Azmi and Karim, 2008).

Several theories have explained on the possible emergence or evolution of WR. One theory states that WR was produced as a result of outcrossing between cultivated rice (CR) species and their relatives in the wild or between different cultivars while other theories consider weedy species to be derived from natural mutations (Catling, 1992; Abdullah *et al.*, 1996; Gressel, 1999; Federici *et al.*, 2001).

One phenomenon related to WR is what is known as “volunteer seeding”. It is generally defined as seeds (usually of inferior quality) that are already present in the field that would germinate and grow into a crop, as opposed to those selected superior seeds of a crop which are sown to produce a good harvestable crop.

In terms of chromosome numbers, most of the different types of WR have the same genome as CR genome AA, 2n=24 (Azmi and Karim, 2008). Apparently, according to Azmi and Karim (2008) there are ten different genomic groups for *Oryza* species, denoted as AA, BB, CC, BBCC, CCDD, EE, FF, GG, JJHH and JJKK. Oka (1990), Gressel (1999), Lu *et al.* (2003) and Lu (2004) stated that species with different genomes are not compatible for intercrossing. The number of rice species from the various reports vary 22 to 26 (see Section 2.2.2).

In Malaysia, WR is of the same species as CR, *Oryza sativa* L., but the former is derived from inferior seed sources produced by CR as a result of unfavourable (drought) growing season as suggested by Watanabe *et al.* (2000). One of its main characteristics is its early shattering of mature seeds which accumulate at the ground level in the paddy fields while CR retain its seeds much longer and harvestable. Thus the seeds of WR would germinate and grow in the paddy fields after harvest season. Germination and growth of WR is much vigorous in the next rice planting season since growth conditions for the WR are made more favourable. The WR will thus compete with the CR in terms of space and nutrients.

In general, rice species including WR are characterized by their capability to self-propagate and to produce seeds (Azmi and Karim, 2008). Apart from this, WR is also known to have the adaptability to withstand different weather conditions and thus it has an added advantage when competing with CR (Baki *et al.*, 2000). On the other hand, Begum *et al.* (2005a, 2005b) had confirmed that WR populations could successfully colonize a CR field to such an extent that they would thus become the dominant weed species.

1.2 The Malaysian Scenario

Baki *et al.* (2000) first reported on the occurrence of WR in paddy fields in the Projek Barat Laut Selangor (PBLS) since 1988 and its subsequent occurrence in the Muda rice scheme in Kedah in the 1990s. The report also stated that the emergence of WR in paddy fields might be attributed to severe droughts which occurred in Peninsular Malaysia in the 1980s. Subsequently, this had led to significant rice crop yield losses in the Malaysian rice production due to growth competition between the CR and the WR. It was also noted that WR had spread to other rice cultivation areas in all parts of Peninsular Malaysia.

Rice cultivation has undergone revolutionary advances especially with the introduction of machineries such as tractors and combine harvesters. These machines are often transported from place to place and they thus become carriers of WR seeds which are physically stuck to their body parts. This phenomenon has been observed and reported by Baki and Shakirin (2010) who specifically mentioned that the movement of farm machinery between granaries in different areas was a contributing factor to the WR infestation problems. On the other hand, Azmi *et al.* (2000) observed that the wide spread of WR in paddy fields throughout Peninsular Malaysia was also due to the shift of rice planting practice from the traditional method of transplanting rice seedlings (from seedbeds to the paddy fields) and to that of the modern practice of direct seeding.

Several factors are thought to cause the appearance of WR in rice fields. Initially the wild rice retains its genetic makeup and grows as separate genepools apart from CR or “cultivars”. Gradually, the initial genetic materials of the WR become mixed with the genetic materials of the CR as a result of natural hybridization including backcrossing. The mingling of genetic resources between

WR and the CR eventually produced new genetic strains of WR which are commonly referred to as the “new unwanted varieties” as mentioned by Azmi and Karim (2008). These new unwanted varieties are also known as “*padi angin*” in Malay (or “wind rice” in English) because of the early shattering characteristics and the lighter grains which are easily detached from the panicles when blown in the wind and thus these grains drop on the ground before rice harvesting.

Baki *et al.* (2000) and Azmi and Karim (2008) explained that the new unwanted varieties or “variants” (new strains of WR) could be triggered to grow competitively with CR as a result of external factors such as unpredictable weather conditions and lack of control in agricultural management. The unpredictability of weather conditions at times in Malaysia has increased the quantity of WR seeds embedded in natural seed bank sat the ground level as mentioned by Azmi and Karim (2008). In addition, the absence of proper control of WR has allowed quick dispersal of WR seeds which is normally unknown to farmers in the field and thus would cause a possible major upsetting of the yield of the whole rice crop Azmi and Karim (2008).

From available data gathered, it is known that at 35% level of WR infestation, the lost yield of CR is about 50-60% or 3.20-3.84 tonnes per hectare per season (Baki, 2004). In extreme cases, up to 75-100% lost yields have been recorded due to WR infestation (Azmi *et al.* unpublished data, in Baki 2004). These estimates are general information gathered by relevant authorities such MARDI based random surveys on rice production in certain rice paddy areas. However, detailed surveys on the effect of WR at different levels of infestation are seldom undertaken or very little known.

1.3 Current Issues

At present Malaysia is only 72 percent self-sufficient in rice production (Gomez, 2011; Zhi, 2011). Despite Malaysian Government's efforts to boost its rice industry, rice production has not increased as expected. So much so Malaysia is still heavily dependent on rice imports. There was even a rice crisis in 2008 when rice exporting countries stopped exporting rice to Malaysia (Childs and Kiawu, 2009; Vengedasalam, 2013), thus rice production is an important security issue in the country.

1.4 Problem Statement

Despite efforts to overcome problems caused by WR in the rice fields in Peninsular Malaysia, the problems have persisted to the present day. Among the major issues faced by the rice industry is the indifferent attitude of rice farmers toward these problems. Some farmers prefer to use CR for seed stock, and do not consider WR as a weed. The lack of interaction and communication among agricultural agencies and insufficiency of integrated technologies to control WR have resulted in minimal attention being given to WR management in Peninsular Malaysia. A group of farmers reportedly secured uncontaminated seed sources from the Pertubuhan Peladang Kawasan ("Regional Farmers Organization"), but seed contamination still occurs. During field inspection for certified seeds, off-type varieties cannot always be differentiated from WR. When differences can be distinguished, the maximum mixture of other varieties permitted is approximately 0.10%, which is equivalent to 0.15 kg per 150 kg CR rate. Little is known about seed contamination resulting from contaminated seed sources in actual rice fields, and information on actual levels of WR infestations in paddy fields throughout

Peninsular Malaysia is lacking. Given that this subject is becoming increasingly critical, more studies are necessary to supplement data.

1.5 The Need to Conduct the Study

Based on ISI Web of Knowledge Journal Citation Reports, there were about 146 studies on WR, which focused on various topics. Most of the studies were done on specifications of WR, while few were done on competition of WR. Only five studies recorded on WR competition by Burgos *et al.* (2006), Chauhan and Johnson (2010), Lawton-Rauh and Burgos (2010) and Ziska *et al.* (2010). Based on the current state of knowledge on the effects of WR on CR production in Peninsular Malaysia as mentioned above, a study of this nature is much needed in order to have better knowledge on the subject. This study is hoped to gather the much needed information especially on the effects of WR at different levels of infestation on the CR.

1.6 Aim and Objectives

The aim of the study is to compare CR yields that are produced by CR at differing conditions, without and with the infestations at different levels of WR (ratio) in cultivation. Three objectives have been identified in this study as follows:-

1. To determine the influence of WR on the Relative Growth Rate (RGR) of CR by comparing CR monoculture with those of mixed culture at different ratios.
2. To determine the influence of WR on the yield components and yield of CR by comparing CR monoculture with those of mixed culture at different ratios.

3. To determine the influence of yield components on yields of CR by comparing CR monoculture with those of mixed culture at different ratios.

1.7 Hypotheses

Based on the three objectives above, the following three hypotheses are formulated to test the statements of these objectives. The objectives and the hypotheses are the basis for the methodology adopted in this study as shown in Chapter 3.

a) Hypothesis for Objective 1 (H_A)

Null hypothesis: $H_{A(0)}$: WR does not affect RGR of CR even with increased levels of infestation.

Alternative hypotheses: $H_{A(1)}$: WR does affect RGR of CR increasingly with increased levels of infestation.

b) Hypothesis for Objective 2 (H_B)

Null hypothesis: $H_{B(0)}$: WR does not affect the yield components and yield of CR even with increased levels of infestation.

Alternative hypothesis: $H_{B(1)}$: WR does affect the yield components and yield of CR increasingly with increased levels of infestation.

c) Hypothesis for Objective 3 (H_C)

Null hypothesis: $H_{C(0)}$: Yield components does not affect yield of CR even with increased levels of infestation.

Alternative hypothesis: $H_{C(1)}$: Yield components does affect yield of CR increasingly with increased levels of infestation.

CHAPTER 2

LITERATURE REVIEW

2.1 Basic Introduction to Rice Crop Science

Yoshida (1981) provided vital information pertaining to the fundamentals of rice crops science. Figure 2.1 shows the growth behaviour of the rice plant.

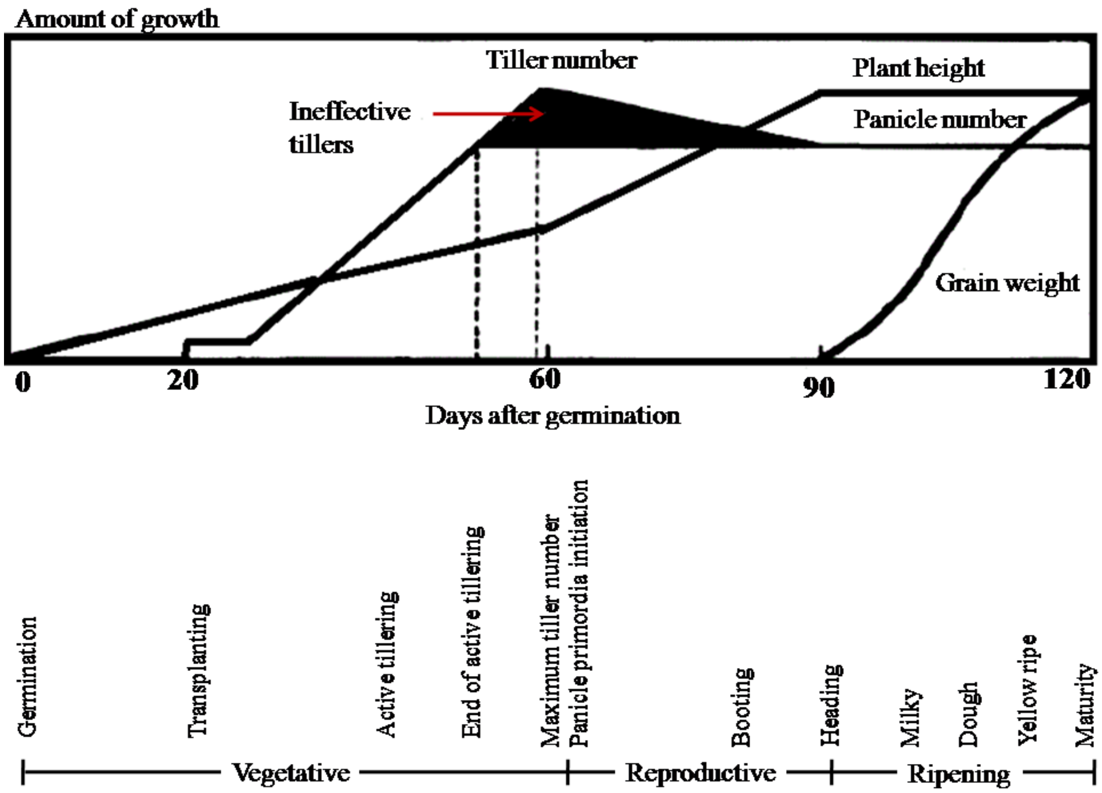

Figure 2.1: Life-history of CR (from Yoshida 1981).

The growth behaviour of the CR plant observed in this study would much refer to the established growth pattern such as the one shown above. Basically the annual CR takes about 3 to 4 months to complete its life-cycle. Based on a 120-day (4-month) growth cycle, the vegetative growth lasts to about 90 days after which vegetative growth will be reduced significantly. Tillering usually starts at about 20 days after sowing and reaches maximum growth at about 60 days after sowing and after which tillering would remain constant or reduced (as shown in Figure 2.1). Panicle initiation starts at about 80 plus days at the booting stage followed by grain filling at about 90 days after sowing. The rice plant should reach maturity in 120 days and after which growth will cease and the plant starts to undergo senescence.

2.2 General Background

A brief background information on rice is provided in this section. The subtopics under this section are those dealing with the origins of rice, taxonomic classification, and information on the species and cultivated varieties of rice in general.

2.2.1 Origins of Rice Culture

According to Zhimin (1999), the Asian-centered rice-planting culture has a wide distribution and a long history, with different hypotheses concerning its origin pointing to several regions including Assam, Yunnan, East Asian Crescent and middle and lower Yangtze River. Zhimin (1999) has also stated that, archaeologically, China has the earliest rice site with a rich culture, tracing both to the middle and lower Yangtze River, and thus subsequently its powerful influence on surrounding areas is well evidenced by Korean and Japanese findings.

The Chang-Watanabe hypothesis (Sato, 2000; History of Rice Cultivation), however, proposed that the Asian CR (*O. sativa* L.) emerged in an area stretching across Assam District of India, upper Myanmar, northen Thailand, northern Lao (PDR), and the southwestern provinces of China.

In the African continent, the species used for CR is *Oryza glaberrima*, and the species has been long in cultivation in Africa before the arrival of the Europeans in the continent (Linares, 2002). However this species was gradually replaced by the Asian *Oryza sativa* and according to Linares (2002) the Asian CR has replaced most of the native CR except in certain traditional areas. In the American continent, rice was introduced by the European settlers in the 17th century. Rice is not known to be native to the Americas.

2.2.2 Classification, Species and Varieties

2.2.2.1 Classification of *Oryza*

Oryza is a genus in the Graminae or Poaceae family, or commonly known as the grass family. The grass family is the fourth largest flowering plant family and contains about 11 000 species in 800 genera worldwide (Peterson 2001). Twenty-three genera contain 100 or more species or about half of all grass species, and almost half of the 800 genera are monotypic or diatypic, i.e. with only one or two species (Peterson, 2001).

APG 3 (Angiosperm Phylogenetic Group III) 2009 classifies rice or *Oryza sativa* L. as follows (also based on Gramene Oryza website; note the rank of Subfamily is used based on GRIN and the rank of Tribe is used used after Tang *et al*,. 2010):-

Kingdom: Plantae - Plants
Subkingdom: Tracheobionta - Vascular plants
Superdivision: Spermatophyta - Seed plants
Division: Magnoliophyta - Flowering plants
Class: Liliopsida - Monocotyledons
Subclass: Commelinidae

Order: Cyperales

Family: Poaceae - Grass family

[Subfamily: Ehrhartoideae]

[Tribe: Oryzeae]

Genus: *Oryza* L. – CR

2.2.2.2 Species and Varieties of Rice

Scientists are still divided on the taxonomy of *Oryza* and the number of species quoted ranges from 21 to 26 species; 21 species (Delouche *et al.* 2007), 22 species (Brondani *et al,.* 2003; Jaiswal *et al,.* 2005; Mabilangan *et al,.* 2008), 23 species (American group – according to Gramene Oryza), 24 species (Jena, 2010; Rice Bank Knowledge), 25 (GRIN database – see the list of species below) and 26 species listed by Gramene Oryza (based on survey of species names list). The list of species in Gramene Oryza is shown in Table 2.1.

A list of rice species based on GRIN database is given below (note: 67 taxa are listed in GRIN but only 25 have been extracted and regarded as valid species and listed here):-

1. *Oryza alta* Swallen (sect. *Oryza* ser. *Latifoliae*)
2. *Oryza australiensis* Domin (sect. *Australiensis*)
3. *Oryza barthii* A. Chev. (sect. *Oryza* ser. *Oryza*)
4. *Oryza brachyantha* A. Chev. & Roehr. (sect. *Brachyantha*)
5. *Oryza eichingeri* Peter (sect. *Oryza* ser. *Latifoliae*)
6. *Oryza glaberrima* Steud. (sect. *Oryza* ser. *Oryza*)
7. *Oryza glumipatula* Steud. (sect. *Oryza* ser. *Oryza*)
8. *Oryza grandiglumis* (Döll) Prodoehl (sect. *Oryza* ser. *Latifoliae*)
9. *Oryza latifolia* Desv. (sect. *Oryza* ser. *Latifoliae*)
10. *Oryza longiglumis* Jansen (sect. *Padia* ser. *Ridleyanae*)
11. *Oryza longistaminata* A. Chev. & Roehr. (sect. *Oryza* ser. *Oryza*)
12. *Oryza malampuzhaensis* Krishnasw. &
13. *Oryza meridionalis* Ng (sect. *Oryza* ser. *Oryza*)
14. *Oryza meyeriana* (Zoll. & Moritzi) Baill.
15. *Oryza minuta* J. Presl (sect. *Oryza* ser. *Latifoliae*)
16. *Oryza neocaledonica* Morat (sect. *Padia* ser. *Meyerianae*)
17. *Oryza nivara* S. D. Sharma & Shastry (sect. *Oryza* ser. *Oryza*)

18. *Oryza officinalis* Wall. ex G. Watt (sect. *Oryza* ser. *Latifoliae*)
19. *Oryza punctata* Kotschy ex Steud. (sect. *Oryza* ser. *Latifoliae*)
20. *Oryza rhizomatis* D. A. Vaughan (sect. *Oryza* ser. *Latifoliae*)
21. *Oryza ridleyi* Hook. f. (sect. *Padia* ser. *Ridleyanae*)
22. *Oryza rufipogon* Griff. (sect. *Oryza* ser. *Oryza*)
23. *Oryza sativa* L. (sect. *Oryza* ser. *Oryza*)
24. *Oryza schlechteri* Pilg. (sect. *Padia* ser. *Schlechterianae*)
25. *Oryza schweinfurthiana* Prodoehl (sect. *Oryza* ser. *Latifoliae*)

Table 2.1: Species of rice (*Oryza*) in the world.

Oryza alta	*Oryza granulata*	*Oryza officinalis*
Oryza australiensis	*Oryza latifolia*	*Oryza perennis*
Oryza barthii	*Oryza longiglumis*	*Oryza punctata*
Oryza brachyantha	*Oryza longistaminata (Oryza glumaepatula)*	*Oryza rhizomatis*
Oryza coarctata	*Oryza malampuzhaensis*	*Oryza ridleyi*
Oryza eichingeri	*Oryza meridionalis*	*Oryza rufipogon*
Oryza glaberrima	*Oryza meyeriana*	*Oryza sativa*
Oryza glumipatula (Oryza glumaepatula)	*Oryza minuta*	*Oryza schlecteri*
Oryza grandiglumis	*Oryza nivara (Oryza sativa* f. *spontanea)*	**Data retrieved October 17, 2006**

(Note: Adapted from Gramene Oryza).

Up until now, the taxonomy of *Oryza* has not been fully resolved, but as for the cultivated species, most scientists accept two species; *Oryza sativa* and *Oryza glaberrima* as the world's widely CR species. The rest of the species are considered wild although a few species of these so-called wild species might be in cultivation e.g. *Oryza longistaminata* or Red Rice which is cultivated in parts of traditional Africa. The non-cultivated species may sometimes be referred to as "WR" (see subsection [e] below).

In Peninsular Malaysia, two species or rice are know to exist; *Oryza rufipogon* (the wild rice species) and *Oryza sativa* (cultivated species). Although *Oryza rufipogon* is considered a wild species, it is however listed in IUCN Red Data Book (or Red List) 2012 release under "Least Concern" (LC) or "Lowest risk". In the IUCN category of threatened species, this category denotes that a species does not qualify for a more “at risk” category. Widespread and abundant taxa are included in this category.

2.2.2.3 Phylogentic Relationship

Recently, there have been many studies on the phylogenetic relationships of *Oryza* species by Song Ge *et al.* (1999), Sacks *et al.* (2006), Duan *et al.* (2007), Zuccolo *et al.* (2007), Ammiraju *et al.* (2010), Tang *et al.* (2010) and Lawton-Rauh and Burgos (2010). The general concensus by scientists agrees that the two CR species *Oryza sativa* and *Oryza glaberrima* are both of genome AA together in the same clade (within the phylogenetic tree) with the non-cultivated species *Oryza rufipogon*, *Oryza glumipatula*, *Oryza longistaminata*, *Oryza barthii*, *Oryza meridionalis* and *Oryza nivara* as shown by Song Ge *et al.* (1999). It is generally believed that *Oryza sativa* is derived from *Oryza rugifogon* and that *Oryza glaberrima* is derived from *Oryza nivara* (Zuccolo *et al.* 2007).

2.2.2.4 The International Rice Genebank

IRRI (International Rice Research Institute) which is based in Los Banos, Philippines holds more than 117,000 “types” of rice - the biggest collection of rice genetic diversity in the world. The genetic diversity of rice is used to breed new rice varieties (IRRI).

2.2.2.5 WR in General

This subject has been introduced earlier in Chapter 1 (Sections 1.2). As can be seen above, there are more than twenty species of rice, two of which are cultivated, and all of which belong to the AA genome (Figure 2.2). There is the tendency for outcrossing, backcrossing and hybridization between populations of different species and varieties. As a result there would exist hybrids and outcrossed rice species and varieties that resemble closely with cultivated. These hybrids or varieties may infest rice fields though volunteer seeding or contaminated seeds.

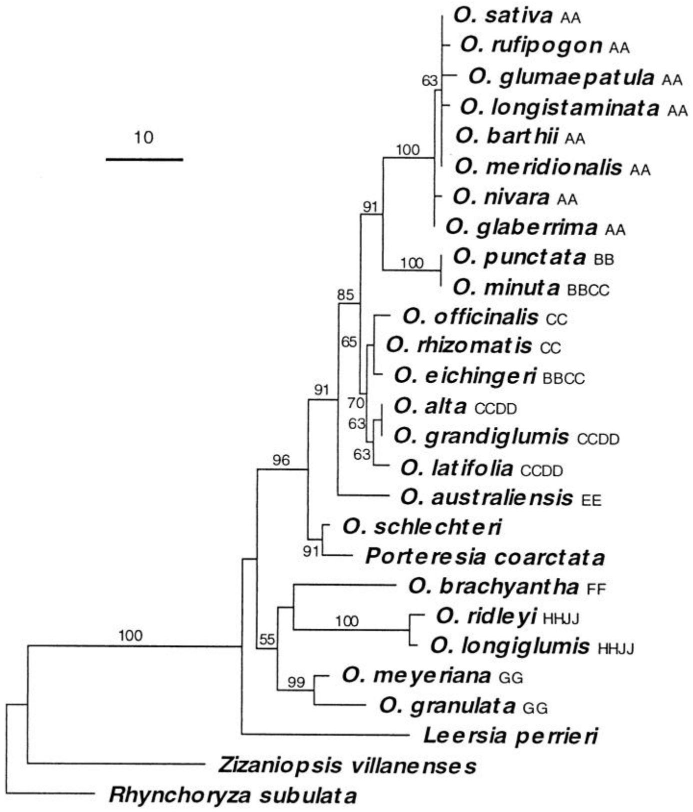

Figure 2.2: Phylogenetic tree showing the AA genome in rice (after Song Ge 1999).

Begum *et al.* (2005a, 2005b) stated that existing weed vegetation could be drastically replaced by the WR of the *Oryza sativa* complex. WR, however, had not been listed as a dominant weed species before the emergence of the WR phenomenon in rice fields, but once it began to emerge in the rice fields, it then started to seriously infest the rice cultivars (Zainal, 2008). Baki *et al.* (2000)

postulated that the emergence of WR in rice fields was probably caused by severe droughts in Peninsular Malaysia in the 1980s.

Baki (2004) reported that WR had began to colonise the MADA rice cultivated areas in the early 1990s, followed by the Besut area (Terengganu) in 1995, Sg. Manik and Kerian areas (Perak) in 1996, Seberang Perai (Pulau Pinang) in 1997, and Seberang Perak (Perak) and Kemubu (Kelantan) areas in 2001. It was also noted that about half of the 700 hectares of rice farm blocks in Selangor areas (Sekinchan, Sungai Leman, Sungai Burong and Sungai Nipah) were infested by WR for Season 2 in 1993 (Baki, 2004).

According to Baki *et al.* (2000), owing to the sympatric occurrence of WR and commercial rice, the WR had the tendency to compete for space and the common pools of nutrients which were necessary for growth and survival. Baki *et al.* (2000) also reported that WR populations in the various rice cultivated areas in Selangor did not show distinct morphological variation.

Methods of WR control have been developed in Peninsular Malaysia to address the WR menace in rice fields such as better water management, application of suitable herbicides, and improved tilling method (Azmi and Karim, 2008). Despite efforts to reduce WR infestations in rice fields, the phenomenon had continued to persist. Baki *et al.* (2000) were of the opinion that the persistence or continued prevalence of WR over CR was an indication of better ecological adaptations by WR compared to the commercial rice varieties.

The use of herbicide-resistant rice cultivars has the potential to improve the efficiency of weed management in rice fields and to increase rice yields (MARDI, 2008). However, any new herbicide that is applied to the rice fields to protect a rice cultivar would consequently induce similar resistence in the WR found in the same area. This would happen through outcrossing (Busconi *et al.*, 2012).

WR normally takes about 90-120 days to mature compared to the commercial variety which takes about 115 days to 120 days (Zainal, 2008). In addition, WR exhibits other advantageous characters over the commercial varieties such as taller plant height, faster growth rate, and earlier seed shattering. Some WR variants are known to have a life-cycle of less than 3 months, thus the seeds mature earlier and dropped into the natural seed banks and remain dormant until the next growing season. At the sametime, the dropped seeds of WR can also germinate and colonise abandoned rice fields after the harvest season.

WR can also originate from the natural hybrids between CR and WR through cross-pollination (Azmi and Karim, 2008; Grillo *et al.*, 2009) as well through introgression (Baki *et al.*, 2000). Introgression or introgressive hybridization is generally defined as the movement of a gene from one species into the gene pool of another by the repeated backcrossing of an interspecific hybrid with one of its parent species. The level of introgression can be determined by outcrossing (Baki *et al.*, 2000). The rate of outcrossing affects the heterozygosity of populations which might also to contribute to the evolutionary potential of WR (Baki *et al.*, 2000). For a non-specific crop, introgression is said to able to influence the genetic variation and possibly also the evolution of its co-existing WR populations (Baki, *et al.*, 2000).

2.2.2.6 WR in Peninsular Malaysia

From personal study and observation, in Peninsular Malaysia, WR can be attributed to four factors were (i) volunteer seedling, (ii) seed contamination, (iii) outcrossing between *Oryza rufipogon* and *Oryza sativa*, (iv) outcrossing between

WR (which is a low quality variety of *Oryza sativa*) and CR (the high quality commercial variety) of the same species *Oryza sativa*. Azmi and Karim (2008) however regarded three factors that help to initiate the population growth of WR i.e. (i) the existence of dormant seeds retained in the soil over crop seasons, (ii) the distribution of the WR seeds through contaminated seeds, and (iii) the return seeds from plants of the previous crop.

2.2.2.7 *Oryza rufipogon* Griff. – A Wild Species of Rice

Most of the following information was retrieved from the IUCN Red Data List website (http://www.iucnredlist.org) on 29th August 2013. The plant description part (botanical description) was retrieved from the Rice Bank Knowledge website (http://www.knowledgebank.irri.org) on 29th August 2013, and Ngu *et al.* (2010).

Oryza rufipogon is the wild species from which the CR, *Oryza sativa*, has been domesticated. It is wide spread in most of the world, being invasive in parts of America. It is considered a weed in rice fields, as it easily crosses with the CR, reducing its market value. No serious threats have been reported for the species and hence it is included in the category Least Concern. It is important for the germplasm which has many resistant genes, and hence is collected and conserved in-situ and ex-situ in China.

Oryza rufipogon is a widely distributed tropical plant. It has been recorded in Asia (Afghanistan, Bangladesh, Cambodia, China, India, Indonesia, Iran, Iraq, Korea, DPR, Republic of Korea, Laos, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, Vietnam), Africa (Egypt, Senegal, Swaziland, Tanzania), North America (USA), Central America, South America (Brazil, Colombia, Ecuador, Guyana, Peru, Venezuela, Oceania), Australia (Australia, Queensland, Papua New Guinea).

Native countries for *Oryza rufipogon* is native to these following countries: Afghanistan; Australia; Bangladesh; Brazil; Cambodia; China (Guangdong, Guangxi, Hunan, Jiangxi, Yunnan); Colombia; Ecuador; Egypt; Guyana; Hong Kong; India (Andhra Pradesh, Assam, Bihar, Goa, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Tamil Nadu, Uttar Pradesh, West Bengal); Indonesia (Irian Jaya, Jawa, Kalimantan, Sulawesi); Iran, Islamic Republic of Iraq; Korea, Democratic People's Republic of Korea, Republic of Lao People's Democratic Republic; Malaysia; Myanmar; Nepal; Pakistan; Papua New Guinea; Peru; Philippines; Senegal; Sri Lanka; Swaziland; Taiwan, Province of China; Tanzania, United Republic of; Thailand; United States; Venezuela; Viet Nam.

The species is widely distributed and has invasive tendencies. The population trend is reported to be increasing. *Oryza rufipogon* grows in shallow water, irrigated fields, pools, ditches and sites with stagnant or slow, running water. It occurs at altitudes from 0 to 1000 m and is suited to sites that support populations of CR. It is naturally found in terrestrial and freshwater swamp ecosystems.

Oryza rufipogon is perennial, tufted, and scrambling grass with nodal tillering; plant height variable (1-5 m) depending on the depth of water; panicles open; spikelets usually 4.5-10.6 mm long and 1.6-3.5 mm wide with awns usually 4-10 cm long; anthers >3 mm reaching 7.4 mm long.

Oryza rufipogon were found growing in swamps, along river banks, irrigation canals and in or at margins of rice fields (Abdullah *et al.*, 1991; Ngu *et al.*, 2010). However, this natural population *Oryza rufipogon* still can be found in Peninsular Malaysia such as Seberang Perai of Pulau Pinang, Kedah, Kelantan and

Terengganu. For Malaysia, this species can be found only in the northern part of Peninsular Malaysia (Seberang Perai of Pulau Pinang, Kedah, Kelantan and Terengganu), growing in swamps, along river banks, irrigation canals and in or at the margins of rice fields (Abdullah *et al.,* 1991; Ngu *et al.,* 2010). *Oryza rufipogon* is a perennial that lives in relatively a seasonal habitats and relies primarily on vegetative production; it is a short day plant that flowers near the end of the monsoon season (October to March). It outcrosses at a much higher rate (7–56%) compared to *Oryza sativa* (1–2%) (Cao *et al.,* 2007; Ngu *et al.,* 2010) and has large, indehiscent and pendant anthers (Grillo *et al.,* 2009; Ngu *et al.,* 2010).

Since *Oryza rufipogon* is one of the most important gene pools for rice breeding, there is an urgent need for its conservation. The results of the present study on population structure of *Oryza rufipogon* can be helpful in designing methods for developing collection and conservation strategies for different populations of *Oryza rufipogon* in Malaysia (Ngu *et al.,* 2010).

2.2.2.8 CR Varieties

Rice has been cultivated in China since ancient times and was introduced to India before the time of the Greeks, and Chinese records of rice cultivation go back 4,000 years (IRRI website; Pearson Education website). Thus, the history of selective breeding for rice a rather long one. To date, more than 117,000 types of rice (cultivars) are kept in the International Rice Genebank at IRRI in the Philippines (see subsection [2.2.2.4] above).

In Peninsular Malaysia, at least forty cultivars have been recorded thus far by MARDI (MARDI 2011) as listed in Table 2.2 below.

Table 2.2: List of rice cultivars in Peninsular Malaysia.

CR	YEAR RELEASED	CR	YEAR RELEASED
Malinja	1964	MR 81	1988
Mahsuri	1965	Pulut Hitam 9 PH9	1990
Ria (IR8)	1966	MR 103	1990
Bahagia	1968	MR 106	1990
Murni	1972	MR 123	1991
Masria Pulut	1972	MR 127	1991
Jaya (C4-63)	1973	MR 159	1995
Sri Malaysia I	1974	MR 167	1995
Pulut Malaysia I	1974	MR 185	1997
Sri Malaysia II	1974	MRQ 50	1999
Sekencang	1979	MR 211	1999
Setanjung	1979	MR 219	2001
Sekembang	1979	MR 220	2003
Kadaria	1981	Maswangi MRQ 74	2005
Pulut Siding	1981	MR 232	2006
Seberang	1984	MRM 16	2010
Manik	1984	MR220 CL1	2010
Muda	1984	MR220 CL2	2010
Makmur	1985	MR 253	2010
MR 84	1986	MR 263	2010

(Note: This table was constructed based on MARDI, 2011)

At present, majority of Peninsular Malaysia rice farmers are encouraged to use seeds of rice cultivars recommended by MARDI. However Chinese rice farmers in the Sekinchan area in Selangor prefer to use their own seed sources including those cultivars developed by selection and breeding conducted by these farmers. Production from the Sekinchan paddy areas is usually higher compared to those areas using MARDI seeds. One such variety is the “Siraj” which is said to contribute about 200-300 % increase in rice yield.

2.2.2.9 Yield of Malaysian (MARDI) Rice Cultivars

Table 2.3: Malaysia rice cultivars.

CR	YIELD (kg/hectare)	YEAR RELEASED
JAYA	3500-5000	1973
MR1 (Setanjung)	4100-6000	1979
Kadaria	2900-5000	1981
MR 52 (Manik)	4000-5000	1984
MR 71 (Muda)	5000-5500	1984
MR 77 (Seberang)	5000-5500	1984
MR 73 (Makmur)	5500-6500	1985
MR 84	4057-6235	1986
MR 81	4200-6000	1989
MR 106	4500-7100	1990
PH 9 (Pulut hitam)	3800-4700	1990
MR 127	4831-7245	1991
MR 159	3500-5400	1995
MR 167	4000-6000	1995
MR 211	6000-9000	1999
MRQ 50	3500-4500	1999
MR 219	7000-10000	2001
MR 220	7000-10000	2003
MRQ 74 (Maswangi)	4500-5500	2005
MR 232	7000-10000	2006
MR 220 CL1	5740-9140	2009
MR 220 CL2	5840-9740	2009
MR253	5600-7000	2010
MR263	5500-7000	2010

(Note: Cultivars in bold are used in this study, compiled from information gathered from MARDI website).

2.2.2.10 General Statistics on Rice Industry in Malaysia

At present, nearly 690,000 hectare are currently under rice cultivation in 2011 in Malaysia (Department of Agriculture; Department of Statistics Malaysia). Nearly 520,000 hectare are in Peninsular Malaysia which contribute to about 2.2 million tonnes of rice in 2001 (Department of Agriculture).

For rice production in rice scheme areas with granaries, a total of nearly 390,000 hectare are under rice cultivation in 2011 with rice production is in the range of about 1.6 million tonnes to nearly 1.9 million tonnes from 2007 to 2011 (Department of Agriculture).

In terms of acreages, the area under rice cultivation for Malaysia does not show marked increase over the years. In 1970 rice cultivation covered about 533,400 hectare and in 2011 it covers about 690,000 hectare (Department of Statistics Malaysia) showing about 30 % increase in over 40 years.

2.3 WR Phenomenon in Peninsular Malaysia

According to Azmi and Karim (2008) WR has been known to become a menace to the rice crop in Peninsular Malaysia since 1988. According to Azmi and Baki (2007), on average about 10 % of the Muda rice scheme area was infected by WR. Based on personal observation, about 5 to 50 % (in terms of area) of the rice field in the Muda rice scheme are infected by WR.

Outcrossing between WR and CR is said to have occurred in various rice cultivated areas in the granary schemes all over Malaysia (Abdullah *et al.,* 1996; Vaughan *et al.,* 1995; Chin, 2001; Shakirin, 2009; Baki and Shakirin, 2010; Zainuddin *et al.,* 2010). This has led to the emergence of various new types of WR in rice field in Peninsular Malaysia. According to Watanabe *et al.* (2000), the WR has different genetic makeups for different areas meaning that they are part of the rice gene-pools of those specific areas and thus confined within such areas. At present, the in-depth study on WR is lacking in Peninsular Malaysia.

2.3.1 Characteristics of WR

2.3.1.1 Morphological and Anatomical Characters

WR (weedy variety of *Oryza sativa*) some what resembles CR but with some minor observable differences. WR tends to be slightly more hardy and sometimes relatively taller than CR, and its internodes are relatively (slightly) longer. A characteristic of WR is the presence of anthocyanin pigment in various parts of the plant including collar, ligule, grain apiculus, stigma and awns as mentioned by Azmi and Karim (2008). Awned WR has longer epidermal hairs (Zainal, 2008). The abaxial epidermis contains a higher number of stomata than the adaxial epidermis (Arrieta-Espinoza *et al.,* 2005; Zainal, 2008)

Baki *et al.* (2000) construed that the differences among the variants of WR could be determined based on the shape of fruit stalks (either compact or otherwise), the presence of reddish purple pigmentation, and the hairy characteristics of the seeds. In addition, differences in the length of rice stalks, the number of spikelets and empty seeds were also noted to occur from variant to variant. The name "Red Rice" as for some species and varieties is due to the pigmentation.

There are four important characters for WR in general; plant height, pigmented grain, easy shattering, and long awn. WR can occur as ecotypes depending on its environment and its morphological features are somewhat comparable to that of CR varieties from the seedling to the reproductive stage (Zainal, 2008). According to Baki *et al.* (2000), most farmers in Peninsular Malaysia are able to differentiate WR from CR based on morphological characteristics.

In general, WR can be distinguished from rice cultivars in terms of height (Zainal, 2008). Azmi and Baki (1995) studied several variants of WR from 18 different locations and it was discovered that some of the characteristic differences