# GENETIC DIVERISTY STUDY BASED ON SEED MORPHOLOGY OF RICE LANDRACES FROM KOTA BELUD, SABAH

IRIS CHUA YIEN PING

DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR THE DEGREE OF BACHELOR
OF AGRICULTURE SCIENCE WITH HONOURS

CROP PRODUCTION PROGRAMME
SCHOOL OF SUSTAINABLE AGRICULTURE
UNIVERSITI MALAYSIA SABAH
2011

PUMS 99:1

# UNIVERSITI MALAYSIA SABAH

## BORANG PENGESAHAN STATUS TESIS

JUDUL: GENETIC DIVERISTY STUDY BASED ON SEED MORPHOLOGY OF RICE LANDRACES FROM KOTA BELUD, SABAH

IJAZAH: SARJANA MUDA SAINS PERTANIAN DENGAN KEPUJIAN (PENGELUARAN TANAMAN)

SAYA: IRIS CHUA YIEN PING SESI PENGAJIAN: 2010/2011
(HURUF BESAR)

Mengaku membenarkan tesis * (LPSM/~~Sarjana/Doktor Falsafah~~) ini disimpan di Perpustakaan Universiti Malaysia Sabah dengan syarat-syarat kegunaan seperti berikut:-

1. Tesis adalah hakmilik Universiti Malaysia Sabah.
2. Perpustakaan Universiti Malaysia Sabah dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan ( / )

[ ] SULIT (Mengandungi maklumta yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di AKTA RAHSIA RASMI 1972)

[ ] TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana Penyelidikan dijalankan)

[ / ] TIDAK TERHAD



Disahkan Oleh:

IRIS

(TANDATANGAN PENULIS)

Alamat Tetap: 26C, LANE 4, KAMPUNG NANGKA ROAD, 96000, SIBU, SARAWAK.

Tarikh: 04/05/2011

(TANDATANGAN PENYELIA)

CHEE FONG TYNG
Pensyarah
Sekolah Pertanian Lestari
Universiti Malaysia Sabah
(NAMA PENYELIA dan cop)

Tarikh: 5/5/2011

Catatan: - * Potong yang tidak berkenaan.

** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak yang berkuasa/organisasi berkenaan dengan menyatakan sebab dan tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.

Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana Secara penyelidikan atau disertasi bagi pengajian secara kerja kursus dan Laporan Projek Sarjana Muda (LPSM)

**DECLARATION**

I hereby declare that this dissertation is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that no part of this dissertation has been previously or concurrently submitted for a degree at this or any other university.

IRIS CHUA YIEN PING
BR07110023
20 APRIL 2011

**VERIFIED BY**

1. MS. CHEE FONG TYNG
   SUPERVISOR

CHEE FONG TYNG
Pensyarah
Sekolah Pertanian Lestari
Universiti Malaysia Sabah

2. DR. ABDUL RAHIM BIN AWANG
   EXAMINER

DR ABDUL RAHIM BIN AWANG
Lecturer / Academic Advisor
School of Sustainable Agriculture
Universiti Malaysia Sabah

3. MR. JIMMER JIMMY
   EXAMINER

4. ASSOC. PROF. DR. MAHMUD SUDIN
   DEAN SCHOOL OF SUSTAINABLE AGRICULTURE

ASSOCIATE PROF. DR MAHMUD SUDIN
DEAN
SCHOOL OF SUSTAINABLE AGRICULTURE
UNIVERSITI MALAYSIA SABAH

**ACKNOWLEDGEMENT**

Apart from my efforts, the success of any project depends on the encouragement and guidance of others. Hence, I would like to take this opportunity to express my gratitude to the people who have been instrumental in the successful completion of this final year project.

First of all, I owe my deepest gratitude to the one above all of us, the omnipresent God, for answering my prayers in giving me the strength to plod on despite my constitution for wanting to give up and throw in the towel. Thank you so much, Dear Lord.

Secondly, I would like to acknowledge the advice and guidance of my supervisor, Miss Chee Fong Tyng from the initial to the final level enabling me to complete my final year project. Thirdly, I would like to thank the examiners for spending their time to read and give comments for my report besides attending my presentation.

Great deals appreciated to both of my beloved parents for their understanding and endless love, through the duration of my studies. I would have never made it this far in life without them. They have been there for me every step of the way, and have supported me through all of my tough decisions.

I wish to express my love and gratitude to my grandmother, siblings and friends for always been there to support me from time to time. Last but not least, I would like to show my gratitude to those who contributed directly and indirectly to this final year project. I am grateful for their constant support and help.

# ABSTRACT

The measurement of morphological variation is the easiest indicator of genetic diversity. Rice landraces often exhibit tremendous morphological diversity. Exploring diversity in a collection of rice landraces is very important for identifying new, undiscovered genes and further improvement of germplasm. Hence, this study was carried out to determine the seed morphological variation of 45 rice landraces which were obtained from Kota Belud, Sabah. A total of 13 seed morphological characteristics, namely awning, awn colour, apiculus colour, lemma and palea colour, lemma and palea pubescence, sterile lemma colour, sterile lemma length, seed length, seed shape (length-width ratio), 100-grain weight, seed coat colour, endosperm type, and scent were evaluated based on the descriptor set by IBPGR-IRRI. Observations on the morphological characters of seed were recorded and analyzed by using Microsoft Excel. Shannon-Weaver diversity index, *H'* was used to estimate each characteristic's diversity index. The *H'* value of awning, awn colour, apiculus colour, lemma and palea colour, lemma and palea pubescence, sterile lemma colour, sterile lemma length, seed coat colour, endosperm type and scent was 0.3460, 0.4292, 0.5409, 0.2444, 0.2944, 0.3656, 0.2257, 0.1479, 0.6296 and 0.6126, respectively. The diversity index, *H'* was found to range from 0.1479 to 0.6296 in this study. The overall H' value was 0.4913. As for the quantitative parameters, 100-grain weight ranged from 1.76 g to 3.29 g. Seed length ranged from 5.4 mm to 7.9 mm whereas width ranged from 1.9 mm to 2.9 mm. The varying degree of the mixed characteristics is due to many genes that are responsible in controlling one characteristic. As a conclusion, Sabah rice landraces posses a range of diversity in their morphology. Such diversity is an important reservoir of useful genes which can be used to enrich the existing varieties with essential favourable agronomic traits.

***KEPELBAGAIAN GENETIK BERDASARKAN MORFOLOGI BIJI BENIH PADI TRADISIONAL DARI KOTA BELUD, SABAH***

## *ABSTRAK*

*Pengukuran variasi morfologi merupakan penunjuk kepelbagaian genetik yang paling mudah. Padi tradisional sering menunjukkan kepelbagaian morfologi yang luar biasa. Penerokaan kepelbagaian genetik dalam koleksi padi tradisional sangat penting dalam mengenalpasti gen yang baru dan seterusnya pembaikan germplasm yang lebih lanjut. Oleh itu, kajian ini dijalankan bagi menentukan tahap variasi morfologi biji benih untuk 45 jenis padi tradisional yang diperolehi dari Kota Belud, Sabah. Sebanyak 13 ciri-ciri morfologi biji benih, iaitu sengkuap, warna sengkuap, warna apiculus, warna lema dan palea, pubertas lema dan palea, warna lema steril, panjang lema steril, panjang benih, bentuk biji benih (nisbah panjang-lebar), 100-berat biij benih, warna kot benih, jenis endosperm, dan aroma dinilai berdasarkan deskriptor yang telah ditetapkan oleh IBPGR-IRRI. Pemerhatian ke atas ciri-ciri morfologi biji benih direkodkan dan dianalisis dengan menggunakan Microsoft Excel. Indeks kepelbagaian Shannon-Weaver, H' digunakan untuk membuat anggaran tahap indeks kepelbagaian bagi setiap ciri. Nilai H' untuk sengkuap, warna sengkuap, warna apiculus, warna lema dan palea, pubertas lema dan palea, warna lema steril, panjang lema steril, warna kot biji benih, jenis endosperm dan aroma masing-masing ialah 0.3460, 0.4292, 0.5409, 0.2444, 0.2944, 0.3656, 0.2257, 0.1479, 0.6296 dan 0.6126. Indeks kepelbagaian, H' berada dalam lingkungan 0.1479 hingga 0.6296 untuk kajian ini. Nilai keseluruhan H' adalah 0.4913. Bagi parameter kuantitatif, 100-berat biji benih berjulat dari 1.76 g hingga 3.29 g. Panjang biji benih berjulat dari 5.4 mm hingga 7.9 mm manakala lebar biji benih berjulat dari 1.9 mm hingga 2.9 mm. Kepelbagaian genetik mengikut varieti, H" berjulat dari 0 hingga 0.1780. Perbezaan dalam ciri-ciri yang bercampur adalah disebabkan wujudnya banyak gen yang bertanggungjawab dalam mengawal satu ciri. Kesimpulannya, beras tradisional Sabah mempunyai kepelbagaian dari segi morfologi. Kepelbagaian itu merupakan gen yang boleh digunakan untuk memperkaya jenis padi yang telah wujud sebelum ini dengan sifat agronomik yang baik dan penting.*

# TABLE OF CONTENTS

**Content** **Page**

## LIST OF TABLES

| Table | | Page |
|---|---|---|

## LIST OF FIGURES

# LIST OF FORMULAE

| Formula | | Page |
|---|---|---|
| 3.1 | Shannon-Weaver diversity index, *H* | 26 |

$$H = -\sum_{i=1}^{n} P_i ln P_i \text{; where}$$

n is the number of descriptor classes for a character; $P_i$ is the relative frequency in the $i^{th}$ class of the $j^{th}$ character. $P_i$ can be obtained by dividing the score of seeds for a character with the total seeds' character and ln is log base 2

| | | |
|---|---|---|
| 3.2 | $H_{max}$ | 26 |

$H_{max}$ = ln(n); where

n is the number of descriptor classes for a character in base 2

| | | |
|---|---|---|
| 3.3 | Relative diversity, *H'* | 26 |

$$H' = \frac{H}{H_{max}}$$

| | | |
|---|---|---|
| 3.4 | $H'' = \frac{\Sigma fx}{\Sigma f}$ | 27 |

$$= \frac{H'_1(n_1)+H'_2(n_2)+......+H'_{12}(n_{12})}{n_1+n_2+......+n_{12}} \text{; where}$$

$H'_1$ is the diversity index for a character of 1 with 1 is a character for a variety and $n_1$ is the total number for a character

## LIST OF SYMBOLS, UNITS AND ABBREVIATIONS

| | |
|---|---|
| 2-AP | 2-acetyl-1-pyrroline |
| Σ | Sum |
| DLL | Dwarfll |
| FAO | Food and Agriculture Organization |
| GPA | Global Plan of Action |
| *H'* | Shannon-Weaver Index |
| HYV | High Yielding Variety |
| IRRI | International Rice Research Institute |
| Kb | Kilo base pairs |
| QTLs | Quantitative Trait Loci |

## CHAPTER 1

## INTRODUCTION

### 1.1 Introduction

Rice (*Oryza sativa* L.) is one of the significant cereal commodities (Lopez, 2008) and is planted on about one tenth of the earth's arable land (Muhammad Rashid *et al.*, 2009). It is the single largest source of the food energy to half of humanity (Eckardt, 2000; Kurata and Yamazaki, 2006). Globally, rice is distributed with a high concentration in Asia (Vaughan *et al.*, 2003). However, there is an urgent need to take all the necessary steps to enhance the productivity of this crop in order to meet the future demand for food which is anticipated from the increased world population (Sundaram *et al.*, 2007). Many breeders are seeking for noble genes found in the rice landraces, which had been reported to post useful gene(s) in order to overcome this shortage (Reeves and Cassaday, 2002).

Rice landraces are defined by Brown in 1978 as "geographically or ecologically distinctive populations which are conspicuously diverse in their genetic composition both between landraces and within them". They are the traditional varieties of rice which are grown by farmers and passed down from one generation to another generation (Pusadee *et al.*, 2009). According to Harlan (1992), rice landraces are identifiable by their unique morphologies and well-established local names.

Rice landraces have been largely replaced by the genetically uniform modern varieties in many parts of Asia (Pingali and Rajaram, 1998). The adoption of new modern varieties means that the land area planted with landraces are gradually disappearing (Guei, 2000). The modern, high yielding rice varieties which are often invariant for many genetic markers lead to the most extreme lost of diversity. Such loss of diversity have serious consequences for the crop from the epidemic disease susceptibility to the lack of evolutionary potential for adaptation to the changing environmental conditions (Pusadee *et al.*, 2009).

The diversity in crop varieties is important for the development of agriculture in order to increase food production, poverty alleviation and promote growth of economic. Shahidullah *et al.* (2009) stated that the diversity which is available in the germplasm serves as an insurance against the unknown needs and conditions too. Thereby, it contributes to the stability of farming systems at local, national and global levels (Singh *et al.*, 2000).

Landraces constitute a good source of unique genes for stress tolerance, high yield stability, adaptability to the environments and genetically dynamics (Frankel *et al.*, 1995; Guei and Traore, 2001). Thus, evaluation and characterization of rice landraces should form an important constituent of the collection efforts. This is because Ogunbayo *et al.* (2007) stated that rice landraces have an enormous built-in genetic diversity due to several generations of growing and selection by farmers and breeders.

The most common characterization method is by observing the morphology of the seed grains. The measurement of the morphological variation which can be obtained easily is the indicator of the genetic diversity. Morphological characters may be ecologically adaptative (Schaal *et al.*, 1991) which are good indicators of genetic variation, local differentiation, or ecotypes.

Grain morphology is among the first visible character for the selection and marking of quality (Sadar *et al.*, 2007). Most farmers prefer medium- to long-grained rice in the rainfed lowlands of Asia. Grain appearance is an important consideration for most of the rice consumers (Ikehashi and Khush, 1979; Jennings *et al.*, 1979; Juliano, 1985). Although all grains are equally translucent after cooking and clarity of endosperm does not affect the taste or texture of rice, people will still prefer rice that has clear endosperm in most of the regions. Aromatic rice is being preferred in some parts of Asia and draws a premium price in certain specialty markets. Webb *et al.* (1979, 1985) noticed that there is a particular trend of cooking quality characters which is related to the grain shape.

Genetic variability for agronomic traits as well as the quality traits in almost all crops is essential in the crop improvement program. This is because this component is transmitted to the next generation (Singh, 1996). Thus, the diversity in grain morphology needs to be examined.

## 1.2 Justification

Landraces are precious genetic resources. This is because they contain huge genetic variability that can be used to complement and broaden the gene pool of the advanced genotypes (Kobayashi *et al.*, 2006). Besides, landraces rice often exhibit tremendous morphological diversity. Exploring diversity in a collection of landraces rice is very important for identifying new genes and further improvement of the germplasm (Aggarwal *et al.*, 2002; Brondani *et al.*, 2006; Jayamani *et al.*, 2007; Thomson *et al.*, 2007). It is belief that there are many undiscovered useful genes which can be found in the landraces rice. These genes aid in improving the resistance of rice towards biotic and abiotic stresses, grain shape, high yield stability, and aroma of rice (Frankel *et al.*, 1995; Guei and Traore, 2001).

Diversity based on the phenological and morphological characters vary with the environmental conditions (Kaylan and Rambabu, 2006). The exact potential of the local landraces genetic, differences from the commercial varieties and the magnitude of heterogeneity especially in the Sabah landraces are not well catalogued. Therefore, the need to characterize available landraces has become essential in the modern crop improvement as suggested by Frey *et al.* (1984), Dale *et al.* (1985) and Rezai and Frey (1990). This study was conducted to identify the seed morphology or phenotypic characteristics of Sabah rice landraces from the Kota Belud District which will become the source of valuable information for the future breeding program.

## 1.3 Research Objective

The objective of this study was to determine the diversity level of rice landraces from Kota Belud, Sabah based on the seed morphology characteristics.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Rice

Rice (*Oryza sativa* L.) belongs to the tribe of Oryzeae which is under the Poaceae sub-family in the grass family of Gramineae (Poaceae). The genus of *Oryza* has been divided into few sections by biosystematists (Chang *et al.*, 1965).

*O. sativa,* a diploid species has AA as its genomic formula. There are 24 chromosomes which can be found in it (Chang *et al.*, 1965). The genetic structure of the *Oryza* genus has been provided by extensive studies using a variety of means: morphological studies, cytogenetics, interspecific hybridization, biochemical and molecular markers (Chang *et al.*, 1965).

The characteristics of a rice plant is illustrated as an annual grass with round, hollow, jointed culms, rather flat and sessile leaf blades, and a terminal panicle. The lifespan of a rice plant can be more than a year under favourable conditions (Chang *et al.*, 1965).

## 2.2 Rice Landraces

Landraces are widespread and popular among farmers. Besides, they are an important part of agriculture as their diverse array in a crop creates genetic diversity in agriculture (Modi, 2004). Fukai *et al.* (1991), Gomez and Kalami (2003), Gomez *et al.* (2003), Irie *et al.* (2003) and Kohli *et al.* (2004) stated that landraces are known to be heterogeneous mixtures of genotypes that carry a range of stress-tolerance genes and others. Besides that, landraces also posses preferred traits which could be used to produce new cultivars or to incorporate desirable traits into varieties (Lynch *et al.*, 1992). These include stress tolerance, high yield stability, adaptability to environments and genetic dynamics (Frankel *et al.*, 1995; Guei and Traore, 2001). Besides, landraces are also important genetic resources for resistance to pests and fungal diseases. For instance, Indian landraces Velluthachira, Bengle and Bhumansam are resistant to rice gall midge; Chemban is resistant to brown plant hopper; Tadukan is resistant to blast; whereas Buhjan and Laka are resistant to sheath blight (Siddiq *et al.*, 2005).

Landraces have been the mainstay of agricultural systems in many developing countries (Hill *et al.*, 1998). However, introduction of modern high yielding rice varieties has caused the landraces unpopular among some farmers (Li *et al.*, 2004) to the extent that some of the landraces have been replaced (Mohapatra *et al.*, 2004). For example, observation in India by Kohli *et al.* (2004) reported that, the primary centre of rice origin had an unspecified large number of landraces. However, most of them were out of cultivation.



Rao *et al.* (2002) warned that the danger of genetic erosion in many varieties of rice landrace in Laos was due to the widespread adoption of modern varieties by farmers. Joshi and Witcombe (2003) argued that introducing modern varieties into areas which are predominated by landraces results in an increase of allelic diversity. Yet, the increase in allelic diversity would still result in the loss of some rice landraces over time.

Although landraces may have lower yields compared to the modern varieties under some conditions, they are still grown largely in approximately 50% of the rainfed rice areas in Asia (Li *et al.*, 2004). This is because they can adapt to specific local conditions better and they are developed for regional uses of rice (Parzies *et al.*, 2004). The genetic variability which can be found within landraces affords the possibility of genetic flexibility. In other words, landraces have the potential to adapt to the conditions of local field and they can adapt to changing environments, farming practices, and specific uses, namely animal versus human consumption (McCouch, 2004).

Genetic divergence among the genotypes plays an important role in the selection of parents which have wider variability for different characters (Nayak *et al.*, 2004). This fact was proved by Chaudhary and Sarawgi (2002) who reported that 50 rice landraces which had been studied by them differed for 19 morphological and quality traits. Chaudhary and Motiramant (2003) evaluated another 54 aromatic rice landrace accessions for the same 19 descriptors in order to obtain genetic variability information and character association of grain quality and yield attributes. A wide range of variation was recorded for most of the characters in the study carried out by them. Heritability in broad sense was very high for all the characters which exhibited high heritability coupled with high genetic advance except the harvest index. Significant variation for morphological and economic traits was also recorded among 11 landraces which were grown in the Tamil Nadu region of India as reported by Gomez and Kalami (2003).

Furthermore, Wood and Lenne (1997) stated that the genetic diversity of traditional landrace varieties is the most immediately useful and economically valuable component of rice biodiversity. Hence, an understanding of the structure, apportionment, and dynamics of local landrace variation is required in order to conserve, manage, and use such germplasm resources efficiently (Pusadee *et al.*, 2009).

Fukuoka *et al.* (2000) reported that morphologically similar landraces revealed great diversity upon random amplified polymorphic DNA analysis in a study of genetic variation for aroma among landraces rice in the Red River Delta, Vietnam. Chaudhary and Sarawgi (2002) reported that other studies of genetic variation in rice landraces have been based on morphological and quality traits only.

## 2.3 Rice Morphology

The study of rice morphology and development is interdisciplinary (Smith and Robert, 2003). Morphological characters are being used as discrete markers in order to provide indicators for the management of crop, identify the growth stage of plant, and provide selection criteria in the programs of crop improvement (Moldenhauer and Gibbons, 2003). Morphological characters are being used to monitor the development of plant. Monitoring is done by visual identification of the plant critical growth stages. For example, emergence, tillering, the first visible sign of panicle formation, booting, heading, and maturation (Moldenhauer *et al.*, 1994). Besides, number of emerged leaves on the main culm is related to number of leaf of the cultivar (Miller *et al.*, 1993; Nemoto *et al.*, 1995; Counce *et al.*, 2000).

### 2.3.1 Root

There are two major types in the root system of *O. sativa*, namely crown roots (including mat roots) and nodal roots. Both of them develop from nodes. However, the crown roots develop from underground nodes whereas nodal roots develop from nodes above the ground.

Rice has a fibrous root system: the temporary seminal roots which also known as the embryonic roots and secondary adventitious roots. The fibrous roots last for only a short time after the germination of seed. Embryonic roots will first form in the seedlings follow by the adventitious roots which are produced from the underground nodes of young culms.

### 2.3.2 Culms

The culm of rice is round, hollow, jointed and hairless. Culm is the stem of a rice plant. A mature rice plant has a main culm and a number of tillers depending on the variety and cultural conditions. Each culm has a certain number of nodes (generally ranging from 13 to 16 nodes) and internodes under a certain condition of environment for a variety of rice (Jules, 2002). The culm of the rice is used as a measurement of the plant height. The height of rice plant can range from 0.4 m to more than 6 m (in floating rice) depending on the variety of rice or environmental conditions (Jules, 2002).

### 2.3.3 Leaves

The leaves are borne on the culm in two ranks with one at each node. Leaves of rice are rather flat. They are long and green in colour. The first rudimentary leaf or prophyllum is found at the tiller base and, with a two-keeled bract only, and has no blade (Jules, 2002).

The uppermost leaf immediately below the panicle is known as the flag leaf. The leaf consists of sheath and blade which are attached at the node, where there is an auricle, and the ligule immediately above the auricle (Jules, 2002). The leaf sheath is continuous with the blade. It envelopes the culm above the node which is varies in length, form, and tightness (Chang *et al.*, 1965).

### 2.3.4 Panicle

The panicle is borne on the uppermost internode of the culm that is always miss-termed as a peduncle. Rice has a terminate panicle. The major structures which can be found in the panicle are the axis, base, primary and secondary branches, pedicel, rudimentary glumes, and spikelets. Each panicle generally bears from 50 to 300 flowers or spikelets (Jules, 2002).

### 2.3.5 Flowers or Spikelets

The rice panicle is a perfect and determinate inflorescence. A spikelet of rice has two sterile lemmas, the rachilla and the floret. A rice floret includes six stamens and a pistil having stigmas, styles, and ovary, which is enclosed by the lemma and palea, sometimes with an awn (Jules, 2002). The awn is a filiform extension of the keel of the lemma. Generally, the sterile lemmas are shorter than the lemma and palea, seldom exceeding one-third the length of the later. Sterile lemmas may be equal or unequal in size, the upper one generally being larger (Chang *et al.*, 1965). The stigma, a plumose structure has a function in catching the pollen for fertilization purpose.

### 2.3.6 Grain

Generally, the rice grain refers to rough rice or paddy consisting of brown rice (or caryopsis) and the hull (Figure 2.1). Brown rice consists of the endosperm, embryo, and several thin layers of differentiated tissues-the-pericarp (the wall of ovary), the seed coat, and the nucellus (Jules, 2002). The seed coat consists of six layers of cells, with the aleurone layer which is the innermost. The embryo of rice is small and contains the embryonic leaves (plumule) that enclosed by a sheath (coleoptiles), embryonic primary root (radicle) ensheathed by the coleorhizae, and the joining part (mesocotyl) (Jules, 2002).

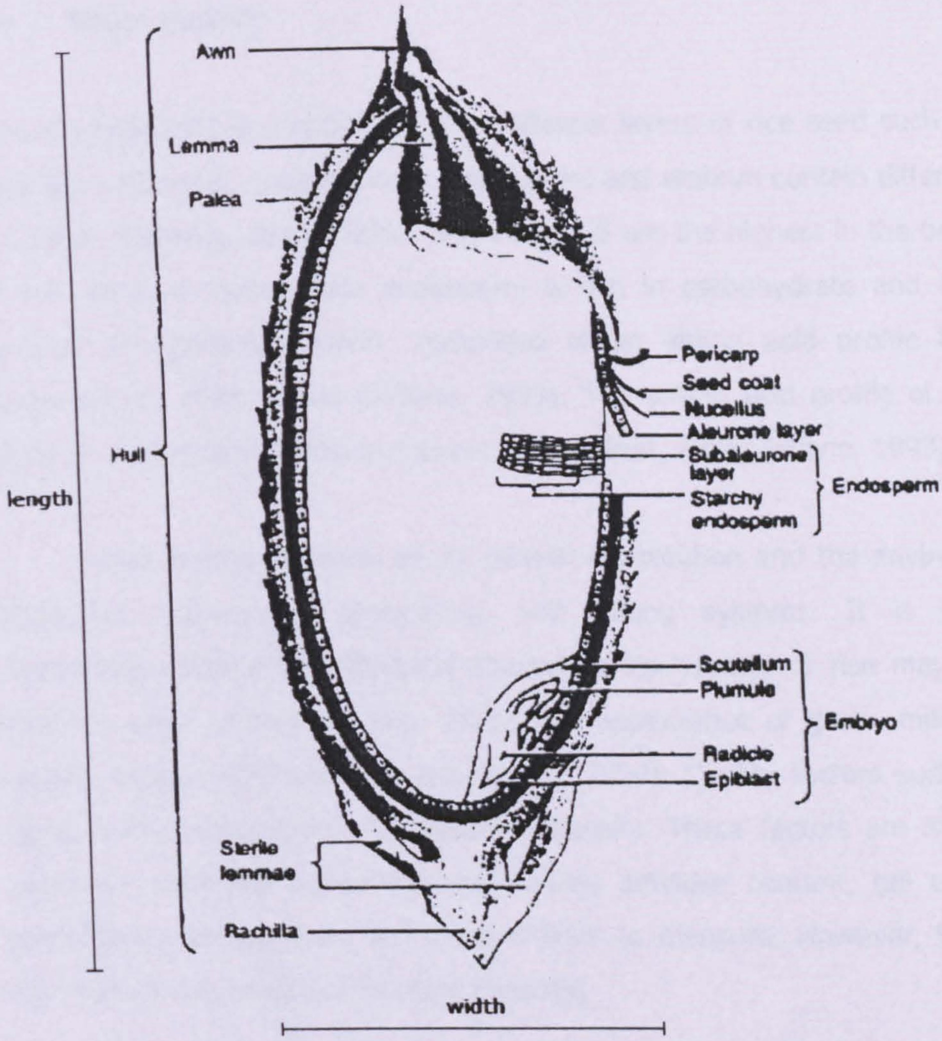


Figure 2.1: Structure of rice grain
Source: Juliano, 1993

The endosperm of rice is enclosed by the aleurone layer which lies beneath the tegmen. Starch granules embedded in a proteinaceous matrix can be found in the white starchy endosperm. The starch fraction is composed almost entirely of amylopectin and turns reddish-brown when stained with weak potassium iodide-iodine solution in the waxy (glutinous) varieties (Chang *et al.*, 1965). As for the common non-waxy (non-glutinous) type, the starch fraction contains amylase in addition to amylopectin. It will turn into dark blue colour when stained with potassium iodide-iodine solution. Besides that, the starchy endosperm also contains sugars, fats, organic matter, and crude fibber (Chang *et al.*, 1965).

## 2.4 Grain Quality

Rice is wholesome and nutritious. The different layers of rice seed such as outer hull, caryopsis, aleurone, sub-aleurone, endosperm; and embryo contain differing amount of nutrients. Minerals, dietary fibber and Vitamin B are the highest in the bran and lowest in the aleurone layers. Rice endosperm is rich in carbohydrate and contains a fair amount of digestible protein, composed of an amino acid profile that compares favourably to other grains (Juliano, 1993). The amino acid profile of rice is high in glutamic and aspartic acids, but low in lysine (Grist, 1986; Juliano, 1993).

Grain quality depends on its genetic constitution and the environment of crop production, harvesting, processing, and milling systems. It is determined by measurable physical and chemical characteristics. Quality of rice may be considered from the point of view in size, shape and appearance of grain, milling quality and cooking properties (Dela Cruz and Khush, 2000). Quality factors such as grain size, shape, and chalkiness can be assessed visually. These factors are the easiest to be measured. Chemical characteristics, namely amylose content, gel consistency, and gelatinization temperature are more difficult to measure. However, they are just as important to the programs of plant breeding.

### 2.4.1 Grain Length and Shape

The length of rice grains is determined after the grains are being hulled. The sizes of the grains are classified into short, medium, long, and extra long as described by Graham (2002; Table 2.1):

Table 2.1 Classification of grain size

| Grain Size | Length (mm) |
|---|---|
| Extra long | Greater than 7.50 |
| Long | 6.61 – 7.50 |
| Medium | 5.51 – 6.60 |
| Short | Less than 5.51 |

Source: Graham, 2002

The ratio of length to width of brown rice grains is used to determine the grain shape. The major classifications are round, bold, medium, and slender (Graham, 2002; Table 2.2):

## REFERENCES

Abbasi, F. M., Sagar, M. A., Akram, M. and Ashraf, M. 1995. Agronomic and Quality Traits of Some Elite Rice Genotypes. *Pakistan Journal of Scientific and Industrial Research* **38**: 348–350

Aggarwal, R. K., Shenoy, V. V., Ramadevi, J., Rajkumar, R. and Singh, L. 2002. Molecular Characterization of Some Indian Basmati and Other Elite Rice Genotypes Using Fluorescent-AFLP. *Theoretical and Applied Genetics* **105**: 680–690

Agrawal, G. K., Abe, K., Yamazaki, M., Mivao, A. and Hiroshika, H. 2005. Conservation of the E-function for Floral Organ Identity in Rice Revealed by the Analysis of Tissue Culture-Induced Loss-of-Function Mutants of the *OsMADS1* Gene. *Plant Molecular Biology* **59**: 125–135

Ahn, S. N., Bollich, C. N. and Tanksley, S. D. 1992. RFLP Tagging of the Gene for Aroma in Rice. *Theoretical and Applied Genetics* **84**: 825–828

Akiko, Y., Takuya, S., Wakana, T., Hiro-Yuki, H. 2009. The Homeotic Gene *Long Sterile Lemma (G1)* Specifies Sterile Lemma Identity in the Rice Spikelet. *Proceedings of the National Academy of Sciences USA* **106(47)**: 20103–20108

Akram, M., Abbasi, F. M., Sagar, M. A. and Ashraf, M. 1994. Increasing Rice Productivity through Better Utilization of Germplasm. In: *Proceedings of a National Seminar on Genetic Resources of Cereals and Their Utilization.* 8-10 February 1994. Islamabad, Pakistan. 107–114

Ali, S. S., Jafri, S. J. H., Khan, T. Z., Mahmood, A. and Butt, M. A. 2000. Heritability of Yield and Yield Components or Rice. *Pakistan Journal of Agricultural Research* **16**: 89–91

Anthony, H. D. Brown, Michael, T. Clegg, Alex, I. Kahler, Bruce, S. Weir. 1990. Plant Population Genetics, Breeding, and Genetic Resources. Sinauer Associates, Inc, Sunderland

Bajracharya, J., Steele, K. A., Jarvvis, D. I., Sthapit, B. R. and Witcombe, J. R. 2006. Rice Landrace Diversity in Nepal: Variability of Agro-morphological Traits and SSR Markers in Landraces from a High-altitude Site. *Field Crop Research* **95(2-3)**: 327–335

Balma, D. and Burkina, F. 2000. A Training Guide of In Situ Conservation On-Farm. In: Jarvis, D. and Ndung'u-Skilton, J. (eds.). *Seed Selection and Exchange.* International Plant Genetic Resources Institute, Rome, Italy

Bansal, U. K., Saini, R. G. and Rani, N. S. 2000. Heterosis and Combining Ability for Yield, its Components, and Quality Traits in Some Scented Rices (*Oryza sativa* L.). *Tropical Agriculture* **77**: 181–187

Berner, D. K. and Hoff, B. J. 1986. Inheritance of Scent in American Long Grain Rice. *Crop Science* **26**: 876–878

Bioversity International, IRRI and WARDA. 2007. Descriptors for Wild and Cultivated Rice (*Oryza* spp.). International, Rome, Italy; International Rice Research Institute, Los Banos, Philippines; WARDA, Africa Rice Center, Cotonou, Benin

Bohn, M., Friedrich, UTZ. H. and Melchinger, A. B. 1999. Genetic Similarities among Winter Wheat Cultivars Determined on the Basis of RFLPs and SSRs and Their Use for Predicting Progeny Variance. *Crop Science* **39(1)**: 228–237

Bommert, P., Satoh-Nagasawa, N., Jackson, D. and Hirano, H-Y. 2005. Genetics and Evolution of Inflorescence and Flower Development in Grasses. *Plant Cell Physiology* **46**: 69–78

Bradbury, L. M. T., Fitzgerald, T. L., Henry, R. J., Jin, Q. and Waters, D. L. E. 2005. The Gene for Fragrance in Rice. *Plant Biotechnology Journal* **3**: 363–30

Brondani, C., Borba, Tereza Cristina Oliveira, Rangel, Paulo Hideo Nakano and Brondani, Rosana Pereira Vianellio. 2006. Determination of Genetic Variability of Traditional Varieties of Brazilian Rice Using Microsatellite Markers. *Genetics and Molecular Biology* **26**: 676–684

Brown, A. H. D. 1978. Isozymes, Plant Population Genetics Structure and Genetic Conservation. *Theoretical and Applied Genetics* **52**: 145–157

Buttery, R. G., Ling, L. C., Juliano, B. O. and Turnbaugh, J. G. 1983. Cooked Rice Aroma and 2-acetyl-1-pyrroline. *Journal of Agriculture and Food Chemistry* **31**: 823–826

Champagne, E. T. 2008. Rice Aroma and Flavour. *Cereal Chemistry* **85**: 445–454

Chang, T. T. and Bardenas, E. A. 1965. The Morphology and Varietal Characteristics of the Rice Plant. The International Rice Research Institute. *Technology Bulletin 4*, 40

Chang, T. T., Bardenas, E. A. and Rosario, A. C. 1965. The Morphology and Varietal Characteristics of the Rice Plant. The Phillipines: International Rice Research Institute

Chaudhary, M. and Motiramant, N. K. 2003. Variability and Association Among Yield Attributes and Grain Quality in Traditional Aromatic Rice Accessions. *Crop Improvement* **30(1)**: 84–90

Chaudhary, M. and Sarawgi, A. K. 2002. Genetic Divergence in Traditional Aromatic Rice Accessions of Madhya Pradesh and Chhattisgarh, India. *International Rice Research Notes* **29**: 146–150

Chen, Z. X., Wu, I. G., Dina, W. N., Chen, H. M., Wu, P. and Shi, C. H. 2006. Morphogenesis and Molecular Basis on *Naked Seed Rice*. A Novel Homeotic Mutation of *OsMADS1* Regulating Transcript Level of *AP3* Homologue in Rice. *Planta* **223**: 882–890

Clay, J. 1991. Cultural Survival and Conservation: Lessons from the Past Twenty Years in: Common Wealth of Australia (1993): Biodiversity Series Paper No. 1. Department of Environment, sports Territories, Canberra

Counce, P. A., Keisling, T. C., and Mitchell, A. J. 2000. A Uniform, Adaptive and Objective System for Expressing Rice Development. *Crop Science* **40(2)**: 436–443

Cromwell, E., Cooper, D. and Mulvany, P. 1999. Agricultural Biodiversity and Livelihood: Issues and Entry Points: Paper for DFID Linking Policy and Practice in Biodiversity Project (LPPB), Overseas Development Institute (ODI), Food and Agriculture Organization FAO and Intermediate Technology Development Group (ITDG)

Dale, M. F. B., Ford-Loyd, B. V. and Arnold, M. H. 1985. Variation in Some Agronomically Important Characters in A Germplasm Collection of Beet. *Euphytica* **24**: 449–455

Datta, S. and Bouis, H. E. 2000. Application of Biotechnology to Improving the Nutritional Quality of Rice. *Food and Nutrition Bulletin* **21**: 451–456

Dela Cruz, N. and Khush, G. S. 2000. Rice Grain Quality Evaluation Procedures. In: Singh, R.K., Singh, U.S., Khush, G.S. (Ed.). *Aromatic Rices.* Oxford and IBH publishing Co. Pvt. Ltd. New Delhi

Dhillon, B. S., Tyagi, R. K., Arjun Lal and Saxena, S. 2004. *Plant Genetic Resource Management.* Narosa Publishing House Pvt. Ltd.

Eckardt, N. A. 2000. Sequencing the Rice Genome. *Plant Cell* **12**: 2011–2017

Fan, C., Xing, Y., Mao, H., Lu, T., Han, B., and Xu, C. 2006. *GS3*, a Major QTL for Grain Length and Weight and Minor QTL for Grain Width and Thickness in Rice, Encodes a Putative Transmembrance Protein. *Theoretical and Applied Genetics* **112**: 1164–1171

Frances, H., Bligh, J., Larkin, P. D., Roach, P. S., Jones, C. A., Fu, H. and Park, W. D. 1998. Use of Alternate Splices Sites in Granule-Bound Starch Synthase mRNA From Low-Amylose Rice Varieties. *Plant Molecular Biology* **38**: 407–415

Frankel, O. H., Burdon, J. J. and Paecock, W. J. 1995. Landraces in Transit-the Treat Perceived. *Diversity* **11**: 14–15

Frei, M. and Becker, K. 2004. Agro-biodiveristy in Subsistence-Oriented Farming Systems in Philippine Upland Region: Nutritional Considerations. *Biodiversity and Conservation* **13**: 1591–1610

Frei, M. and Becker, K. 2005. A Novel Correlation between Lipid Components and All-*Trans*-β-Carotene in Differently Colored Rice Landraces. *Journal of the Science of Food and Agriculture* **85**: 2380–2384

Frey, K. J., Cox, T. S., Rodgers, D. M. and Barnel-Cox, P. 1984. Increasing Cereal Yields With Genes from Wild and Weedy Species. In: Chopra, V. L., Joshi, B. C., Sharma, R. P., Bansal, H. C. (Eds.). Proc 15th International Genetic Congress, Oxford and IBH Publishing Company, New Delhi

Fukai, S., Li, L., Vizmonte, P. T. and Fischer, K. S. 1991. Control of Grain Yield by Sink Capacity and Assimilate Supply in Various Rice (*Oryza sativa*) Cultivars. *Experimental Agriculture* **27**: 127–135

Fukuoka, S., Suu, T. D., Trinh, L. N., Nagamine, T. and Okuno, K. 2000. Spatial and Temporal Aspect of Genetic Variation in Landraces of Aromatic Rice in Red River Delta, Vietnam Revealed by RADP Markers. 187–189. In: Oono, K. (Ed.). *In-situ Conservation Research. The Seventh Ministry of Agriculture, Forestry and Fisheries (MAFF) Japan International Workshop on Genetic Resources.* National Institute of Agrobiological Resources Tsukuba, Ibaraki, Japan

Ganesh, S. K., Vivekanandan, P., Nadarajan, N., Chandra Babu, R., Shanmugasundaram, P., Priya, P. A. and Manickavelu, A. 2004. Genetic Improvement for Drought Tolerance in Rice (*Oryza sativa* L.). In: *III. Germplasm Characterization and Improvement. Rockefeller Foundation Workshop on Drought.* CIMMYT, Mexico: 98–99

Gomez, S. M. and Kalami, A. 2003. Scope of Landraces for Future Drought Tolerance Breeding Programme in Rice (*Oryza sativa* L.). *Plant Archives* **3**: 77–79

Gomez, S. M., Rangasamy, P. and Kalami, A. 2003. Assessment of Quality Parameters of Rice Crosses Under Drought Condition. *Plant Archives* **3**: 295–297

Graham, R. 2002. A Proposal for IRRI to Establish a Grain Quality and Nutrition Research Center. IRRI Discussion Paper Series No. 44. Los Banos (Philippines): International Rice Research Institute. 15 p

Gravuer, K., von Wettberg, E. and Schmitt, J. 2005. Population Differentiation and Genetic Variation Inform Translocation Decisions for *Liatris scariosa* var. *novae-angliae,* a Rare New Zealand Grassland Perennial. *Conservation Biology* **124**: 155–167

Gregorio, G. B. 2002. Progress in Breeding for Trace Minerals in Staple Crops. *Journal of Nutrition* **132**: 500S–502S

Grist, D. H. 1986. *Rice,* 6th Edition. Singapore: Longman

Guei, G. R. 2000. Participatory Varietal Selection and Rice Biodiversity at Community Levels. West Africa Rice Development Association, 13–21

Guei, R. G. and Traore, K. 2001. New Approach to Germplasm Exchange for Sustainable Increase of Rice Biodiversity and Production in Africa. International Rice Commission. *Newsletter* **50**: 49–58

Harlan, J. 1992. *Crop and Man,* 2nd Edition. Am Soc Agron, Madison, Wisconsin

Harlan, J. R. and de Wet, J. M. 1972. A Simplified Classification of Cultivated Sorghum. *Crop Science* **12**: 172–176

Hien, N. L., Yoshihashi, T., Sarhadi, W. A. and Hirata, Y. 2006. Sensory Test for Aroma and Quantitative Analysis of 2-acetyl-1-pyrroline in Asian Aromatic Rice Varieties. *Plant Production Science* **9**: 294–297

Hill, J., Becker, H. C. and Tigerstedt, P. M. A. 1998. Quantitative and Ecological Aspects of Plant Breeding. London: Chapman and Hall

Hutchenson, K. 1970. A test for Comparing Diversities Based on the Shannon Formular. *Journal of Theorical Biology* **29**: 151–154

IBPGR-IRRI. 1980. *Descriptors for Rice Oryza Sativa L.* Manila, The Philippines: IRRI

Ikehashi, H. and Khush, G. S. 1979. Methodology of Assessing Appearance of the Rice Grain, Including Chalkiness and Whiteness. In: *Chemical Aspects of Rice Grain Quality*. IRRI, Manila, Philippines. 224–229

Irie, K., Aye, K., Nagamine, T., Fujimaki, H. and Kikuchi, F. 2003. Varietal Variations of Heading Time Among Rice Landraces in Myanmar. *Japanese Journal of Tropical Agriculture* **47**: 198–205

IRRI (International Rice Research Institute). 1970. Catalog of Rice Cultivars and Breeding Lines (*Oryza sativa* L.) in the World Collection of the International Rice Research Institute. Los Baños, Philippines. 281

Jayamani, P., Negrão, S., Martins, M., Ma□ãs, B. and Oliveira, M. M. 2007. Genetics Relatedness of Portuguese Rice Accessions from Diverse Origins as Assessed by Microsatellite Markers. *Crop Science* **47**: 879–886

Jennings, P. R., Coffman, W. R. and Kauffman, H. E. 1979. *Rice Improvement.* Manila, Philippines: IRRI

Jeon, J. S., Jang, S. Lee, S., Nam, J. Kim, C., Lee, S. H., Chung, Y. Y., Kim, S. R., Lee, H. Y. and Cho, Y. G. 2000. *Leafy Hull Sterile1* is A Homeotic Mutation in A Rice MADS Box Gene Affecting Rice Flower Development. *Plant Cell* **12**: 871–884

Jezussek, M., Juliano, B. O. and Schieberle, P. 2002. Comparison of Key Aroma Compounds in Cooked Brown Rice Varieties Based On Aroma Extract Dilution Analyses. *Journal of Agriculture and Food Chemistry* **50**: 1101–1105

Joshi, K. D. and Witcombe, J. R. 2003. The Impact of Participatory Plant Breeding on Landrace Biodiversity: A Case Study for Highland Rice in Nepal. *Euphytica* **134**: 117–125

Jules, J. 2002. *The Natural History of Rice.* Purdue University, United States

Juliano, B. O. 1985. Criteria and Tests for Rice Grain Qualities. In: Juliano, B. O. (Ed.). *Rice: Chemistry and Technology.* American Association of Cereal Chemists, Inc., St. Paul, Minnesota, USA. 443–524

Juliano, B. O. 1993. Rice in Human Nutrition. The Food and Agricultural Organization of the United Nations Rome. 162

Juliano, B. O. and Villareal, C. P. 1993. *Grain Quality Evaluation of World Rice.* IRRI, Manila

Kadam, B. S., Ghorpade, D. S. and Desale, J. S. 1980. Genic Analysis in Rice – IV. *Indian Journal of Genetics and Plant Breeding* **40(2)**: 354–365

Kalyan, C. B. and Rambabu Naravaneni. 2006. SSR Marker Based DNA Fingerprinting and Diversity Study in Rice (*Oryza sativa* L.). *African Journal of Biotechnology* **5(9)**: 684–688

Kennedy, G. and Burlingame, B. 2003. Analysis of Food Composition Data on Rice from a Plant Genetic Resources Perspective. *Food Chemistry* **80**: 589–596

Kobayashi, Asako, Ebana, Kaworu, Fukuoka, Shuichi and Nagamine, Tsukasa. 2006. Microsatellite Markers Revealed the Genetic Diversity of An Old Japanese Rice Landrace 'Echizen'. *Genetic Resources and Crop Evolution* **53**: 499–506

Kohli, S., Mohapatra, T., Das, S. R., Singh, A. K., Tandon, V. and Sharma, R. P. 2004. Composite Genetic Structure of Landraces Revealed by STMS Markers. *Current Science* **86**: 850–854

Kovach, M. J., Sweeney, M. T. and McCouch, S. R. 2007. New Insight Into the History of Rice Domestication. *TRENDS in Genetics* **23(11)**: 578–587

Kurakazu, T., Sobrizal, K. and Yoshimura, A. 2001. Mapping of Genes for Awn on Chromosome 4 and 5 in Rice Using Oryza meridionalis Introgression Lines. *Rice Genetics Newsletters* **18**: 26–27

Kurata, N. and Yamazaki, Y. 2006. Oryzabase. An Integrated Biological and Genome Information Database for Rice. *Plant Physiology* **40**: 12–17

Lam, H. S. and Proctor, A. 2003. Milled Rice Oxidation Volatiles and Odour Development. *Journal of Food Science* **68**: 2676–2681

Li, Z. K., Lafitte, R., Vijayakumar, C. H. M., Fu, B. Y., Gao, Y. M., Xu, J. L., Ali, J., Zhao, M. F., Yu, S. B., Domingo, J., Maghirang, R., Khush, G. S. and Mackill, D. 2004. Developing High Yield and Drought Tolerance Rice Cultivars and Discovering the Complex Genetic Network Underlying Drought Tolerance in Rice. 222-224. In: Poland, D., Sawkins, M., Ribaut, J. M. and Hoisington D. (Eds.). Resilient Crops for Water Limited Environments: Proceedings of a Workshop Held at Cuernavaca, Mexico. 24–28

Lin, L. H. and Wu, W. R. 2003. Mapping of QTLs Underlying Grain Shape and Grain Weight in Rice. *Molecular Plant Breeding* **1**: 337–342

Lopez, S. J. 2008. TaqMan Based Real Time PCR Method for Quantitative Detection of Basmati Rice Adulteration with Non-basmati Rice. *European Food Research and Technology* **227(2)**: 619–622

Lorieux, M., Petrov, M., Huang, N., Guiderdoni, E. and Ghesquière. 1996. Aroma in Rice: Genetic Analysis of A Quantitative Trait. *Theoretical and Applied Genetics* **93**: 1145–1151

Lucca, P., Wunn, J., Hurrell, R. and Potrykus, I. 2000. Development of Iron-rich Rice and Iimprovement of Its Absorption in Humans by Genetic Engineering. *Journal of Plant Nutrition* **23**: 1983–1988

Lynch, J., Gonzalez, A., Tohme, J. M. and Garcia, J. A. 1992. Variation in Characters Related to Leaf Photosynthesis in Wild Bean Populations. *Crop Science* **32**: 663–640

Magurran, A. E. 1988. *Ecological Diversity and its Measurement.* Princeton University Press, Princeton, NJ.

Mann, C. 1997. Reseeding the Green Revolution. *Science* **277**: 1038–1042

McCouch, S. 2004. Diversifying Selection in Plant Breeding. *PloS Biology* **2**: 1507–1512

Miller, B. C., Foin, T. C. and Hill, J. E. 1993. CARICE: A Rice Model for Scheduling and Evaluating Management Actions. *Agronomy Journal* **85**: 938–947

Modi, A. T. 2004. Short-term Preservation of Maize Landrace Seed and Taro Propagules Using Indigenous Storage Methods. *South Africa Journal of Botany* **70**: 16–23

Mohapatra, T. S. K., Das, S. R., Singh, A. K. Tandon, V. and Shama, R. P. 2004. Composite Structure of Rice Landraces Revealed by STMS Markers. *Current Science* **86**: 850–854

Moldenhauer, K. A. K. and Gibbons, J. H. 2003. Rice Morphology and Development. In *Rice: Origin, History, Technology, and Production.* Rice Research and Extension Center, University of Arkansas, Stuttgart, Arkansas

Moldenhauer, K. A. K., Wells, B. and Helms, R. 1994. Rice Growth Stages. In Helms, R. S. (ed.), *Rice Production Handbook.* Little Rock, AR, 5–12

Muhammad Rashid, Liu, R. H., Jin, W., Xu, Y. H., Wang, F. L., Tao, Y. Z., Wang, J. M., Akbar, A. C., Chen, J. Q. and Guang, Y. H. 2009. Genomic Diversity Among Basmati Rice (*Oryza sativa* L) Mutants Obtained Through $^{60}$Co Gamma Radiations Using AFLP Markers. *African Journal of Biotechnology* **8(24)**: 6777–6783

Nagao, S. and Takahashi, M. 1951. ditto, XIII. Further Studies on the Gene *Pl* Responsible for the Development of Anthocyanin Coloration in Leaf of Rice (Japanese) *ditto* **1**: 129–136

Nagao, S. and Takahashi, M. 1963. Trial Construction of Twelve Linkage Groups in Japanese Rice. Genetical Studies on Rice Plant. XXVII. *Journal of the Faculty of Agriculture, Hokkaido University* **53(1)**: 72–130

Nayak, A. R., Chaudhury, D. and Reddy, J. N. 2004. Genetic Divergence in Scented Rice. *Oryza* **41**: 79–82

Nemoto, K., Morita, S. and Baba, T. 1995. Shoot and Root Development in Rice Related to the Phyllochron. *Crop Science* **35**: 24–29

Newbold, P., Carlson, W. and Thorne, B. 2009. *Statistics for Business and Economics. Seventh Edition*. Pearson Education

Nguyen, L. H., Wakil Ahmad Sarhadi, Yosei, O. and Hirata, Y. 2007. Genetic Diversity of Morphological Responses and the relationships among Asia Aromatic Rice (*Oryza sativa* L.) Cultivars. *Tropics* **16(4)**: 343–355

Nguyen, T. L., Pham, t. B. T., Nguyen, C. T., Bui, C. B. and Adbelbagi, I. 2009. Genetic Diversity of Salt Tolerance Rice Landraces in Vietnam. *Journal of Plant Breeding and Crop Science* **1(5)**: 230–243

Ntanos, D. A. and Koutroubas, S. D. 2001. Agronomic Diversity among Rice (*Oryza sativa* L.) Lines in a Germplasm Collection in Greece. In: *Workshop on The New Development in Rice Agronomy and its Effects on Yield and Quality in Mediterranean Areas, Edirne (Turkey)*. 13–15 September 2000. France

Ogunbayo, S. A., Ojo, D. K., Popoola, A. R., Ariyo, O. J., SiÃ, M., Sanni, K. A., Nwilene, F. E., Somado, E. A., Guei, R. G., Tia, D. D., Oyelakin, O. O. and Shittu, A. 2007. Genetic Comparisons of Landrace Rice Accessions by Morphological and RAPDs Techniques. *Asian Journal Plant Science* **6**: 653–666

Parzies, H. K., Spoor, W. and Ennos, R. A. 2004. Inferring Seed Exchange between Farmers from Population Genetic Structure of Barley Landrace Arabi Aswad from Northern Syria. *Genetic Resources and Crop Evolution* **51**: 471–478

Pingali, L. P. and Rajaram, S. 1998. *Technological Opportunities for Sustaining Wheat Productivity Growth Toward 2020*. Washington, DC.

Prasad, K. Parameswaran, S. and Viiavraghavan, U. 2005. *OsMADS1*, a Rice MADS-Box Factor. Controls Differentiation of Specific Cell Types in the Lemma and Palea And is An Early-Acting Regulator of Inner Floral Organs. *Plant Journals* **43**: 915–928

Prasad, K. Sriram, P., Kumar, C. S., Kushalappa, K. and Viiavraghavan, U. 2001. Ectopic Expression of Rice OsMADS1 Reveals a Role in Specifying the Lemma and Palea, Grass Floral Organs Analogous to Sepals. *Development Genes and Evolution* **211**: 281–290

Pusadee, T., Sansanee Jamjod, Chiang, Y. C., Benjavan Rerkasem, and Barbara A. Schaal. 2009. *Genetic Structure and Isolation by Distance in a Landrace of Thai Rice* **106**: 13880–13885

Rao, A. S., Bounphanousay, C., Schiller, J. M. and Jackson, M. T. 2002. Collection, Classification, and Conservation of Cultivated and Wild Rices of the Lao PDR. *Genetic Resources and Crop Evolution* **49**: 75–81

Rao, P. K. E., de Wet, J. M. J., Reddy, V. Gopal and Mengesha, M. H. 1992. Diversity in the Small Millets Collection at ICRISAT in Advances in Small Millets. Oxford and IBH Publishing Company Private Limited. 331

Rao, V. R. 2001. *Characterization and Evaluation of Plant Genetic Resources*. IPGRI-APO, Serdang, Malaysia

Redona, E. D. and Mackill, D. J. 1998. Quantitative Trait Locus Analysis for Rice Panicle and Grain Characteristics. *Theoretical and Applied Genetics* **96**: 957–963

Reeves, T. G and Cassaday, K. 2002. History and Past Achievements of Plant Breeding. *Australian Journal of Agricultural Research* **53(8)**: 851–863

Rezai, A. and Frey, K. J. 1990. Multivariate Analysis of Variation Among Wild Oat Accessions-seed Traits. *Euphytica* **49**: 111–119

Rice trade. 2010. Rice Nutrition-Comparison of Different Rice Types. http://www.rice-trade.com/articles/rice-nutrition.html. Accessed on: 12 March 2011. Verified on: 8 April 2011

Riley, K., Rao, V. R., Zhou, M. D. and Quek, P. 1996. Characterization and Evaluation of Plant Genetic Resources – Present Status and Future Challenges. Plant Genetic Resources: Characterization and Evaluation - New Approaches for Improved Use of Plant Genetic Resources. 7–30. In: *The Proceedings of the Fourth Ministry of Agricukture, Forestry and Fisheries, Japan (MAFF) International Workshop on Genetic Resources.* 1996. NIAR, Tsukkuba

Sadar Uddin Siddiqui, Toshihiro Kumamaru and Hikaru Satoh. 2007. Pakistan Rice Genetic Resources-II: Distribution Pattern of Grain Morphology Diversity. *Pakistan Journal of Botany* **39(5)**: 1533–1538

Saitoh, K., Onishi, K., Mikami, I., Thidar, K. and Sano, Y. 2004. Allelic Diversification at the *C ($OsC_1$)* Locus of Wild and Cultivated Rice. Genetics **168**: 997–1007

Sano, Y. 2000. Genetic Architecture and Complexity as Revealed at the Molecular Level in Wild and Cultivated Rices: 13-16. In: *Integration of Biodiversity and Genome Technology for Crop Improvement.* (Ed.). National Institute Agrobiology Resources, Tsukuba, Japan: 181

Schaal, B. A., Leverich, W. J. and Rogstad, S. H. 1991. A Comparison of Methods for Assessing Genetic Variation in Plant Conservation Biology. In: Falk, D. A., Holsinger, K. E., (Eds.). Genetics and Conservation of Rare Plants. New York: Oxford University Press. 283p

Shahidullah, S. M., Hanafi, M. M., Ashrafuzzaman, M., Razi Ismail, M. and Khair, A. 2009. Genetic Diversity in Grain Quality and Nutrition of Aromatic Rices. *African Journal of Biotechnology* **8**: 1238–1246

Shomura, A., Izawa, T., Ebana, K., Ebitani, T., Kanegae, H., Konishi, S. and Yano, M. 2008. Deletion in A Gene Associated with Grain Size Increased Yields During Rice Dosmetication. *National Genetics* **40**: 1023–1028

Siddiq, E. A., Saxena, S. and Malik, S. S. 2005. Plant Genetic Resources: Food Grain Crops. In: Dhillon, B. S., Saxena, S., Agrawal, A., Tyagi, R. K. (Eds.). *Indian Society of Plant Genetic Resources.* New Dehli, India. 27–57

Singh, A. K., Singh, S. B. and Singh, S. M. 1996. Genetic Divergence in Scented and Fine Genotypes of Rice (*Oryza sativa* L.). *Annals of Agricultural Research* **17(2)**: 163–166

Singh, R. K., Gautam, P. L., Sanjeev, S. and Singh, S. 2000. Scented Rice Germplasm: Conservation, Evaluation and Utilization. In: Singh R. K., Singh U. S., Khush U. S. (Eds.). *Aromatic Rices*. Oxford and IBH publishing Co. Pvt. Ltd. New Delhi. 107–133

Smith, C. W. and Robert, H. D. 2003. *Rice: Origin, History, Technology, and Production*. John Wiley and Sons, Incorporation, Hoboken, New Jersey

Smith, J. S. C. and Smith, O. S. 1992. Fingerprinting Crop Varieties. *Advance Agronomy* **47**: 85–140

Song, X. J., Huang, W., Shi, M., Zhu, M. Z. and Lin, H. X. 2007. QTL for Rice Grain Width and Weight Encodes a Previously Unknown RING-type E3 Ubiquitin Ligase. *Nature Genetics* **39**: 623–630

Sood, B. C. and Siddiq, E. A. 1978. A Rapid Technique for Scent Determination in Rice. *Indian Journal of Genetics and Plant Breeding* **38**: 268–271

Sundaram, G. R., Venkatesan, T. and Kunnummal, K. V. 2007. Genetic Diversity Among Cultivars, Landraces and Wild Relatives of Rice as Revealed by Microsatellite Markers. *Journal of Applied Genetics* **48(4)**: 337–345

Tan, Y. F., Xing, Y. Z. Li, J. X., Yu, S. B., Xu, C. G. and Zhang, Q. F. 2000. Genetic Bases of Appearance Quality of Rice Grains in Shanyou 63, an Elite Rice Hybrid. *Theoretical and Applied Genetics* **101**: 823–829

Thomson, Michael J., Septiningshin, Endand M., Suwardjo, Fatimah, Sanroso, Tri J., Silitonga, Tiur, S. and McCouch, Susan, R. 2007. Genetic Diversity Analysis of Traditional and Improved Indonesian Rice (*Oryza sativa* L.) Germplasm Using Microsatellite Markers. *Theoretical and Applied Genetics* **114**: 559–568

Tian, L. and DellaPenna, D. 2001. The Promise of Agricultural Biotechnology for Human Health. Meeting Report on the Keystone Symposium "Plant Food for Human Health: Manipulation Plant Metabolism to Enhance Nutritional Quality

Tilman, D. 1998. The Greening of the Green Revolution. *Nature* **396**: 211–212

Tripathi, R. S. and Rao, M. J. B. K. 1979. Inheritance and Linkage Relationship of Scent in Rice. *Euphytica* **28**: 319–323

Tsuzuki, E. and Shimokawa, E. 1990. Inheritance of Aroma in Rice. *Euphytica* **46**: 157–159

Unnevehr, L. J., Duff, B. and Juliano, B. O. 1992. *Consumer Demand for Rice Grain Quality*. International Rice Research Institute, Manila, and International Development Research Center, Ottawa

Vaughan, D. A. 1991. Choosing Rice Germplasm for Evaluation. *Euphytica* **54**: 147–154

Vaughan, D. A., Morishima, H. and Kadowaki, K. 2003. Diversity in the *Oryza* Genus. *Current Opinion in Plant Molecular Biology* **6**: 139–146

Wan, X. Y., Wan, J. M., Jiang, L., Wang, J. K., Zhai, H. Q., Weng, J. F., Wang, H. L., Lei, C. L., Wang, J. L., Zhang, X., Cheng, Z. J. and Guo, X. P. 2006. QTL Analysis for Rice Grain Length and Fine Mapping of An Identified QTL with Stable and Major Effects. *Theoretical and Applied Genetics* **112**: 1258–1270

Wang, N. Y., Zheng, F. Q., Shen, G. Z., Gao, J. P. and Snustad, D. P. 1995. The Amylose Content in Rice Endosperm is Related to the Post-Transcriptional Regulation of the Waxy Gene. *The Plant Journal* **7**: 613–622

Webb, B. D., Bollich, C. N., Carnahan, H. L., Kuenzl, K. A. and MscKenzie, K. S. 1985. Utilization and Characteristics and Qualities of United States Rice. In: *Rice Quality and Marketing*. IRRI. Los Baños, Philippines. 25–35

Webb, B. D., Bollich, C. N., Johnson, T. H. and Mcilrath, W. O. 1979. Components or Rice Quality: Their Identification, Methodology and Stage of Application in United States Breeding Programs. In: *Proc. Workshop on Chemical Aspects of Rice Grain Quality*. IRRI. Los Baños, Philippines. 191–205

Weng, J. F., Gu, S. H., Wan, X., Gao, H., Guo, T., Su, N., Lei, C. L., Zhang, X., Cheng, Z. J., Guo, X. P., Wang, J. L., Jiang, L., Zhai, H. Q. and Wan, J. M. 2008. Isolation and Initial Characterization of *GW5*, a Major QTL Associated with Rice Grain Width and Weight. *Cell Research* **18**: 1199–1209

Widjaja, R., Craske, J. D. and Wootton, D. 1996. Comparative Studies on Volatile Components of Non-fragrant and Fragrant Rices. *Journal of Science of Food and Agriculture* **70**: 151–161

Wood, D. and Lenne, M. J. 1997. The Conservation of Agrobiodiversity On-Farm: Questioning the Emerging Paradigm. *Biodiversity and Conservation* **6**: 109–129

Ye, G. Y., Yao, H. W., Shu Q. Y., Cheng, X., Hu, C., Xia, Y. W., Gao, M. W. and Altosaar, I. 2003. High Levels of Stable Resistance in Transgenic Rice with a Cry I Ab Gene from *Bacillus thuringiensis* Berliner to Rice Leaffolder, *Cnaphalocrocis medinalis* (Guenee) Under Field Conditions. *Crop Protection* **22(1)**: 171–178

Yoshihashi, T. 2002. Quantitative Analysis on 2-acetyl-1-pyrroline of Aromatic Rice by Stable Isotope Dilution Method and Model Studies on Its Formation During Cooking. *Journal of Food Science* **67**: 619–622

Yoshihashi, T., Nguyen, T. T. H. and Kabaki, N. 2004. Area Dependency of 2-acetyl-1-pyrroline Content in An Aromatic Rice Variety, Khao Dawk Mali 105. *Japanese Agriculture Research Quarterly* **38**: 105–109

Yoshimura, A., Takano-Kai, N. and Anno, C. 2004. Linkage Mapping of Genes for Short Panicle and Awn in Rice. *Rice Genetics Newletter* **21**: 17–18

Zafar, N., Aziz, S. and Masood, S. 2004. Phenotypic Divergence for Agro-Morphological Traits among Landrace Genotypes of Rice (*Oryza sativa* L.) from Pakistan. *International Journal of Agriculture and Biology* **6(2)**: 335–339

Zar, J. H. 2010. *Biostatistical Analysis*. Prentice Hall, Upper Saddle River, New Jersey