



UNIVERSITI PUTRA MALAYSIA

***SALINITY TOLERANCE IN SELECTED RICE CULTIVARS
IN SARAWAK***

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FSPM 2008 24**

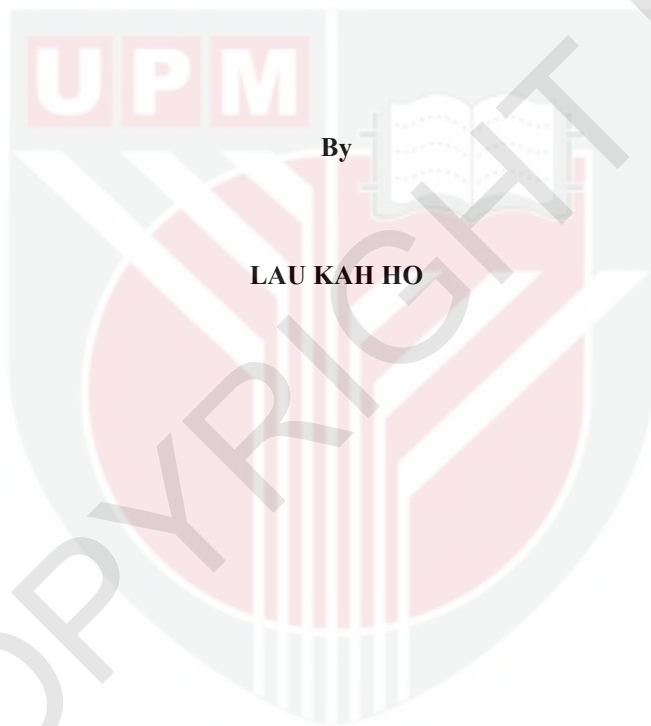
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Salinity tolerance in selected rice cultivars in Sarawak / by
Lau Kah Ho.



By

LAU KAH HO

**A Project Report Submitted in Partial Fulfillment of the Requirement
For the Degree of Bachelor of Biotechnology Science in the
Faculty of Agriculture and Food Sciences
Universiti Putra Malaysia Bintulu Campus**

2008

The most graceful

*Especially dedicated to my beloved parents,
Dad, Lau Kam Chong,
Mum, Ng Aun Bee.*

Thank you for your enormous care and support

ABSTRACT

A study was conducted on thirteen local lowland rice cultivars in Sarawak. In this study, all thirteen cultivars were treated with two levels of salinity treatments (1,000 and 10,000 ppm) and a control from germination to early seedling growth in pots. There were no significant differences in germination, and shoot and root length of seedlings at 8 days after incubation. Rice growth performance was affected by salt-stress. Seedling height was stunted. Seedling height assessment at 9 weeks after germination showed all rice cultivars, except ARC 2 were significantly reduced in height with 10,000 ppm salinity treatment compared to the control. Cultivars with less than 10% reduction in plant height with the 10,000 ppm salinity treatment were ARC 2, Adan Sederhana, Rotan, and Serendah Kuning, indicating significant salinity tolerance ability. Aceh 62, Bario Halus, Biris, Bario Sederhana, Kuduk, Lasak, and Ukong had moderate tolerance to salinity. Bario 2 and Suratani were the least tolerant cultivars.

Keywords: *Oryza sativa*, salinity tolerance, NaCl, CaCl₂

ABSTRAK

Satu kajian telah dijalankan ke atas tiga belas kultivar padi tempatan Sarawak. Dalam kajian ini, kesemua tiga belas jenis kultivar telah dirawat dengan dua tahap larutan kemasinan (1,000 dan 10,000 ppm) dan satu kawalan daripada percambahan sehingga pertumbuhan awal anak pokok yang ditanam dalam pasu. Rawatan tidak memberi perbezaan bererti terhadap percambahan, dan kepanjangan pucuk dan akar anak pokok pada 8 hari selepas eraman. Prestasi pertumbuhan anak padi dipengaruhi dengan desakan kemasinan. Ketinggian anak pokok terbantut. Penilaian ketinggian anak pokok 9 minggu selepas percambahan menunjukkan ketinggian semua kultivar padi selain ARC 2, telah terbantut dengan rawatan 10,000 ppm larutan kemasinan berbanding dengan kawalan. Kultivar yang menunjukkan perencatan ketinggian kurang daripada 10% pada 10,000 ppm larutan kemasinan adalah ARC 2, Adan Sederhana, Rotan, dan Serendah Kuning, dan ini menunjukkan kebolehan pertahanan terhadap kemasinan. Aceh 62, Bario Halus, Biris, Bario Sederhana, Kuduk, Lasak, dan Ukong menunjukkan toleransi sederhana. Kultivar Bario 2 dan Suratani menunjukkan tahap toleransi yang paling rendah terhadap kemasinan.

ACKNOWLEDGEMENTS

First of all, I would like to express the sincerest appreciation and heartfelt gratitude in particular to my supervisor, Assoc. Prof. Dr. Rajan Amartalingam, for his guidance, advice, encouragement and constructive criticism throughout the duration of the project. His constant support in this study is gratefully acknowledged.

I would like to extend my sincere gratitude to Assoc. Prof. Dr. Joseph Bong Choon Fah, Dr. Yiu Pang Hung, Dr. Osumanu Haruna Ahmed and Mr. Wong Sie Chuong, for their enormous guidance, advice and concern that helped me during the study period. Their constant support in this study is gratefully appreciated.

Thanks are extended to Miss Salehah Salleh, Mrs. Siti Fatimah Razali and other staff in the Department of Crop Science for their help and support during the field and laboratory work. Special thanks to Shankari Shyamala, Wong Ling Chie, Sia Fong Eng, Hoe Pik Kheng, Chan Seow Phan, Tan Wee Cheat, Sze Hua Kiong, Leong Sew Seng, Lim Chin Tsong and the rest of my friends for their help, encouragement and support towards the completion of this study.

Finally, I would like to express my deepest gratitude to my mother for her care, support and understanding.

I certify that this research project report entitled “Salinity Tolerance in Selected Rice Cultivars in Sarawak” has been examined and approved as a partial fulfillment of the requirement for the degree of Bachelor of Bioindustry Science in the Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia Bintulu Campus.

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LIST OF ABBREVIATIONS

ANOVA	=	Analysis of Variance
CaCl ₂	=	Calcium Chloride
cm	=	Centimeter
RCBD	=	Randomized Complete Block Design
CV	=	Coefficient of variation
dF	=	Degree of Freedom
dS/m	=	Deci-Siemens Per Meter
DOA	=	Department of Agriculture
DNMRT	=	Duncan New Multiple Range Test
E.C.	=	Electrical Conductivity
F	=	F-test
Log	=	Logarithm
NaCl	=	Sodium Chloride
ns	=	Not Significant
Mha	=	Million Hectares
mmhos/ cm	=	Millimeter Hos Per Centimeter
MOA	=	Ministry of Agriculture
P	=	Probability value
ppm	=	Parts Per Million
R ²	=	Square of the Multiple Correlations
RCBD	=	Randomized Complete Block Design

SAS	=	Standard Analysis System
SS	=	Sum of Square
UPMKB	=	Universiti Putra Malaysia Bintulu Campus
USDA	=	United States Department of Agriculture
$\mu\text{S/m}$	=	Micro-Siemens Per Meier
%	=	Percent



CHAPTER 1

INTRODUCTION

1.1 Importance of Rice

Rice is a grain producing plant under the genus *Oryza* (Smith and Dilday, 2003). The rice produced for human daily energy supply comes from *Oryza sativa* Linn in Asia and *Oryza glaberrima* in West Africa. *Oryza* is a modest-sized genus that consists of 20 well recognized wild species and two advanced cultigens, *O. sativa* and *O. glaberrima*. Rice (also called paddy rice) can be categorized as upland rice or lowland rice (Smith and Dilday, 2003).

Rice has fed more people than any other crop for thousands of years (Janick, 2002). It is the staple food for much of the world's population (Bienvenido, 1993; Smith and Dilday, 2003; Renault and Facon, 2004). Half of the world population depends on rice for their daily nutrient requirements (Renault and Facon, 2004). Huang *et al.* (2000) had reported that rice is the most important food crop in China. According to Bienvenido (1993), rice as a nutritional grain can supply most of the nutrients needed for human growth. Furthermore, rice can be transformed to a variety of forms through processing, and these include rice bran oil, wine, rice cakes and others (Janick, 2002). In short, rice is a vital and unique crop which has played an important role in the progress of human civilization.

Rice is the second largest crop in terms of planted acreage after wheat (Janick, 2002). The major rice growing regions are found in Asian countries, Latin America and Africa. About 85% of the total rice production is for human consumption. In Malaysia rice is the third most vital crop after oil palm and rubber (Begum *et al.*, 2005).

1.2 Salinity

The term salinity is used to define issues related to the excessive presence of salts in the soil profile. Salts are present naturally in soils, surface water and ground water. Changes in landscape have resulted due to salt redistribution and accumulation at or close to the soil surface. For examples, the rising of water tables causes upward movement of dissolved salts which may be left behind after the water evaporates at the soil surface. Over time, salts accumulate at the soil surface and the root zone and this causes salinity levels to increase. This process normally occurs in areas which are called discharge sites (Wild *et al.*, 2004).

Salts consist of groups of ions with an electrical charge and exist as either cations (positive charge) or anions (negative charge), which determine the loss or gain of electrons. Salts exist in a variety of different chemical forms and structures that may affect salinity levels. Examples of such salts are sodium chloride, calcium chloride, and potassium chloride, and each may produce different degrees of salinity. For example, sodium chloride has a higher degree of salinity than calcium chloride. The degree of

salinity is usually measured using an Electrical Conductivity meter (E.C. meter), where electrical conductivity is a measure of total salts in solution (Wild *et al.*, 2004).

Salinity is defined as the concentration of dissolved mineral salts present in water or soils on a unit volume or weight basis (Majerus, 1996). The major solutes of dissolved mineral salts are the cations sodium (Na), calcium (Ca), magnesium (Mg) and potassium (K), and the anions chloride (Cl), sulfate (SO₄), bicarbonate (HCO₃), carbonate (CO₃), and nitrate (NO₃). Salinity is expressed in a number of ways: mol/l (equivalents per liter), mg/l (ppm), electrical conductivity EC (dS/m or mmhos/cm) and total dissolved solids (TDS, %).

Actually, salts are useful trace elements for cell building and plant growth, but in excess salts can be troublesome and cause salt-stress in plants. Lafitte *et al.* (2004) reported salt stress as a major constraint to cereal production worldwide. Metternicht and Zinck (2003) described that the global extent of primary salt-affected soil is about 955 Mha, while secondary salinization affects some 77 Mha, with 50% of these in irrigated areas. The secondary salinization is caused by irrational human activity as well as global warming, with the consequent rise in sea levels and increase in storm incidences, particularly in coastal areas (Peltier and Tushingham, 1989; Pessarakli and Szaboles, 1999; Wassmann *et al.*, 2004). In Asia alone, 21.5 Mha are affected, of which 12 Mha are saline and 9.5 Mha are alkaline or sodic (Lafitte *et al.*, 2004).

Salinity is a major problem for both irrigated and rainfed agriculture (Munns, 2002). Liska *et al.* (2004) also reported that one of the major limiting factors for the proliferation of plants is salinity and it can inhibit central metabolic activities such as photosynthesis. Photosynthetic activity decreases when plants are grown under saline conditions leading to reduced growth and productivity (Netondo *et al.*, 2002). Salinity effects on plants include ion toxicity, osmotic stress, mineral deficiencies, physiological and biochemical perturbation, and combination of these stresses (Munns, 1993, 2002; Neumann, 1977; Yeo, 1998; Hasegawa *et al.*, 2000).

Wild *et al.* (2004) noted that significant quantities of salts in soils will impact plant growth in three ways. Firstly, salts exert an osmotic effect preventing plants from absorbing water molecules from soil; secondly, some salts have specific ions which can be toxic to plants, for example high chloride content in irrigation water can lead to leaf burn, particularly with foliar application; thirdly, specific soil effects impact plant growth by degrading soil structure. In short, it can be concluded that the salt content can affect photosynthetic rate of plants due to water deficiency and defoliation occurs with excessive salt. According to Yeo *et al.* (1985), excessive salt or salinity did not initially reduce net photosynthesis in the whole plant, but affected the older leaves in which sodium accumulated. They also reported that photosynthesis was reduced by half at high sodium concentrations in the leaf, although concentration of chlorophyll was not reduced.

1.3 Rice and Salinity Tolerance

According to Foad and Abdelbagi (2007), soil salinity is a widespread problem limiting productivity of cereal crops worldwide. Salinity imposes both ionic and osmotic stresses on plants (Munns, 2006; Foad and Abdelbagi, 2007) and salt exclusion from photosynthetic tissues was considered an important mechanism associated with salt tolerance in monocots (Yeo *et al.*, 1990; Moradi *et al.*, 2003; Davenport *et al.*, 2005). Foad and Abdelbagi (2007) reported that salt stress caused rapid closure of stomata as an initial response.

However, rice is a moderately salt-sensitive crop species (Maas and Hoffman, 1977; Bhumbra and Abrol, 1978; Shannon *et al.*, 1998; Shaheen and Hood-Nowotny, 2005). The sensitivity of rice at different growth stages varies with salinity stress (Mass and Hoffman, 1977; Flowers and Yeo, 1981; Lutts *et al.*, 1995). In general, the young seedling stages are the most sensitive to salinity stress compared to other growth stages, and less so at reproduction (Flowers and Yeo, 1981; Lutts *et al.*, 1995).

Foad and Abdelbagi (2007) also reported that rice is particularly sensitive to salt stress during the seedling stage, with consequent poor crop establishment, while during reproduction salinity can severely disrupt grain formation and yield. In general, rice is relatively tolerant to salt stress during germination, active tillering and towards maturity, but was sensitive during early seedling development and reproductive stages (Pearson and Bernstein, 1959; Zheng *et al.*, 2006). However, salinity tolerance at the

seedling and reproductive stages is only weakly associated (Moradi and Ismail, 2006); hence, the discovery of contributing traits at both stages is essential for developing resilient salt-tolerant cultivars.

In coastal rice growing areas in Malaysia lower yields are generally associated with salinity. One way to improve yields is to develop varieties that are tolerant to specific saline conditions. Hence, there is a need to identify cultivars potential for saline conditions besides other limiting factors.

1.4 Objective

To study salinity-tolerance among selected traditional rice cultivars in Sarawak.

CHAPTER 2

LITERATURE REVIEW

2.1 Rice

2.1.1 Taxonomy

Based on Krush and Brar (1998) rice belongs to family Poaceae (Gramineae), subfamily Bamboosoideae and tribe Oryzeae; this tribe has 11 genera of which *Oryza* is the only genus with cultivated species. The genus *Oryza* has over 120,000 varieties which is the richest gene bank in the kingdom Plantae. Vaughan (1989; cited in Krush and Brar, 1998) described the genus *Oryza* as having four species complexes: *sativa* complex, *officinalis* complex, *meyeriana* complex and *ridleyi* complex; but there were two species that could not be categorized in any of these groups; these were *Oryza brachyantha* and *Oryza schlechteri*. *Oryza sativa* and *Oryza glaberrima* and another six wild taxa have been placed in *sativa* complex. Bertin *et al.* (1971) described 20 wild species and 2 cultivated species (cutigens) in the genus *Oryza*; the cultivated species are African rice (*O. glaberrima* Steud.) and Asian rice (*Oryza sativa* Linn). *Oryza sativa* Linn is by far the more widely utilized of the two. Further, cultivated rice (also called paddy rice) can be divided in to upland or lowland cultivars (Smith and Dilday, 2003).

Rice has three main developmental phases: the vegetative phase (from germination to panicle initiation), the productive phase (from panicle initiation to flowering), and the ripening phase (from flowering to maturity) (Janick, 2002).

Oryza sativa is a highly variable species and distributed worldwide. Kato *et al* (1928) has classified rice to indica and japonica cultivars according to geographic region. Indica are adapted to the tropics and Japonica adapted to the temperate regions and tropical uplands.

2.1.2 Nutrition

According to Bienvenido (1993), rice not only provides human daily energy but can supply most of the nutrients that humans need for growth. It is a rich source of dietary energy, and a good source of thiamine, riboflavin and niacin. Unmilled rice contains a significant amount of dietary fiber to fulfill human requirements. The amino acid profile of rice shows that it is high in glutamic and aspartic acid, while lysine is limiting.

According to Ang *et al.* (1999), white rice and refined white flour are the common cereal forms that are consumed worldwide. Rice flour contain about 74-77 % carbohydrates (essential starch) and 7-10% protein by weight, with lipid content of 1% or less. Cooked rice contains about 25-28% carbohydrates and 2-3% protein. There is

no cholesterol and only a trace amount of saturated fatty acids, and hence is considered a healthy food.

2.1.3 Importance and Economic Value of Rice

Over thousands of years, rice (*Oryza sativa*) has fed more people than any other crop, especially in much of Asia, where life without rice has been unthinkable (Janick, 2002; Narciso and Hossain, 2002; Renault and Facon, 2004). Bienvenido (1993) reported that rice is the predominant staple food in 17 countries in Asia and the Pacific, nine countries in North and South America and eight countries in Africa. Rice provides 20 percent of the world's dietary energy supply, while wheat supplies 19 percent and maize 5 percent. In short, half of the world population receive their daily nutrient uptake requirements from rice (Renault and Facon, 2004). In addition rice provides 23 percent of the global per capita protein requirements (Janick, 2002). Narciso and Hossain (2002) had also described the daily calories consumed through rice is around 30 – 80%.

Thus, rice has become the second largest crop in terms of planted acreage after wheat (Janick, 2002). The major rice growing regions are found in Asian countries, Latin America and Africa. In Asia, where people typically eat rice 2 or 3 times a day, 250 million rice farms produce more than 90% of the world's rice. It was estimated that the global rice production is 596.5 million tons from 155 million hectares (Mha) in 1999; and about 85% of the total rice production is for human consumption (Janick, 2002).

In China, rice is one of the most significant economic food crops (Huang *et al.*, 2000). In China and India, total cereal consumption provides 69% and 63% total energy, respectively. In higher income areas, such as Hong Kong, Singapore, and Japan, cereals provide about 40% total energy supply, while the consumption of cereals in Bangladesh and Cambodia accounts for 84% of the total energy supply. Furthermore, CGIAR (1997) forecasted that demands for rice in Bangladesh is constantly rising with nearly 2.3 million people being added each year to its population of about 120 million. Hence, production increases must be achieved at a faster rate than in most other countries, as the land planted to rice is not expanding. Malaysia is also a rice-based country, and rice is the third most vital crop in Malaysia (Begum *et al.*, 2005). These production and consumption figures show that rice cultivation is important to the world's food energy supply.

Besides consumption as steamed rice, it can be transformed to other forms of food through processing. These processed rice products include rice cakes, rice bran oil, wine, and others (Janick, 2002). Thus, rice is by far the most important staple food in most Asian countries.

2.2 Salinity

2.2.1 Definition

Salinity is a term used to define a situation as under saline condition due to presence of total salts in excess of an acceptable standard level. This includes all type of salts, either as chlorides or sulphates (Wild *et al.*, 2004).

Majerus (1996) defines the term salinity as the concentration of dissolved mineral salts present in water or soil on a unit volume or weight basis. The major solutes comprising dissolved mineral salts are the cations sodium (Na), calcium (Ca), magnesium (Mg) and potassium (K), and the anions chloride (Cl), sulfate (SO₄), bicarbonate (HCO₃), carbonate (CO₃), and nitrate (NO₃). Salinity is expressed in a number of ways: mol/l (equivalents per liter), mg/l (ppm), electrical conductivity EC (dS/m or mmhos/cm) and total dissolved solids (TDS, %).

According to Slinger and Tenison (2005), a soil is said to be saline when it has enough of any soluble salt to affect plant growth. The degree of salinity can be classified as outlined in Table 1.

Table 1: Salinity classes.

Class	Level of salinity	EC _e (dS/m)
I	Slightly saline	1.5-2
II	Moderately saline	2-6
III	Highly saline	6-15
IV	Extremely saline	>15

2.2.2 Causes of Salinity

According to Wild *et al.* (2004), salinity or saline condition is present with appearance of high levels of salts in the soil, surface water or ground water system. Salt redistribution and accumulation at or close to the soil surface have been impacted by landscape changes over time. When the water table rises, the dissolved salts will be carried up until the root zone or the soil surface, and will accumulate when the water molecules evaporate at the surface. Over a long period, the accumulated salts will increase the salinity level. This process usually occurs in areas which are called discharge sites.

Soil salinity is strongly linked to water movement through the soil profile (Majerus, 1996). When sub-soil moisture containing salts moves upwards and evaporates, salts are precipitated at or near the soil surface. This problem can result from dry land saline

seeps, improper drainage or water management on irrigated soils, or cultivation of naturally saline soils. However, irrigation is a common cause by which agricultural land is degraded, as salt dissolved in the irrigation water is left in the soil following evapotranspiration. The usual answer is to leach the salt through the soil profile (Hoffman, 1990) with yet more water. In addition, Kijne *et al.* (2003) noticed that salinity is linked to the seawater table, and the salinity level in coastal soils increased indirectly by way sea water intrusion whenever the water table has been lowered by mining for ground water.

Salts can be in different chemical forms and structures, and specific forms determine the degree of salinity. The chemical form of a salt can comprise of different combinations of elements, such as sodium chloride, calcium chloride, potassium chloride and others, and each will confer different degrees of salinity (Wild *et al.*, 2004).

Salts commonly found in soils and their predicted risk potential to soil and plants are illustrated in Table 2 (Wild *et al.*, 2004).

Table 2: Salts commonly found in soil and their risk potential to soil and plants.

Cations	Anions			
	Chloride	Sulphate	Bicarbonate	Carbonate
Sodium	Sodium Chloride ***	Sodium Sulphate ***	Sodium Bicarbonate *** (Baking Soda)	Sodium Carbonate ***
Magnesium	Magnesium Chloride ***	Magnesium Sulphate *** (Epsom Salts)	Magnesium Bicarbonate **	Magnesium Carbonate *
Calcium	Calcium Chloride **	Calcium Sulphate * (Gypsum)	Calcium Bicarbonate *	Calcium Carbonate * (Lime)

* Low Risk.

** Medium Risk.

*** High Risk.

2.2.3 Limitation of Salinity

While several salts may be essential as micronutrients that plants need to build cell tissue for good growth performance, excessive amounts of salt in a plantation or orchard or vegetable farm can be an obstacle to crop management. High concentrations of particular ions interfere with uptake of other nutrients and may become toxic to plants; hence, nutrient deficiency symptoms appear (Kijne *et al.*, 2003).

Metternicht and Zinck (2003) described that salt affected soils can be categorized to two stages: a primary stage, where its' global extent is about 955 Mha; and a secondary salinization stage which affects some 77 Mha, with 50% of these in irrigated areas. The secondary salinization is attributed to irrational human activities, as well as global warming, with the consequent rise in the sea level and increase in storm incidences, particularly in coastal areas (Peltier and Tushingham, 1989; Pessarakli and Szaboles, 1999; Wassmann *et al.*, 2004). The Tsunami at the end of 2004 caused vast beachside areas to be salinized by the high dissolved salt content in sea water (IRRI, 2005). In Asia alone, 21.5 Mha are affected, of which 12 Mha are saline and 9.5 Mha are alkaline or sodic (Lafitte *et al.*, 2004).

The symptoms of excessive salt resemble those caused by drought or root injury; they include stunted, yellow foliage; premature autumn leaf coloration; death of leaf margins (scorch); and twig dieback. However, if salt is excessive in the soil, the new leaves may

die as chloride ions accumulate in them. This could be lethal to the entire plant if it occurs over several consecutive years (Perry, 2007).

With respect to crop management, high salinity causes less crop survival. Salinity limits the proliferation of plants and inhibits central metabolic activities such as photosynthesis; and salinity stress leads to a series of changes in basic biosynthetic functions, including photosynthesis and photorespiration, and amino acid and carbohydrate synthesis (Kawasaki *et al.*, 2001; Ozturk *et al.*, 2002; Seki *et al.*, 2002; Liska *et al.*, 2004).

Decreased photosynthetic activities reduce plant growth and productivity (Wentz, 2001; Netondo *et al.*, 2002; Moradi and Ismail, 2006). Soil salinity adversely affects productivity and quality of the crop produced (Chinnusamy and Zhu, 2003).

High salt levels also interfere with germination of seeds (Wentz, 2001). As soil salinity levels increase, the stress on germinating seedlings also increases; salinity can be toxic to young plants and restrict nutrient uptake, prevent roots from performing their osmotic function effectively, and hence, water and nutrients cannot move into plant roots.

Salinity imposes both ionic and osmotic stresses on plants (Munns *et al.*, 2006). In short, the osmotic effect alters the water relation of the plant, and reduces the rate of cell expansion; and leads to a reduction in the rate of development of new roots, leaves and lateral shoots. It also reduces stomatal conductance, which leads to reduced

photosynthesis; thus it causes accelerated senescence of old leaves. While the old leaves die earlier, it may not affect the rate of new leaf production for some time.

Salinity affects virtually all aspects of a plant's physiology. The ability to survive in saline environment requires multiple adaptations of the plant. For example, in the halophyte *Suaeda maritima* tolerance requires tight coupling of growth and ion accumulation (Yeo and Flowers, 1986; review by Flowers *et al.*, 1999). Eventually, the plant dies due to nutrient and water deficiency.

2.2.4 Salinity Effects of Sodium Chloride (NaCl) on Crops

Soil salinity is a major abiotic stress that reduces plant growth and ranks among the leading factors limiting agricultural productivity. The sessile nature of plants has favored the evolution of mechanisms to cope with varying salt concentrations in the environment. Na^+ is not essential for plant growth, and under salt stress, it hinders uptake of the important mineral nutrient K^+ and competes for its enzyme binding sites. Maintaining a high K^+ and low Na^+ homeostasis in the cytoplasm is thus essential for plant salt tolerance. In *Arabidopsis thaliana*, an ionic homeostasis regulatory pathway activated by salt stress has been identified through molecular and genetic characterization of several overly salt sensitive (sos) mutants that are defective in K^+/Na^+ homeostasis (Liu and Zhu, 1998; Liu *et al.*, 2000; Shi *et al.*, 2000).

Hasegawa *et al.* (2000) described that most of the plants can adapt to low or moderate salinities, but their growth is severely limited above 200 mM NaCl. Gross uptake of Na⁺ is poorly correlated with growth and survival because net transport interacts with vigor and degree of dwarfing, and NaCl is compartmentalized within the plant confounding any simple relationship between tissue concentrations, growth reduction and toxicity symptoms (Yeo and Flower, 1986).

Na⁺ and Cl⁻ are the dominant ions in most saline soil, but they usually far exceed the requirement of plants. The excess cause osmotic stress to roots, and result in disturbance of plant water relations, and toxic ion accumulation; which interfere with activities of various enzymes and plant metabolism (Läuchli *et al.*, 1994; Bernstein *et al.*, 1995; Munns, 2002; Lacerda *et al.*, 2003).

Yeo and Flowers (1986) observed that gross uptake of Na⁺ is poorly correlated with growth and survival because NaCl is compartmentalized within the plant, confounding any simple relationship between tissue concentration, growth reduction and toxicity symptoms.

Yoshida (2002) has described that high concentrations of Na⁺ reduce cellular activity by interfering with vital Na⁺-sensitive enzymes and by affecting K⁺ transport. Then, the plants suffer from K⁺ deficiency.

Resistance to excess Na^+ is not conferred by a single factor, but by a sum of a number of contributory traits which include variations in NaCl entry via membrane leakage or apoplastic pathways; preferential accumulation of Na^+ in the older leaves; and tolerance of NaCl within the leaf tissue may reflect differences in apoplastic salt load.

2.3 Impact of Salinity on Rice Production

2.3.1 Effect of Salinity on Production

Lafitte *et al.* (2004) reviewed salt stress as one of the major constraints to cereal production worldwide. Salinity is also one of the major obstacles to increasing production in rice growing areas worldwide (Zeng and Shannon, 2000). Rice, the most important cereal crop in many parts of the world, is rated as an especially salt-sensitive crop (Maas and Hoffman, 1997; Shannon *et al.*, 1998; Walia *et al.*, 2005; Ismail *et al.*, 2006).

Productivity is reported to diminish with accumulation of salts in the soil (Kijne, 1999).

Munns (2002) described salinity disturbs both irrigated and rainfed agriculture.

In recent years, the use of recirculating water systems in rice production have increased in many areas of the USA to address environmental concerns related to problems caused by drainage (Scardaci *et al.*, 1996). The use of recirculating water systems coupled with

regulations for water holding have reduced certain hazards to the environment, but have increased salinity levels in the standing water of rice fields.

Grattan *et al.* (2002) reported an average seasonal salinity of field water in excess of 1.9 dS/m can reduce grain yields; current guidelines indicate that salinity affects rice yield at or above 3.0 dS/m. Beside that, salinity had a negative impact on a number of yield components including stand establishment; panicles, tillers and spikelets per plant; floret sterility; individual grain size; and even delayed heading. The yield components of tiller number per plant, spikelet number per plant, fertility, and kernel weight were believed to have their own critical development periods that can affect the final grain yield (Zeng and Shannon, 2000). Hence, there is a great urgency to address the problem of salinity, especially with an increasing global population.

2.3.2 Salinity and Growth Stages of Rice

Rice responds differently to salt-stresses at different growth stages. Moradi and Ismail (2006) described rice as particularly sensitive to salt stress during the seedling stage, with consequent poor crop establishment, as well as during reproduction where salinity can severely disrupt grain formation and yields.

Rice is relatively tolerant of salt stress during germination, active tillering and towards maturity, and is most sensitive during the early seedling and reproductive stages

(Pearson and Bernstein, 1959; Kaddah, 1963; Flowers and Yeo, 1981; Heenan *et al.*, 1988; Lutts *et al.*, 1995; Lafitte *et al.*, 2004; Zheng *et al.*, 2001). Salinity effects on rice were most prominent in very slow draining soils. Electrical conductivity threshold in irrigation water (EC_w) can increase to 2.0 dS/m during the vegetative (mid-season) stage (Evans, 2006).

Zeng and Shannon (2000) reported significant reduction in seedling shoot dry weight to salinity as low as 1.9 dS/m and the survival or germination rate was significantly reduced at 3.4 dS/m. The threshold value of salinity on seedling survival rate for cultivar M-202 was between 1.9 and 3.4 dS/m. However, they observed that at low salt levels (i.e., 1.9 and 3.4 dS/m) significant reduction of seedling growth occurred at higher cumulative thermal time than those seedlings at higher salt levels (i.e., 4.5 dS/m and higher). This indicated that plants affected by salts at low concentrations can tolerate salt stress for longer durations before significant reduction of seedling growth occurs.

Grattan *et al.* (2002) also observed that emergence and seedling growth stages were most sensitive to salinity in particular the three-leaf to panicle-initiation stages. A salinity of 1.9 dS/m in the field significantly reduced seedling growth and final grain yields.

The reproductive stage is seriously impacted by high salinity conditions (Pearson and Bernstein, 1959; Lafitte *et al.*, 2004; Zheng *et al.*, 2001), through delayed emergence of

panicle and flowering (Khatun *et al.*, 1995) and decreased seed set through reduced pollen viability (Khatun and Flowers, 1995; Khatun *et al.*, 1995).

Heenan *et al.* (1988) emphasized that varieties differ in their degree of tolerance at all stages, and the order of tolerance varied considerably between stages. Australian long grain variety Pelde was tolerant at germination but most intolerant during early vegetative growth and reproductive development, while the Japanese variety Somewake was intolerant during germination and vegetative growth but most tolerant during reproductive development. Differences in cultivar tolerance have been reported by other researches (Narale *et al.*, 1969; Khan *et al.*, 1997; review by Zeng and Shannon, 2000). Seed germination was not significantly affected up to 16.3 dS/m, but was severely inhibited when salinity increased to 22 dS/m (Heenan *et al.*, 1988). The suppression of germination at very high salt levels might be mainly due to osmotic stress (Narale *et al.*, 1969; Heenan *et al.*, 1988). Plants that survive very high saline conditions have less spikelets per panicle, shorter panicle length and significantly reduced final grain yield (Sajjad, 1984; Heenan *et al.*, 1988; Cui *et al.*, 1995; Khatun *et al.*, 1995).

2.4 Global Significance of Salt-tolerant Crops

The saline soil is ubiquitous in the Earth; and not many plants species can survive saline situations. So, thresholds of salinity effects on plant growth and the interrelationships among yield components under salinity stress will help to develop better vegetation management practices.

From a global context, plants have the ability to purify the air, soil and water on the earth (Yoshida, 2002). Salt tolerance would be an especially important ability to bestow upon plants for both agricultural and industrial purposes, because high salinity conditions represent major barriers to growth. Many industries depend on plants as raw materials, and decreasing plant resources can have serious economic consequences.

Salt-tolerant crops offer immediate solutions to address salinity issues, enhance productivity and improve self-sufficiency in food production (Scardaci *et al.*, 1996; CGIAR, 1997; Shannon *et al.*, 1998; Zeng and Shannon, 2000).

2.5 Salinity in Malaysian Soils

The extent of soil salinity in Peninsular Malaysia has been reported to cover 225,790 ha (Yeop *et al.*, 1982); the extent in Sarawak is reported to be 229,440 ha (Zahari *et al.*, 1987). Lim (2000) reported saline areas in Malaysia in excess of 1.0 mill. Ha (Table 3).

Table 3: Extent of saline soils in Malaysia. (Lim, 1981)

Region	Area (ha)
Peninsular Malaysia	186,523.4
Sarawak	571,078.0
Sabah	358,434.0
Total	1,116,035.4

Most soils in the coastal clay plains, whether in Peninsular Malaysia, Sarawak or Sabah, in their natural state, are not very suitable for agriculture because of their saline characteristic. For instance, in the Soil-Crop Suitability Classification system for Peninsular Malaysia, salinity is listed as one of 13 other soil factors, as major limitations to crop growth (Wong, 1996). The four categories of tolerance limits for crops commonly grown on Malaysia are as listed below:

E.C. > 4 dS/m	very serious limitation
E.C. = 2 – 4 dS/m	serious limitation
E.C. = 1 – 2 dS/m	moderate limitation
E.C. = 0.1 – 1.0 dS/m	minor limitation

Varieties of rice differ in resistance to salinity levels (especially sodium chloride salinity). Within varieties, which are not homozygous lines, there is very high variability in sodium uptake and in survival under saline conditions by individual plants. There is a negative correlation between sodium (and chloride) accumulation by individual plants and their survival in saline conditions, demonstrating that variability amongst individuals fits the same pattern as has become generalized for varietal differences in glycophyte species (Flowers and Yeo, 1981).

2.5.1 Salinity by Geographical Regions

Malaysia has three distinct geographical regions: Peninsular Malaysia, Sarawak and Sabah. Malaysia is one of the countries in Asian with a long coastline bordered by sea water.

This geographical feature leads to the constraint termed 'problem soil' with regard to agricultural activities, as seawater intrusions are the main cause of soil salinization. Saline soils occur along the coastal areas of west Peninsular Malaysia, the coasts and

deltas of Sarawak, especially the southern part, and the east coast of Sabah (Haslim, 2003).

Malaysia has a significant proportion of mangrove forests which are associated with saline soils, classified as Thionic Fluvisol (Deratil and Donson, 1994). There is a major mangrove ecosystem in Sabah covering a total area of 365,345 ha (Rahman and Alex, 1996).

The Thionic soils, which are poorly drained, have sulphuric properties and are commonly saline. The Gley soils, developed from accreting alluvium, found in deltaic areas and emerged coastal plains are also generally saline (Haslim, 2003). The Weston association of soils found in Sabah, are also composed mainly of saline soils.

2.5.2 Agricultural Activity and Salinity

Agricultural activities also influence salinity levels. Over-fertilizing can lead to increases in saline condition (Haslim, 2003). Wong and Jaafar (1993) demonstrated yield reductions in salt-sensitive vegetable species in the Cameron Highlands, in central Peninsular Malaysia, due to increases in levels to as high as 3.41 dS/m. With limited rainfall salt accumulation in soils increase, and salinity can increase to as high as 6.4 dS/m.

2.6 Importance of Salinity Tolerant Rice Cultivars for Malaysia

Rice is the staple food of Malaysians, serves as the main energy food source (MOA, 1999), and the future consumption and demand for rice is expected to increase significantly (GOM, 1996). However, Malaysia is only about 70% self-sufficient in rice production.

One of the limitations is that the major rice-growing regions, termed 'granary areas', are situated on or adjacent to coastal saline lands. The saline conditions limit rice growth performance and yields (Haslim, 2003).

Salinity tolerant rice cultivars can increase yields and consequently reduce the import of rice to fulfil the local demand.

The main objective of the present study was to screen local traditional rice cultivars to identify potential cultivars for future development of new varieties suitable for saline soil conditions.

CHAPTER 3

MATERIALS AND METHODS

3.1 Plant Materials

A total of 13 traditional lowland rice cultivars (*Oryza sativus* L.) in Sarawak were selected for the study: Acheh 62, Adan Sederhana, ARC-2, Bario 2, Bario Halus, Bario Sederhana, Biris, Kuduk, Lasak, Rotan, Serendah Kuning, Suratani, and Ukong. The seeds were obtained from the Sarawak Department of Agriculture.

3.2 Salt Treatments

The stock salt solution was prepared using a mixture of two types of salts, sodium chloride (NaCl) and calcium dichloride (CaCl₂) in a ratio of 2 molar NaCl to 1 molar CaCl₂ (Yeo and Flower, 1986; Wild *et al.*, 2004). The treatment solutions were prepared by serial dilution with distilled water to obtain 1,000 and 10,000 ppm (338 and 1912 $\mu\text{S}/\text{m}$) salt concentrations. Distilled water was used as the control. The salinity of all solutions was measured in $\mu\text{S}/\text{cm}$ using an Electrical Conductivity (E.C.) meter.

3.3 Salinity Tolerance of the Selected Traditional Rice Cultivars

Rice cultivars Aceh 62, Adan Sederhana, ARC-2, Bario 2, Bario Halus, Bario Sederhana, Biris, Kuduk, Lasak, Rotan, Serendah Kuning, Suratani, and Ukong were used in this experiment. The salinity levels tested were two different concentrations of salt solutions (1,000 and 10,000 ppm) and a distilled water control. There were a total of 39 treatment combinations in 3 replicates.

A total of 10 unsterilized seeds were placed into each of 9 cm petri dishes lined with filter paper (Whatman No. 1) and then covered with another layer of filter paper. Each dish received 5 ml of the respective salt treatments. Treatments were topped-up after three days after the start of experiment, and every two days thereafter, with 2 ml of the respective treatments.

The germination of seedlings was recorded after 5 days and the length of roots was measured on the eighth day. A seedling with a minimum radical length of 2 mm long was considered as germinated. After 14 days, surviving seedlings were transplanted in to pots in a netted greenhouse.

A total of 3 seedlings from each treatment were transplanted into each 10 cm pot filled with 3:1 (top soil to sand) soil mixture. The pots were arranged in a randomized complete block design (RCBD) in a split-plot arrangement with salinity as main plot treatments and cultivars as split-plot treatments. The salinity levels tested were two

different concentrations of salt solutions (1,000 ppm and 10,000 ppm) and a distilled water control. There were a total of 39 treatment combinations in 3 replicates with 13 varieties.

The water level was maintained by placing the pots in 45 x 30 x 15 cm trays half filled with water. The same salinity treatments were continuously provided twice a week (50 ml per pot) until the end of the experiment.

Chlorpyrifos and carbofuran were used as recommended to prevent damage from insect pests. One hundred ml of 1% fertilizer solution (13: 27: 27 + TE) was added to each pot every week for crop growth. The height of shoots was recorded after nine weeks.

3.4 Data Analysis

Data was analyzed by the ANOVA procedure using SAS – Version 9.1 statistical software. The data was transformed using either Logarithmic or Square-root transformation as required prior to analysis.

CHAPTER 4

RESULTS

4.1 Effect of Salinity Treatments on Germination

The results showed that the higher salinity treatment (10,000 ppm) produced a significant increase in germination compared to the control, for ARC 2 and Kuduk (Appendix 1.1, Table 4). With variety Aceh 62, Adan Sederhana, Bario 2, Bario Halus, Bario Sederhana, Biris, Lasak and Suratani, there were no significant differences between the salinity treatments. With respect to Kuduk, Rotan and Ukong, it is not clear why the germination was low at 1,000 ppm compared to 10,000 ppm.

Table 4: Effect of salinity treatments on germination of 13 local rice cultivars at 4 days after treatment (%).

Variety	Germination Rate (%)			
	Treatments [NaCl : CaCl ₂ (2:1), ppm]			
	0 (Control)	1,000	10,000	Means
Aceb 62	90.00 a	90.00 a	93.33 a	91.11
Adan Sederhana	83.33 a	76.66 a	83.33 a	81.11
ARC 2	0.00 b	0.00 b	36.66 a	12.22
Bario 2	73.33 a	73.33 a	86.66 a	77.77
Bario Halus	90.00 a	86.66 a	100.00 a	92.22
Bario Sederhana	80.00 a	83.33 a	96.66 a	86.66
Biris	83.33 a	86.66 a	100.00 a	90.00
Kuduk	60.00 b	33.33 c	93.33 a	62.22
Lasak	83.33 a	83.33 a	96.66 a	87.77
Rotan	53.33 ab	36.66 b	73.33 a	54.44
Serendah Kuning	93.33 ab	80.00 b	96.66 a	90.00
Suratani	6.66 a	0.00 a	0.00 a	2.22
Ukong	60.00 ab	33.33 b	86.66 a	60.00
Means	65.97	58.71	80.25	

Means within rows with the same alphabets are not significantly different at $p < 0.05$ (DNMRT); CV = 17.40479.

4.2 Effect of Salinity Treatments on Shoot Length

The results showed that the higher salinity treatment (10,000 ppm) produced a significant increase in shoot length compared to the control, except for Rotan and Suratani (Appendix 1.2, Table 5). With variety Rotan, there were no significant differences between the salinity treatments. With respect to all varieties except for the Rotan, it is not clear why the shoot length assessment was low at 1,000 ppm compared to 10,000 ppm.



Table 5: Effect of salinity treatments on shoot length of 13 local rice cultivars at 8 days after treatment.

Variety	Shoot Length (cm) ¹			
	Treatments [NaCl : CaCl ₂ (2:1), ppm]			
	0 (Control)	1,000	10,000	Means
Acch 62	2.20 b	2.47 b	3.82 a	2.83
Adan Sederhana	1.99 b	2.00 b	3.93 a	2.46
ARC 2	0.08 b	0.11 b	0.97 a	0.39
Bario 2	1.76 b	2.47 ab	2.62 a	2.28
Bario Halus	2.03 b	1.85 b	3.68 a	2.52
Bario Sederhana	1.47 b	1.35 b	3.02 a	2.46
Biris	1.78 b	1.86 b	3.01 a	2.22
Kuduk	1.28 b	1.17 b	2.56 a	1.67
Lasak	1.90 b	2.08 b	3.66 a	2.55
Rotan	1.13 a	1.09 a	1.63 a	1.28
Serendah Kuning	1.61 b	1.68 b	2.53 a	1.94
Suratani	0.05 ab	0.01 b	0.21 a	0.09
Ukong	1.15 b	1.05 b	2.73 a	1.64
Means	1.42	1.47	2.60	

¹ The data was transformed [$\sqrt{(x+1)}$] prior to statistical analysis.

Means within rows with the same alphabets are not significantly different at $p < 0.05$ (DNMRT); CV = 19.36804.

4.3 Effect of Salinity Treatments on Root Length

The results showed that the higher salinity treatment (10,000 ppm) had a stimulatory effect on early growth and produced a significant increase in root length compared to the control, except for Kuduk, Serendah Kuning and Suratani (Appendix 1.3, Table 6). With variety Kuduk, Serendah Kuning and Suratani, there were no significant differences between the salinity treatments.



Table 6: Effect of salinity treatments on root length of 13 local rice cultivars at 8 days after treatment.

Variety	Root Length (cm) ¹			
	Treatments [NaCl : CaCl ₂ (2:1), ppm]			
	0 (Control)	1,000	10,000	Means
Aceh 62	2.20 b	2.47 ab	3.82 a	3.13
Adan Sederhana	2.75 b	2.83 b	3.82 a	2.70
ARC 2	2.60 b	2.09 b	3.41 a	0.42
Bario 2	0.10 b	0.09 b	1.07 a	2.37
Bario Halus	1.81 b	2.52 ab	2.79 a	2.85
Bario Sederhana	2.75 b	2.12 b	3.67 a	1.87
Biris	0.95 b	1.24 b	3.43 a	3.19
Kuduk	2.30 a	3.02 a	4.24 a	0.92
Lasak	0.88 b	0.71 b	1.16 a	2.97
Rotan	2.75 b	2.21 b	3.95 a	1.42
Serendah Kuning	1.15 a	1.17 a	1.94 a	2.47
Suratani	2.11 a	2.43 a	2.88 a	0.16
Ukong	1.14 b	1.10 b	1.94 a	1.39
Means	1.64	1.66	2.67	

¹ The data was transformed [$\sqrt{(x+2)}$] prior to statistical analysis.

Means within rows with the same alphabets are not significantly different at $p < 0.05$ (DNMRT); CV = 19.22607.

4.4 Effect of Salinity Treatments on Plant Height

The plant height data after 9 weeks of growth showed strong inhibitory effect on seedlings due to salinity, except for ARC 2 where salinity effect was not evident (Appendix 1.4, Table 7). At 10,000 ppm salinity level, there was a significant decrease in plant height compared to the control, except for ARC 2. Variety Adan Sederhana, Bario 2 and Lasak, showed highly significant differences between the salinity treatments for plant height assessment. The results also showed that the salinity level of 1,000 ppm appeared to have a stimulatory effect on plant height of seedlings, except for Suratani. In the 10,000 ppm salinity treatment all rice cultivars were significantly reduced in height. Varieties Bario 2 and Suratani were adversely affected with 50.56% and 56.11% reduction in plant height, respectively with the 10,000 ppm salinity treatment.

Table 7: Effect of salinity treatments on plant height of 13 local rice cultivars at 9 weeks after transplanting in the netted greenhouse.

Variety	Plant Height (cm) ¹			Means
	(% reduction relative to control) ²			
	Salinity Treatments			
	0 ppm (Control)	1,000 ppm	10,000 ppm	
Aceh 62	87.86 a	88.41 a (- 0.62)	69.65 b (20.72)	81.97
Adan Sederhana	83.48 b	93.00 a (- 11.40)	75.77 c (9.23)	84.08
ARC 2	54.15 a	56.80 a (- 4.89)	57.83 a (- 6.79)	56.25
Bario 2	66.41 b	75.30 a (- 13.38)	32.83 c (50.56)	58.18
Bario Halus	79.15 a	94.13 a (- 18.92)	60.56 b (23.48)	77.95
Bario Sederhana	79.56 a	93.31 a (- 17.28)	68.62 b (13.75)	80.50
Biris	93.76 a	98.44 a (- 4.99)	68.24 b (27.21)	86.81
Kuduk	101.83 a	104.64 a (- 2.75)	89.80 b (11.81)	98.75
Lasak	88.50 b	97.56 a (- 10.23)	77.83 c (12.05)	87.96
Rotan	74.70 b	81.66 a (- 9.31)	71.28 b (4.57)	75.88
Serendah Kuning	70.17 a	71.37 a (- 1.71)	65.33 b (6.89)	68.96
Suratani	42.25 a	36.81 a (12.87)	18.54 b (56.11)	32.53
Ukong	92.23 ab	98.96 a (- 7.29)	80.51 b (12.70)	90.57
Means	78.00	83.87	64.37	

¹ The data was transformed [Log (x)] prior to statistical analysis.

² Value in parenthesis are % reduction in plant height relative to the control.

Means within rows with the same alphabets are not significantly different at $p < 0.05$ (DNMRT); CV = 2.065900.

CHAPTER 5

DISCUSSION

Oryza sativa. is a salinity sensitive crop. The study on thirteen different local Sarawak varieties, Aceh62, Adan Sederhana, ARC-2, Bario 2, Bario Halus, Bario Sederhana, Biris, Kuduk, Lasak, Rotan, Serendah Kuning, Suratani, and Ukong showed considerable differences, and variations in salinity tolerance capacity.

The results showed that the salinity treatments had no clear effects on seed germination. Normally, rice cultivars can survive saline conditions during germination. Furthermore, rice is relatively more tolerant to salt-stress during the germination period than other stages (Pearson and Bernstein, 1959; Kaddah, 1963; Flowers and Yeo, 1981; Heenan *et al.*, 1988; Lutts *et al.*, 1995; Lafitte *et al.*, 2004; Zheng *et al.*, 2001). Moradi and Ismail (2006) described rice respond differently to salt-stresses at different growth stages, in particular during the seedling and fruiting stage (reproduction). The absence of salinity effects on germination and early shoot and root lengths in this study was in agreement with results reported by other researchers.

According to the results, most local rice cultivars produced a significant stimulatory response with the 10,000 ppm salinity treatment compared to the control during germination and early seedling growth. The absorption of salts at this stage appears to have contributed towards cell tissue building and stimulate cell elongation.

The obvious effect of salinity on seedling growth was evident after 9 weeks of growth (Table 7). Thus, the seedlings at this stage of growth were least tolerant and plants were stunted due to salt-stress. Zeng and Shannon (2000) had reported that rice seedling growth performance was reduced with salinity level as low as 1.9 dS/m. The 10,000 ppm (1912 μ S/m) salinity treatment used in this study is slightly saline in the salinity class (Slinger and Tenison, 2005), with moderate limitation on crops growth (Wong, 1996).

The present study was designed to evaluate differences in salinity tolerance among the cultivars tested. Salinity tolerance over a range of saline conditions would have been useful to better predict the behavior of each cultivar tested. This was not possible due to the scarcity of seeds availability for testing.

However among the thirteen local varieties tested, ARC 2 showed the strongest salinity tolerance. Cultivars with less than 10% reduction in plant height with the 10,000 ppm salinity treatment were ARC 2, Adan Sederhana, Rotan, and Serendah Kuning, indicating significant salinity tolerance ability. Aceh 62, Bario Halus, Biris, Bario Sederhana, Kuduk, Lasak, and Ukong had moderate tolerance to salinity. Bario 2 and Suratani were the least tolerant cultivars.

CHAPTER 6

CONCLUSION

The results suggested that cultivars ARC 2, Adan Sederhana, Rotan and Serendah Kuning were the most salinity-tolerant compared to the other cultivars. The rice cultivars Bario 2 and Suratani were least tolerant to saline conditions.



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APPEDICES

Appendix 1.1: ANOVA of data on effect of salinity treatments on germination of 13 local rice cultivars at 4 days after treatment (%).

Source	Df	SS	MS	F	P
Replicate	2	0.0597	0.0298	2.1100	0.1281 (ns)
A (Salinity)	2	0.9381	0.4691	33.2000	<0.0001***
B (Variety)	12	9.7325	0.8110	57.4100	<0.0001***
A x B	24	0.7619	0.0317	2.2500	0.0041**
Error	76	1.0737	0.0141		
Total	116	12.5658			

* Significant at alpha = 0.05

** Significant at alpha = 0.01

*** Significant at alpha = 0.001

CV = 17.40479

R² = 0.914556

Appendix 1.2a: ANOVA of data on effects of salinity treatments on shoot length of 13 local rice cultivars at 8 days after treatment (cm).

Source	Df	SS	MS	F	P
Replicate	2	3.2082	1.6041	1.5100	0.2224 (ns)
A (Salinity)	2	348.4493	174.2246	163.5000	<0.0001***
B (Variety)	12	740.8703	61.7392	57.9400	<0.0001***
A x B	24	72.9981	3.0416	2.8500	<0.0001***
Error	1129	1203.0804	1.0656		
Total	1169	2368.6062			

* Significant at alpha = 0.05

** Significant at alpha = 0.01

*** Significant at alpha = 0.001

CV = 56.25148

R² = 0.492072

Appendix 1.2b: ANOVA of data on effects of salinity treatments on shoot length of 13 local rice cultivars at 8 days after treatment (cm). [Data were transformed to $\sqrt{(x+2)}$.]

Source	Df	SS	MS	F	P
Replicate	2	0.3120	0.1560	1.5700	0.2081 (ns)
A (Salinity)	2	26.2929	13.1465	132.4500	<0.0001***
B (Variety)	12	77.7505	6.4792	65.2800	<0.0001***
A x B	24	4.9691	0.2070	2.0900	0.0017**
Error	1129	112.0575	0.0993		
Total	1169	221.3821			

Data were transformed to $\sqrt{(x+2)}$.

* Significant at alpha = 0.05

** Significant at alpha = 0.01

*** Significant at alpha = 0.001

CV = 19.36804

R² = 0.493828

Appendix 1.3a: ANOVA of data on effects of salinity treatments on root length of 13 local rice cultivars at 8 days after treatment (cm).

Source	Df	SS	MS	F	P
Replicate	2	18.9268	9.4634	3.9200	0.0201*
A (Salinity)	2	268.4298	134.2149	55.5700	<0.0001***
B (Variety)	12	1167.5190	97.2932	40.2900	<0.0001***
A x B	24	105.5700	4.3987	1.8200	0.0092**
Error	1129	2726.5881	2.4150		
Total	1169	4287.0332			

* Significant at alpha = 0.05

** Significant at alpha = 0.01

*** Significant at alpha = 0.001

CV = 77.94861

R² = 0.363992

Appendix 1.3b: ANOVA of data on effects of salinity treatments on root length of 13 local rice cultivars at 8 days after treatment (cm). [Data were transformed to $\sqrt{(x+2)}$.]

Source	Df	SS	MS	F	P
Replicate	2	1.1434	0.5717	4.1000	0.0169*
A (Salinity)	2	15.0864	7.5432	54.0300	<0.0001***
B (Variety)	12	74.4222	6.2019	44.4300	<0.0001***
A x B	24	5.6066	0.2336	1.6700	0.0222*
Error	1129	157.6111	0.1396		
Total	1169	253.8696			

Data were transformed to $\sqrt{(x+2)}$.

- * Significant at alpha = 0.05
- ** Significant at alpha = 0.01
- *** Significant at alpha = 0.001

CV = 19.22607

R² = 0.379165

Appendix 1.4a: ANOVA on data of effects of salinity treatments on plant height of 13 local rice cultivars at 9 weeks after transplanting in the netted greenhouse.

Source	Df	SS	MS	F	P
Replicate	2	23435.9717	11717.9858	2.0300	<0.0001***
A (Salinity)	2	1790.0619	895.0310	2.0300	0.1330 (ns)
B (Variety)	12	101438.6597	9453.2216	19.1800	<0.0001***
A x B	24	9559.5528	398.3147	0.9000	0.5972(ns)
Error	278	136631.5803	440.7470		
Total	318	272855.8264			

* Significant at alpha = 0.05

** Significant at alpha = 0.01

*** Significant at alpha = 0.001

CV = 27.83600

R² = 0.499254

Appendix 1.4b: ANOVA on data of effects of salinity treatments on plant height of 13 local rice cultivars at 9 weeks after transplanting in the netted greenhouse. [Data were transformed to Log(x).]

Source	Df	SS	MS	F	P
Replicate	2	0.2119	0.1060	12.8100	<0.0001***
A (Salinity)	2	3.6276	1.8138	219.2900	<0.0001***
B (Variety)	12	3.7208	0.3101	37.4900	<0.0001***
A x B	24	0.7152	0.0298	3.6000	<0.0001***
Error	278	2.2994	0.0083		
Total	318	10.5749			

Data were transformed to Log(x).

* Significant at alpha = 0.05

** Significant at alpha = 0.01

*** Significant at alpha = 0.001

CV = 2.065900

R² = 0.782562

PUBLICATION OF THE PROJECT UNDERTAKING

This is to certify that I have no objection to publish the project entitled “**Salinity Tolerance in Selected Rice Cultivars in Sarawak**” by the supervisor in a joint authorship. However, it has to be evaluated by the Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia Bintulu Campus and published in a form approved by the Faculty.



Lau Kah Ho

Date: 16 April 2008