Genetic Studies of Grain and Morphological Traits in Early Generation Crosses of Malawi Rice (*Oryza sativa* L.) Landraces and NERICA Varieties

By

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Thesis Abstract

Rice (*Oryza sativa* L.) is the second most important cereal crop in Malawi. Rice productivity in the dominant (85%) rainfed ecosystem is very low, with mean yield of only 1.4 t ha^{-1}. Farmers plant traditional landraces that have low yield potential and are susceptible to various stresses such as drought and diseases. Development and introduction of improved rice varieties, with stress tolerance traits from introduced varieties, such as the New Rice for Africa (NERICAs), could significantly increase productivity. Previous attempts to introduce high yielding irrigated varieties into the dominant rainfed ecosystem in Malawi have not been successful because farmers basically did not adopt the varieties, claiming that the varieties were lacking in grain traits that they preferred but that the traits were present in their landraces. The notable traits mentioned, through previous informal surveys, were long grains, medium to slender shape and aromatic grain with intermediate gelatinization temperature. No formal study has been conducted to ascertain the preferences, and the genetic control of the traits, including yield and yield related traits, have not been studied. The objectives of this study were to: 1) confirm farmers' preferences for grain traits using participatory rural appraisal; 2) determine amount of genetic variability for yield and yield related traits in Malawi rice landraces, 3) determine the genetic control and correlations of grain length, grain shape and 1000-grain weight, 4) determine the inheritance of aroma and gelatinization temperature and, 5) determine the genetic control, correlations and path coefficients of yield and yield related traits, in F_2 generations of Malawi rice landraces and NERICA varieties crosses.

To confirm the farmers' preferences for grain traits, a participatory rural appraisal was conducted in 2006 in two villages that were representative of rainfed rice growing areas in Malawi. The villages were Liundi and Nawanga in Machinga and Salima Districts, respectively. Qualitative and quantitative data were collected through questionnaires and discussions with 190 respondents, as well as through observations. To determine variability among Malawi rice landraces, 19 landraces were planted at Lifuwu in a Randomized Complete Block Design with three replicates in 2006. Data on plant height, days to 50% flowering, number of panicles per hill, panicle length, number of filled grains per panicle, 1000-grain weight, panicle weight, grain length and grain yield were collected and analyzed. Four Malawi rice landraces were crossed to four NERICA varieties in 2006 in a North Carolina Design II mating scheme to determine the genetic control of grain size. F_1 plants were raised in 2007 and in 2008, 16 F_2 populations together with their parents were planted in a Randomized Complete Block Design with three replicates at Lifuwu. Data on grain length, grain shape and 1000-grain weight were collected and analyzed. To determine the inheritance of aroma and gelatinization temperature, four Malawi rice landraces were crossed to four NERICA varieties in 2006 and F_1 plants were raised in 2007. In 2008, 16 F_2 populations together with their parents were planted in a Randomized Complete Block Design with three replicates at Lifuwu. Aroma and gelatinization temperature were evaluated. To determine the gene action of yield and yield related traits, four Malawi rice landraces were crossed to four NERICA varieties in 2006 in a North Carolina Design II mating scheme and F_1 plants were raised in 2007. In 2008, 16 F_2 populations together with their parents were planted in a Randomized Complete Block Design with three replicates at Lifuwu. Data on grain yield, the number of panicles per hill, days to 50% flowering, panicle length, panicle weight and 1000-grain weight were collected and analyzed

The participatory rural appraisal confirmed that that long, slender or medium shape grains, with aroma and intermediate gelatinization temperature were the key traits preferred by farmers. Therefore the farmer preferred traits of long, slender grains, with aroma and medium gelatinization temperature, must be selected for in any high yielding varieties to be developed for the rainfed rice ecosystem. Results showed that differences were significant (P=0.05) for all the traits that were studied. Heritability estimates were low to moderate: 18.3% for panicle weight, 40.0% for panicles per hill and 56.3% for days to 50% flowering date. The high genetic variability among the landraces could be used in a breeding programme to develop improved varieties for various morphological traits. The number of panicles per hill and 1000-grain weight combined moderate heritabilities with relatively high genetic advance and therefore could be reliable traits for yield improvement.

Genetic analysis of grain size showed that Malawi rice landraces were variable for all three grain size characteristics, namely grain length, grain shape and 1000-grain weight. NERICA varieties were variable for 1000-grain weight. Sixteen F_2 progenies were variable for all three characteristics, and the variability was significant (P=0.05). Heritability estimates were high (45.4%) for grain length and low for grain shape (12.3%) and for 1000-grain weight (14.3%) suggesting that early generation selection would be effective for grain length. Predominance of additive gene action for grain length and grain shape suggested that early generation selection would be effective for these traits. Selection for 1000-grain weight would be more effective in later generations because of preponderance of non-additive gene action in the control of this trait. The correlation between grain length and grain shape was positive (r=0.769) and highly significant (P=0.01) suggesting that breeders would choose to select for both traits simultaneously, or they would choose one of the traits to develop varieties with long grains and medium shape.

Crosses between aromatic and non-aromatic varieties had non-aromatic F_1. The F_2 progenies segregated into 3:1 ratio for non-aromatic: aromatic suggesting that, in the Malawi rice landraces, aroma was probably simply inherited through a single recessive gene. F_1 progenies, between parents with high and intermediate gelatinization temperatures had intermediate gelatinization temperature. F_2 progenies segregated into 1:3 ratios for high; intermediate gelatinization temperature in three out of four crosses suggesting control by one dominant gene. The segregation pattern in one cross was not significantly different from 3:13 ratio for high: intermediate suggesting that two dominant genes, one an inhibitor, were controlling the trait. Breeding and selecting for aroma and intermediate gelatinization temperature could be accomplished relatively easily because the traits are simply inherited.

The genetic variability for yield and yield related traits was wide and significant (P=0.05) in the F_2 populations of Malawi rice landraces and NERICA varieties crosses indicating that the populations would be valuable sources to develop varieties with improved yield. Panicle weight and the number of panicles per hill were positively correlated with, and had high direct effects on grain yield, therefore they could be used to indirectly select for high yield. Grain yield, the number of panicles per hill and plant height were predominantly controlled by additive gene action suggesting that bulk breeding methods would be adopted for these traits. The days to 50% flowering, panicle weight and 1000-grain weight were predominantly under the control of non-additive gene action suggesting that hybrid development would be profitable for these traits. Faya Mpata, Faya Zidyana and NERICA 3 could be the best parents for improving yield and yield related traits because they had high general combining abilities for the traits.

Declaration

I, Tenyson Mzengeza, declare that:

(i) The research reported in this thesis, except where otherwise indicated, is my original research.

(ii) This thesis has not been submitted for any degree or examination at any other university.

(iii) This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from those persons.

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As research supervisors we agree to submission of this dissertation for examination:

Signed:……………………………………………..Date……………..………..……………….

Prof. Pangirayi Tongoona (Supervisor)

Signed:……………………………………………..Date………………...………………….

Dr. John Derera (Co-supervisor)

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Dedication

To Chifundo Masukali Mandala and Charles Masauko Maganga, both departed.

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List of Abbreviations

2-AP	2-acetyl-1-pyrolline
AC	Amylose Content
ASV	Alkali Spreading Value
FAO	Food and Agriculture Organization
FPR	Farmer Participatory Research
Gca	General combining ability
GL	Grain Length
GOM	Government of Malawi
GS	Grain Shape
GT	Gelatinization Temperature
GW	Grain Width
IRRI	International Rice Research Institute
ITC	International Trade Centre
NERICA	New Rice for Africa
NPT	New Plant Type
PPB	Participatory Plant Breeding
PRA	Participatory Rural Appraisal
PVS	Participatory Variety selection
sca	Specific combining ability
TGW	1000-grain weight
WARDA	West African Rice Development Association

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Introduction to Thesis

1. Rice in the world

Rice (*Oryza sativa* L.) is an important crop that provides food for almost half of the world's population (Schalbroeck, 2001). Rice is the second most consumed among the cereal crops that include maize, wheat, barley sorghum, and millet (Food and Agricultural Organization (FAO), 2008). Rice is a crop that is native to Asia but trade and export have spread it all over the world. Still over 90% of the total world production of 634 million metric tons is grown in Asia and almost all of it is for domestic consumption. World production of rice has increased in the past seven years from 598 million metric tons in 2000 to 634 million metric tons in 2007. The area grown to rice has remained relatively constant at 154 million hectares over the same period (FAO, 2008). Despite the increase in rice production over the years, shortages occur due to demand exceeding supply. The shortages have led to increases in the price of rice. A dramatic increase occurred in the six months between October 2007 and April 2008 when prices doubled (BBC News, 2008). Production in Africa is only 3% of the world total and the biggest producing countries are in the West of the continent and include Nigeria, Cote d'Ivoire and Mali (Schalbroeck, 2001). Other countries where production is significant include Egypt, Madagascar and Tanzania. In the southern part of Africa, Mozambique and Malawi are the largest rice producers with a combined total production of 224,000 metric tons in 2006 (FAO, 2008).

2. Rice production in Malawi

In Malawi, rice is grown solely by smallholder farmers in fields less than 1.0 ha on average. It is the second most important cereal crop after maize based on output although more land is planted to sorghum than rice as shown in Table 0.1 for cereal production estimates for 2006 season. The table shows that rice yield of 1.74 t ha^{-1} was higher than that of maize (0.62 t ha^{-1}) and other cereal crops. Within the rice crop in Malawi, improved varieties, mostly grown under irrigation, gave 23% higher yields than the local varieties, which were grown under rainfed conditions.

Rice is grown under three ecosystems namely irrigated lowland, rainfed lowland, and rainfed upland. The irrigated lowland occupies 15% of the total rice area which was estimated to be 52 500 ha in 2007. High-yielding varieties, with average yields of up to 5 t ha^{-1} are utilized in the irrigation schemes and two croppings can be grown per year. Eighty five percent area is in the rainfed lowland and rainfed upland ecosystems occupy 85% of the rice area. The varieties grown in these ecosystems are mostly landraces that average 1.2 t ha^{-1}.

Table 0.1: Cereal crops production (kg), area (ha) and mean yield (t ha^{-1}) during 2006 crop season.

Crop	**Area (ha)**	**Production (kg)**	**Mean yield(t ha^{-1})**
Maize [1]	1 624 303	2 611 486	0.62
Local varieties	654 176	573 593	0.88
Composite + Hybrid varieties	970 127	2 037 893	2.10
Rice [2]	52 461	91 450	1.74
Local varieties	31 507	44 518	1.41
Improved varieties	20 954	46 932	2.24
Wheat	1 656	2 000	1.21
Sorghum	70 644	54 309	0.77
Millets	41 491	27 037	0.65

Source: Ministry of Agriculture and Food Security, GOM (2007). 1 Local varieties e.g. Mkangala, Kaluluwede; Composites + Hybrids e.g. MH18, CCC; 2 Local varieties e.g. Singano, Hali ya Bibi; Improved varieties e.g. Senga, Nunkile.

Between 2000 and 2002 the area grown to rice expanded by 12 500ha and output increased from 43 000 metric tons to 56 000 metric tons during the same period (Table 0.2). The area grown to rice and the output decreased from 2003 up to 2005. In 2005 production dropped due to drought which affected all crops. Both the area grown to rice and the output increased in 2006 but remained constant up to 2007. Similar declining trends have only been recorded in wheat among the cereal crops in Malawi (Table 0.2).

The stagnant growth in rice area and output is obviously very worrisome for two reasons. The first reason is that rice is contributing very little to food security in Malawi (Chirwa,et al., 2006) . The second reason maybe that farmers, who rely on rice as their main source of livelihood, will neither attain food self-sufficiency nor generate cash income from surplus harvest. Clearly, there must be problems that confront rice farmers, which result in decreasing area and output. There is a need to identify these problems, together with the farmers, and then to try to find means to overcome some of these problems.

Table 0.2: Area ('000 ha) and production ('000 t) of cereal crops in Malawi from 2000 to 2007.

Year	Rice		Maize		Sorghum		Millet		Wheat	
	Area	Output	Area	Output	Area	Output	Area	Output	Area	Output
2000	44	72	1 435	2 501	55	37	34	19	2.3	1.8
2001	50	93	1 446	1 713	54	37	34	20	2.5	2.2
2002	56	92	1 488	1 557	54	39	34	21	2.7	1.5
2003	56	88	1 550	1 983	60	45	36	25	2.0	1.5
2004	43	50	1 538	1 608	63	41	37	17	2.2	1.7
2005	35	41	1 618	1 225	35	18	36	16	2.2	1.7
2006	53	92	1 621	2 577	71	54	42	27	1.7	2.0
2007	53	92	1 689	3 445	74	74	50	32	2.0	4.6

Source: FAO, 2008.

3. Statement of the research problem

Farmers are confronted with production constraints in rice farming in Malawi. Rice production in Malawi can increase if rainfed areas are targeted and this can be achieved by: a) expanding the area under production, b) encouraging farmers to take up new cultural practices and use new high yielding varieties, c) establishing viable rice seed production and distribution system, d) adopting agricultural policy to subsidize rice seed and inorganic fertilizer, and e) strengthening the agricultural extension service to consolidate all the above.

Among the above options, the first and high impact intervention could be achieved by providing farmers with high yielding varieties to increase the productivity. The Green Revolution in Asia started because rice farmers adopted high yielding rice varieties among other factors that included fertilizer-responsiveness and a high degree of resistance to insects and diseases (Swaminathan, 2007). Providing high yielding rice varieties to rainfed rice farmers could possibly be a major factor in adding value to rice for the benefit of farmers and stakeholders in the rice industry.

Rainfed rice farmers in Malawi plant traditional varieties (landraces) that have low yield potential, of about 1.2 t ha^{-1} . This low productivity results in overall low rice production in Malawi. Farmers continue to grow the landraces because of preferred grain traits, an argument which has not been confirmed formally. There is lack of genetic information on the preferred grain traits for the landraces of Malawi.

4. Justification for the study

In order to design breeding programmes that allow development of varieties possessing the positive attributes of the Malawi rice, there is need to know: a) the genetics of the traits of interest, b) if there is adequate genetic variability in the germplasm to be improved, c) what amount of the variability is genetic and therefore can be transmitted from parent to off-spring irrespective of environment, d) what amount of genetic gain can be expected from successive generations of the off-spring. The challenge, therefore, is to design scientific studies that would provide knowledge to use in developing improved rice varieties.

Many studies have been conducted to understand the genetic control of grain size, aroma and gelatinization temperature, as well as yield-related traits in rice populations in different countries (Gupta et al., 2006; Rabiei et al., 2004; Bansal et al., 2000; Samonte et al., 1998). Despite the many studies none of them have been conducted on rice in Malawi. There is need, therefore, to conduct similar studies on the Malawi rice landraces because genetic studies have not been conducted on them up till now. It is important to study the genetic variation available in Malawi rice landraces, especially for traits that are preferred by farmers.

It is also important to understand the genetic control of and correlations between rice traits in order to design effective breeding and selection strategies (Dhanraj and Jagadish, 1987; Pinson, 1994; Gravois and McNew, 1993). This study will complement existing rice variety research for the irrigated secosystem in Malawi by studying the genetic variability present in Malawi rice landraces, and understanding the genetic control for grain size, aroma and gelatinization temperature. In Malawi, rice farmers have indicated, in informal surveys, that these traits are economically important. Grain size and grain quality (amylose content, gel consistency) of rice, in addition to yield, determine economic returns for rice farmers in all rice growing countries in the world (Zhang et al., 2008).

The increase and stability of rice production are essential to attain food security and provide cash income for the farming families in Malawi. One of the ways to increase and stabilize the production is to encourage farmers to use high yielding varieties that also possess traits that farmers prefer. Such traits, indicated by farmers in informal surveys, include large grain size and aromatic grains with intermediate gelatinization temperature. High yielding varieties, with large sized, aromatic grains with intermediate gelatinization temperature would be readily adopted by farmers. The impact of the adoption will be a rise in rainfed rice productivity above the present average of 1.2 t ha^{-1}, and high economic returns from selling rice accepted by consumers. This will make a significant contribution to food security and cash income for rice farmers in Malawi.

5. Research objectives

The overall objective of this study was to find out the nature of the genetic variability of grain traits and yield components in Malawi rice landraces that rainfed farmers prefer to grow for food and cash income. There were five specific objectives of this study and these were to:

a) use participatory rural appraisal tools to confirm farmers' preferences for grain traits;
b) investigate amount of genetic variability for yield and yield related traits in Malawi rice landraces,
c) determine gene actions for and correlations between grain length, grain shape and 1000-grain weight,
d) find out the mode of inheritance of aroma and gelatinization temperature, and
e) find out the inheritance, correlations, path coefficients and combining abilities for yield and yield related traits.

6. Research hypotheses

The assumption of this study was that the genetic variation within Malawi rice landraces is wide enough to select for yield related traits. The specific hypotheses were that:

a) Farmers recognise that use of landraces is a major production constraint in the rainfed rice production ecosystem in Malawi, but the landraces possess specific traits that they prefer;

b) Within Malawi rice landraces there is highly heritable genetic variation, for yield and yield related traits, and this variation can be exploited in a breeding programme to develop high yielding varieties that farmers can adopt;

c) In progenies of Malawi rice landrace x NERICA varieties crosses, the heritabilities for grain length, grain shape and 1000-grain weight are high; the three grain size characteristics are positively correlated; and additive gene effects are more important than non-additive gene effects;

d) The aroma and intermediate gelatinization temperature traits in Malawi rice landraces are simply inherited; and

e) In progenies derived from Malawi rice landraces x NERICA varieties, heritabilities for yield related traits are high, the yield related traits directly affect yield and additive gene effects are more important than non-additive gene effects.

7. Structure of thesis

The thesis is arranged in chapters as follows:

- Chapter 1: Literature Review
- Chapter 2: Perception of Farmers on Variety Trait Preferences in Two Rainfed Rice Growing Areas in Malawi
- Chapter 3: Genetic Variability for Yield Related Traits in Malawi Rice (*Oryza sativa* L.) Landraces
- Chapter 4: Genetic Analysis of Grain Size in F_2 Generation of Crosses of Malawi Rice (*Oryza sativa* L.) Landraces and NERICA Variety Crosses

- Chapter 5: Inheritance of Aroma and Gelatinization Temperature in F_2 Generation of Malawi Rice (*Oryza sativa* L.) Landraces and NERICA Variety Crosses
- Chapter 6: Evaluation of Yield and Yield Components in F_2 generation of Malawi Rice (*Oryza sativa* L.) Landraces and NERICA Variety Crosses
- Chapter 7: Thesis Overview

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1.1 The Rice genus

Rice belongs to the genus *Oryza* in the Graminae or grass family. The *Oryza* (*O.*) genus comprises 23 species, 21 of which are wild relatives with diploid or tetraploid genomes, and only two are cultivated. The cultivated species are *Oryza sativa* and *Oryza glaberrima*. Based on a study of 16 *Oryza* species and 42 morphological traits, Morishima and Oka (1970) (cited by Khush, 2000) proposed classifying the *Oryza* species into three complexes namely 1) *O. sativa* and its relatives, 2) O*. officinalis* and its relatives, and 3) distantly related species. Recently Khush (2000) re-grouped the *Oryza* species into five complexes based on chromosome number, genomic composition and distribution in the world (Table 1.1). The wild species of rice, such as *O. nirvara* and *O. glaberrima,* contain useful genes that can be transferred into the cultivated species *O. sativa* (Brar et al., 1996; Multani et al., 1994). The introgression of these useful genes from the wild into the cultivated species, or sometimes within the cultivated species, is difficult; because of infertility in F_1 generations or dysfunctional hybrids (Jena and Khush, 1990). According to Khush (2000) the degree of ease of gene transfer across species can be used to classify rice species into three gene pools. With reference to Table 1.1, the first and primary gene pool consists of the *O. sativa* complex with the AA genome. The secondary gene pool consists of all the diploid and tetraploid species in the *O. officinalis* complex. The third or tertiary gene pool comprises the species with the GG, HHJJ and unknown genomes, and crosses involving this pool are extremely difficult to accomplish.

Gene transfer within the *O. sativa* complex can be accomplished, sometimes easily, by conventional crossing but gene transfer between the *O. sativa* and the *O. officinalis* complexes can only be accomplished through embryo transfer and rescue techniques (Khush, 2000). A recent novel and successful transfer of genes between the two complexes was accomplished at the West Africa Rice Development Association (WARDA) through crosses between *O. glaberrima* and *O. sativa*. *Oryza glaberrima* rice was domesticated in West Africa and has the genes for, among other traits, moderate to high levels of resistance to drought, acidity, rice blast and rice yellow mottle virus diseases. *O. glaberrima*, however, is low-yielding, has high grain shattering, and is susceptible to lodging due to weak culms (Jones et al., 1997).

Table 1.1: List of *Oryza* species complexes and species (Species) based on chromosome number (2N), genomic composition (Genome) and distribution (Distribution) [1]**.**

Species	**2N**	**Genome**	**Distribution**
***O. sativa* complex**			
O. sativa L.	24	AA	Worldwide
O. nirvara Sharma et Shastry.	24	AA	T and ST Asia
O. rufipigon Griff.	24	AA	T and ST Asia, T Australia
O. breviligulata A. Chev. et Roehr.	24	A^gA^g	Africa
O. glaberrima Steud.	24	A^gA^g	W. Africa
O. longistaminata A. Chev. et Roehr.	24	A^gA^g	Africa
O. meridionalis Ng	24	A^mA^m	T. Australia
O. *glumaepatula* Steud.	24	$A^{gp}A^{gp}$	S and C America
O. officinalis complex			
O. punctata Kotschy ex Steud.	24	BB	Africa
O. punctata Kotschy ex Steud	48	BBCC	Africa
O. minuta J.S. Presl. ex C.B. Presl.	48	BBCC	Philippines and Papua New Guinea
O. officinalis Wall ex Watt	24	CC	T and ST Asia, T Australia
O. rhizomatis Vaughan	24	CC	Sri Lanka
O. eichingeri A. Peter	24	CC	S Asia and E Africa
O. latifolia desv.	48	CCDD	S and C America
O. alta Swallen.	48	CCDD	S and C America
O. grandiglumis (Doell) Prod.	48	CCDD	S and C America
O. australiensis Domin.	24	EE	T Australia
O. brachyantha A. Chev. et Roehr	24	FF	Africa
O. meyeriana complex			
O. granulate Nees et Arn ex watt	24	GG	S and SE Asia
O. meyeriana (Zoll. Et Mor. Ex Steud.) Baill.	24	GG	SE Asia
O. ridleyi complex			
O. longiglumis Jansen	48	HHJJ	Irian Jaya, Indonesia and Papua New Guinea
O. ridleyi Hook. f.	48	HHJJ	S Asia
Unknown genome			
O. schlechteri Pilger	48	unknown	Papua New Guinea

[1] Source: Khush (2000). T = Tropical; ST = Sub-tropical; S = South; SE = Southeast; W = West; E = East; C = Central

The high-yielding *O. sativa* rice is not susceptible to lodging, in part because of semi-dwarf height (less than 110 cm) or, for the intermediate or tall types, because of strong stems. In addition the grain is firmly attached to the panicle and, therefore, does not shatter easily. This rice, however, does not possess the drought stress tolerance traits of *O. glaberrima*. Selection among the progeny from the interspecific crosses between *O. sativa* and *O. glaberrima* resulted into development and release of the New Rice for Africa (NERICA or NERICA) varieties. As stated by Semagn et al. (2007), the NERICAs have the potential to improve the productivity, profitability as well as the sustainability of rice in Africa.

1.2 Origin and distribution of rice

Oryza sativa species was domesticated from wild species around 9000 years ago in Asia, particularly in the area around the Himalaya Mountains, in India. For that reason, *O. sativa* is called Asian rice. The area is considered the centre of origin for rice because the largest diversity of the cultivated rice species is found there (Khush, 2000). The *O. sativa* then spread worldwide to areas including Africa and South America. Other wild species independently evolved in West Africa and led to the domestication of *O. glaberrima* Steud. Species, the African rice (Sharma and Steele, 1978).

There are about 21 wild relatives of rice, five of which are indigenous to Africa (Vaughan, 1994). Five African wild relatives of *0. sativa* include *O. barthii, 0. brachyantha, 0. eichingeri, 0. longistaminata* and *0. punctata*. *0. barthii, 0. longistaminata* and *0. punctata* wild relatives of rice are found in Malawi. A collection mission by the Malawi Plant Genetic Resources Centre in 1997 collected 55 samples from across the country (Chiwona, 1997). The wild relatives have small grains and are not aromatic. However, these wild relatives of rice could be sources of useful genes for drought and disease tolerance (Brar et al., 1996; Multani et al., 1994) that could be transferred into the cultivated species of Malawi rice.

1.3 Rice landraces

Landraces are widespread and popular among farmers, and are an important part of agriculture because their diverse array in a crop creates genetic diversity in agriculture (Modi, 2004) in the same way that wild plant populations also represent a source of genetic variability (Berrocal-Ibarra et al., 1993). The genetic variability is a key component of breeding programmes aimed at broadening the gene pool of rice and other crops (Brar and Khush, 1997). Landraces are known to be heterogeneous mixtures of genotypes carrying a range of stress-tolerance genes (Kohli et al., 2004; Gomez and Kalami, 2003; Gomez et al., 2003; Irie et al., 2003; Fukai et al., 1991). Landraces also possess traits that are most preferred by farmers and can be used to produce new cultivars or to incorporate desirable traits into varieties (Lynch et al., 1992).

In rice, as in many other crops, landraces have not been bred as varieties, but have become adapted to the local conditions of environment and inputs where they are cultivated (Frankel et al., 1995). Landraces have been the mainstay of agricultural systems in many developing countries (Hill et al., 1998). However, large-scale adoption and commercial cultivation of high-yielding varieties have resulted in the gradual replacement of landraces (Brush et al., 1995). For example, Kohli et al. (2004) observed that India, the primary centre of origin of rice, had an unspecified large number of landraces but most of them were out of cultivation then.

Several workers have found and reported genetic variability for traits for higher yield, for tolerance to various stresses and for improved grain quality. Gomez et al. (2003) evaluated rice landraces in India and found variability for quality traits such as milled rice percentage and kernel length. Irie et al. (2003) reported great diversity for photoperiod sensitivity, based on number of days to heading, among 1 240 rice landraces of Myanmar. Significant variation for physiological and economic traits was recorded among 11 landraces grown in the Tamil Nadu region of India by Gomez and Kalami (2003).

In a study of genetic variation for aroma among rice landraces in the Red River Delta, Vietnam, Fukuoka et al. (2000) reported that morphologically similar landraces revealed great diversity upon random amplified polymorphic DNA analysis. Other studies of genetic variation in rice landraces have been on morphological and quality traits (Chaudhary and Sarawgi, 2002) and post-flowering photosynthetic activities under waterlogged conditions (Adak et al., 1998). Apart from genetic variability, breeders can find material adapted for marginal environments within landraces (Hill et al., 1998). Weltzein and Fischbeck (1990) compared the yield of eight barley landraces, from Syria and Jordan, against a modern cultivar. They found that in low-yielding stress environments all the landraces out-yielded the modern cultivar.

Despite the research already done, the role of landraces in contributing germplasm to breeding programmes has not been fully appreciated (Hill et al., 1998). This has been due to inadequate testing (Hill et al., 1998) or lack of genetic information about the landraces. Information from genetic studies could be useful in designing breeding programmes that will best exploit economically important grain quality and yield related traits when developing new varieties (Falconer and Mackay, 1996).

1.4 Rice grain quality, yield and components

Traits of economic importance in rice include grain size aroma, gelatinization temperature, and yield and yield related traits (Ashikari et al., 2005; Tan et al., 1999). Apart from high grain yield, grain size and grain quality (amylase content, gel consistency, gelatinization temperature) are two major targets for breeding programmes (Rabiei et al., 2004a). Rice quality is evaluated using several characteristics including cooking and eating qualities (Han et al., 2004). Two of the important cooking and eating qualities are aroma, a sensory characteristic, and gelatinization temperature, a cooking characteristic. Rice grain size is defined by characteristics such as length, width and shape and these characters affect the appearance of the grain. Grain size has a direct effect on the marketability and the commercial success of rice varieties (Redona and Mackill, 1998). Commercial varieties in most Asian countries have medium and long grain for example the Basmati varieties of India and Pakistan. In some countries for example Japan and Sri Lanka short grain is preferred. The rice market in Malawi prefers long grain varieties, and farmers prefer to grow long grain varieties to satisfy the preference. Rice grain quality includes milling, appearance, cooking and nutritional qualities (He et al., 1999). Among these, rice consumers in Malawi give more attention to the cooking quality of which aroma and high gelatinization temperature are most preferred. The characteristics of aroma and grain elongation on cooking often occur together in varieties (Bhattacharjee et al., 2002). The rice breeding programme in Malawi, therefore, should target grain size, grain quality and indeed high yield, among other traits.

1.4.1 Rice grain size

Grain size and number are important components of the domestication of crop plants (Pozzi et al., 2004) and they have an influence on the propagation and dissemination of flowering crop plants (Moles et al., 2005). The ability to increase grain yield depends on several yield components including grain size measured as the mass of 1000 kernels and grain number counted per plant or per unit area (Gupta et al., 2006). Apart from direct contribution to yield, grain size has an impact on consumer preference for particular shape (Gupta et al., 2006; Rabiei et al., 2004b). Large variation for grain size and number exists in plants and generally plants with small seeds normally produce many seeds. For example, seeds range in size from 0.0001mg in orchids (*Cycnoches ventricosum*) to 20kg in double coconut (*Lodoicea maldivica*) and variation in number of seeds per fruit is also very wide, from one seed in the coconut, to 40 000 000 in the orchids (Moles et al., 2005).

Physical characteristics of the rice grain that are of interest to breeders include its length, its width and its weight (Takeda, 1991). The grain weight in rice is commonly reported as the weight of 1000 grains that are well filled. The ratio of the grain length to the grain width defines the grain shape. There is no international standard for grain length and grain shape but the International Rice Research Institute (IRRI, 2002) developed a scale for germplasm evaluation presented in Table 1.4. A consumer preference for particular grain shape, as well as grain length varies for different countries. In most Asian countries, consumers prefer medium shape and long grain, while bold shape and short grain is preferred in Japan and Sri Lanka (Redona and Mackill, 1998). The slender shaped and long grained Basmati rices of India and Pakistan are preferred in those countries, and they fetch premium prices both on the domestic and the international market. Consumers in Malawi prefer slender shaped and long grained rice; therefore, breeding must focus on long and slender grains.

Takeda (1991) and Yoshida (1981) stated that the rice grain develops inside its rigid hull and for that reason the size and shape of the kernel are determined by it irrespective of the environment. Grain length and-1000 grain weight are the commonly measured and used characteristics for grain size and they are strongly correlated (Takeda, 1991). Between the two, grain length is the strongest determinant of grain size (Takeda, 1986). Increasing grain size has been proposed as one of the means to increase not only paddy yield but also the milling yield of rice

(Venkateswarlu et al., 1987). Vergara et al. (1990) cited by Gravois and Helms (1992) suggested that increasing the number of large grains on a panicle could result in raising the yield plateau of rice. Therefore, grain size plays an important role in determining yield and consequently has generated a lot of interest for breeders to study the genetic control for this trait (Takeda, 1991).

Table 1.2: Grain size classification for grain length (GL) and grain shape (GS)

Grain length		Grain shape	
Size (mm)	**Class**	**GL:GW ratio**	**Class**
<5.50	Short	<1.0	Round
5.51-6.60	Medium	1.1-2.0	Bold
6.61-7.50	Long	21.-3.0	Medium
>7.50	Extra long	>3.0	Slender

Source: Jennings et al. (1979)

1.4.2 Rice aroma

Aroma is one of the traits responsible for the popularity of some varieties, for example Basmati and Jasmine in Asia (Bansal et al., 2000). In some countries, however, aromatic rices are not popular probably because of association with low yields, making it unattractive for growers, or a lack of marketing promotion (Berner and Hoff, 1986). Traditional Basmati varieties are neither indicas nor japonicas, but cluster as a genetically distinct group when tested with isozymes (Glaszmann, 1987) and microsatellites (Garris et al., 2005). It is imperative to perform similar tests on the aromatic *Faya* rices of Malawi in order to cluster them in relation to the traditional Basmati, Jasmines, and other aromatic varieties.

The aroma associated with the presence of 2-acetyl-1-pyrroline is most closely associated with the aroma of Basmati and Jasmine types of rice (Hien et al., 2006; Bradbury et al. 2005; Yoshihashi, 2002; Lorieux et al., 1996; Widjaja et al., 1996; Buttery et al., 1983;). Many other compounds are also found that cause aroma in aromatic rice cultivars (Lam and Proctor, 2003; Jezussek et al., 2002; Widjaja et al., 1996). The dominant role of 2-AP has been established because it is the only compound that shows consistent relationship between its quantitative value and qualitative sensory test results of aroma in aromatic varieties (Champagne, 2008;

Yoshihashi et al., 2004). It can be assumed, therefore, that 2-AP is present in all aromatic rice varieties of the world. The marker for the aroma gene *fgr,* has been linked to the restriction fragment length polymorphisms (RFLP) marker RG28 on chromosome 8 at a genetic distance of 4.5 cM (Garland et al., 2000; Ahn et al., 1992).

The chemical structure of 2-AP is shown in Figure 1.1. Aroma in rice can be detected using both qualitative and quantitative methods. The qualitative methods include smelling leaf tissue and raw or cooked grains with or without reacting with solutions of 1.7% potassium hydroxide (Sood and Siddiq, 1978). The quantitative identification of 2-acetyle-1-pyrroline includes the use of gas chromatography mass spectrometry selected ion monitoring (GC-MS-SIM) (Yoshihashi et al., 2004; Lorieux et al., 1996; Widjaja et al., 1996).

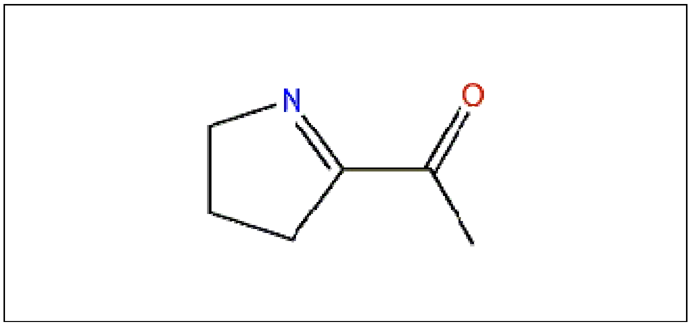

Figure 1.1: The chemical structure of 2-acetyl-I-pyrolline

1.4.2.1 Assessment of rice aroma

The qualitative assessment for aroma is a sensory test that basically involves chewing or sniffing rice grain or leaf samples by trained panelists (Berner and Hoff, 1986; Sood and Siddiq, 1978). The amount of aroma is indicated by descriptive scores such as the three point scale of 0 for non-aromatic, 1 for lightly scented, 2 for moderately scented and 3 for strongly scented which is used at International Rice Research Institute (IRRI, 2002). The grain or leaf samples can be manipulated in order to enhance the sensory test. The variations to the basic test are: raw versus cooked grain, whole grain versus flour, and the addition of potassium hydroxide (KOH) to grain or leaf samples (Berner and Hoff, 1986; Sood and Siddiq, 1978). Tasting individual grains for aroma has been used by rice breeding programme in Australia (Reinke et al., 1991) and is the only method used for the selection of aromatic breeding lines in the rice breeding programme in Malawi.

The qualitative methods, of smelling or chewing, are subjective and not always reliable as the ability to distinguish between aromatic and non-aromatic samples diminishes with each successive analysis. Enhancement with chemicals, by smelling leaf tissue or grains after heating in water or reacting with solutions of KOH can cause damage to the nose (Sood and Siddiq, 1978). Sensory methods, therefore, have limitations when processing large numbers of samples. Quantitative identification of 2-AP, using gas chromatography for example, requires large samples of tissue therefore may not be used early in the breeding programme and the process is time consuming (Lorieux et al., 1996; Widjaja et al., 1996). Bergman et al. (2000) indicated that quantitative analysis of 2-AP is expensive because of the equipment that most rice breeding programmes, including that in Malawi, might not afford. Therefore, sensory tests remain the better option for analysis of aroma in rice.

1.4.3 Rice gelatinization temperature

Gelatinization temperature (GT) is the range of temperature in which at least 90% of the starch granules in rice grains swell irreversibly in hot water with loss of crystallinity and birefringence (Dela and Khush, 2000). The GT ranges from 55°C to 79°C and, based on this range, Juliano (1979) described three classes of GT which were: 1) low GT (55°C to 69°C), 2) intermediate GT (70°C to 74°C) and 3) high GT (more than 74°C). Ghosh and Govindaswamy (1972) indicated that the cooking quality of rice is influenced by the GT as well as the quality and quantity of starch in the rice grain. In a study conducted by Tomar and Nanda (1985), they indicated that the GT played an important role in water uptake by, and volume expansion and elongation of rice grains.

Gelatinization temperature is measured indirectly the by the alkali spreading value (ASV), a method that was developed by Little et al. (1958). A simplified method to determine GT was proposed by (Bhattacharya et al. 1982). Milled rice grains are soaked in 1.5% or 1.7% potassium hydroxide (KOH). Rice grains with high GT remain unchanged while grains with low GT rice disintegrate completely. Rice grains with intermediate GT are partially affected.

Apart from gelatinization temperature, the cooking quality of rice can also be attributed to two other physico-chemical properties of the grain, namely amylase content and gel consistency (Juliano, 1985; Webb, 1980; Little et al., 1958). Amylose content determines the hardness of cooked rice and the rice-water ratio (Singh et al., 2000). Amylose content is analyzed by methods developed by Juliano (1971). On the basis of their amylase content, rice varieties are grouped into waxy (0-2%), very low (3-9%), low (10-19%), intermediate (20-25%), and high (>25%) (Kumar and Khush, 1986). Gel consistency is an index of cooked rice texture and is based on the consistency of rice paste (Singh et al., 2000). Gel consistency depends on the variations of amylopectin fractions in the rice grain endosperm (Juliano and Perdon, 1975). Gel consistency is measured by the length of milled rice paste in a culture tube of cold gel (Cagampang et al., 1973). Amylose content has been reported to have positive correlations with both gelatinization temperature and gel consistency (Juliano and Villareal, 1993). Nkori Kibanda and Luzi-Kihupi (2007) reported negative correlations between amylase content and gelatinization temperature. The analysis of amylose content and gel consistency requires specialized equipment which many breeding programmes many not have. Amylose content and gel consistency may, therefore, be inferred from gelatinization temperature which is easy to analyze.

1.4.4 Yield and yield components of rice

Optimizing yield is one of the most important goals for most farmers. Yield is a complex character that can be determined by several components (Özer et al., 1999). It is necessary to determine the association between yield and some of the components that have a great effect on yield. This information on the association is of great importance to breeders in selecting desirable genotypes (Özer et al., 1999; Fukai et al., 1991; Weng et al., 1982). Grain yield is a response variable caused by the interaction of yield components or yield-related traits.

Yield components in rice can be arranged into three orders (Samonte et al., 1998). The first-order comprises panicle number per unit area or per plant, and panicle weight per unit area or per plant. The product of these two traits can be used for the indirect estimate of grain yield in rice (Gravois and McNew, 1993). The second order yield components are further divided into two sub-groups. The first sub-group comprises components of panicle number which include plant height, panicle length, and number of days to flowering or maturity. The second sub-group comprises components of panicle weight which are the number of filled grains per panicle and 1000-grain weight. Third-order components include the total number of grains per panicle and other traits that interact to influence the number of filled grains per panicle and the 1000-grain weight (Gravois and McNew, 1993). Studying the genetic control of yield as well as yield related and grain quality traits is important for rice breeders to develop high yielding varieties that would be readily adopted by farmers (Witcombe et al., 2005).

1.5 Gene action

Traits that breeders wish to improve are either quantitative or qualitative in nature (Kearsey and Pooni, 1996). Quantitative traits show continuous variation whereas qualitative traits are discrete (Hill et al, 1998; Kearsey and Pooni, 1996). Quantitative traits are usually governed by a number of genes while qualitative genes are governed by one or two genes, and are simply inherited (Hill et al, 1998; Kearsey and Pooni, 1996). The chemical structure and mode of transmission, from parent to progeny, are similar for qualitative and quantitative traits (Chahal and Gosal, 2002). The aim of rice breeding is to improve qualitative and/or quantitative traits but, to plan an appropriate breeding strategy, breeders need to know the behavior of the genes (gene action) that control particular traits. The methodology of biometric or quantitative genetics is used to study the inheritance and gene action (additive, dominance and epistasis) of quantitative traits (Falconer and Mackay, 1996).

Additive gene action results into a homozygote that is intermediate in phenotype between homozygotes parents for the alternative alleles, and there is no dominance of one allele over another (Falconer and Mackay. 1996; Mather and Jinks, 1982). The additive gene action will make some parent, among many in a population, to generally combine favourably with all other parents. This is called the general combining ability defined as the difference between the mean performance of a given male (or female) and the mean of the progeny from all the males (or females) (Kearsey and Pooni, 1996). Dominance gene action results into a heterozygote whose phenotype may not be midway between two parents but inclined towards one of its parents. The amount of inclination can be stated in terms of the degree of dominance, which might be complete dominance, partial dominance, or over-dominance (Chahal and Gosal, 2002). As opposed to the additive gene action, the dominance gene action is responsible for the favourable combinations between specific parents. This is called the specific combining ability, defined as the deviations of specific crosses from the average expected of all crosses (Kearsey and Pooni, 1996).

Epistatic gene action occurs because of the interaction of genes that are at different loci, and may involve all possible combinations within additive or dominance gene effects, or between additive and dominance gene effects (Falconer and Mackay, 1996). Many genetic studies do not estimate epistatic gene action, because of the need for a high number of generations among other reasons (Viana, 2000), and instead limit analysis to the additive and dominance gene action. Viana (2005) found that neglecting epistasis overestimates the heritability calculated from genetic studies that use only the additive and dominance effects of genes.

Rice breeders need the information on nature and magnitude of gene action in order to design efficient breeding programmes for rice improvement (Malini et al., 2006). Mating designs are used to quantify the genetic components that are of great interest to breeders.

1.6 Mating designs

Mating designs are used to generate information on the structure of populations, and also on the genetic control or gene action of various traits (Hallauer and Miranda, 1989; Griffing, 1956; Hayman, 1954). Thus the designs provide information on the nature and amount of genetic variation and combining abilities of parents and their crosses. Mating designs can be classified as one, two, three, or four factor designs, depending on the type of control imposed on the parents to be mated. Simple and commonly used are two factor designs that include the diallel, the North Carolina Design (NCD) I and NCD II. Other designs are triallel and quadriallel. In any genetic study, a breeder should choose a simple design but that will provide the required estimates. According to Hallauer (2007) NCD II mating scheme is a preferable cross-classification design because a greater number of parents is used to generate fewer number of crosses than in a diallel design (Hill et al., 1998).

The North Carolina design II mating scheme, or factorial design, was proposed and described by Comstock and Robinson (1948). Different sets of parents are used as males and females in this mating scheme (Hallauer and Miranda, 1989). The mating scheme results in progenies that are composed of male half-sib families, female half-sib families and male x female full-sib families. General and specific combining ability estimates are estimated from the expected mean squares in the analysis of variance of the North Carolina design II (Hallauer and Miranda, 1989). Estimates of additive and dominance genetic variances, as well as heritability are obtained directly from the components of the analysis of variance (Henning and Shaun Townsend, 2005).

North Carolina design II mating schemes have been used to estimate genetic variances and heritabilities in hop (Henning and Shaun Townsend, 2005), in beans (Elia, 2003) and in maize (Derera et al., 2001). In rice, Efisue et al. (2008a and 2008b) used the NCD II mating scheme to study seed set and drought tolerance in crosses between *Oryza sativa, Oryza glaberrima* and interspecific progenies. Manickavelu et al. (2006) generated 40 crosses by NCD II mating scheme to study drought tolerance traits in rice. To investigate gene action controlling protein content in indica rice, Shi et al. (1999) crossed nine female parents and five male parents in a NCD II mating to generate crosses for the study. Gravois and Helms (1992) used NCD II mating scheme to generate 32 hybrids to study genetic effects of rice grain weight and density.

1.7 Combining ability

According to Griffing (1956), the concepts of general combining ability (gca) and specific combining ability (sca) were introduced by Sprague and Tatum (1942). They defined gca as the average performance of a parental line in hybrid combinations and sca as combinations that are either better or poorer than would be expected of the average performance of the parent inbred lines. Genotypic variance can be divided into two components, the general combining ability (gca) and the specific combining ability (sca) (Griffing, 1956). The estimates of gca and sca are measures of the additive and dominance components of phenotypic variation (Griffing, 1956). Combining ability analysis helps to identify suitable parents to be used to improve desirable traits in a breeding programme (Won et al., 2002). The analysis also helps to identify superior cross combinations for traits.

If the variance due to gca is greater than the variance due to sca for a trait, it indicates the predominant role of additive gene action (Khanorkar et al., 1984). Additive variance expresses the proportion of trait which can be transmitted from parents to offspring, thus reflecting the degree of resemblance between progenies and their parents (Falconer and Mackay, 1996). If, however, the variance due to sca is greater than the variance due to gca, it indicates predominance of dominance or epistasis (Mohanty and Khush, 1985). Non-additive gene action embraces all types of variation that includes dominance and epistasis (Falconer and Mackay, 1996) and may not be transmitted from parents to offspring.

1.8 Genetic studies of grain quality, yield and yield related traits in rice

1.8.1 Genetic studies of rice grain size

The genes that influence grain size have been identified in rice (Fan et al., 2006; Sakamoto et al., 2006; Ashikari et al., 2005). Studies of grain size have shown different results concerning its genetic control. The genetic control of grain length has been reported to be monogenic, digenic, trigenic or under the control of polygenes (Chang, 1997; Somrith et al., 1979). Similar varied findings have also been reported for grain width (Chang, 1997). The polygenic inheritance of grain weight has been reported to have partial dominance, additive effects and even non-allelic interactions (Somrith et al., 1979). Three genes involved in grain size for rice have been identified and named as grain size3 (GS3), OsDWARFF4, and dwarfII (dII) (Gupta et al., 2006). In a cross between IR8 and IR42, the large grain size of IR8 was found to be controlled by two major genes for length and width and determined that the gene action controlling grain size was additive.

Other workers have stated that rice grain size is a quantitative trait controlled by polygenes and that additive gene action is more important than non-additive gene action (He et al., 1999; Takeda, 1991). Srivastava and Seshu (1983) found that rice grain length was predominantly controlled by additive gene action. Similar findings were reported by Sarawgi et al. (1991). Grain shape was reported to be under the control of additive gene action by Shi et al. (2000) and Shi and Zhu (1996). Zhang et al. (2006), Munhot et al. (2000) and Gosh (1993) also reported on the predominant role of additive gene action in the control of grain shape in rice. Srivastava and Seshu (1983) found that 1000-grain weight was under the control of additive gene action but Sharma et al. (1996) found that the 1000-grain weight was controlled by non-additive gene action. Gravois and Helms (1992) found that the additive variation for grain weight was close to zero in crosses involving 16 parents from a population of southern USA long-grained rice. He suggested that grain size in the population could be increased by utilizing germplasm from elsewhere. The inheritance of grain size in Malawi rice landraces has not been studied before.

1.8.2 Inheritance studies of rice aroma

There are a few inconsistencies among different studies on inheritance of aroma (Tsuzuki and Shimokawa 1990; Berner and Hoff, 1986). Berner and Hoff (1986) attributed the conflicting information to ineffective scent evaluation methods. However, Tsuzuki and Shimokawa (1990) suggested that genes for aroma might vary among varieties, therefore giving different results. Studies of segregation ratios of F_2 in different populations have suggested that varying numbers of genes, either dominant or recessive, are responsible for aroma (Berner and Hoff, 1986; Sood and Siddiq, 1978; Tripathi and Rao, 1979). However, it has been established that in most varieties, a single recessive gene is responsible for aroma determined by the level of 2-AP (Lorieux et al., 1996).

After crossing aromatic and non-aromatic parental types, and using gas chromatography, Dong et al. (2001) and Pinson (1994) found segregation ratios of 1:3 for aromatic:non-aromatic plants in the F_2 generation. The result indicated a single gene ratio in the F_2 progeny and that the non-aromatic was the dominant trait. Earlier, Berner and Hoff (1986) and Sood and Siddiq (1978) reported that the aroma trait was controlled by a single gene that was recessive to the non-aroma trait. Tsuzuki and Shimokawa (1990) made crosses between an aromatic variety and non-aromatic varieties. They observed a segregating pattern of 3:13 for aroma:non-aroma, which indicated segregation of two genes, where one of the genes acted as an inhibitor to the other when dominant. Tripathi and Rao (1979) found segregation ratios of 7:9 for aromatic:non-aromatic which indicated that two genes, when homozygous recessive at either locus, controlled the aroma.

1.8.3 Inheritance studies of rice gelatinization temperature

Various studies have been conducted on the inheritance of gelatinization temperature (GT) in rice, most of which have indicated that a single major gene is responsible for gelatinization temperature (Bao et al., 2002; Umemoto et al., 2002; He et al., 1999). A bimodal distribution was found by Puri and Siddiq (1980) when they made the crosses between medium and high GT. In crosses between medium GT x medium GT and high

GT x high GT, Puri and Siddiq (1980) reported a unimodal curve. Heda and Reddy (1986) found bimodal and unimodal curves in their studies of inheritance of GT. McKenzie and Rutger (1983) found bimodal frequency distributions for gelatinization temperature and concluded that a single gene with major effect was controlling GT. Shen et al. (2006) have summarized that the inheritance of gelatinization temperature is complicated.

Polygenic nature of inheritance for gelatinization temperature has also been suggested by McKenzie and Rutger (1983). The interaction of two pairs of major genes with duplicate gene action and cumulative effect was reported by Tomar and Nanda (1985). Hsieh and Wang (1988) reported that gelatinization temperature was under the control of both dominant and additive genes. Additive gene action for gelatinization temperature was also reported by Somrith et al. (1979).

Table 1.3: Scores for Alkali spreading value (ASV) and its relationship to Gelatinization Temperature (GT).

Reaction of grains after soaking	ASV	GT class
1-Not affected but chalky	Low	High
2-Swollen	Low	High
3-Swollen with collar incomplete or narrow	Low or intermediate	Intermediate
4-Swollen with collar complete and wide	Intermediate	Intermediate
5-Split with collar complete and wide	Intermediate	Intermediate
6-Dispersed merging with collar	High	Low
7-Completely dispersed and cleared	High	Low

Source: Standard Evaluation System for Rice (IRRI, 2002).

1.8.4 Genetic studies of yield and yield related traits in rice

Various genetic studies have indicated the importance of both additive and non-additive gene action for yield and yield related traits in rice (Malini et al., 2006; Pradhan et al., 2006; Srivastava and Verma, 2004; Vanaja et al; 2003). Some studies (Malini et al., 2006; Allahgholipour and Ali, 2006; Vanaja et al., 2003) have reported the preponderance of non-additive gene action for yield and yield related traits. Manuel and Palanisamy (1989) and Yadav et al. (1989) reported that non-additive gene action was predominant for the control of grain yield in rice. Vyas and Kumar (2008) and Kausik and Sharma (1988) reported preponderance of non-additive gene action for panicle length, the number of panicles per hill, plant height and days to 50% flowering. Population improvement methods would be effective strategies to exploit non-additive gene effects (Joshi, 1979) while simple pedigree selection methods would be effective for the improvement of traits that are largely controlled by additive gene action (Joshi, 1979).

1.9 Heritability

Success of breeders in changing the characteristics of a population depends on the degree of correspondence between phenotypic and genotypic values (Singh and Ceccarelli, 1995; Dabholkar, 1992). The degree of correspondence is provided by a quantitative measure called heritability, which describes a particular trait and a particular population (Dabholkar, 1992). Heritability is divided into broad-sense and narrow-sense, depending whether it refers to the genotypic value or breeding value, respectively (Falconer, 1988). The ratio of genetic variance to phenotypic variance is called broad-sense heritability or genetic determination and is an expression of the extent to which individual phenotypes are determined by the genotypes. The ratio of additive variance to phenotypic variance is called narrow-sense heritability and is an expression of the extent to which phenotypes are determined by the genes transmitted from parents to progenies (Dabholkar, 1992; Falconer, 1988).

Gene action (additive or non-additive effects) play an important role in determining heritability in that traits controlled by additive gene effects tend to have higher heritability values than traits controlled by non-additive gene effects (Dabholkar, 1992; Falconer, 1988). Takeda and Saito (1983) reported high realized heritability for grain weight in rice. Their heritability estimates ranged from 63% to 90%. The high heritability estimates were an indication that there were high expectations for further improvement in later generations. On the other hand, Kato (1997) estimated realized heritability of 16% for number of panicles per plant and 20% to 33% for number of grains per panicle in rice, indicating that these traits were highly influenced by the environment. Sürek and Korkut (1998) estimated high narrow sense heritability for grain weight, moderate for the number of spikelets per panicle, and low for the number of panicles per plant in rice. The different heritability estimates imply that in some populations, the additive genetic effects would be transmitted to progeny, while in other populations non-additive effects had greater effects probably because of environmental effects. Gravois and McNew (1993) estimated realized heritability of 45% in rice for panicle number and

31% for panicle weight. This means that progress can be achieved by selecting for these two traits, especially for panicle number.

1.10 Correlation

Correlations are of interest to breeders because they allow indirect selection of one trait through another trait, especially when the heritabilities are high (Falconer, 1988; Rosielle and Hamblin, 1981). The correlations between traits can be at phenotypic or genotypic level (Falconer, 1988; Hallauer and Miranda, 1989). The relationship at phenotypic level, or phenotypic correlation, involves genetic and environmental effects and can be directly observed from measurements of traits (Hallauer and Miranda, 1989). The relationship at genotypic level, or genetic correlation, involves the genetic effects of traits. Phenotypic and genotypic correlation can be estimated from components of variance (Sughroue and Hallauer; 1997).

The relationship between rice yield and yield components has been studied extensively at phenotypic level (Gravois and McNew, 1993; Fukai et al., 1991). Rice grain yield has been reported as positively correlated with plant height, panicle length and panicle weight (Samonte et al., 1998; Reddy et al., 1997), number of grains per panicle and 1000-grain weight (Samonte et al., 1998; Geetha et al., 1994), number of days to 50 percent flowering and number of days to maturity (Geetha et al., 1994). Bansal et al. (2000) and Dhanraj and Jagadish (1987) reported that yield per plant was positively correlated with the number of productive tillers, panicles and spikelets per plant and 1000-grain weight. Feil (1992) and Prasad et al. (1988) observed positive correlations between grain yield per plant and yield components: total spikelets per panicle, fertile grains per panicle and 1000-grain weight. Ramakrishnan et al. (2006) and Bai et al. (1992) reported positive correlation of grain yield with number of productive tillers, and number of grains per panicle. Sürek et al. (1998) reported that grain yield per plant was significantly correlated with the number of panicles per plant and 1000-grain weight.

Venkateswarlu et al. (1986) examined the effect of the high-density grain on grain yield and suggested that increasing the proportion of high-density grains would increase grain yield by as much as 30%. Gravois and McNew (1993) suggested that the selection for increased yield via selection for either panicle weight, or panicle number alone, would be ineffective. However, a selection index that included selection for both increased panicle weight and panicle number to increase yield was estimated to be

91% as effective as selecting for yield directly (Gravois and McNew, 1993). Kato (1990) reported that selection for grain size of rice was effective even in early segregating generations after crossing. Therefore selecting grain size trait can be used, in early generations for example F_2, to select plants that will be high yielding in later generations.

Feil (1992) reported that among the components of grain yield of a cereal crop, the number of spikelets per panicle appeared to be a predominant key character in the development of high-yielding cultivars. Morales (1986) suggested that number of grains per panicle and 1000-grain weight might be considered important criteria for increasing yield per unit area. Moeljopawiro (1989) and Reuben and Katuli (1989) reported that grains per panicle was the yield component with the greatest effect. Contrary to this finding was the report by İbrahim et al. (1990) that productive tillers were the most reliable characters for selecting genotypes of rice. Mehetre et al. (1994) reported that the filled grains per panicle were an important yield-contributing character.

Morales (1986) suggested that number of grains per panicle and 1000 grain weight might be considered important criteria for increasing yield per unit area. On the other hand, Moeljopawiro (1989) and Reuben and Katuli (1989) reported that grains per panicle was the yield component with the greatest effect. On the contrary, İbrahim et al. (1990) found out that the number of productive tillers was the most reliable character in selecting genotypes of rice and Mehetre et al. (1994) reported that the filled grains per panicle was an important yield-contributing character.

1.11 Path analysis

Yield and its components are considered to be interdependent and the degree of this interdependency can be obtained by correlation analysis. Correlation analysis is a useful tool that provides an indication of the degree of association between two variables indicated by correlation coefficients as the statistics (Steel et al., 1997; Gomez and Gomez, 1984). A simple correlation analysis between yield and its components does not provide detail of the interrelationships among the components themselves (Kozak et al., 2007; Ssangoa et al., 2004). Interrelationships between components may be direct and/or indirect but correlation analysis does not reveal this (Gravois and Helms, 1992). Another tool called path analysis can be used to partition the relationship between components into direct and indirect effects. So in addition to correlation analysis, path analysis can be used in order to understand the complex relationships among traits. Path analysis can also identify those components that contribute more than others to yield. The method first described by Dewey and Lu (1959) represents the conventional method or approach to path analysis (Kozak et al., 2007).

Zahid et al. (2006) reported that 1000-grain weight had high and positive direct effects on rice yield. Surek and Beser (2003) and Yolanda and Das (1995) also reported that 1000-grain weight had high direct effects on yield. Zahid et al. (2006) and Prasad et al. (2001) found that the number of panicles per hill and plant height had negative direct effects on yield. Kumar (1992) and Ramakrishnayya et al. (1991) found that plant height had positive and direct effect on grain yield. Reuben and Katuli (1989) also reported on positive direct effect of plant height on rice yield.

1.12 Farmer participation in breeding

Involving farmers more actively in plant breeding has been much advocated and described as participatory plant breeding (PPB) (Gyawali et al. 2007). The reasons for involving farmers can vary from empowerment (Sperling et al., 1993) to increasing the efficiency of classical breeding (Witcombe et al., 2005; 1996). Such increases in efficiency are achieved because farmer participation better orients the breeding programme to the needs of the clients. Hence, the purpose of involving farmers is to improve client orientation, and highly client-oriented breeding describes this purpose, while PPB describes an activity (Witcombe et al., 2005). Much research has been done into evaluating varieties with farmers and this process is now commonly termed participatory varietal, or variety, selection (PVS).

Participatory rural appraisal (PRA) has been extensively used to identify constraints to production and variety preferences in crops (Doward et al., 2007; Singh, 2004). Various workers have used PRA to study the situation of rice farmers and to elicit their preferences for variety traits. In the Sikasso region of Mali, Efisue et al. (2008c) found that farmers in the upland and lowland ecologies preferred early maturing varieties to mitigate drought. They further found that farmers preferred tall varieties for the two reasons that harvesting was easier and the straw was a building material. Singh and Shrivastava (2004) used PRA to learn farmers' perceptions on rice yield constraints in

Durg District of Chhattisgarh, India. They found that apart from good yield potential, farmers also preferred varieties that did not require high input of fertilizer. A PRA of rice farmers in Malawi would obtain information on production constraints and variety preferences.

1.13 Rice production constraints

There are a number of constraints in rice production and these can be broadly classified into three major categories: biological, physical and socioeconomic (Ramasamy et al., 1996). These constraints account for the yield gap between the genetic potential of a rice variety and the actual yield in the the field. The yield gap can be divided into two parts: yield gap I and yield gap II (Widawsky and O'Toole, 1990). Yield gap I is the difference between an experiment station's maximum yield and the potential average yield achievable under favourable farm conditions (Lin and Shen, 1996). This yield gap is due to differences in the varieties and production environment which cannot be easily managed. Yield gap II is the difference between the average farm yields and yields that can be attained under well-managed and favourable conditions. Yield gap II is caused by technological and socioeconomic constraints such as the use of impure seeds and poor water management.

1.14 Summary

Generally, this literature review showed the many complexes of the Rice Genus, and the successful interspecific cross between two rice complexes namely *Oryza sativa* and *Oryza glaberrima*. Selections from the crosses resulted in the New rice for Africa (NERICA) varieties. The NERICAs could be directly introduced into a rice farming system, or they could be crossed to rice landraces that farmers grow.

Rice landraces are widespread and popular among farmers. They are an important part of agriculture because they provide genetic diversity. Landraces possess traits that are most preferred by farmers and consumers. They can be used to produce new varieties or to incorporate desirable traits into new varieties. Participatory rural appraisal studies can be used to find out the farmers' desired traits. Among many, some of the traits that are targets for breeding are grain size, aroma, gelatinization temperature, and yield components.

Grain size of rice is defined in terms of length, width, 1000 grain weight, and shape (length: width ratio). Consumer preferences for rice grain shape are varied. For example, consumers in Japan and Sri Lanka prefer bold shaped and short grains, while Malawian consumers prefer slender shaped and long grains. The importance of grain size has generated a lot of genetic studies for the trait. Some studies have indicated that rice grain size is a quantitative trait controlled by many genes and that additive gene action is more important than dominance. No such studies have been reported on rice in Malawi.

Rice quality is evaluated using several characteristics including aroma, a sensory characteristic, and gelatinization temperature, a cooking characteristic. The aroma in rice is mainly associated with the presence of a compound called 2-acetyl-1-pyrroline. Many other compounds are also found that cause aroma in aromatic rice cultivars. There are inconsistencies among different studies on the inheritance of aroma attributed to ineffective scent evaluation methods, or that genes for aroma might vary among varieties, therefore giving different results. However, it has been established that in most varieties, a single recessive gene might be responsible for aroma. Gelatinization temperature, measured by the alkali spreading value, is thought to be simply inherited with only one or two major genes.

Grain yield is a complex character determined by several components some of which have a great effect on yield. Information on the association between yield and its components is of great importance to breeders in selecting desirable genotypes. Yield components in rice include panicle number per unit area or per plant and panicle weight per unit area or per plant. The product of these two traits can be used for the indirect estimate of grain yield in rice. Other components include panicle length, the number of filled grains per panicle and 1000-grain weight. Studying the genetic control of yield components is important for rice breeders to develop high yielding varieties since the components determine yield.

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Chapter 2: Perception of Farmers on Variety Trait Preferences in Two Rainfed Rice Growing Areas in Malawi

Abstract

There is a need to adopt participatory plant breeding in Malawi, an innovative approach that would involve farmers in developing high yielding rice varieties. Therefore, a participatory rural appraisal was conducted in 2006 as the first step in participatory plant breeding, a new direction for rice variety development in Malawi. The objectives of the PRA were 1) to identify constraints to rice production in the rainfed ecosystem, and 2) to determine farmers' preferences in rainfed rice varieties. The participatory rural appraisal was conducted in two randomly selected villages of Liundi and Nawanga in the districts of Machinga and Salima. The two villages were a representation of the plateau or rift valley areas in which rainfed rice is grown in Malawi. The primary quantitative data for this study were collected through questionnaires that were administered to 190 respondents in the two villages. Qualitative and additional quantitative data were obtained by use of transect walks and matrix ranking and scoring. The results showed that rice was the major food and cash crop for the rainfed rice farmers whose average per capita land size was 0.6 ha. The study found that use of landraces, proliferation of weeds, and inadequate extension advice were the major constraints to rice production. This study also established that large grain size, aromatic grain, and early maturity were key traits preferred by farmers. The rice breeding programme for rainfed ecosystem in Malawi could address the constraint of use of landraces by developing improved high yielding varieties large grain size and aroma.

Keywords: Rice, Rainfed ecosystem, Participatory rural appraisal, variety preferences, grain size, aroma.

2.1 Introduction

In Malawi rice (*Oryza sativa* L.) is the second most important cereal crop after maize and it is a source of both food and cash income to rice farmers. Rice is grown mainly in low-altitude areas along the shores of Lake Malawi and Lake Chirwa, along the banks of the Shire River and in low lying areas beneath mountain foothills. Sizeable and increasing production is also found in swamps and "dambo" areas in medium- and high-altitude areas of Chitipa, Mzimba, Dedza and Mchinji districts. The rice growing areas range in altitude from 50 m to 2 500 m above sea level. Average temperatures in these areas are 14 ^{o}C to 35 ^{o}C with annual rainfall range of 600 mm to 2400 mm per annum. The soils are of alluvial origin with variable texture ranging from sandy clay loams to clay loams, medium to low nutrient content with pH 5.5 to 8.5 (Dzowela, 1974). Specifically the soils in which rice is grown in Malawi have low levels of nutrients and most farmers do not apply any type of fertilizer (Sistani et al., 1998). Rice is grown solely by smallholder farmers in fields that are less than 1.0 ha on average, a figure that is in agreement with recent findings by the Department of Lands (GOM, 2002). Rice production is carried out in three environmental conditions based on the rice ecosystem classification by the International Rice Research Institute (IRRI, 1994). The three ecosystems are: irrigated, rainfed lowland, and rainfed upland. Approximately 15% of the rice area is irrigated, and two crops can be grown per year. The greater and remaining 85% is rainfed and shared between lowland (70%) and upland (15%).

The area grown to rice in Malawi was approximately 52461 ha in the 2006 crop season, and total production for that year was 91 450 t (GOM, 2007). Based on these figures, therefore, the productivity of rice in 2006 in Malawi was 1.74 t ha^{-1}. The area and production figures for the irrigated ecosystem were 20954 ha and 46932 t, respectively, translating to 2.24 t ha^{-1} average national yields. This was lower than the 6 t ha^{-1} potential yield obtained in researcher-managed irrigated variety trials. The area and production figures for the rainfed lowland and rainfed upland ecosystems, combined, were 31507 ha and 44518 t, respectively. The productivity for these two ecosystems was, therefore, 1.41 t ha^{-1}. These figures clearly indicate that generally the productivity of rice in Malawi is very low and that among the ecosystems the two rainfed ecosystems are the least productive. Raising productivity in the rainfed ecosystem, therefore, can greatly contribute to an overall increase in productivity from the average of 1.41 t ha^{-1} obtained in 2006 to an average of 4 t ha^{-1} which are achieved in researcher- managed rainfed variety experiments. An increase in rice productivity will contribute to national food security and poverty reduction, two of the priority areas set by the Government of Malawi in its development plans (GOM, 2006; 2005).

Chirwa et al. (2006) reported that low productivity in the agriculture sector in Malawi was emanating from production constraints faced by farmers. They identified the constraints in maize to be unfavourable climate, poor access to credit and markets, inadequate infrastructure, and most importantly use of low yielding varieties. The low productivity of rice, especially in the rainfed ecosystem, could be attributed to similar constraints, subject to verification by the rice farmers themselves. Among several options to remove the production constraints, perhaps the first and high impact intervention could be providing farmers with high yielding rice varieties. If farmers were provided with and they used high yielding rice varieties rice production could increase dramatically. To ensure that varieties are appropriate, and that they will be readily adopted it is important to know what traits they prefer to be present in those varieties. This information can be solicited from the farmers through methods that include participatory rural appraisal (PRA).

Participatory rural appraisal is a tool for interacting with rural and urban people, understanding their situation and learning from them, using an interdisciplinary team of researchers (Blaney and Thibault, 2003). Participatory rural appraisal has been extensively used to identify constraints to production and variety preferences in crops (Doward et al., 2007; Singh, 2004). The advantages of PRA are that reliable results can be obtained speedily, its open format allows for wide input from farmers, and secondary data can be incorporated (Chambers et al., 1989; Haverkort et al., 1991). Participatory rural appraisal has been used by different workers to study the situation of rice farmers and to elicit their preferences for variety traits. In the Sikasso region of Mali, Efisue et al. (2008) found that farmers in the upland and lowland ecologies preferred early maturing varieties to mitigate drought. They further found that farmers preferred tall varieties for the two reasons that harvesting was easier and the straw was a building material. Singh and Shrivastava (2004) used PRA to study farmers' perceptions on rice yield constraints in Durg District of Chhattisgarh, India. They found that apart from high yield potential, farmers also preferred varieties that did not require high input of fertilizer.

Efisue et al. (2008) recently stated that participatory rural appraisal is a viable tool in participatory plant breeding (PPB). To add to that statement, participatory rural appraisal should be the first step in participatory plant breeding. Participatory plant breeding can be defined as a process in which plant breeders and farmers collaborate during the development of a variety, from the initial stages up to official release (Ceccarelli et al., 2003). In conventional breeding, plant breeders decide on variety constitution without involving farmers, which may often lead to limited adoption of the variety (Smith et al., 2001). In participatory plant breeding, however, the involvement of farmers ensures widespread and significant adoption (Ceccarelli et al., 2003).

The rice breeding programme at Lifuwu Research Station in Malawi has been conducting variety research, targeted at the irrigated ecosystem, since 1975. Over the years high yielding rice varieties have been developed for and introduced into the irrigated ecosystem. Efforts to introduce those varieties into the rainfed ecosystem were not successful. Equally unsuccessful were efforts to develop similar high yielding varieties for the rainfed ecosystem. Farmers simply did not take up the varieties, claiming that they were not as good as their traditional varieties. Thus the research station was conducting the variety development year after year without eliciting farmers' trait preferences, and there were no reports of any previous attempt to do so.

That approach needed to change, so that farmers would participate in rice breeding. The participatory plant breeding approach had to be adopted to develop higher yielding varieties for the rainfed ecosystem. Therefore, a PRA was organised in 2006 as the first step in participatory plant breeding, a new direction for rice variety development in Malawi. The first objective of this PRA exercise was to learn and analyze the situation of rainfed rice farmers in Malawi. The second objective was to identify constraints that the farmers confront in rainfed rice production. The third objective was to identify variety traits preferred by the farmers.

2.2 Materials and Methods

2.2.1 Study area

Two districts of Machinga and Salima, noted for rainfed rice production in Malawi, were selected for the PRA. Fieldwork was conducted in two villages namely Liundi and Nawanga, in the two districts, where rice is the main crop grown by farmers. Liundi is in Traditional Authority Mposa in Machinga District in the Southern Region of Malawi. Nawanga is in Traditional Authority Bibi Kuluunda in Salima District in the Central

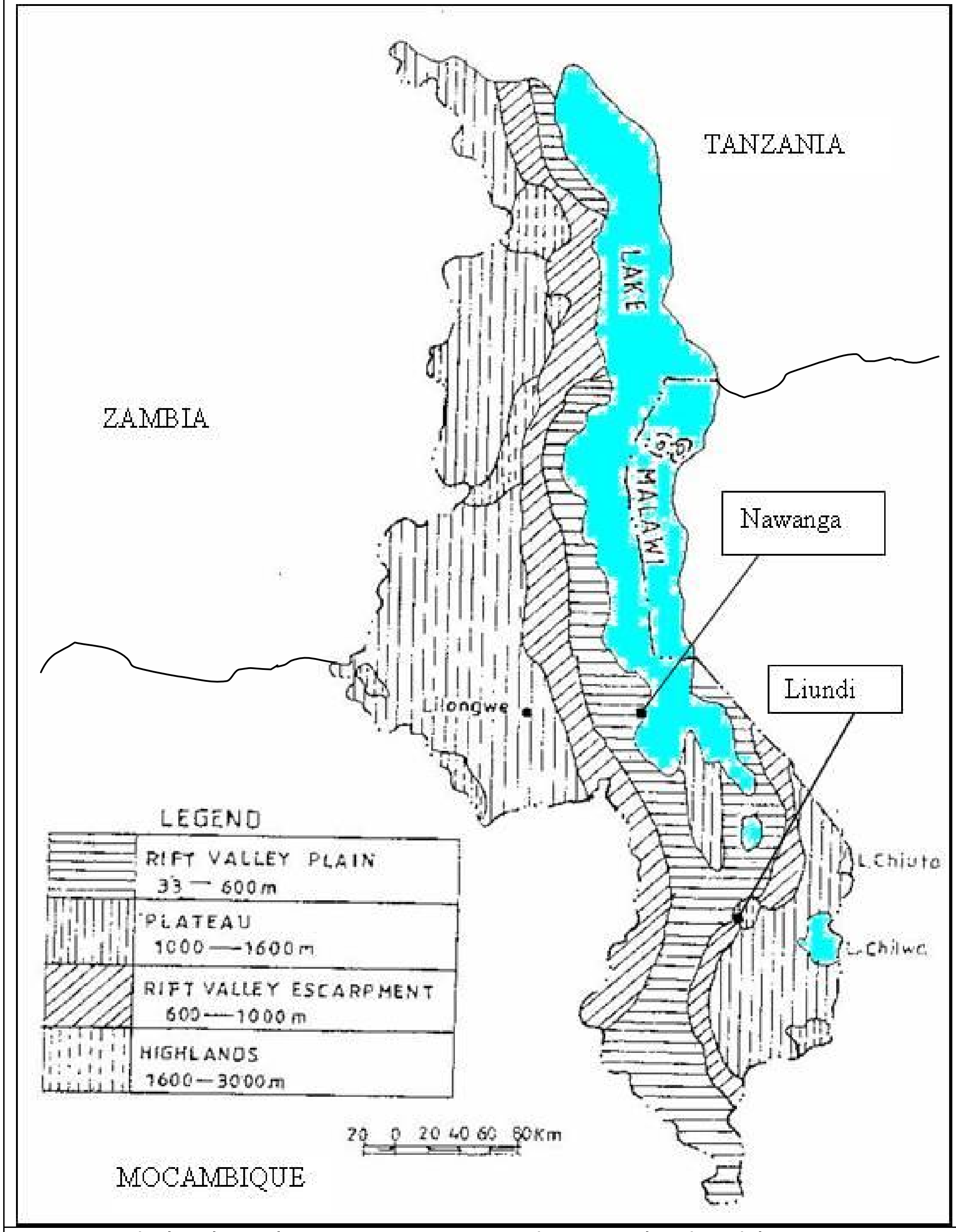
Region of Malawi. Geographical characteristics of the two study sites are shown in Table 2.1

Table 2. 1: Characteristics of the two study sites in Zomba and Salima, Malawi.

	Village	
Characteristic	**Liundi**	**Nawanga**
Latitude (South)	15° 07'	13° 40'
Longitude (East)	35° 30'	34° 35'
Elevation (masl)	1500	500
Average annual rainfall (mm) [a]	1 334	1 253
Annual temperature range (°C) [a]	15.9-26.4	20.4-29.7
Population size	343	290
Predominant ethnic tribes	Lomwe, Yawo	Yawo, Tonga

[a] Recorded at Namwera Extension Planning Area, Zomba, and at Lifuwu Research Station, Salima.

These sites are representative of the areas in which rainfed rice is grown in Malawi. Malawi is divided into four major topographical classes namely highlands, plateaus, rift valley escarpment, and rift valley plains (Figure 2.1). Major rainfed rice growing areas are in the plateaus and the rift valley plains. The plateaus are at elevations ranging from 1 000 to 1 600 metres above sea level with swampy valleys. The rift valley plains are at elevations below 600 metres above sea level and are characterized by seasonal flooding and extreme heat during the wet season from November to April. Liundi village is situated in the plateaus while Nawanga is in the rift valley plains (Figure 2.1).



Source: Agricultural Development Programme: Environment al and Social Impact Assessment, Ministry of Agriculture and Food Security, Government of Malawi (2008).

Figure 2.1: Map of Malawi showing the principal physiographic units and location of the two study sites.

2.2.2 Sampling procedure

The two districts were randomly chosen from among the eight major rainfed rice growing districts in Malawi, the other five being Chikwawa, Phalombe, Mangochi, Machinga, Nkhota Kota, and Karonga. In each district, the District Agricultural Development Officer (DADO), who is the local agricultural extension agent, randomly chose one of four Extension Planning Areas (EPAs) and one village in the Extension Planning Area. The study sampled a total of 190 households, 103 in Liundi and 87 in Nawanga. A total of 40 literate farmers composed of 20 men and 20 women were chosen for focus group discussions (Figure 2.2 and 2.3). Ten literate farmers at each site made up a team to do the matrix scoring and ranking of production constraints and preferred traits. Literate farmers were defined as those that had attended minimum of five out of eight years of primary school education in Malawi.

2.2.3 Data collection

The data collection team for the study comprised of the rice breeder, the District Agricultural Development Officer, the Agricultural Extension Development Officer from the Extension Planning Areas, Agricultural Research Officers from Lifuwu Research Station, and Environmental Health Officers from Salima District Hospital. The primary quantitative data for this study were collected through questionnaires that were administered through the District Agricultural Development Officers. Qualitative and additional quantitative data, including preferences for variety traits such as aroma and gelatinization temperature, were obtained by use of participatory rural appraisal tools that included village sketch mapping; transect walks, historical calendars, seasonal calendars, Venn diagrams, single list scoring-based ranking, and matrix ranking and scoring. In using the various participatory rural appraisal tools, the District Agricultural Development Officers were the lead persons, while the research team made observations, listened and took notes. The study also reviewed secondary data mainly from, the Malawi Meteorological Service Office, the National Statistical Office, the Department of Agricultural Research Services, the Agricultural Development Divisions, and the District Assemblies of Salima and Machinga.

Figure 2.2: Female farmers in a group drawing seasonal calendars, at Nawanga.

Figure 2.3: Male farmers drawing a resource map of Nawanga Village

2.2.4 Data analysis

The primary data collected in this study was analysed using non-parametric statistics and summarised into averages or percentages, using the SPSS 15.0 computer software (SPSS, 2006). Single-list scoring-based ranking suggested by Matata et al. (2001) was used to rate problems in rice production. Single list weighed category-based scoring (Matata et al., 2001) was adopted to rank traits that farmers would prefer in rice varieties.

2.3 Results

2.3.1 Socio-economic situation of farmers

A prominent geographical feature of Liundi is the Chikala Hills to the north of the village. The Naminyala River runs from the Chikala Hills into the Naminyala dambo in the middle of the village and emerges to the south and out of the village. The Naminyala “dambo” is seasonally flooded during the wet season especially from the onset of rains in mid-November up to the end of January. All the rice fields are in this dambo, and rice is the only crop that can be grown during the wet season as all other crops do not tolerate the flooded conditions. The dambo does not dry out hence there is enough moisture and farmers grow vegetables in the dry season.

An outstanding geographical feature in Nawanga village is the Lake Malawi to the east of the village. Open-water fishing from the Lake was of great significance on two accounts. Firstly, fishing was the second most important source of livelihood after rice farming. Secondly, men did not participate in farming but instead concentrated on fishing. In Nawanga village, therefore, rice and indeed any crop farming is exclusively done by women. Rice variety development in Malawi based on participatory plant breeding must deliberately emphasize women participation.

Most of the land used for smallholder farming is under customary land tenure in Malawi (Chirwa et al., 2006). This study found that all the land in the two study sites was held or occupied under customary law, confirming the findings by Chirwa et al. (2006). The land security is informal and rights on disposal are restricted. The results showed that 80% of the farmers in the two rainfed rice growing areas had less than 1.0 ha of land (Table 2.2). Alwang and Siegel (1999) indicated that 70% of the smallholder farmers in

Malawi owned less than 1.0 ha of land, which was close to the findings in this study than the 1999 national estimate of 55% (GOM, 2002). The average land size for farmers in the two study sites was calculated to be 0.6ha for each household, and this was similar to the figure reported by Alwang and Siegel (1999). The mean rainfed rice yields were estimated to be 1 410 kg ha^{-1} in 2006 (GOM, 2007), therefore, each household harvested about 846 kg of rice from average of 1.6 ha or even less since other crops were also planted. It is exciting to imagine that a mean average yield of 2 500 kg ha^{-1}, by way of high yielding varieties, would suggest a harvest of 1 500 kg per household.

Table 2.2: Landholding size per household in the two study sites, Liundi (n=103) and Nawanga (n=87)

Land holding size (ha)	Liundi % respondents	Nawanga % respondents
0 – 0.5	43	32
0.5 – 1.0	41	51
1.0 – 1.5	7	9
1.5 – 2.0	1	2
>2.0	8	6

2.3.2 Farming systems and livelihoods

The results from this study showed that across the two sites the predominant crop was rice which occupied 49% of the area (Table 2.3). The second predominant crops across sites were maize and root crops (cassava and sweet potatoes) both occupying 18% of the farming area. Individual site analysis, however, showed that maize was second to rice in Liundi while root crops were second to rice in Nawanga. The implication of this finding is that promoting rice growing in different areas must take into account the competing crop which may vary in different areas. The study found that rice was the only crop grown as a pure stand, while all other crops could be grown in pure stands or in mixtures. The popular mixed crop patterns were maize and legumes, and maize and root crops. The legumes grown in mixture with maize included common beans, groundnuts, pigeon peas and garden peas in Liundi, and soybean only in the sandy soils of Nawanga. Other crops grown in the two villages are vegetables and fruits.

Table 2.3: Crops grown by farmers in Liundi and Nawanga Villages

	Village		
	Liundi	Nawanga	All
Crops grown		Area %	
Rice	42	56	49
Maize	27	8	17.5
Roots	13	23	18
Maize/Legumes	9	1	5
Maize/Roots	7	2	4.5
Other [a]	2	10	6
Total	100	100	100

[a] Source: Salima and Machinga Agricultural Development Divisions Crop Estimates for 2006/07 Season.

In the two study sites, rice was the fundamental crop of farmers' livelihoods. In focus group as well as general discussions rice was mentioned as the centre of the farming system and also the major food and cash crop (Table 2.4). While the farmers in Liundi had ten crops as food crops, the farmers in Nawanga had only four. Farmers in Liundi also had more crops as sources of cash than the farmers in Nawanga (Table 2.4). This stark difference can possibly be explained by the fact that Liundi village is situated in a favourable plateau ecology than Nawanga village which is in the rift valley ecology (Figure 2.1; Table 2.1). Petty trading and "ganyu" were the common off-farm sources of income in the two sites. Fishing was the major off-farm income activity in Nawanga village.

Table 2.4: Farming systems and livelihoods of Liundi and Nawanga Villages

Village	Farming system	Major food crops	Major cash crops	Major livestock	Main off-farm activities
Liundi	Maize, rice	Rice, maize, sorghum, millets, cassava, beans groundnuts, pigeon peas, sweet potatoes, pumpkin	Rice, cassava, vegetables, cowpeas, pigeon peas	Goats, chickens	Brick-making, selling firewood, ganyu, beer brewing, petty trading
Nawanga	Rice, cassava	Rice, maize, sweet potatoes, cassava	Rice, sugarcane	Cattle, chickens	Fishing, petty trading, selling thatch, ganyu, remittances

2.3.3 Rice production

The observations in this study were that rice was grown in low-lying fields with sandy loam to clay soils that were poorly drained. These soils are typical of the rainfed rice growing areas in Malawi (Dzowela, 1984) and the poor drainage is a challenge to develop varieties that can withstand prolonged periods of submergence. The seasonal calendar for rainfed rice involved many activities that spanned a period of nine months starting from September up to May. Land was ploughed by hand between September and November, although farmers admitted that ploughing in June or July would be good because the soil would still be moist and easy to work. Rice sowing started at the onset of the rains (mid-November in the southern parts of Malawi which includes Liundi, up to the end of December in central Malawi including Nawanga). Seed was either sown directly into the field by broadcasting or drilling, or sown on to nursery beds for random transplanting a month afterwards. Subsequent activities in rice farming included weeding, applying fertilizer, and bird-scaring. Rice was harvested between mid-May and the first week of June. All farm operations were done by hand, and hand tools used included hand hoes, pangas, slashers and sickles for harvesting. Respondents in Liundi and Nawanga described rice farming as laborious and very expensive and said that they were faced with constraints, such as proliferation of weeds and high cost of inputs, which made rice farming less attractive.

2.3.4 Production constraints in rainfed rice

Farmers highlighted a range of production constraints in rainfed rice that, if alleviated would probably result into yield improvements. The farmers' perceptions, from a total of 190 respondents in the two study sites, are shown in Table 2.5. The first production constraint was the use of low yielding varieties. The traditional varieties that farmers used are low-yielding cultivars, with average yields of only 1.2 t ha^{-1} under farmer conditions. The second production constraint mentioned by farmers was weed infestation in their fields. Many farmers weeded their rice crop once and only very late after the plants had already been affected. The most difficult weed, locally called Nadanga, was identified as *Echinochloa species* which is not easy to distinguish from young rice seedlings.

The third constraint that limited rice production in the study sites was the absence of extension services. Other important constraints were absence of implements, drought, and the high cost of farm inputs particularly inorganic fertilizers. The last three constraints that may be of lesser importance were flooding, absence of farmer clubs, and insect pests.

Table 2.5: Farmers' perception of major constraints to rainfed rice production in Liundi and Nawanga.

Perceived constraint	% of respondents (n=190)
Unsuitable varieties	84
Proliferation of weeds	60
Absence of extension service	52
Absence of mechanical implements	48
Drought	42
High cost of inputs	42
Damage from wild animals	35
Inability to access credit	33
Non-profitable markets	23
Poor quality seed	23
Floods	20
Weak farmers' organization	10
Insect pests	7

2.3.5 Ranking of production constraints by key I\informants

A group of ten key informants in each village ranked the list of major production constraints, and the results are presented in Table 2.6 for Liundi village and Table 2.7 for Nawanga village. In Liundi village the matrix scoring and ranking identified unsuitable varieties, proliferation of weeds, and absence of extension advice as the top three constraints. In Nawanga village, the top three constraints were identified as unsuitable varieties, absence of extension services, and damage from wild animals for example birds and hippopotamuses. Among the identified constraints the use of unsuitable varieties would be the target for intervention by the rice breeding programme in Malawi.

Table 2.6: Single list scoring-based ranking of problems in rice production by key informants in Liundi village.

Problems identified	Key informants										Total score	Ranking
	1	2	3	4	5	6	7	8	9	10		
Absence of mechanical implements	1	0	1	0	2	1	0	1	0	1	7	5
Drought	0	0	1	2	0	0	1	0	0	1	8	6
Insects	0	0	0	0	1	0	1	1	0	0	3	9
High cost of inputs	2	3	2	1	0	1	0	0	2	1	14	4
Absence of extension service	2	1	2	0	1	0	2	3	4	1	16	3
Poor quality seed	0	0	1	1	0	0	1	0	0	1	4	8
Proliferation of weeds	3	2	1	1	2	1	3	2	0	2	17	2
Floods	0	2	0	1	1	1	0	0	0	0	7	7
Unsuitable varieties	1	1	1	3	2	5	1	2	3	2	21	1
Number of stones	9	9	9	9	9	9	9	9	9	9	90	

Table 2.7: Single list scoring-based ranking of problems in rice production by key informants in Nawanga village.

Problems identified	Key informants										Total score	Ranking
	1	2	3	4	5	6	7	8	9	10		
Absence of mechanical implements	1	0	1	1	0	1	0	1	0	1	6	6
Access to credit	1	2	1	3	1	1	2	1	2	1	15	4
Red rice	0	1	0	1	0	1	1	0	1	2	7	7
Absence of extension service	3	2	1	2	3	1	2	1	2	1	18	2
Drought	0	0	2	1	1	1	0	0	1	1	7	8
Unsuitable varieties	4	1	3	2	2	3	3	2	1	2	23	1
Proliferation of weeds	0	0	1	0	1	1	0	0	0	1	4	11
Damage from wild animals	2	2	1	1	3	1	2	1	1	1	15	3
Non-remunerative markets	1	1	2	1	0	2	2	2	1	1	13	5
“Solomon” fish	0	0	0	0	0	0	0	1	1	0	2	12
Weak farmers’ organization	0	1	0	0	0	0	0	2	1	1	5	9
Poor quality seed	0	2	0	0	1	0	0	1	1	0	5	10
Number of stones	12	12	12	12	12	12	12	12	12	12	120	

2.3.6 Rice cultivars grown

The results of the study revealed that the varieties grown by farmers, in the two study sites under rainfed conditions, were traditional landraces. These are collectively known as *Faya*, a name that has no known meaning, except that it might be a Bantu term of Swahili origin. *Faya* is also the name used to describe some local varieties in Tanzania, and the variation of the name is *Faia* in Mozambique. Within the two study sites, farmers gave various vernacular names to these landraces which had striking phenotypic similarities in grain size and aroma. The names, mentioned by farmers in both villages, included *Faya Kachulu* (named after an area in Salima), *Faya Khanda* (named after Khanda irrigation scheme in Zomba), *Hali ya Bibi* (Swahili for health of the lady), *Faya Mozambique* (the landrace came from across Lake Malawi), *Zambia* (a cultivar from Mchinji district bordering Zambia), *Kanchikope* (winged grains), *Chimdima* (referring to black colour of grain hull), and *Kilombero* (a pure line released variety).

2.3.7 Ranking of traits preferred in rice varieties

Farmers were knowledgeable about the local landraces' prominent desirable and undesirable traits which are listed in Table 2.7 for Liundi village and Table 2.8 for Nawanga village. The list indicated that the landraces possessed traits such as large grain size and aroma that farmers were satisfied with. On the other hand, there were traits such as drought susceptibility and long maturity period that farmers did not want. There are other characters, for example tall plant height, grain shattering, and photoperiod-sensitivity, were both desirable and undesirable. It would seem that a high yielding ideal variety would have to have some of the following traits:

- Medium plant height
- Disease resistance
- Large and slender grain
- Aromatic grain that spreads when cooked
- Early maturity
- Drought tolerance
- Submergence tolerance
- Profuse tillering.

Table 2.8: Lists of desirable and undesirable traits in farmers' varieties and reasons for the choice, Liundi and Nawanga villages.

	Reason specified by respondents in Liundi	**Reason specified by respondents in Nawanga**
Desirable traits		
Tall plant height	Weeds are suppressed	Easy to harvest panicles; suppresses weeds
Grain shattering	Easy to thresh	Easy to thresh
Disease resistance	Landraces are not attacked by diseases	Not listed
Photoperiod-sensitivity	Plants flower by third week of March irrespective of time of planting	Plants flower irrespective of time of planting
Long and slender	Preferred by consumers and farmers	Preferred by consumers; attractive to the eye
Big and white	Preferred by consumers and farmers	Preferred by consumers and farmers
Aromatic	Demanded by traders and liked by consumers	Demanded by traders and liked by consumers
Spreads at cooking	Is not sticky, therefore preferred when eating (by hand)	Is not sticky, therefore preferred when eating (by hand)
Undesirable traits		
Tall plant height	Not given	Liable to fall over when there are strong winds
Weak culm/lodging	Forced to bend too low when harvesting	Forced to bend too low when harvesting
Low tillering	Less grains per planting station	Less grains per planting station; less straw for thatch
Grain shattering	Loss of grain after falling to the ground, especially serious when birds land on panicles	Not given
Susceptibility to drought	Plants do not recover with a drought period of even one week	Plants do not recover with a drought period of even one week
Inability to withstand submergence	One week of submergence kills seedlings, especially if the weather is hot	One week of submergence kills seedlings, especially if the weather is hot
Photoperiod-sensitivity	Plants will not tiller when planted last week of March	Not given
Long duration	Takes too long to harvest if planted in December	Takes too long to harvest if planted in December
Awnlessness	Does not deter birds therefore prone to damage	Does not deter birds therefore prone to damage
Low yield	(Not well articulated)	(Not well articulated)

The desired traits listed above were prioritized, by the key informants in each area, and the results of the six top ranked traits are presented in Table 2.5. In both areas, aroma and large grains were ranked the top two traits that were desired in varieties. Early maturity and medium height were the third or fourth ranked traits by respondents at Liundi or Nawanga. The other preferred traits were drought tolerance, heavy panicles and profuse tillering.

Table 2.9: Single list weighed category-based scoring of preferred traits in rice varieties from focus groups at two study sites

Trait	Number of key informants reporting			Total score	Total weighted score	Ranking
	Most important Weight=3	Second most important Weight=2	Third most important Weight=1			
			Liundi village			
Aroma	5	0	0	5	15	1
Early maturity	2	2	0	4	10	3
Large grains	3	1	1	5	11	2
Drought tolerance	0	1	0	1	4	5
Medium height	1	2	1	4	8	4
Heavy panicle	0	1	0	1	2	6
			Nawanga village			
Aroma	6	0	0	6	18	1
Large grains	3	2	1	6	14	2
Medium height	1	2	0	3	7	3
Profuse tillering	0	1	0	1	2	6
Early maturity	0	2	0	2	4	4
Drought tolerance	0	1	1	2	3	5

2.4 Discussion

2.4.1 Rice production and constraints

Informal and unpublished surveys (Chirwa et al., 2006) identified six constraints to increased irrigated rice production in Malawi. The constraints were: 1) proliferation of weeds, 2) high cost of fertilizer, 3) damage caused by wild animals, 4) non-profitable markets, 5) use of poor quality seed and 6) poor drainage. This study has confirmed that similar constraints are perceived by farmers as barriers to increased rainfed rice production. In addition this study has also identified constraints specific to the rainfed ecosystem. The major constraints in the rainfed ecosystem include proliferation of weeds, absence of agricultural extension services, absence of mechanical implements, and use of low yielding landraces. Weeds were prioritized as the second most important constraint. Field observations during transect walks indicated that the most serious weed types were grasses, The most common one was barnyard grass (*Echinochloa* species), *Mpungadziwe* in vernacular. *Mpungadziwe* translates into "rice of the pond", which aptly identifies this weed that is highly adapted to water (Cesar et al., 1993).

The study revealed that the agricultural extension service was not very effective in advising farmers on rice production. The farmers in Nawanga area indicated that they had never been contacted by extension officers in the past 20 years. Agricultural extension officers apparently made visits to Liundi but they delivered messages on maize. According to NSO (2005), only 13.1% of smallholder households in Malawi had received advice from extension staff in the 2005 crop growing season. That study found that only one percent of farmers in Mulanje district received extension advice on any food crop. The access to extension was highest for Chitipa district at 45%. The erosion of extension services was also evident in cash crops as reported by Chirwa and Kydd (2005) who found that the collapse of the extension services had contributed to the low productivity among smallholder tea farmers. The implication of this situation is that even if a high yielding rainfed rice variety were developed, the impact would be insignificant in the absence of support from the extension service.

The study showed that farmers did not use any mechanical implements in rainfed rice farming. The use of hand implements in all the farming operations was drudgery that contributed to low productivity in rice. The absence of implements is closely associated with the other constraints namely weak farmers' organization, access to credit, and non-profitable markets. If farmers were organized, into clubs for example, they could perhaps attract or negotiate loans from various organizations. They could also bargain for higher prices for their rice which could results in higher returns from rainfed rice farming.

The findings from this study showed that the use of low-yielding landraces was the principal constraint to increased production in rainfed rice. This constraint is the challenge to rice breeders in Malawi, and is the best opportunity for rice breeders to raise the productivity of rainfed rice. Some notable traits that contributed to low potential yield of these varieties included tall plant height, low tillering ability and late maturity. Late maturity is linked to photoperiod sensitivity of the rice varieties that rainfed farmers in Malawi use. Malawi rice landraces are photoperiod sensitive, similar to the reaction of other traditional rain-fed cultivars (Mackill et al., 1996). Photoperiod sensitivity refers to the flowering reaction of a plant to the period of sunshine, the day-length. Rice is generally a short-day plant in which long day-lengths delay flowering while short day-lengths accelerate flowering (De Datta, 1981). In addition, the Malawi rice landraces are 'date fixed' because they have a set flowering date within the season (Grist, 1975). Therefore, early planting extends the growing period of the landraces. The response from farmers in this study was, however, not conclusive because they listed photoperiod sensitivity as desirable and undesirable.

2.4.2 Variety trait preferences

Aroma is a distinct characteristic of Malawi rice landraces. According to Bradbury et al. (2005) the aroma of rice is associated with the presence of a chemical compound called 2-acetyl-l-pyrroline (2-AP). This compound is found in Basmati and Jasmine, the aromatic rices of India and Pakistan (Widjaja et al., 1996). It is very probable that the same compound is responsible for the aroma in Malawi rice landraces. The 2-AP is controlled by a recessive gene that has been mapped to chromosome 8 of rice (Bradbury et al., 2005). This trait is preferred by consumers and therefore guarantees that farmers will sell their produce, although not always at a premium price. Farmers did indicate that a 50 kg bag of aromatic rice would be sold for 100 Malawi Kwacha (MK) per kg, while a bag of non-aromatic rice would be sold for 70 Malawi Kwacha per kg (MK140 equivalent to US$1 in 2006). Breeding for aroma is tricky because of the recessive nature of the gene and also the difficulty of assessing the aroma of individual grains of rice (Champagne, 2008). However, selecting for aroma would be easy because genetic markers for the aroma gene have been developed by several workers including Jin et al. (2003) and Cordeiro et al. (2002). Associated with aroma, as part of grain quality, was the preference for rice that takes a long time to cook, and spreads after cooking, thus rice grains with intermediate gelatinization temperature or non-sticky rice. While non-stickiness is preferred in Malawi, most consumers in Bangladesh prefer sticky rice (Dipti et al., 2003). The amount of time it takes for rice to cook is photometrically determined by the gelatinization temperature as low (<70 °C), intermediate (70-74°C), and high (>74°C). Alternatively, gelatinization temperature can be estimated by the alkali digestion value (ADV) and classified as low (6-9), intermediate (4-5), intermediate (3), and high (1-2) (Faruq et al., 2004; McKenzie and Rutger, 1983).

The responses by farmers in this study indicated the preference for high gelatinization temperature. Therefore, one of the breeding objectives would be to select for intermediate to high gelatinization temperature. And it would appear that the Malawi landraces have intermediate to high gelatinization temperature, similar to most traditional varieties in Southeast Asia (Khush and Juliano, 1985). The inheritance of gelatinization temperature is probably governed by major genes, with high gelatinization temperature dominant over low gelatinization temperature (Chang and Somrith, 1979).

The second preferred trait was large grain size which is mainly determined by the weight of 1000 grains, but also includes the grain length, and the grain shape or length to width ratio (Tan et al., 2000). These grain traits are quantitatively inherited and breeding or selecting for these is complicated because of the effect of the cytoplasm and endosperm (Koutroubas et al., 2004; Shi et al., 2000). A breeding programme for these grain size traits would utilize conventional methods since they are easy to score for.

Other preferred traits revealed by this study were medium height (or semi-dwarf height), early maturity, and photoperiod insensitivity. Semi-dwarf height and early maturity are two of the morphological traits that have been built into the high yielding varieties in crops such as rice and wheat (Fageira et al., 2006). Plant breeders at the International Rice Research Institute combined semi-dwarf height, early maturity and photoperiod insensitivity, among other traits, into new improved varieties (Yoshida, 1981). The most famous of the varieties were IR8, IR20 and IR22. These varieties produced a record 11 t ha^{-1} and were some of the varieties responsible for the “Green Revolution” in Asia. A breeding programme that can develop rainfed rice varieties combining the farmer preferred traits of large aromatic grains has the potential to increase rice productivity in Malawi.

Semi-dwarf height confers lodging resistance in varieties. Lodging causes great losses in both grain quantity and quality. Furthermore, lodging results into difficulties in harvesting and increases demand for grain drying, and consequently results in increased production cost. In this study, farmers also indicated preference for tall plant height because, they said, tall varieties help to suppress weeds. Early maturing rice escapes late season drought that normally occurs in March of each year. The farmers said that although they could grow rice in the dry season, they preferred vegetables. The reason was that the long duration rice varieties being used did not fit into the four month dry season between July and October. Varieties of shorter duration, 110 days to maturity for example, would enable farmers to grow rice twice a year.

Early maturity trait is closely associated with drought tolerance that farmers indicated as another preferred trait. These contrasting preferences imply that breeding objectives will be opposing. However, breeding for semi-dwarf stature would be recommended, with the hope that appropriate weed control technologies would be developed in order to increase yield. Fortunately, photoperiod sensitivity is easy to select for in a breeding program. A technique used for selection among breeding lines for the irrigated ecosystem at Lifuwu Research Station eliminates photoperiod sensitive populations simply by planting any generation in the off-season in June. Any photoperiod sensitive population will not flower, and therefore will be eliminated. By contrast, a photoperiod insensitive population will flower and therefore will be advanced to the next generation. By adopting a similar technique, either photoperiod sensitive or photoperiod insensitive cultivars could be developed for the rainfed ecosystem.

2.5 Conclusions and implications for breeding

This PRA study revealed that farmers faced many challenges in rainfed rice farming. The farmers knew the major constraints that contributed to low rice production. The constraints included use of low yielding traditional varieties, proliferation of weeds, absence of extension advice, and high cost of inputs. The farmers recognized that the use of traditional varieties was the largest contributory factor among the production constraints. They described these traditional varieties as possessing desirable traits of large grain size, aromatic grain, and grain that separates when cooked. On the other hand, they also described that the varieties' undesirable traits were intolerance to drought and susceptibility to lodging. The varieties were also described to be tall and photoperiod-sensitive but these traits were not clearly categorized as positive or negative. Among several interventions, the farmers agreed among themselves that introducing new high yielding varieties would lead to achieving higher yields than the average yields of 1.2 t ha^{-1} for the traditional varieties.

The farmers were willing to use new high yielding rice varieties but that such varieties would have to have large grains with aroma and not sticky when cooked. Witcombe and Virk (1997) discussed that when choosing which varieties to grow, farmers consider not only the yield but other traits that may add value to their crop. Many breeding programmes do not take into account these other traits at the start of development of varieties. Instead breeders opt to assess the other traits in later generations of breeding, often near to release of the varieties. As a result these varieties do not meet the requirements of farmers (Tripp et al., 1997) hence either adoption is low, or they do not adopt them at all. This study has revealed that for any high yielding varieties that rice breeders in Malawi hope to develop, farmers will assess those varieties for large grain size and grain quality, among other traits.

In line with the observations above, this participatory rural appraisal confirmed the importance of considering the farmers' preferred traits in order to develop varieties that will have a high adoption rate. This means that any future rice breeding and selection strategy, targeting the rainfed ecosystem in Malawi, must put emphasis on grain size and grain quality, in addition to high yield. In this regard, and as a first step, there is need for rice breeders in Malawi to know the genetic behaviour of these farmer preferred traits in the traditional rice varieties. This study was a quick and effective method that was used to assess the situation of representative rainfed rice farmers in Malawi, to identify production constraints, and to know the traits preferred in rice varieties.

The study may not have captured all the traits that farmers prefer across the rainfed rice ecosystem of Malawi so there is need to gather additional information or data using quantitative methods and to include more study sites that represent rice growing areas in Malawi. This study also captured environmental and socio-economic differences between the two study areas that were chosen to represent the rainfed rice growing areas in Malawi. The significance of this is that any future participatory rice breeding must target more farmers in more areas. In conclusion, results of this survey identified the production practices, production constraints, farmers' preferences and uses of rice which are important baseline information guide to formulate excellent and farmer-oriented breeding objectives.

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Chapter 3: Genetic Variability for Yield Related Traits in Malawi Rice (*Oryza sativa* L.) Landraces

Abstract

Traditional rice varieties or landraces are adapted to the rainfed conditions in Malawi, and are preferred by both farmers and consumers. However, no studies had been conducted on the landraces to determine the extent of variability for and the inheritance of yield related traits. This study was conducted to determine genetic variability for eight yield related traits, and to estimate the heritability and correlations among the traits. The traits were plant height, days to 50% flowering, number of panicles per hill, panicle length, number of filled grains per panicle, 1000-grain weight, panicle weight, and grain length. A total of 19 landraces, collected from farmers' fields in the rice growing areas in Malawi between 1997 and 2005, were planted at Lifuwu Research Station in Malawi in 2005/2006 crop season in a randomized complete block design with three replications. A released variety was included as a check. Differences between genotypes were significant (P=0.05) for all the traits that were studied except for grain length. The highest genotypic coefficient of variation of 22.9% was obtained for panicles per hill, which also showed the highest phenotypic coefficient of variation of 57.4%. Heritability estimates were generally low to moderate, ranging from 18.3% for panicle weight, through 40.0% for panicles per hill, to 56.3% for days to 50% flowering date. The highest genetic advances were 46.9% for panicles per hill, 27.4% for yield per hill, and 18.3% for 1000 grain weight. The conclusions from this study are that: 1) there was high genetic variability among the landraces, and the variability could be used in a breeding programme to develop improved varieties for morphological traits; 2) panicles per hill and 1000-grain weight had moderate heritability and relatively high genetic advance compared to the other traits and therefore they could be reliable traits to for yield improvement; 3) panicles per hill had positive and significant (P=0.01) correlations with yield per hill and therefore could be a reliable trait to use to indirectly select for high yielding breeding lines.

Keywords: Rice, Landraces, Genetic variability, Heritability, Genetic advance.

3.1 Introduction

Traditional rice varieties or landraces are adapted to the areas where they are found or grown (Li et al., 2004). The landraces constitute a rich source of rice biodiversity (Mohapatra et al., 2004) and are important reservoirs of valuable traits which can be utilized in developing new varieties (Hanamaratti et al., 2008). Landraces are often adapted to a variety of agro-ecological zones (Mohapatra et al., 2004), most of which are marginal environments. Marginal environments for rice include the drought prone upland ecologies, swamps and flood-prone areas, and all rainfed areas in general. The introduction of modern high yielding rice varieties has made the landraces unpopular among some farmers (Li et al., 2004) to the extent that some landraces have been replaced (Mohapatra et al., 2004). Landraces are still grown in approximately 50% of the rainfed rice areas in Asia largely because they tolerate stresses and have favoured grain quality (Li et al., 2004). Mohapatra et al. (2004) reported that landraces are still grown by resource-poor farmers of Orissa in India. Although undocumented, it is estimated that 80% of the rainfed rice area in Malawi is grown to landraces.

Appa Rao et al. (2002) warned of the danger of genetic erosion of many traditional rice varieties in Laos due to widespread adoption of modern varieties by farmers. Joshi and Witcombe (2003) argued that introducing modern varieties into areas that are predominated by landraces results into an increase in allelic diversity. However, the increase in allelic diversity would still result in loss of some landraces over time. Joshi and Witcombe (2003) studying the impact of participatory plant breeding (PPB) on rice landrace diversity in Nepal found that modern rice varieties occupied 21% of hitherto landrace land overtime after introduction.

Agnihotri et al. (2006) collected 30 rice landraces from a village in Kumaun in Indian central Himalaya. They used three different concentrations of sodium chloride as salinity stress levels to screen the landraces. They found that the landraces possessed salinity tolerance that could be useful to develop new varieties. Gomez and Kalami (2003) studied variability for root characters and yield-related traits in 11 rice landraces grown by farmers in Madurai, Tamil Nadu region of India and they found high variability for all the ten traits studied. They singled out plant height, panicles per plant, and yield per plant as the traits to use during selection because these traits had high heritability as well as high genetic advance. Chaudhary and Sarawgi (2002) reported that 50 rice landraces they studied differed for 19 morphological and quality traits. High genetic variability was also observed for eight yield components in 53 rice landraces from Gorkha and Tanahun districts in Nepal by Joshi and Witcombe (1997).

Fukuoka et al. (2006) successfully used random amplified polymorphic DNA (RAPD) markers to narrow down a sample of 320 aromatic rice landraces found in the Namdinh Province in Vietnam to 38 distinct genotypes. In the same study Fukuoka et al. (2006) compared variability of genotypes between populations in farmers' fields and a duplicate set grown 'on-station" and found that variability decreased in the "on-station" population, suggesting that genetic drift had occurred. Sarma and Bahar (2005) used RAPD markers and found considerable variability among 23 rice landraces they collected from farmers' fields in three villages in Assam, India. In other crops RAPD markers have also been used to study variability (Shoaib and Arabi, 2006; He Xue et al., 2006; Yamanaka et al., 2006). Mohapatra et al. (2004) used sequence-tagged microsatellite site (STMS) markers to check if two landraces were genetically different from commercial high yielding varieties in Orissa region of India. They generated DNA profiles based on 48 mapped STMS markers and found that there was a high degree of genetic diversity between the two groups. The commercial varieties were genetically uniform, while the landraces were found to be heterogeneous (Mohapatra et al., 2004).

In Malawi, conventional plant breeding methods are used to make single crosses between landraces and modern high yielding varieties from the International Rice Research Institute in Philippines. Up till now, the breeding was aimed at developing varieties for the irrigated ecosystem. However, the largest rice ecosystem is rainfed, with a share of 80% of total rice area, has been neglected. Developing high yielding varieties for this ecosystem can increase national rice productivity, currently estimated to be 1.2t ha^{-1}. The success of any planned rice breeding programme depends on both the magnitude of variability and the heritability of characters (Vanaja and Babu, 2006). This study was undertaken to determine the variability in Malawi rice landraces for selected agronomic traits on the premise that there is highly heritable genetic variation which could be exploited in a breeding programme to develop high yielding varieties that farmers would adopt. The specific objectives of the study were 1) to find out if genetic variability exists in the landraces and, 2) the amount of that variability which is heritable, in order to design appropriate breeding and selection strategies that will best exploit any variability found and to create farmer-preferred varieties.

3.2 Methodology

Location of study

The experiment was conducted at Lifuwu Research Station under rainfed conditions with supplemental irrigation. The location of the station is latitude 13^{o} 40’ S and longitude 34^{o} 35’ S at 500 m altitude. The station receives annual average rainfall of 1 253 mm, and highest and lowest annual temperatures are 29.7 ^{o}C and 20.4 ^{o}C, respectively, with annual mean temperature of 25.1 ^{o}C. The soils of the station were described by Sistani et al. (1998) as Vertisols of 45% clay with average pH 8.3 and 1.6% organic matter.

Germplasm

Nineteen landrace accessions were selected from among fifty that are an active collection held at the Lifuwu Research Station in Salima. The active collection is a subset of 192 Malawi rice landrace accessions collected by the International Plant Genetic Resources Institute (IPGRI) in 1978, by ORSTROM in 1980 (Appa Rao, 1980) and by the Malawi Plant Genetic Resources Centre in 1997. Geographically these active accessions cover longitudes from 33^{O} to 36^{O} E and latitudes 9^{O} 20$^{'}$ to 17^{O} 10$^{'}$ S. The landraces, as females, have been routinely crossed to IRRI introductions in hybridization breeding to develop high yielding varieties for the irrigated ecosystem in Malawi. Based on that work it is known that the landraces are photoperiod sensitive and have aromatic grain, although the magnitude of both characteristics has not been studied. The accessions are listed in Table 3.1 below. In addition to the 19 landraces, Kilombero, a released pure line selection, was also included in the experiment.

Table 3.1: List of landraces of rice utilized in the present study, and where they were collected in Malawi.

Landrace name	District of collection	Longitude E	Latitude S
Zambia	Karonga	$33^{o}\ 45^{'}$	$9^{o}\ 40^{'}$
Mwansungo	Karonga	$33^{o}\ 00^{'}$	$10^{o}\ 00^{'}$
Mwangulu	Karonga	$34^{o}\ 05^{'}$	$10^{o}\ 15^{'}$
Manda	Nkhata Bay	$34^{o}\ 00^{'}$	$11^{o}\ 40^{'}$
Strain Faya	Nkhata Bay	$34^{o}\ 15^{''}$	$12^{o}\ 00^{'}$
Kota Kota	Nkhota Kota	$34^{o}\ 15^{'}$	$12^{o}\ 50^{'}$
Faya Zidyana	Nkhota Kota	$34^{o}\ 15^{'}$	$13^{o}\ 00^{'}$
Faya Kachulu	Salima	$34^{o}\ 35^{'}$	$13^{o}\ 40^{'}$
White Faya1	Salima	$34^{o}\ 35^{'}$	$13^{o}\ 40^{'}$
Mangochi	Salima	$34^{o}\ 35^{'}$	$13^{o}\ 40^{'}$
Amanda	Mangochi	$35^{o}\ 10^{'}$	$14^{o}\ 40^{'}$
Fayala	Mangochi	$35^{o}\ 10^{'}$	$14^{o}\ 40^{'}$
Limanda	Mangochi	$35^{o}\ 10^{'}$	$14^{o}\ 40^{'}$
Chilikumwayi	Zomba	$35^{o}\ 30^{'}$	$15^{o}\ 10^{'}$
Faya Khanda	Zomba	$35^{o}\ 30^{'}$	$15^{o}\ 10^{'}$
White Faya	Zomba	$35^{o}\ 30^{'}$	$15^{o}\ 10^{'}$
Kanchikope	Mulanje	$35^{o}\ 50^{'}$	$15^{o}\ 50^{'}$
Kidney	Mulanje	$35^{o}\ 50^{'}$	$15^{o}\ 50^{'}$
Faya Mpata	Mulanje	$35^{o}\ 50^{'}$	$15^{o}\ 50^{'}$

Experimental layout and treatment

The experiment was laid out in a Randomized Complete Block Design with three replicates. Each entry was planted in plots of gross size 5 m x 3 m and net size 4 m x 2 m. The spacing between plant stations was 25 cm x 25 cm with transplanting one seedling per plant station in December, 2005. Fertilizer was applied at the rate of 80 + 50 + 25 kg per ha NPK, with half of the N and all P and K basal dressed on the day of transplanting, and the remaining half of the N 30 applied days after transplanting.

Data collection

Data on plant height, days to 50% flowering date, number of panicles per hill, panicle weight, panicle length, number of filled grains per panicle, 1000-grain weight and grain yield per hill were recorded. The data were collected on 10 plants per replicate from the middle of each net plot at plant growth stages as outlined by IRRI (2002). Plant height was measured in cm from the surface of the soil to the tip of the tallest tiller on any hill (or planting station) at maturity stage. Days to 50% flowering were counted from the day of sowing to the day when 50% of the tillers in a hill had flowered. Panicles per hill were recorded as the actual number of tillers per plant (station), including the main tiller, at booting stage. Panicle weight was obtained by weighing all the tillers at each hill and recorded in grams at 14% moisture content. Panicle length was measured in centimetres from the base to the tip of the longest panicle on each hill. The numbers of filled grains per panicle were recorded by counting all filled grains on the panicle whose length had been measured on each hill. Grain yield was recorded at maturity stage as the weight in grams per hill standardized to 14% moisture content.

Data analysis

All data collected were subjected to the analysis of variance (ANOVA) to obtain mean sum of squares for genotypes and the residual, according to Steel et al., (1997). The ANOVA model for the randomized complete block design at the one location and in the one year of this study was:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \epsilon_{ij},$$

where the term Y_{ij} is the observed value of the i^{th} genotype in the j^{th} replicate (where i=1 to 20, and j=1 to 3); μ is the grand mean; α_i is the treatment effect for the i^{th} genotype, with the genotypes assumed to be random; β_j is the block effect for the j^{th} block; β_{ij} is the random error associated with the Y_{ij} experimental unit.

For each trait, estimates calculated included means, range, standard errors, least significant differences at P=0.05, and the yield of entries relative to the mean yield. Genetic parameters were estimated by the methods of Johnson et al. (1955) which have been used recently by Karim et al. (2007). The genetic variance was calculated as the difference between the genotype mean sum of squares and the residual sum of squares, divided by the number of replicates. Phenotypic variance was calculated as the sum of genotype and residual sum of squares. The coefficient of variation for genotype (GCV) and phenotype (PCV) were obtained by dividing the square root of the appropriate variance by the mean as follows:

$$GCV = ((\sqrt{\sigma^2_g})/mean) \times 100, \text{ and}$$

$$PCV = ((\sqrt{\sigma^2_p})/mean) \times 100$$

where σ^2_g is the genotypic variance, σ^2_p is the phenotypic variance, and mean is the grand mean of the trait measured. Heritability in the broad sense was calculated as the ratio of the variances of genotype and phenotype using the formula by Johnson et al. (1955) as follows:

$$(\sigma^2_g /(\sigma^2_g + \sigma^2_p)) \times 100$$

where σ^2_g is the genotypic variance, and σ^2_p is the phenotypic variance.

The estimates of genetic advance were obtained as per following steps: the square root of the phenotypic variance was multiplied by the broad sense heritability, and the product multiplied by k=2.06, the selection differential expressed in standard deviations (Karim et al., 2007). The selection differential of k=2.06 assumed that 5% of individual plants would be selected from the population (Kearsey and Pooni, 1991). Genotypic correlation (r_g) and phenotypic correlation (r_p) were calculated for all the traits using the methods suggested by Al-Jibouri et al. (1958) and Kwon and Torrrie (1964) as follows:

$$r_g = (Cov_{XY})/\sqrt{(Var_X * Var_Y)},$$

where Cov_{XY} is the covariance of the two traits X and Y; Var_X is the variance of the trait X, and Var_Y is the variance of the trait Y.

$$r_p = (M_{XY})/\sqrt{(MS_x * MS_Y)}$$

where M_{XY} is the mean product for traits X and Y; MS_x is the mean squares for trait X, and MS_Y is the mean squares for trait Y.

The genotypic correlation, $r_{g,}$ between two traits was considered significant if the absolute value exceeded twice the standard error, which was calculated using the formula suggested by Robertson (1959). The statistical test for the phenotypic correlation, r_p, was determined by using the “t” test as described by Steel et al., (1997). All computations were accomplished using Genstat statistical software commands (Payne et al., 2007). Results are presented for the nine traits that were measured and also for grain yield per hectare converted from grain yield per hill.

3.3 Results

3.3.1 Analysis of variance

Differences between genotypes were significant (P=0.05) for seven yield related traits that were studied (Table 3.2). The traits were plant height, days to 50% flowering date, number of panicles per hill, panicle length, number of filled grains per panicle, 1000-grain weight, panicle weight. The differences between the rice landraces, and the pure line variety Kilombero, were not significant for grain length (Table 3.2).

The results of grain yield per hill showed that the highest yielding landraces were Kilombero, Manda and Faya Zidyana with 18.3, 18.1, and 18.1 g per hill, respectively (Table 3.3). Faya Khanda and Kidney landraces had the lowest yields of 10.6 and 10.5 g per hill, respectively.

3.3.2 Genetic variability

Genotypic variance (GV) and phenotypic variance (PV) results are presented in Table 3.4. Table 3.5 shows the genotypic coefficient of variation (GCV), and the phenotypic coefficient of variation (PCV). The GCV ranged from 2.10% to 21.9%, while PCV ranged from 4.78% to 57.36%. Among the traits studied, the highest GCV of 21.9% was obtained for number of panicles per hill (PPH), followed by grain yield per hill (GYPH) with 13.4%, and 1000 grain weight (TGW) with 8.8%. Among these, number of panicles per hill showed more than 50% variation at phenotypic level, while the grain yield per hill and panicle weight showed phenotypic variability of more than 30% (Table 3.4).

Table 3.2: Analysis of variance for yield and yield related traits in 20 genotypes comprising 19 Malawi rice landraces and one pure line selection

Sources of variation	**Df**	**Mean sum of squares**									
		PHT (cm)	**DTF**	**PL (cm)**	**PPH**	**FGP**	**TGW (g)**	**PWT (g)**	**GL (cm)**	**GYPH (g)**	**YHa^{-1}**
Replication	2	0.067	1.050	34.003	0.601	48.610	1.617	44.200	0.592	9.180	0.239
Genotype	19	32.817*	55.610*	9.551*	5.841*	55.900*	24.821*	32.430*	1.422	20.196*	0.515
Error	38	8.751	1.489	4.262	2.056	20.380	4.424	26.510	0.275	8.665	0.222
CV%		2.2	1.1	10.4	29.4	4.7	7.1	23.0	5.70	20.1	20.1
Variance ratio		3.75	37.36	2.24	2.84	2.74	5.61	1.22	5.18	2.32	2.32

*Significant at P=0.05; PHT=plant height (cm); DTF=days to 50% flowering; PL=panicle length (cm); PPH=number of panicles per hill; FGP=number of filled grains per panicle; TGW=1000-grain weight; PWT=panicle weight (g); GL=grain length (cm); GYPH=grain yield per hill (g); YHA^{-1}=grain yield per hectare (t ha^{-1}).

Table 3.3: Estimates of mean values for yield and yield related traits in 20 genotypes comprising 19 Malawi rice landraces and one pure line selection

Landrace	PH	DTF	PL	PPH	FGP	TGW	PW	GL	GYPH	YHa^{-1}	RY
Amanda	128.0	98	16.5	7	104	24.3	27.0	8.3	17.7	2.83	121
Chilikumwayi	137.7	107	20.7	5	93	29.3	22.0	9.6	15.7	2.51	107
F/Kachulu	134.3	108	18.6	3	95	32.0	19.0	9.9	11.4	1.82	78
F/ Khanda	136.3	108	18.1	4	98	31.7	17.5	9.5	10.6	1.69	72
Faya Mpata	126.0	97	16.8	7	103	24.7	27.7	8.3	16.6	2.65	113
F/Zidyana	137.0	109	21.3	5	94	28.3	22.3	8.3	18.1	2.90	124
Fayala	136.3	109	21.0	5	95	30.3	21.0	9.7	14.6	2.33	100
Kanchikope	134.0	108	22.0	6	95	30.7	23.0	9.4	13.3	2.12	91
Kidney	134.3	108	22.2	3	94	28.7	22.7	9.9	10.5	1.68	72
Kilombero	142.0	109	21.7	6	94	33.7	23.7	10.3	18.3	2.93	125
Kota Kota	133.7	109	20.3	4	92	30.0	20.3	9.0	15.4	2.47	106
Limanda	134.0	98	17.5	7	104	24.7	26.3	8.3	17.4	2.79	119
Manda	134.0	98	17.3	8	103	24.7	28.0	8.8	18.1	2.90	124
Mangochi	144.7	108	19.2	3	94	28.3	23.0	9.6	15.0	2.40	103
Mwangulu	134.7	108	21.7	3	93	31.0	19.3	9.3	15.9	2.54	109
Mwansungo	136.7	108	20.3	4	94	32.3	18.3	8.7	11.7	1.87	80
Strain Faya	136.7	108	21.1	4	95	31.7	19.9	8.5	13.5	2.16	92
White Faya	136.7	109	19.4	4	90	32.3	26.7	10.5	13.9	2.22	95
White Faya1	135.3	109	19.7	5	94	29.3	21.7	10.1	12.9	2.07	88
Zambia	135.3	109	20.2	5	91	31.3	18.7	8.6	12.2	1.95	83
Mean	134.2	106	19.7	5	96	29.0	22.0	9.3	14.6	2.34	
SE ±	1.7	0.7	1.2	0.8	2.6	1.2	3.0	0.3	1.7	0.27	
LSD (P=0.01)	3.8	1.9	3.7	3.1	6.4	3.3	7.4	0.7	5.8	0.87	

PHT=plant height (cm); DTF=days to 50% flowering; PL=panicle length (cm); PPH=number of panicles per hill; FGP=number of filled grains per panicle; TGW=1000-grain weight; PWT=panicle weight (g); GL=grain length (cm); GYPH=grain yield per hill (g); YHA^{-1}=grain yield per hectare (t ha^{-1}), RY=relative yield.

Table 3.4: Population mean (Mean), range, genotypic variance (GV), phenotypic variance (PV) and error variance (EV) for yield related traits in 20 genotypes comprising 19 Malawi rice landraces and one pure line selection.

Characters	Mean±SE	Range	GV	PV	EV
Plant height (cm)	134.8±1.7	125-144	8.02	41.57	8.75
Days to 50% flowering	106.3±0.7	96-110	18.04	57.10	1.49
Panicle length (cm)	19.7±1.2	16-28	1.75	13.18	4.26
No. of panicles per hill	4.9±0.8	2-8	1.26	7.90	2.06
No. of filled grains per panicle	96.0±2.6	83-109	11.84	76.28	20.38
1000-grain weight (g)	29.5±1.2	23-34	6.80	29.24	4.42
Panicle weight (g)	22.4±3.0	11.8-32.0	1.97	58.94	26.51
Grain length (cm)	9.3±0.3	7.8-11.8	0.38	1.69	0.28
Yield per hill (g)	14.6±1.7	7.6-21.7	3.84	28.86	8.67
Yield per ha (t)	2.34±0.27	1.68-2.93	0.10	0.74	0.22

3.3.3 Heritabilities and genetic advance

Heritability in a broad sense (H^2) and genetic advance in percent of the mean (GAM) for the characters that were studied are presented in Table 3.5. The heritability estimates in a broad- sense (H^2) were generally low for all the traits in the landraces (Table 3.5). Among the traits, the highest estimates were obtained for days to 50% flowering (DTF), followed by 1000-grain weight and grain length. High GAM was recorded for panicles per hill, yield per hill and 1000-grain weight. The traits that combined high broad-sense heritability with high genetic advance as percent of mean were panicles per hill and 1000-grain weight. The yield per hill had the third highest estimates of genotypic coefficient of variation and genetic advance as percent of the mean although the broad-sense heritability was low at 36.5%.

Table 3.5: Genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), heritability in the broad sense (H^2), genetic advance (GA), and genetic advance in percent of mean (GAM) for yield related traits in 20 genotypes comprising 19 Malawi rice landraces and one pure line selection

Trait	GCV	PCV	H^2 (%)	GA	GAM
Plant height (cm)	2.10	4.78	43.9	5.8	4.3
Days to 50% flowering	4.0	7.11	56.3	8.8	8.3
Panicle length (cm)	6.72	18.43	36.5	2.8	14.2
No. of panicles per hill	22.91	57.36	40.0	2.3	46.9
Filled grains per panicle	3.58	9.10	39.3	7.1	7.4
1000-grain weight (g)	8.84	18.33	48.3	5.4	18.3
Panicle weight (g)	6.27	34.27	18.3	2.9	12.9
Grain length (cm)	6.63	13.98	47.4	1.3	13.7
Yield per hill (g)	13.42	36.80	36.5	4.0	27.4
Yield per ha (t)	13.51	36.76	36.8	0.7	0.3

Moderate heritabilities and relatively high genetic advance as percent of the mean (GAM) were recorded for panicles per hill (40.0% and 46.9%) and 1000-grain weight (48.3% and 18.3%). Panicle length and yield per hill had moderate heritabilities of 36.5%, but with low genetic advance as percent of the mean (14.2% and 27.4%, respectively).

3.3.4 Correlations

Estimates of genotypic and phenotypic correlation coefficients between all possible trait combinations are presented in Table 3.6. The number of days to 50% flowering date had positive and significant genotypic correlations with plant height (r=0.574, P=0.01), panicle length (r=0.577, P=0.01) and grain length (r=0.446, P=0.01). The days to 50% flowering were negatively correlated with number of panicles per hill and the yield per hill.

Table 3.6: Genotypic correlation coefficients (r_g) and phenotypic correlation coefficients (r_p) among nine morphological traits in 20 genotypes comprising 19 Malawi rice landraces and one pure line selection.

Trait		**DTF**	**PL**	**PPH**	**FGP**	**TGW**	**PW**	**GL**	**GYPH**
PH	$\mathbf{r_g}$	0.574**	0.481*	-0.479*	-0.154	0.167	-0.415	0.085	-0.135
	$\mathbf{r_p}$	0.768**	0.473*	-0.468*	0.452*	0.714**	-0.512**	0.315	-0.243
DTF	$\mathbf{r_g}$		0.577**	-0.622**	-0.447*	0.378	-0.555**	0.446**	-0.563**
	$\mathbf{r_p}$		0.531**	-0.616**	0.704**	0.699**	-0.555**	0.849**	-0.398*
PL	$\mathbf{r_g}$			-0.297	-0.185	0.153	-0.393	0.140	0.071
	$\mathbf{r_p}$			-0.279	-0.352*	0.334	-0.348	0.116	0.079
PPH	$\mathbf{r_g}$				-0.018	-0.042	0.381	0.055	0.358*
	$\mathbf{r_p}$				0.192	-0.546**	0.458*	-0.278	0.428*
FGP	$\mathbf{r_g}$					-0.925**	0.102	-0.828	0.622**
	$\mathbf{r_p}$					-0.542**	-0.367	-0.306	0.256
TGW	$\mathbf{r_g}$						-0.123	0.84588	-0.677**
	$\mathbf{r_p}$						-0.537**	0.362	-0.340*
PW	$\mathbf{r_g}$							0.106	0.297
	$\mathbf{r_p}$							-0.075	0.376
GL	$\mathbf{r_g}$								-0.594**
	$\mathbf{r_p}$								-0.209

* and ** = Significant at P=0.05 and P=0.01 respectively. PH=plant height (cm); DTF=days to 50% flowering; Pl=panicle length (cm); PPH=number of panicles per hill; FGP=number of filled grains per panicle; TGW=1000-grain weight; PW=panicle weight (g); GL=grain length (cm); GYPH=grain yield per hill (g).

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The genotypic correlation between 1000-grain weight and grain length was positive and highly significant (r=0.845, P=0.01). There were negative and highly significant genotypic correlations between yields per hill and 1000-grain weight (r=-0.677, P=0.01), and grain length (r=-0.594, P=0.01).

3.4 Discussion

The results from this study indicated that there was high genetic variability among the 19 landrace genotypes, and the variability could be used in a breeding programme to develop improved varieties for the traits. The only trait that did not show any significant variation was found to be grain length. Breeding for long or extra long grain in Malawi would, therefore, necessitate use of exotic germplasm. The range of values for the traits studied were also broad confirming the wide genetic variability that may be available within the Malawi rice landraces. For example, the difference in the number of days to 50% flowering was found to be as much as 14 days. The significance of that flowering behaviour is that there could be possibility of breeding varieties that could mature two weeks earlier and therefore escape late season dry spells.

The results showed that half of the genotypes had 1000-grain weight of between 31.7 g and 33.7 g which indicated that all the studied landraces could be used in a breeding programme to develop varieties with heavy grains. Among these, the number of panicles per hill showed more than 50% variation at phenotypic level, while the grain yield per hill and panicle weight showed phenotypic variability of more than 30%. All the other traits had less than 20% variation at phenotypic level.

Johnson et al. (1955) suggested that heritability estimates, used together with genetic advance as percent of mean (GAM) could be useful in predicting the performance of the best selected individuals in a population. The broad-sense heritability estimates were high for days to 50% flowering, 1000-grain weight and grain length. Therefore these three traits maybe employed to select for superior genotypes among progeny that may be generated from their crosses. High GAM was recorded for panicles per hill, yield per hill, and 1000-grain weight. The two traits that combined high broad-sense heritability with high GAM, in this study were the number of panicles per hill and the 1000-grain weight. This probably indicates that these traits would be passed on to hybrid progenies. The implication of this finding is that phenotypic selection for the improvement of the number of panicles per hill and 1000-grain weight would be effective and useful in progenies from the landraces. The grain yield per hill would also be a useful trait to select for because this trait had the third highest estimates of genotypic coefficient of variation and GAM although the heritability was low.

The moderate heritabilities and relatively high GAM for number of panicles per hill and 1000-grain weight could be an indication of additive gene action for these traits and, hence, these traits could be improved through selection. Panicle length and grain yield per hill had moderate heritabilities but with low GAM and that could be attributed to non-additive gene effects. These traits could be improved by crossing the landraces to genotypes with higher values for these traits, and then selecting for progenies segregating positively for long panicles and high grain yield. The low heritabilities and low GAM showed by the traits of number of filled grains per panicle and panicle weight suggested the involvement of epistatic interactions. The implication is that selection in the early generation of progenies from these landraces would be ineffective (Holland, 2001).

The number of panicles per hill and number of filled grains per panicle had positive and significant genotypic correlations with yield per hill. Selection of parents based on yield alone could be misleading because yield is a complex trait that is controlled by many genes (Ramakrishnan et al., 2006). Therefore the number of panicles per hill and the number of filled grains per panicle could be used to select for high yielding breeding lines that could be developed from crosses involving the landraces in this study. The significant negative correlation between 1000-grain weight and grain yield per hill found in this study was probably due to reduced number of panicles per unit area so that even though 1000 grains were measured, the total number of grains on a planting hill was few. Takeda (1991) indicated that although grain yield is a product of the number and weight of grains, large grains do not necessarily cause high grain yield because of the negative association between number of grain and grain weight.

The results further indicated that panicles per hill and number of filled grains per panicle had positive and significant genotypic correlations with yield per hill. Ramakrishnan et al. (2006) also found positive genotypic correlations between panicles per hill, number of filled grains per panicle and grain yield. The heavy and long grains of the landraces probably resulted in low yields per hill. The days to 50% flowering were positively correlated to plant height, panicle length and grain length.

Ramakrishnan et al. (2006) and Thirumeni and Subramamanian (1999) reported similar findings.

3.5 Conclusion

Genetic variability does exist within the Malawi rice landraces in seven of the eight traits that were studied. The number of panicles per hill and the 1000-grain weight were found to be the two traits with high heritability values and high values of genetic advance as percent of mean. These two traits would be the most likely to be passed on to progeny generated from crosses involving the 19 landraces. The number of panicles per hill and the numbers of filled grains per panicle were positively correlated with yield. Therefore, selecting for these two traits would probably result in selection of high yielding genotypes.

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Appendix 3.1: Map of Malawi showing the eight districts from which landraces were collected in 2006.

Source: http://www.lib.utexas.edu/maps/africa/malawi.jpg.

Chapter 4: Genetic Analysis of Grain Size in F_2 Generation of Malawi Rice (*Oryza sativa* L.) Landraces and NERICA Variety Crosses

Abstract

Grain size, defined by length, shape (length/width ratio) and 1000-grain weight, are important quality traits in rice trade with different preferences among consumers. The objectives of this study were therefore to 1) determine the genetic variability for grain size in rice varieties, 2) study the inheritance and nature of relationships between grain length, grain shape (length/width ratio), and 1000-grain weight. In 2006, four Malawi rice landraces were crossed to four NERICA varieties in a North Carolina design II mating scheme to generate F_2 populations for the study. The crosses were evaluated at Lifuwu research Station in Salima in 2008. Results showed that landraces were variable for all three grain characteristics, while NERICA varieties were variable only for 1000-grain weight. Progeny were variable for grain length, grain shape, and 1000-grain weight, and the variability was significant (P=0.05). The progeny were found to have long grain with medium to slender shape. The heritability estimates were moderate (45.4%) for grain length and low for grain shape (12.3%) and for 1000-grain weight (14.3%) suggesting that selection for these traits would be recommended for advanced generations. The correlation between grain length and grain shape was positive (r=0.769) and highly significant (P=0.01). The correlation between grain length and 1000-grain weight was also positive (r=0.214) and significant (P=0.05. The correlation between grain shape and 1000-grain weight was negative (r=-0.369) and significant (P=0.05). The strong and positive correlation between grain length and grain shape suggested that breeders could select for both traits simultaneously, or they could choose one of the traits to develop varieties with long grains and medium shape. Combining ability analysis revealed the presence of both additive and non-additive gene action for all the grain. Predominance of additive gene action for grain length and grain shape suggested that early generation selection would be effective for these traits. Selection for 1000-grain weight would be more effective in later generations because of preponderance of non-additive gene action in the control of this trait.

Keywords: Grain length, grain shape, 1000-grain weight, Heritability, Correlation.

4.1 Introduction

Food security offered by rice as the world's major staple food depends on increasing the grain yield. The grain yield of rice depends on several components including number of panicles per plant, number of grains per panicle and grain quality characteristics (Fan et al., 2006; Gupta et al., 2006). Grain quality is both objective and subjective depending on the end-use (Koutroubus et al., 2004) but components of grain quality commonly agreed upon include nutritional and milling qualities, and the appearance, of which grain size is one component. Grain size is an important character to study not only because of its contribution to yield but also because of its influence in rice marketing and trade (Gupta et al., 2006). Grain size is an important quality trait in rice trade with different preferences among consumers (Fan et al., 2006). For example consumers in the USA and most Asian countries prefer long slender grains (Juliano and Villareal, 1993; Unnevehr et al., 1992). Gupta et al. (2006) also stated that grain size has an impact on end-quality products such as flour yield after milling and protein content.

Three genes involved in grain size for rice have been identified and named as grain size3 (GS3), OsDWARFF4, and dwarfII (dII) (Gupta et al., 2006). Molecular markers have been utilized to identify the many QTLs associated with rice grain size components (Fan et al., 2006). Studies involving normal crosses, doubled-haploids and interspecific crosses carried out by some workers have found a major QTL for grain size components to reside on chromosome 3 (Aluko et al., 2004; Thomson et al., 2003; Kubo et al., 2001; Tan et al., 2000; Redona and Mackill, 1998; Huang et al., 1997). The use of QTL mapping techniques has further refined the identification process to the extent of pinpointing the chromosomal regions where the genes and QTLs are located (Gupta et al. 2006).

Grain size is usually evaluated by two criteria: the grain weight and the grain shape (Tan et al., 2000; Fan et al., 2006). Grain weight and grain shape (length, width, length:width ratio) are positively correlated characters (Fan et al., 2006). Rasheed et al. (2002) found that grain length was positively correlated with 1000-grain weight. Studies of the components of grain size have shown different results concerning its genetic control. The genetic control of grain length has been reported to be monogenic, digenic, trigenic or under the control of polygenes (Somrith et al., 1979; Chang, 1997). Similar varied findings also apply to grain width (Chang, 1997). The polygenic inheritance of grain weight has been reported to show partial dominance, additive effects and even non-allelic interactions (Somrith et al., 1979). Kumar et al. (2007) found that grain length was predominantly controlled by additive gene action. Venkatesan et al. (2007) reported that non-additive gene action played a major role in the control of grain shape. Selvi et al. (2001) and Ganesan and Rangaswamy (1998) found preponderance of non-additive gene action for the control of both grain length and grain shape while Kumar et al. (2007) reported that both additive and non-additive gene action were equally important in the genetic control of grain shape.

Results of a participatory rural appraisal, presented in Chapter 2 in this thesis, confirmed that rainfed rice farmers in Malawi prefer, among other traits, long and medium shaped grains. The present study described the genetic analysis of three characteristics of grain size namely grain length, grain shape (length/width ratio), and 1000-grain weight in the segregating F_2 populations of crosses between Malawi rice landraces and NERICA varieties. The hypothesis was that the three grain characteristics are highly heritable and positively correlated. The objectives of this investigation, therefore, were to: 1) study the genetic variability for grain length, grain shape (length/width ratio), and 1000-grain weight in Malawi rice landrace and NERICA varieties, 2) to investigate the nature of relationships between grain length, grain shape (length/width ratio), and 1000-grain weight. And 3) study the heritabilities and combining ability for grain length, grain shape (length/width ratio) and 1000-grain weight.

4.2 Materials and Methods

Location of study

The experiment was carried out in 2006 and 2007 at the irrigated fields of Lifuwu Research Station situated at latitude 13^o $40^'$ S and longitude 34^o $35^'$ S, at an elevation of 500 metres above sea level. The station receives annual average rainfall of 1 253mm and highest and lowest annual temperatures are 29.7 ^oC and 20.4 ^oC, respectively, with annual mean temperature of 25.1 ^oC. The soils of the station are described as Vertisols of 45% clay with average pH 8.3 and 1.6% organic matter (Sistani et al., 1998).

Germplasm

The germplasm used in the study were four Malawi rice landraces, four upland NERICA rice varieties and 16 F_2 populations derived from crosses between the Malawi rices landraces and NERICA rice varieties. The crosses were made using the North Carolina Design II (NCD II) mating scheme, with the Malawi rice landraces as females and the upland NERICA varieties as males, respectively. The description of the germplasm is shown in Table 4.1.

Table 4.1: List of germplasm used in the study

Variety/Population	Parentage	Origin
Faya Mpata	Landrace	Malawi Rice Collection
Accession 21	Landrace	Malawi Rice Collection
Accession 29	Landrace	Malawi Rice Collection
Accession 63	Landrace	Malawi Rice Collection
NERICA 3	WAB 56-104/CG14	WARDA
NERICA 4	WAB 56-104/CG14	WARDA
NERICA 5	WAB 56-104/CG 14	WARDA
NERICA 6	WAB 56-104/CG 14	WARDA
Faya Mpata x NERICA 3	F_2	
Faya Mpata x NERICA 4	F_2	
Faya Mpata x NERICA 5	F_2	
Faya Mpata x NERICA 6	F_2	
Accession 21 x NERICA 3	F_2	
Accession 21 x NERICA 4	F_2	
Accession 21 x NERICA 5	F_2	
Accession 21 x NERICA 6	F_2	
Accession 29 x NERICA 3	F_2	
Accession 29 x NERICA 4	F_2	
Accession 29 x NERICA 5	F_2	
Accession 29 x NERICA 6	F_2	
Accession 63 x NERICA 3	F_2	
Accession 63 x NERICA 4	F_2	
Accession 63 x NERICA 5	F_2	
Accession 63 x NERICA 6	F_2	

Experimental design and management

The experiment was laid out in a Randomized Complete Block Design with three replicates. Each entry was planted in plots of gross size 5 m x 3 m and the net size was 4 m x 2 m. The spacing between plant stations was 30 cm x 30 cm with transplanting one seedling per plant station in December, 2006. Fertilizer was applied at the rate of 80 + 50 + 25 kg ha^{-1} NPK, with half of the N and all P and K basal dressed on the day of transplanting, and the remaining half of the N applied 30 days after transplanting.

Data collection

Grain parameters were recorded at harvest. Panicles were threshed and sun-dried until they reached 14% moisture content. The moisture content was measured using an Autocomp Grainmini moisture meter. After sun-drying, the measurements of grain length, grain shape (length/width ratio) and 1000-grain weight were taken in the laboratory. For the analysis of variance, 12 grains were measured for each population. For the frequency distributions, 10 fully-filled grains were sampled from five plants in each of the three replicates, making a total of 150 measurements per cross. The grain length and width were measured in mm using a vernier caliper. The grain shape was calculated as the ratio of the grain length to the grain width. Grain weight in grams for 100 grains was measured for each cross, and converted to 1000-grain weight in common with other studies.

Data analysis

The grain parameters that were analysed in this study were grain length, grain shape and 1000-grain weight. These traits were indicated as preferred traits by farmers in a participatory rural appraisal reported in Chapter 2 in this thesis. All data collected were subjected to the analysis of variance (ANOVA), using Genstat statistical software (Payne et al., 2007), to obtain mean sum of squares for genotypes and the residual, according to Steel et al. (1997). The ANOVA model for the randomized complete block design at the one location and in the one year was:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \epsilon_{ij},$$

where: Y_{ij} is the observed value of the i^{th} genotype for the j^{th} replicate (where i=1 to 8 and j=1 to 3); μ is the grand mean; $α_{ij}$ is the treatment effect for the i^{th} genotype, with the genotypes assumed to be random; $β_{ij}$ is the block effect for the j^{th} block; $Є_{ij}$ is the random error associated with the Y_{ij} experimental unit. For each trait, estimates calculated included means, range and standard errors. The following ANOVA (Table 4.2) for the North Carolina design II (NCD II) mating scheme (Hill et al., 1998) was used:

Table 4.2: General ANOVA for NCD II and how effects were tested.

Source	Df*	Mean squares	Variance components	F-test
Landraces	f-1	MS_f	$б^2_e + rб^2_{fm} + rmб^2_f$	MS_f/ MS_{fm}
NERICAs	m-1	MS_m	$б^2_e + rб^2_{fm} + rfб^2_m$	MS_m/ MS_{fm}
Landraces x NERICAs	(f-1)(m-1)	MS_{fm}	$б^2_e + rб^2_{fm}$	MS_{fm}/ MS_e
Error	fm(r-1)	MS_e	$б^2_e$	

* f = 4 landrace females; m = 4 NERICA males; r = 12 observations within populations.

In the analysis of combining ability, the variation in the crosses was partitioned into general combining ability (GCA) and specific combining ability (SCA) according to the methods described by Simmonds (1979). The adapted genetic model was as follows:

$$Y_{fmk} = μ + GCA_f + GCA_m + SCA_{fm} + r_k + e_{fmk}$$

Where Y_{fmk} is the mean of the cross between f and m varieties; GCA_f is the general combining ability of female f; GCA_m is the general combining ability of male m; SCA_{fm} is the specific combining ability between female f and male m; rk is the replication effects; e_{fmk} is the error term. The grain length and grain shape (length/width ratio) were described in four classes according to the measurements as shown in Table 4.3.

Table 4.3: Grain classification for length (GL) and shape (GS)

Grain length		Grain shape	
Size (mm)	**Class**	**GL:GW ratio**	**Class**
<5.50	Short	<1.0	Round
5.51-6.60	Medium	1.1-2.0	Bold
6.61-7.50	Long	2.1.-3.0	Medium
>7.50	Extra long	>3.0	Slender

Source: Jennings et al. (1979); GL:GW ratio = grain length/grain width ratio.

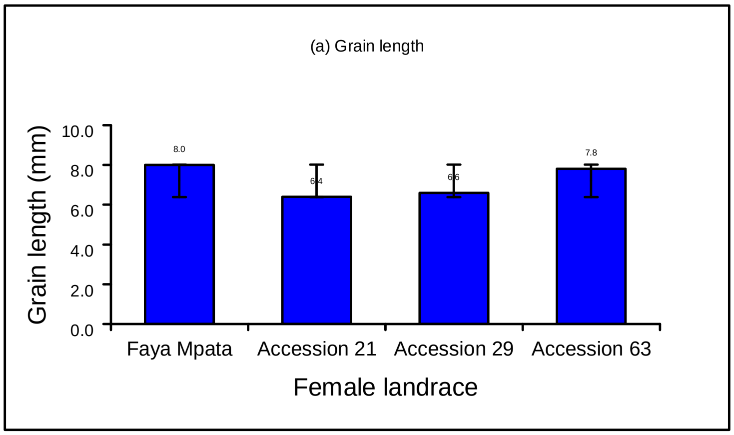
4.3 Results

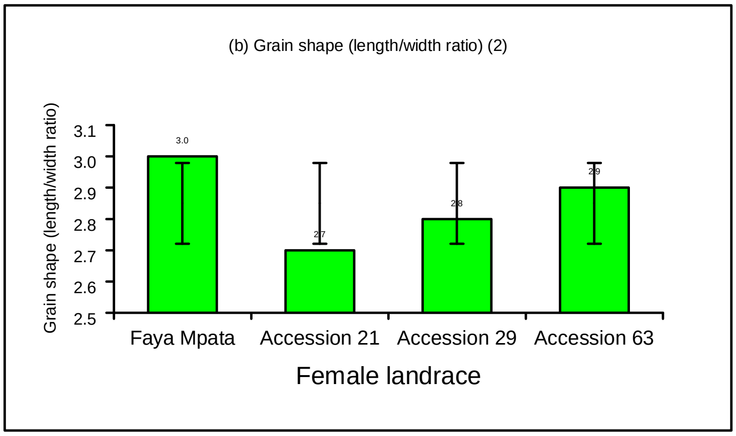
4.3.1 Variability in parents

Results showed that there were significant differences among the landraces for grain length (P=0.05) and grain shape (P=0.05). The range of grain length was from 6.4 mm to 8.0 mm. The average grain lengths for Faya Mpata and Accession 63 were 8.0 mm and 7.8 mm, respectively. The average grain length for Accession 26 was 6.4 mm, while that of Accession 21 was 6.4 mm (Figure 4.1).

Grain shape (length/width ratio) was found to be slender (3.0) for Faya Mpata (Figure 4.1). In the other landraces, the grain shape was as follows: medium (2.7) for Accession 21, medium (2.8) for Accession 29, and medium (2.9) for Accession 63. There were no significant differences among the landraces for 1000-grain weight although Accession 21 had the heavier grains with mean of 27.5 g followed by Faya Mpata with 27.0 g (Figure 4.1), Accession 29 and Accession 63 had light grains, weighing 26.4 g and 26.7 g, respectively.

Among the NERICA varieties, significant differences (P=0.05) in grain characteristics were only obtained for 1000-grain weight and NERICA 6 had the heaviest grains weighing 27.8 g, followed by NERICA 5 with 27.1 g per 1000 grains (Figure 4.2). The 1000-grain weights for NERICA 3 and NERICA 4 were 26.1 g and 26.4 g, respectively. The range of grain length was 6.8 mm to 7.4 mm (Figure 4.2). The average grain length for NERICA 3 was 7.4 mm while that of NERICA 4 was 7.3 mm. The average grain lengths for NERICA 5 and NERICA 6 were 6.8 mm and 6.9 mm, respectively. All the NERICA varieties had medium shape grains, ranging from 2.7 to 2.9 (Figure 4.2).





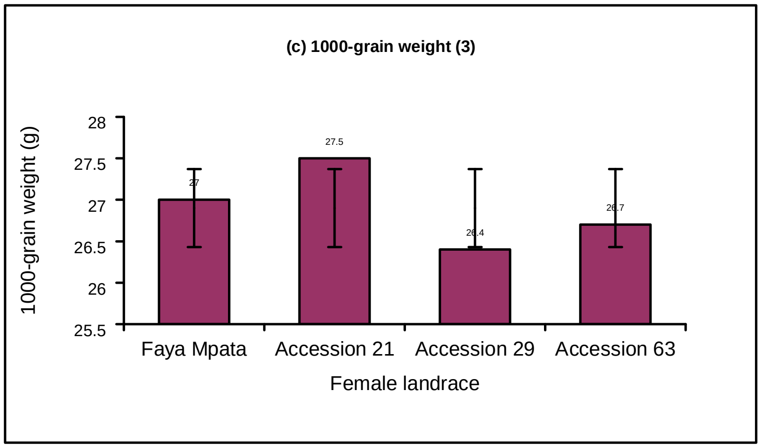
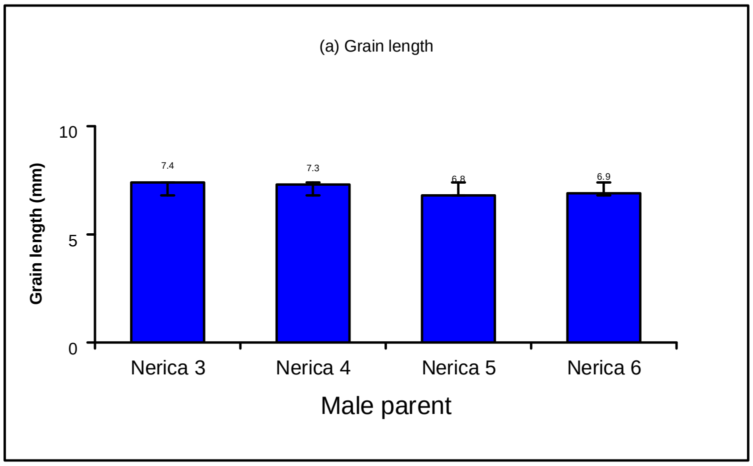
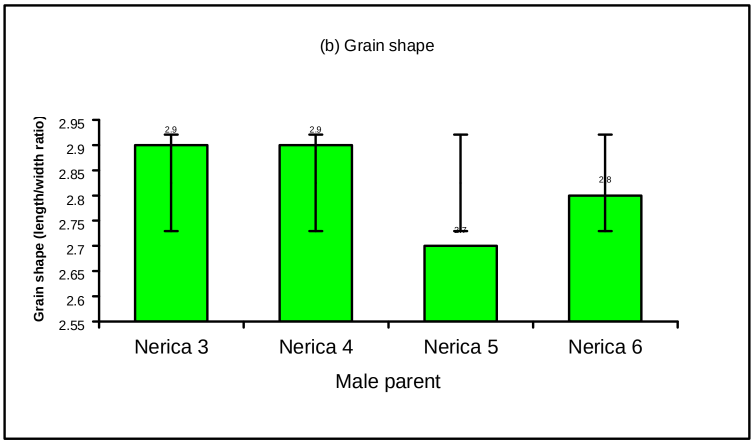


Figure 4. 1: Grain length (a), grain shape (b) and 1000-grain weight (c) for four Malawi rice landraces. Grain shape classes are: <1.0 = round; 1.1-2.0 = bold; 2.1-3.0 = medium; >3.0 = slender. (Average values: grain length = 7.2; grain shape = 2.9 (medium); 1000-grain weight = 26.9g)





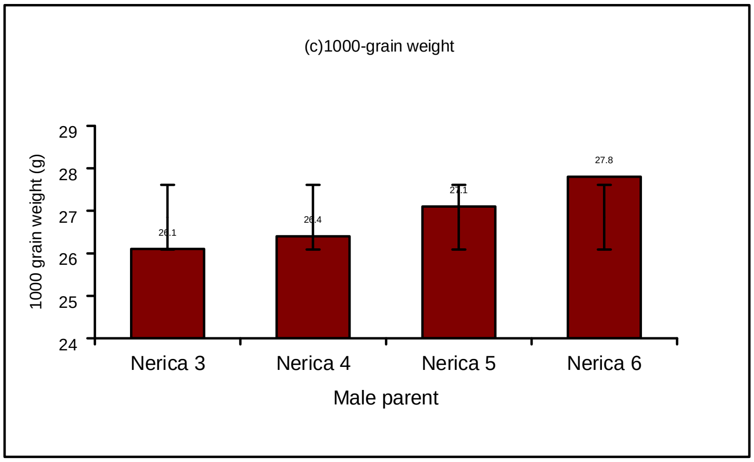


Figure 4. 2: Grain length (1), grain shape (2) and 1000-grain weight (3) for four NERICA varieties. Grain shape classes are: <1.0 = round; 1.1-2.0 = bold; 2.1-3.0 = medium; >3.0 = slender. (Average values: grain length = 7.1; grain shape = 2.8 (medium); 1000-grain weight = 26.8g)

4.3.2 Variability in crosses

There were significant differences (P=0.05) among the 16 F_2 populations for grain length, grain shape and 1000-grain weight (Table 4.4). Phenotypic distributions of F_2 progenies (Figures 4.3, 4.4 and 4.5) showed different categories as follows:

1) progenies values less than the mean value of the lowest parent (negative transgressive segregants),
2) progenies values more than the mean value of the highest parent (positive transgressive segregants),
3) Progenies values equal to the parental mean values and
4) Progenies values in between the parental mean values.

4.3.2.1 Grain length

The data for transgressive segregants are shown in Appendix 4.3. In the cross Faya Mpata x NERICA 6 (Figure 4.3), 9.0% of the progenies were positive transgressive segregants, while in the crosses of Faya Mpata x NERICA 3 (Figure 4.3), Faya Mpata x NERICA 4 (Figure 4.3) and Faya Mpata x NERICA 6 (Figure 4.3), there were 7.0% positive segregants. The highest proportion (63.3%) of negative segregants was obtained from the cross Faya Mpata x NERICA 3 (Figure 4.3). In the crosses of Accession 21, the highest number of positive transgressive segregants was 59.0% (Accession 21 x NERICA 5, Figure 4.3), and the lowest was 24.0% (Accession 21 x NERICA 3) (Figure 4.3). The proportion of negative segregants was 14.0% for the other three crosses involving Accession 21. The highest numbers of progenies that were positive segregants in crosses of Accession 29 were obtained as follows: 78.0% from Accession 29 x NERICA 5 (Figure 4.3), 74.0% from Accession 29 x NERICA 6 (Figure 4.3). The cross Accession 29 x NERICA 3 (Figure 4.3) had the lowest number of positive segregants (25.3%). In all the four crosses of Accession 29, an average of 22.0% of the progenies negative transgressive segregants (Figures 4.3).

The proportion of positive transgressive segregants for crosses involving Accession 63 was 12.2% on average (Figures 4.3) . The highest number of negative transgressive segregants was 59.3% from the cross Accession 63 x NERICA 3 (Figure 4.3). The proportions of negative transgressive segregants were 50.0%, 44.7% and 37.3% for Accession 63 x NERICA 4 (Figure 4.3), Accession 63 x NERICA 5 (Figure 4.3) and Accession 63 x NERICA 6 (Figure 4.3), respectively.


(a) Faya Mpata x Nerica 3

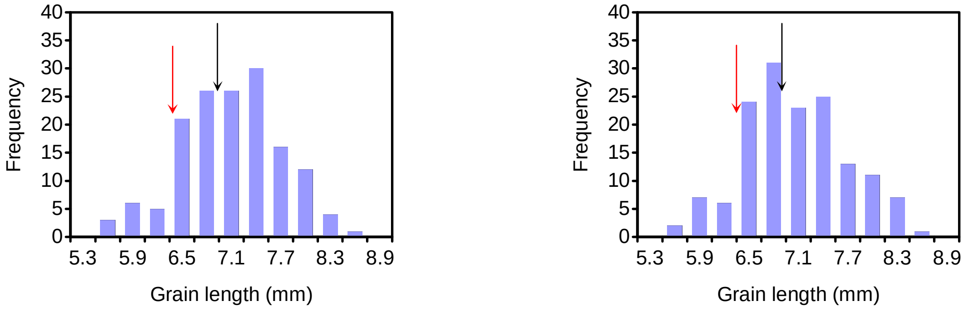
(b) Faya Mpata x Nerica 4


(c) Faya Mpata x Nerica 5

(d) Faya Mpata x Nerica 6

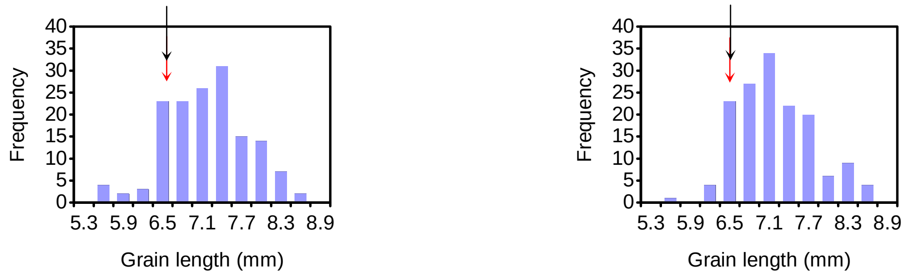

(e) Accession 21 x Nerica 3

(f) Accession 21 x Nerica 4


(g) Accession 21 x Nerica 5

(h) Accession 21 x Nerica 6

Figure 4.3: Frequency distribution of grain length (mm) in 16 F_2 populations. Arrows indicate mean value of female (red) and male (black) parents.


(i) Accession 29 x Nerica 3

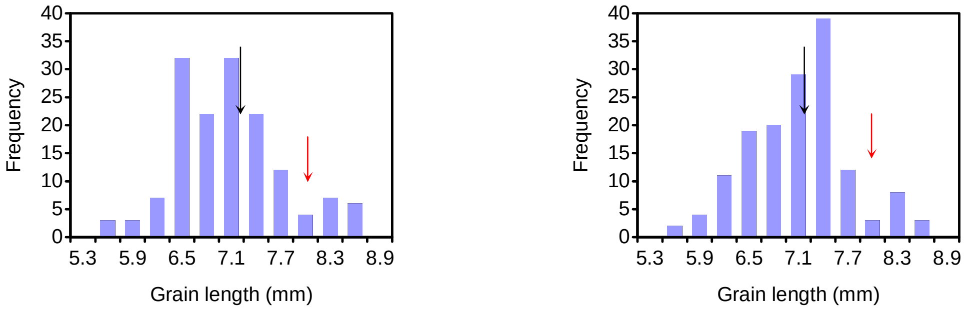
(j) Accession 29 x Nerica 4


(k) Accession 29 x Nerica 5

(l) Accession 29 x Nerica 6


(m) Accession 63 x Nerica 3

(n) Accession 63 x Nerica 4


(o) Accession 63 x Nerica 5

(p) Accession 63 x Nerica 6

Figure 4.3 (continued): Frequency distribution of grain length (mm) in 16 F_2 populations. Arrows indicate mean value of female (red) and male (black) parents.

4.3.2.2 Grain shape

The proportions of positive transgressive segregants were 28.7% for Faya Mpata x NERICA 6 and an average 23.0% for Faya Mpata x NERICA 3, Faya Mpata x NERICA 4 and Faya Mpata x NERICA 5, respectively (Figure 4.4). High number of progenies that were negative transgressive segregants were obtained from Faya Mpata x NERICA 3 (61.3%) (Figure4.4) and Faya Mpata x NERICA 4 (62.7%) (Figure 4.4).

In the crosses involving Accession 21, the proportions of positive transgressive progenies were as follows: 66.0% for Accession 21 x NERICA 6 (Figure 4.4), 64.0% for Accession 21 x NERICA 5 (Figure 4.4), 32.7% for Accession 21 x NERICA 4 (Figure 4.4) and 28.7% for Accession 21 x NERICA 3 (Figure 4.4).

In the crosses involving Accession 29, 28.9% of the progenies were positive transgressive segregants, on average (Figures 4.4). The number of progenies that were negative segregants were 58.0% for Accession 29 x NERICA 4 (Figure 4.4), 57.3% for Accession 29 x NERICA 6 (Figure 4.4), 53.3% for Accession 29 x NERICA 5 (Figure 4.4) and 50.0% for Accession 29 x NERICA 3 (Figure 4.4).

The average number of positive segregants was found to be 30.0% for all crosses involving Accession 63 and the NERICA varieties (Figures 4.4). Interestingly, the number of proportion of negative transgressive segregants was found to be 70.0% in the same crosses. This was not surprising because the mean grain shape of both the female parent (Accession 63) and the male parents (NERICA 3, NERICA 4, NERICA 5 and NERICA 6) was 2.9 (medium shape) (Figures 4.4).

(a) Faya Mpata x Nerica 3

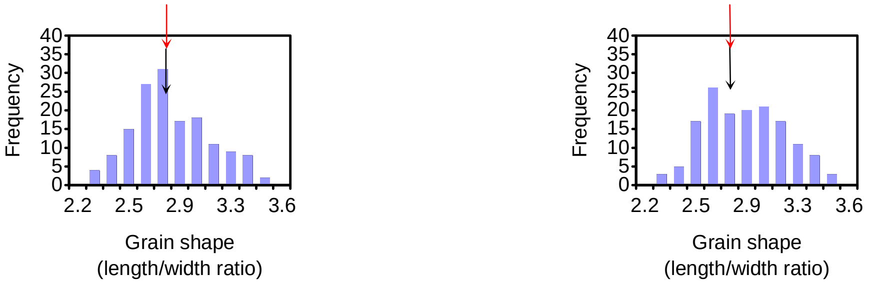
(b) Faya Mpata x Nerica 4

(c) Faya Mpata x Nerica 5

(d) Faya Mpata x Nerica 6

(e) Accession 21 x Nerica 3

(f) Accession 21 x Nerica 4



(g) Accession 21 x Nerica 5

(h) Accession 21 x Nerica 6

Figure 4.4: Frequency distribution of grain shape (length/width ratio) in 16 F_2 populations. Arrows indicate mean value of female (red) and male (black) parents. Grain shape classes are: <1.0 = round; 1.1-2.0 = bold; 2.1-3.0 = medium; >3.0 = slender.


(i) Accession 29 x Nerica 3

(j) Accession 29 x Nerica 4


(k) Accession 29 x Nerica 5

(l) Accession 29 x Nerica 6


(m) Accession 63 x Nerica 3

(n) Accession 63 x Nerica 4


(o) Accession 63 x Nerica 5

(p) Accession 63 x Nerica 6

Figure 4.4 (continued): Frequency distribution of grain shape (length/width ratio) in 16 F_2 populations. Arrows indicate mean value of female (red) and male (black) parents. Grain shape classes are: <1.0 = round; 1.1-2.0 = bold; 2.1-3.0 = medium; >3.0 = slender.

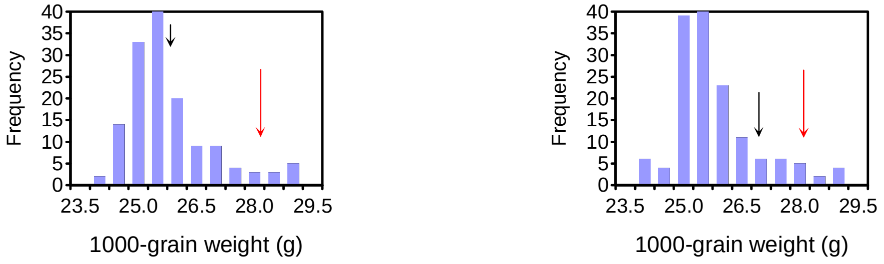
4.3.3.3 1000-grain weight

In the crosses involving Faya Mpata landraces, the proportions of positive segregants were 8.0% for Faya Mpata x NERICA 6 (Figure 4.5), 10.0% for both Faya Mpata x NERICA 3 (Figure 4.5) and Faya Mpata x NERICA 5 (Figure 4.5) and 11.3% for Faya Mpata x NERICA 4 (Figure 4.5). The proportions of negative transgressive segregants were 90.0%, 88.0%, 78.0% and 77.3% for Faya Mpata x NERICA 5, Faya Mpata x NERICA 6, Faya Mpata x NERICA 3 and Faya Mpata x NERICA 4, respectively (Figure 4.5).

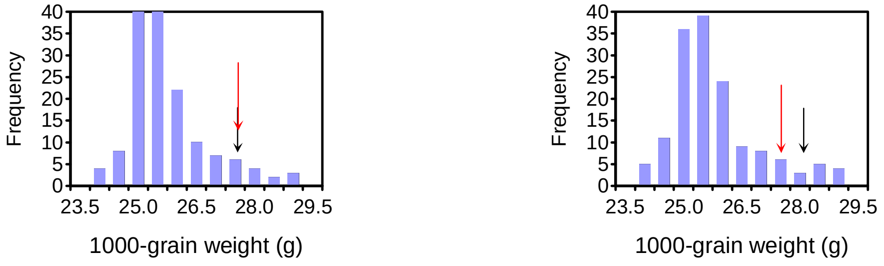
The number of positive transgressive segregants was found to be 8.6% for Accession 21 x NERICA 6 (Figure 4.6), 7.3% for Accession 21 x NERICA 4 (Figure 4.5), and 6.7% for both Accession 21 x NERICA 3 and Accession 21 x NERICA 5 (Figures 4.5). The highest number of negative segregants (88.0%) was obtained from Accession 21 x NERICA 5 (Figure 4.5), while the lowest (74.0%) was from Accession x NERICA 4 (Figure 4.5).

In crosses involving Accession 29, the proportion of positive transgressive segregants was obtained as follows: 30.1% for Accession 29 x NERICA 5 (Figure 4.5), 29.3% for Accession 29 x NERICA 3 (Figure 4.5), 28.0% for Accession 29 x NERICA 6 (Figure 4.5), and 27.3% for Accession 29 x NERICA 4 (Figure 4.5). The proportion of negative segregants for 1000-grain weight ranged from 48.7% for Accession 29 x NERICA 5 to 55.3% for Accession 29 x NERICA 6 (Figures 4.5).

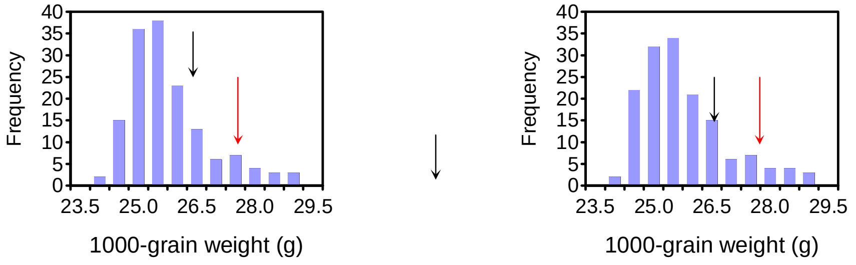
The proportion of progenies that were positive segregants for 1000-grain weight were 22.0% for Accession 63 x NERICA 3 (Figure 4.5), 20.1% for Accession 63 x NERICA 6 (Figure 4.5), 15.3% for Accession 63 x NERICA 4 (Figure 4.5), and 11.3% for Accession 63 x NERICA 5 (Figure 4.5). The proportions of negative transgressive segregants were 70.1%, for both Accession 63 x NERICA 3 and Accession 63 x NERICA 5, and 78.7% and 78.0% for Accession 63 x NERICA 4 and Accession 63 x NERICA 6, respectively (Figure 4.5).


(a) Faya Mpata x Nerica 3

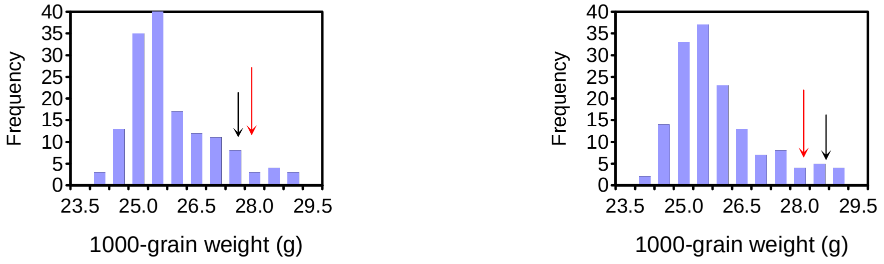
(b) Faya Mpata x Nerica 4


(c) Faya Mpata x Nerica 5

(d) Faya Mpata x Nerica 6

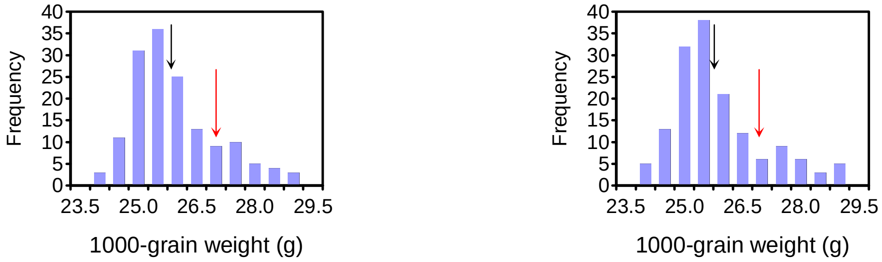

(e) Accession 21 x Nerica 3

(f) Accession 21 x Nerica 4

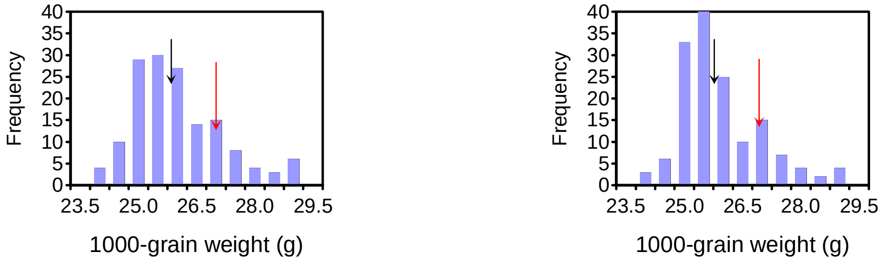

(g) Accession 21 x Nerica 5

(h) Accession 21 x Nerica 6

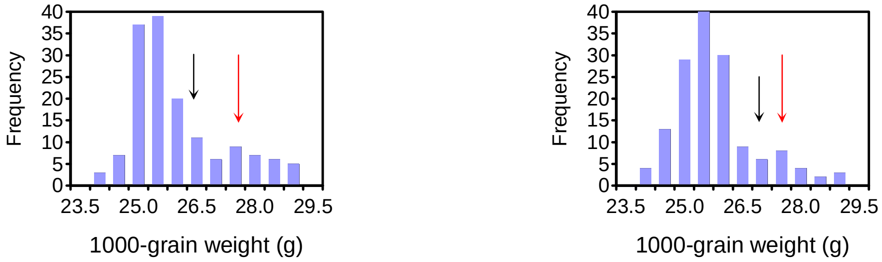
Figure 4.5: Frequency distribution of 1000-grain weight (g) in 16 F_2 populations. Arrows indicate mean value of female (red) and male (black) parents.


(i) Accession 29 x Nerica 3

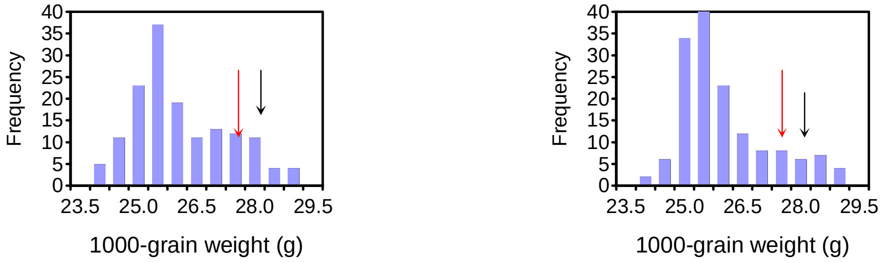
(j) Accession 29 x Nerica 4


(k) Accession 29 x Nerica 5

(l) Accession 29 x Nerica 6


(m) Accession 63 x Nerica 3

(n) Accession 63 x Nerica 4


(o) Accession 63 x Nerica 5

(p) Accession 63 x Nerica 6

Figure 4.5 (continued): Frequency distribution of 1000-grain weight (g) in 16 F_2 populations. Arrows indicate mean value of female (red) and male (black) parents.

4.3.4 Combining ability analysis

The analysis revealed significant (P=0.05) general combining ability variances of Malawi rice landraces for grain length and grain shape (Table 4.4). The general combining ability variance of NERICA varieties for 1000-grain weight was also significant at 5% level of probability (Table 4.4). The general combining ability variances of landraces for 1000-grain weight and of NERICA varieties for grain length and grain shape were not significant (Table 4.4). The analysis of combining ability also revealed significant specific combining ability variances for grain length, grain shape and 1000-grain weight (Table 4.4).

General combining ability analysis showed that all Malawi rice landrace parents had highly significant (P=0.01) general combining ability effects for grain length (Table 4.5). The general combining ability effects of the landraces were not significant for grain shape and 1000-grain weight (Table 4.5). Among the NERICAs, general combining ability effects were significant (P=0.05) for all four parents for grain length, for NERICA 3 for 1000-grain weight, and highly significant for NERICA 6 for 1000-grain weight (Table 4.5).

Specific combining ability analysis of grain length showed highly significant (P=0.01) effects for the following crosses; Accession 29 x NERICA 6 (0.317), Accession 63 x NERICA 5 (0.341), Faya Mpata x NERICA 5 (-0.334) and Accession 21 x NERICA 5 (-0.324) (Table 4.6). Positive and significant (P=0.05) specific combining ability effects were shown by Faya Mpata x NERICANERICA 3 (0.219) and Accession 29 x NERICA 3 (0.249) (Table 4.6).

Positive specific combining ability effects for grain shape were observed for Accession 63 x NERICA 5 (0.142, P=0.001) and Faya Mpata x NERICA 3 (0.138, P=0.05), while negative effects were observed for Faya Mpata x NERICA 5 (-0.179, P=0.05) and Accession 29 x NERICA (Table 4.6). Specific combining ability effects were positive and highly significant for 1000-grain weight in the crosses Accession 21 x NERICA 6 (0.633) and Accession 29 x NERICA 3 (0.850) (Table 4.6).

Table 4.4: Analysis of variance for grain size characters in 16 F_2 populations of Malawi rice landraces x NERICA varieties crosses.

Source of variation[1]	Df	Mean sum of squares		
		Grain length (mm)	Grain shape	1000-grain weight (g)
Landraces	3	38.743*	0.799*	10.257
NERICAs	3	3.278	0.456	50.618*
Landraces x NERICAs	9	1.199*	0.170*	7.169*
Error	176	0.036	0.016	0.894

[1] For combining ability analysis: Landraces = gca (females), NERICAs= gca (males), Landraces x NERICAs=sca (females x males); Df=degrees of freedom; * Significant at 5% level of probability.

Table 4.5: General combining ability (GCA) estimates for grain length, grain shape and 1000-grain weight for 8 parents.

Source	Grain length	Grain shape	1000-grain weight
	GCA landraces		
Faya Mpata	0.804**	0.068	0.083
Accession 21	-0.866**	-0.103	0.484
Accession 29	-0.696**	-0.010	-0.533
Accession 63	0.757**	0.044	-0.033
	GCA NERICAs		
NERICA 3	0.234*	0.085	-1.117*
NERICA 4	0.211*	0.049	-0.517
NERICA 5	-0.244*	-0.071	0.350
NERICA 6	-0.201*	-0.063	1.284**

*= significant at 5% level of probability; ** significant at 1% level of probability.

Table 4.6: Specific combining ability (SCA) estimates for grain length, grain shape and 1000-grain weight for F_2 progenies.

Source	Grain length (mm)	Grain shape (length/width ratio)	1000-grain weight (g)
Faya Mpata x NERICA 3	0.219*	0.138*	0.317*
Faya Mpata x NERICA 4	-0.131	-0.031	-0.550**
Faya Mpata x NERICA 5	-0.334**	-0.179*	0.400*
Faya Mpata x NERICA 6	0.246*	0.073	-0.167
Accession 21 x NERICA 3	0.169	0.029	-1.283**
Accession 21 x NERICA 4	-0.094	-0.054	0.316*
Accession 21 x NERICA 5	-0.324**	-0.109	0.333*
Accession 21 x NERICA 6	0.249*	0.134	0.633**
Accession 29 x NERICA 3	-0.236*	-0.064**	0.850**
Accession 29 x NERICA 4	0.147	0.044	0.383*
Accession 29 x NERICA 5	0.317**	0.146	-1.000**
Accession 29 x NERICA 6	-0.229*	-0.126	-0.234
Accession 63 x NERICA 3	-0.152	-0.103	0.116
Accession 63 x NERICA 4	0.078	0.042	-0.150
Accession 63 x NERICA 5	0.341**	0.142**	0.267
Accession 63 x NERICA 6	-0.266*	-0.081	-0.233

*= significant at 5% level of probability; ** significant at 1% level of probability.

4.3.3 Heritability and correlation

The estimates of heritability in the narrow-sense are presented in Table 4.7. The heritability of grain length was estimated to be 45.4%. The narrow-sense heritability for grain shape (length/width ratio) was estimated as 12.3%, while that of 1000-grain weight was estimated to be 14.3% (Table 4.7).

The computation of the correlations among the three grain size characteristics are shown in Table 4.8. Grain length was positively correlated with both grain shape and 1000-grain weight. The correlation estimate between grain length and grain shape was highly significant (r=0.769, P=0.01). The correlation between grain length and the 1000-grain weight was also highly significant (r=0.214, P=0.01). The correlation between grain shape and 1000-grain weight was negative and significant (r=-0.356, P=0.05) (Table 4.8).

Table 4.7: Range, mean, estimates of variance components, and narrow sense heritability for grain characters in 16 F_2 populations of crosses between Malawi landraces and NERICA varieties.

Characters	**Range**	**V_A**	**V_D**	**V_E**	**V_P**	**h^2 (%)**
Grain length (mm)	5.6-8.6	1.321	0.388	1.199	2.908	45.4
Grain shape	2.3-3.5	0.031	0.051	0.170	0.252	12.3
1000-grain weight (g)	24-29	1.551	2.091	7.169	10.812	14.3

V_A=additive variance; V_D=dominance variance; V_E=environmental variance; V_P=phenotypic variance; h^2=narrow sense heritability.

Table 4.8: Correlation coefficients among three traits in 16 F_2 populations.

Trait	**Grain length**	**Grain shape**
Grain shape	0.769 **	
1000-grain weight	0.214 **	-0.356 *

* Represents significance at 5% level; ** represents significance at 1% level.

4.4 Discussion

Most crosses in this study had no genetic variability between specific parents for specific traits. However, the rationale for making the crosses was to generate a mix of progenies possessing traits for all three grain traits of length, shape and 1000-grain weight. The landraces Faya Mpata and Accession 63 had extra-long grains while all the NERICA varieties had long grains. Both long grains and extra long grains are desirable grain characteristics in Malawi. Faya Mpata, Accession 63, and the four NERICA varieties could be used as sources of long and extra-long grain traits. Good general combiners for desirable grain length were Faya Mpata, Accession 63, NERICA 3 and NERICA 4. All four parents, both landraces and NERICA varieties, had the preferred medium grain shape implying that they could be sources of medium grain shape trait. Combining ability results, however, revealed that good general combiners for the desirable medium grain shape were Faya Mpata, Accession 63, NERICA 3 and NERICA 4. Among NERICA varieties, NERICA 5 and NERICA 6 had the heaviest grains indicated by the 1000-grain weight. The 1000-grain weight is one of the four major determinants of grain yield in rice (De Datta, 1981). Therefore, NERICA 5 and NERICA 6 could be sources of increased 1000-grain weight. Good combiners for 1000-grain weight were Accession 21 and NERICA 6. It was not surprising that good combiners for 1000-grain weight were not good combiners for either grain length or grain shape because the 1000-grain weight was found to be negatively correlated with grain shape and weakly correlated with grain length.

The frequency distribution for grain length appeared continuous in all the 16 F_2 populations. Similar to the segregation for grain length, the distribution for grain shape also appeared to be continuous in all the 16 F_2 populations. The frequency distribution for 1000-grain weight appeared to be negatively skewed to the left for all the 16 F_2 populations. This indicated that majority of the progenies had 1000-grain weight less than the population mean. Hill et al. (1998) indicated that preponderance of dominance gene effects towards increased expression of a trait contributes to negatively skewed distributions of phenotypes. Probably similar inference could be ascribed to the negatively skewed distributions for 1000-grain weight in this study. This suggests that most of the alleles for 1000-grain weight are dominant and, therefore, selection for 1000-grain weight would not be effective in early generations. The negatively skewed phenotypic distributions for 1000-grain weight also indicated non-additive gene action for this character, suggesting that selection for this trait should start in late generations.

Combining ability results indicated that both additive and non-additive gene action controlled grain length, grain shape and 1000-grain weight. The exceptions were that, for the parents used in this study, additive gene action was not revealed for: 1) grain length and grain shape in the NERICA varieties, and 2) 1000-grain weight in the Malawi rice landraces. The relatively high magnitude of general combining ability variances indicated the predominant role of additive gene action in the control of grain length, grain shape and 1000-grain weight. Kumar et al. (2007) reported predominance of additive gene action for grain length and 1000-grain weight but found that both additive and non-additive gene action were equally important for controlling grain shape. The findings in this study suggested that early generation selection for grain length, grain shape and 1000-grain weight would not be effective. Based on heritability estimates, however, early generation selection would be effective for grain length because its estimates were moderate (45.4%). Yoshida et al. (2002) reported high heritability estimates for grain length (91.6%). The low heritability estimates for grain shape (12.3%) and 1000-grain weight (14.3%) suggested that it could be prudent to delay selection for grain shape and 1000-grain weight to advanced generations, for example in the F_5 generation, except for crosses involving NERICA 3 and NERICA 6.

There were progeny that had grain length, grain shape and 1000-grain weights similar to or higher than that of the parents indicating transgressive segregation. The transgressive segregation probably indicated complementary gene action between the parents. There is likelihood of improving grain length, grain shape and 1000-grain weight beyond the parent values. Therefore, it would be possible to identify breeding lines with extra long grains, slender shape and heavier grains from among the populations generated in this study. High number of transgressive segregants for grain length, could be obtained from the following four populations: 1) Accession 21 x NERICA 5, 2) Accession 29 x NERICA 5, 3) Accession 29 x NERICA 6 and 4) Accession 63 x NERICA 3. High number of positive segregants for grain shape could be obtained from only two populations namely Accession 21 x NERICA 5 and Accession 21 x NERICA 6. A high number of positive segregants for 1000-grain weight could be obtained from the following hybrids: Accession 29 x NERICA 3, Accession 29 x NERICA 4, Accession 29 x NERICA 5 and Accession 29 x NERICA 6. Based on specific combining abilities, the best hybrids for desirable grain length were Accession 29 x NERICA 5 and Accession 63 x NERICA 5, the latter also was the best hybrid for grain shape together with the hybrid Faya Mpata x NERICA 3. Five hybrid combinations were identified as the best for increased 1000-grain weight and these were: Accession 29 x NERICA 3, Accession 29 x NERICA 4, and all combinations of Accession 21 with exception of Accession 21 x NERICA 3.

In this study, the correlation between grain length and grain shape was found to be positive and strong. Rabiei et al. (2004) also found positive and strong correlation (r=0.729) between grain length and grain shape. The strong and positive correlation found suggests that both grain length and grain shape could be selected for simultaneously. Alternatively either grain length or grain shape could be useful to select for both traits. The 1000-grain weight was significantly (P=0.01) correlated with grain length but the correlation was low (r=0.214). Rabiei et al. (2004) found positive (r=0.342) correlation between grain length and 1000-grain weight. Yoshida et al. (2002) also reported positive (r=0.481) and significant correlation between grain length and 1000-grain weight. This correlation suggested that 1000-grain weight would not be a useful indicator of grain length. The 1000-grain weight was negatively correlated with grain shape. The negative correlations suggested that selecting for low density grains would not result in selecting for medium shaped grains.

4.5 Conclusion

The two landrace parents namely Faya Mpata and Accession 63 could be good sources for improvement of grain length and grain shape. Two NERICA varieties, NERICA 3 and NERICA 4, could be good sources for the improvement of grain length, while NERICA 5 and NERICA 6 could be good sources for the improvement of 1000-grain weight, if desired. Based on narrow-sense heritability estimates, selection for grain length trait could be effective in early generations because of its high heritability while selection for grain shape and 1000-grain weight would be effective in advanced generations. Positive selection for slender grain length would result in simultaneous selection of medium-shaped grains. Predominance of additive gene action suggests that selection for grain length and grain shape would be effective in early generations, while selection for 1000-grain weight would have to be delayed because of its negative or weak association with the other traits. Faya Mpata, Accession 63, NERICA 3 and NERICA 4 would be the best parents to use to improve grain length and grain shape while Accession 21 and NERICA 6 would be best parents for increased 1000-grain weight.

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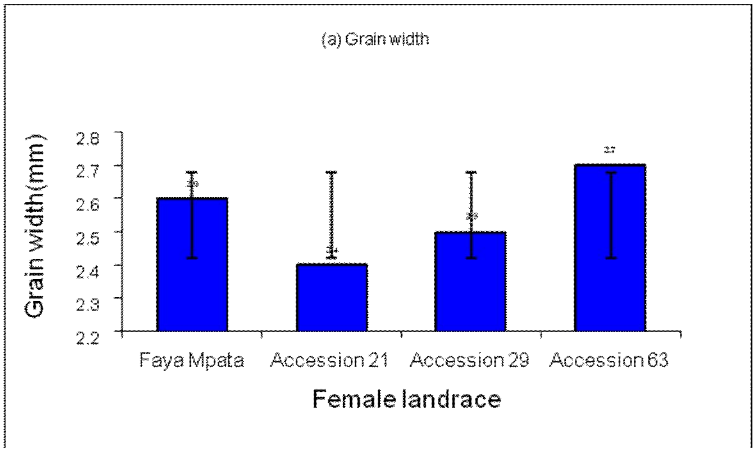
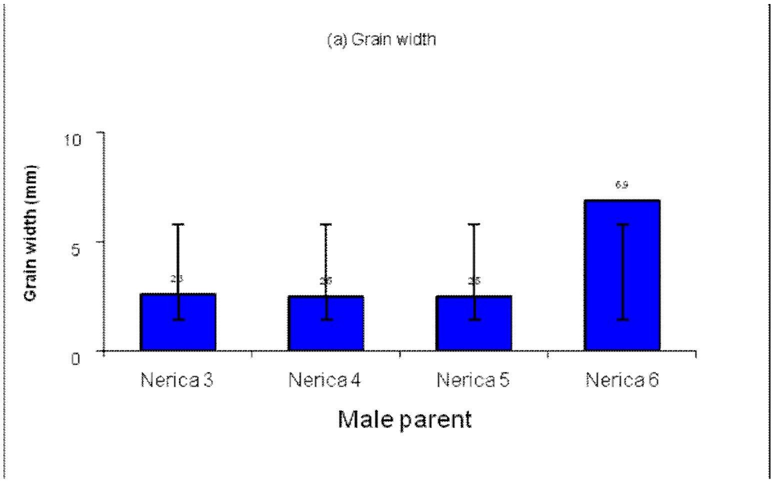
Appendix 4. 1: Grain width for four Malawi rice landraces and four NERICA varieties





Appendix 4. 2: Grain length (mm), grain shape, 1000-grain weight (g) and grain width (9mm) for four Malawi rice landraces and four NERICA varieties. Grain shape classes are: <1.0 = round; 1.1-2.0 = bold; 2.1-3.0 = medium; >3.0 = slender. (Average values: grain length = 7.1; grain shape = 2.8 (medium); 1000-grain weight = 26.8g)

Parent	Grain length	Grain shape	1000-grain weight	Grain width
		Female		
Faya Mpata	8.0	3.0	27.0	2.6
Accession 21	6.4	2.7	27.5	2.4
Accession 29	6.6	2.6	26.4	2.5
Accession 63	7.8	2.9	26.7	2.7
Mean	7.2	2.9	26.9	2.6
		Male		
NERICA 3	7.4	2.9	26.1	2.6
NERICA 4	7.3	2.9	26.4	2.5
NERICA 5	6.8	2.7	27.1	2.5
NERICA 6	6.9	2.8	27.8	2.4
Mean	7.1	2.8	26.8	2.5

Appendix 4.3: Proportions of transgressive segregants in the crosses of Malawi rice landraces and Nerica varieties.

Percent posistive transgressive segregants (%)			
Cross	Grain length	Grain shape	1000-grain weight
Faya Mpata x NERICA 6	9.0	28.7	8.0
Faya Mpata x NERICA 3	7.0	23.0	7.0
Faya Mpata x NERICA 4	7.0	23.0	7.0
Faya Mpata x NERICA 5	7.0	23.0	7.0
Accession 21 x NERICA 5	59.0	64.0	6.7
Accession 21 x NERICA 3	24.0	28.7	6.7
Accession 29 x NERICA 5	78.0	28.9	30.1
Accessiojn 29 x NERICA 6	74.0	28.9	28.0
Accession 29 x NERICA 3	25.3	30.0	29.3
Accession 63 x NERICA 3	12.2	30.0	22.0

Percent negative transgressive segregants (%)			
Faya Mpata x NERICA 3	63.3	61.3	78.0
Accession 21 x NERICA 5	14.0	60.0	88.0
Accession 29 x NERICA 3	22.0	50.0	0
Accession 29 x NERICA 4	22.0	58.0	0
Accession 29 x NERICA 5	22.0	53.3	0
Accession 29 x NERICA 6	22.0	57.3	0
Accession 63 x NERICA 3	59.3	70.070.1	0

Chapter 5: Inheritance of Aroma and Gelatinization Temperature in F_2 Generation of Malawi Rice (*Oryza sativa* L.) Landraces and NERICA Varieties Crosses

Abstract

Farmers and consumers in Malawi have indicated preference for rice varieties with aromatic grains in addition to intermediate gelatinization temperature. Knowledge of the inheritance of the two traits could be used to design an effective breeding strategy targeting the two traits. This study was conducted to obtain information on the mode of inheritance of aroma and gelatinization temperature in the segregating populations of crosses between two aromatic Malawi rice landraces with intermediate gelatinization temperature, and two non-aromatic NERICA rice varieties with high gelatinization temperature. In the crosses between the aromatic Malawi rice landraces and the non-aromatic NERICA varieties, the F_2 progenies in all the four crosses in this study segregated into the ratio of 3:1 for non-aromatic:aromatic, suggesting that a single recessive gene was controlling aroma. Among the four crosses, the highest proportions of the desirable progenies with strong aroma were found in the cross involving Faya Mpata and NERICA 4 parent varieties. Segregating progenies in F_2 generation showed a pattern that was not significantly different from 1:3 ratio for high:intermediate gelatinization temperature in three populations, namely Faya Mpata x NERICA 4, Faya Kachulu x NERICA 3 and Faya Kachulu x NERICA 4, suggesting that a single dominant gene was controlling the trait. The segregation of F_2 progenies in the cross Faya Mpata x NERICA 3 was not significantly different from 3:13 ratio for high:intermediate gelatinization temperature suggesting that two dominant genes, one acting as an inhibitor, were controlling the trait. The distribution of gelatinization temperature was unimodal and appeared continuous in the four populations, probably indicating quantitative inheritance. The results found in this study, therefore, have suggested that in the Malawi rice landraces, both the aroma and gelatinization temperature are probably simply inherited and breeding and selecting for these traits would be accomplished relatively easily.

Keywords: Rice landraces, NERICA, Inheritance, Aroma, Gelatinization temperature.

5.1 Introduction

The quality of rice grains can be described in terms of sensory and cooking qualities (Khatun et al., 2006; Singh et al., 2000). The chief sensory characteristic of rice grain is the aroma which is present in stems, leaves and grains of the rice plant (Buttery et al. (1983). Aroma is associated mainly with the presence of a compound called 2-acetyl-1-pyrroline or 2-AP (Bradbury et al., 2005; Widjaja et al. 1996; Buttery et al., 1983) which, in turn, is most closely associated with the aroma of Basmati and Jasmine types of rice (Hien et al. 2006; Yoshihashi et al. 2004; Lorieux et al. 1996; Widjaja et al. 1996; Buttery et al. 1983). There are many aromatic rices in the world, and the notable varieties are Basmati and Jasmine rices that are widely cultivated in India and Pakistan, respectively (Bradbury et al., 2005). Many other aromatic varieties are grown worldwide and demand for aromatic rice is increasing (Dudhare and Jadhav, 2006) and aromatic rice fetches higher prices than non-aromatic rice in both national and international markets (Tsuzuki and Shimokawa, 1990; Berner and Hoff, 1986). The aroma of Malawi *Faya* rices could as well be associated with the chemical compound 2-acetyl-1-pyrolline. In Malawi, *Kilombero* and *Faya14M69* are aromatic pure line selections from the *Faya* gene pool.

The chemical 2-acetyl-l-pyrroline is and various qualitative methods have been devised to detect and evaluate aroma (Sood and Siddiq, 1978; Nadaf et al., 2006). The methods include smelling grains after heating in water and smelling leaf tissue or grains (Sood and Siddiq, 1978; Nagaraju et al. (1975). Sood and Siddiq (1978) developed a rapid technique for scent determination in which leaf tissue or grains are treated with 1.7% potassium hydroxide (KOH) and then the released aroma is inhaled. This technique is used as a basic technique for detection of aroma

Inheritance studies of aroma have found different results (Ali et al., 1993; Lin, 1990). Some of the studies reported progeny segregation ratios of 1:3 for aromatic: non-aromatic plants which suggested monogenic inheritance by a single recessive gene (Berner and Hoff, 1986; Sood and Siddiq, 1978). Similar results were reported by Dong et al. (2001) and Pinson (1994). Tsuzuki and Shimokawa (1990) reported progeny segregation ratio of 3:13 for aromatic:non -aromatic, which indicated interaction between a recessive gene and an inhibitor gene. Geetha et al., (1994), Tripathi and Rao (1979) and Dhulappanavar (1976) found segregation ratios of 7:9 for aromatic:

non-aromatic, which indicated the presence of two complimentary genes that controlled aroma.

Cooking quality of rice grains includes gelatinization temperature (Shoba Rani et al., 2006) which is determined by the properties of the starch in the milled grains (Shoba Rani et al., 2006). Gelatinization temperature refers to the critical temperature range over which the starch in the grain becomes soluble and the grain swells irreversibly (Jennings et al., 1979). Rice with low gelatinization temperature takes long to cook and becomes sticky while rice with high gelatinization temperature takes a shorter time and the grains separate (Jennings et al., 1979). The Alkali spreading value (ASV) method is used to estimate gelatinization temperature (Shoba Rani et al., 2006) and equates the digestibility of grain starch by an alkali chemical to gelatinization temperature and cooking time of milled rice.

The few studies on gelatinization temperature in rice have reported inconsistencies in the mode of its inheritance (Farouq et al., 2004). Jennings et al. (1979) stated that gelatinization temperature was probably simply inherited, under the control of one or two major genes. Tan et al. (1999) reported that gelatinization temperature was controlled by one gene. In close agreement was the study by Heidelberg and Li (1999) which reported that gelatinization temperature was controlled by a single gene, with a modifier. Mohamad (2004) reported two classes of progeny in the ratio of 1:3 for high gelatinization temperature: intermediate gelatinization temperature, which indicated that one gene was involved in the inheritance of the trait. Kiani et al. (2008) reported that the inheritance of gelatinization temperature was monogenic, involving one major gene but with modifiers.

The rice industry in Malawi prefers rice that is aromatic and with intermediate gelatinization temperature. Rice farmers, dictated by the preferences of consumers consider aroma, and intermediate gelatinization temperature, to be valuable variety traits. These preferences justify the need for genetic studies of aroma and gelatinization temperature in landraces that farmers grow in Malawi. The hypothesis is that both aroma and high gelatinization temperature traits in Malawi rice landraces are simply inherited. The objective of this study was to determine the inheritance of aroma and gelatinization temperature in Malawi rice landraces, through genetic analysis of the segregating populations of crosses between Malawi rice landraces and NERICA rice varieties.

5.2 Materials and Methods

Location of study

The experiment was laid out at Lifuwu Research Station, in the Central Region District of Salima in Malawi. Lifuwu Research Station is located at latitude 13° 40' South and longitude 34° 35' East, at an altitude of 500m. The station receives annual average rainfall of 1 253mm and highest and lowest annual temperatures are 29.7 °C and 20.4 °C, respectively, with annual mean temperature of 25.1 °C. The soils of the station have previously been described as Vertisols of 45% clay with average pH 8.3 and 1.6% organic matter (Sistani et al., 1998).

Germplasm

In this study, a total of four rice varieties were used as parents and four populations were derived from the parents. The parent varieties were the aromatic Malawi rice landraces, Faya Mpata and Faya Kachulu, which have intermediate gelatinization temperature, and NERICA 3 and NERICA 4, non-aromatic varieties with high gelatinization temperature. The crosses were made in 2006 utilizing the landraces and the NERICA varieties as female and male parents, respectively. There were two groups of experiments: 1) four aromatic x non-aromatic populations and 2) four intermediate x high gelatinization temperature populations, in cross combinations as follows:

1. Faya Mpata x NERICA 3
2. Faya Mpata x NERICA 4
3. Faya Kachulu x NERICA 3
4. Faya Kachulu x NERICA 4.

Experimental layout

In 2007, the F_1 progenies resulting from the four cross combinations were planted in bulk plots to eliminate selfed plants, and the true crosses were advanced to F_2. The true crosses were identified by planting the F_1 between its female and male parent. Any F_1 plant that resembled the female parent was not a true cross. The parents, F_1 and the four F_2 populations were planted in a Randomized Complete Block Design with three replications in 2008. Each entry was planted in plots of gross size 6 m x 4 m and net size of 4 m x 3 m. The spacing between plant stations was 20 cm x 20 cm and one seedling was transplanted per plant station. The total numbers of plant stations were 600 and 300 in the gross and net plots, respectively. Fertilizer was applied at the rate of 80 + 50 + 25 kg ha^{-1} NPK, with half of the N and all P and K applied as basal dressing on the day of transplanting, and the remaining half of the N applied as top dressing 30 days after transplanting.

Leaf scoring for presence or absence of aroma

Leaf aroma was determined in leaves of the plants according to the method described by Sood and Siddiq (1978) and recently used by Sun et al. (2008). When the plants were at the tillering stage, 2g of tissue were cut from two leaves of each plant. The leaf tissue was cut into pieces and placed in petri dishes containing 10mL of 1.7% potassium hydroxide. The petri dishes were kept at room temperature (≈25°C) for about 10 minutes and then opened one by one and the samples smelled and rated for the presence or absence of aroma by two panelists. The female parent Faya Mpata and the male parent NERICA 3 were used as aromatic and non-aromatic reference samples, respectively.

Thirty parent plants and 30 F_1 plants, as well as 80 F_2 plants were randomly chosen from the net plot (4m x 3m) and they were scored for the presence or absence of aroma based on the method by Sood and Siddiq (1978) and Sun et al. (2008). Plants, from which the leaf was taken, were divided into two classes: 1) Non-aromatic and 2) Aromatic. Scoring was on a 1-4 scale with 1 = absence of aroma, 2 = slight aroma, 3 = moderate aroma and 4 = strong aroma, respectively. Plants that were scored 1= no aroma were classified as non-aromatic while all plants that were scored 2 = slight aroma, 3 = moderate aroma and 4 = strong aroma were classified as aromatic. This classification was based on rice marketing trends in Malawi, where different degrees of aroma (slight, moderate or strong) are classified simply as aroma.

The leaf samples were assessed by a rating panel of five people who were selected for their ability to differentiate between the aromatic Faya 14M69 and the non-aromatic NERICA 2 varieties which were the standard references. These were presented to the panelists before tasting the study samples. The observed segregation ratios of the crosses in the four F_2 populations were individually tested by chi-square analysis against expected ratio for a single gene inheritance. Homogeneity chi-square tests, as done by Ullrich and Eslick (1978), of the frequency distributions for the four populations were applied. The homogeneity tests were applied in order to: 1) determine whether the four F_2 populations were homogeneous, and 2) to pool the homogeneous populations and test for fit to the expected ratio.

Grain scoring for aroma in F_2 progenies

The sensory test for grain aroma was carried out by sensory taste according to the basic technique proposed by Sood and Siddiq (1978) and modified by Lorieux et al. (1996) and Sun et al. (2008). The grain aroma in the F_2 population of the cross Faya Mpata x NERICA 3 was assessed by a rating panel of five people who were selected for their ability to differentiate between Faya Mpata and NERICA 3 which were the reference aromatic and non-aromatic varieties. The aromatic Faya 14M69 and the non-aromatic NERICA 2 varieties were taken as standard references. These were presented to the panelists before tasting the study samples.

The grain aroma was rated on F_3 seeds but inferred upon the corresponding previous F_2 progenies (Sun et al., 2008). The procedure by Kibria et al. (2008) was adopted in which grains from individual plants were soaked in 10 ml 1.7% KOH solution at room temperature (approximately 27^0C in the laboratory) in a covered conical flask for one hour. Five panelists chewed individual seeds and scored them on a1-4 scale with 1 = no aroma, 2 = slight aroma, 3 = moderate aroma and 4 = strong aroma. The numbers of seeds in each category were plotted on a frequency scale. A total 60 seeds each for the parents were tasted. The total numbers of seeds that were tasted in the F_2 progenies are presented in Table 4.1.

Table 5.1: Total number of grains scored for aroma in four F_2 progenies

Population	Number of grains
Faya Mpata x NERICA 3	60
Faya Mpata x NERICA 4	65
Faya Kachulu x NERICA 3	56
Faya Kachulu x NERICA 4	66

Gelatinization Temperature

The gelatinization temperature (GT) was indirectly estimated by the degree of alkaline dispersion by using the alkali spreading value (ASV) technique developed by Little et al. (1958), extensively used at the International Rice Research Institute (IRRI, 1979), and modified by Faruq et al. (2004). Milled grain samples were placed in 10ml of 1.7% potassium hydroxide (KOH) in Petri dishes of 10cm diameter. The Petri dishes were put in a water bath for 24 hours and were then scored for spreading. The alkali spreading values (ASV) were determined by visual scoring of the appearance of the grains and the degree of dispersion on a 1-7 linear scale as:

1 = grains not affected
2 = grains swollen
3 = grains swollen, grain collar incomplete and narrow
4 = grains swollen, grain collar complete and wide
5 = grains split or segmented, grain collar complete and wide
6 = grain dispersed, merging with collar
7 = grain completely dispersed and intermingled.

The reference varieties were Faya 14M69, a variety with intermediate gelatinization temperature, and NERICA 1, a variety with high gelatinization temperature.

Segregation ratios were determined in parents, F_1 progenies and F_2 progenies for three categories of gelatinization temperature (GT) of:

1. High GT = ASV of 1-2
2. Intermediate GT = ASV of 3-5
3. Low GT = ASV of 6-7.

The classification was based on the relationship between ASV and gelatinization temperature (GT) as shown in Table 5.3. The gelatinization temperature was determined on 50 grains of parents, 50 grains of F_1 and 200 grains of F_2 progenies. The observed segregation ratios of the crosses in the four F_2 populations were individually tested by chi-square analysis against expected ratio for a single gene inheritance. Homogeneity chi-square tests, as done by Ullrich and Eslick (1978), of the frequency distributions for the four populations were applied. The homogeneity tests were applied in order to: 1) determine whether the four F_2 populations were homogeneous, and 2) to pool the homogeneous populations and test for fit to expected ratio. The alkali spreading values from 150 F_3 grains were used to plot frequency distributions of the alkali spreading values.

Table 5.2: Scores for Alkali Spreading Value (ASV) and its relationship to Gelatinization Temperature (GT).

Reaction of grains after soaking	A SV	GT
1-Not affected but chalky	Low	High
2-Swollen	Low	High
3-Swollen with collar incomplete or narrow	Intermediate	Intermediate
4-Swollen with collar complete and wide	Intermediate	Intermediate)
5-Split or segmented with collar complete and wide	Intermediate	Intermediate
6-Dispersed merging with collar	High	Low
7-Completely dispersed and cleared	High	Low

Source: Standard Evaluation System for Rice (IRRI, 2002).

5.3 Results

5.3.1 Chi-square test for inheritance of aroma

In the four crosses of Faya Mpata x NERICA 3, Faya Mpata x NERICA 4, Faya Kachulu x NERICA 3 and Faya Kachulu x NERICA 4 the female parents, Faya Mpata and Faya Kachulu were aromatic while the male parents, NERICA 3 and NERICA 4, were non-aromatic (Table 5.3). In the crosses between the aromatic and non-aromatic varieties, all the F_1 plants were non-aromatic (Table 5.3).

Results of presence or absence of aroma in F_2 plants, in each of the four crosses, are presented in Table 5.3. In the cross Faya Mpata x NERICA 3, 56 out of 80 plants were non-aromatic while 24 plants were aromatic. In the cross Faya Mpata x NERICA 4, 66 out of 80 plants were non-aromatic and 14 were aromatic. Out of 80 F_2 plants in the cross Faya Kachulu x NERICA 3, 50 were non-aromatic and 22 were aromatic (Table 5.3). In the cross Faya Kachulu x NERICA 4, out of 80 plants 53 were non-aromatic while 27 were aromatic.

Individual chi-square values for the segregation ratios were found to be 1.06, 2.400, 0.267 and 3.627 for Faya Mpata x NERICA 3, Faya Mpata x NERICA 4, Faya Kachulu x NERICA 3 and Faya Kachulu x NERICA 4 F_2 populations, respectively (Tables 5.3). These chi-square values, for the individual populations, were non-significant and

Table 5.3: Phenotypic segregation of parents, F_1 and F_2 plants for aroma in four rice crosses and their respective chi-square values against expected 3:1 ratio for non-aromatic:aromatic.

Population		**Number of plants**					**X^2**
		Total	**Non-aromatic**		**Aromatic**		
			Observed	**Expected**	**Observed**	**Expected**	
(a) Population 1							
Faya Mpata	P_1	30			30		
NERICA 3	P_2	30	30				
Faya Mpata x NERICA 3	F_1	30	30				
Faya Mpata x NERICA 3	F_2	80	56	60	24	20	1.067ns
(b) Population 2							
Faya Mpata	P_1	30			30		
NERICA 4	P_2	30	30				
Faya Mpata/NERICA 4	F_1	30	30				
Faya Mpata/NERICA 4	F_2	80	66	60	14	20	2.400ns
(c) Population 3							
Faya Kachulu	P_1	30			30		
NERICA 3	P_2	30	30				
Faya Kachulu/NERICA 3	F_1	30	30				
Faya Kachulu/NERICA 3	F_2	80	58	60	22	20	0.267ns
(d) Population 4							
Faya Kachulu	P_1	30			30		
NERICA 4	P_2	30	30				
Faya Kachulu/NERICA 4	F_1	30	30				
Faya Kachulu/NERICA 4	F_2	80	53	60	27	20	3.267ns
(e) Test for homogeneity (all 4 populations)							
Total X^2							7.001**
Pooled X^2	F_2	320	233	240	87	80	0.817ns
Homogeneity (Total X^2- Pooled X^2)							6.184*
(f) Test for homogeneity (Populations a, b and c)							
Total X^2							3.734ns
Pooled X^2	F_2	240	180	180	60	60	0
Homogeneity(TotalX^2- Pooled X^2)							3.734ns

ns = observed segregation not significantly different from the expected segregation ratio of 3:1 for non-aromatic:aromatic; * = significant at P=0.05, ** = significant at P=0.01, when tested against $X^2_{1, 0.05} = 3.84$ and $X^2_{1, 0.01}= 6.635$; P_1 and P_2 denote the female and male parents in the cross, respectively.

therefore fitted a 3:1 ratio. The total chi-square value (7.001) was highly significant (P=0.01) while the pooled chi-square value (0.817) for the four crosses was non-significant (Table 5.3). However, the test of homogeneity of chi-square values (6.184) revealed significant (P=0.05) differences (Table 5.3) and therefore some population was the reason for the heterogeneity of chi-square values. By iteration, the cross Faya Kachulu x NERICA 4 (Table 5.3) was found to be the cause, and was removed from the pooled estimates of chi-square values. The test of the total chi-square value (3.734) and the homogeneity of chi-square value (3.734) for the other three populations was not significant (Table 5.3).

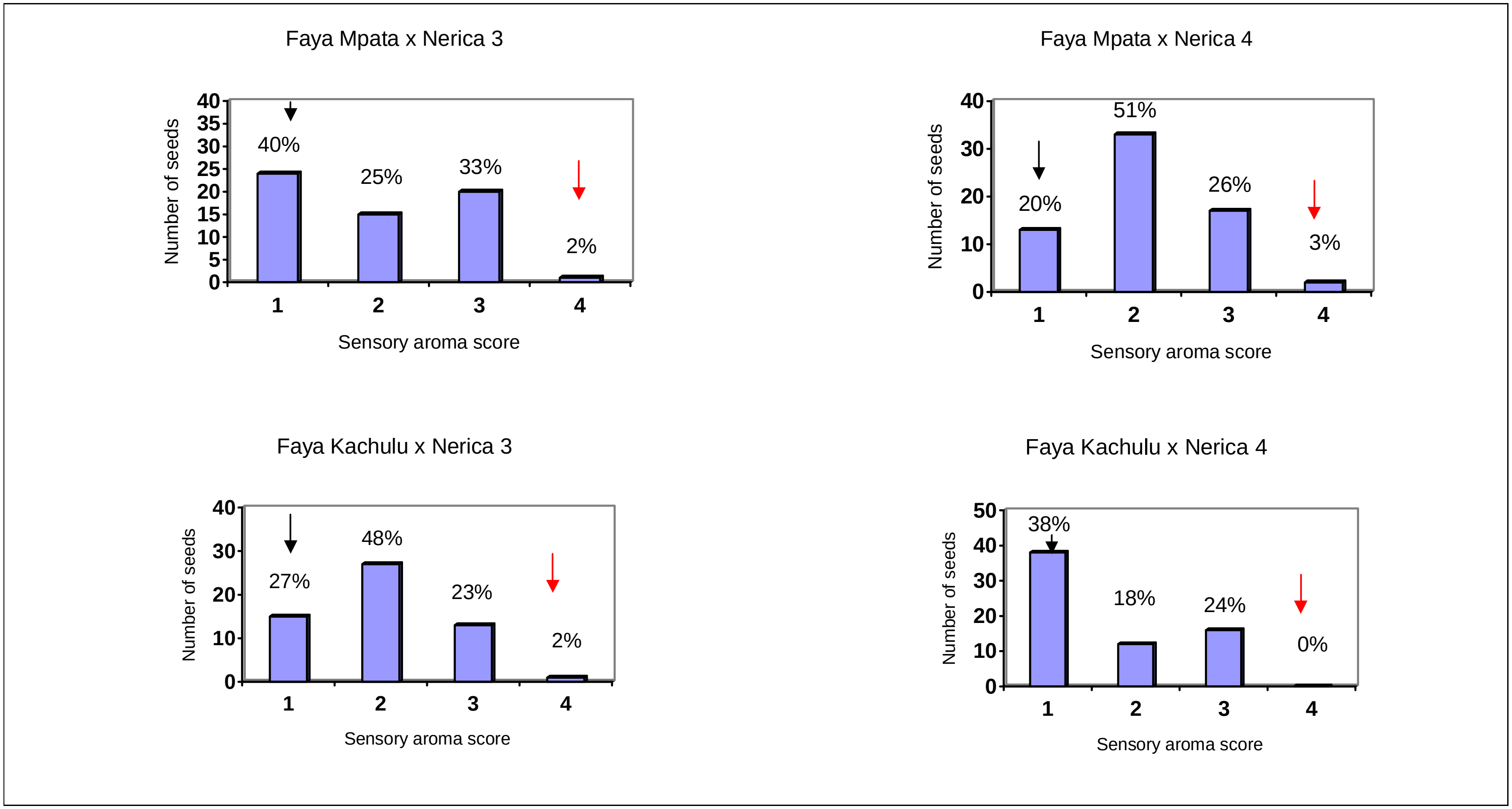
5.3.2 Phenotypic distribution of aroma in F_2 progenies

Frequency distributions of aroma scores in the F_2 populations are shown in Figure 5.1 for the four crosses. The mean scores for the landrace parents Faya Mpata and Faya Kachulu were 4 (representing strong aroma) while the mean scores for NERICA 3 and NERICA 4 were 1 for no aroma. In the cross Faya Mpata x NERICA 3, 40% of the F_2 progeny scored 1 for no aroma while 2% scored 4 for strong aroma (Figure 5.1).

For the rest of the progenies in the cross, 25% scored 2 for slight aroma and 33% scored 3 for moderate aroma. In the cross Faya Mpata x NERICA 4, the distribution of the progenies was as follows: 20% scored 1 for no aroma, 3% scored 4 for strong aroma, 51% scored 2 for slight aroma and 26% scored 3 for moderate aroma.

The distribution in the cross Faya Kachulu x NERICA 3 showed that 27% of the F_2 progenies had no aroma (score of 1) while 2% scored 4 for strong aroma (Figure 5.1). Close to a half (48%) of the sampled F_2 progenies had score of 2 for slight aroma and 23% had score of 3 for moderate aroma.

More than half (58%) of the progenies in the cross Faya Kachulu x NERICA 4 had score of 1 for no aroma, 18% had score of 2 for slight aroma and 24% had score of 3 for moderate aroma (Figure 5.1). There were no progeny with a score of 4 for strong aroma in the cross Faya Kachulu x NERICA 4.



Faya Mpata x Nerica 3

Faya Mpata x Nerica 4

Faya Kachulu x Nerica 3

Faya Kachulu x Nerica 4

Figure 5.1: Frequency distribution of grain aroma scores in 4 F_2 populations. Score description: 1 = no aroma; 2 = slight aroma; 3 = moderate aroma; 4 = strong aroma. Arrows denote score for female (red) and male (black) parents. The scores were on F_3 grains, but are inferred on corresponding F_2 plants.

5.3.3 Chi-square test and inheritance of gelatinization temperature

Results in Table 5.4 showed that the F_1 hybrids between landrace parents, with intermediate gelatinization temperature, and NERICA varieties, with high gelatinization temperature, all had intermediate gelatinization temperature. The 200 F_2 progenies in the cross Faya Mpata x NERICA 4 segregated into 59 with high gelatinization temperature and 141 with intermediate gelatinization temperature (Table 5.4). The chi-square value (2.160) for goodness of fit to a 3:1 ratio was not significant.

In the cross Faya Kachulu x NERICA 3, 42 F_2 progenies had high gelatinization temperature while 158 had intermediate gelatinization temperature and the chi-square value (1.707) was not significant (Table 5.4). In the cross Faya Kachulu x NERICA 4 cross, the F_2 progenies segregated into 45 and 155 for high gelatinization temperature and intermediate gelatinization temperature, respectively (Table 5.4). The chi-square value (0.667) was not significant.

The total chi-square (4.534) and the test of homogeneity chi-square were both significant (Figure 5.4) although the pooled chi-square value (0.143) for the three crosses was non-significant. By iteration, the cross Faya Mpata x NERICA 4 (Table 5.4) was found to be the cause of heterogeneity, and was removed from the pooled estimates of chi-square values. The test of the total chi-square value (2.374) and the homogeneity of chi-square value (0.121) for the other two populations was not significant (Table 5.4).

In the cross Faya Mpata x NERICA 3, the F_1 hybrids had intermediate gelatinization temperature while 35 F_2 progenies out of 200 had high gelatinization temperature while 165 progenies had intermediate gelatinization temperature (Table 5.5). The non significant chi-square value (2.05) indicated that the segregation did not significantly deviate from the hypothesis that they are a good fit to a 3:13 segregation ratio.

Table 5.4: Phenotypic segregation of parents, F_1 and F_2 plants for gelatinization temperature (GT) in three rice crosses and their respective chi-square values against expected 1:3 ratio for high GT:intermediate GT

Population		**Total number of plants**					**X^2**
		Total	**High GT**		**I/mediate GT**		
			Observed	**Expected**	**Observed**	**Expected**	
(a) Population 1							
Faya Mpata	P_1	50			50		
NERICA 4	P_2	50	50				
Faya Mpata/NERICA 4	F_1	50		50	50		
Faya Mpata/NERICA 4	F_2	200	59	50	141	150	2.160ns
(b) Population 2							
Faya Kachulu	P_1	50			50		
NERICA 3	P_2	50	50				
Faya Kachulu/NERICA 3	F_1	50		50			
Faya Kachulu/NERICA 3	F_2	200	42	50	158	150	1.707ns
(c) Population 3							
Faya Kachulu	P_1	50			50		
NERICA 4	P_2	50	50				
Faya Kachulu/NERICA 4	F_1	50		50			
Faya Kachulu/NERICA 4	F_2	200	45	50	155	150	0.667ns
(d) Test for homogeneity (all populations)							
Total X^2							4.534*
Pooled X^2	F_2	600	146	150	454	450	0.143ns
Homogeneity (Total X^2- Pooled X^2)							4.391*
(e) Test for homogeneity (Populations b and c)							
Total X^2							2.374ns
Pooled X^2	F_2	400	87	100	313	300	2.253ns
Homogeneity (Total X^2- Pooled X^2)							0.121ns

ns = observed segregation not significantly different from the expected segregation ratio of 1:3 for high GT:intermediate GT; * = significant at P=0.05, when tested against $X^2_{1,\,0.05}$= 3.840 and $X^2_{1,\,0.01}$= 6.635; P_1 and P_2 denote the female and male parents in the cross, respectively.

Table 5.5: Phenotypic segregation of parents, F_1 and F_2 plants for gelatinization temperature (GT) in one rice cross and the chi-square value against expected 3:13 ratio for high GT:intermediate GT

Population		Total number of plants					X^2
		Total	High GT		I/mediate GT		
			Observed	Expected	Observed	Expected	
Faya Mpata	P_1	50			50		
NERICA 4	P_2	50	50				
Faya Mpata x NERICA 3	F_1	50		50	50		
Faya Mpata x NERICA 3	F_2	200	35	37.5	165	162.5	0.205ns

ns = observed segregation ratio not significantly different from expected ratio of 3:13 for high GT:intermediate GT; significant when tested against and $X^2_{1,\ 0.05}$= 3.840 and $X^2_{1,\ 0.01}$= 6.635; P_1 and P_2 denote the female and male parent in the cross, respectively.

5.3.4 Phenotypic distribution of alkali spreading values in F_2 progenies

Frequency distributions for alkali spreading values (ASV) are presented in Figure 5.2. The mean ASVs were 2 and 4 for the NERICA male parents and landrace female parents, respectively. In the cross Faya Mpata x NERICA 3, 9.5% of the progenies had ASV equal to NERICA 3 and 33% had ASVs equal Faya Mpata. In the cross Faya Mpata x NERICA 4, 25% of the progenies were equal to NERICA 4 in ASVs while 22.5% were equal to Faya Mpata (Figure 5.2).

The proportion of progenies that had mean ASVs equal to parents in the cross Faya Khanda x NERICA 3 were as follows: 17% equal to NERICA 3 and 33.5% equal to Faya Khanda. In the cross Faya Kachulu x NERICA 4, 20.5% of the progenies had ASVs equal to NERICA 4 and 40.5% had ASVs equal to Faya Kachulu (Figure 5.2).

By calculation, out of 200 progenies, the proportion of progenies with intermediate gelatinization temperature (ASV 3-5), equivalent to female landraces, were as follows: 79.5% in Faya Mpata x NERICA 3, 73.5% in Faya Kachulu x NERICA 4, 73% in Faya Kachulu x NERICA 3 and 69.5% in Faya Mpata x NERICA 4 (Figure 5.2). The proportion of transgressive segregants (low gelatinization temperature, ASV 6-7) were obtained as follows: 6% in Faya Kachulu x NERICA 3, 4.5% in Faya Mpata x NERICA 3, 4% in Faya Kachulu x NERICA 4 and 1% in Faya Kachulu x NERICA 4 (Figure 5.1).

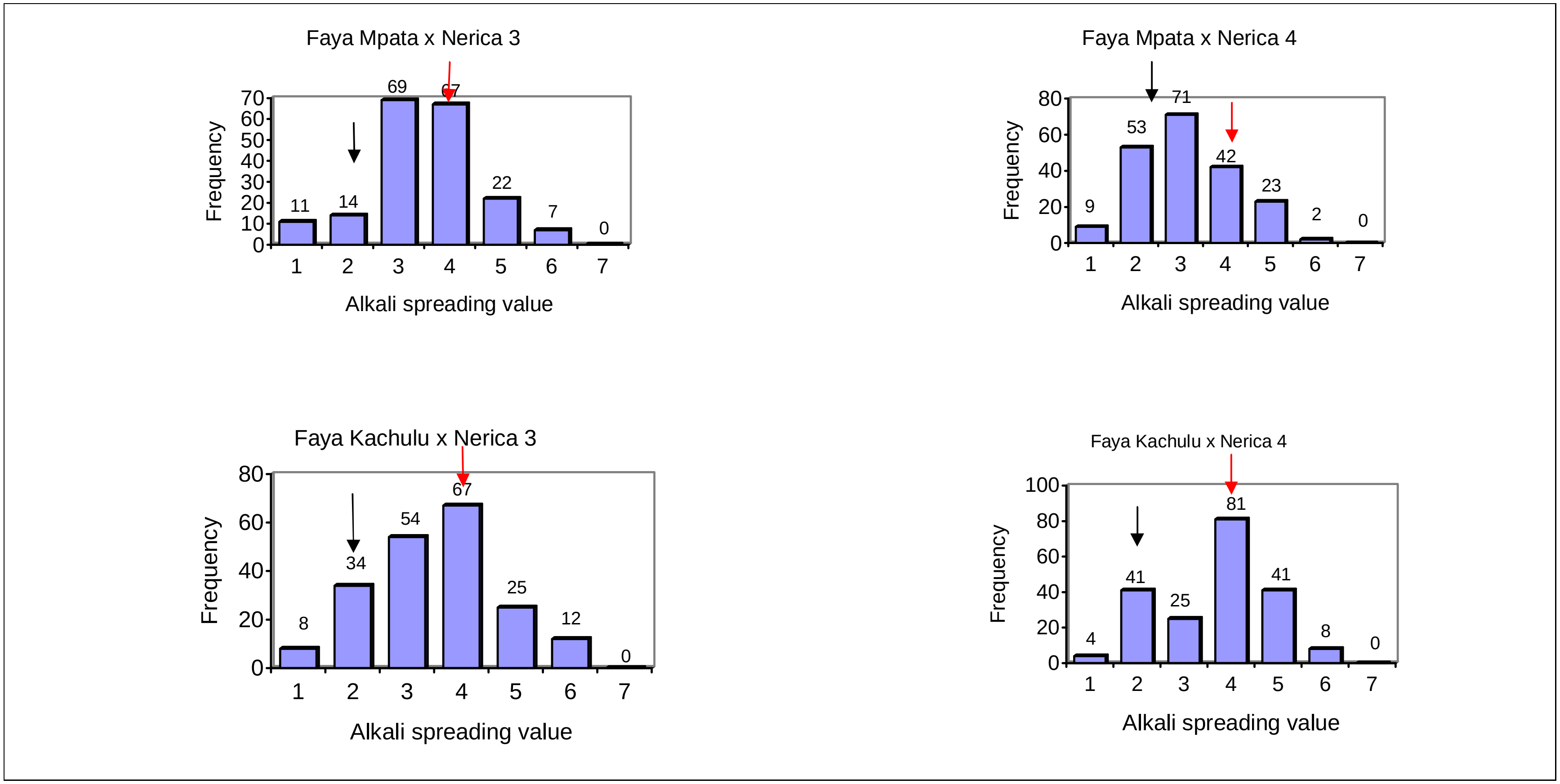


Figure 5. 2: Frequency distribution of seeds by alkali spreading value (ASV) in 4 F_2 populations. ASV 1-2 = High GT; ASV 3-5 = Intermediate GT; ASV 6-7 = Low GT. Arrows denote mean ASV of female (red) and male (black) parents.

5.4 Discussion

In the crosses between the aromatic Malawi rice landraces and the non-aromatic NERICA varieties, all the F_1 hybrids were non-aromatic suggesting that aroma was a recessive trait in the landraces. Akhatar et al. (1995) and Ali et al. (1994) also found that crosses between aromatic and non-aromatic varieties resulted in non-aromatic F_1 hybrids. The F_2 progenies in all the four crosses in this study segregated into the ratio of 3:1 for non-aromatic:aromatic, suggesting a monogenic Mendellian ratio. Dudhare and Jadhav (2006) found similar results in an inheritance study of six aromatic and four non-aromatic rice varieties in India. Similar findings were reported by other workers including Dong et al. (2000) and Gupta et al., 2006).

The absence of aroma in the F_1 and segregation of the F_2 into two classes of 3 non-aromatic to 1 aromatic ratio have, therefore, suggested that the aroma in the two Malawi rice landraces is probably simply inherited through a single recessive gene. Segregating F_2 populations involving one aromatic parent have been known to give different non-aromatic:aromatic ratios depending on the non-aromatic parent used. For example, Dudhare and Jadhav (2006) found that when the aromatic Krishnabogh was crossed to the non-aromatic Swarna variety, the F_2 segregated into 3 non-aromatic:1 aromatic, suggesting a monogenic recessive inheritance. When the same aromatic Krishnabogh was crossed to the non-aromatic IR 64, the segregation ratio was 15 non-aromatic:1 aromatic, suggesting duplicate gene epistatic interaction in the inheritance of the aroma. Vivekanandan and Giridharan (1994) reported both monogenic and digenic recessive inheritance in the F_2 population of a cross involving the aromatic Pusa Basmati variety.

Among the four crosses, the highest proportion of the desirable progenies with strong aroma were found in the cross Faya Mpata x NERICA 4. Two crosses namely Faya Mpata x NERICA 3 and Faya Kachulu x NERICA 4 had similar proportion of progeny with moderate aroma. No progenies with strong aroma were found in the cross Faya Mpata x NERICA 4. A third of the progenies in Faya Mpata x NERICA 3 and Faya Mpata x NERICA 3 had moderate aroma. The observed differences could probably be due to the presence of suppressor genes or modifiers.

All the F_1 progenies, between landraces with intermediate gelatinization temperature and NERICA varieties with high intermediate gelatinization temperature, had intermediate gelatinization temperature. This suggested that intermediate gelatinization temperature trait was dominant over the high gelatinization temperature. A similar finding was reported by Hsieh and Wang (1988). Faruq et al. (2004) found results similar to these in a study of inheritance of gelatinization temperature. They reported that crosses between varieties with high gelatinization temperature and intermediate gelatinization temperature resulted into progeny that had intermediate gelatinization temperature. Faruq et al. (2004) interpreted the result as a probable indication of dominance of intermediate over high gelatinization temperature.

Analysis of segregating progenies in F_2 generation showed that the pattern was suited to a 3:1 ratio for intermediate gelatinization temperature:high gelatinization temperature in the crosses Faya Mpata x NERICA 4, Faya Kachulu x NERICA 3 and Faya Kachulu and NERICA 4. In these three crosses gelatinization temperature was probably under the control of a single gene. The segregation pattern in the cross Faya Mpata x NERICA 4 was suited to a 3:13 ratio for intermediate gelatinization temperature:high gelatinization temperature. In this cross, therefore, gelatinization temperature was probably under the control of two genes, where one gene, when dominant, inhibited the other gene.

The distribution of gelatinization temperature was unimodal and appeared continuous in the crosses Faya Mpata x NERICA 3, Faya Mpata x NERICA 4 and Faya Kachulu x NERICA 3. The continuous distribution probably indicated quantitative inheritance as also found by Puri and Siddiq (1980) in low x low, intermediate x intermediate and high x high gelatinization temperature parents. Heda and Reddy (1986) also found continuous and unimodal distribution in low x intermediate and intermediate x intermediate gelatinization temperature parents. The distribution in Faya Kachulu x NERICA 4 appeared continuous but unimodal. Similar results have been reported by Puri and Siddiq (1980) and Heda and Reddy (1986). Different results concerning the inheritance of gelatinization temperature have led workers to conclude that the inheritance of gelatinization temperature may be complex in nature (Kiani et al., 2008; Mohamad et al., 2004).

The highest proportion of progenies, with alkali spreading value equal to that of the landraces, were obtained from Faya Kachulu x NERICA 3 cross. The crosses Faya Mpata x NERICA 3 and Faya Kachulu x NERICA 3 had equal proportions of progeny with alkali spreading values equivalent to the landraces. In terms of gelatinization temperature class, the highest number of progenies, with the preferred intermediate gelatinization temperature was obtained from Faya Mpata x NERICA 3 and Faya Kachulu x NERICA 3. Transgressive segregants, with low gelatinization temperature, were present suggesting that there was recombination of genes between the high and the intermediate gelatinization temperature parents. Singh et al., (2000) indicated that transgressive segregation may be caused by modifier genes. The presence of the transgressive segregants in this study may also be attributed to the presence of modifier genes.

5.5 Conclusion

The segregation patterns observed in this study showed that a single recessive gene was responsible for the aroma trait of the four Malawi rice landraces. The implication of this finding is that breeding and selecting for aroma trait may be accomplished relatively easily because the trait is simply inherited. A high number of breeding lines with strong aroma may be recovered from the segregating populations of the cross Faya Mpata x NERICA 4. A high number of breeding lines with moderate aroma may be found within the cross Faya Mpata x NERICA 3. The inheritance of intermediate gelatinization temperature was not very clear but was probably controlled by a single dominant gene in three Malawi landraces, and probably by two dominant genes in one landrace. A high number of breeding lines with preferred intermediate gelatinization temperature could be found from the crosses Faya Kachulu x NERICA 3 and Faya Mpata x NERICA 3.

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Chapter 6: Evaluation of Yield and Yield Components in F_2 generation of Malawi Rice (*Oryza sativa* L.) Landraces and NERICA Variety Crosses

Abstract

Information on the genetic control of yield and yield related traits is lacking for Malawi rice landraces. The objectives of this study were to 1) estimate the genetic variability and heritabilities 2) determine the correlations and path coefficients and 3) determine the general and specific combining abilities for yield and yield related traits. A North Carolina Design II mating scheme was used to generate 16 F_2 populations by making crosses between four Malawi rice landraces and four NERICA varieties. The parents and F_2 populations were grown in a Randomized Complete Block design with three replicates in 2008. There was considerable variability that would facilitate selection for yield related traits such as number of panicles per hill, panicle length and panicle weight. Heritability estimates were found to be high for panicle weight (64.1%), 1000-grain weight (63.2%), plant height (55.5%) and grain yield (48.7%) indicating substantial contribution of additive gene effects in the traits. Selection for these traits would be effective in early generations. There were significant ($P=0.05$) positive correlations between grain yield and panicle weight ($r=0.79$) and number of panicles per hill ($r=0.55$) suggesting that they would be effective for indirect selection for yield. Panicle weight, the number of panicles per hill and days to 50% flowering had highest direct effects on yield. Significant general and specific combining abilities indicated the importance of both additive and non-additive gene actions in the control of yield and yield related traits. Bulk breeding would be an effective strategy for the improvement of grain yield, the number of panicles per hill and plant height because additive gene effects were relatively more important that non-additive gene effects in these traits. The findings also suggest that development of hybrid varieties could also be profitable, especially for days to 50% flowering, panicle length, panicle weight and 1000-grain weight because, for these traits, non-additive gene actions were relatively more important than additive gene actions. Faya Mpata, Faya Zidyana and NERICA 3 could be the best parents for breeding to improve grain yield due to their general combining abilities for yield and at least any other three yield related traits.

Keywords: Rice landraces, NERICA, Heritability, Genotypic correlation, Path coefficient, General combining ability, Specific combining ability.

6.1 Introduction

Optimizing yield is one of the most important goals for most farmers. In order to formulate efficient breeding programmes, for improvement of yield, it is essential to characterize the nature and mode of gene action that determines the yield and its components (Vanaja et al., 2003). Combining ability analysis, proposed by Griffing (1956), is a statistical technique to study the nature of gene action in quantitative traits. Combining ability analysis is also used to classify parental lines in terms of their hybrid performance (Ali and Khan, 1998; Yadav et al., 1998; Bhutta et al., 1997) and to identify potential parents and superior combinations for rice traits (Singh et al., 2007; Panwar, 2005; Chakraborty et al., 1994). Several workers have used combining ability analysis in order to study gene action for yield and yield related traits in rice. Sharma et al. (2005) reported that non-additive gene action was predominant in the control of plant height, days to 50% flowering, panicle length, 1000-grain weight and grain yield. Rosamma and Vijayakumar (2005) found that non-additive gene action was predominant for the control of grain yield in rice. Kumar et al. (2007) indicated that both additive and non-additive gene action were important for yield and yield related traits. Venkatesan et al. (2007) reported that non-additive gene action was predominant in the control of days to 50% flowering, plant height, the number of panicles per hill, and the grain yield while Kumar et al. (2007) indicated that additive gene action was predominant for the control of these traits.

Heritability of a trait is important in determining its response to selection and grain yield is known to have low heritability. Gravois and McNew (1993) estimated 45% heritability in rice for number of panicles per hill and 31% for panicle weight. Takeda and Saito (1983) reported high heritability for 1000-grain weight. The heritability estimates ranged from 63% to 90% (Takeda and Saito, 1983). On the other hand, Kato (1997) estimated 16% heritability for the number of panicles per hill and 20% to 33% for number of spikelets per panicle. Sürek and Korkut (1998) reported high narrow-sense heritability for 1000-grain weight, moderate for the number of spikelets per panicle and low for the number of panicles per hill.

Yield is a complex character that is determined by several components. It is necessary to determine the correlations between yield and components that have a great effect on yield (Özer et al., 1999; Gravois and McNew, 1993). The correlations are of great importance to breeders because they can be used to indirectly select for high yielding genotypes (Özer et al., 1999; Feil, 1992). A correlation study on yield and its contributing characters in rice by Ramakrishnan et al. (2006) concluded that the selection concentrated on spikelet sterility and number of grains per panicle could be advantageous because of positive correlations of these traits with grain yield. Venkateswarlu et al. (1986) examined the effect of the high density grain on grain yield. They suggested that increasing the proportion of high density grains would enhance potential yield. An estimated 30% increase in grain yield is possible by increasing the number of grains per panicle. On the other hand, Kato (1997) reported that selection for grain size of rice was effective even during early generations after crossing. Sürek et al. (1998) reported that grain yield per plant was significantly correlated with the number of panicles per plant and 1000-grain weight.

While correlation coefficients are very important in determining traits that affect grain yield, they are insufficient to determine whether the traits affect grain yields directly or indirectly (Mebrahtu et al., 1991; Bhatt, 1973). Path coefficients determine both the direct and indirect effects (Dewey and Lu, 1959). Path coefficient analysis is used to organize and present relationships between dependent and independent variables (Samonte et al., 1998). Path coefficient analysis divides the correlation coefficients into direct and indirect effect (Board et al., 1997; Gravois and Helms, 1992). Path-coefficient analysis has been used by breeders to assist in identifying traits that are useful as selection criteria to improve yield in rice (Mustafa and Yassir Elsheikh, 2007; Natarajan et al., 2005; Surek and Beser, 2003; Rao et al., 1997). Some workers such Surek and Beser (2003) and Yolanda and Das (1995) found that 1000-grain weight had the high direct effect on yield. Zahid et al. (2005) and Prasad et al. (2001) found that the number of panicles per hill and plant height had negative direct effects on rice yield.

Information on genetic control of yield related traits would be essential but is lacking for the Malawi rice landraces hence the need to generate that information. The hypotheses of this study were that 1) there is highly heritable genetic variation for yield related traits in progenies from Malawi rice landraces, 2) the Malawi rice landraces can produce recombinants with superior grain yield traits, and 3) yield related traits are positively correlated with and have high direct effects on grain yield. The objectives were to 1) estimate the genetic variability and heritabilities for yield related traits, 2) determine the correlations and path coefficients for yield related traits, and 3) determine the general and specific combining abilities for yield and yield related traits in F_2 populations of crosses between Malawi rice landraces and NERICA varieties.

6.2 Materials and Methods

Location of study

The experiment was carried out at the irrigated fields of Lifuwu Research Station at latitude 13^o 40$^'$ S and longitude 34^o 35$^'$ S. The elevation of the station is 500 metres above sea level. The station receives annual average rainfall of 1 253mm and highest and lowest annual temperatures are 29.7 ^{o}C and 20.4 ^{o}C, respectively, with annual mean temperature of 25.1 ^{o}C. The soils of the station are described as Vertisols of 45% clay with average pH 8.3 and 1.6% organic matter (Sistani et al., 1998).

Germplasm used in the study

There were a total of 16 F_2 populations generated by mating Malawi rice landraces and NERICA rice varieties, in a North Carolina design II scheme (Comstock and Robinson, 1948) in 2006. The parents and 16 cross combinations are shown in Table 6.1.

Experimental Design and Management

In 2007, the F_1 were planted in bulk plots to eliminate selfed plants, and the true crosses were planted as F_2 in 2008. The true crosses were identified by planting the F_1 between its female and male parent. Any F_1 plant that resembled the female parent was not a true cross. The F_2 experiment was laid out in a Randomized Complete Block Design with three replications. Each entry was planted in plots of gross size 5 m x 3 m and net size 4 m x2 m. The spacing between plant stations was 30 cm x 30 cm with transplanting one seedling per plant station in December, 2007. Fertilizer was applied at the rate of 80 + 50 + 25 kg ha^{-1} NPK, with half the N and all P and K basal dressed on the day of transplanting, and the remaining half of N, 30 days after transplanting.

Table 6.1: The cross combinations and the number of lines planted in the experiment.

Variety/Population	Parentage	Origin
Faya Mpata	Landrace	Malawi Rice Collection
Faya Khanda	Landrace	Malawi Rice Collection
Faya Kachulu	Landrace	Malawi Rice Collection
Faya Zidyana	Landrace	Malawi Rice Collection
NERICA 3	WAB 56-104/CG14	WARDA
NERICA 4	WAB 56-104/CG14	WARDA
NERICA 5	WAB 56-104/CG 14	WARDA
NERICA 6	WAB 56-104/CG 14	WARDA
Faya Mpata x NERICA 3	F_2	
Faya Mpata x NERICA 4	F_2	
Faya Mpata x NERICA 5	F_2	
Faya Mpata x NERICA 6	F_2	
Faya Khanda x NERICA 3	F_2	
Faya Khanda x NERICA 4	F_2	
Faya Khanda x NERICA 5	F_2	
Faya Khanda x NERICA 6	F_2	
Faya Kachulu x NERICA 3	F_2	
Faya Kachulu x NERICA 4	F_2	
Faya Kachulu x NERICA 5	F_2	
Faya Kachulu x NERICA 6	F_2	
Faya Zidyana x NERICA 3	F_2	
Faya Zidyana x NERICA 4	F_2	
Faya Zidyana x NERICA 5	F_2	
Faya Zidyana x NERICA 6	F_2	

Data collection

Data on plant height, days to 50% flowering, number of panicles per hill, panicle weight, panicle length, number of filled grains per panicle, 1000-grain weight and grain yield per hill were recorded. The data were collected on four plants from each replicate from the middle of each net plot at growth stages outlined in the Standard System for Evaluation of Rice (IRRI, 2002). Plant height was measured in cm from the surface of the soil to the tip of the tallest tiller on any hill at maturity stage. Days to 50% flowering were counted from the day of sowing to the day when 50% of the tillers in a hill had flowered. Panicles per hill were recorded as the actual number of tillers per plant (station), including the main tiller, at booting stage. Panicle weight was obtained by weighing all the tillers at each hill and recorded in grams at 14% moisture content. Panicle length was measured in cm from the base to the tip of the panicles in each hill. Number of filled grains per panicle was recorded as the average number on each hill. Grain yield was recorded at maturity stage as the weight in grams per hill standardized to 14% moisture content.

Data analysis

All data collected were subjected to the analysis of variance (ANOVA). The ANOVA model for the randomized complete block design at the one location and in the one year was: $Y_{ij} = μ + α_i + β_j + Є_{ij,}$ where: Y_{ij} is the observed value of the i^{th} genotype for the j^{th} replicate (where i=1 to 4 and j=1 to 3); μ is the grand mean; $α_i$ is the treatment effect for the i^{th} genotype, with the genotypes assumed to be random; $β_j$ is the block effect for the j^{th} block; $β_{ij}$ is the random error associated with the Y_{ij} experimental unit. The following ANOVA (Table 6.2) for the North Carolina design II (NCD II) mating scheme (Hill et al., 1998) was used:

Table 6.2: General ANOVA for NCD II and how effects were tested.

Source	**Df***	**Mean squares**	**Variance components**	**F-test**
Landraces	f-1	MS_f	$б^2_e + rб^2_{fm} + rmб^2_f$	MS_f / MS_{fm}
NERICAs	m-1	MS_m	$б^2_e + rб^2_{fm} + rfб^2_m$	MS_m / MS_{fm}
Landraces x NERICAs	(f-1)(m-1)	MS_{fm}	$б^2_e + rб^2_{fm}$	MS_{fm} / MS_e
Error	fm(r-1)	MS_e	$б^2_e$	

* f = 4 landrace females; m = 4 NERICA males; r = 12 observations within populations.

Genetic parameters of additive, dominance, and phenotypic variance, as well as heritability in the narrow-sense were estimated by decomposing the expected mean squares into components as suggested by Hallauer and Miranda (1989). Genotypic correlation (r_g) and phenotypic correlation (r_p) were calculated for all the traits using the methods suggested by Al-Jibouri et al. (1958) and Kwon and Torrie (1964) as follows:

$$r_g = (Cov_{XY})/\sqrt{}(Var_X * Var_Y),$$

Where,

Cov_{XY} = the covariance of the two traits X and Y'

Var_X = the variance of the trait X, and

Var_Y = the variance of the trait Y.

$$r_p = (M_{XY})/\sqrt{}(MS_x*MS_Y)$$

Where:

M_{XY} = the mean product for traits X and Y,

MS_x = the mean squares for trait X, and

MS_Y = the mean squares for trait Y.

The r_g between two traits was considered significant if the absolute value exceeded twice the standard error, which was calculated using the formula suggested by Robertson (1959). The statistical test for the r_p was determined by using the "t" test as described by Steel et al. (1997).

The path coefficients were calculated following the methods of Dewey and Lu, (1959). To obtain the path coefficients, the procedure outlined by Surek and Beser (2003) was followed. The path coefficients were the direct effects of any yield component as the independent variable, towards grain yield, the dependent variable. The indirect effects were computed as the sum of the products between path coefficients and the genotypic correlations of the yield related traits. The residual effect of the path analysis was computed as the square root of the products of path coefficients and the genotypic correlations (Surek and Beser, 2003). There are no significance tests of path coefficients (Dogan, 2004) so the coefficients were just compared with their absolute values. The signs of the coefficients show the direction of the direct or indirect effect of a particular trait on yield (Dewey and Lu, 1959). High absolute values indicated greater effect. All computations were accomplished using Genstat statistical software commands (Payne et al., 2007).

In the analysis for combining ability, the variation in the crosses was partitioned into general combining ability (GCA) and specific combining ability (SCA) according to the methods described by Simmonds (1979). The adapted genetic model was as follows:

$$Y_{fmk} = \mu + GCA_f + GCA_m + SCA_{fm} + r_k + e_{fmk}$$

Where Y is the mean of the cross between f and m varieties; GCA_f is the general combining ability of female f; GCA_m is the general combining ability of male m; SCA_{fm} is the specific combining ability between female f and male m; r_k is the replication effect; e_{fm} is the error term.

6.3 Results

6.3.1 Variability, heritability and degree of dominance

Results showed significant (P=0.01) differences among the four landraces for the yield and yield related traits (Table 6.3). The traits were grain yield per hill, plant height, panicle weight, and 1000-grain weight. Significant differences (P=0.01) for six yield related traits were observed among the NERICA varieties. The NERICA varieties did not differ for grain yield per hill (Table 6.3). Between the F_2 progeny, significant differences (P=0.01) were observed for grain yield and yield related traits (Table 6.3). The range of phenotypic values for grain yield was found to be 9.9 g to 19.9 g per hill (Table 6.4). The number of panicles per hill ranged from one to eight. The range of plant height for the F_2 progenies was 120 cm to 140 cm and they flowered within the range of 87 to 99 days (Table 6.4). The ranges of panicle length and panicle weight were, respectively, 17.6 cm to 27.4 cm and 13.4 g to 29.8 g. The range of the 1000-grain weight was 27.7 g to 33.7 g (Table 6.4).

The estimates of heritability in the narrow sense are shown in Table 6.4. Among the traits the highest heritability in the narrow sense was found for panicle weight (64.1%) followed by 1000-grain weight (63.2%), plant height (55.5%). Moderate heritability in the narrow sense was found for grain yield per hill (48.7%). Low heritability was found for number of panicles per hill (16.1%), days to 50% flowering and for panicle length (6.3%) (Table 6.4). Very high degree of dominance or over dominance was recorded for panicle length (1.31) while high degree of dominance was recorded for number of panicles per hill (0.83) and plant height (0.48) (Table 6.4). The degree of dominance was moderate for days to 50% flowering date (0.41) and grain yield per hill (0.33). Low degree of dominance was recorded for panicle weight (0.25) and 1000-grain weight (0.19) (Table 6.4).

Table 6.3: Analysis of variance for yield and yield components in the F_2 populations of crosses between Malawi rice landraces and NERICA varieties.

Source of variation	df[1]	Mean sum of squares						
		GYPH (g)	PPH	PH (cm)	DTF	PL (cm)	PW (g)	TGW (g)
Landraces	3	67.142**	7.727**	169.172**	12.727**	15.284**	347.751**	273.178**
NERICAs	3	3.771ns	5.922**	39.964**	8.352**	12.655**	326.426**	254.566**
Landraces x NERICAs	9	3.388**	2.422**	9.903**	3.741**	8.439**	18.255**	13.562**
Error	176	2.531	1.657	4.554	3.449	6.073	13.2	11.42

[1] Df = degrees of freedom; ns = non-significant; * = Significant at 5% level. * = Significant at 1% level .GYPH=grain yield per hill; PPH=number of panicles per hill; Ph=plant height; DTF=days to 50% flowering date; PL=panicle length; PW=panicle weight; TGW=1000-grain weight.

Table 6.4: Range and estimates of variance components, and narrow sense heritability[1] for yield and yield related traits in 16 F_2 populations

Characters	**Range**	**V_A**	**V_D**	**V_E**	**V_P**	**h^2 ±SE(%)**	**Degree of dominance (d)[2]**
Grain yield per hill (g)	9.9-19.5	2.672	0.286	2.531	5.489	48.7±1.35	0.33
No. of panicles per hill	1-8	0.367	0.255	1.657	2.279	16.1±1.09	0.83
Plant height (cm)	120-140	7.889	1.783	4.554	14.226	55.5±0.26	0.48
Days to 50% flowering	87-99	0.566	0.097	3.449	4.112	13.8±1.39	0.41
Panicle length (cm)	17.6-27.4	0.461	0.789	6.073	7.323	6.3±0.51	1.31
Panicle weight (g)	13.4-29.8	26.569	1.685	13.200	41.454	64.1±0.05	0.25
1000 grain weight (g)	27.7-33.7	20.859	0.714	11.420	32.993	63.2±0.03	0.19

[1] V_A = additive variance; V_D = dominance variance; V_E = environmental variance; V_P = phenotypic variance; h^2 = narrow sense heritability; [2] Degree of dominance=$(\sqrt{V_D}/\sqrt{V_A})$.

6.3.5 Combining ability analysis

Relative importance of GCA and SCA effects

Table 6.5 shows the percentages of sum of squares attributable to combining ability effects for grain yield and yield related traits. The general combining ability of landraces were greater than the general combining ability of NERICA varieties for grain yield, number of panicles per hill and plant height. General combining ability effects for NERICA varieties were larger than corresponding effects for landraces for days to 50% flowering date, panicle length, panicle weight and 1000-grain weight (Table 6.5).

Generally, specific combining ability effects were larger than general combining ability effects in five out of the seven traits (Table 6.5). Specific combining ability contributed largely to number of panicles per hill, days to 50% flowering date, panicle length, panicle weight and 1000-grain weight. General combining ability effects were predominant for grain yield and plant height (Table 6.5).

Table 6.5: Percentages of cross sum of squares attributable to general combining ability (GCA) and specific combining ability (SCA) effects for grain yield and yield related traits

	Percentage cross sum of squares			
Trait	**GCA landraces**	**GCA NERICAs**	**Total GCA**	**SCA**
Grain yield per hill	86	5	91	9
No. of panicles per hill	39	10	49	51
Plant height	90	1	91	9
Days to 50% flowering	7	9	16	84
Panicle length	4	15	19	81
Panicle weight	11	15	26	74
1000-grain weight	15	21	36	64

General combining ability (gca) effects of parents

Among the landrace parents, significant and positive gca effects were found in Faya Zidyana (0.823, P=0.05) and Faya Mpata (1.207, P=0.01) for grain yield (Table 6.6). For the number of panicles per hill gca effects were low but positive for Faya Zidyana (0.078) and positive and significant (P=0.05) for Faya Khanda. Positive and highly significant (P=0.01) gca effects for plant height were found in Faya Khanda (3.235) and Faya Zidyana (3.673). The gca effects of Faya Kachulu and Faya Khanda were negative and highly significant (P=0.01) for grain yield (Table 6.6). Faya Mpata and Faya Kachulu had negative gca effects for both the number of panicles per hill and plant height (Table 6.6). The gca effects were highly significant (P=0.01) for plant height. The gca effects were non-significant for days to 50% flowering, panicle length, panicle weight and 1000-grain weight (Table 6.6). Faya Mpata had positive gca effects for days to 50% flowering (0.0.318) and panicle weight (0.452) while Faya Khanda had positive gca effects for 1000-grain weight only (Table 6.6). Faya Kachulu had positive gca effects for days to 50% flowering, panicle length and panicle weight. Faya Zidyana had negative gca effects for days to 50% flowering, panicle weight and 1000-grain weight (Table 6.6).

Among the NERICA varieties the only significant (P=0.05) gca effect was found in NERICA 3 for grain yield (Table 6.6). NERICA 4, NERICA 5 and NERICA 6 all had negative gca effects for grain yield (Table 6.6). NERICA 3 and NERICA 4 had negative gca effects for the number of panicles per hill (-0.130 and -0.193, respectively) and positive gca effects for plant height (0.275 and 0.423, respectively) (Table 6.6). In contrast, NERICA 5 and NERICA 6 had positive gca effects for the number of panicles per hill (0.078 and 0.245, respectively) and negative gca effects for plant height (-0.600 and -0.097, respectively). For the trait of days to 50% flowering, only NERICA 6 had negative gca effects among the male parents (Table 6.6). The gca effects of both panicle length and panicle weight were positive for NERICA 3 (0.408 and 0.694, respectively) while they were negative for the other male NERICAs with the exception of NERICA 6 for gca effects for panicle length were positive but low (Table 6.6). Only NERICA 4 had positive gca effects (0.451) for 1000-grain weight while the effects were negative for the other three NERICAs (Table 6.6).

Table 6.6: General combining ability (GCA) estimates for grain yield and yield related traits for 8 parents.

Source	GYPH (g)	PPH	PH (cm)	DTF	PL (cm)	PW (g)	TGW (g)
			GCA landraces				
Faya Mpata	1.207**	-0.318	-3.077**	0.318	-0.222	0.452	-0.284
Faya Khanda	-0.991**	0.537*	3.235**	-0.162	-0.004	-0.453	0.341
Faya Kachulu	-1.039**	-0.297	-3.830**	0.046	0.166	0.192	-0.030
Faya Zidyana	0.823*	0.078	3.673**	-0.202	0.061	-0.191	-0.028
			GCA NERICAs				
NERICA 3	0.382*	-0.130	0.275	0.191	0.408	0.694	-0.125
NERICA 4	-0.293	-0.193	0.423	0.111	-0.174	-0.188	0.451
NERICA 5	-0.049	0.078	-0.600	0.088	-0.302	-0.186	-0.084
NERICA 6	-0.039	0.245	-0.097	-0.389	0.068	-0.321	-0.242

*= significant at 5% level of probability; ** significant at 1% level of probability. GYPH=grain yield per hill; PPH=number of panicles per hill; PH=plant height; DTF=days to 50% flowering date; PL=panicle length; PW=panicle weight; TGW=1000-grain weight.

Specific combining ability (sca) effects of F_2 progenies

Five crosses showed high positive sca effects for grain yield and these were Faya Khanda x NERICA 3 (0.683, P=0.05), Faya Mpata x NERICA 4 (0.548), Faya Zidyana x NERICA 5 (0.441), Faya Kachulu x NERICA 4 (0.137) and Faya Mpata x NERICA 6 (0.133) (Table 6.7). Four crosses also had positive gca effects for yield but the effects were low. The crosses were Faya Kachulu x NERICA 5 (0.077), Faya Khanda x NERICA 6 (0.074), Faya Zidyana x NERICA 6 (0.070) and Faya Kachulu x NERICA 3 (0.064) (Table 6.7).

For the number of panicles per hill in Table 6.7, positive and significant (P=0.05) sca effects were obtained in the crosses Faya Mpata x NERICA 6 (0.547), Faya Zidyana x NERICA 3 (0.484) and Faya Zidyana x NERICA 4 (0.464). High sca effects for the number of panicle per hill were found for Faya Kachulu x NERICA 5 (0.380) and Faya Kachulu x NERICA (0.422). Two crosses, namely Faya Kachulu x NERICA 3 and Faya Zidyana x NERICA 6, had negative sca effects (-0.682 and -0.745, respectively) that were significant (Table 6.7).

Table 6.7: Specific combining ability (SCA) estimates for grain yield and yield related traits for F_2 progenies.

Source	GYPH (g)	PPH	PH (cm)	DTF	PL (cm)	PW (g)	TGW (g)
Faya Mpata x NERICA 3	-0.484	-0.224	1.287**	0.747*	0.124	0.208	-0.083
Faya Mpata x NERICA 4	0.548	-0.078	-0.275	0.307	0.207	0.593	-0.124
Faya Mpata x NERICA 5	-0.197	-0.245	-0.380	-0.151	0.487	0.208	0.522
Faya Mpata x NERICA 6	0.133	0.547*	-0.632	-0.903*	-0.818	-1.009	-0.314
Faya Khanda x NERICA 3	0.683*	0.422	1.140*	0.827	0.927*	-0.169	-0.660
Faya Khanda x NERICA 4	-0.436	-0.266	0.827	-0.523	-0.031	1.806*	0.215
Faya Khanda x NERICA 5	-0.321	0.068	-1.358*	-0.901*	-0.381	-0.319	0.611
Faya Khanda x NERICA 6	0.074	-0.224	-0.610	0.597	-0.516	-1.317*	-0.166
Faya Kachulu x NERICA 3	0.064	-0.682*	0.162	0.099	0.374	0.278	-0.125
Faya Kachulu x NERICA 4	0.137	-0.120	-1.070*	-0.591	-0.003	-1.677*	0.500
Faya Kachulu x NERICA 5	0.077	0.380	0.995*	0.452	-0.443	-0.012	-0.662
Faya Kachulu x NERICA 6	-0.278	0.422	-0.088	0.039	0.072	1.411*	0.286
Faya Zidyana x NERICA 3	-0.263	0.484*	-2.590**	-1.673*	-1.426*	-0.317	0.868
Faya Zidyana x NERICA 4	-0.248	0.464*	0.517	0.807*	-0.173	-0.722	-0.591
Faya Zidyana x NERICA 5	0.441	-0.203	0.743	0.599	0.337	0.123	-0.471
Faya Zidyana x NERICA 6	0.070	-0.745*	1.330**	0.267	1.262*	0.916	0.194

*= significant at 5% level of probability; ** significant at 1% level of probability. GYPH=grain yield per hill; PPH=number of panicles per hill; PH=plant height; DTF=days to 50% flowering date; PL=panicle length; PW=panicle weight; TGW=1000-grain weight.

Highly significant (P=0.01) sca effects for panicle length were found in the cross Faya Khanda x NERICA 3 (0.458) and Faya Zidyana x NERICA 4 (0.333) while positive and significant (P=0.05) sca effects were obtained from the cross Faya Khanda x NERICA 4 (0.187) (Table 6.7). Positive but non-significant sca effects were obtained for panicle length in the crosses Faya Khanda x NERICA 5 (0.667), Faya Mpata x NERICA 3 (0.580), Faya Kachulu x NERICA 3 (0.330) and Faya Zidyana x NERICA 5 (Table 6.7).

The sca effects for plant height were highly significant (P=0.01) for Faya Mpata x NERICA 3 (1.287) and Faya Zidyana x NERICA 6 (1.330), and significant (P=0.05) for Faya Khanda x NERICA 3 (1.140) and Faya Kachulu x NERICA 5 (Table 6.7). Positive sca effects for plant height were also positive for four other crosses, namely Faya Khanda x NERICA 4 (0.827), Faya Kachulu x NERICA 3 (0.162), Faya Zidyana x NERICA 4 (0.743) and Faya Zidyana x NERICA 5 (0.743) (Table 6.7). The sca effects for plant height were negative and significant in the following three crosses: Faya Khanda x NERICA 5 (-1.358, P=0.05), Faya Kachulu x NERICA 4 (-1.070, P=0.05) and Faya Zidyana x NERICA 3 (-2.590, P=0.01) (Table 6.7).

The sca effects for days to 50% flowering were positive in ten out of 16 crosses (Table 6.7). The crosses, and their effects, included Faya Mpata x NERICA 3 (0.747, P=0.05), Faya Zidyana x NERICA 4 (0.807, P=0.05), Faya Khanda x NERICA 3 (0.383), Faya Khanda x NERICA 6 (0.597) and Faya Zidyana x NERICA 5 (0.599) (Table 6.7). Significant (P=0.05) but negative sca effects for days to 50% flowering were found for Faya Mpata x NERICA 6 (-0.903), Faya Khanda x NERICA 5 (-0.901) and Faya Zidyana x NERICA 3 (-1.673) (Table 6.7).

Significant (P=0.05) and positive sca effects for panicle length were found in two crosses, namely Faya Khanda x NERICA 3 (0.927) and Faya Zidyana x NERICA 6 (1.262) (Table 6.7). High positive effects were also found in Faya Mpata x NERICA 5 (0.487), Faya Kachulu x NERICA 3 (0.374) and Faya Zidyana x NERICA 5 (Table 6.7). Negative (-1.426) and significant (P=0.05) sca effects for panicle length were found in the cross Faya Zidyana x NERICA 3 (Table 6.7).

Positive and significant (P=0.05) sca effects for panicle weight were found in the crosses Faya Khanda x NERICA 4 (1.806) and Faya Kachulu x NERICA 6 (1.411) (Table 6.7). In six of the 16 crosses, sca effects for panicle weight were positive but non-significant (Table 6.9). The crosses were Faya Mpata x NERICA 3 (0.208), Faya Mpata x NERICA 4 (0.593), Faya Mpata x NERICA 5 (0.208), Faya Kachulu x NERICA 3 (0.278), Faya Zidyana x NERICA 5 (0.123) and Faya Zidyana x NERICA 6 (0.916). Two crosses, namely Faya Khanda x NERICA 6 and Faya Kachulu x NERICA 4 had negative and significant sca effects for panicle weight (Table 6.7).

The specific combining ability effects for 1000-grain weight were positive in seven out of the 16 crosses (Table 6.7). The crosses were as follows: Faya Mpata x NERICA 5 (0.522), Faya Khanda x NERICA4 (0.215), Faya Khanda x NERICA 5 (0.611), Faya Kachulu x NERICA 4 (0.500) Faya Kachulu x NERICA 6 (0.286), Faya Zidyana x NERICA 3 (0.868) and Faya Zidyana x NERICA 6 (0.194) (Table 6.7). Negative sca effects for 1000-grain weight were found in crosses that included Faya Khanda x NERICA 3 (-0.660), Faya Kachulu x NERICA 5 (-0.662) and Faya Zidyana x NERICA 4 (-0.591) (Table 6.7).

6.3.3 Correlations

Generally, between different traits the genotypic correlations were higher than phenotypic correlations but the differences between them were very small (Table 6.8). Results are presented for genotypic correlations. Grain yield showed positive and significant (P=0.05) correlations with panicle weight (r=0.79) and number of panicles per hill (r=0.55). The positive correlations between grain yield and plant height (r=0.42), days to 50% flowering (0.21), 1000-grain weight (r=0.17) and panicle length (r=0.08) were not significant (Table 6.8). The number of panicles per hill were positively correlated with panicle weight (r=0.26) and plant height (r=0.12) but the correlations were not significant (Table 6.8) . The correlation between number of panicles per hill and 1000-grain weight was negative and significant (r=-0.63, P=0.05). The correlation between number of panicles per hill with days to 50% flowering (r=-0.035) and panicle length (r=-0.33) were not significant (Table 6.8).

Significant (P=0.05) positive correlation was found between plant height and panicle length (r=0.84 (Table 6.8). Positive but non-significant correlations were also found between plant height and days to 50% flowering (r=0.14), as well as 1000-grain weight (r=0.11). Plant height was negatively correlated with panicle weight (r=-0.77) and the correlation was significant (P=0.05). The number of days to 50% flowering were positively correlated to the panicle weight (r=0.94) and the correlation was significant (P=0.05) (Table 6.8). The negative correlations between days to 50% flowering and panicle length (r=-0.11) as well as 1000-grain weight (r=-0.07) were not significant. Positive but non-significant correlations were found between panicle length and panicle weight (r=0.50), as well as 1000-grain weight (r=0.27). The correlation between panicle weight and 1000-grain weight was negative (r=-0.30) and non-significant (Table 6.8).

Table 6.8: Genotypic (G) and phenotypic (P) correlation of yield traits in 16 F_2 populations of Malawi rice landraces x NERICA varieties crosses.

Traits	Correlation	No. of panicles per hill	Plant height (cm)	Days to 50% flowering	Panicle length (cm)	Panicle weight (g)	1000 grain weight (g)
Yield per hill (g)	G	0.55*	0.42	0.21	0.08	0.79*	0.17
	P	0.55*	0.36	0.32	0.17	0.66*	0.27
Panicles per hill	G		0.12	-0.35	-0.33	0.26	-0.63*
	P		0.12	-0.11	-0.34	0.30	-0.64*
Plant height (cm)	G			0.14	0.84*	-0.77*	0.11
	P			0.12	0.86*	-0.29	0.07
Days to 50% flowering	G				-0.11	0.94*	-0.07
	P				-0.12	0.75*	-0.09
Panicle length (cm)	G					0.50	0.27
	P					0.51	0.46
Panicle weight (g)	G						-0.30
	P						-0.20

* Significant at 5% probability level.

6.3.4 Path coefficient analysis

The estimates of direct and indirect contributions of number of panicles per hill, plant height, days to 50% flowering date, panicle length, panicle weight and 1000-grain weight to grain yield are presented in Table 6.9. The results showed that maximum contribution to grain yield was from panicle weight (76.0%) followed by panicles per hill (66.9%). Direct contributions from the other yield related traits were: 41.8% from 1000-grain weight, 24.3% from days to 50% flowering, 17.9% from panicle length and 4.6% from plant height (Table 6.9).

The direct effect of panicles per hill on grain yield was positive (0.543), so too were the indirect effects through plant height (0.112) and panicle weight (0.026) (Table 6.9). The indirect effects of number of panicles per hill were negative via days to 50% flowering, panicle length and 1000-grain weight (Table 6.6). The direct effect of plant height on grain yield was negative as was the indirect effect through panicle weight (Table 6.9). Plant height had indirect positive effects on grain yield through number of panicles per hill (0.112), days to 50% flowering date (0.123), panicle length (0.184) and 1000-grain weight (0.107). The number of days to 50% flowering had a positive direct effect on grain yield (0.106), and positive indirect effects via plant height (0.123) and panicle weight (0.094) (Table 6.9). The number of days to 50 % flowering had negative indirect effects on grain yield via number of panicles per hill, panicle length and 1000-grain weight (Table 6.9).

Panicle length had negative direct effects on grain yield (-0.079) and also negative indirect effects on grain yield through number of panicles per hill (-0.093) and days to 50% flowering date (Table 6.9). The indirect effects of panicle length on grain yield were positive via plant height (0.184), panicle weight (0.05) and 1000-grain weight (0.027). Panicle weight was found to have direct positive effects on grain yield (0.793) (Table 6.9). Indirect effects of panicle weight on grain yield were positive through number of panicles per hill (0.026), days to 50% flowering (0.094) and panicle length (0.05). Panicle weight had negative indirect effects on grain yield via plant height (0.077) and 1000-grain weight (-0.003) (Table 6.9). The 1000-grain weight had negative effects on grain yield directly (-0.175), as well as indirectly via number of panicles per hill days to 50% flowering, panicle length and panicle weight as shown in Table 6.9. The only positive effect of 1000-grain on grain yield (0.107) was indirectly through plant height (Table 6.9).

Table 6.9: Path coefficients showing direct and indirect effects of different yield related traits on grain yield

Path		Path coefficient	Contribution (%)[1]
PPH versus grain yield		r = 0.55* [2]	
Direct effect		0.543	66.9
Indirect via	PH	0.112	13.8
Indirect via	DTF	-0.035	4.3
Indirect via	PL	-0.093	11.5
Indirect via	PW	0.026	3.2
Indirect via	TGW	-0.003	0.4
PH versus grain yield		r = 0.42	
Direct effect		-0.029	4.6
Indirect via	PPH	0.112	17.7
Indirect via	DTF	0.123	19.5
Indirect via	PL	0.184	29.1
Indirect via	PW	-0.077	12.2
Indirect via	TGW	0.107	16.9
DTF versus grain yield		r = 0.21	
Direct effect		0.106	24.3
Indirect via	PPH	-0.035	8.0
Indirect via	PH	0.123	28.2
Indirect via	PL	-0.009	2.1
Indirect via	PW	0.094	21.6
Indirect via	TGW	-0.069	15.8
PL versus grain yield		r = 0.08	
Direct effect		-0.079	17.9
Indirect via	PPH	-0.093	21.0
Indirect via	PH	0.184	41.6
Indirect via	DTF	-0.009	2.0
Indirect via	PW	0.05	11.3
Indirect via	TGW	0.027	6.1
PW versus grain yield		r = 0.79*	
Direct effect		0.793	76.0
Indirect via	PPH	0.026	2.5
Indirect via	PH	-0.077	7.4
Indirect via	DTF	0.094	9.0
Indirect via	PL	0.05	4.8
Indirect via	TGW	-0.003	0.3
TGW versus grain yield		r = 0.17	
Direct effect		-0.175	41.8
Indirect via	PPH	-0.003	0.8
Indirect via	PH	0.107	29.8
Indirect via	DTF	-0.069	19.2
Indirect via	PL	-0.027	7.5
Indirect via	PW	-0.003	0.8

[1] Based on absolute values of direct and indirect effect within a trait (Turk et al., 2008); [2] r = genotypic correlation with yield; * = significant at 5% level of probability. GYPH=grain yield per hill; PPH=number of panicles per hill; Ph=plant height; DTF=days to 50% flowering date; PL=panicle length; PW=panicle weight; TGW=1000-grain weight.

A figurative presentation of the path coefficients (direct effects) and correlations between grain yield and yield related traits is shown in Figure 6.1.

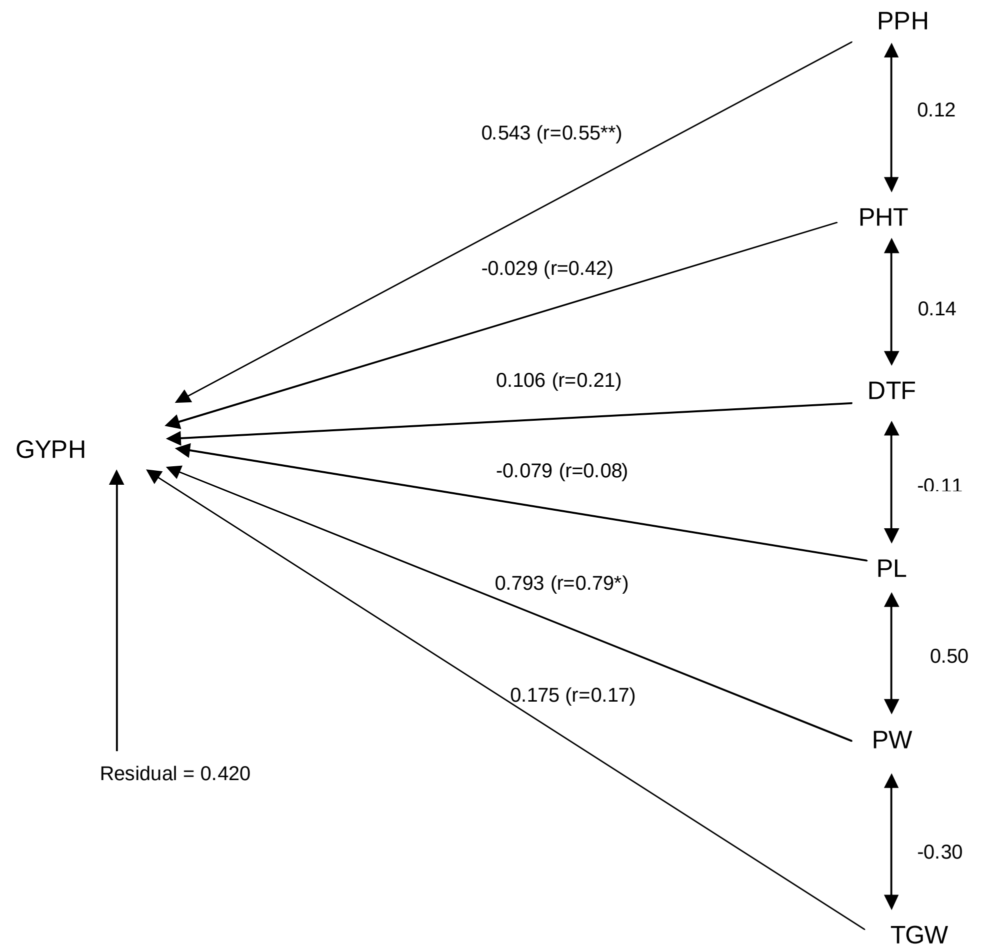

Figure 6.1: Path coefficients with correlations (single arrows) and correlation coefficients (double arrow) for the path analysis of grain yield and yield related traits. GYPH=grain yield per hill; PPH=number of panicles per hill; Ph=plant height; DTF=days to 50% flowering date; PL=panicle length; PW=panicle weight; TGW=1000-grain weight.

6.4 Discussion

There was considerable variability within the F_2 populations for grain yield and the six yield related traits that were studied. The wide range of phenotypic values recorded for all the traits confirmed the variability, implying the potential of the populations to generate genotypes with varying levels of the traits. Maximum genetic variability is found in the F_2 generation. Therefore, there is potential for effective selection for the yield related traits such as number of panicles per hill, panicle length and panicle weight within the populations developed in this study.

Heritability estimates were found to be high for panicle weight, 1000-grain weight, plant height and grain yield per hill. High heritability estimates for 1000-grain weight and plant height were also found by Verma and Srivastava (2004), Dwivedi and Senadhira (1999) and Luzi-Kihupi (1998). Chakraborty et al. (2004) found high narrow-sense heritability for plant height and grain yield. The high heritability estimates indicate substantial contribution of additive gene effects to the expression of these traits. Selection for these traits would be useful in early generations (Verma and Srivastava, 2004). A yield related trait with higher heritability estimate than the primary trait (yield) would be more effective when used in indirect selection (Fehr, 1987). In this study, therefore, panicle weight and 1000-grain weight, with high narrow-sense heritability estimates, would be useful in indirectly selecting for yield especially if they were positively related to yield.

Low heritability estimates were found for number of panicles per hill and panicle length. Subramanian and Rathinam (1984) reported low narrow-sense heritability for number of panicles per hill while Chakraborty et al. (2004) found low narrow-sense heritability for panicle length. The low heritability estimates indicate the importance of non-additive gene effects for the two traits. Early generation selection would, therefore, be ineffective for number of panicles per hill and panicle length.

Very high degree of dominance was recorded for panicle length, similar to the finding by Chakraborty et al. (2004). High degree of dominance was recorded for number of panicles per hill and plant height in agreement with the findings of Chakraborty et al. (2004). The results in this study probably mean that the genes controlling panicle length, the number of panicles per hill and plant height show overdominance. This finding suggests that development of hybrid varieties for these traits would be valuable.

Moderate degree of dominance was recorded for days to 50% flowering and grain yield, while low degree of dominance was recorded for panicle weight and 1000-grain weight. The results suggest incomplete dominance for the genes controlling days to 50% flowering, panicle weight and 1000-grain weight. Pureline varieties would be advantageous for these traits.

There were positive correlations between grain yield and yield related traits, suggesting that selecting for any of the traits could probably select for high yielding genotypes. The negative correlations between number of panicles per hill and 1000-grain weight, and between plant height and panicle weight suggests that compromises should be made when attempting to simultaneously use these traits to select for high yield. Direct selection for yield in early generations usually is ineffective because heterozygosity is high and recessive genes are masked (Mckill et al., 1996). The results in this study, therefore, suggest that panicle weight, number of panicles per hill and 1000-grain weight would be useful traits for indirect selection for grain yield. Luzi-Kihupi (1998) also found that 1000-grain weight and the number of panicles per hill had strong direct effect on yield.

Positive direct effect on grain yield was obtained from panicle weight followed by number of panicles per hill and days to 50% flowering. Agathi et al. (2007) also found that the number of panicles per hill had direct effect on grain yield. Habib et al. (2005) and Chaudhury and Das (1998) found that days to 50% flowering had positive direct effect on yield. The number of panicles per hill had positive indirect contribution to yield through panicle weight and plant height. Similarly, days to 50% flowering had positive indirect effects on yield via panicle weight and plant height. The implication of this finding is that panicle weight, the number of hill per hill and days to 50% flowering would be important traits for indirect selection for yield. The importance of these traits is strengthened by the fact that the traits were also positively correlated with grain yield. Panicle weight would be the most important of the three traits because estimates of heritability were highest (64%) for this trait than for either number of panicles per hill (16%) or days to 50% flowering (13%). Panicle length had positive indirect effect on yield through plant height. Indirect positive contributions to yield were obtained from panicle length through 1000-grain weight and plant height, and from 1000-grain weight through plant height.

Plant height and panicle length had negative direct effect on yield. Other workers reported that plant height had direct effects on yield (Kumar, 1992; Ibrahim et al., 1990; Rubben and Katuli, 1989). The two traits also had negative indirect effects on yield via panicle weight, number of panicles per hill and days to 50% flowering. These findings suggest that tall plants that have long panicles are not indicators of high yield and would have no value in selecting for yield, despite positive correlations with yield. The 1000-grain weight had both negative direct effect on yield as well as negative indirect effects through all other traits except plant height. This finding is in sharp contrast to results reported by other workers who found that 1000-grain weight had direct effect on yield (Samonte et al., 1998; Surek et al., 1998; Mehetre et al., 1994). The 1000-grain weight, therefore, would be of little value in selecting for high yield, especially because it was also found to be weakly correlated (r=0.17) to grain yield in this study. The residual effect found in this study was 42% indicating that 58% of the variability in grain yield was contributed by the six yield related traits. Therefore, other traits not included in this study also contribute to yield.

Significant general and specific combining abilities indicated the importance of both additive and non-additive gene actions in the control of the traits that were studied, namely grain yield, the number of panicles per hill, plant height, days to 50% flowering, panicle length, panicle weight and 1000-grain weight. Kumar et al. (2007) found that additive gene action was important for plant height, days to 50% flowering and 1000-grain weight, while non-additive gene action was important for grain yield and panicle length in rice. Chakraborty et al. (2004 found similar results for days to 50% flowering, plant height, number of panicles per hill, panicle length and grain yield per hill. Sharma et al. (2005) reported that non-additive gene action played a major role for plant height, days to 50% flowering, panicle length, 1000-grain weight and grain yield per plant. The findings in this study suggested that simple selection methods, such as pedigree selection or pureline selection, could be adopted in the improvement of these traits. Pureline or pedigree selection would be important for grain yield, the number of panicles per hill and plant height because additive gene effects were relatively more important that non-additive gene effects in these traits. The findings also suggest that development of hybrid varieties could also be profitable, especially for days to 50% flowering, panicle length, panicle weight and 1000-grain weight because, for these traits, non-additive gene actions were relatively more important than additive gene actions.

Faya Mpata, Faya Zidyana and NERICA 3 parents could be used to develop promising varieties with high yields due to their high general combining abilities while three hybrid populations, namely Faya Mpata x NERICA 4, Faya Khanda x NERICA 3 and Faya Zidyana x NERICA 5, could be potential sources of hybrid varieties with improved yields due to their high specific combining abilities. Parents with high general combining abilities for increased number of panicle per hill and panicle weight were Faya Khanda and NERICA 6.

6.5 Conclusion

The wide genetic variation among the F_2 populations that were developed in this study will be valuable in a selection programme to produce varieties with improved yield and yield related traits. Early generation selection would be recommended for panicle weight and plant height because these traits had high estimates of heritability. Selection for the number of panicles per hill and panicle length would be delayed to later generations because heritability estimates for these traits were low. Bulk population breeding could be an important strategy for traits such as yield because this trait was predominantly controlled by additive gene actions. Development of hybrid varieties for traits such as days to 50% flowering, panicle weight and 1000-grain weight would be adopted due to the relative importance of non-additive gene action for these traits. Panicle weight and the number of panicles per hill could be used to indirectly select for yield because they were positively correlated with and had high direct effects on grain yield. Plant height, panicle length and 1000-grain weight had negative direct effects on yield and therefore would not be appropriate traits to indirectly select for yield. Faya Mpata, Faya Zidyana and NERICA 3 could be the best parents in crosses aimed at increasing grain yield due to their general combining abilities for yield and at least any other three yield related traits. Faya Mpata x NERICA 4, Faya Khanda x NERICA 3 and Faya Zidyana x NERICA 5 could be potential hybrid combinations for developing improved varieties due to their specific combining abilities for yield and at least any other four yield related traits.

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Chapter 7: Thesis Overview

7.1 Introduction

This chapter of the thesis provides an overview of the study, re-stating the objectives and hypotheses, and presenting the major findings. The implications of the findings and the suggestions for future research are also narrated.

The study had the following research objectives:

a) To establish the constraints that confront rainfed rice farmers in Malawi and find out the traits that the farmers consider to be important in varieties;
b) To explore if there is genetic variability in the rice landraces that Malawi farmers grow and to know the traits that could be improved;
c) To determine gene action controlling grain size (length, shape and weight) in Malawi rice landraces;
d) To determine the gene action controlling aroma and high gelatinization temperature in Malawi rice landraces; and
e) To determine the inheritance of grain yield and yield related traits and their correlations and path coefficients in early generation crosses of Malawi landraces and NERICA rice varieties.

The following research hypotheses were tested in this study:

a) In the rainfed rice production ecosystem in Malawi, farmers recognise that use of landraces is a major production constraint but the landraces possess specific traits the farmers prefer;
b) There is highly heritable genetic variation, for yield and yield related traits, within Malawi rice landraces and this variation could be exploited in a breeding programme to develop high yielding varieties that farmers would adopt;
c) The heritabilities for grain length, grain shape and 1000-grain weight, in progenies of Malawi rice landrace x NERICA crosses, are high and the three grain characteristics are positively correlated;
d) The aroma and intermediate gelatinization temperature traits in Malawi rice landraces are simply inherited; and

e) In progenies derived from Malawi rice landraces x NERICA varieties, heritabilities for yield related traits are high, the yield related traits directly affect yield and additive gene effects are more important than non-additive gene effects.

7.2 Summary of the major findings and their Implications

The participatory rural appraisal (PRA) study revealed that farmers face many challenges in rainfed rice farming. The farmers recognize the constraints and realize that the constraints contribute to low productivity. The major constraints are: a) the use of low yielding traditional varieties, b) proliferation of weeds, c) absence of extension advice, and d) high cost of inputs. Farmers know that the use of traditional varieties or landraces is the largest contributory factor among the production constraints.

Farmers describe their traditional varieties as possessing positive traits that include: a) large grain size, b) aromatic grain, and c) grain that takes a long time to cook and separates when cooked .i.e. intermediate gelatinization temperature. The farmers are aware that their varieties have negative traits such as: a) intolerance to drought, and b) susceptibility to lodging. Among several interventions, the farmers agree among themselves that introducing new high yielding varieties would lead to achieving higher yields than the average yields of 1.2t ha^{-1} for the traditional varieties. The farmers are prepared to use new high yielding rice varieties but that such varieties should have large grains with aroma, and non-sticky when cooked i.e. intermediate gelatinization temperature.

When choosing which varieties to grow, farmers consider not only the yield but other traits that may add value to their crop (Witcombe and Virk, 1997). Many breeders opt not to assess the other traits or they assess them in later generations of breeding, often near to release of the varieties. As a result these varieties do not meet the requirement of farmers (Tripp et al., 1997) hence either adoption is low, or they do not adopt them at all. The variety trait preferences of rainfed rice farmers have been confirmed in this study, and any future variety development will incorporate such traits. Hopefully, the rate of adoption will be increased.

There is high genetic variability for plant height, days to 50% flowering, number of panicles per hill, panicle length, number of filled grains per panicle, 1000 grain weight, and panicle weight, among the Malawi landraces evaluated in this study. The variability will be exploited in a breeding programme to develop improved varieties for these traits. The ranges of phenotypic values for the various traits were wide and this confirms the wide genetic variability that may be available.

Four genotypes, namely Amanda, Faya Mpata, Limanda, and Manda flowered eleven days earlier than the other landraces and the check variety Kilombero. The significance of that flowering behaviour is the possibility of breeding varieties that would mature two weeks earlier and therefore escape late season dry spells. The heritability estimates in broad sense were generally low for all the traits therefore selection of superior genotypes based on phenotypic performance will not be useful in these landraces, except perhaps for days to 50% flowering, 1000-grain weight and grain length, which have relatively higher heritability.

The traits that combined high heritability and high genetic advance as a percent of the mean were the number of panicles per hill, panicle length, 1000-grain weight and grain length. These three traits would be transmitted to hybrid progenies and selection will lead to an advance in population mean. Johnson et al. (1955) suggested that heritability estimates used together with genetic advance as percent of mean (GAM) could be useful in predicting the performance of the best selected individuals in a population.

Days to 50% flowering had positive and significant genotypic correlations with plant height, panicle length and grain length. The days to 50% flowering would, therefore, be an indication of genotypes with desirable panicle length and grain length early in the season for the population of landraces that were studied. Grain length and 1000-grain weight are negatively associated with grain yield. The implication of this finding is that breeding lines with long or extra-long, heavy grains will not automatically result in high yield potential.

Farmers, and the rice trade in Malawi, prefer long grains or extra long grains. Long or extra long grains measure above 6.6mm in length. Faya Mpata and Accession 63 have extra-long grains while NERICA 3, NERICA 4, NERICA 5 and NERICA 6 have long grains. These varieties are good sources of long and extra-long grain traits in a breeding programme.

In terms of shape, farmers in Malawi prefer medium-shaped grains. Medium shaped grains have a grain length/width ratio of more than 2.0. All the eight parents used in the study had medium-shaped grain and, therefore, they will be dependable sources for the grain shape. If heavy grains, indicated by 1000-grain weight, are preferred then NERICA 5 and NERICA 6 could be good parents to use to breed for long grain.

There is potential to find breeding lines with extra long grains from among the progenies generated in this study. High number of transgressive segregants for grain length can be found within Accession 21 x NERICA 5, Accession 29 x NERICA 5, Accession 29 x NERICA 6 and Accession 63 x NERICA 3. There were fewer transgressive segregants for grain shape compared to transgressive segregants for grain length. High number of positive segregants could be obtained from only two populations namely Accession 21 x NERICA 5 and Accession 21 x NERICA 6. A high number of positive segregants for 1000-grain weight will be found in crosses such as Accession 29 x NERICA 3, Accession 29 x NERICA 4, Accession 29 x NERICA 5 and Accession 29 x NERICA 6.

Heritability estimates were moderate to low for the grain characteristics. The heritability estimates found in this study suggest that selection for the grain characteristics will not be useful in early generations. Therefore it will be prudent to delay selection until the F_4 or F_5 generations. Pedigree selection will not be the ideal method. Bulking the progenies until the later generation will be the ideal method.

The strong and positive correlation between grain length and grain shape can be used to select for both traits simultaneously. Alternatively, either grain length or grain shape can be the primary trait to select for. The negative correlation between 1000-grain weight and grain shape could present a problem if the latter is one of the objectives, because selecting for low density grains may result in selecting for bold shaped grains, which are not preferred by rice farmers in Malawi.

The aroma in Malawi rice landraces is controlled by a single recessive gene. The implication of this finding is that breeding and selecting for aroma trait would be accomplished relatively easily. The simple sensory technique used in this study is adequate to identify aromatic segregants in subsequent generations. A high number of breeding lines with strong aroma can be found within cross Faya Mpata x NERICA 4. A high number of breeding lines moderate aroma can be found in the cross Faya Mpata x NERICA 3.

The inheritance of intermediate gelatinization temperature in the Malawi rice landraces appears to be controlled by a single dominant gene in three crosses, and two dominant genes in one cross. If the inheritance is simple, as determined, then breeding and selecting for intermediate gelatinization temperature can be accomplished relatively easily. Breeding lines with preferred intermediate gelatinization temperature can be found from the crosses: Faya Kachulu x NERICA 3 and Faya Mpata x NERICA 3. The highest proportion of progenies, with alkali spreading value equal to that of the landraces, can be found in Faya Kachulu x NERICA 3 cross. The crosses: Faya Mpata x NERICA 3 and Faya Kachulu x NERICA 3 had equal proportions of progeny with alkali spreading values equivalent to the landraces. In terms of gelatinization temperature class, the highest number of progenies, with the preferred intermediate gelatinization temperature, can be found in Faya Mpata x NERICA 3 and Faya Kachulu x NERICA 3 crosses.

There is variability within the F_2 populations for grain yield and yield related traits confirmed by the wide range of phenotypic values. There is potential to obtain genotypes with varying levels of the traits within the populations, especially for number of panicles per hill, panicle length and panicle weight.

Heritability estimates were high for panicle weight, 1000-grain weight, plant height and grain yield per hill indicating substantial contribution of additive gene effects to the expression of these traits. Selection for these traits could be performed in early generations because yield related traits with higher heritability estimates than the primary trait (yield) could be effective when used for indirect selection (Fehr, 1987). Low heritability estimates indicate the importance of non-additive gene effects hence ineffectiveness of early generation selection (Verma and Srivastava, 2004). Selection for traits such as number of panicles per hill and panicle length will have to be performed in later generations because their heritability estimates are low.

Selecting for any of the yield related traits will probably result in selection for high yielding genotypes because of positive correlations between grain yield and yield related traits. Panicle weight and number of panicles per hill will be the most preferred traits to select for yield because they had positive direct effect on yield. Non-additive gene effects were more important than additive gene effects for the days to 50% flowering, panicle length, panicle weight and 1000-grain weight therefore they would be preferred traits for hybrid variety development. Bulk breeding methods would be adopted in order to exploit the additive gene actions for traits such as yield. Faya

Mpata, Faya Zidyana and NERICA 3 could be the best parents in crosses aimed at increasing grain yield and yield related traits. Faya Mpata x NERICA 4, Faya Khanda x NERICA 3 and Faya Zidyana x NERICA 5 could be potential hybrid combinations for developing high yielding varieties.

7.3 Conclusion and the way forward

The findings from this study have shown that there is wide genetic variability for yield and the eight morphological traits studied among the 19 Malawi rice landraces. There is need to conduct similar investigations on the other (approximately 170) Malawi rice landrace collections. It would also be important to study genetic variability for additional traits such as drought tolerance and grain shattering. The participatory rural appraisal identified drought tolerance as one of the preferred traits in rice varieties for the rainfed ecosystem in Malawi. The inheritance of aroma and intermediate gelatinization temperature was determined to be simple therefore it will be relatively easy to breed and select for these traits and also to incorporate the traits into existing varieties for example Senga and the NERICAs, through back-crossing. Generally, it has been determined that grain length, grain shape and grain yield are predominantly controlled by additive gene action. For the improvement of these traits, therefore, bulk population breeding strategies would be recommended. For traits such as days to 50% flowering and 1000-grain weight, found to be predominantly controlled by non-additive gene action, the recommendation would be to delay selection for these traits until F_5 or F_6 generation.

A rice breeder at Lifuwu Research Station recently completed intensive training in hybrid rice production in The Peoples' Republic of China. There are prospects, therefore, that the rice breeding programme at Lifuwu Research Station will shortly embark on hybrid rice breeding and production. The seed harvested from the F_2 populations generated in this study will be planted as F_3 families in 2010, and selections will be performed both within and between families; breeding lines with desirable traits will be advanced into the F_4 generation in 2011. There is need for further study of the various traits utilizing additional sites and years in order to capture genotype by environment interactions. Genotype by environment interactions were not captured in this study due to insufficient seed caused by high sterility. The probable causes of the sterility may be: 1) incompatibility between Malawi rice landraces (*Oryza* *sativa*) and the NERICA varieties (*Oryza sativa x Oryza glaberrima*), and 2) photoperiod sensitivity of the Malawi rice landraces. These probable causes may have to be scientifically explored.

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