INHERITANCE OF FLAG LEAF ANGLE IN TWO RICE (*Oryza sativa*) CULTIVARS

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JULIANA MARIAMA VANGAHUN

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DECLARATION

I hereby declare that, except for references cited in relation to other people's work, this work is the result of my own research and it has not been submitted either in part or whole for any other degree elsewhere.

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Juliana Mariama Vangahun Date

(Candidate)

We declare that we have supervised the student in undertaking the study submitted herein and confirm that she has our permission to submit.

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Prof. Richard Akromah Date

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Dr. Paul Kofi Dartey Date

……………………….. ……………………………

Dr J. Sarkodie- Addo Date

Head of Department

DEDICATION

This thesis is dedicated to my Father M.S Vangahun of blessed memory, for believing in me and educating me.

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ABSTRACT

The leaf posture of a genotype determines the amount of solar radiation intercepted by the genotype. The flag leaf in cereals has been recognized to contribute largely to the filling of grains because it supplies photosynthetic products mainly to the panicle. Genetic segregation patterns were studied in two lowland rice (*oryza sativa*) genotypes with different flag leaf angles, Nerica L19 or WAB2155 (with horizontal flag leaf angle) and WAS161-B-9-3or Nerica L 41 (with erect flag leaf angle). Data were obtain at grain filling for all the generations, there were six generations including the two parents ($P_1$and P_2), F1and F2, and the backcrosses with each parent (B_{C1} and B_{C2}). Genetic differences were detected among genotypes with erect flag leaf and horizontal flag leaf. Segregant data showed the existence of one gene (3:1 ratio) controlling the expression of flag leaf angle. Data suggest that efficient selection for erect flag leaf type in rice is possible and that considerable genetic improvement can be expected for flag leaf angle. Heritability estimate as well as F_2 frequency distribution of plant height, panicle length, 1000 seed weight, flag leaf length, spikelet per plant, number of tillers and number of panicle per plant indicated the presence of additive and non additive effects in the control of the traits. Transgressive segregation towards the shorter parent was observed for flag leaf length and plant height.

TABLE OF CONTENTS

Title **Page**

LIST OF TABLES

LIST OF FIGURES

FIGURES **PAGE**

CHAPTER 1

1.0 INTRODUCTION

Rice belongs to the genus *Oryza*, of the family *Gramineae*, and is a widely cultivated crop (FAO, 2000; Syed and Khaliq, 2008). It is a staple food crop and more than half of the world's populations depend on it for consumption and income generation (Bucheyeki *et al*., 2011). About 95 percent of the global output of rice is produced and consumed in developing countries (FAO, 2000). In 1996, rice was consumed by about 5.8 billion people in 176 countries. It is the most important food crop for 2.89 billion people in Asia, 40 million people in Africa, and 1.3 million people in the Americas (FAO, 2000).The average consumption of these populations is over 100 kg/person/year; equivalent to 700 and 2,200 calories/day/person.

Juliano (1994) reported that, rice contributes about 20% and 13% of the world's capital energy and protein respectively. Rice by-products have many uses; these include 'tatamin' mat made from rice straw, beer or sake brewed from rice, rice vinegar for seasoning rice, rice bran for animal feed and rice hull for generating energy; making synthetic fiber as well as fertilizer (FAO, 1996).

It is a widely cultivated crop, and a great number of rice varieties and lines have been developed through varietal improvement and genetic resource conservation, evaluation and utilization programmes at various national and international institutions (FAO, 2000).

In Ghana, rice is now an important staple food due to rapid urbanization and it is consumed by almost every household (MOFA, 2000). Per capita rice consumption increased from

17.5 kg to 38 kg between the years 1999-2008 and is estimated to get to 63 kg by the year 2018 (MoFA, 2009). MoFA (2009) revealed that, the estimated national rice consumption stands at 561, 400 metric tons per year, whiles rice produced locally is 107,900 metric tons leaving a gap of 453,500 metric tons, which have to be imported (Directorate of Crop Science, MoFA, 2010). Ghana depends largely on imported rice to make up the deficit in rice supply. It is estimated that, about 66% of this increasing domestic demand is met by import from Asia and USA, amounting to about USD 700 million in monetary terms (MoFA, 2000).

Local rice production hardly meets the annual rice demand in Ghana (Bam *et al*., 1998). Low yield is one of the main challenges of rice production in Ghana, either due to plant genotype, pest or production practice. The intensification of rice production would play an important role in the provision of food and cash security to farmers, which will help make the Vision 2020 meaningful in the lives of farmers. This can be done through the manipulation of the plant's posture. Yoshida and Ahn (1968) postulated that erect green leaves are more efficient photosynthesisers and make better use of soil nitrogen; pale-green droopy leaves are less efficient and poor users of soil nitrogen. The flag leaf posture is also important with regard to light interception for photosynthesis. Flag leaf contributes most to grain yield, greater carbohydrate translocation from vegetative plant parts to the spikelet and larger leaf area index (LAI) during the grain filling period (Davood *et al*., 2009). Photosynthesis is the primary source of grain yield in rice (*Oryza sativa L*) (Yue *et al*., 2006). The leaf posture of a genotype determines the amount of photosynthetic activity perform by the leaf. In the rice crop, several factors influence the response of photosynthesis to light; one of them is leaf angle, that has been identified as influencing the degree of light saturation of upper leaves (Mahdavi *et al*., 2004).

The flag leaf morphology significantly affects yield, grain quality, maturity, pest preference, absorption of plant growth regulators, by canopy and other important production parameters in crops including rice (Fan *et al*., 2007). The amount of light penetration into the canopy and shape of flag leaf varies with genotype, and the type of leaf posture include: curved (lax or droopy) (Angus *et al.*, 1972; Araus *et al*., 1993), and planophile or erectophile shapes (Borojevic, 1988). A lot of work has been done on the contribution of flag leaf in grain filling in rice, however, much work have not been done on a consistent difference for grain yield between erect-type and droopy flag leaf type rice cultivars. Characters such as leaf inclination and leaf shape, for example, are simply inherited and can greatly influence crop canopy structure and radiation interception (Ratikanta and Humberto, 2010). Such characters could be rapidly modified by selection to increase crop photosynthesis and yield. The inheritance of flag leaf has been reported to be controlled by one or two genes (Cristaldo *et al*., 1992). According to Sharma *et al*. (2003), yield components breeding to increase grain yield would be most effective if components involved were highly heritable and genetically independent or positively correlated in early generations. In rice, visual selection would be effective for yield and its component traits due to high heritability in F_2 as observed by Sun (1979) and Kumar *et al*. (2009).

Objectives of the study

This study looked at the inheritance of flag leaf angle in two lowland NERICA varieties with the following specific objectives:

- To determine the gene control of flag leaf angle
- To estimate the heritability of other grain yielding traits of rice.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1.0 Origin and Types of Rice

Rice is an ancient agricultural crop. Radio- carbon dating of strata containing traces of rice, found in excavation in Zhejiang Province in South China, indicates that rice cultivation in china was underway 7,000 years ago. Chang (1964a) identified a region including Northeastern India, Northern Bangladesh and a triangle adjoining Burma, Thailand, Laos, Vietnam and Southern china as the probable primary center of domestication of rice.

There are two cultivated species of rice: *Oryza sativa L* (genome AA, 2n = 2× = 24,), the Asian rice and *O. glaberrima Steud*. (genome A^gA^g, 2n = 2× = 24,) the African rice. The Asian rice species, O. sativa is spread in large parts of the world and is more diverse than *O. glaberrima* (Sarla and Swamy, 2005). *O. sativa* is broadly divided based on morphological and physiological characteristics into indica, japonica and javanica subspecies. The indica and the japonica types are by far the most important. Both *O. sativa* and *O. glaberrima* are normally grown as annuals although *O. sativa* may be maintained as a perennial if protected from frost and drought (Sohl, 2005). There are divergent views regarding the ancestry of cultivated rice. It is believed that O. sativa and *O. glaberrima* had a common progenitor which is unknown and may not exist following a sequence from wild perennial to wild annual to cultivated annual ancestors (Sarla and Swamy, 2005). It is well established that *O. longistaminata* and *O. barthii* are the progenitors of *O. glaberrima*, while *O. rufipogon* and *O. nivara* gave rise to *O. sativa* (Ishi *et al*., 2001). The two wild species are diploid weedy species containing the AA genomes and are distributed widely throughout Southeastern Asia where they hybridize freely with cultivated rice (Sohl, 2005). *O. glaberrima* differs from *O. sativa* in many qualitative and quantitative traits (Sarla and Swamy, 2005). In the field, *Oryza glaberrima* differs from *Oryza sativa* by its short, roundish, tough ligules and the small number of secondary branches on its panicles (Morishima, 1984).

2.1.1. Rice Ecology

In Ghana, the total area (hectares) under rice cultivation in various ecologies is estimated to be 81,000 ha with most of the cultivation being on rainfed upland (MoFA- SRID, 2007).

2.1.2 Rainfed upland

Rice yields in upland systems average about 1 t ha^{-1}. Weed competition is the most important yield reducing factor (Johnson *et al*., 1998) followed by drought, blast, soil acidity and general soil infertility. Farmers traditionally manage these stresses through long periods of bush fallow. More recently, population growth has led to a dramatic reduction in fallow periods and to extend periods of cropping in many areas, with resulting increase in weed pressure and in soil infertility. Additional weed competition further reduces labor productivity in upland rice based production systems, which are already generally limited by labor availability during the main cropping season. Farmers also face increased risks of crop failure and generally lower productivity levels. Very early maturing varieties with tolerance to drought and blast are required in the dry zones where the growing season is short, while medium to late maturing and acid-tolerant varieties are needed for higher rainfall areas. Desirable agronomic traits include good vigor at seedling and vegetative stages for weed suppression, intermediate to tall stature, lodging resistance and moderate tillering ability. Of great importance is tolerance to soil acidity and

Phosphorus deficiency. Modest inputs of organic fertilizer or soil amendments, such as rock phosphate, or the use of fallow legumes may counter soil fertility decline in upland environment and improve yields. Fallow legumes may also reduce weed infestation levels in the following rice crop (Bor, 1960).

2.1.3 Rainfed lowland

Rice yield in rainfed lowlands (Flood plains and valley bottoms) depends on the degree of water control and vary from 1 to 3 t ha-1. These systems have a high potential for intensification, which is pushed by local land pressures and pulled by urban market demand. With improved water control, use of external inputs may become attractive and rice yields may be increased rapidly in these systems that are inherently much more stable than the upland areas. Biophysical factors affecting rice yields in rainfed lowland fields include weeds, drought, flooding, and soil nutrient supply, iron toxicity, blast, rice yellow mottle virus (RYMV) and Africa rice gall midge (AFGRM). High yield potential is the priority objective in breeding for rainfed lowlands, combined with weed competitiveness, short duration, resistances to blast, RYMV and AFRGM, and tolerance to iron toxicity. The major socio-economic constraints include resource availability, production risk, knowledge on best-bet crop management practices, and human health problems (Beachell, 1959).

2.1.4 Irrigated rice

Irrigated rice-growing areas are divided into three subcategories based on temperature. Two are found in west and Central Africa: favorable temperature and low-temperature, tropical irrigated zones. The latter is restricted to the mid-altitude areas of Cameroon. The former is represented by the dry-season irrigated rice that is found in all agro-ecological zones from the rain forest to the Sahel. While nearly all the rice grown in Mauritania (Sahel) is irrigated, only 12-14% (0.5 million ha) of the total rice area in West and Central Africa is irrigated. This includes substantial areas in Cameroon (80%), Niger (55%), Mali (30%) and Burkina Faso (20%). Irrigated rice in these countries (except Cameroon) is mainly in the Sudan Savanna and Sahel, which account for nearly 60% of the irrigated rice in West and Central Africa (Defoer *et al*., 2002).

In Cote d'Ivoire, about 24,500 ha (7% of total area) is irrigated. Yields potential (10 t/ha) is higher in these drier zones than in others, because of higher solar radiation and low disease stress (Halick and Kelly, 1959). Wetland or paddy rice production has been sustained over millennia and can be considered one of the world's most sustainable and productive farming systems. On an annual basis, irrigated rice is often 10 times more productive than upland rice, over 12 times more productive than deep-water rice, and five times more productive than rain fed rice. Irrigated rice accounts for 55 percent of the global harvested area and contributes 75 percent of global rice production, which is about 410 million tonnes (M t) of rice per year (Dobermann and Fairhurst, 2000).

2.2.0 The cultivation and importance of rice in Sub Saharan Africa (SSA)

Rice is one of the most important cereal crops cultivated in Sub-Saharan Africa (SSA). It is ranked as the fourth most important crop in terms of production after sorghum, maize and millet (FAO, 2006). Rice occupies 10% of the total land under cereal production and produces 15% of the total cereal production (FAO, 2006). Nwanze *et al*. (2006) reported that approximately 20 million farmers in SSA grow rice and about 100 million people depend on it for their livelihoods. Between 1961 and 2003, the annual consumption of rice increased annually by 4.4% and among the major cereal crops cultivated, rice is the most rapidly growing food source in Africa (Kormawa *et al*., 2004). Equally, between 1985 and 2003, the increase in annual rice production was 4%, while production growth for the first and second most important cereals crops (sorghum and maize) was only 2.5% and 2.4%, respectively.

Rice production in Sub Saharan Africa has steadily increased since the 1970s, reaching almost 7 Mt of milled rice at the end of the last decade. Fagade (2000) reported that the increase in rice production is about 70 percent due to expansion in area and 30 percent due to yield increase). Nonetheless, demand for rice in Western and Central Africa has far outstripped the local production (WARDA, 2007). The gap between rice demand and regional supply is still increasing; in 1998 it was about 4 Mt of milled rice for sub-Saharan Africa as a whole. Nigeria was the major importer of rice in 1999/2000 with about 1 Mt. Sub-Saharan Africa has become a major player in international rice markets, accounting for 32% of global imports in 2006, at a record level of 9 million tons per year. Africa's emergence as a big rice importer is due to the fact that during the last decade rice has become the most rapidly growing source of food in Sub-Saharan Africa (WARDA, 2008). Also, due to population growth (4% per annum), rising incomes and shift in consumer preferences in favour of rice, especially in urban areas (WARDA, 2008), the relative growth in demand for rice is faster in SSA than anywhere in the world (WARDA, 2005) and Ghana is not an exception. The per capital consumption is estimated to have more than double from 7.0 kg/year in 1994/95 and is said to be increasing at a rate of over 20% per annum. About 66% of this increasing domestic demand is met by imports from Asia and the USA (MoFA, 2000).

2.3.0. Morphology of the Rice Plant

Biosystematists recently divided the genus *Oryza* into several sections and placed *O. sativa* under series Sativa in section Sativae. The rice plant may be characterized as an annual grass, with round, hollow, jointed culms, rather flat, sessile leaf blades, and a terminal panicle, under favorable conditions, the plant may grow more than one year (Chang, 1965). As other taxa in the tribe Oryzeae, rice is adapted to an aquatic habitat (Juliano *et al*., 1964). While the ensuing description is based on the ubiquitous *O. sativa* L., the morphologic terms can also apply to the cultivated species of Africa, *O. glaberrima Steud*. (2n = 24). *O. glaberrima* differs from *O. sativa* mainly in a lack of secondary branching on the primary branches of the panicle and in minor differences related to pubescence on the lemmas and length of the ligule. *O. glaberrima* is strictly an annual (Chang, 1965). The rice plant varies in size from dwarf mutants only 3 to 4 m tall to floating varieties more than 7 m tall (Oka, 1958). The great majority of commercial varieties range from 1 to 2 m in height. The vegetative organs consist of roots, culms, and leaves (IRRI, 2007). A branch of the plant bearing the culm, leaves, roots and often a panicle is a tiller. The leaves are borne on the culm in two ranks, one at each node. The leaf consists of the sheath and blade. The leaf sheath is continuous with the blade. It envelops the culm above the node in varying length, form, and tightness. A swelling at the base of the leaf sheath just above the point of its insertion on the culm is the sheath pulvinus (IRRI, 2007). The sheath pulvinus is usually above the nodal septum and is frequently mis-termed the node. The blades are generally flat and sessile. Varieties differ in blade length, width, area, shape, color, angle, and pubescence. The uppermost leaf below the panicle is the flag leaf. The flag leaf generally differs from the others in shape, size, and angle. Varieties also differ in leaf number.

2.4.0. Morphology of the Flag Leaf

In rice, the flag leaf is metabolically active and has been a subject of study by number of investigators (Prakash *et al*., 2011). The flag leaf morphology significantly affects yield, grain quality, maturity, pest preference, absorption of plant growth regulators, by canopy and other important production parameters in crops including rice (Fan *et al*., 2007).

The leaf sheath and leaf blade are continuous. A circular collar joins the leaf blade and the leaf sheath. The leaf sheath is wrapped around the Culm above the node (IRRI, 2007).

With many parallel veins on the upper surface of the leaf, the underside of the leaf blade is smooth with a prominent ridge in the middle; the midrib. Most leaves possess small, paired ear-like appendages on either side of the base of the blade. These appendages are called auricles. Auricles may not be present on older leaves. Another leaf appendage is the ligule, a papery membrane at the inside juncture between the leaf sheath and the blade. It can have either a smooth or hair-like surface. The length, color, and shape of the ligule differ according to variety (IRRI, 2007). In rice, leaf length is much more variable than leaf width and leaf length is closely associated with leaf angle. The longer the leaves, the droopier the leaves, as a result, short and small leaves are associated with erect leaves (Yoshida, 1972). Davood *et al.* (2009) showed that for increasing rice grain yield, flag leaf must be wide and vertical.

2.4.1. Importance of Flag Leaf in Rice

The top three leaves especially flag leaf contributes most to grain yield (Ray *et al*., 1983, Misra, 1986).The flag leaf contributes largely to the filling of grains because it supplies photosynthetic products, mainly to the panicle (Jennings *et al.*, 1964). It has been assigned an important role in terms of supply of photosynthates to the grains (Asana, 1968;

Ramadas and Rajendrudu, 1977). In any crop, the leaves and other green tissues are the original sources of assimilates, greater carbohydrate translocation from vegetative plant parts to the spikelets and larger leaf area index (LAI) during the grain filling period (Song *et al*., 1990).

The leaf (source) being the organ of photosynthesis is considered to be the important determinant which is characterized for higher photosynthetic capacities (Prakash *et al*., 2011). It has been proven that the flag leaf, stem and head are the closest source to the grain (Prakash *et al*., 2011). Grain yield increase would be effectively rested with the basis of the capabilities of yield components and other closely associated traits (Xue *et al*., 2008, Sharma *et al*., 2003). The morphological traits of flag leaf such as size and shape, and physiological traits of flag leaf such as chlorophyll content and photosynthesis capacity have been considered to be the important determinants of grain yield in cereals (Chen *et al*., 1995; Hirota *et al*., 1990). Therefore, flag leaf is one of the greatest components in determining grain yield potential in cereal crops (Xue *et al*., 2008). Flag leaf has an important role in rice yield by increasing grain weight in amount of 41 to 43 percent (Yoshida, 1972). Flag leaf area could be chosen as a factor for increasing rice grain yield (Davood *et al*., 2009). For this reason flag leaf is an activist leaf at grain filling period. Fan *et al*. (2007) reported that flag leaf strongly contribute to grain filling after heading, while flag leaf shape is one of the main factors determining its photosynthetic ability. Rice for reaching to maximum grain yield need sufficient LAI for best photosynthesis activity while in rice 60-90% of total carbon in the panicles at harvest is derived from photosynthesis after heading, while 80% or more of nitrogen (N) in the panicles at harvest is absorbed before heading and remobilized from vegetative organs (Yoshida, 1972). Davood *et al*. (2009) reported leaf senescence during reproductive and maturity stage to be directly related to biomass production and grain yield of rice crop. Flag leaf angle had an important effect for increasing rice grain yield. Grain yield is a function of photosynthesis products and optimum distribution, and arrangement of leaves increase the efficiency of biomass production in crop cultivars. Modification of flag leaf angle have been emphasized by investigators as a means of obtaining better light utilization, with more upright leaves permitting the penetration of solar energy into lower leaves of aerial structure of plant (Jennings *et al*., 2003; Donald, 1968). So flag leaf photosynthesis activity has an important effect on rice grain yield. Flag leaf help in maintaining photosynthesis during the grain-filling period, this could increase yield capacity because photosynthesis during ripening contributes to grain carbohydrate by 60–100% (Yoshida, 1981). Results of shading experiments by many workers have shown that carbohydrates contributed by assimilating green parts above flag leaf nodes amount to more than 85% of the total accumulation in the grain (Yap and Harvey, 1971). Flag leaf appeared to play a major role in enhancing productivity (Padmaja, 1991). Therefore efforts were made to relate the flag leaf area with yield parameters *viz*., number of panicles, panicle length, number of grains per panicle, 1000 grain weight, grain yield per plant, grain yield per m^2, dry matter per m^2 and yield (t/ha) in order to assess and identify the productive cultures for selection. Jennings *et al*. (1979) reported that flag leaves also help to stabilize yield because erect, moderately long flag leaves, such as those of CICA 4, help protect ripening grain against bird damage.

2.4.2 Inheritance of Flag Leaf

The inheritances of flag leaf angle have been reported to be controlled by one or two genes (Cristaldo *et al*., 1992). Kobayashi *et al.* (2006) reported flag leaf traits such as flag leaf length, width and angle (FLL, FLW and FLA respectively) are inherited quantitatively and influenced largely by growth environment. Mori *et al.* (1973), Iwata and Omura (1984) reported curly leaf mutant to be a pleitropic gene, which is recessive and reduces the width of leaf lamina while Murata *et al.* (2000) reported narrow leaf mutant to be recessive. Studies on the genetics of flag leaf width by Kobayashi *et al.* (2003) and Mei *et al.* (2003), reported several dominant QTL's. Bharadwaj *et al*. (2005) revealed that the width of flag leaf to be governed by a dominant gene and propose *FLAG LEAF WIDTH 1* [*FLW1*] and *FLAG LEAF WIDTH 2* [*FLW2*] responsible for wide flag leaf in JNPT 89 and JNPT 63-01, respectively to be dominant over narrow flag leaf. Fan *et al*. (2007) suggested that the three flag (LL, LW, RLW) shape traits were quantitatively inherited traits. The previous results of QTL analysis with a doubled haploid population in rice showed that leaf shape was a quantitatively inherited trait (Fan *et al*., 2007).

2.4.3. Cultivar Difference in Flag Leaf

Cultivars with erect flag leaf and panicle are most popular over droopy flag leaf and panicle, e.g. Liaoning 5 and Shennongai from China (Wang *et al*., 2004). "Toyonishi" and "Akihikari" introduced from Japan, "Jaya" from India, "Bg 90-2" from Sri Lanka and "IR8" from International Rice Research Institute (IRRI). Many of the high yielding varieties in these areas have erect flag leaves. According to Jennings (1979) many breeders discard lines with unusually long flag leaves extending 30 cm or more past the panicles, because they suspect that this trait encourages mutual shading.

2.5.0. Importance of Leaf Orientation

Leaf posture (LP) considerably affects the interception of incident radiation and its distribution within the canopy (Monneveux *et al*., 2004). Monsi and Saeki (1953) pointed out in their epoch-making paper that the inclination of leaves forming plant canopies plays a decisive role in the interception of light by canopies and in canopy photosynthesis. Leaf arrangement as illustrated by the spatial distribution of leaf area greatly influences not only the canopy microenvironment but also canopy photosynthesis (Yoshida, 1972). Source capacity depends on light reception determined by plant type and photosynthesis efficiency (Yonezawa, 1997). Evidences indicating how the leaf inclination angle influences canopy photosynthesis have been reported with rice by Tanaka (1972). The flag leaf can be erect, intermediate or droopy. Chang *et al.* (1965), had described erect leaf as an angle of 30^o or less from the perpendicular, Spreading or droopy leaf as having a pronounced spreading habit, leaning more than 60^oc from the perpendicular, and intermediate; the angle is intermediate between erect and spreading.

2.5.1. Erect Flag Leaf

Among several leaf characters associated with high yielding ability, erect leaf habit seems the most important (Yoshida, 1972). Erect leaves permit greater penetration and more even distribution of light into the crop and, thus, higher photosynthetic activity (Jennings, 1979**).** Yan *et al*. (2012) had reported that erect leaves increase leaf area index (LAI), which is defined as single-side leaf area per unit of area, thus increasing the capture of light for photosynthesis and nitrogen use in dense plantings. In a canopy with very erect leaves, such as that of improved rice varieties, the tip of the lower leaves may receive more sunlight than the basal part of the flag leaf, thus contributing to the total photosynthesis of the crop canopy (Yoshida, 1972). Hence, direct evidence of effect of erect leaves in increasing photosynthesis and hence yields have been reported for rice (Tanaka *et al.*, 1969). Erect leaves have a higher leaf area index (single-side leaf area per unit of land area), which increases the capture of light for photosynthesis and nitrogen use in dense plantings (Yang and Hwa, 2008). This in turn improves dry matter accumulation in panicles and increases yield (Sinclair and Sheehy, 1999). The higher photosynthetic activity of an erect leaved canopy produced a higher grain yield (Yoshida, 1972). A canopy that has more erect leaves and a smaller extinction coefficient, with better light-intercepting structure, has a larger critical or optimum LAI and a higher maximum canopy photosynthesis rate. Studies have shown that erect flag leaves intercept more solar radiation than droopy leaves (Monneveux *et al*., 2004). Comparing the leaf arrangements of high and low yielding rice cultivars, Tsunoda (1964) also revealed the close correlation between the erectness of leaves and yield. He concluded that high crop yield is generally observed for rice cultivars with erect leaves.

2.5.2. Droopy Flag leaf

In a canopy with flat leaves the whole area of the top leaf is more exposed to sunlight than lower leaves (Yoshida, 1972).). Studies have also shown that erect leaf canopies can yield more than droopy canopies under adequate water availability (Yoshida, 1972). But according to (Yoshida, 1981) , there is only one rice experiment indicating that the droopy-leaved canopy has a lower crop photosynthesis than the erect- leaved canopy at high light intensities.

2.5.3. Leaf Size, Shape and Length

Much attention has been paid to leaf shape of rice in the process of ideotype breeding (Yan *et al*., 2006). The length, width, angle and area are the three traits determining the shape and size of a leaf, among which the area is attributable to the length and width with higher correlations between length and area than between width and area (Yan and Wang 1990; Peng *et al*., 2008; Li *et al*., 2000). Light interception by a canopy of leaves is strongly influenced by the leaves' size and shape, angle, and azimuthal orientation, vertical separation and horizontal arrangement, and by absorption by non leaf structure (Chandler, 1969; Yoshida, 1972). According to Yonezawa (1997), improvement of flag leaf traits through plant breeding had led to a drastic increase in grain yield, and flag leaf length has long been recognized as one of the key factors in the formulation of new plant ideotype for high-yielding potential in rice (Yuan, 1997). Watson (1951) reached the conclusion that variation in leaf area and leaf area duration was the main cause of difference in yield. Leaf length is extremely variable in rice. Among the factors that affect light interception by a canopy of leaves, leaf angle has attracted special attention in term of total photosynthesis (Yoshida, 1972). Asama (1981) reported that flag leaf angle can influence grain yield of a crop genotype. According to Jennings *et al*. (1979), because leaf angle is directly associated with leaf length, short leaves are more erect than long ones. Short leaves are more evenly distributed throughout the canopy so mutual shading is reduced and light is more efficiently used (Jennings *et al*., 1979, Tanaka, 1966).

2.6.0 Leaf Area Index

An increase in grain yield can be achieved by increasing the harvest index, which indicates the partitioning of assimilation products to grain, and or total biomass production (San-Oh *et al*., 2008). Biomass production is considered to be a function of the amount of solar radiation, interception rate of solar radiation by leaves and conversion factor of intercepted solar energy to biomass production (Hay and Porter, 2006).

A large leaf area index (LAI) is necessary to intercept solar radiation. However, the size of LAI needed to give maximum crop photosynthesis depends on the leaf orientation of the canopy (Yoshida, 1981). The leaf orientation affects photosynthesis because it determines the light environment within a canopy (Yoshida, 1981). In a rice canopy in which leaves are very erect near the top and become more horizontal towards the ground, reduces the foliar absorption coefficient of the upper leaves, leaving more light for the lower leaves (Yoshida, 1981). The LAI values necessary to intercept 95% of the incident light in rice canopies suggest that a LAI of 4-5 is needed for good rice photosynthesis (Yoshida, 1981). The unit leaf area is the basis of measuring productivity in different plant species and varieties during their growth and development under a particular environmental condition prevailing over the season (Akmal *et al*., 2000). According to Dickson (1991), leaf area increase contributes to canopy development. As the leaf area increases, a greater photosynthetically active surface area become available and it would therefore be expected that the production rate would be greater the higher the leaf area index (Akmal *et al*., 2000). Akmal *et al.* (2000) reported that flag leaf area contribution is higher than other leaves during spike development. Production of tiller number per plant also depends on leaf number per main tillers which also contributes to final grain yield (Camble and Davidson, 1979). Yoshida and Ahn (1968) reported in his model that erect leaves are the most efficient arrangement for maximum photosynthesis when LAI is large. When sunlight is high and LAI is large, an erect leaved canopy has a larger sunlit leaf surface than a droopy – leaved canopy, but it receives lower light intensity per unit leaf surface according to the cosine law (Yoshida, 1972). Since photosynthetic efficiency is high at low light intensity as seen from the light photosynthesis curve of a single leaf, and since the major portion of daily photosynthesis is attained when sun angle is high, it follows that an erect leaved canopy gives a higher rate of daily photosynthesis than a droopy-leaved one (Isobe, 1969). In other words, the area of leaf surface that intercepts solar radiation is the most important factor. As a result, the importance of leaf area index (LAI) as a determinant of dry matter production and hence yield has been extensively used in subsequent studies on analysis of dry matter production (Yoshida 1972). When the LAI is small, canopy CO_2 assimilation rate increases linearly with the increase in the LAI (Yoshida, 1972).

2.6.1. Harvest Index

The term 'harvest index' (HI) was first introduced by Donald (1962) who defined it as the ratio of economic yield to total biomass yield. According to Maobe *et al*. (2010), dry matter yield is closely related to intercept of photosynthetically active radiation and rate of conversion of intercepted light into biomass also known as radiation use efficiency (RUE). Crop growth rate depends on the amount of radiation intercepted and it conversion into dry matter (Fageria, 2000). Plant biomass production is linearly coupled with the amount of water transpired, and higher water use efficiency (WUE) is often a trade-off against lower biomass production (Yang and Zhang, 2010).

Photosynthetic products produce by green plant are divided into roots, shoot and grain in the process of dry matter portioning (Fageria and Baligar, 2005). Harvest index reflects the division of photosynthates between the grains and the vegetative plant and improvement in harvest index emphasize the importance of carbon allocation in grain production (Moabe *et al*., 2010). Dry matter weight is an very important plant component for determining grain yield, and crop improvement has been primary based on the concept of maximizing grain yield per unit of dry matter produced (Fageria and Baligar, 2005). An increase in grain yield can be achieved by increasing the harvest index, which indicates the partitioning of assimilation products to grain, and or total biomass production (San-Oh *et al*., 2008). On the other hand, Harvest index has been shown to be a variable factor in crop production

(Yang and Zhang, 2010). Variations in harvest index within a crop are mainly attributed to differences in crop management (Yang *et al*., 2000; Guo *et al*., 2004; Kemanian *et al*., 2007).

2.7.0 Correlation between Flag Leaf and Grain Yield

Yoshida (1972) reported that of all the factors that affect light interception by a canopy of leaves, leaf angle has attracted special attention in terms of total photosynthesis. Mahdavi *et al*. (2004) reported that flag leaf angle had positive correlation with grain yield and biological yield. But, Mohtashami (1998) reported a significant negative correlation between leaf angle and grain yield in rice. Falster and Westoby (2003) showed that steeper leaf angle function to reduce exposure to excess light levels during the middle of the more than to maximize carbon gain. Cultivars with greater flag leaf area generally have high grain weight (Mahmood and Chowdhry, 2000). According to Monyo and Whittington (1971) a significant positive correlation coefficient of 0.41 for the association between grain yield per tiller and flag leaf area in wheat. Similarly Briggs and Aylenfisu (1980) recorded a positive and significant association of flag leaf area with grain yield per plant and 1000 grain weight. Davood *et al*. (2009) reported a positive correlation between flag leaf angle and photosynthesis material translocation and spikelet's fertility increase also for increasing grain yield in rice. According to Blake *et al.* (2007), the duration of green leaves after heading was positively correlated with yield in two spring wheat crosses. Flag leaf area duration has been shown to be highly associated with yield (Welbank *et al*., 1966; Yap, 1970). Roy and Kar (1992) also reported significant positive association between boot leaf length and grain yield per plant. Hsu and Walton (1971) also suggested relationship between flag leaf and yield rather than the total area. The grain yield and yield related traits were positively related to flag leaf area (Ashrafuzzaman, *et al*., 2009). Therefore, efforts were made to relate the flag leaf area with yield parameters *viz*., number of panicles, panicle length, number of grains per panicle, 1000 grain weight, grain yield per plant, grain yield per m^2, dry matter per m^2 and yield (t/ha) in order to assess and identify the productive cultures for selection.

2.8.0 Rice Photosynthesis

More than 90% of crop biomass is derived from photosynthetic products (Amane, 2011). Therefore, many crop scientists have believed that enhancing photosynthesis at the level of the single leaf would increase yields (Amane, 2011). On the other hand, a lack of correlation between photosynthesis and plant yield has been frequently observed when different genotypes of a crop are compared (Takana andTsunoda, 1971). Since many recent studies on elevated [CO_2] experiments show a close relationship between enhanced photosynthesis, biomass, and yield, this suggests that increasing photosynthesis increases yield when other genetic factors are not altered (Long *et al*., 2006). In addition, Murata (1981) reviewed the relationship between potential leaf photosynthesis and maximal crop growth rate of many crops and found a highly positive correlation between them. This also indicates that photosynthesis at the single-leaf level can be an important factor for potential biomass production. The canopy structure as well as the physiological properties of leaves with respect to photosynthesis and respiration, therefore, can play an important role in the competition between plants**.** The larger the penetration of solar radiation, the larger the canopy photosynthesis, therefore, the net assimilation rate (NAR) is higher in the canopy with more erect leaves at a given LAI. In rice, 60-90% of total carbon in the panicles at harvest is from photosynthesis after heading while 80% or more of nitrogen (N) in the panicles at harvest is absorbed before heading and remobilized from vegetative organs

(Davood *et al.*, 2009). Grain yield is composed of yield components; panicles per m^2, spikelet per panicle, percentage of ripened grains and 1000-grain weight. The improvement of sink size through increasing number of panicles per plant and number of spikelet per panicle has been one of the major strategies to achieve the higher yield potential so far (Jeong *et al*., 2005). Increase in panicle length and number of panicles per plant might have contributed for increased grains per panicle resulting in enhanced grain yield.

2.9.0 Components of Variation

The component of variations are the measured and expressed as variance. According to Allard (1960) and Falconer (1989) the total variance, which is also the phenotypic variance (V_P) is the sum of genetic variance (V_G) and environmental effects (V_E). Genetic variance is further partitioned as follows; $V_G = V_A + V_D + V_1$

2.9.1 Dominance gene action

According to Weaver and Hendrick (1997) dominance occurs in different forms. It may be complete, where either mutant or wild- type allele is dominant. It may be incomplete or partial, where the heterozygote has a phenotype that is within the limits of the two homozygote (parent) or the two traits may be co-dominant, where both alleles are expressed in the heterozygote. The curve for dominant gene action would be skewed to the dominant side.

2.9.2 Heritability

Ghosh and Sharma (2012) define heritability estimate as a component which provide information regarding the amount of transmissible genetic variation out of the total variation and determines response to selection. The degree to which the genes of an individual influence the phenotype variation is described by the heritability of a given trait. It is important to know that heritability estimate is specific to a given population and environment (Bhadru *et al*., 2012). The most important function of heritability in the study of quantitative characters is it role to predict and indicate the reliability of the phenotypic value as a guide to breeding value (Falconer and Mackay, 1996). Characters not greatly influenced by environment usually have a high heritability. This may influence the choice of the breeder to decide which selection procedure to use and which selection method would be most useful to improve the character to predict the gain from selection and to determine the relative importance of genetic effects (Bhadru *et al*., 2012). Heritability estimation in a given population depends on the partitioning of observed variation into component that reflects unobserved genetic and environmental factors (Wray and Visscher, 2008). Heritability can be either broad sense or narrow sense. Broad sense heritability is the relative magnitude of genotypic and phenotypic variance for the traits and it is used as a predictive role in selection procedures (Allard, 1960). This gives an idea of the total variation ascribable to genotypic effects, which are exploitable portion of variation (Falconer, 1989). Narrow sense heritability is the ratio of V_A/ V_P and it expresses the extent to which phenotypes are determined by the genes transmitted by the parents. It is also simply known as heritability (Falconer, 1989).

Fahliani *et al*. (2010) have reported both low and high heritability estimate of traits in rice. They also reported that, low heritability of a trait shows that environmental factors strongly influence character and breeding for such character is difficult. High heritability on the other hand indicates the scope of genetic improvement of these characters through selection. High heritability has been reported for flag leaf length (Ghosh and Sharma, 2012, Satyanarayana, *et al.*, 2005; Kobayashi *et al.*, 2003), and for flag leaf angle by (Yan, 1990).

The estimate of the heritability alone is not very much useful on predicting resultant effect for selecting the best individual because it includes the effect of both additive genes as well as non additive genes (Rita *et al*., 2009). Heritability combined with high genetic advance would be an appropriate tool in predicting the resultant effect in selecting the best genotypes for yield and its contributing traits. It helps in determining the influence of the environment on the expression of the genotypic and reliability of characters (Singh *et al*., 2011).

2.9.3 Genetic advance

The estimate of genetic advance as per cent of mean provides more reliable information regarding the effectiveness of selection in improving the traits. Genetic advance denotes the improvement in the genotypic value of the new population over the original population (Ghosh and Sharma, 2012). Rita *et al*. (2009) reported moderate to high genetic advance for yield contributing trait in rice. High heritability with high genetic advance indicates the control of additive gene and selection may be effective for such characters.

CHAPTER 3

3.0. MATERIALS AND METHODS

3.1. Site of Experiment

The study was conducted at the plant house, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology (KNUST), and Nobewam (N 06^{o} 38'122'',W001^{o} 16' 54.7'',195m above sea level) both in the Ashanti region of Ghana from March 2011 to May 2012. The experiment at KNUST was done in pots, whilst that at Nobewam was done in the field.

3.2. Source of plant materials

The experimental material consisted of two lowland NERICA varieties with diverse flag leaf angles: WAB2155 (NERICA L 19) has droopy flag leaves (SES score = 5 - Horizontal), and WAS161-B-9-3 (NERICA 41) has erect flag leaves (SES score = 1 - Erect). Seeds of the two rice varieties were obtained from the Cereals Division, Crops Research Institute, Fumesua, Ashanti Region, Ghana.

3.2.1 Crosses

Reciprocal crosses were made between the two parents at KNUST to obtain F_1 individuals. The F_1 were grown at KNUST, and backcrosses to either parent were also made there. The F_2 and BC_1 individuals were field grown in Nobewam.

3.3 Pot culture of F_1 plant

The F_1 seeds were pre-germinated in a white tissue paper for four days nursed for 21 days and transplanted one per bucket. The buckets were filled with sterilized top soil to avoid soil contamination. Sowing of the varieties was staggered over a two –week period in order to synchronize flowering in the varieties. The hybrid plants were provided with 8 g of N P K (15:15:15) at tillering and 4 g of Sulphate of Ammonia at panicle initiation. Other routine lowland rice field operations like irrigation, application of insecticides and hand weeding were employed whenever necessary.

Some F_1 were allowed to self to produce F_2. Some panicles from same F_1 plants were backcrossed to either parent to generate the backcross populations.

3.4 Field planting

Land preparation involved slashing weeds and puddling the soil with a power tiller. Bunding was done to allow good and independent water management.

3.5 Evaluation of parents and other generations

3.5.1 Field experiment

Parental seeds as well as seeds of F_1, F_2 and Backcrosses were pre germinated on white tissue paper on 26th of December 2012 and nursed in buckets three days later. All seedlings were transplanted to an irrigated lowland field (dimension = 64 x 17) at Nobewam on 25 and 26 January 2012, at a density of a single plant per hill spaced at 40 cmx40 cm. The recommended fertilizer rate of 90-60-60- Kg/ha- N-P_2O_5-K_2O was applied: 60-60-60 at tillering topdressed with 30kg/ha N (using urea) at panicle initiation. Initial weeds were controlled by spraying with a post emergence selective weedicide Pronil-plus which is a combination of 2-4-D (2, 4 dichlorophenoxyacetic acid) and Propanil (2-chloro-4-ethylamine-6-isopropylamino-s-triazine). This was followed with hand picking. Plots were irrigated whenever necessary.

3.5.2. Data collection

Data were taken on flag leaf angle and flag leaf length

Flag leaf angle between 1^o to 30^o were classified as erect, and above 30^o to 60^o were classified as horizontal. This was done in order to classify the flag leaf angle into discrete classes. The flag leaf length was determined by selecting 10 plants randomly each of P_1, P_2 and F_1. For the F_2 and backcross populations, Data were taken on individual plants. Measurement was taken in cm from the leaf ligule to the tip of the leaf using a measuring tape.

3.5.3 Data Analysis

Analysis of variance (ANOVA) was carried out for leaf length for each variety. When the results of the analysis showed significant difference, multiple mean comparisons were carried out using LSD at 5% to separate means.

Broad sense and narrow sense heritabilities were calculated using the variance of the parents, F_1, F_2 and backcross generations (BC_1 and BC_2) to estimate phenotypic (V_P), environmental (V_E), total genetic (V_G), additive genetic (V_A) and dominance genetic (V_D) variances.

Given that:

$V_P = V_{F2}$

$V_E = (V_{P1} + V_{P2} + V_{F1})/3$

$V_G = V_{F2} – V_E$

$V_A = 2(V_{F2}) - V_{BC1} – V_{BC2}$

$V_D = V_{BC1} + V_{BC2} – V_{F2} - V_E$

Broad sense heritability = $h^2_b = (V_A + V_D)/ V_{F2}$, where V_A+V_D represent the genetic variance of F_2 (Allard, 1960), while narrow sense heritability = $h^2_n = V_A/V_{F2}$ (Warner, 1952).

Chi-square values of the data obtained from F_2 segregation population of each cross were computed following the procedure described by Gomez and Gomez (1984). Line graphs showing frequency distribution of plant height and panicle length in F_2 generation were also drawn using MS Excel and interpreted according to the method of Ahmed *et al.* (1995).

CHAPTER 4

4.0 RESULTS

4.1 Genetic control of flag leaf angle

In this experiment (WAB2155 / WAS161-B-9-3), F_1 plants and their reciprocals were all erect (Table 2). The F_2 generation segregated into 735 erect and 235 horizontal plants fitting into 3:1 ratios, with a chi square value (χ^2 = 0.309). The test cross (backcross to WAB2155) segregated into a ratio of 28 erect to 22 horizontal plants fitting into a 1:1 ratio (χ^2 = 0.76). The backcrosses to WAS161-B-9-3 plants were all erect. This indicates that flag leaf angle is under the control of a single gene with complete dominance.

Table 1. Number of hybrid seeds obtained from the crosses.

Cross	Number of individuals
F_1 NERICA L19/ WAS 161-B-9-3	**10**
F_1 WAS 161-B-9-3/ NERICA L19	**10**
F_2 NERICA L 19/ WAS 161-B-9-3	**970**
F_2 WAS 161-B-9-3/ NERICA L 19	**60**
BC_{1a} (NERICA L19/WAS161-B-9-3//NERICAL L19	**50**
BC_{1b} (NERICAL L19/ WAS161-B-9-3//WAS161-B-9-3)	**50**
BC_{1c} (WAS161-B-9-3/NERICAL L19// NERICAL L19	**50**
BC_{1d} (WAS161-B-9-3/NERICAL L19//WAS161-B-9-3)	**50**

Table 2. Number of progenies obtained in the segregating generations and the respective derived chi squared valves.

Cross		Erect	Horizontal	Ratio	χ^2	P
F_2 (WAB2155/WAS161-B-9-3)	obs	735	235	3.12	0.309	3.841
	exp	727.5	242.5	3:1		
BC_{1a} (WAB2155/ WAS161-B-9-3//19)	obs	28	22	1.12	0.72	3.841
	exp	25	25	1:1		
BC_{2a} (WAB2155/WAS161-B-9-3// WAS161-B-9-3)	obs	50	0	3:0		
Reciprocals						
F_2 (WAS161-B-9-3/WAB2155)	obs	44	16	2.75	0.092	3.841
	exp	45	15	3:1		
BC_{1b}(WAS161-B-9-3/ WAB2155// WAB2155)	obs	24	26	1.08	0.08	3.841
	exp	25	25	1:1		
BC_{2b}(WAS161-B-9-3/ WAB2155// WAS161-B-9-3)	obs	50	0	3:0		

At 5%, χ^2 (1 d.f) = 3.841

4.2 Basic statistics on important traits in progenies of the crosses

Mean flag leaf length and plant height values (Table 3) WAB2155 were higher than that for WAS161-B-9-3 (NL 41). The mean flag leaf length, height, and panicle length, for F_1, F_2, B_1, and B_2 of the crosses were higher than WAS 161-B-9-3 but lower than WAB2155. The range of variation and variance for all three characters in F_2 were higher than parents and F_1. Variance in flag leaf length of B_2 and shape of B_1 were lower than their corresponding F_2. The CV in F_2 is highest for flag leaf length (20.10%) followed by plant height (6.43%). Also the mean value of plant height was higher in WAB2155 (152.75 cm) than WAS 161-B-9-3(109.62 cm).

Table 3. Basic statistics on the important traits on the progenies of the crosses

Character	Generation	Mean	Range	Variance	ST DEV	C.V
Tillers/plant	N L19	24.0 ± 1.12	18-30	12.46	3.53	14.7
	WAS161-B-9-3	36.0 ± 1.39	22- 41	7.34	2.71	7.52
	F_1	33.3 ± 1.28	27 -50	16.48	4.06	12.18
	F_2	26.49 ± 2.25	36-51	50.55	7.11	27.34
	B_{C1}	31.71 ± 1.85	22- 41	34.10	5.84	18.41
	B_{C2}	28.29 ± 1.80	21-40	32.40	5.69	20.12
Flag leaf Length (cm)	N L19	34.32 ± 0.85	29.8 - 43.9	7.24	2.69	7.83
	WAS161-B-9-3	25.37± 0.96	19.1 - 27.1	8.76	2.96	11.68
	F_1	24.83± 0.77	19.1 - 25.6	5.90	2.43	9.79
	F_2	29.12 ± 1.85	21.1- 36.3	34.22	5.85	20.10
	B_{C1}	26.46 ± 1.42	21.8 - 29.3	20.16	4.49	16.99
	B_{C2}	31.61 ± 1.63	26.2- 44.2	26.62	5.16	16.99
Plant height (cm)	WAB2155	152.75 ± 4.38	145 - 158	18.74	4.33	2.84
	WAS161-B-9-3	109.62 ± 4.17	110.5 - 119.6	17.38	4.17	3.8
	F_1	124.22 ± 1.60	119 - 131.2	25.5	5.05	3.38
	F_2	122.15 ± 2.68	110.1 -129.9	60.99	7.81	6.43
	B_{C1}	123.91 ± 1.91	110.1 – 132.0	36.60	6.05	4.88
	B_{C2}	127.96 ± 2.18	112. 2 -135.4	47.47	6.89	5.39
No of panicle/plant	WAB2155	24.7 ± 0.78	13- 32	4.60	2.16	9.93
	WAS161-B-9-3	30.1 ± 0.59	26-42	3.42	1.85	6.16
	F_1	25.4 ± 1.33	15-32	4.00	2.00	16.49
	F_2	27.20 ± 1.75	18-35	30.8	5.55	20.39
	B_{C1}	24.34 ± 1.61	18-32	25.80	5.08	20.85
	Bc2	25.37 ± 1.21	15-32	14.60	3.83	16.32

Table 3 cont'd. Basic statistics on the important traits in the progenies of the crosses.

Panicle length(cm)	WAB2155	28.82 ± 0.47	27.1 - 30.2	3.42	1.85	5.20
	WAS161-B-9-3	24.65 ± 0.51	26.0 - 28.5	4.00	2.01	6.01
	F_1	26.74 ± 0.81	25. 2 -29 .4	6.55	2.56	9.57
	F_2	27.32 ± 0.94	23.2 - 30.3	8.88	2.98	10.90
	B_{C1}	27.50 ± 0.89	21.6 -30.5	10.49	2.82	10.27
Spikelets /Panicle	WAB2155	302.4 ± 4.36	275-399	190.44	13.80	4.56
	WAS161-B-9-3	291.2 ± 4.70	218-345	221.41	14.88.	5.11
	F_1	286.6 ± 13.19	201-320	406.42	20.16	7.03
	F_2	235.03± 16.16	119-324	2,610.2	51.09	21.74
	B_{C1}	226.0 ± 15.40	158- 299	2,370.7	48.69	21.54
	B_{C2}	230.66 ±10.04	161-267	1,062.1	32.59	14.08
1000 seed wt (g)	WAB2155	22.98 ± 0.24	22-24	0.56	0.75	3.25
	WAS161-B-9-3	24.83 ± 0.29	23.7-26.3	0.86	0.93	3.74
	F_1	27.54 ± 0.21	27-28.65	0.43	0.66	2.39
	F_2	22.61 ± 1.28	17.3-28.3	16.32	4.04	17.85
	B_{C1}	22.79 ± 0.95.	19.1 -25.4	9.06	3.01	13.19
	B_{C2}	22.36 ± 1.70	18.2 - 28.0	11.56	3.40	15.20

4.3 Heritability estimates

Heritability was estimated for each trait, the result is presented below (Table 4). Broad sense heritability estimate was high for plant height, number of tillers per plant, number of spikelet per panicle, 1000 seed weight and number of panicle per plant but low for panicle length. 1000 seed weight recorded highest heritabilities for both broad sense (0.96) and narrow sense (0.74) followed by number of panicle per plant which recorded (0.87) and

(0.80) for both broad sense and narrow sense heritabilities respectively. This was followed by number of spikelets per panicle (0.89) and (0.68), Number of Tillers per plant (0.76) and (0.68), Flag leaf length (0.79) and (0.63), and plant height (0.71) and (0.62) for both broad sense and narrow sense heritabilities respectively. This indicates that the phenotype is highly correlated to the genotype and that contribution of environmental conditions was relatively low for these traits. Panicle length recorded lowest broad sense (0.47) and narrow sense (0.62) heritabilities. Low heritability of panicle length shows that environmental factors strongly influence this character.

Table 4: Heritability Estimates for each character calculated from estimated variance component.

Character	**Heritability**	
	Broad Sense	Narrow Sense
Plant height	0.71	0.62
Panicle length	0.47	0.23
No of Tillers	0.76	0.68
Flag leaf length	0.79	0.63
No of Panicle/plant	0.87	0.80
No of Spikelet	0.89	0.68
1000 Seed wt	0.96	0.74

4.4 Frequency distribution graph

F_2 frequency distribution curve that is unimodal indicates that the trait is under polygenic control; bimodal distribution indicates the predominance of major genes in the control of the trait. Fig 1.2, 1.4 and 1.6 showed a bimodal frequency distribution and Fig 1.1, 1.3, 1.5 and 1.7 showed a unimodal frequency distribution, which indicates the predominance of polygenes in the control of these traits. The small peaks on Fig 1.1, 1.3, 1.5 and 1.7 indicate that plant height, Tillers per plant, panicle per plant and spikelets per panicle were under polygenic control with few modifier genes. The frequency distribution of flag leaf length (Fig 1.2), 1000 seed weight (Fig. 1.4), and panicle length (Fig 1.5) were bimodal with transgression towards the shorter short , which indicate the predominance of major genes in control of these traits.

The frequency distributions of the classes are shown below (Fig 1.1 - 1.7).

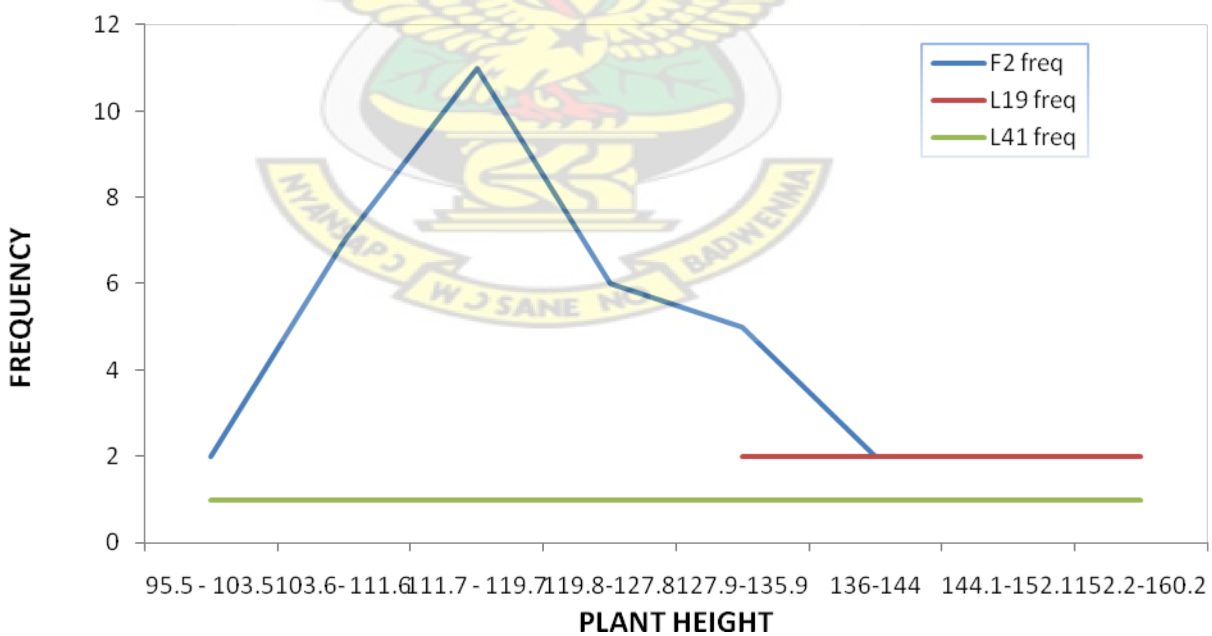
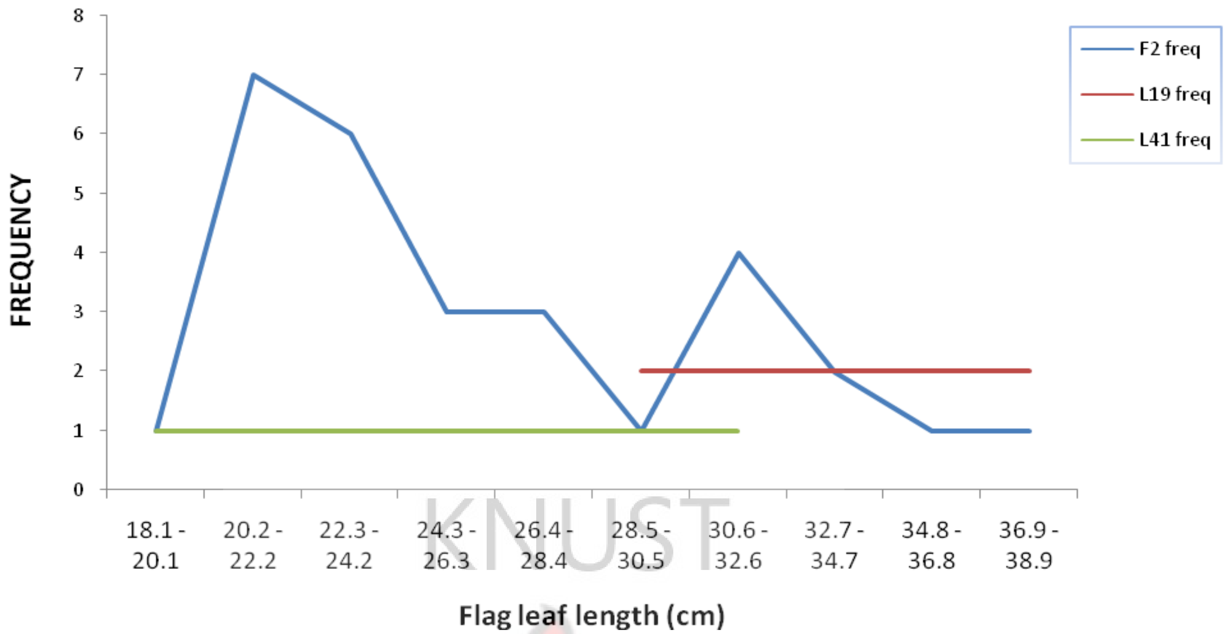


Fig. 1.1 Frequency distribution of plant height in F_2 generation of the cross WAB2155 / WAS161-B-9-3.



Fig, 1.2 Frequency distribution of flag leaf length (cm) in F_2 generation of the cross WAB2155/WAS161-B-9-3

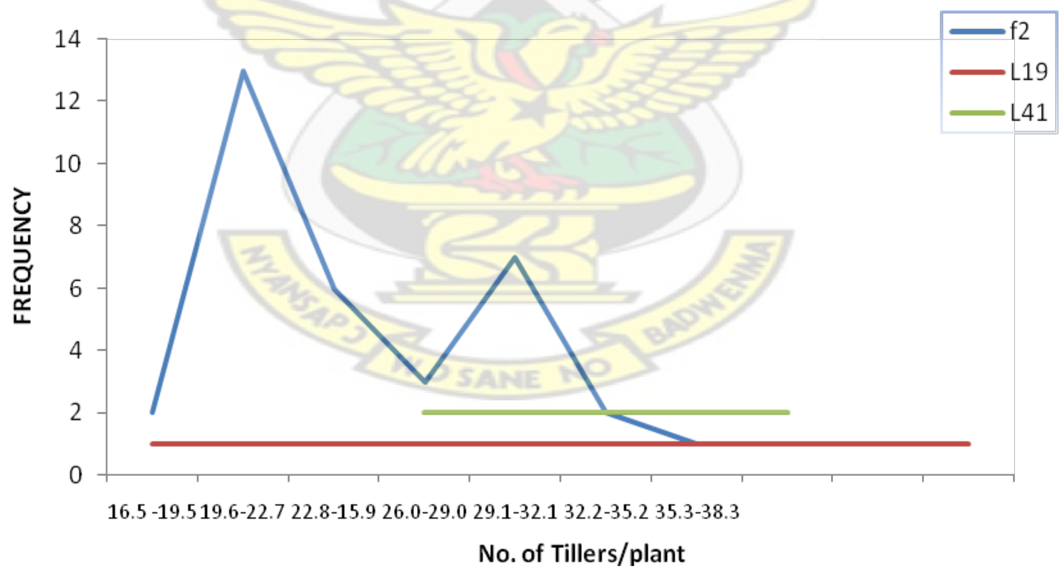


FIG. 1.3 Frequency distribution Numbers of Tillers / plant in the F_2 generation of the cross WAB2155/WAS161-B-9-3.

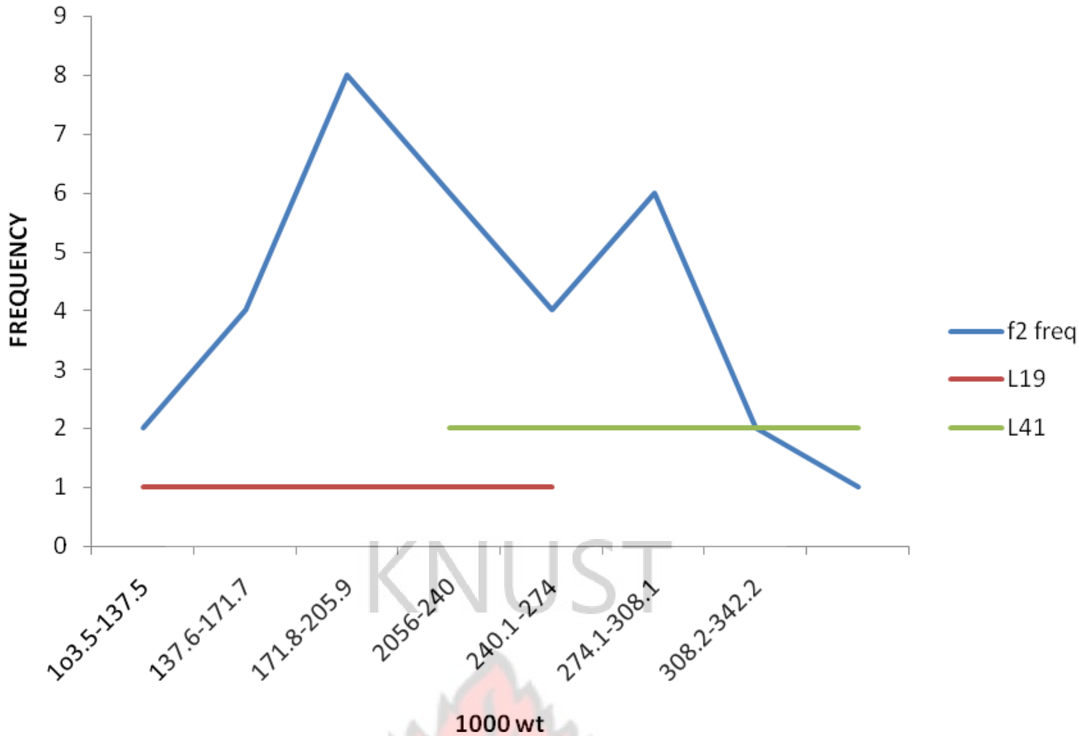


Fig.1.4 Frequency distribution of 1000 seed weight in the F_2 generation of the cross WAB2155 / WAS161-B-9-3

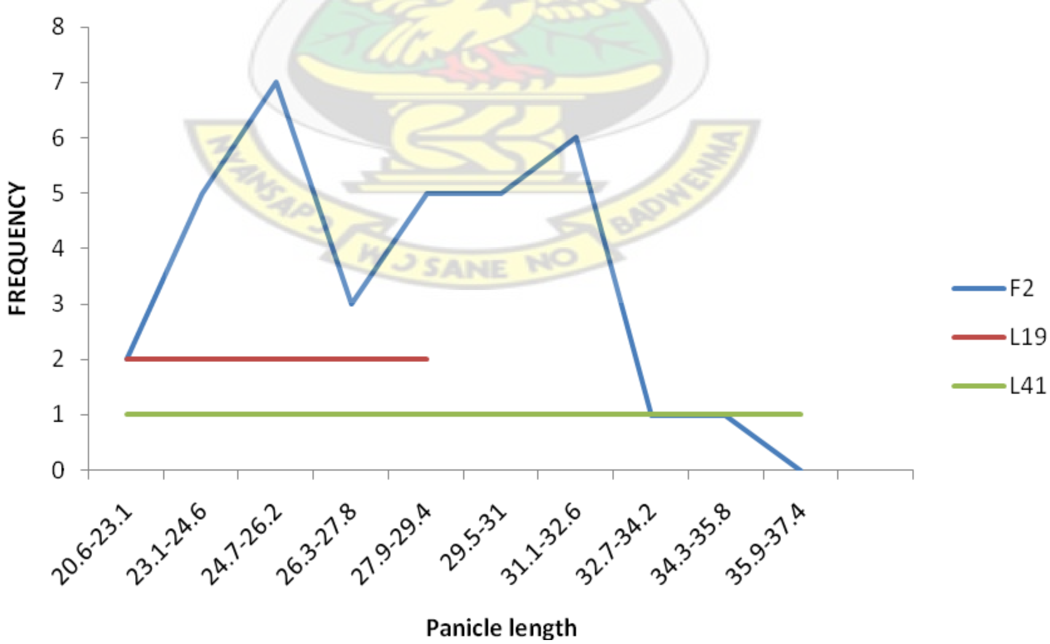


FIG1.5 Frequency distribution of panicle length in the F_2 generation of the cross WAB2155 / WAS161-B-9-3

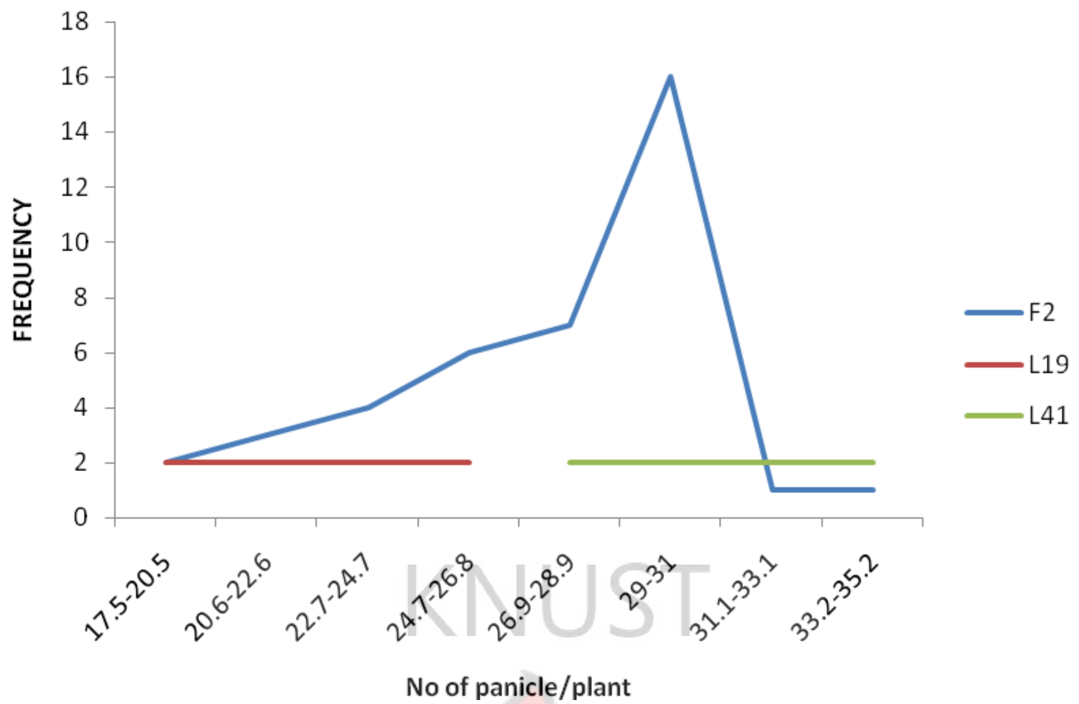


FIG.1.6 Frequency distribution of panicle length in the F_2 generation of the cross WAB2155 / WAS161-B-9-3

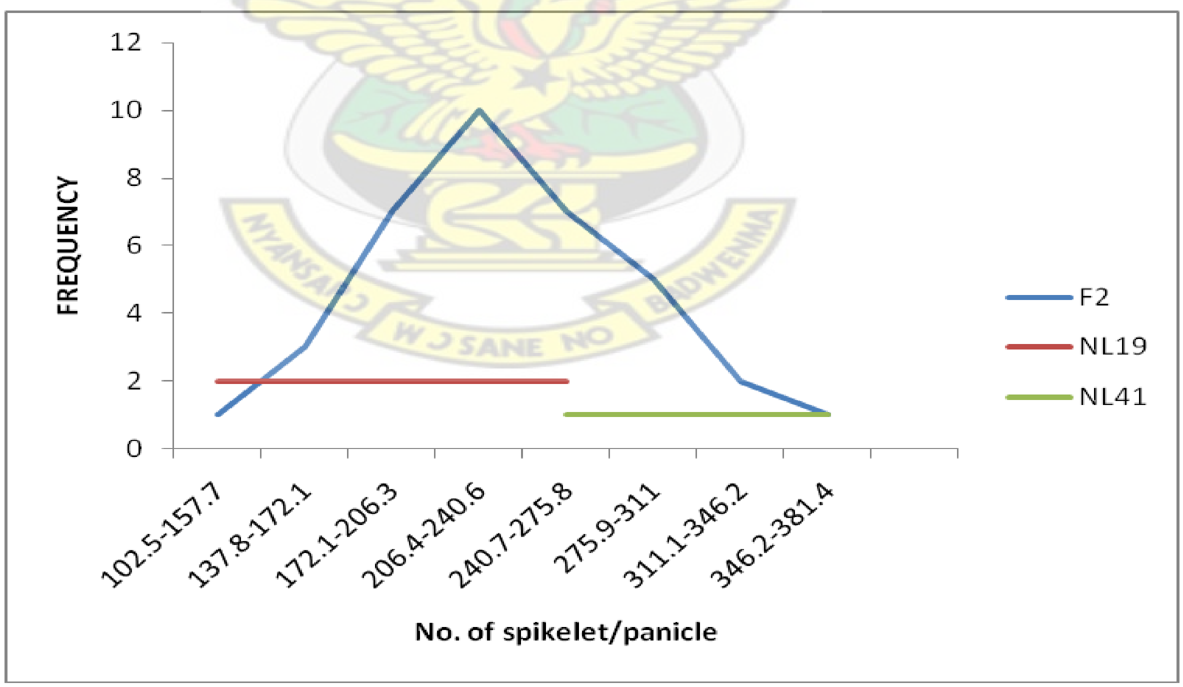


Fig 1.7 Frequency distribution of No. of spikelets per panicle in F_2 generation of the cross

WAB2155 / WAS161-B-9-3

CHAPTER 5

5.0 DISCUSSION

Very little progress can be made in plant breeding without information on the mode of inheritance of traits that are of economic importance. The inheritance of flag leaf angle was studied because earlier reports have suggested that flag leaf characteristics significantly contribute to yield (Chen *et al*., 1995, Carvalho, 1974). The determination of the genetic control of the inheritance of the trait is important and enables the breeder to transfer such a trait into the genetic backgrounds of other desirable varieties lacking the trait. A single gene control will permit selection during the first segregating generation.

Two varieties were used in the current study: WAB2155 and WAS 161-B-9-3. WAB2155 exhibits a horizontal flag leaf posture and WAS161-B-9-3 exhibit an erect flag leaf posture. From the preliminary studies of the parental varieties, WAS161-B-9-3 was shorter, has shorter and erect flag leaf, and shorter panicles. WAB2155 is a tall plant, with long and horizontal flag leaf, longer panicle. A cross was made between these two parents to study the inheritance of flag leaf angle in the two rice varieties.

5.1 Inheritance of flag leaf angle

WAS161-B-9-3 was used as donor in an attempt to incorporate erect flag leaf into WAB2155. In the cross between (WAB2155 / WAS 161-B-9-3) (horizontal / erect flag leaf angle), F_1 plants and their reciprocals were all erect indicating that erect flag leaf is completely dominant over horizontal flag leaf. This also indicates that the gene action was not under maternal effects. The F_2 generation of WAB2155 /WAS 161-B-9-3 segregated into 735 erect and 235 horizontal plants fitting into 3:1 ratio (χ^2 =0.309). The test cross (backcross to WAB2155) segregated into a ratio of 28 erect to 22 horizontal plants fitting into a 1:1 ratio (χ^2 = 0.72). The backcrosses to WAS 161-B-9-3 were all erect. The backcross values showed that the cross between the two parents (WAB2155 / WAS161-B-9-3) was successful and true because the backcrossing of the heterozygote F_1 to the homozygote dominant erect flag leaf parent gave progenies with only erect flag leaves. However, backcrossing the heterozygote F_1 to the homozygote recessive parent resulted in a segregation of half of the progenies with erect flag leaf angle and the other half with a horizontal flag leaf angle. The observation indicates that angle of flag leaf is under a single gene control with erect flag leaf angle exhibiting complete dominance over horizontal flag leaf angle. The F_2 generation of WAB2155 / WAS 161-B-9-3 had a 3:1 ratio of segregation indicating that the difference between the parents was at one locus, with dominance for erect flag leaf angle. Similar results have been reported by Cristaldo *et al*. (1992) in wheat. Kobayashi *et al*. (2003) have reported that flag leaf traits in rice, such as flag leaf length, width and angle (FLL, FLW and FLA respectively), are inherited quantitatively and influenced largely by growth environment. This was however contradicted by Bharadwaj *et al*. (2005) who reported the width of flag leaf to be governed by a dominant gene. They revealed that wide flag leaf is dominant over narrow flag leaf and a single gene pair governs the width of flag leaf. In this study, it was found out that erect flag leaf is dominant over horizontal flag leaf angle and that flag leaf angle is governed by a single gene. The considerable difference between the erect and horizontal flag leaf, suggests that a major gene differentiates the parent in the control of flag leaf angle. Other investigators have also indicated that continuous variance traits, which are normally considered to be under the control of a large number of genes with small effects, may present Mendelian type variation controlled by one or a few genes (Cristaldo *et al*., 1992, Qualset, 1979). An anonymous publisher (1971) has also reported flag leaf angle in rice to be controlled by one recessive gene. Anonymous (1971) has remarked that the lack of agreement among researchers as to whether a single recessive gene, two or more genes control flag leaf angle in rice appears to be related to the difference in the varieties, growth stage and also the difference in the method used in evaluating the shape of the angle.

The use of the erect leaf trait as a selection criterion is effective because of its high heritability. However, the monogenic inheritance found indicates little flexibility in trait manipulation, mainly due to restricted possibility of obtaining variability through new recombinant types.

5.2.0 Genetic analysis of flag leaf length

Mean flag leaf length in WAB2155 (34.32 cm) (Table 3) was constantly higher than that of WAS 161-B-9-3, which indicates that WAB2155 has a higher tendency of bending than WAS161-B-9-3, this agrees with the findings of Akmal *et al.* (2000) who reported that the longer the flag leaf the more droopier it becomes. Mean F_1 value was below the parental limits, with shorter flag leaf length similar to WAS161-B-9-3 indicating the inheritance of this trait to be under the control of a major gene. The range of variation in F_2 showed transgressive segregation towards the shorter flag leaf length. Flag leaf length exhibit high broad sense heritability which indicate that the phenotype is highly correlated with the genotype. In other words, the contribution of environmental conditions was relatively low for this trait. The high heritability of flag leaf length is in conformity with Bhadru *et al.* (2012), and also agrees with the findings of Ghosh and Sharma (2012) who reported high heritability of flag leaf length among rice's genotypes, therefore breeding for such characters are easy to operate. The frequency distribution in F_2 formed a bimodal (Fig 1.1) curve with transgression towards the parent with shorter flag leaf length confirming the predominance of major genes in the control of this trait. This agrees with the findings of Ahmed *et al*. (1995) who reported bimodal F_2 frequency distributions (major gene control) in three rice crosses.

5.2.1 Genetic analysis of plant height

Morphological characteristics such as plant height have been considered important traits in breeding both super rice and bio-energy crops. The mean plant height for WAB2155 (152.75 cm) was higher than WAS161-B-9-3 (109.62 cm). The F_2 plant recorded highest variance component and highest coefficient of variation. High broad sense and narrow sense heritability was recorded for plant height. This agrees with the findings of Fahliani *et al*. (2010) who reported high broad sense and narrow sense heritability estimate for plant height. The mean F_1 value for the cross is within the two parental limits. The range of variation and variance for this trait in F_2 was higher than those of the parents and F_1.The CV was highest in F_2 compared to F_1 and the parents. F_2 frequency distribution was unimodal (1.2) for plant height, indicating that the trait was under polygenic control. This is in agreement with the findings of Ahmed *et al*. (1995) who reported the predominance of polygenic control in three different rice crosses. The observation is characteristic of a quantitative (measurable) trait such as plant height. Tall plants are a disadvantage in rice production, as they are prone to lodging during strong monsoon seasons. The production of F_1 plants that were intermediate in height to the parents shows it is possible to modify plant height in the tall parent (WAB2155). The NERICA lines have been accepted in West

Africa because of their tolerance to drought stress. Breeding efforts such as in this study would be useful in attempts to modify plant height to the intermediate type.

5.2.2. Genetic analysis of 1000 seed weight

The mean weight of WAS161-B-9-3 (24.83g) was more than WAB2155 (22.98 g) (Table 3). Mean F_1 values were within parental limits indicating that the inheritance of this trait is partially or incompletely dominant. F_2 frequency distribution (Fig.1.4) was bimodal with transgressive segregation towards WAS161-B-9-3. This indicates a predominance of major genes. The predominance of major genes has been reported by Ahmed *et al*. (1995). The high narrow sense heritability confirms that additive genes were more than major genes in the control of seed weight. High broad sense heritability was estimated for this trait, this is in conformity with the findings of Ghosh and Sharma (2012) who has also reported high heritability for this trait.

5.2.3 Genetic analysis of panicle length

Panicle length is an important trait which contributes to yield in rice because it determines the number of spikelets that will be produced. Conversely, if the panicle is too long, it breaks easily. The F_1 values show negative heterosis with the F_1 mean exceeding the lower parental mean in length. The range of variation in F_2 as compared to the parental range showed transgressive segregation towards higher values (Table 3 and Fig. 1.5).

F_2 frequency distribution was unimodal (Fig. 1.5) indicating that the trait was under polygenic control. This is confirmed by the medium to low heritabilities (Table 4) obtained for this trait. This is in agreement with the findings of others (Jennings *et al*., 1979, Wayne and Dilday, 2003; Fahliani *et al*., 2010) who reported low heritability for panicle length.

Low heritability of panicle length showed that environmental factors strongly influence these characters.

5.2.4 Genetic analysis of number of panicles per plant

The mean F_1 value was within parental means indicating that the inheritance of the trait is partially dominant. The range of variation in F_2 showed transgressive segregation towards lower values (Table 3). Number of panicles per plant had high broad and narrow sense heritabilities; this is in agreement with Ghosh and Sharma (2012) who had reported high broad and narrow sense heritability in rice for number of panicles per plant. F_2 frequency distribution was unimodal (Fig.1.6) indicating the predominance of additive genes in the control of this trait.

5.2.5 Genetic analysis of number of Tillers per plant

The number of effective tillers per plant is an important criterion in classification and selection of rice varieties. The mean F_1 value was within parental means. F_2 frequency distribution was bimodal (Fig.1.3) confirming the presence of major genes in control of this trait. Heritability for both broad and narrow sense was high indicating the absence of environmental factors in exhibiting this trait. This is in conformity with the findings of Fahliani *et al*. (2010) and Ghosh and Sharma (2012) who had reported high narrow and broad sense heritabilities.

5.2.6 Genetic analysis of number of spikelets per panicle

F_2 frequency distribution was unimodal (Fig. 1.7) for spikelets per panicle indicating that the trait was under polygenic control. This is confirmed by the high broad and narrow sense heritabilities (Table 4) obtain for this trait. This is in support with the findings of Ghosh and Sharma (2012). Mean F_1 value is within parental limit indicating the presence of dominant genes

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

This study found a single gene control with complete dominance of erect leaf angle over horizontal leaf angle as opposed to multiple gene control. However, a careful review of literature compared to this study suggests that, there are differences in the number of genes controlling flag leaf trait in different varieties. The reciprocal F_1 were also erect which shows that the erect leaf trait was not affected by direction of the cross and hence no maternal effects.

The inheritance of flag leaf length is dominant with some transgressive segregation towards shorter leaf length in the cross made in this study. The possibility of obtaining individuals with longer flag leaf length than WAB2155 is, therefore low.

Heritability estimates were high for this trait; it is therefore advisable to start selection for this trait in earlier generations.

The inheritance of plant height showed some transgressive segregation towards the shorter parent in the cross made in this study. Heritability estimate were also high. Selection for this trait would, therefore, be effective in the earlier generations.

Heritability estimates for all the other traits observed were high with the exception of panicle length which gives low heritability for both broad and narrow sense. It is, therefore, advisable to start the selection of this trait from F_3 onwards when broad sense heritability is expected to be higher.

RECOMMENDATION

It is recommended that further work be carried out (By mapping) to identify the single gene that is responsible for the inheritance of flag leaf angle in low land varieties by the use of molecular procedures.

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