GENETIC ANALYSIS OF TOLERANCE TO IRON TOXICITY IN RICE (*ORYZA SATIVA* L.)

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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES AHMADU BELLO UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD
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DEPARTMENT OF PLANT SCIENCE,
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DECLARATION

I declare that the work in this dissertation entitled "GENETIC ANALYSIS OF TOLERANCE TO IRON TOXICITY IN RICE (*ORYZA SATIVA* L.) has been carried out by me in the Department of Plant Science, Ahmadu Bello University, Zaria. The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other University.

MAIWA'AZI ABU BARDE	_____	_____
Student	Signature	Date

CERTIFICATION

This dissertation entitled, GENETIC ANALYSIS OF TOLERANCE TO IRON TOXICITY IN RICE (*ORYZA SATIVA* L.) by MAIWA'AZI, Abu Barde meets the regulations governing the award of the Master of Science degree in Plant Breeding of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This work is dedicated to Almighty God the creator of all things, visible and invisible, living and none living and to my late parents, Evangelist Abu Barde and Mrs Asibi (Yabyikuzo) and my late sisters Mrs Juma Esu, Mrs Hannatu Jezhi and Mrs Rifkatu Musa who have gone ahead and my brother Adamu Abu, Sarkin Noman Kugbalu also to rice farmers and everyone who loves rice.

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"The moon moves slowly, but it crosses the town."

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LIST OF ABBREVIATIONS

Fe^{2+}	Ferrus iron
Fe^{3+}	Ferric Iron
ANOVA	Analysis of Variance
GCA	General Combining Ability
SCA	Specific Combining Ability
GCV	Genotypic Coefficient of Variation
PCV	Phenotypic Coefficient of Variation
H2BS	Heritability in Broad Sense
SSA	Sub Saharan Africa
FAOSTAT	Food and Agriculture Organization statistics
IRRI	International Rice Research Institute
SES	Standard Evaluation System
CARD	Coalition for African Rice Development
WARDA	West Africa Rice Development Association
CEC	Cation Exchange Capacity
DNA	Deoxyribonucleic Acid
Et al	And other(s)
ROS	Reactive Oxygen Species
NCRI	National Cereal Research Institute
K	Potassium
IITA	International Institute for Tropical Agriculture
AOAC	Association of Analytical Chemists
pH	The measure of acidity or basicity of soil
Ca	Calcium
Mg	Magnesium
FARO	Federal Agriculture Released Oryzae
F_1	First filial generation
SAS	Statistical Analysis System
LSD	Least Significant Difference
Df	Degree of freedom
MS	Means Square
EMS	Expected Means Square
**	Highly significant at< 0.01 probability level
*	Significant
MA	Mugineic Acid
YS	Yellow Stripe
NA	Nicotiamine
DMA	Deoxy Mugineic Acid
N	Nitrogen

Zn	Zinc
NASC	National Agricultural Seeds Council
Fe_20_2	Hematite
Fe_30_4	Magnetite
$FeC0_3$	Siderite
Fe00H	Geothite
NERICA	New Rice for Africa
$Mgkg^{-1}$	Milligram per kilogram
RCBD	Randomized Complete Block Design

ABSTRACT

The objective of the present study was to determine genetic variability for some agronomic traits and iron toxicity, determine mode of gene action associated with tolerance to iron toxicity and the degree of association between iron toxicity, yield and yield components in rice. The study was carried out using eight (8) parents of rice which comprised of three (3) susceptible and five (5) tolerant to iron toxicity. These were crossed in a half diallel mating design and population generated 28 F_1. The parents, F_1 population along with two checks were evaluated during the 2017/2018 dry season at an iron toxicity spot in-situ at Edozhigi, Niger state. The experiment was laid in a randomized complete block design and replicated three times. Data were collected and analysed on grain yield, days to 50% flowering, number of tillers, number of leaves, plant height, panicle length, number of seeds per panicle, panicle exertion, number of effective tillers, 1000 grain weight, first iron toxicity score and second iron toxicity score. Results showed highly significance ($P<0.01$) differences among the genotypes for all the traits which revealed large amount of genetic variability in the parents that could be suitable to initiate selection for crop improvement programme. Results from grain yield of the parents ranged from 2830 kg/ha for FARO 60 to 8210 kg/ha for FARO 57. Grain yield of the variety cross hybrids ranged from 2550 kg/ha for FARO 44 × FARO 61 to 7045 kg/ha for SUAKOKO 8 × CK-21 which out yielded the commercial checks Alh. Baba (4225 kg/ha) and Ewodufagi (4435 kg/ha). General Combining Ability (GCA) and Specific Combining Ability (SCA) mean squares were significant for grain yield, number of tillers, plant height, number of effective tillers and number of seed per panicle under iron toxicity hotspot, indicating the importance of additive and non-additive gene action for controlling the traits. FARO 52, SUAKOKO 8, CK-21 and CK-43 were

good general combiners for grain yield under iron toxicity hot spot conditions. There was preponderance of additive gene effects over non-additive gene effects for all the traits measured indicating that additive gene action was more important in the inheritance of the traits under iron toxicity hotspot. Estimates of variance due to GCA and SCA and their ratios showed preponderance of additive gene effect controlling the adaptive traits for iron toxicity tolerance, estimates of both PCV and GCV revealed low for plant height. In general, PCV values were slightly higher than the GCV values indicating that the traits were less influenced by the environment. High broad sense heritability was recorded for all the traits studied. Significant positive phenotypic correlation existed between grain yield of the F_1 hybrids with plant height (r = 0.60**), number of tillers (r = 0.44*), panicle length (r = 0.42*) and number opf effective tillers (r = 0.37*) and negatively correlated with number of leaves (r = -0.45*), panicle exertion (r = -0.64*), first and second iron toxicity scores (r = -0.70*) and (r = -0.60*), respectively under iron toxicity hotspot. Significant negative correlation was observed between iron toxicity and grain yield (r = -0.41*, r = -0.46*). Number of tillers (r = -0.70**, r = -0.60**), plant height (r = -0.73**, r = -0.77**), panicle length (r = -0.66**, r = -0.69**), number of seeds per panicle (r = -0.54**, r = -0.41*) and number of effective tillers (r = -0.74, r = -0.65**). The F_1 genotype FARO 52 x CK-21 was recommended for more extensive test in regions prone to iron toxicity for adoption and production to alleviate the problem of food insecurity in the country.

CHAPTER ONE

1.1 INTRODUCTION

Rice (*Oryza sativa* Linn) belongs to the family of grass (Poeceae) Chandrasekaran *et al.* (2007). It is one of the world's most important food crops with a total production of around 600 million tons, occupying 11% of the world's total arable land (Guimaraes, 2009). The crop supplies 2,808 calories/person/day, which represents 21% of the total calorie supply consumed by humans. Rice is an important annual crop in Nigeria. It is one of the major staples. The crop is commonly consumed even as a food crop for household food security. The average Nigerian, consumes 24.8l kg of rice per year, representing 9% of annual calorie intake (IRRI, 2001). Rice production in Africa has grown from a yearly average growth rate of (1.76%) in 1991-2001 to more than double (3.96%) in 2002–2013 (FAOSTAT, 2014). Thus, rice is a key cereal crop in sub-Saharan Africa (SSA) (Seck *et al.,* 2012). Although rice production has increased since the 1970s, domestic production meets only 60% of the demand. Annually, Africa imports about 13 million tons of milled rice which is equivalent to about one-third of the world market. In 2008, growing concern about global food security led to a hike in food prices, particularly in rice, that consequently led to social unrest (Saito *et al.,* 2015). As a result of this 'rice crisis', African governments and the international donor community embarked on ambitious rice-development programs to achieve self-sufficiency (Saito *et al.*, 2015). In Nigeria, lowland rice is cultivated on an estimated area of 3 million hectares out of which 1.8 million hectares are prone to iron toxicity (NCRI, 2012). One of the areas where rice is commonly grown in Nigeria is Edozhigi village in Bida Local Government Area of Niger State. The people of this environment are predominantly lowland rice farmers. A survey conducted by the West African Rice Development Association (WARDA) in the area showed that average yield of lowland rice at Edozhigi seldom

exceeds 1.5 tons ha^{-1} (Narteh and Sahrawat, 1999). Iron toxicity is a major constraint to rice production in some important production areas. Iron toxicity is a nutritional disorder associated with high level of ferrous iron concentration in the soil and is found mainly in waterlogged lowlands (Cherif *et al.,* 2009). The response of rice to iron toxicity varies among different rice varieties. Some varieties have the mechanism to retain high iron levels in their roots or as oxides in the rhizosphere while other varieties are susceptible to iron toxicity, expressed in poor adaptability to iron toxicity stressed environment (Mandal *et al.,* 2004). Fukuda *et al.* (2012), reported that the surest way to counter iron toxicity is by using tolerant rice varieties. Genetic improvement of iron-toxicity tolerance implies the need of varietal screening to make good use of the existing diversity for iron toxicity tolerance. Lowland soils in Nigeria have high concentrations of iron. This is an impediment to rice production in the lowlands. Rice is mostly grown by small holder farmers in Nigeria who depend on good harvests as their source of income. Since rice is a staple food in Nigeria, a low production due to iron toxicity threatens the country's food security.

1.1 Justification

Several researches have been carried out on iron toxicity effects on rice production around the world. But in Nigeria, works on iron toxicity in rice have been based on mere selection. Therefore, adequate information has not been clearly understood about the constraint. Understanding of the genetic basis of iron tolerance mechanisms can provide useful information that will guide in designing strategic programme for the breeding of iron toxicity tolerant rice varieties. Consequently, knowing genetic bases of the materials formed the basis of this research.

1.2 Main Objective

To improve yield of lowland rice production in iron toxic prone fields in Nigeria by planting iron toxicity tolerant rice varieties in iron toxic lowlands.

1.3 Specific Objectives

The objectives of the present study were to determine;

i. Genetic variability of some agronomic traits for iron toxicity in rice.

ii. Mode of gene action associated with tolerance to iron toxicity in rice.

iii. The degree of association between iron toxicity, yield and yield components in rice.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and Distribution of Rice

Oryza sativa and *Oryza glaberrima* are the only cultivated species in the genus *Oryza* which comprises 22 valid species (Chopra, 2001). Based on Pan-tropical and wide distribution of *Oryza* species, it is speculated that the Gondwana super continent, which is believed to have got fractured during early cretaceous period (130 million years ago) into the present day Africa, South America, South and South East Asia, Australia and Antarctica, the species also drifted along to form distinct geographical habit (Chopra, 2001). Rice researchers are in agreement that the large belt extending from North East hills of India to the mountain ranges of the main land of South East Asia and South West China could be the primary Centre of origin of *Oryza sativa,* while Niger River Delta in Africa as the primary Centre of origin of *Oryza glaberrima,* (Sarla and Swamy 2013). Niches that provided Conducive environment for eco genetic differentiation facilitated by migration, natural and human selection became the Centre of diversity of the cultivated species. However, it is difficult to precisely demarcate between origin and domestication of the cultivated rice. Nevertheless, it is speculated that, it might have originated around 10 million years back from the wild/weedy progenitor species by series of mutations, intercrossing and natural selection. *Oryza sativa* was domesticated between, 7000 and 10,000 years ago given the fact that the oldest remains of Asian cultivated rice found in East china and North India dated back to 7000 years and that grain samples of wide rice excavated at Non, Nok Tha in Northern Thailand are more than 6000 years old, (Chopra, 2001). The African rice, believed to have been domesticated at least 3500 years later, has been inferred from various

evidences, found in the Niger basin around 1500 BC and in Guinea 400 years later (Chopra, 2001). Cultivated rice belongs to the grass species *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice) (Chandrasekaran *et al.*, 2007). It is a staple food for almost half of the world's population (Nanda and Agrawal, 2015 and Maclean *et al.*, 2002), grown in a wide range of environments. According to Nanda and Agrawal (2015), rice is the second largest cereal crop in the world after maize. It is the most rapidly growing food source in Africa and an important element of food security in an increasing number of Low Income and Food Deficit (LIFD) countries. More than 90% of global rice production is harvested from irrigated or rain-fed lowland rice fields and it accounts for more than 70% of human caloric intake (Nanda and Agrawal, 2015). According to FAOSTAT (2012) data, rice is the most important grain with regard to human nutrition and caloric intake. In Africa, rice is one of the popular foods and it is now the fastest-growing staple food crop. The relative growth in demand for rice is faster in Africa than anywhere else in the world (WARDA, 2005). During the past three decades the crop has witnessed consistent increases in demand and its growing importance is evident in the strategic food security planning policies of many countries. With the exception of a few countries that have attained self-sufficiency in rice production, rice demand exceeds production and large quantities of rice are imported to meet demand at a huge cost in hard currencies.

2.2 Economic Importance of Rice

Rice has grown in importance as a component of Nigerian diets. An average Nigerian consumes about 24.8 kg of rice per year, representing 9 per cent of total caloric intake and 23 percent of the total cereal consumption FAO, (2003). Rice is also used for making wine, bear, and confectioneries. Starch made from rice is used in foods, cosmetics, and textile manufacture

(Nanda and Agrawal, 2015). Rice straw is used in feeding livestock and also used for the manufacture of straw board and ceiling board, braiding baskets, mats, mushroom culture, thatching roof, and mulching. It serves as an important source of vitamin B complex especially when the kernel is not polished (Nanda and Agrawal, 2015). Njavara rice is a variety of rice from Kerela, India known for its use in Ayurvedic rejuvenation therapies. It is a short duration variety, harvested within 60 – 70 days. It rejuvenates the muscles and nerves. It is used in the treatment of diarrhea, vomiting, jaundice and cough (Nanda and Agrawal, 2015). Other ailments treated with this variety of rice includes, small pox, diabetes, breast cancer because of its content of anti-carcinogenic properties. It increases milk flow in lactating mothers. It cures piles, snake bite, stomach ulcer, rheumatism and arthritis. Njavara rice is a unique land race with great antiquity (Nanda and Agrawal, 2015).

2.3 Production Constraints

In Nigeria, rice production has emerged as one of the fastest growing agricultural sub-sector and its consumption has moved from a ceremonial to a staple food in many Nigerian homes within the last two decades, such that some families cannot do without it in a day (Onuk *et al.*, 2010). Nwachukwu, (2008), reported that as a staple food in Nigeria, rice accounts for 40% of the diet of the country's population and it plays a major role in the political stability in the country. Low land rice growing environment covers about 75% of Nigerian rice growing ecosystems. Despite being the largest rice producer in West Africa, Nigeria is still a rice-deficit nation (Rahji and Adewumi, 2008). One of the major constraints to rice production in the inland valleys of Nigeria is Iron toxicity. Nigeria has a wide range of arable rice growing environments including the inland valleys on an estimated area of 3 million hectares out of which 1.8 million hectares are

prone to iron toxicity (NCRI, 2012). The inland valley of West Africa which covers 30% of the total rice producing area is highly prone to iron toxicity (Audebert, 2006 and Olaleye *et al.,* 2009). Iron toxicity is a nutritional disorder causing poor growth and severe yield loss in West African lowland rice field. This nutritional disorder is often caused by the microbial reduction of insoluble iron-III (Fe^{3+}) into soluble iron-II (Fe^{2+}), under flooded conditions which can be taken up by rice plants in excess amounts (Dada and Aminu, 2013). Rice is a profligate user of water. It uses 3000-5000 litres of water to produce 1 kilogram of paddy rice, which is about 2 to 3 times more than the quantity required in producing 1 kilogram of other cereals such as maize or wheat (Cantrell, 2002). Iron toxicity in rice plants occurs when the plants absorb a large amount of iron from the soil. This happens when high concentrations of ferric iron (Fe^{3+}) is reduced into its soluble ferrous form (Fe^{2+}) by microorganisms under anaerobic conditions (Gross *et al*., 2003). All types of lowlands (mangrove, irrigated and rain fed) can be affected by this constraint; with or without water management. Iron toxicity is characterized by "bronzing" or "yellowing" of oldest rice leaves which often lead to retardation of growth factors especially plant height, tillering potentials, as well as higher level of panicle sterility. Additionally, symptoms commonly observed are rusty leaf spots (bronzing), leaf edges are dark brown and poor development of the root system (Dobbermann and Fairhurst, 2000). Rice plants usually maintain 60-300 mg/kg $^{-1}$ of Fe while Fe deficient plant may have 10-30 mg/kg $^{-1}$. The critical level for occurrence of iron toxicity in rice plants is 300 mg/kg^{-1} Fe in the soil, however, Fe concentration may rise to 400-1000 mg/kg^{-1} (Anumalla *et al.,* 2019). The iron toxicity is one of the commonly observed soil nutritional disorder that affects millions of hectares of rice land, especially in South East Asia and West Africa. This disrupts or over-expresses a number of metabolic processes, resulting in damage of the rice plant (Becker and Asch 2005). The sources of the iron could be from the soil

solution in the lowland itself or by natural seepage or runoffs from adjoining slopes. The Fe^{2+} solution formed usually causes element disequilibrium in the soil solution, which is translocated into the plant (Dada and Aminu, 2013). Reduction in the productivity of lowland rice has been reported to be directly proportional to concentration of Fe^{2+} in the solution and the tolerance of the cultivar type (Audebert, 2006). Lowland soils in Nigeria have high concentration of iron. This is an impediment to rice production in the lowlands. Rice is mostly grown by small holder farmers in Nigeria who depend on the harvests as their source of income. Nonetheless, fertilizer utilization among poor resource rice growers is still below the recommended rate. Notwithstanding, rice production in Nigeria faces many constraints and one of the constraints is iron toxicity. Iron toxicity is a nutrient disorder in plants which is brought about by the uptake of Fe^{2+} to concentrations exceeding 300 mg kg^{-1} (Anumalla *et al.,* 2019). The Quantity of fertilizer applied especially to arable crops by Nigerian farmers has been generally sub-optimal (Philips *et al.,* 2009). Diatta and Sahrawat (2006), reported that application of nutrients such as N, P, K and Zn could help in controlling harmful effect of iron toxicity on rice field. Report of Audebert (2006), revealed that this problem can be solved with the development of tolerant varieties, the use of appropriate cropping systems, fertilizer application and water management. Fukuda *et al.* (2012), reported that the surest way to counter iron toxicity is by planting tolerant rice varieties

2.4 Iron Toxicity in the Soil

2.4.1 Iron Ttoxicity in the Soil and its characteristics

Most soils contain iron. Iron minerals commonly found in soils include goethite (FeOOH), hematite (Fe_2O_4), pyrite (FeS), siderite ($FeCO_3$), and magnetite (Fe_3O_4) (Fageria *et al.,* 2003). When parent materials weather, they release significant amounts of minerals in the soil including

iron. In reduced or submerged soils, (Fe^{2+}) concentration can reach high levels. Rice plants growing in high Fe concentration, take up Fe in excess of plant demand, causing toxicity to plant tissues. Iron toxicity occurs in a wide range of soil types, but mostly in ultisols, oxisols and acid sulfate soils. These soils have high ion activity and potential acidity irrespective of organic matter content and soil texture. General characteristics shared by most Fe-toxic soils are high amounts of reducible Fe, low pH, high Cation Exchange Capacity (CEC) and exchangeable potassium content. It is also characterized by high reactivity and content of Fe^{3+} oxide hydrates. Soil temperature, low temperature brings late but high and persistent concentration of water soluble Fe. Salt content, salt increases Fe concentration in soil solution and low percolation rate in the soil. Texture, CEC and organic matter content influence the concentration of ferrous iron in soil solution in which iron toxicity occurs. Variations can be observed depending on soil texture and environmental conditions. For instance, iron toxicity was reported to be more severe during the dry season when the vapor pressure deficit is high compared to the wet season (Becker and Asch, 2005).

2.4.2 Conditions for Fe^{3+} reduction

The expression of iron toxicity severity in the rice rhizosphere has been related to many soil factors. These included the content and type of clay minerals, the amount of exchangeable soil Fe^{2+}, the soil pH and the presence of stress factors. The concentration of soil Fe^{2+} is less in clay soils than in sandy soils. Clay was found to control the content and distribution of iron in both Alfisols and Vertisols. Clay content may have great potential for Fe^{2+} dynamics as a result of its CEC. Acid sulfate soils are characterized by the presence of sulfuric horizon and generally content iron in large amount resulting in low soil pH, < 3.5, (Sarwani *et al.*, 2006). Acid sulfate

soils have Fe^{2+} concentrations of up to 5000 mg kg^{-1}. The acid can dissolve metals such as Aluminum and if discharged into rivers and estuaries, the combination of metals and acidity can kill both plants and animals (Stauber and Apte, 2016).

2.4.3 Distribution of iron in soils

Seasonal changes due to rainfall pattern (rain fed rice) or drainage and irrigation (irrigated rice) affect iron distribution in the soils. Irrespective of these conditions, changes in redox potential (Eh) and Fe concentrations are found on a small scale horizontally in the soil profile and vertically between the bulk soil and the rhizosphere. The level of Fe in the crop is a function of the type of crop and the amount of iron availability in the soil. The concentration of Fe^{2+} is less in clay soil than in sandy soils. There is a relationship between the level of Fe and the clay content of the soil, pH and organic matter. The availability of most micro nutrient is largely pH dependent. Availability decreases as pH increases (Joy *et al.*, 2015). Three soil compartments can be distinguished in paddy soil profiles and they include a thin toxic surface layer, the reduced puddle bulk soil and the toxic rhizosphere soil and rhizoplane (Liesack *et al.*, 2000). The horizontal distribution of Eh and reduced Fe in the profile has been described by (Ratering and Schnell 2000). The depth of the toxic surface layer varies between 2 and 10 mm and is partially determined by a nitrate-dependent microbial re-oxidation of Fe^{2+}. The highest Fe^{2+} concentration was found at 2-15 cm soil depth. Concentration of Fe^{2+} declines in deeper layers or below the plough pan. This is where the soil contains less organic matter than in the puddle soil. The nature and the amount of various form of iron depend on soil texture, pH, Calcium Carbonate ($CaCO_3$) level, organic content and soil characteristics (Sharma *et al.*, 2008). Horizontal variations in Fe^{2+} are linked to the oxic rhizosphere soil, which is the result of oxygen release from rice roots. Soil

organic matter and pH have the strongest influence Fe levels in the soils. Fe levels decrease as pH increases and as organic matter decreases (Douglas, 2002). Plants can obtain Fe in its ironic forms such as Fe^{2+} (Ferrus form) and Fe^{3+} (Ferric form), but Fe^{3+} is insoluble at neutral and high pH making Fe in available to plants in alkaline and calcarious soils (Douglas, 2002).

2.5 Iron Toxicity in Rice Plant

2.5.1 Uptake and transport of iron

Rice is a profligate user of water. It uses 3000-5000 liters of water to produce 1 kilogram of paddy rice, which is about 2 to 3 times more than the quantity required in producing 1 kilogram of other cereals such as maize or wheat, (Cantrell,2002). Rice plants have the tendency of taking up more iron than most of the other plants, and Fe^{2+} is the iron species prevailing in paddy fields. Additionally to the effects of high intracellular Fe concentrations on plant growth, high concentration of Fe^{2+} in the rhizosphere has antagonistic effects in the uptake of many essential nutrients such as xxx and yyy (Fageria *et al.*, 2008). Thus, iron toxicity is often described as a multiple nutrient disorder. Rice plants are able to take up iron from the rhizosphere as Fe^{3+}/phytosiderophore complex but also as Fe^{2+} (Ishimaru *et al*., 2006). In aerobic environments, where iron is among the most limiting nutrients for plant growth primarily as a result of the low solubility of the oxidized ferric form (Zuo and Zhang, 2011); (Samaranayake *et al.,* 2012), iron is absorbed as Fe^{3+}/phytosiderophore. Iron in the form of Fe (OH)3 is solubilized by phytosiderophores from the mugineic acid (MA) family to form a Fe (III)-MA complex. The Fe (III)–MA complex is then transported through the root membrane via a transporter from the Yellow Stripe (YS) family (Inoue *et al.*, 2009). YS Fe transporter was first isolated in maize and named YS1 (Curie *et al*., 2001). Within the rice cells, Fe may move in the form of Fe-citrate,

Fe^{2+}-nicotianamine (NA) and $Fe^{3+-\ 2}$'-deoxymugineic acid (DMA) (Koike *et al*., 2004). These complexes are readily taken up by specific receptors which will ensure the passage of Fe from one cellular compartment to another (Bashir *et al.,* 2006). Fe translocation from the roots to the shoots and its distribution to organs are done through the xylem and phloem saps in the form of Fe/chelator complex (Hell and Stephan, 2003). Fe is bound to chelators (citrate, NA or DMA) to prevent formation of free radicals (Kim and Guerinot, 2007).

2.5.2 Symptoms of iron toxicity effects

Appearance of iron toxicity symptoms in rice is a result of excessive Fe^{2+} uptake by rice roots and its translocation into leaves. Excess Fe^{2+} uptake elevates production of toxic oxygen radicals that can damage cell structural components and impair physiological processes (Becker and Asch, 2005). For instance, oxygen radicals can destroy membrane lipids and DNA (Fukuda *et al.,* 2012). When plants absorb high amounts of iron, discoloration of leaves can be observed. This phenomenon is called leaf bronzing and may be due to oxidized polyphenols. Leaf bronzing begins as small brown spots on the tip of lower leaves and extends towards the leaf base (Wu *et al.,* 2014). The spots coalesce and the lower leaves turn dark purplish brown and eventually die. Other symptoms depend on the stage when leaf bronzing occurs. If bronzing occurs at the seedling stage, the plants remain stunted with limited tillering potential. During the vegetative stage, the symptoms are reduced plant height and dry-matter accumulation with the shoot being more affected than the root biomass (Wan *et al.,* 2005).

2.6 Mechanisms of Tolerance to Iron Toxicity

2.6.1 Physiological avoidance and exclusion

Tolerance to iron toxicity in rice is governed by age, nutritional status and chemical environment. The physiological status of a rice plant under submerged soil condition greatly modifies its ability to tolerate high iron concentration in the soil solution. In the presence of P, K, Zn and N, low effects of iron toxicity can be observed (Audebert and Sahrawat, 2000). Rice roots play three important functions to counter iron toxicity. These include oxidation of iron in the rhizosphere to keep iron concentration low in the growth media. In this process, molecular oxygen is transferred from the shoots to the roots through air chambers and aerenchyma and then diffused into the medium. This makes the rhizosphere more oxidized than the bulk growing soil. The oxidative power of the roots greatly influences the chemosphere around it and leads to the oxidation of ferrous iron (Fe) in the soil solution into its ferric iron (Fe) (Mandal *et al.*, 2004). Thus, a diminished ability of the rice roots to oxidize Fe into Fe results in a higher uptake of iron (Sahrawat, 2000). The oxidizing power of the rice roots is greater at the growing points and at the elongating parts than at the basal parts of the roots (Mandal *et al.,* 2004). This process is known as exclusion and it leads to a considerable Fe accumulation and the formation of iron plaque around rice roots (Jiang *et al.,* 2009). Roots can also retain Fe in the root tissues after Fe is taken up from the rhizosphere. This in turn decreases the translocation of iron from the root to the shoot (Jiang *et al.,* 2009). According to Audebert and Sahrawat (2000), iron toxicity-tolerant rice cultivars absorb less iron or translocate less iron from the roots to the leaves. Both processes are called physiological avoidance. Iron-tolerant rice cultivars accumulate less iron in the photo-synthesizing leaves and maintain superior photosynthetic potential in the presence of absorbed iron in the leaves (Audebert and Sahrawat, 2000). Since plant growth depends on dry matter

production by leaves (Jiang *et al.,* 2009), rice cultivars tolerant to iron toxicity are expected to have higher shoot biomass than susceptible ones.

2.6.2 Inclusion of iron toxicity in rice plant

In other iron-tolerant varieties, relatively high levels of Fe can be found in the tissues without severe toxicity symptoms. These varieties are thought to have good adaptation mechanisms to increasing reactive oxygen species (ROS) brought about by Fenton reactions as a result of iron toxicity. This is achieved by the use of antioxidants such as ascorbic acid and reduced glutathione (Gallie, 2013) but also by the activation of enzymes such as superoxide dismutase, peroxidase and catalase which protect plants from ROS damage (Fang *et al.,* 2001). Another mechanism is storage of Fe in non-reactive forms such as Fe-ferritin or Fe-phytate. Storage in the apoplast and vacuole, and detoxification of Fe-induced reactive oxygen species (ROS) by antioxidant enzymes are the mostly reported tolerance mechanisms (Dufey *et al.,* 2009).

2.7 Varietal Selection and Screening for Resistance to Iron Toxicity in Rice

Fukuda *et al*. (2012) reported that the surest way to counter iron toxicity is by using tolerant rice varieties. Many cultivars are hypothesized to exhibit tolerance rather than avoidance or exclusion mechanisms (Becker and Asch 2005).These mechanisms could be important selection criteria of tolerant rice genotypes. On the other hand, successful crop improvement depends on genetic variability that arises from genetic diversity (Rana and Bhat, 2004). Lack of genetic diversity may limit breeding progress and gain from selection (Cornelius and Sneller, 2002). Breeders have developed a wide array of cultivars with various degrees of adaptation, using traditional breeding methods (Wan *et al.,* 2003).

2.8 Genetic Variability

For improvement of any character, plant breeder has to select superior individual based on their phenotypic expression. This however, may sometimes mislead, because development of a character is a result of heritable and non heritable components. However, under such circumstances, coefficient of variation is the best tool to measure the relative magnitude of variation among the characters and to predict the existing in the given population, Painkra (2014). Variability refers to the presence of differences among the individual plant population due to their genetic composition and the environment in which they are raised (Sumanth *et al*, 2017). Plant breeders depend on genetic variability as a source of desired alleles; once variability has been achieved in a genetic population, the breeder imposes a selection pressure and advances only the desired plant to the next generation (Acquaah, 2007). The knowledge of genetic variability is an essential requirement in crop improvement programme. The success of any breeding programme depends on the extent of variability creation. The creation, selection and maintenance of variable genotypes of a crop are the ultimate aim of any plant breeder. The presence of variability is thus prerequisite to undergo selection procedure for identification of diverse parents to be used in hybridization programme (Painkra, 2014). Development of high yielding varieties requires the knowledge of existing genetic variability (Harsha *et al.*, 2017). Genetic parameters such as genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) are useful in detecting the amount of variability present in the germplasm (Harsha *et al*, 2017). The presence of significant amount of variability in the initial breeding materials assures the production of suitable recombinants for crop improvement (Harsha, *et al.*, 2017). Variability however, is the basis of plant breeding because any crop improvement depends on the amount and direction of genetic association of the traits in the base population

(Tuhina-khatun *et al.*, 2015).Selection will be effective when there is a significant amount of variability among the breeding materials (Girma *et al.*, 2018).

2.9 Heritability

Christian *et al*. (2018), reported that heritability is defined as the proportion of observed variation that can be attributed to genetic variances known to be unique to the given population under study and the growing environment. Abdourasmane *et al.* (2016), reported that the estimates of heritability are very helpful to plant breeder in determining the characters to be considered for selection. The major function of heritability estimates is to provide information on transmission of characters from the parents to the progeny. Heritability analyses estimate the relative contributions of differences in genetic and non genetic factors to the total phenotypic variance in a population. It is an important concept in quantitative genetics, particularly in selective breeding. Heritability estimates provide authentic information about a particular genetic attribute which will be transmitted to the successive generations and constitute an effective guide for breeders in the choice of parents for crop improvement programme. According to Robinson *et al*. (1949), heritability of a trait is considered low when the value is 0-30%, moderate is 30-60% and high is 60% and above.

2.10 Correlation Studies in Rice

Harsha *et al.* (2017), reported that correlation studies measures the degree of association among traits. The knowledge of correlation is important to plant breeder. It is done to reveal the association between yield and its component traits. Abdourasmane *et al.* (2016), reported that If genetic association exists, selection for one trait will cause changes in the other traits; such changes are known as correlated response. Generally plant breeders make selection for one or

two attributes at a time, and then it becomes important to know the effect on other trait. Simple phenotypic correlation indicates broadly the type of association that exists between various attributes. Sadeghi (2011), reported positive significant association in rice for grain yield with grains per panicle, days to maturity, number of productive tillers and days to flowering. A better understanding of the relationship between grain yield and its component traits become necessary for making an efficient selection for the development of new varieties with improved economically important traits (Kumar *et al.*, 2013). The knowledge on genotypic and phenotypic correlation among yield components and their relationship with yield is very important in selecting superior genotypes.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Experimental Site and Climate

The research was conducted at the National Cereals Research Institute (NCRI) research field Edozhigi, Bida in Niger State from November 2017 to February 2018. NCRI research field Edozhigi is known to be an iron toxicity hot spot located in the Southern Guinea Savannah agro ecological region of Nigeria which has geographical bearing of latitude 09^0 45' N, longitude 06^0 $07^{'}$ E and altitude 50.57m above the sea level. It has bimodal rainfall pattern with an annual rainfall of about 900-1050 mm distributed between May and October. The average daily temperature is 35^0C with an annual mean of 27.4^0C and the mean relative humidity of about 52-73% (Ogah 2013).

3.2 Soil Sample Analysis

Soil samples were analyzed at the National Cereals Research Institute Central Service Laboratory using Association of Analytical Chemists (AOAC, 2009) to determine the level of Iron toxicity, p^H level, sodium, potassium, calcium, and magnesium. Soil samples were taken, air dried, grounded and sieved through a 2 mm screen before texture, physical and chemical analysis. Soil p^H was measured by a glass electrode using a soil water/kcl ratio of 1.2. Organic Carbon was extracted by sulfuric acid with potassium dichromate to determine iron ammonium sulfate (Table 3.1). Total phosphorus (P) content was determined by digestion with per chloric acid method and extractable P was determined using NH_4F-HCsolution (Bray 1). Exchangeable cations were determined by spectrophotometry after extraction with neutral ammonium acetate.

Table 3.1: Soil Analysis of the Study Area: Edozhigi, Bida, Niger State, 2018

Parameters	0-15cm value	15-30cm value
Sand (%)	84.96	83.24
Silt (%)	10.56	8.28
Clay (%)	4.48	8.48
USDA Textural Class	**Sandy loam**	**Sandy loam**
pH (H_20)	4.64	4.65
Organic Carbon (%)	0.59	0.68
Organic Matter (%)	1.02	1.18
Total Nitrogen (%)	0.15	0.10
Available Phosphorus (mg/kg)	25.00	26.88
Exchangeable Bases (Cmol/kg)		
Calcium (Ca^{2+})	2.48	2.88
Magnesium (Mg^{2+})	4.63	5.90
Sodium (Na^{+})	0.17	0.13
Potassium (K^{+})	0.15	0.20
Exchangeable Acidity (Cmol/kg)	0.05	0.08
Cation Exchange Capacity (Cmol/kg)	7.48	9.19
Fe ($mgkg^{-1}$)	546	537

3.3 Experimental Materials

The experimental materials comprised of eight genotypes of rice five obtained from the National Cereals Research Institute (NCRI) Badeggi, Niger State and three from West African Rice Centre, Ibadan. The description of the rice genotypes is presented in Table 3.2

3.4 Development of F_1 Population

The eight rice genotypes were mated using half diallel mating design method IV model I to generate 28 F_1 (Table 3.3). Seeds were planted in 128 buckets in four successions at an interval of one week (32 buckets in each succession) to synchronize flowering. Emasculation was carried out between 07.00 am and 09.00 am which involved direct removal of anthers before anthesis. In rice, anthers are enclosed in lemma and palea. Scissors was used to cut the un-matured caryopsis to expose the anthers and carefully removed with forceps without causing damage to the style and stigma. For the hybridization, flowers containing matured pollen grains from the male plants were shed on the emasculated panicles between 10am and 12noon. Pollinated flowers were covered with envelops sizeable enough to avoid contaminations and damages, (Mohanan, 2010).

3.5 Field Evaluation of the F_1 Genotypes and their Parents

The eight parents, 28 F_1 hybrids and two checks making a total of 38 entries were evaluated at an iron toxicity spot in-situ at Edozhigi, Niger State. Plots were laid in a randomized complete block design with three replications. The genotypes were randomly planted with five stands per plot at 20 cm x 20 cm inter and intra row spacing respectively. All cultural practices for rice production were carried out in accordance with the recommendations of the NCRI, Badeggi.

Table 3.2: Description of the Genetic Materials used for the Study

Genotype/variety	Source	Potential yield (kg/ha)	Plant height (cm)	Maturity days	Reaction to Iron Toxicity
FARO 44 (P_1)	NCRI	6442	115	95-105	S
FARO52 (P_2)	NCRI	6710	129	125-135	T
FARO 60(P_3)	NCRI	6754	120	100-115	S
FARO 57 (P_4)	NCRI	7954	124	120 -135	T
FARO61(P_5)	NCRI	6312	115	100-110	S
SUAKOKO 8 (P_6)	WARDA	5500	141	115 -120	T
CK- 21 (P_7)	WARDA	5000	130	120-130	T
CK- 43 (P_8)	WARDA	5000	75-80	80 – 90	T

Source: NCRI/ WARDA 2017**, S:** Susceptible, T: Tolerant

Table 3.3: Diallel Method IV Model 1 adopted to develop the Plant Population used in the Study

	P_2	**P_3**	**P_4**	**P_5**	**P_6**	**P_7**	**P_8**
P_1	P_1P_2	P_1P_3	P_1P_4	P_1P_5	P_1P_6	P_1P_7	P_1P_8
P_2		P_2P_3	P_2P_4	P_2P_5	P_2P_6	P_2P_7	P_2P_8
P_3			P_3P_4	P_3P_5	P_3P_6	P_3P_7	P_3P_8
P_4				P_4P_5	P_4P_6	P_4P_7	P_4P_8
P_5					P_5P_6	P_5P_7	P_5P_8
P_6						P_6P_7	P_6P_8
P_7							P_7P_8
P_8							

Key: P1: FARO 44, P2: FARO 52, P3: FARO 60, P4: FARO 61, P5: SUAKOKO 8, P6:FARO57

P7: CK-21, P8: CK-43

3.6 Data Collection

Data were collected on the five stands of each plot on the followings traits:

Plant height at maturity (cm): The distance from the ground level to the base of flag leaf were measured in cm at maturity using meter rule for all the genotypes.

Number of tillers: The number of tillers per stand was counted on each plot at maturity.

Number of leaves: The number of leaves was counted per plant at booting stage.

Days to 50% flowering were recorded: It was noted in days from the date of sowing to the opening of first flower on approximately 50% plants of each plot.

Panicle length (cm): This was measured as distances from the base of panicle to the tip of the topmost grain of the panicle.

Number of seeds per panicle: Number of seeds of five panicles one from each stand were counted in each plot).

Iron toxicity score: This was recorded on the scale 1 to 9. Where 1.0= highly resistance, 3.0= resistance, 5.0 = moderately susceptible, 7.0= susceptible and 9.0=highly susceptible ($IRRI_{SES,}$ 2001).

Grain Yield after harvest (g): The weight of threshed grains per plot was measured in grams.

Number of effective tillers: The tillers that produce panicles were counted from each stand on each plot.

One thousand (1000) grain weight (g): 1000-grain weights were counted from the threshed grains per plot and weighed using weighing digital scale.

Panicle Exertion: is the measure (cm), between the panicle and the flag leave sheath after anthsis.

3.7 Statistical Analysis

The data collected were subjected to analysis of variance (ANOVA) the ANOVA table for one location is present in table 3.4. Using general linear model procedure of Statistical Analysis System (SAS) package (2002). Significant difference between treatments means were compared using least significant difference (LSD) using linear model as shown below:

$$Y_{ijk} = \mu + \alpha_i + r_j + \ell_{ijk}$$

Where,

Y_{ijk} is the observation in treatment i and block j and k,

μ is the overall mean

α_i is the effect of treatment,

r_j is the effect of j^{th} replication

ℓ_{ijk} is the random error

Table 3.4: Analysis of Variance Table for one location

Source of variation	Df	MS	EMS
Replication	(r-1)		
Genotypes	(g-1)	MS_2	$\sigma_e^2 + r\frac{\left(\sum gi\right)^2}{g-1}$
Error	(r-1)(g-1)	MS_1	σ_ℓ^2

Where g= number of genotypes, –

r = number of replication,

σ_ℓ^2 =error variance and

σ_g^2 genotypic variance.

3.8 Diallel Method IV Model I Analysis of Combining Ability

The data collected were subjected to one way analysis of variance (ANOVA) using Statistical Analysis System (SAS) computer software package using the linear model below:

$$y_{ij} = \mu + M_i + F_j + MF_{ij} + R_k + \ell_{ijk}$$

Where;

$y_{ij} =$ observed trait value,

$\mu =$ mean effect,

$M_i =$ effect of the i^{th} male,

$F_j =$ effect of j^{th} female,

$R_k =$ effect of K^{th} replication,

$MF_{ij} =$ effect of interaction between i^{th} male and j^{th} female and

$\ell_{ijk} =$ experimental error

Table 3.5: Diallel Method IV Model I Analysis of Combining Ability for one location

Source of variation	Df	MS	Expected Mean Square
Replication	$r-1$		
Cross	$[n(n-1)/2]-1$	M_4	$\sigma_e^2 + rK_C^2$
GCA	$(n-1)$	M_3	$\sigma_e^2 + [rc(n\text{-}2)/(n\text{-}1)]K^2_{GCA}$
SCA	n(n-3)/2	M_2	$\sigma_e^2 + \{2rc/[n(n\text{-}3)]\}K^2_{SCA}$
Error	$(r-1)\{[n(n-1)/2]-1\}$	M_1	σ_e^2
Total	rn-1		

Where : r and n refer to number of replications and parents per diallel respectively.

Genetic interpretations

σ_a^2 = Additive genetic variance

σ_d^2 =Dominance genetic variance

σ_e^2 = error variance

K^2_{GCA} **=** is the variance of effects derived from the mean square of GCA,

K^2_{SCA} = is the variance of effects derived from the mean square of SCA, and

K^2_{CxC} = is the variance of effects derived from the mean square of the interaction of the genotype with the conditions.

For estimation of variance component, random model were assumed as follows:

Table 3.6 Analysis of Random Model for one location

Source of variation	Df	MS	EMS
Replication	(r-1)	M_3	
Genotype	(g-1)	M_2	$\sigma_e^2 + r\sigma_g^2$
Error	(g-1)(r-1)	M_1	σ_e^2

Where g = number of genotypes

r= number of replications

df= degree of freedom

MS=Mean square

EMS= Expected mean square

σ_g^2 = genotypic variance.

σ_ℓ^2 =error variance

3.9 Coefficient of Variation

The coefficient of variation for different characters was estimated using the formula suggested by Singh and Chaudhary (1985)

$$GCV = \frac{\sqrt{\sigma_g^2}}{\bar{x}} \times 100\%$$

Where:

GCV = genotypic coefficient of variation,

σ_g^2 = estimate of genetic variance,

$\bar{x}$ = grand mean of the respective character

Phenotypic coefficient of variation

$$PCV = \frac{\sqrt{\sigma_{ph}^2}}{\bar{x}} \times 100\%$$

Where:

PCV = Phenotypic coefficient of variation,

σ_{ph}^2 = estimate of phenotypic variance,

$\bar{x}$ = grand mean of the respected character.

The PCV and GCV values were categorized as low, moderate and high as suggested by Siva-subramanian and Madhava, (1973)

<0-10%=(low)

10-20% (moderate)

>20% (High).

3.10 Estimation of Heritability

Heritability in broad sense (h^2_{bs}) is defined as the proportion of the genotypic variance to the total phenotypic variance and estimated using the formula suggested by Johnson *et al*., (1955).

$$H_b\% = \frac{\sigma_g^2}{\sigma_{ph}^2} \times 100$$

Where: $\sigma_{ph}^2 = \sigma_g^2 + \sigma_{e/r}^2$

For the purpose of estimating heritability, random model was assumed.

The heritability estimates were categorized according to (Robinson *et al*., 1949) as 0-30% (low), 30-60% (moderate), 60% and above (high).

3.11 Correlation Analysis

Pearson correlation coefficient was employed to estimate the relationships between yield and its related traits using standard procedure suggested by SAS software version 9.0 (2002) was used in executing the analysis.

$$r_g = \frac{Cov(xy)}{\sqrt{\sigma_x^2 \times \sigma_y^2}}$$

2 Where: r_g = correlation of g; $Cov(xy)$ =covariance of trait x and y; σ_x^2 =variance of x; σ_Y^2 =variance of y.

CHAPTER FOUR

4.0 RESULTS

4.1 Analysis of Variance and Mean Performance

The results of the analysis of variance showed highly significant ($P<0.01$) difference among the genotypes for all traits measured under iron toxicity hotspot (Table 4.1). The highest mean performance for grain yield among parents was observed in FARO 57 (8210 kg/ha) with the first and second iron toxicity scores of 3.0 and 5.0, respectively, while the lowest mean performance for grain yield was observed in FARO 60 (2830 kg/ha) with first and second iron toxicity scores of 4.3 and 7.0, respectively with a mean value of 4429 kg, (Table 4.2).

Days to 50% flowering varied among the parents between 57days for FARO 61 to 93 days for CK-21 with an average value of 77days. The number of tillers per plant varied between 20 tillers for FARO 44 to 47 tillers for CK-43 with the mean value of 32 tillers. Number of leaves per plant ranged from 4 leaves for Suakoko 8 to 8 leaves for CK-43 with the mean value of 6.0 leaves. Plant height varied from 53.1cm for FARO 60 to 138.6cm for CK-21 with a mean value of 95.6 cm. Panicle length varied considerably among the parents between 17cm for FARO 60 to 28cm FARO 57 with an average value of 23.7 cm. Number of seeds per panicle differed among parents between 76 for FARO 44 to 254 for FARO 57 with a mean value of 159 seeds. Panicle exertion among the genotypes ranged from 1.0cm each for FARO 52, FARO 57, Suakoko 8, CK-21 and CK-43 to 5.0cm for FARO 60 with an average value of 2.1cm. Highest number of effective tillers was recorded for CK-43 (41.0) while 14 were observed for Faro 44 as the lowest with the mean value of 28.

Table 4.1: Analysis of variance (ANOVA) for grain yield and other agronomic traits under iron toxicity at Edozhigi in 2018

Source of variation	df	Grain yield (kg/ha)	Days to flowering	Number of tiller	Number of leaves	plant height (cm)	panicle length (cm)	Number of seed per panicle	Panicle exertion (cm)	Number of effective tillers	1000 grain weight (g)	1st iron score (ses)	2nd iron score (ses)
Replication	2	23.36	8.18	19.27	0.62	97.47	3.59	32.11	0.48	13.01	0.03	2.11	2.81
Genotype	37	3733.03**	383.48**	139.89**	2.18**	1755.86**	20.05**	6450.62**	4.99**	195.61**	27.03**	4.99**	10.59**
Error	70	93.73	49.28	17.36	0.42	138.96	2.11	550.35	0.86	37.53	2.55	1.73	1.86

****=** Significant at 0.01 probability level; df=Degree of Freedom.

Table 4.2: Mean performance for Parents and F_1 genotypes of rice under iron toxicity condition at Edozhigi in 2018

Genotype	Grain yield (kg/ha)	Days to flowering	Number of tillers	Number of leaves	plant height (cm)	panicle length (cm)	Number of seeds per panicle	Panicle exertion (cm)	Number of effective tillers	1000 grain weight (g)	1st iron score (ses)	2nd iron score (ses)
Parents												
Faro 44	3020	84.0	21.0	6.0	61.9	20.9	76.0	3.7	14.0	27.2	5.0	7.0
Faro 52	7560	89.0	36.0	6.0	85.7	26.2	158.0	1.0	32.0	26.2	2.3	3.0
Faro 60	2830	69.0	27.0	6.0	53.1	17.4	95.0	5.0	17.0	27.3	4.3	7.0
Faro 57	8210	89.0	42.0	5.0	72.5	28.3	254.0	1.0	40.0	29.2	3.0	5.0
Faro 61	2955	57.0	28.0	7.0	65.7	21.5	85.0	3.0	18.0	26.6	4.3	6.3
Suakoko 8	6105	77.0	34.0	5.0	119	26.3	175.0	1.0	31.0	36.2	1.0	2.3
CK-21	7355	93.0	33.0	4.0	138.6	27.2	235.0	1.0	31.0	31.2	1.7	1.7
CK-43	6225	69.0	47.0	8.0	101.3	20.3	114.0	1.0	41.0	36.8	1.7	2.3
Hybrids												
Faro 44 x Faro 52	3025	76.0	27.0	6.0	68.4	21.4	124.0	3.0	21.0	27.3	5.0	7.0
Faro 44 x Faro 60	2590	57.0	26.0	6.0	65.9	22.3	94.0	5.0	17.0	26.5	5.7	7.0
Faro 44 x Faro 57	3675	88.0	33.0	6.0	78.3	23.1	204.0	1.0	27.0	28.6	3.7	6.3
Faro 44 x Faro 61	2550	77.0	22.0	6.0	67.4	19.5	109.0	4.3	16.0	26.8	4.3	7.0
Faro 44 x Suakoko 8	3240	89.0	27.0	5.0	103.3	24.4	133.0	2.3	23.0	30.2	3.0	3.7
Faro 44 x CK- 21	3855	75.0	36.0	6.0	105.7	24.3	181.0	1.0.	33.0	27.4	3.0	5.0
Faro 44 x CK- 43	3890	59.0	34.0	7.0	98.6	23.9	125.0	1.7	31.0	29.9	3.0	4.3
Faro 52 x Faro 60	3575	69.0	32.0	5.0	111.0	25.9	166.0	1.7	29.0	24.6	1.7	3.0
Faro 52 x Faro 57	5595	76.0	27.0	6.0	68.4	22.9	124.0	3.0	21.0	27.3	4.3	7.0
Faro 52 x Faro 61	3940	68.0	32.0	7.0	83.9	25.8	244.0	1.0	29.0	28.6	3.0	5.0
Faro 52 x Suakoko 8	6010	88.0	44.0	5.0	104.7	27.1	217.0	1.0	41.0	25.9	2.3	2.3
Faro 52 x CK- 21	6870	67.0	37.0	5.0	106.4	24.7	143.0	1.0	28.0	23.9	1.0	1.7
Faro 52 x CK- 43	6525	74.0	30.0	5.0	109.3	25.7	153.0	2.3	26.0	26.1	4.3	4.3

Table 4.2 Cont'd

Genotype	Grain yield (kg/ha)	Days to flowering	Number of tillers	Number of leaves	plant height (cm)	panicle length (cm)	Number of seeds per panicle	Panicle exertion (cm)	Number of effective tillers	1000 grain weight (g)	1st iron score (ses)	2nd iron score (ses)
Faro 60 x Faro 57	3290	56.0	34.0	7.0	85.4	23.0	173.0	3.7	30.0	29.2	3.7	7.0
Faro 60 x Faro 61	2640	82.0	23.0	7.0	68.8	17.9	101.0	4.3	15.0	26.2	5.7	7.0
Faro 60 x Suakoko 8	3140	56.0	34.0	5.0	101.2	27.7	165.0	2.3	35.0	28.9	1.7	3.7
Faro 60 x CK-21	3455	86.0	34.0	5.0	91.8	23.9	188.0	1.0	31.0	30.3	2.3	2.3
Faro 60 x CK- 43	3315	57.0	30.0	6.0	117.1	25.0	163.0	1.0	30.0	27.9	3.0	3.0
Faro 57 x Faro 61	3070	85.0	31.0	7.0	77.5	24.3	191.0	1.7	27.0	24.9	3.7	4.3
Faro 57 x Suakoko 8	3760	79.0	31.0	5.0	97.5	24.5	177.0	2.3	26.0	28.9	3.0	3.0
Faro 57 x CK- 21	5905	79.0	41.0	5.0	133.5	25.0	217	1.0	36.0	28.0	2.3	4.3
Faro 57 x CK- 43	6675	68.0	30.0	6.0	127.5	26.3	184.0	1.0	27.0	28.9	3.7	4.3
Faro 61 x Suakoko 8	3050	68.0	30.0	6.0	71.3	23.0	127.0	3.0	22.0	26.9	3.7	5.0
Faro 61 x CK- 21	2860	76.0	36.0	6.0	124.1	26.1	199.0	1.0	33.0	29.0	1.7	3.0
Faro 61 x CK- 43	3585	56.0	33.0	7.0	104.7	23.9	181.0	1.0	30.0	27.9	3.0	3.0
Suakoko 8 x CK-21	7045	77.0	29.0	4.0	121.8	25.9	162.0	1.0	24.0	30.3	1.7	2.3
Suakoko 8 x CK- 43	6725	68.0	41.0	4.0	130.8	25.5	124.0	1.0	36.0	37.0	2.3	2.3
CK- 21 x CK- 43	5960	68.0	53.0	6.0	136.6	23.8	216.0	1.0	50.0	28.2	1.0	1.7
Check 1(Alh Baba)	4225	67.0	27.0	5.0	74.2	19.1	157.0	4.3	21.0	24.0	3.7	6.3
Check 2 (Ewodufagi)	4435	76.0	23.0	4.0	98.8	22.6	122.0	3.0	19.0	26.4	3.7	4.3
MEAN	4429	77.0	32.0	6.0	95.6	23.9	159.0	2.1	28.0	28.3	3.1	4.4
CV(%)	10.6	10.0	13.0	11.0	12.3	6.1	15.0	26.9	22.0	5.6	23.1	21.8
LSD (0.05%)	15.8	11.0	6.80	1.0	19.2	2.4	38.0	1.5	10.0	2.6	2.1	2.2

One thousand (1000) grain weight varied from 26.2g for FARO 52 to 36.8g for CK-43 with an average value of 28.3g. First iron toxicity score ranged from 1.0 for Suakoko 8 to 5.0 for FARO 44 with a mean value of 3.1, while second iron toxicity score also varied from 1.7 for CK-21 to 7.0 each for FARO 44 and FARO 60 with an average value of 4.4.

Among the F_1crosses, highest grain yield 7045 kg/ha was recorded for Suakoko 8 x CK-21 with first and second iron toxicity scores of 1.7 and 2.3, respectively, while the lowest mean performance for grain yield 2550 kg/ha was recorded for FARO 44 x FARO 61 with first and second iron toxicity scores of 4.3 and 7.0, respectively, with the mean value of 4429 kg/ha.

The earliest days to 50% flowering was recorded 56 days each for FARO 60 x FARO 57, FARO 60 x Suakoko 8 and FARO 61 x CK-43 and 89 days each for FARO 44 x FARO 57and FARO 52 x Suakoko 8 and FARO 44 x Suakok 8 as the latest with a mean value of 77. The number of tillers varied between 22 tillers for FARO44 x FARO61 to 53 tillers for CK-21 x CK43 with the mean value of 32.0. Number of leaves per plant ranged from 4 leaves for Suakoko 8 x CK43 to 7 leaves for FARO61 x CK43 with a mean value of 6.

Plant height varied between 65.9cm for FARO 44 x FARO 60 to 136.6 cm for CK21 x CK43 with a mean value of 95.6. Panicle length varied between 17.9 cm for FARO 60 x FARO 61 to 27.7cm for FARO 60 x Suakoko 8 with an average value of 23.9. Number of seeds per panicle ranged from 94 seeds for FARO 44 x FARO 60 to 244 seeds for F_1 FARO 52 x FARO 61 with mean value of 159. Panicle exertion ranged from 1 cm to 5 cm with mean value of 2.1cm. Number of effective tillers was recorded highest 50 tillers for CK-21 x CK-43 and recorded lowest 15 tillers for FARO 60 x FARO 61 with an average value of 28. The mean value of 1000 seeds weight was 28.3g, the weight varied from 26.2g for FARO 60 x FARO 61 to 37.0g for

Suakoko 8 x CK-43. The first iron toxicity score ranged from 1.0 each for FARO 52 x CK-21 and CK-21 x CK-43 to 5.7 each for FARO 44 x FARO 60 and FARO 60 x FARO 61 with an average value of 3.1. The second iron toxicity score ranged from 1.7 each for FARO 52 x CK-21 and CK-21 x CK 43 to 7.0 each for FARO 44 x FARO 52, FARO 44 x FARO 60, FARO44 x FARO 61, FARO 52 x FARO57, FARO 60 x FARO 57 and FARO 60 x FARO 61 with an average value of 4.4.

4.2 Phenotypic and Genotypic Coefficient of Variation (PCV and GCV) and Heritability

The PCV values were slightly higher than their corresponding GCV values (Table4.3). High PCV and GCV (106.5 and 101.8), respectively, were recorded for panicle exertion while moderate PCV and GCV were recorded for panicle length (18.7 and 18.2) as well as for 1000 grain weight (18.4 and 17.9), respectively.

High broad sense heritability was observed for all traits under iron toxicity hotspot condition. The results ranged from (70.45%) for first iron score to (97.52%) for grain yield with (97.52%) for grain yield as the highest, followed by (92.38%) for plant height, (91.81%) for number of seeds per panicle and (90.99%) for1000 grain weight. While (70.45%) for first iron toxicity score as the lowest, followed by (82.42%) for number of leaves, (82.49%) for number of effective tillers and (83.85%) for second iron toxicity score.

Table 4.3: Variance components for iron toxicity and agronomic traits of rice F_{1S} at Edozhigi in 2018

Traits	σ_g^2	σ_e^2	σ_{ph}^2	PCV(%)	GCV(%)	H_b (%)
Grain yield	3686.1	93.73	3779.90	67.2	66.8	97.52
Days to 50% flowering	358.9	49.28	408.12	27.4	26.5	87.93
Number of tillers	131.2	17.36	148.57	36.5	35.4	88.31
Number of leaves	2.0	0.42	2.39	26.5	25.2	82.42
Number of seeds per panicle	6175.8	550.35	6725.80	50.5	49.4	91.81
Panicle exertion	4.6	0.86	5.42	106.5	101.8	84.13
panicle length	19.0	2.11	21.11	18.7	18.2	90.00
plant height	1686.4	138.96	1825.34	43.8	43.0	92.38
Number of effective tillers	176.8	37.53	214.38	50.3	47.8	82.49
1000 grain weight	25.7	2.55	28.31	18.4	17.9	90.99
1st iron score	4.1	1.73	5.86	72.1	65.6	70.45
2nd iron score	9.7	1.86	11.52	74.0	70.7	83.85

σ_g^2=Genotypic variance, σ_e^2=Environmental variance, σ_{ph}^2=Phenotypic variance, PCV= Phenotypic coefficient of variation, GCV= Genotypic coefficient of variation, H_b %=Broad sense heritability.

4.3 Combining Ability and Gene Action

The analysis of variance for general combining ability (GCA) and specific combining ability (SCA) of F_1 genotypes showed highly significant ($P<0.01$) differences for all traits measured (Table 4.4). The mean squares due to GCA and SCA were highly significant ($P<0.01$) for most of the traits except for the number of seeds per panicle, first and second iron toxicity scores which were non significantly different.

4.4 Estimate of General Combining Ability Effects for Grain Yield and other Agronomic Traits of Rice under Iron Toxicity Hotspot at Edozhigi

A highly significant ($P<0.01$) positive GCA effects for grain yield were observed for FARO 52 (19.93). Highly significant ($p<0.01$) positive GCA effects for grain yield were observed for suakoko 8(8.67) and highly significant ($P<0.01$) negative GCA effects of first and second iron toxicity scores of (-0.73) and (-1.19), respectively, (Table 4.5). Highly significant ($p<0.01$) positive GCA effects for days to 50% flowering were observed for FARO 57 (3.42) and Suakoko 8 (3.42) and highly significant negative GCA effects were observed for FARO 60 (-6.70) and CK-43 (-5.5).

Table 4.4: Analysis of variance for General combining ability (GCA) and specific combining ability (SCA) evaluated at iron toxicity condition at Edozhigi, in 2018

Source of variation	df	Grain yield (kg/ha)	Days to flowering	Number of tillers	Number of leaves	plant height (cm)	panicle length (cm)	Panicle exertion (cm)	Number of effective tillers	Number of seed per panicle	1000 grain weight (g)	1st iron score (ses)	2nd iron score (ses)
Replication	2	35.11	3.06	36.05	0.86	98.93	5.09	0.49	20.47	24.62	0.06	2.13	2.59
Genotype	37	3614**	364**	126.41**	2.12**	1707.60**	19.67**	4.85**	181.14**	6263.00**	26.11**	4.84**	10.30**
GCA	7	13046.07**	515.99**	326.50**	7.10**	6077.39**	39.94**	15.43**	461.20**	12478.29**	60.71**	15.20**	20.05**
SCA	27	1112.49**	328.85**	84.21**	0.94**	574.29**	12.31**	2.82**	111.23**	3897.31	14.44**	2.21	1.73
Error	70	102.9422	54.8194	22.6187	0.42067	140.711	2.05154	0.87474	42.7898	562.205	2.68021	1.75461	1.88636

** =Significant at 0.01 probability level; df=Degree of freedom

Table 4.5: Estimate of General combining ability and Specific combining ability effects for grain yield and other agronomic traits of rice under iron toxicity condition at Edozhigi in 2018

Genotype	Grain yield	Days to 50% flowering	Number of tillers	Number of leaves	Plant height	Panicle length	Number of seeds per panicle	Panicle exersion	No. of effective tillers	1000 grain weight	1st iron score	2nd iron score
Parent												
Faro 44	-24.41**	2.46*	-4.56**	0.11	-16.13**	-1.63**	-31.14**	0.78**	-5.60**	-0.32	1.02**	1.65**
Faro 52	19.93**	1.84	0.08	-0.15	-4.58**	0.94**	3.91	-0.22	-0.12	-2.09**	-0.1	-0.19
Faro 60	-26.93**	-6.70**	-2.81**	0.06	-10.52**	-1.22**	-18.77**	1.03**	-2.81**	-0.69**	0.44*	0.73**
Faro 57	12.64**	3.42**	0.74	0.24**	-4.23*	0.65**	28.36**	-0.14	0.84	-0.19	0.31	0.81**
Faro 61	-27.38**	-2.12*	-3.49**	0.76**	-14.38**	-1.37**	-7.17*	0.45**	-4.38**	-1.18**	0.60**	0.81**
Suakoko 8	8.67**	3.42**	1.03	-0.90**	8.90**	1.43**	-1.82	-0.22	1.5	2.23**	-0.73**	-1.19**
CK-21	19.25**	3.26**	4.64**	-0.46**	22.51**	1.02**	30.82**	-0.97**	5.04**	0.22	1.23**	-1.52**
CK-43	18.23**	-5.58**	4.37**	0.34**	18.43**	0.18	-4.2	-0.71875**	5.53**	2.03**	-0.31	-1.10**
SE±	**1.23**	**0.98**	**0.58**	**0.09**	**1.72**	**0.20**	**3.24**	**0.13**	**0.85**	**0.21**	**0.18**	**0.19**
Faro 44 x Faro 52	-24.07**	-1.63	-1.26	0.1	-8.2	-2.01**	-10.89	0.47	-1.68	1.38*	1.02*	1.27*
Faro 44 x Faro 60	14.16**	-11.76**	0.7	-0.31	-4.79	1.01	-17.75*	1.22**	-3.32	-0.75	1.15*	0.35
Faro 44 x Faro 57	-3.77	8.79**	3.82	0.11	1.32	0.01	45.39**	-1.61**	3.56	0.78	-0.73	-0.4
Faro 44 x Faro 61	13.77**	3.66	-2.75	-0.32	0.6	-1.58**	-14.48	1.14**	-2.36	0.01	-0.35	0.27
Faro 44 x Suakoko 8	-8.51**	9.45**	-1.8	0.05	13.19**	0.49	2.97	-0.2	-0.7	0.03	-0.35	-1.06*
Faro 44 x CK- 21	-6.75*	-3.71	2.65	0.61*	2.05	0.84	19.20*	-0.78*	5.29*	-0.83	0.15	0.6
Faro 44 x CK- 43	-25.17**	-16.96**	4.94	-0.83	2.18	1.18	22.33	-0.5	5.87	0.35	-0.67	0.08
Faro 52 x Faro 60	-10.51**	0.2	1.73	-0.25	28.79**	2.10**	18.67*	-1.11**	3.46	-0.94	-1.73**	-1.81**
Faro 52 x Faro 57	-0.08	-7.92**	-7.65	0.03	-16.03**	-2.13**	-72.99**	1.39**	-9.63**	1.20*	0.73	1.44**

Table 4.5 Contd

Genotype	Grain yield	Days to 50% flowering	Number of tillers	Number of leaves	Plant height	Panicle lenght	Number of seeds per pan	Panicle exersion	No. of effective tillers	1000 grain weight	1st iron score	2nd iron score
Faro 52 x Faro 61	-2.74	-5.05	2.68	0.25	5.52	2.12**	85.67**	-1.20**	5.62*	3.61**	-0.56	0.1
Faro 52 x Suakoko 8	2.55	9.41**	9.83	0.11	3.11	0.59	53.25**	-0.53	11.15**	-2.57**	0.1	-0.56
Faro 52 x CK- 21	9.24**	-11.4	-0.66	0.07	-8.83	-1.33*	-53.12**	0.22	-5.39*	-2.56**	-0.73*	-0.9*
Faro 52 x CK- 43	-19.03**	-6.92	-9.95	-1.29**	0.59	0.22	3.31	1.83**	-10.91*	-4.22**	2.21*	2.25*
Faro 60 x Faro 57	-8.92**	-14.05**	3.27	0.56*	2.84	-0.54	1.22	0.80*	3.7	1.83**	-0.15	1.19*
Faro 60 x Faro 61	18.10**	17.49**	-3.63	0.17	-3.61	-3.59**	-35.19**	0.89*	-5.81*	-0.22	1.56**	1.19*
Faro 60 x Suakoko 8	-7.99*	-14.05**	3.45	-0.37	5.52	3.34**	23.66**	-0.45	7.91**	-0.96	-1.10*	-0.15
Faro 60 x CK-21	-12.26**	16.45**	-0.37	-0.01	-17.49**	0.03	14.42	-1.03**	0.84	2.45**	0.06	-1.15*
Faro 60 x CK- 43	-35.43*	-13.13**	-4.38	0.72	34.98**	6.20**	52.83**	-2.25**	4.53	-2.13*	-0.58	-2.17*
Faro 57 x Faro 61	-12.84**	10.37**	1.15	0.72**	-1.16	0.88	8.28	-0.61	2.6	-2.05**	-0.31	-1.56**
Faro 57 x Suakoko 8	-35.09**	-1.51	-3.63	-0.08	-4.51	-1.72**	-11.07	0.72	-4.74*	-1.43*	0.35	-0.9
Faro 57 x CK- 21	-2.80	-1.34	2.95	-0.19	17.89**	-0.77	-4.37	0.14	1.58	-0.35	0.19	0.77
Faro 57 x CK- 43	-36.33**	-11.33*	-16.03	0.63	32.41**	-1.6	-37.04*	0.58	-17.69**	-2.49*	1.29	1.25
Faro 61 x Suakoko 8	-9.28**	-6.63*	-0.13	0.13	-20.49**	-1.18	-25.74**	0.8	-3.32	-2.44**	0.73	1.10*
Faro 61 x CK- 21	-23.72**	1.87	-2.86	-0.51*	18.64**	2.31**	13.16	-0.45	4.47*	1.64**	-0.77	-0.56
Faro 61 x CK- 43	-32.97**	2.46	1.85	0.89*	6.26	0.85	92.43**	-0.83	2.09	-1.88	-0.42	-1.42
Suakoko 8 x CK-21	24.00**	-12.01**	-9.27	0.08	-6.91	-0.63	-28.79**	0.22	-10.54*	-0.47	0.56	0.77
Suakoko 8 x CK- 43	2.78	21.00**	3.39	-1.91**	2.27	0.52	-48.75**	0.5	0.5	0.99	0.92	-0.08
CK- 21 x CK- 43	-26.88**	-15.50**	20.34	0.67	2.08	-2.57*	16.22	-0.25	18.31**	-4.82**	-1.58	-0.42
SE±	3.28	2.63	2.92	0.24	4.59	0.54	8.67	0.35	2.28	0.57	0.48	0.52

The result showed highly significant positive GCA effects for CK-21 and CK-43(4.64 and 4.37), respectively, and highly significant negative GCA effects were also observed for FARO 44 (-4.56), FARO 60 (-2.81) and FARO 61 (-3.49). Highly significant positive GCA effects were observed for number of leaves for FARO 57 (0.24), FARO 61 (0.076) and CK-43 (0.34) and highly significant negative GCA effects were recorded for Suakoko 8 (-0.90) and CK-21 (-0.34). A highly significant positive GCA effects were observed for plant height for Suakoko 8 (8.90), (CK-21 (22.51) and CK-43 (18.43) while a significant negative GCA effects were observed for FARO 44 (-16.13), FARO 60 (-10.52), FARO 52 (-4.85) and FARO 61 (-14.38). Highly significant positive GCA effects were observed for panicle length for FARO 52 (0.94), FARO 57 (0.65) and FARO 61 (-1.37) showed highly significant negative GCA effects. Highly significant positive GCA effects were for number of seeds per panicle for FARO 57 (28.36) and CK-21 (30.82), while FARO 44 (-31.14) and FARO 60 (-18.77) showed highly significant GCA negative effects. The significant positive GCA effects were observed for panicle exertion 61 (0.45) and FARO 60(1.03) while CK-21 (-0.97) and CK- 43 (-0.72) recorded highly significant negative GCA effects. On number of effective tillers, CK-21 (5.04) and CK-43 (5.53) recorded highly significant positive GCA effects while FARO 44 (-5.60), FARO 6O (-2.81) and FARO 61 (-4.38) showed highly significant negative GCA effects. On one thousand (1000) grain weight Suakoko 8 (2.23) and CK-43 (2.03) showed highly significant positive GCA effects whereas highly significant negative GCA effects were observed for FARO 52 (-2.09), FARO 60 (-0.69 and FARO 61 (-1.18). First iron toxicity score, showed highly significant positive GCA effects for FARO 44 (1.02) and FARO 61 (0.60) while highly significant negative GCA effects was observed for Suakoko 8 (-0.73) and CK-21 (-1.23). The second iron toxicity score showed highly

significantly positive GCA effects for FARO 44 (1.65), FARO 60 (0.73), FARO 57 (0.81) and FARO 61 (0.81) while Suakoko 8, CK-21, and CK- 43 recorded highly significant negative GCA effects (-1.19), (-1.52), and (-1.10), respectively.

4.5 Estimate of Specific Combining Ability (SCA) effects for Grain Yield and other Agronomic Traits of Rice under Iron Toxicity Hotspot at Edozhigi

A highly significant (P<0.01) positive SCA effects for grain yield were observed for FARO 52 x CK-21 (9.24) and also showed high significant negative SCA effects for first and second iron toxicity scores(-0.73) and (-0.9), respectively, (Table 4.5). Highly significant (p<0.01) positive SCA effects were observed for days to 50% flowering in Suakoko 8 x CK-43 (21.00) and highly significant (p<0.01) negative SCA effects were observed for FARO 60 x FARO 57 (-14.05).

Highly significant positive SCA effects were observed for number of leaves for FARO 57 x FARO 61 (0.72) and highly significant (p<0.01) negative SCA effects were observed for Suakoko 8 x CK- 43 (-1.91). High significant (P<0.05) positive SCA effects for number of leaves for FARO 44 x CK-21 (0.61) while FARO 52 x CK-43 (-1.29) showed highly significant negative SCA effects for number of leaves. Highly significant positive SCA effects for plant height were observed for FARO 57 x CK-43 (32.41) and highly significant negative SCA effects for plant height were observed for FARO 61 x Suakoko 8 (-20.49).

Highly significant positive SCA effects were observed for panicle length for FARO 52 x FARO 60 (2.10) while highly significant negative SCA effects were observed for panicle length for FARO 44 x FARO 61 (-1.58). Highly significant positive SCA effects were observed for number of seeds per panicle for FARO 61 x CK-43 (92.43) and highly significant

negative SCA effects were observed for number of seeds per panicle for FARO 52 x FARO 57 (-72.99). Highly significant positive SCA effects were observed for panicle exertion for FARO 44 x FARO 60 (1.22), while highly significant, but negative SCA effects were expressed in FARO 44 x FARO 57 (-1.61). High significant positive SCA effects were observed for number of effective tillers for FARO 44 x CK-21 (5.29) and significant negative effects was observed in FARO 52 x CK- 21 (-5.39). While highly significant positive SCA effects were recorded for one thousand (1000) grain weight for FARO 52 x FARO 61 (3.61) and highly significant negative SCA effects were observed for FARO 52 x Suakok 8 (-2.57). First iron toxicity score showed highly significant positive SCA effects in FARO 60 x FARO 61 (1.56) and highly significant negative SCA effects were observed for FARO 52 x 60 (-1.73). Second iron toxicity score showed highly significant positive SCA effects in FARO 52 x FARO 57 (1.44) and while highly significant negative SCA effects were observed in FARO 52 x FARO 60 (-1.81).

4.6 Variance Component of GCA and SCA on Iron Toxicity and Agronomic Traits of rice F1 Genotypes

The GCA variances were generally higher than the SCA variances for all the traits studied except for days to 50% flowering (9207.92), number of tillers (2357.88), panicle length (344.74) and number of seeds per panicle (109124.58), (Table 4.6). The highest GCA were observed in grain yield (91322.48) followed by number of seeds per panicle (87348.01) and plant height (42541.75) whereas the lowest were associated with number of leaves (49.75), panicle exertion (94.45) and 1st iron score (106.07). The number of seeds per panicle (109124.58) revealed the highest SCA followed by grain yield (31149.61) and plant height (16080.11) while the lowest were linked with number of leaves (26.26), panicle exertion

Table 4.6: Variance component of GCA and SCA on iron toxicity and agronomic trais of rice F_1s at Edozhigi in 2018

Source of variation	Grain yield (kg/ha)	Days to flowering	Number of tillers	Number of leaves	plant height (cm)	panicle length (cm)	Number of seeds per panicle	Panicle exertion (cm)	Number of effective tillers	1000 grain weight (g)	1st iron score (ses)	2nd iron score (ses)
σ^2_{GCA}	91322.48	3611.95	2285.46	49.75	42541.75	279.56	87348.01	94.45	3229.08	425.00	106.07	264.76
σ^2_{SCA}	31149.61	9207.92	2357.88	26.26	16080.11	344.74	109124.58	69.10	3114.52	404.34	61.87	91.32
$\frac{\sigma^2_{GCA}}{\sigma^2_{SCA}}$	2.93	0.39	0.97	1.90	2.65	0.81	0.80	1.37	1.04	1.05	1.71	2.90

(69.10) and first iron score (61.87). The GCA/SCA ratios ranged from 0.39 for days to 50% flowering to 2.93 for grain yield. The highest ratio was reported for grain yield (2.93) followed by 2nd iron score (2.90) and plant height (2.65) while the lowest were seen in days to 50% flowering (0.39) followed by number of seeds per panicle (0.80), number of tillers (0.97) and panicle length (0.81).The following traits: days to 50% flowering, number tillers, panicle length and number of seeds per panicle recorded GCA/SCA ratios less than one (1) less than unity.

4.7 Correlation Coefficient

The result of phenotypic correlation coefficient for grain yield and other measured traits evaluated in rice is presented in Table 4.7. Grain yield was highly significant and positively correlated with plant height (r =0.60**), number of tillers (r =0.44*), panicle length (r =0.42*) number of seeds per panicle (r =0.21*) and number of effective tillers (r =0.73*), and significant negative correlation for number of leaves (r = -0.45*), panicle exertion (r = -0,46*) first iron score (r = -0.41*) and the second iron score (r = -0.46*). Grain yield was positively correlated with Days to 50% flowering (r =0.07) and 1000 grain weight (r =0.17). Days to 50% flowering was negatively correlated with most of the traits studied except number of seeds per panicle (r =0.16) and first iron score (r =0.06) that revealed positive correlation. Number of tillers was highly significant and positively correlated with plant height (r =0.64**), panicle length (r =0.52**), number of seeds per panicle (r =0.62**) and number effective tillers (r =0.95**), but highly significant and negatively correlated with panicle exertion (r = -0.64**) as well as first and second iron scores, (r = -0.70**) and (r = -0.60**), respectively.

Number of leaves showed significant and positive correlation with first iron score (r =0.37*) and second iron score iron score (r =0.38*), but negatively correlated with plant height (r = -0.34), panicle length (r = -0.31), number of effective tillers (r = -0.10 and 1000 grain weight (r = -0.26). Plant height showed highly significant and positive correlated with panicle length (r =0.68**) as well as number of effective tillers (r =0.71**). Significant positive correlation was also recorded with number of seeds per panicle (r =0.44*) and 1000grain weight (r =0.39*). Plant height also showed highly significant and negatively correlated with panicle exertion (r = -0.72**), first and second iron scores (r = -0.73**) and (r = -0.77**), respectively. Panicle length showed highly significant and positive correlation with number of seeds per panicle (r =0.54**) and number of effective tillers (r =0.63**), but highly significant and negative correlated with panicle exertion (r = -0.75**), first iron score (r = -0.66**) and second iron score r = -0.69**). Number of seeds per panicle was highly significant and positively correlated with number of effective tillers (r =0.70**), but showed highly significant and negatively correlated with panicle exertion (r = -0.69**) and first iron score (r = -0.54**). Second iron score shoed significant negative correlation with grain yield (r = -0.41*). Panicle exertion showed highly significant and positively correlated with first and second iron scores (r =0.73**) and (r =0.75**), respectively, but had highly significant negative correlation with number of effective tillers (r= -0.72**).

Table: 4.7: Correlation analysis of grain yield and other measured traits evaluated for Rice under Iron toxicity hotspot at Edozhigi in 2018

	Grain yield (kg/ha)	Days to flowering	Number of tillers	Number of leaves	Plant height (cm)	Panicle length (cm)	Number of seeds per panicle	Panicle exertion (cm)	Number of effective tillers	1000 grain weight (g)	1st iron score (ses)	2nd iron score (ses)
Grain yield (g)												
Days to flowering	0.07											
Number of tillers	0.44*	-0.05										
Number of leaves	-0.45*	-0.11	-0.13									
Plant height (cm)	0.60**	-0.09	0.64**	-0.34								
Panicle length (cm)	0.42*	-0.08	0.52**	-0.31	0.68**							
Number of seeds per panicle	0.21*	0.16	0.62**	0.17	0.44*	0.54**						
Panicle exertion (cm)	-0.46*	-0.14	-0.64**	0.05	-0.72**	-0.75**	-0.69**					
Number of effective tillers	0.37*	-0.09	0.95**	-0.10	0.71**	0.63**	0.70**	-0.72**				
1000 grain weight (g)	0.17	-0.04	0.26	-0.26	0.39*	0.31	0.02	-0.33	0.30			
1st iron score (ses)	-0.41*	0.06	-0.70**	0.37*	-0.73**	-0.66**	-0.54**	0.73**	-0.74**	-0.21		
2nd iron score (ses)	-0.46*	-0.02	-0.60**	0.38*	-0.77**	-0.69**	-0.41*	0.75**	-0.65**	-0.25	0.85**	

CHAPTER FIVE

5.0 DISCUSSION

5.1 Analysis of Variance and Mean Performance

The analysis of variance showed highly significant difference among the genotypes for all the traits measured. This suggested that there was an inherent genetic difference among the genotypes. The genetic variability in breeding is very important especially for desirable traits. The more variability in a population is the more opportunity for crop improvement for desirable traits in that population. Harsha, *et al*. (2017) pointed out that the source of any kind of selection depends on the existence of the genetic variability. Significant variability for various traits in different sets of genotypes were also reported by rice researchers in their experimental materials Abdul Fiyaz, *et al*. (2011), Abdourasmane *et al*. (2016) and Bhatt *et al*. (2016) in rice genotypes. Significant differences for characters in the present set of genotypes suggested a positive scope for improvement of various traits through simple selection which is in agreement with Painkra, (2014).

5.2 Mean Performance

A wide range in mean performance was observed for grain yield, days to 50% flowering, number of effective tillers, number of leaves, plant height and other traits. This signified that there is high contribution of both positive and negative genes among the genotypes studied. This is in conformity with Bhatt *et al*. (2016). Wide range in mean performance among the genotypes also indicated the presence of significant amount of genetic variability for the most traits studied. This is in conformity with the results reported by Mulugeta *et al.* (2012), on mean performance

and ranges for the measured traits among rice genotypes. Similar results had been reported that crosses of unrelated lines of rice yielded better than crosses of related lines, (Ismaila 2012). And Bhatt *et al,* (2016), also confirmed that the cross between distance genotypes may be expected to exhibit high heterosis through desirable segregation in later generation of hybridization. Mean performance of the cross between tolerant varieties tended to yield higher; FARO 52 x FARO 57 (5595 kg/ha), FARO 52 x Ck-21 (6870 kg/ha) than those between tolerance and susceptible genotypes; FARO 57 x FARO 44 (3675 kg/ha), FARO 44s x Ck-21 (3855 kg/ha) and those between susceptible genotypes; FARO 44 x FARO 60 (2590 kg/ha) and FARO 60 x FARO 61 (2640 kg/ha).This is in conformity with results reported by Ismaila and Echekwu (2015). Mean performance of some varieties as well as some hybrids with high iron toxicity/ leaf bronzing scores had low grain yield, low number of tillers, stunted plant height, low number of seeds per panicles and low number of effective of tillers. Devi *et al,* (2018), reported that for each increase in leaf bronzing symptom score, yield reduction occurs approximately by 400 kg/ha. Based on the leaf bronzing score, FARO 44, FARO 60 and hybrid FARO 44 x FARO 61 had low mean performance of grain yield and other traits which could indicate that these varieties are susceptible to iron toxicity or have little or no adaptation mechanism as reported by Jiang *et al.*(2009) or are less capable of oxidizing large amount of iron translocated to the shoot Devi *et al,* (2018). Choosing breeding populations with a high mean performance is straight forward.

5.3 Coefficient of Variation and Heritability

Coefficient of variation provides the relative measure of variability among the different traits. Genotypic coefficient of variation (GCV) gives the implication of genetic potential of traits under study in crop improvement through selection (Johnson *et al.,* 1955). The GCV was high

for most of the traits measured except for panicle height and 1000 grain weight that measured moderate GCV. Similar trend was observed for phenotypic coefficient of variation (PCV), but close relationship between GCV and PCV was found in all the traits. However, PCV values were slightly greater than GCV values, revealing very little influence of environment and predominance of genetic factors for their expression of the traits. This implies that there is a good scope for yield improvement through phenotypic selection for grain yield. In addition, it indicates the presence of sufficient genetic variability for observed traits and may facilitate the success of the selection process. This present study is similar to findings reported by Abdul Fiyaz *et al.* (2011), Singh *et al.* (2013), Dutta *et al* (2013), Aditya and Bhartiya (2013), Konate *et al*. (2016) and Abayneh (2018). Considering the amount of genetic variation alone will not be of much use to the breeder unless supplemented with the information on heritability estimate that gives a measure of the heritable portion of the total variation. It was suggested by Abdul Fiyaz *et al*, (2011) that the GCV along with heritability estimate could provide a better picture of the amount of genetic advance to be expected by phenotypic selection. Since heritability is dependent on phenotypic variability and in addition to selection intensity, the heritability estimates will be effective and reliable in predicting response to selection Johnson *et al*. (1955). Heritability in broad sense includes both additive and non-additive gene effects Hanson *et al.* (1956). In the present study, broad sense heritability was estimated. Nevertheless, high broad sense heritability estimates were recorded for all the traits studied. This indicated high breeding value which has additive genetic effects which is important for crop improvement. This present study is in conformity with the findings reported by Mulugeta *et al.* (2012) and Ismaila. (2012) who observed high broad sense heritability in all traits studied in rice genotypes.

5.4 Analysis of Variance for Gene Action

The analysis variance for gene action showed highly significant difference among the genotypes for all traits measured with both additive genes and non additive genes playing important roles in most of the traits. However, the SCA revealed the existence of highly significant differences for most of the traits except for number of seeds per panicle and first iron toxicity score for which the difference was not significant. The relatively greater importance of GCA than SCA implies that breeding progress could be effective using recurrent selection in improving yield and other traits in iron toxicity condition. This present study is in conformity with the results reported by Ismaila (2012).

5.5 Combining Ability

5.5.1 General combining ability effects

Combining ability refers to the ability of a parent to transmit desirable performance to its hybrid progenies or crosses. Painkra, (2014) pointed out that combining ability of parents gives important information of the choice of parent in terms of expected performance of their progenies. The significance of GCA and SCA mean squares suggested the importance of both additive and non-additive variances for all the characters studied. The highly significant positive GCA effects observed among, SUAKOKO 8, CK-21, FARO 52, and CK-43 for grain yield and also highly significant negative GCA effects of first and second iron scores indicated that these parents are tolerant to iron toxicity and may be preferred for hybridization and selection programmes. The SCA effects revealed that for hybrid rice development, cross FARO 52 x CK-21 with highly significant positive SCA effects for grain yield and with high significant negative SCA effects of first and second iron toxicity scores could be better choice for most of the traits

including yield under iron toxicity condition. This showed combining ability and gene effects revealing contribution of both additive and non additive gene effects playing important roles for all traits studied. This is in conformity with the results reported by Painkra, (2014). Positive GCA effects are desirable for grain yield and number of effective tillers, but negative GCA effects are desirable for rice crop plant height because of lodging and days to 50% flowering because of earliness. In the present study, parents FARO 52 and FARO 57 were found to be good general combiners in the right direction for grain yield per plant, plant height and number of effective tillers. Similar findings were recorded by Gnanasekaran *et al.,* (2006), Sharma (2006) and Ismaila, and Echekwu (2015) whose research work reported rice genotypes with good GCA effects for plant height and number of tillers. The parent materials are potential varieties for future breeding programmes aimed at developing new hybrids tolerant to iron toxicity.

5.5.2 Specific combining ability effects

SCA effect is the index that determines the usefulness of a particular cross combination in the exploitation of heterosis. Shorter culm reduces the respiratory loss. On the other hand, tall stature facilitates light penetration. Thus an optimum plant height is however, desirable. Short statured plant height is a desirable trait in rice crop to avoid greater yield loss due to lodging. This is in line with Chandrasekaran *et al.* (2007). Six hybrids FARO 44 x SUAKOKO 8, FARO 52 x FARO60, FARO 60 x CK-43, FARO 57 x CK-21, FARO 57 x CK-43 and FARO 61 x CK-21 expressed positive SCA effects reflecting an increase in plant stature. FARO 52 x FARO 57, FARO 60 x CK-21 and FARO 61 x SUAKOKO 8 showed negative SCA fell in the category of average effects. The cross FARO 52 x FARO 57 exhibited the best showing negative SCA

effects for plant height indicating that improvement in plant height in terms of intermediate or short stature can be achieved by exploitation of hybrid vigor in this cross combination.

Number of effective tillers per plant and increased panicle length are also desirable traits for increased grain yield per plant in rice. The cross combinations FARO 44 x FARO 60, FARO 44 x FARO 57, FARO 44 x CK-21, FARO 44 x CK-43, FARO 52 x FARO 60, FARO 52 x FARO 61, FARO 52 x SUAKOKO 8, FARO 60 x FARO 57, FARO 61 x CK-43, SUAKOKO 8 x CK-43 and CK-21 x CK-43 had positive SCA effects for number of effective tillers per plant. These results are in conformity with the reports of Mehla *et al.*, (2000), Sharma and Mani, (2005) and Sharma (2006) who reported similar SCA estimates of number of tillers per plant. Grain yield is the ultimate objective of rice breeding programme. The cross combinations; FARO 44 x FARO 60, FARO 44 x FARO 61, FARO 52 x CK-21, FARO 60 x FARO 61 and SUAKOKO 8 x CK-21 had positive SCA effects for grain yield per plot indicating relative importance of non-additive gene effects for these traits. Ismaila, (2012) reported that non-additive gene effects were predominant for grain yield and its components. In the present study, it was observed that cross combinations which expressed high SCA effects for grain yield, invariably exhibited positive SCA effects for one or more yield related traits also. These results are in line with Ismaila and Echekwu, 2015 who reported good specific cross combinations in rice. None of the cross combinations were found to be good specific cross combinations for all the characters studied. Generally, in most of the cross combinations at least one general combiner was involved for all the traits under study along with grain yield. It also indicated both additive and none-additive types of gene action. While selecting the best specific combination for yield, it would be important to give due considerations to yield related traits. Leaf bronzing score is often recorded to screen plants for tolerance to ferrous iron toxicity (Devi *et al*., 2018). In the study, leaf

symptom scoring was performed to study the rice genotypes' response to excess iron. The rice genotypes showed varying degrees of leaf bronzing in response to excess iron. Leaf bronzing score ranged from 1.0 to 9.0 in response to pulse stress according to IRRI, (2001), Standard evaluation system (SES), 1.0 is considered highly resistance, 3.0 resistance, 5.0 moderately susceptible, 7.0 susceptible and 9.0 highly susceptible. Parents Suakoko 8, Ck-21 and Ck-43 with high significant positive GCA effects and with high significant negative GCA effects of iron scores can be utilized for hybridization programme for selection of superior combination in segregating progenies in iron toxicity condition as explained by Muller *et al*., (2015). This study conforms to the results reported by Devi *et al.* (2018), that such varieties are capable of oxidizing large amount of iron translocated to the shoots.

5.5.3 Gene action

With significant GCA and non-significant SCA mean squares, performance of hybrid can be adequately predicted on the basis of GCA effects of the Parents, that is, parents with high GCA effect provides high yielding crosses. The ratio of GCA to SCA (additive / non additive genes) ranged from 0.39 (days to 50% flowering) to 2.93 (grain yield). Among the twelve traits, four: traits including days to 50% flowering, number of tillers, panicle length and number of seeds per panicle showed less than unity (lower than 1) and eight traits recorded more than unity (greater than 1). Lower than unity indicated higher importance of non additive genes in the expression of the traits or non additive component had a more significant role in the inheritance of days to 50% to flowering, number of tillers, panicle length and number of seeds per panicle. Furthermore, GCA/SCA ratio in the hybrids lower than one (1) indicated that the non additive component of genetic variance made a larger contribution to the total genetic variance for grain yield than the

additive one as reported by Dragan *et al,* (2000). Traits showing more than unity indicate preponderance of additive gene action in inheritance of these traits. Similar results were reported by Painkra, (2014). The relatively greater importance of GCA than of SCA suggests that recurrent selection would be effective in improving yield and other traits in iron toxicity soils.

5.6 Correlation Coefficient

In the correlation analysis, it was observed that most of the traits were either significantly positively or negatively correlated with grain yield per plant. In this study, number of tillers, plant height, panicle length, number of seeds per panicle and number of effective tillers significantly positively correlated with grain yield. Similar observations were reported by Ahmadikhah (2010) who pointed out that significant positive phenotypic correlation existed between yield and some traits which are indications that selection in favor of these traits can lead to positive indirect selection for high grain yield. It also agreed with the reports of Ukaoma *et al.* (2013), Baloch *et al*. (2016) and Sravan *et al.* (2016). Days to 50% flowering and1000 (g) grain weight showed positive, but low correlation with the grain yield. Similarly, Christian *et al*., (2018) pointed out that positive, but low correlations between yield and some parameters might lead to improved grain yield. Number of leaves, panicle exertion as well as 1^{st} and 2^{nd} iron toxicity scores significantly and negatively correlated with grain yield. The negative correlations observed between grain yield and some traits in this experiment suggested that indirect selection of these traits for improve grain yield might not be successful. Also in this present experiment, it was observed that Days to 50% flowering, number of tillers, number of leaves, plant height, panicle length, number of seeds per panicle, as well as 1000 grain weight negatively correlated with both 1st and 2nd iron toxicity scores. Similar observations were reported by Audebert and

Sahrawat (2000) and Baruah *et al*. (2007), that iron toxicity has adverse effects on rice yield and yield traits. Hence correlation study helps the plant breeder during selection and provides the understanding of yield components. The correlation association among traits is an important factor when dealing with a complex character such as yield that is controlled by many genes and highly influenced by the environment.

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 SUMMARY

Nigeria has a wide range of arable rice growing environments including the inland valleys. Despite being the largest rice producer in West Africa, Nigeria is still a rice deficit nation. One of the major constraints to rice production in the inland valleys of Nigeria is iron (Fe) toxicity. This constraint which is wide spread in West Africa is not clearly known. The understanding of the genetic basis of Fe tolerance mechanisms can provide useful information for the breeding of tolerant varieties. Based on the aforementioned, the research was conducted to achieve the following objectives; (1) to determine genetic variability of some agronomic traits and iron toxicity in rice (2) to determine mode of gene action associated with resistance to iron toxicity and (3) to determine the degree of association between iron toxicity, yield and yield components in rice.

Eight rice varieties were planted and crossed using incomplete diallel mating design to generate 28 hybrids which were evaluated along with the eight parents and two checks (Alhaji Baba and Ewodufagi) at Edozhigi during the 2017/ 2018 dry season. Data were collected on grain yield, days to 50% flowering, number of tillers, number of leaves, plant height, panicle length, number of seeds per panicle, panicle exertion, number of effective tillers, 1000 grain weight, first and second iron toxicity scores were subjected to diallel analysis of variance (ANOVA) for both parents and hybrids, using Statistical Analysis System (SAS) software package (2002).

The results from the study are summarized as follows:

1) Grain yield of parents ranged from 2830 kg/ha for FARO 60 to 8210 kg/ha for FARO 57.

2) Grain yield of variety cross hybrids ranged from 2550 kg/ha for FARO 44 x FARO 61 to 7045 kg/ha for SUAKOKO 8 x CK-21.
3) GCA and SCA mean squares were significant for most measured traits under iron toxicity hotspot, indicating importance of additive and non-additive gene action for controlling the traits.
4) There was preponderance of additive gene effects over non-additive gene effects for all the traits measured indicating that additive gene action was more important in the inheritance of the traits under iron toxicity hotspot.
5) FARO 52, SUAKOKO 8, CK-21 and CK-43 were good general combiners for grain yield under iron toxicity hot spot conditions.
6) High broad sense heritability was recorded for all the traits studied.
7) Significant positive correlation existed between grain yield of the F_1 hybrids with plant height (r = 0.60**), number of tillers (r = 0.44*), panicle length (r = 0.42*) and number of effective tillers (r = 0.37*) and negatively correlated with number of leaves (r = -0.45*), panicle exertion (r = -0.64*), first and second iron scores (r = -0.70*) and (r = -0.60*), respectively under iron toxicity hotspot.

6.2 CONCLUSIONS

1.) Presence of substantial additive gene effects suggests that reciprocal recurrent selection would be effective in improving populations and developing superior cultivar for iron toxicity soil. Based on mean performance of populations, their GCA effects, recurrent selection that exploit both GCA and SCA effects, would include Faro 57, Faro 52, CK-21, CK-43 and suakoko 8 for developing superior cultivars under iron toxicity conditions.

2) Additive gene and non additive gene actions were observed controlling all measured traits including iron toxicity, indicating the possibility of developing desirable genotypes that can be advanced for recurrent selection and production under iron toxicity, or used in rice breeding programmes.

3) Significant negative correlation was observed between iron toxicity scores and grain yield (r = -0.41*, r = -0.46*), number of tillers (r = -0.70**, r = -0.60**), plant height (r = -0.73**, r = -0.77**), panicle length (r = -0.66**, r = -0.69**), number of seeds per panicle (r = -0.54**, r = -0.41*) and number of effective tillers (r = -0.74, r = -0.65**) which implies that selection for increased grain yield, number of tillers, number of seeds per panicle, number of effective tillers, tall plant height and long panicle length, will decrease effect of iron toxicity concentration in rice.

6.3 RECOMMENDATIONS

The following recommendations are highlighted from the present study:

1) Iron toxicity tolerant F_1 genotypes (Suakoko 8 x CK-21, Suakoko 8 x CK-43, FARO 52 x CK-43, FARO 52 x Suakoko 8 and CK-21 x CK- 43) with high mean performances for grain yield were identified in the study which could be advanced extensively in more hot spot regions prone to iron toxicity for adoption and production by farmers in Nigeria.
2) The F_1 genotype identified in this study including FARO 52 x CK-21 with highly significant positive SCA effects for grain yield (9.24) and with high significant negative effects of first and second iron toxicity scores (-0.73) and (-0.90), respectively, should also be tested extensively in more hot spot regions prone to iron toxicity for adoption and production to alleviate food security problems in Nigeria.

6.4 CONTRIBUTIONS TO KNOWLEDGE

1) The study developed some iron toxicity tolerant F_1 genotypes (Suakoko 8 x CK-21, FARO 52 x CK-21, Suakoko 8 x CK-43, FARO 52 x CK-43, FARO 52 x Suakoko 8 and CK-21 x CK-43) with high mean performances for grain yield which could be useful to rice breeders interested in breeding for iron toxicity tolerance and synthetic cultivars for iron toxicity prone regions in Nigeria.

2) The study showed that additive gene action controlled some traits indicating preponderance of additive gene action in inheritance of those traits.

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