COMBINING ABILITY FOR TOLERANCE TO IRON TOXICITY IN RICE (*Oryza sativa* L.)

By

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THESIS

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DECLARATION

I, hereby declare that this thesis entitled "Combining ability for tolerance to iron toxicity in rice (*Oryza sativa* L.)" is a bona-fide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled **"Combining ability for tolerance to iron toxicity in rice (*Oryza sativa* L.)"** is a record of research work done independently by **Mrs. Tess Joseph** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABBREVIATIONS

%	Per cent
ANOVA	Analysis of Variance
ARS	Agricultural Research Station
DES	Directorate of Economics and Statistics
DRR	Directorate of Rice Research
cm	Centimeter
CL	Culm Length
CMS	Cytoplasmic Male Sterility
g	Gram
GA	Genetic advance
GCA	General Combining Ability Variance
gca	General Combining Ability effects
GCC	Genotypic Correlation Coefficient
GCV	Genotypic coefficient of variation
GG	Genetic gain
G/P	Grains/panicle

GW	1000 Grain Weight
GY	Grain Yield/plant
h^2	Heritability
IITA	International institute for Tropical Agriculture
IRRI	International Rice Research Institute
KAU	Kerala Agricultural University
kg	Kilogram
mm	Millimitre
mg	milligram
PCC	Phenotypic Correlation Coefficient
PCV	Phenotypic coefficient of variation
PH	Plant Height
PL	Panicle Length
POP	Package of Practice
ppm	Parts per million
PT	Productive tillers/plant
RARS	Regional Agricultural Research Station
SCA	Specific Combining Ability Variance
sca	Specific Combining Ability effects

S/P	Spikelets/panicle
SL	Shoot Length
SS	Seed set per cent
SW	Shoot Weight
RARS	Regional Agricultural Research Station
RBD	Randomized Complete Block Design
RRS	Rice Research Station
RL	Root Length
RW	Root Weight
TT	Total tillers/plant
TGMS	Temperature Sensitive Genetic Male Sterility
QTL	Quantitative Trait Loci
VS	Visual Scoring for iron toxicity symptoms
WARDA	West African Rice Development Association

Introduction

I. INTRODUCTION

Rice has shaped the culture, diet and socio-economic status of millions of people world over. For more than half of the humanity 'rice is life'. It constitutes the staple food of about two-third of the world population. About ninety per cent of the rice is cultivated and consumed in its homeland -- Asia. Rice serves as the staple food for a large segment of the Indian population apart from being a major food crop cultivated in the country. In Kerala too, rice occupies the prime place among the food crops cultivated. During 2012-13, the net cropped area of rice in Kerala was 19.7 million hectares with an annual production of 0.51 million tones and a productivity of 2577 kg /ha (DES, 2014).

Rice is grown under varying eco-systems, on a variety of soils under varying climatic and hydrological conditions ranging from waterlogged and poorly drained to well drained situations. Among several factors that influence the, growth of rice crop, iron toxicity is one of the major abiotic stresses that affect its production and productivity in lowlands. Iron toxicity is a widespread problem for rice cultivation not only in India but also in South and Southeast Asia, South America, and West Africa (Shimzu *et al.*, 2005). It has been reported in more than 50% of lowland rice in Sri Lanka, Vietnam, Malaysia, Indonesia, Philippines, Brazil, Columbia and Madagascar. In India iron toxicity is reported especially in Kerala, Orissa, West Bengal and Andaman Islands (Mandal *et al.*, 2004).

All types of lowland (irrigated, rainfed), with or without water control, can be affected by iron toxicity. Productivity of rice may slump by 10 to 100% depending on the iron concentration and the tolerance of the cultivar used (Asch *et al.*, 2005). The yield loss induced by the iron toxicity is frequently associated with a low soil nutritional status. In flooded soils, high concentrations of reduced iron lead to excessive Fe^{2+} uptake causing the development of the typical symptom- copper colouring of the leaves called leaf bronzing. Iron toxicity is also found to affect the growth, root and leaf development and influence nutrient uptake, retention, and processing thereby affecting yield.

Kerala occupying the extreme end of west coast enjoys a tropical humid climate with an annual rainfall of 3000 mm. The tropical climate itself is responsible for leaching from soils, accumulation of iron and aluminium oxides in surface soils and rendering it acidic in reaction (Santhosh, 2013). Being a state where the demand and production ratio in rice is widening due to the declining trend in rice cultivation, further yield reduction due to increasing significant occurrences of iron toxicity make it a serious long term threat to rice production.

Many attempts have been made to ameliorate iron toxic soil conditions. This includes among others, digging ditches around the fields and repeated washing after accumulation of irrigation or submersion water, use of lime, dolomite, or chalk to correct the effects of the toxicity. However varietal tolerance provides a cost- effective practical means for increasing rice production and thereby the land suitable for cultivating rice. Genetic differences among rice cultivars for iron toxicity tolerance have been identified through breeding and screening efforts by several workers (Mohanty and Panda, 1991, Sahrawat, 2004).

Exploitation of inter-varietal variability to iron toxicity reaction to combat the stress is realized to be the sustainable and cheap alternative to combat this stress. Development of tolerant varieties of rice may be achieved through judicious use of conventional and non conventional breeding technologies.

Considering the impact of iron toxicity on rice productivity in Kerala, breeding efforts to improve tolerance to iron toxicity is of utmost importance. Such efforts will be fruitful only if the mechanism of gene action for iron toxicity tolerance is known. Hence, the present study has been formulated with the following objectives.

i) To delineate the nature and extent of variability for yield and yield attributes and estimate the genetic parameters.
ii) To elucidate the association among iron toxicity tolerance, yield and yield attributes.
iii) To assess the general combining ability of parents and specific combining ability of hybrids and infer the gene effects.
iv) To quantify the magnitude of heterosis in hybrids.

Review of Literature

II. REVIEW OF LITERATURE

The importance of rice in the socio-economic status of Keralites need not be over-emphasized. As in many high humid tropical Asian countries, rice crop in Kerala is also subjected to serious threat of iron toxicity. Although, several approaches to ameliorate iron toxic soil conditions have been attempted, the most economic and viable proposition to overcome this problem is the use of tolerant varieties. As a prelude to launching extensive breeding programmes, a thorough understanding of the genetics of iron toxicity tolerance in rice is necessary for devising an efficient plant breeding programme. A clear understanding on the choice of parental materials, contributing component characters, breeding and selection methods, nature of combining ability, heterosis, pertinent information on gene action, character association and targeted character improvement sought are thus necessary in rice breeding programme and should be secured fairly in advance. The literature on the above aspects in rice is reviewed under the following headings.

1. Combining ability analysis
2. Heterosis
3. Variability studies
4. Correlation analysis
5. Path analysis
6. Screening of genotypes for tolerance to iron toxicity

2.1. Combining ability analysis

The combining ability analysis provides information on the components of variance *viz.*, additive and dominance variance, and estimates of parameters such as *gca* and *sca* which facilitates adoption of a correct breeding strategy to bring out genetic improvement in the target traits and the choice of parents and crosses to be selected in a breeding programme.

A number of workers have attempted to understand and document the genetic architecture governing different economic attributes in rice through combining ability analysis. It was Sprague and Tatum (1942) who put forth the concept of combining ability. Later Griffing (1956) suggested that general combining ability included both additive as well as additive x additive interaction effects and specific combining ability include dominance and epistatic deviation.

Line x Tester technique advocated by Kempthrone (1957) is one of the several techniques for combining ability studies which is used to evaluate varieties or strains in terms of their genetic make. It is a good approach for screening the germplasm on the basis of GCA and SCA variance and effects. It helps to find out the nature of gene action involved in the expression of various quantitative traits.

In a study conducted by Gholipur *et al.,* (2005) to determine the general and specific combining ability of the parental lines, four restorers and two male sterility lines were selected as lines and testers, respectively. Results indicated that the effect of *gca* was significant for number of grains per panicle, plant height and days to 50% flowering in line No.1 (IR60819R), indicating the importance of additive gene effects for these characters. In line No.2 (IR68749R), the effect of *gca* was significant for grain yield, 100-grain weight, plant height, days to 50% flowering and grain weight. The *gca* of two testers was not significant for all the characters studied. The effect of *sca* was positive and significant for grain yield in hybrids of IR68281A/IR60966R, IR58025A/IR60819R and IR68281A/IR42686R.

Lines- IET 13846, IET 15391 and IET 11819 as females, and testers- Pusa Basmati-1, Taraori basmati, Kasturi, Basmati, Mahi, Sugandha, Pakistani Basmati, IR

64, Ratna, Suraksha and Narendra as males were crossed in Line x Tester mating design by Panwar (2005). Data were recorded for days to 50% flowering, days to maturity, plant height, productive tillers per plant, filled grains per panicle, spikelet fertility, biological yield per plant, harvest index, 1000-grain weight and grain yield per plant. The estimates of general combining ability effects of lines and testers showed that IET 13846, Kasturi, Basmati 370, Pusa Basmati-1, Taraori Basmati and IR 64 were good general combiners for grain yield per plant. A total of fourteen crosses exhibited positive significant specific combining ability (*sca*) effects for grain yield per plant, where eight crosses involved one parent with high general combining ability (*gca*) effects and the other having either high of low combining ability effect indicating additive and non-additive genetic interaction.

The performance of thirty-nine inter-specific rice hybrids with wide compatible gene as one of the parents was evaluated through Line x Tester method by Sivakumar and Bapu (2005). Preponderance of non additive gene action was observed for all the eight traits studied *viz.*, plant height, days to fifty per cent flowering, number of tillers/plant, panicle length, grains/panicle and grain weight.

Biswas and Julfiquar (2006) crossed five lines and eight testers in Line x Tester fashion to study heterosis in relation to combining ability in rice involving cytoplasmic- genetic male sterility. In the study, non additive gene action was preponderant for all the traits *viz.*,plant height, days to fifty per cent flowering, panicles/plant, panicle length, filled grains/panicle, spikelet sterility, thousand grain weight and grain yield per plant. The estimates of *gca* revealed none of the parent was general combiner for the traits studied.

In a Line x Tester analysis conducted by Alam *et al.,* (2007) comprising five lines and five testers, the SCA variances were found significant for most of the characters, while GCA variances were not significant among all the eight yield and yield contributing characters. Ratio of SCA and GCA variances were higher indicating preponderance of non-additive gene actions in the inheritance of all the characters, except filled spikelets per panicle. Among the CMS parents, IR75595A and IR62829A were found to be good general combiners for most of the characters. Among the male parents, BAU509R and BAU525R were observed to be good general combiners for most of the characters studied. The cross combinations IR62829A × BAU509R, IR62829A × BAU523R, Jin23A × BAU507R, DakshahiA × BAU525R and LuhaguraA × BAU523R were observed to be good specific cross combinations for grain yield and most of the other seven yield related characters.

Lakshmi *et al.,* (2008) studied fifteen crosses from five lines and three testers for grain yield and yield components in rice. Results revealed significant differences among the testers and lines and line × tester interaction for all the yield and yield contributing characters, except 100-grain weight were found in the analysis of variance for combining ability suggesting the importance of both additive and non-additive gene action in the inheritance of the characters studied. Samba Mashuri among the lines and Lalnakanda 41 among testers showed good general combining ability effects for yield and most of the yield attributes. Among the hybrids, IR 20 (L2)/Lalnakanda-41 (T1), Samba mashuri (L3)/Lalnakanda 41 (T1) and Polasa prabha (L4)/Tulasi (T2) were identified as good performers for grain yield.

In an attempt made to assess the combining ability of eleven rice genotypes and their thirty hybrids generated by crossing in Line x Tester fashion by Karthikeyan *et al.,* (2009), the ratio of additive to dominance variances indicated preponderance of non additive gene action for the characters namely, plant height, number of productive tillers, boot leaf length, panicle length, grain weight per primary panicle and grain yield per plant. Among the lines IR 65847-3B-6-2 and IR 65192-4B-8-1 showed good combining ability for grain yield per plant, panicle length and grain weight per panicle. It indicated the existence of good relationship between *per se* performance and *gca* effects of parents. With regard to specific combining ability effects, all the hybrids recorded additive gene action except IR 65847-3B-6-2 X ADT 45. The hybrids IR 65847-3B-6-2 X ADT 45 recorded non additive gene action especially of dominance X dominance type.

Line x Tester analysis performed on thirty F_1's along with ten lines and three testers by Shikari, *et al.,* (2009) showed that traits grain yield and grains per panicle manifested additive genetic control while effective tillers per plant and 1000-seed weight recorded high dominance component in the study. SKAU-105 and SKAU-338 recorded significant positive *gca* for effective tillers, panicle length and grain yield per hectare.

Bhageri and Jelodar (2010) conducted a study of combining ability and heterosis on twelve F_1 hybrids generated by line × tester mating design. Analysis of variance revealed significant differences among genotypes, crosses, lines, testers and line × tester interactions for tiller number, plant height, days to 50% flowering, panicle length, number of spikelets per panicle, spikelet fertility and grain yield traits. Variances of SCA were higher than the GCA variances for traits except for plant height which indicated predominance of non-additive gene action in the inheritance of the traits. The proportional contribution of testers was observed to be higher than that of the interactions of line × tester that revealed the higher estimates of GCA variance that is additive gene action among the testers used. Within CMS parents, IR62829A and among male parents, IR50 and Poya were observed to be good general combiners for most of the characters studied. The cross combinations IR62829A × Mosa-tarom, IR68899A × Poya, IR58025A × IR50 and IR58025A × Poya were observed to be good specific cross combinations for grain yield and most of its related traits due to highly significant *sca* and heterotic effects.

A Line x Tester analysis conducted by Kumar *et al.,* (2010) in rice with seven ovule parents and four pollinator parents revealed dominant gene action for all the six traits namely, days to 50 percent flowering, plant height, number of productive tillers per plant, number of grains per panicle, hundred grain weight and grain yield per plant. Parents JAYA and CRAC 2221-67 were good general combiners for grain yield per plant and most of the yield traits. The cross combinations CRAC2221-67 x JAYA and IR6331-1-B-3R-B-24-3 X JAYA were the best specific combiners for grain yield per plant.

In a study conducted by Mirarab and Ahmadikah (2010) on genetics of phenological traits *viz.,* heading date, plant height and panicle length in rice hybrids generated by crossing five lines with two testers in line × tester mating design showed that *gca* effect was only significant for heading date and *sca* effect was significant for heading date and plant height. Four parents including three lines (Neda-A/IR36, IR36 and Pouya) and one tester (Usen) showed highest negative *gca* effect for heading date and were identified as better general combiners for early maturation. Lines Pouya and IR42 showed highest negative *gca* effects for plant height, indicating that these lines were good general combiners for reducing plant height.

Milan *et al.,* (2010) carried out combining ability analysis for grain yield and its components in short duration rice under irrigated condition in a Line x Tester design and found that NDR 358, NDR359 and IR50 among lines and Ratna among testers were best among general combiners for grain yield per plant and majority of yield contributing traits. The best specific combiner for yield was Jhona 349 x Ratna. A comparison between variance due to SCA and GCA revealed significant non additive genetic variance for all the traits *viz.,* days to fifty per cent flowering, plant height, panicle bearing tillers/plant, panicle length, primary branches/panicle, secondary branches/panicle.

A study of half diallel crosses conducted by Rahimi, *et al.,* (2010) revealed that both additive and non-additive gene effects contributed to the inheritance of the traits *viz.,*growth period, reproductive period, flag leaf area, plant height, panicle length, number of panicles per plant, number of grains per panicle, 1000-grain weight, grain yield, brown grain length and brown grain.

A Line × tester analysis undertaken by Saleem *et al.,* (2010) to evaluate the performance of twenty seven F_1 hybrids along with twelve parents in Basmati rice revealed high significant differences among treatments, parents, parents vs. crosses and crosses for number of tillers per plant, panicle length, number of grains per panicle, fertility percentage, 1000-grain weight and yield per plant. The estimates of variance of specific combining ability effects, ratio of variance of general combining ability to specific combining ability and degree of dominance indicated preponderance of non-additive gene effects for each trait. Role of testers in the expression of most of the yield components was more than lines and line × tester interaction. However, line × tester interaction contributed more than lines and testers for yield per plant. Three lines viz., Basmati 2000, Super Basmati and Kashmir Basmati and one tester Basmati-385 were identified as good general combiners based on their mean performance and *gca* effects for yield and its various traits.

In a study by Najeed *et al.,* (2011), thirty inter-varietal (fifteen indica x indica and fifteen japonica x japonica) and fifteen inter-subspecific (indica x japonica) crosses were generated through half diallel and line x tester mating. Variance estimates due to SCA were found to be higher in magnitude than the corresponding GCA variances resulting in relatively higher non additive variance for most of the characters *viz.,* pollen sterility, spikelet sterility, plant height, number of panicles/plant, panicle length except for days to 50% flowering, days to maturity and grain yield/plant. The parents P1 (Jehlum), P3 (SR-1), P8 (K-332), P11 (Kohsar) and P12 (K-508) were found promising combiners for most of the traits.

Four lines and ten testers were crossed by Patil *et al.,* (2011) in Line x Tester manner and the F_1s were evaluated to estimate the combining ability for yield and its components in rice. The study indicated that the magnitude of SCA variances was higher than GCA variances for all the characters *viz.,* days to 50 per cent flowering, days to maturity, panicle per plant, panicle length, plant height, grains per panicle, 1000 grain weight, harvesting index (%), amylose content (%) and protein content (%) revealing the predominance of non-additive gene action. IR-66, GR-6 and Lal Kada were found to be good combiners for grain yield per plant from the *gca* estimates. The crosses Sathi34-36x Lal Kada, GR-9 x Lal Kada, GR-5 x Safed Kada, Sathi 34-36 x GR-6, GR-8 x IR-28 were found to be the best specific combinations.

One hundred and fifteen hybrids were developed by Saidaiah *et al.,* (2011) utilizing five CMS lines and twenty three testers which were mated in Line x Tester manner. Significant differences were found among parents for all the characters studied indicated the predominance of dominance gene action in governing yield and yield related traits *viz.,*plant height, productive tillers per plant, panicle length, panicle weight, filled grains per panicle, spikelet fertility %, 1000 grain weight and grain yield per plant. Among parents, two CMS lines (APMS 6A and CRMS 32A) and six testers (1096, 612-1, GQ-70, GQ-120, KMR 3 and SG 27-77) were found to be good general combiners for yield and other yield attributes. The hybrids APMS 6A x 612-1, PUSA 5A x KMR-3, CRMS 32A x IR 43 exhibited higher specific combining ability with at least one of the parent possessing positive alleles for grain yield. The interrelationship of GCA with SCA revealed that predominance of non additive gene action viz., additive x dominance and dominance x dominance type for gene interaction for most of the hybrid combinations which could be exploited for heterosis breeding programme in rice.

Gene action studies were carried out on sodic tolerance traits in rice by Shanthi *et al.,* (2011) using fourteen diverse parental lines and fifty four hybrids generated through Line x Tester mating. Analysis of variance for combining ability revealed significance of line x tester interaction indicating the importance of non-additive gene action in controlling all the physiological traits, yield and yield attributes studied *viz.,* chlorophyll a, chlorophyll b, total chlorophyll, chlorophyll a/b, chlorophyll stability index, sodium content in shoot, potassium content in shoot, sodium/potassium ration of shoot, catalase, peroxidase, days to fifty per cent flowering, plant height, productive tillers/plant, panicle length, grains/panicle, spikelet fertility, hundred grain weight, single plant yield and harvest index. However, the significance of mean squares due to lines and testers indicated prevalence of additive type of gene action for most of the characters studied. BPT 5204, TRY (R) 2 and IR 36 among the lines and Pokkali and CT9993 among the testers were identified as best combiners for sodic tolorance, yield and yield contributing characters.

A study by Bhadru *et al.,* (2012) to estimate combining ability on grain yield and yield contributing characters over locations and seasons revealed that for majority of the characters (days to fifty per cent flowering, plant height, panicle weight, flag leaf width, productive tillers per plant, filled grains per panicle, productivity per day, 1000 grain weight and grain yield per plant) except panicle length and flag leaf length during *kharif* season over both the season registered higher SCA variances than GCA variances indicating the preponderance of non additive gene action. IR79156A, IR 68897 and tester R-51 were performed well under different seasons and locations.

General and specific combining ability study conducted by Ghara, *et al.,*(2012) on fifty F_1 hybrids generated through line x tester manner, along with fifteen rice genotypes (five CMS lines and ten restorer lines). Data were recorded for tiller number, plant height, days to 50% flowering, panicle length, number of spikelets per panicle, spikelet fertility and grain yield. Variances of SCA were higher than variances of GCA indicating the predominance of non additive gene action in the inheritance of traits. Within lines, Nemat A and among male parents Alhamitarom were identified as good general combiners for most of the characters studied. The cross Nemat A x IR9 was good specific cross combination for yield and most characters.

Line x tester analysis with three CMS lines and seven elite testers was conducted by Ghosh *et al.,* (2012). The SCA variance was found to be greater than the GCA variance for grain yield and yield components (days to fifty per cent flowering, flag leaf length, flag leaf breadth, flag leaf area, plant height, productive tillers/plant, pollen fertility (%), sterile spikelets per panicle, fertile spikelets per panicle, spikelets fertility percent, panicle length, 1000 seed weight, grain yield per plant and head rice recovery per cent) suggesting the preponderance of dominance and epistatic gene action in expression of these traits.

A study undertaken by Nayak *et al.,* (2012) to understand the combining ability for yield and quality traits in aromatic rice involving eight parents and their corresponding sixteen F_1 crosses obtained through Line x Tester mating design indicated the predominance of non-additive genetic variance (GCA/SCA of <1.0) for most of the yield and quality characters *viz.,* number of panicles per plant, panicle length, number of filled grains per panicle, grain yield, volume expansion ratio, water uptake, alkali spreading value and protein. Days to 50% flowering and 250 grain weight were under the influence of additive gene action.

In a study undertaken by Padmavathi *et al.,* (2012) to estimate the combining ability for yield and yield components trait in hybrid rice, non-additive gene action was found to be predominant in all the characters (plant height, number of tillers/ plant, panicle length, number of filled grains /panicle, spikelet fertility per cent and grain yield plant). In the CMS lines, APMS 9A and APMS 10A and in the testers *viz,* MTU II-110-9-1-1-1-1, MTU II-187-6-1-1, MTU II-143-26-2, MTU II 290-42-1 and

MTU II 283-7-1-1 were found to be good general combiners. In the crosses, APMS 10A x MTU II-290-42-1, APMS 6A x MTU II-187-6-1-1 and APMS 6A x MTU II-110-9-1-1-1-1 were identified as most promising hybrids for grain yield per plant.

Patil *et al.,* (2012) carried out an experiment involving twenty four hybrids from a set of three females (lines) and eight males (testers) along with parents in Line x Tester design to estimate the extent of combining ability for yield and its component characters. Combining ability analysis revealed that SCA variances were higher than GCA variances for all the characters (days to fifty per cent flowering, panicles/plant, panicle length, plant height, grains/panicle, grain yield /plant, thousand grain weight, amylase content, protein content and L/B ratio) studied except for days to maturity which indicated non additive gene action for the traits. Sathi 34-36, GR-5 among males and Jaya among females were identified as good general combiners for yield and other yield contributing traits.

A study conducted by Singh and Babu, (2012) to estimate the magnitude of heterosis and combining ability in relation to yield and some morphological traits in upland rice revealed that among lines, IR81413-B-B-75-3 and among testers IR4371-54-1-1 were good general combiners for grain yield per plant. Hybrid IR81413-B-B-75-3/IR81429-B-31 was identified as best specific combiner for grain yield per plant with some other morphological traits.

A study was undertaken by Gopikannan and Ganesh (2013) to estimate combining ability, gene action and proportional contribution of cross components in rice genotypes under sodicity. Results revealed that specific combining ability (SCA) variance was higher in magnitude than the corresponding general combining ability (GCA) variances for all the traits under study which indicated preponderance of non-additive gene action governing these traits. Results of *per se* and *gca* effects of parents revealed that multiple crosses involving IR 20, CO (R) 50, FL478, TRY (R) 2 and CSR 23 would be considered as invaluable sources of genetic materials.

In the combining ability analysis carried out by Koli *et al.*, (2013) for grain yield and its contributing traits in line x tester mating design, significant differences among parents, crosses and line x tester interaction for all the traits were noticed. General combining ability effects indicated that, IET 12016 was found best general combiner for grain yield per plant, panicles per unit area and number of spikelets per panicle. The crosses IET 19695/Pusa Sugandha 4, IET12016/Pusa Sugandha 4 and IET 19695/Pusa Sugandha 4 were found to be the best specific combiner for grain yield and panicles per m^2. The superior crosses were found to involve at least one parent with high *gca* and other parent having high, average and low *gca* effects.

Eighteen hybrids resulting from crossing of three CMS lines with six testers in Line x Tester manner studied by Latha *et al.*, (2013) revealed existence of significant differences between line x tester interaction for grain yield. Results indicated that the SCA variance attributed heavily in the expression of traits (days to 50 per cent flowering, plant height (cm), number of tillers per plant, number of productive tillers per plant, panicle length (cm), pollen fertility (%), spikelet fertility (%), biological yield per plant (g) and grain yield per plant (g) and 1000- grain weight (g)) pointing out the importance of dominance or non additive variances for all the traits.

2.2. Heterosis

Heterosis was first reported by Jones (1926). It indicates the superiority or inferiority of F_1 in comparison to either or both the parents or over a standard check variety for the trait under study. The three estimates of heterosis *viz.*, relative heterosis, heterobeltiosis and standard heterosis measure the F_1 superiority over mid parent, better parent, and standard check. The expression of heterosis varied with crosses, so also with characters (Lokaprakash *et al.,* 1992). To know the potentiality of hybrids, the magnitude and direction of heterosis is important (Singh *et al.,*1995).

Exploitation of heterosis in rice has been considered as an important tool for overcoming the present yield barrier. There is a close relationship between the frequency of crosses showing significant *sca* and those with high specific combiners. Wang and Tand (1998) observed a close and consistent positive relationship between heterosis and combining ability complying that the heterosis of a hybrid combination could be reliably predicted by combining ability. However, the *per se* performance of hybrids, appeared to be not dependent on the *sca* or heterosis (Bobby and Nadarajan, 1994). A brief review of literature on heterosis in rice is given below.

Table 1. Review on heterosis and its range

Sl.no.	**Relative heterosis**	**Heterobeltiosis**	**Standard Heterosis**	**Authors**
Plant height	-17.10 to 21.20	-31.80 to 11.80		Biswas and Julfiquar (2006)
		33.44 to 105.87	-30.32 to 51.62	Tirkey *et al.,* (2006)
	-27.25 to 16.37	-35.38 to 5.08		Palaniraja *et al.,* (2010)
			-0.03 to 28.27	Hussain and Sanghera (2012)
		1.03 to 39.59	-15.81 to 15.55	Saidah *et al.,*(2012)
	-10.43 to 12.35	-11.43 to 8.88	-7.56 to 9.02	Latha *et al.,*(2013)
Days to fifty per cent flowering	-10.70 to 3.00	-15.50 to -0.90		Biswas and Julfiquar (2006)
		-2.16 to 11.54	-6.46 to 5.94	Tirkey *et al.,* (2006)
	-11.50 to 10.24	-18.67 to 4.03		Palaniraja *et al.,* (2010)

			-7.23 to 5.26	Hussain and Sanghera (2012)
	-11.50 to -5.32	-15.61 to -11.43	-17.58 to -13.21	Nayak *et al.*, (2012)
		-7.13 to 14.13	-4.76 to 9.86	Saidah *et al.*, (2012)
	-10.43 to 12.35	-11.43 to 8.88	-7.56 to 9.02	Latha *et al.*, (2013)
Panicle length	-14.10 to 18.70	-25.00 to 10.00		Biswas and Julfiquar (2006)
		-25.38 to 27.815	-88.57 to 131.75	Tirkey *et al.*, (2006)
	-21.05 to 15.33	-29.66 to 9.05		Palaniraja *et al.*, (2010)
			-0.77 to 30.15	Hussain and Sanghera (2012)
	16.82 to 17.29	9.06	42.47 to 58.65	Nayak *et al.*, (2012)
		-7.86 to 16.50	-11.54 to 6.37	Saidah *et al.*, (2012)
	-2.05 to 18.81	-7.75 to 18.50	9.50 to 23.08	Latha *et al.*, (2013)
Grains/ panicle	-55.90 to 68.20	-60.20 to 62.40		Biswas and Julfiquar (2006)
	-11.66 to 8.16	-21.50 to 5.25		Palaniraja *et al.*, (2010)
		-13.47 to 20.82	-3.64 to 27.87	Satheeshkumar and Sarvanan (2011)
Spikelets/ panicle			-7.17 to 12.07	Hussain and Sanghera (2012)
Spikelet fertility	-50.20 to 273.70	-55.70 to 203.00		Biswas and Julfiquar (2006)
	-98.92 to -6.27	-98.99 to -10.04	-98.94 to -10.93	Latha *et al.*,(2013)
Productive tillers/plant	-22.80 to 62.60	-30.00 to 55.20		Biswas and Julfiquar (2006)
	-16.17 to 27.66	-26.92 to 22.02		Palaniraja *et al.*,(2010)
		-19.26 to 41.44	-36.09 to 5.92	Satheeshkumar and Sarvanan (2011)
	9.68 to 69.57	30.77 to 69.57	78.95 to 105.26	Nayak *et al.*, (2012)
			-28.01 to 21.20	Hussain and Sanghera (2012)

		-5.64 to 60.29	-23.76 to 26.16	Saidah *et al.*, (2012)
	-24.50 to 23.10	-33.69 to 11.54	-21.43 to 25.71	Latha *et al.*, (2013)
Total tillers/plant		-38.64 to 50.01	-66.66 to 83.33	Tirkey *et al.*, (2006)
	-22.48 to 21.58	-30.56 to 19.52		Palaniraja *et al.*, (2010)
			-23.63 to 33.33	Hussain and Sanghera (2012)
	-27.32 to 20.54	-32.87 to 10.00	-25.68 to 18.92	Latha *et al.*, (2013)
1000 grain weight	-7.10 to 20.10	-20.80 to 9.10		Biswas and Julfiquar (2006)
		-27.57 to 29.12	-18.41 to 24.01	Tirkey *et al.*, (2006)
	-21.40 to 13.91	-27.45 to 4.01	-43.68 to -18.25	Latha *et al.*, (2013)
Grain yield/plant	-58.00 to 95.30	-59.40 to 86.10		Biswas and Julfiquar (2006)
		-92.87 to 41.74	-92.87 to 51.76	Tirkey *et al.*, (2006)
	-13.88 to 16.28	-25.74 to 8.68		Palaniraja *et al.*, (2010)
		11.98 to 63.01	34.67 to 74.19	Satheeshkumar and Sarvanan (2011)
			25.88 to 44.70	Hussain and Sanghera (2012)
	51.11 to 89.25	44.42 to 87.24	63.15 to 107.09	Nayak *et al.*, (2012)
		-19.46 to 88.28	-42.28 to 36.54	Saidah *et al.*, (2012)
	-57.52 to 82.37	-70.59 to 68.37	-78.49 to 4.30	Latha *et al.*, (2013)

2.3. Variability studies

An insight into the magnitude of variability available is of utmost importance as it provides the basis for selection (Singh, 1990). The extent of genetic variability existing in a crop is preferable as greater the diversity, wider the scope for selection.

The total variation (phenotypic variation) present in a population arises due to genotypic and environmental effects. Mather and Jinks (1971) divided the phenotypic variance into three components, namely 1) Heritable fixable (additive variance), 2) Heritable non- fixable (dominance and epistatic components), 3) non heritable non fixable components (environmental fraction). Only the additive component contributes to genetic advance under selection. Hence it is deemed necessary to split the overall variability into its heritable and non heritable components resorting to estimation of genetic parameters such as genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV), heritability (h^2) and genetic advance.

2.3.1 Heritability and genetic advance

Heritability plays an important role in the selection process in plant breeding. Since it is estimated from fixable (additive) genetic variance, it plays an important role in the selection of elite genotypes from segregating population.

Genetic advance is a measure of genetic gain under selection. It is the difference between the mean genotypic value of the selected lines and the mean genotypic value of the parental population. Studies related to variability in rice are enumeratedbelow.

Table 2. Studies on variability in rice

Characters	PCV	GCV	h^2	Genetic gain	Authors
Plant height	Low	Low	High	Moderate	Borkakati *et al.*, (2005)
	Moderate	Moderate	High	High	Sabesan *et al.*, (2009) Karthikeyan *et al.*, (2010)
	High	High	High	High	Pal *et al.*, (2010)
	Moderate	Moderate	High	High	Jayasudha and Sharma (2010) Singh *et al.*, (2011)
	Moderate	Low	High	Moderate	Fiyaz *et al.*, (2011)
	Low	Low	High		Akhtar *et al.*, (2011)
	Moderate	Moderate	High	Moderate	Quatadah *et al.*, (2012)
Days to fifty per cent flowering	Moderate	Low	High	Moderate	Borkakati *et al.*, (2005) Fiyaz *et al.*, (2011) Singh *et al.*, (2011)
	Moderate	Moderate	High	High	Karthikeyan *et al.*, (2010)
	Low	Low	High	Moderate	Sabesan *et al.*, (2009) Pal *et al.*, (2010)
	Low	Low	High	Low	Quatadah *et al.*, (2012)
	Low	Low	Moderate	Moderate	Bhadru *et al.*, (2012)
Total tillers/plant	High	High	High	Low	Pal *et al.*, (2010)

	High	High	High		Akhtar *et al.*, (2011)
Productive tillers/plant	Moderate	Low	High	Moderate	Karthikeyan *et al.*, (2010)
	High	High	High	High	Sabesan *et al.*, (2009)
	High	High	High	Low	Jayasudha and Sharma (2010)
	High	Low	Moderate	Low	Fiyaz *et al.*, (2011)
Panicle length	Low	Low	High	Moderate	Karthikeyan *et al.*, (2010) Kumar *et al.*, (2012)
	Moderate	Low	Moderate	Moderate	Pal *et al.*, (2010)
	Moderate	Moderate	High	Low	Jayasudha and Sharma (2010)
	Moderate	Low	Moderate		Idrisl *et al.*, (2012
	Low	Low	High	Low	Singh *et al.*, (2011)
	Low	Low	Moderate	Low	Bhadru *et al.*, (2012)
Spikelets/panicle	High	High	High	High	Fiyaz *et al.*, (2011) Singh *et al.*, (2011)
	High	Moderate	High	High	Quatadah *et al.*, (2012)
Grains/panicle	High	High	Moderate	High	Karim *et al.*, (2007)
	High	High	High	High	Sabesan *et al.*, (2009)
	High	High	Moderate		Idrisl *et al.*, (2012)
	High	High	High		Akhtar *et al.*, (2011)

	Moderate	Moderate	High	High	Kumar *et al.*, (2012)
	High	Moderate	Moderate	High	Bhadru *et al.*, (2012)
1000 grain weight	High	High	High	High	Karim *et al.*, (2007)
	Moderate	Moderate	High	High	Karthikeyan *et al.*, (2010) Pal *et al.*, (2010) Fiyaz *et al.*, (2011)
	Moderate	Moderate	Moderate	High	Bhadru *et al.*, (2012)
	Low	Low	High		Akhtar *et al.*, (2011)
Grain yield/plant	High	High	High	High	Borkakati *et al.*, (2005) Sabesan *et al.*, (2009) Karthikeyan *et al.*, (2010) Fiyaz *et al.*, (2011)
	High	High	Moderate	High	Karim *et al.*, (2007)
	High	High	High	Moderate	Jayasudha and Sharma (2010)
	High	Moderate	High	Low	Quatadah *et al.*, (2012)

2.4. Correlation analysis

Correlation refers to the degree and direction of association between two or more than two variables. It measures the mutual relationship between various plant characters and determines the component characters on which selection can be based for genetic improvement of yield. Its value ranges between -1 to +1. A positive correlation occurs due to coupling phase of linkage and negative correlation arises due to repulsion phase of linkage of genes controlling two different traits.

Many authors computed genotypic and phenotypic correlation coefficients to bring out the relationship of different traits with yield and also with the yield contributing characters. The extent of environmental influence can also be known through the analysis. The review on correlation in rice is presented below.

Table 3. Correlation studies of yield components with grain yield

Characters	Phenotypic coefficient of correlation		Genotypic coefficient of correlation	
	Positive	Negative	Positive	Negative
Grain yield vs Plant height	Bastian, *et al.*,(2008) Chakraborty *et al.*,(2010) Bhadru, *et al.*,(2011) Rangare *et al.*,(2012) Bhadru *et al.*,(2012)	Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011)	Girolkar *et al.*,(2008) Bastian, *et al.*,(2008) Chakraborty *et al.*,(2010) Bhadru, *et al.*,(2011) Fiyaz *et al.*,(2011) Rangare *et al.*,(2012) Bhadru *et al.*,(2012)	Chandra *et al.*,(2009) Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011)

Grain yield vs Days to fifty per cent flowering	Bastian, *et al.*,(2008) Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011) Bhadru *et al.*,(2012) Rangare *et al.*,(2012)	Bhadru, *et al.*,(2011) Santhi *et al.*,(2011)	Bastian, *et al.*,(2008) Chandra *et al.*,(2009) Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011) Fiyaz *et al.*,(2011) Rangare *et al.*,(2012)	Girolkar *et al.*,(2008) Bhadru, *et al.*,(2011) Santhi *et al.*,(2011) Bhadru *et al.*,(2012)
Grain yield vs Total tillers per plant	Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011)		Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011)	
Grain yield vs Productive tillers per plant	Jayasudha *et al.*,(2010) Santhi *et al.*,(2011) Basavaraja *et al.*,(2011) Rangare *et al.*,(2012) Bhadru *et al.*,(2012)	Bhadru, *et al.*,(2011)	Chandra *et al.*,(2009) Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011) Fiyaz *et al.*,(2011) Santhi *et al.*,(2011) Bhadru *et al.*,(2012) Rangare *et al.*,(2012)	Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008) Bhadru, *et al.*,(2011)

Grain yield vs Panicle length	Bastian, *et al.*,(2008) Chakraborty *et al.*,(2010) Basavaraja *et al.*,(2011) Bhadru, *et al.*,(2011) Idrisl *et al.*, (2012) Rangare *et al.*,(2012)	Jayasudha *et al.*,(2010)	Bastian, *et al.*,(2008) Chandra *et al.*,(2009) Chakraborty *et al.*,(2010) Basavaraja *et al.*,(2011) Bhadru, *et al.*,(2011) Fiyaz *et al.*,(2011) Idrisl *et al.*, (2012) Rangare *et al.*,(2012)	Girolkar *et al.*,(2008) Jayasudha *et al.*,(2010)
Grain yield vs Spikelets per panicle	Rangare *et al.*,(2012)		Girolkar *et al.*,(2008) Chandra *et al.*,(2009) Fiyaz *et al.*,(2011) Rangare *et al.*,(2012)	
Grain yield vs Grains per panicle	Bastian, *et al.*,(2008) Chakraborty *et al.*,(2010) Santhi *et al.*,(2011) Idrisl *et al.*, (2012)		Bastian, *et al.*,(2008) Chakraborty *et al.*,(2010) Santhi *et al.*,(2011) Idrisl *et al.*, (2012)	
Grain yield vs 1000 grain weight	Bhadru, *et al.*,(2011) Bhadru *et al.*,(2012)		Chandra *et al.*,(2009) Bhadru, *et al.*,(2011) Fiyaz *et al.*,(2011), Bhadru *et al.*,(2012)	

Table 4. Studies on inter correlation among yield components

Characters	Phenotypic coefficient of correlation		Genotypic coefficient of correlation	
	Positive	Negative	Positive	Negative
Intercorrelation among plant height and other yield components				
Plant height vs Total tillers/plant	Basavaraja *et al.*,(2011)	Jayasudha *et al.*,(2010) Akhtar *et al.*,(2011)		Tandelkar *et al.*,(2008) Jayasudha *et al.*,(2010) Akhtar *et al.*,(2011) Basavaraja *et al.*, (2011)
Plant height vs Productive tillers/plant	Vinothin *et al.*,(2008) Bhadru, *et al.*,(2011) Bhadru *et al.*,(2012)	Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011)	Chandra *et al.*,(2009) Bhadru, *et al.*,(2011) Fiyaz *et al.*,(2011) Rajamadhan *et al.*,(2011)	Girolkar *et al.*,(2008) Vinothin *et al.*,(2008) Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011) Bhadru *et al.*,(2012)
Plant height vs Panicle length	Vinothin *et al.*,(2008) Chakraborty *et al.*, (2010) Jayasudha *et al.*,(2010) Bhadru, *et al.*,(2011) Basavaraja *et al.*,(2011) Bhadru *et al.*,(2012)	Bastian, *et al.*,(2008)	Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008) Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Chakraborty *et al.*,(2010) Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011) Bhadru, *et al.*,(2011) Fiyaz *et al.*,(2011)	Bastian, *et al.*,(2008)

			Rajamadhan *et al.*,(2011) Bhadru *et al.*,(2012)	
Plant height vs Spikelets/panicle	Basavaraja *et al.*,(2011) Rangare *et al.*,(2012)		Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008) Basavaraja *et al.*,(2011) Fiyaz *et al.*,(2011) Rangare *et al.*,(2012)	
Plant height vs Grains/panicle	Bastian, *et al.*,(2008) Vinothin *et al.*,(2008) Chakraborty *et al.*, (2010) Bhadru, *et al.*,(2011)		Bastian, *et al.*,(2008) Girolkar *et al.*,(2008) Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Chakraborty *et al.*,(2010) Bhadru, *et al.*,(2011) Rajamadhan *et al.*,(2011)	
Plant height vs 1000 grain weight	Vinothin *et al.*,(2008) Akhtar *et al.*,(2011)	Bhadru *et al.*,(2012)	Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Fiyaz *et al.*,(2011)	Bhadru *et al.*,(2012)
Plant height vs Root length	Vinothin *et al.*,(2008)		Vinothin *et al.*,(2008) Akhtar *et al.*,(2011)	
Plant height vs Root weight	Vinothin *et al.*,(2008)		Vinothin *et al.*,(2008)	
Intercorrelation among days to fifty per cent flowering and other yield components				
Days to fifty per cent flowering	Bastian, *et al.*,(2008) Jayasudha *et al.*,(2010)		Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008)	Chandra *et al.*,(2009)

vs **Plant height**	Basavaraja *et al.*,(2011) Bhadru, *et al.*,(2011) Bhadru *et al.*,(2012) Rangare *et al.*,(2012)		Bastian, *et al.*,(2008) Jayasudha *et al.*,(2010) Bhadru, *et al.*,(2011) Basavaraja *et al.*,(2011) Rajamadhan *et al.*,(2011) Bhadru *et al.*,(2012) Rangare *et al.*,(2012)	
Days to fifty per cent flowering **vs** **Total tillers per plant**	Basavaraja *et al.*,(2011)	Jayasudha *et al.*,(2010)	Basavaraja *et al.*,(2011)	Tandelkar *et al.*,(2008) Jayasudha *et al.*,(2010)
Days to fifty per cent flowering **vs** **Productive tillers per plant**	Jayasudha *et al.*,(2010) Bhadru, *et al.*,(2011) Rangare *et al.*,(2012) Bhadru *et al.*,(2012)	Vinothin *et al.*,(2008) Basavaraja *et al.*,(2011) Santhi *et al.*,(2011)	Chandra *et al.*,(2009) Jayasudha *et al.*,(2010) Bhadru, *et al.*,(2011) Fiyaz *et al.*,(2011) Rajamadhan *et al.*,(2011) Bhadru *et al.*,(2012) Rangare *et al.*,(2012)	Girolkar *et al.*,(2008) Vinothin *et al.*,(2008) Santhi *et al.*,(2011)
Days to fifty per cent flowering **vs** **Panicle length**	Bastian, *et al.*,(2008) Vinothin *et al.*,(2008) Bhadru, *et al.*,(2011) Bhadru *et al.*,(2012) Rangare *et al.*,(2012)	Jayasudha *et al.*,(2010)	Bastian, *et al.*,(2008) Tandelkar *et al.*,(2008) Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Bhadru, *et al.*,(2011) Fiyaz *et al.*,(2011) Rajamadhan *et al.*,(2011) Bhadru *et al.*,(2012)	Girolkar *et al.*,(2008) Jayasudha *et al.*,(2010)

			Rangare *et al.*,(2012)	
Days to fifty per cent flowering vs Spikelets per panicle			Girolkar *et al.*,(2008) Basavaraja *et al.*,(2011) Fiyaz *et al.*,(2011) Rangare *et al.*,(2012)	Tandelkar *et al.*,(2008)
Days to fifty per cent flowering vs Grains per panicle	Vinothin *et al.*,(2008) Bhadru, *et al.*,(2011)	Santhi *et al.*,(2011)	Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Bhadru, *et al.*,(2011) Rajamadhan *et al.*,(2011)	Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008) Santhi *et al.*,(2011)
Days to fifty per cent flowering vs 1000 grain weight	Vinothin *et al.*,(2008) Bhadru *et al.*,(2012)	Bhadru, *et al.*,(2011)	Vinothin *et al.*,(2008) Bhadru *et al.*,(2012)	Chandra *et al.*,(2009) Bhadru, *et al.*,(2011) Fiyaz *et al.*,(2011)
Days to fifty per cent flowering vs Root Length	Vinothin *et al.*,(2008)		Vinothin *et al.*,(2008)	
Days to fifty per cent flowering vs Root weight	Vinothin *et al.*,(2008)		Vinothin *et al.*,(2008)	
Inter correlation among total tillers/plant and other yield components				
Total tillers/plant vs Productive tillers/plant	Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011)		Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011)	
Total tillers/plant	Jayasudha *et al.*,(2010)		Jayasudha *et al.*,(2010)	

vs **Panicle length**				
Total tillers/plant vs Spikelets/panicle	Basavaraja *et al.*,(2011)		Basavaraja *et al.*,(2011)	Tandelkar *et al.*,(2008)
Total tillers/plant vs Grains/panicle				Tandelkar *et al.*,(2008)
Total tillers/plant vs 1000 grain weight		Akhtar *et al.*,(2011)	Akhtar *et al.*,(2011)	
Grain yield	Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011)		Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011)	
Inter correlation among productive tillers/plant and other yield components				
Productive tillers/plant vs Plant height	Rangare *et al.*,(2012)			Rangare *et al.*,(2012)
Productive tillers/plant vs Panicle length	Jayasudha *et al.*,(2010) Rangare *et al.*,(2012)	Vinothin *et al.*,(2008)	Chandra *et al.*,(2009) Jayasudha *et al.*,(2010) Fiyaz *et al.*,(2011) Rajamadhan *et al.*,(2011) Rangare *et al.*,(2012)	Vinothin *et al.*,(2008)
Productive tillers/plant vs Spikelets/panicle	Basavaraja *et al.*,(2011) Rangare *et al.*,(2012)		Basavaraja *et al.*,(2011) Fiyaz *et al.*,(2011) Rangare *et al.*,(2012)	Girolkar *et al.*,(2008)
Productive	Bhadru, *et al.*,(2011)	Vinothin *et al.*,(2008)	Santhi *et al.*,(2011)	Girolkar *et al.*,(2008)

tillers/plant vs Grains/panicle	Santhi *et al.*,(2011)		Rajamadhan *et al.*,(2011)	Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Bhadru, *et al.*,(2011)
Productive tillers/plant vs 1000 grain weight	Vinothin *et al.*,(2008) Bhadru *et al.*,(2012)	Bhadru, *et al.*,(2011)	Vinothin *et al.*,(2008) Fiyaz *et al.*,(2011) Bhadru *et al.*,(2012)	Chandra *et al.*,(2009) Bhadru, *et al.*,(2011)
Productive tillers/plant vs Root weight		Vinothin *et al.*,(2008)		Vinothin *et al.*,(2008)
Intercorrelation among panicle length and other yield components				
Panicle length vs Plant height	Rangare *et al.*,(2012)		Rangare *et al.*,(2012)	
Panicle length vs Total tillers/plant	Basavaraja *et al.*,(2011)		Basavaraja *et al.*,(2011)	
Panicle length vs Productive tillers /plant	Basavaraja *et al.*,(2011) Bhadru, *et al.*,(2011)		Basavaraja *et al.*,(2011) Bhadru, *et al.*,(2011)	Girolkar *et al.*,(2008)
Panicle length vs Spikelets/panicle	Basavaraja *et al.*,(2011) Rangare *et al.*,(2012)		Girolkar *et al.*,(2008) Basavaraja *et al.*,(2011) Fiyaz *et al.*,(2011) Rangare *et al.*,(2012)	
Panicle length vs Grains/panicle	Bastian, *et al.*,(2008) Chakraborty *et al.*,(2010)		Bastian, *et al.*,(2008) Chandra *et al.*,(2009) Chakraborty *et*	Girolkar *et al.*,(2008)

	Bhadru, *et al.*,(2011) Idrisl *et al.*, (2012)		*al.*,(2010) Bhadru, *et al.*,(2011) Rajamadhan *et al.*,(2011) Idrisl *et al.*, (2012)	
Panicle length vs 1000 grain weight	Vinothin *et al.*,(2008) Bhadru, *et al.*,(2011)		Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Bhadru, *et al.*,(2011)	Fiyaz *et al.*,(2011)
Intercorrelation among spikelets/panicle with other yield components				
Spikelets/panicle vs Grains per panicle			Girolkar *et al.*,(2008)	
Spikelets/panicle vs 1000 grain weight			Chandra *et al.*,(2009) Fiyaz *et al.*,(2011)	
Inter correlation among grains/panicle and other yield components				
Grains/panicle vs Plant height		Akhtar *et al.*,(2011)		Akhtar *et al.*,(2011)
Grains/panicle vs Total tillers/plant		Akhtar *et al.*,(2011)		Akhtar *et al.*,(2011)
Grains/panicle vs Panicle length	Vinothin *et al.*,(2008)		Vinothin *et al.*,(2008)	
Grains/panicle vs Spikelets/panicle			Tandelkar *et al.*,(2008)	
Grains/panicle	Vinothin *et al.*,(2008)		Vinothin *et al.*,(2008)	

vs 1000 grain weight	Akhtar *et al.*,(2011)		Akhtar *et al.*,(2011)	
Grains/panicle vs Root weight	Vinothin *et al.*,(2008)		Vinothin *et al.*,(2008)	
Inter correlation among root length and other yield components				
Root length Vs Productive tillers/ plant		Vinothin *et al.*,(2008)		Vinothin *et al.*,(2008)
Root length vs Panicle length	Vinothin *et al.*,(2008)		Vinothin *et al.*,(2008)	
Root length vs Grains/panicle	Vinothin *et al.*,(2008)		Vinothin *et al.*,(2008)	
Root length vs 1000 grain weight		Vinothin *et al.*,(2008)		Vinothin *et al.*,(2008)
Root length vs Root weight	Vinothin *et al.*,(2008)		Vinothin *et al.*,(2008)	
Intercorrelation among root weight and other yield components				
Root weight vs Panicle length	Vinothin *et al.*,(2008)		Vinothin *et al.*,(2008)	
Root weight vs 1000 grain weight	Vinothin *et al.*,(2008)		Vinothin *et al.*,(2008)	

2.5. Path Analysis

The grain yield is influenced by several component characters, which internally maintain a balance. Increase in any one component decreases the other consequently there is a little change in the yield. Path coefficient analysis is important for portioning the genotypic correlation coeffiecient into direct and indirect effects of component characters. A path coeffiecient is simply a standardized partial regression coeffiecient and as such, it measures the direct influence of one variable upon another (Dewey and Lu, 1959). From this we can estimate the actual contribution of an attribute and its influence through other characters.

Table 5. Studies on direct effects of yield components on grain yield

Characters	**Positive**	**Negative**
Plant height	Girolkar *et al.*,(2008) Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011) Rajamadhan *et al.*,(2011)	Tandelkar *et al.*,(2008) Vinothin *et al.*,(2008) Bastian, *et al.*,(2008) Chandra *et al.*,(2009) Akhtar *et al.*,(2011) Fiyaz *et al.*,(2011) Rangare *et al.*,(2012)
Days to flowering	Bastian, *et al.*,(2008) Chandra *et al.*,(2009) Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011) Fiyaz *et al.*,(2011) Santhi *et al.*,(2011)	Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008) Vinothin *et al.*,(2008) Rajamadhan *et al.*,(2011)
Total tillers/plant	Tandelkar *et al.*,(2008)	Jayasudha *et al.*,(2010) Akhtar *et al.*,(2011) Basavaraja *et al.*,(2011)
Productive tillers/plant	Girolkar *et al.*,(2008) Vinothin *et al.*,(2008) Chandra *et al.*,(2009)	Basavaraja *et al.*,(2011)

	Jayasudha *et al.*,(2010) Fiyaz *et al.*,(2011) Rajamadhan *et al.*,(2011) Santhi *et al.*,(2011) Rangare *et al.*,(2012)	
Panicle length	Girolkar *et al.*,(2008) Vinothin *et al.*,(2008) Chakraborty *et al.*,(2010) Basavaraja *et al.*,(2011) Rajamadhan *et al.*,(2011) Rangare *et al.*,(2012)	Bastian, *et al.*,(2008) Tandelkar *et al.*,(2008) Chandra *et al.*,(2009) Jayasudha *et al.*,(2010) Fiyaz *et al.*,(2011)
Spikelets/panicle	Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008)	Basavaraja *et al.*,(2011) Fiyaz *et al.*,(2011) Rangare *et al.*,(2012)
Grains/panicle	Bastian, *et al.*,(2008) Chandra *et al.*,(2009) Santhi *et al.*,(2011)	Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008) Vinothin *et al.*,(2008) Chakraborty *et al.*,(2010) Akhtar *et al.*,(2011) Rajamadhan *et al.*,(2011) Rangare *et al.*,(2012)
1000 grain weight	Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Akhtar *et al.*,(2011) Fiyaz *et al.*,(2011)	
Root length	Vinothin *et al.*,(2008)	
Root weight	Vinothin *et al.*,(2008)	

Table 6. Studies on indirect effects of yield components on grain yield

Characters	**Positive**	**Negative**
Indirect effects of other yield components through plant height on yield		
Days to fifty per cent flowering	Bastian, *et al.*,(2008) Basavaraja *et al.*,(2011) Rajamadhan *et al.*,(2011) Rangare *et al.*,(2012)	Tandelkar *et al.*,(2008) Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Jayasudha *et al.*,(2010) Fiyaz *et al.*,(2011)
Total tillers/plant	Jayasudha *et al.*,(2010) Akhtar *et al.*,(2011) Basavaraja *et al.*,(2011)	Tandelkar *et al.*,(2008)

Productive tillers/plant	Chandra *et al.*,(2009) Basavaraja *et al.*,(2011) Fiyaz *et al.*,(2011) Rajamadhan *et al.*,(2011)	Girolkar *et al.*,(2008) Vinothin *et al.*,(2008) Jayasudha *et al.*,(2010) Rangare *et al.*,(2012)
Panicle Length	Bastian, *et al.*,(2008) Girolkar *et al.*,(2008) Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Chakraborty *et al.*,(2010) Rajamadhan *et al.*,(2011) Rangare *et al.*,(2012)	Tandelkar *et al.*,(2008) Jayasudha *et al.*,(2010) Fiyaz *et al.*,(2011)
Spikelets/panicle	Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008)	Basavaraja *et al.*,(2011) Rangare *et al.*,(2012)
Grains/panicle	Bastian, *et al.*,(2008) Chandra *et al.*,(2009) Akhtar *et al.*,(2011) Rajamadhan *et al.*,(2011)	Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008) Vinothin *et al.*,(2008) Chakraborty *et al.*,(2010)
1000 grain weight	Girolkar *et al.*,(2008) Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Akhtar *et al.*,(2011) Fiyaz *et al.*,(2011)	Tandelkar *et al.*,(2008)
Root Length	Vinothin *et al.*,(2008)	
Root weight	Vinothin *et al.*,(2008)	
Indirect effects of other yield components through days to fifty per cent flowering on yield		
Plant height	Basavaraja *et al.*,(2011) Fiyaz *et al.*,(2011) Rajamadhan *et al.*,(2011)	Bastian, *et al.*,(2008) Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008) Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Jayasudha *et al.*,(2010) Rangare *et al.*,(2012)
Total tillers/plant	Jayasudha *et al.*,(2010)	Tandelkar *et al.*,(2008) Basavaraja *et al.*,(2011)
Productive tillers/plant	Chandra *et al.*,(2009) Jayasudha *et al.*,(2010) Fiyaz *et al.*,(2011)	Girolkar *et al.*,(2008) Vinothin *et al.*,(2008) Basavaraja *et al.*,(2011)

	Rajamadhan *et al.*,(2011) Rangare *et al.*,(2012)	Santhi *et al.*,(2011)
Panicle length	Vinothin *et al.*,(2008) Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011) Rajamadhan *et al.*,(2011) Rangare *et al.*,(2012)	Bastian, *et al.*,(2008) Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008) Chandra *et al.*,(2009)
Spikelets/panicle	Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008)	Fiyaz *et al.*,(2011) Rangare *et al.*,(2012)
Grains/panicle	Bastian, *et al.*,(2008) Girolkar *et al.*,(2008)	Tandelkar *et al.*,(2008) Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Santhi *et al.*,(2011)
1000 grain weight	Vinothin *et al.*,(2008)	Chandra *et al.*,(2009) Fiyaz *et al.*,(2011)
Root Length	Vinothin *et al.*,(2008)	
Root weight	Vinothin *et al.*,(2008)	
Indirect effect of other yield components through total tillers/plant on yield		
Plant height	Tandelkar *et al.*,(2008) Akhtar *et al.*,(2011)	Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011)
Days to fifty per cent flowering	Tandelkar *et al.*,(2008) Basavaraja *et al.*,(2011)	Jayasudha *et al.*,(2010)
Productive tillers/plant	Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011)	
Panicle length	Tandelkar *et al.*,(2008) Basavaraja *et al.*,(2011)	Jayasudha *et al.*,(2010)
Spikelets/panicle		Tandelkar *et al.*,(2008) Basavaraja *et al.*,(2011)
Grains/panicle	Tandelkar *et al.*,(2008) Akhtar *et al.*,(2011)	

1000 grain weight		Akhtar *et al.*,(2011)
Indirect effect of other yield components through productive tillers/plant on yield		
Plant height	Vinothin *et al.*,(2008) Basavaraja *et al.*,(2011) Rajamadhan *et al.*,(2011) Rangare *et al.*,(2012)	Girolkar *et al.*,(2008) Chandra *et al.*,(2009) Jayasudha *et al.*,(2010) Fiyaz *et al.*,(2011)
Days to fifty per cent flowering	Girolkar *et al.*,(2008) Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Rajamadhan *et al.*,(2011) Santhi *et al.*,(2011) Rangare *et al.*,(2012)	Basavaraja *et al.*,(2011)
Total tillers/plant		Jayasudha *et al.*,(2010) Basavaraja *et al.*,(2011)
Panicle length	Basavaraja *et al.*,(2011) Rajamadhan *et al.*,(2011) Rangare *et al.*,(2012)	Girolkar *et al.*,(2008) Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Jayasudha *et al.*,(2010)
Spikelets/panicle		Girolkar *et al.*,(2008) Basavaraja *et al.*,(2011) Fiyaz *et al.*,(2011) Rangare *et al.*,(2012)
Grains/panicle	Girolkar *et al.*,(2008) Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Rajamadhan *et al.*,(2011) Santhi *et al.*,(2011)	
1000 grain weight	Vinothin *et al.*,(2008)	Chandra *et al.*,(2009)
Indirect effect of other yield components through panicle length on yield		
Plant height	Bastian, *et al.*,(2008) Girolkar *et al.*,(2008) Chandra *et al.*,(2009) Chakraborty *et al.*,(2010) Jayasudha *et al.*,(2010) Rajamadhan *et al.*,(2011)	Tandelkar *et al.*,(2008) Vinothin *et al.*,(2008) Rangare *et al.*,(2012)
Days to fifty per cent flowering	Girolkar *et al.*,(2008) Bastian, *et al.*,(2008) Chandra *et al.*,(2009) Rajamadhan *et al.*,(2011) Rangare *et al.*,(2012)	Vinothin *et al.*,(2008) Tandelkar *et al.*,(2008) Jayasudha *et al.*,(2010)
Total tillers/plant		Tandelkar *et al.*,(2008)

		Jayasudha *et al.*,(2010)
Productive tillers/plant	Chandra *et al.*,(2009) Jayasudha *et al.*,(2010) Rajamadhan *et al.*,(2011) Rangare *et al.*,(2012)	Girolkar *et al.*,(2008) Vinothin *et al.*,(2008)
Spikelets/panicle	Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008)	Rangare *et al.*,(2012)
Grains/panicle	Girolkar *et al.*,(2008) Bastian, *et al.*,(2008) Rajamadhan *et al.*,(2011)	Tandelkar *et al.*,(2008) Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Chakraborty *et al.*,(2010)
1000 grain weight	Girolkar *et al.*,(2008) Vinothin *et al.*,(2008)	Chandra *et al.*,(2009)
Root Length	Vinothin *et al.*,(2008)	
Root weight	Vinothin *et al.*,(2008)	
Indirect effect of other yield components through spikelets/panicle on yield		
Plant height	Girolkar *et al.*,(2008)	Tandelkar *et al.*,(2008) Basavaraja *et al.*,(2011) Rangare *et al.*,(2012)
Days to fifty per cent flowering	Basavaraja *et al.*,(2011) Rangare *et al.*,(2012)	Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008)
Total tillers/plant		Tandelkar *et al.*,(2008) Basavaraja *et al.*,(2011)
Productive tillers/plant	Basavaraja *et al.*,(2011) Rangare *et al.*,(2012)	Girolkar *et al.*,(2008)
Panicle length	Girolkar *et al.*,(2008) Basavaraja *et al.*,(2011) Rangare *et al.*,(2012)	Tandelkar *et al.*,(2008)
Grains/panicle		Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008)
1000 grain weight		Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008)
Indirect effect of other yield components through grains/panicle on yield		
Plant height	Girolkar *et al.*,(2008)	Tandelkar *et al.*,(2008)

	Rajamadhan *et al.*,(2011) Akhtar *et al.*,(2011)	Vinothin *et al.*,(2008) Bastian, *et al.*,(2008) Chandra *et al.*,(2009)
Days to fifty per cent flowering	Girolkar *et al.*,(2008) Bastian, *et al.*,(2008) Chandra *et al.*,(2009) Chakraborty *et al.*,(2010)	Tandelkar *et al.*,(2008) Vinothin *et al.*,(2008) Santhi *et al.*,(2011) Rajamadhan *et al.*,(2011)
Total tillers/plant	Akhtar *et al.*,(2011)	Tandelkar *et al.*,(2008)
Productive tillers/plant	Santhi *et al.*,(2011) Rajamadhan *et al.*,(2011)	Girolkar *et al.*,(2008) Vinothin *et al.*,(2008) Chandra *et al.*,(2009)
Panicle length	Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Chakraborty *et al.*,(2010) Rajamadhan *et al.*,(2011)	Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008) Bastian, *et al.*,(2008)
Spikelets/panicle	Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008)	
1000 grain weight	Chandra *et al.*,(2009) Akhtar *et al.*,(2011)	Tandelkar *et al.*,(2008) Vinothin *et al.*,(2008)
Root Length	Vinothin *et al.*,(2008)	
Root weight	Vinothin *et al.*,(2008)	
Indirect effect of other yield components through1000 grain weight on yield		
Plant height	Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008)	Vinothin *et al.*,(2008) Chandra *et al.*,(2009) Akhtar *et al.*,(2011)
Days to fifty per cent flowering	Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008) Chandra *et al.*,(2009)	Vinothin *et al.*,(2008)
Total tillers/plant	Akhtar *et al.*,(2011)	Tandelkar *et al.*,(2008)
Productive tillers/plant	Vinothin *et al.*,(2008)	Girolkar *et al.*,(2008) Chandra *et al.*,(2009)
Panicle length	Girolkar *et al.*,(2008) Tandelkar *et al.*,(2008) Vinothin *et al.*,(2008)	Chandra *et al.*,(2009)

Spikelets/panicle	Tandelkar *et al.*,(2008)	Girolkar *et al.*,(2008)
Grains/panicle	Tandelkar *et al.*,(2008) Vinothin *et al.*,(2008) Chandra *et al.*,(2009)	Girolkar *et al.*,(2008) Akhtar *et al.*,(2011)
Root Length		Vinothin *et al.*,(2008)
Root weight		Vinothin *et al.*,(2008)

2.6. Screening of genotypes for tolerance to iron toxicity

Rice cultivars differ in their tolerance for iron toxicity and the selection of rice cultivars with superior iron tolerance is an important approach in breeding varieties for tolerance to iron toxicity. Genetic differences in adaptation to and tolerance to iron toxicity soil conditions have indeed been exploited by several workers (Gunawardena *et al.,* 1982, Nozoe *et al.,* 2008 and De Datta *et al.,*1994). Progress in breeding largely depends upon the efficiency and effectiveness of the screening techniques to identify the true tolerant genotypes, availability of the tolerant genes in the germplasm and selection of desirable lines from the segregating population. Field screening and *in vitro* screening methods are utilized to realize true tolerants for iron toxicity. Review of the works done in the above aspect is briefly discussed under below;

2.6.1. Field screening for tolerance to iron toxicity

Several workers have shown that marked differences exist in rice varieties in their tolerance for excess iron (Sahrawat 2004, Balasubramanian *et al.,* 2007, and Virmani 1977).

Among the lowland and dryland varieties studied in the tropical land of Nigeria, twenty two lines, four of which were *Oryza glaberrima*, were tolerant of high iron concentrations. Variety 2526 (Siam 25 X Malinja 3) and lines with purple pigment were the least affected by iron. Varietal differences in tolerance were more pronounced in moderately toxic soils than in the severely toxic (IITA, 1975)

Among two hundred and seventy nine cultivar screened at IRRI, Phillipines nineteen were tolerant to iron toxicity. Cultivars were mass-screened in Sri Lanka in the glasshouse and field. Among the cultivars tolerant to iron toxicity were IR20, IR29, IR32, Banih, Kuning, Kuatik Putih, IR2070-413-3, IR2071-137-5, IR2071-586-5, IR2307-217-2, IR2798-88-3, IR2798-115-2, IR2863-38-1, IR3864-217-1, IR4427-164-1 and IR4613-54-5 (IRRI, 1977).

With the initiation of the Genetic Evaluation and Utilization (GEU) Program in 1974 mass field screening for iron toxicity tolerance began. Mass screening was followed by yield trials of promising genotypes in greenhouse and field tests. Of four hundred rice lines and cultivars screened in iron toxic field in the Philippines, thirty one including Mahsuri and Monkora were found to be tolerant to iron toxicity (IRRI, 1979).

Ponnamperuma and Solivas (1981) conducted an experiment to study the varietal reactions of rice cultivars to iron toxic acid sulphate soil. Grain yield and reaction to iron toxicity were investigated in three seasons for fifteen varieties. In two dry seasons, IR483-54-2 was the most tolerant and highest-yielding variety. IR483-54-2, IR4422-480-2 and IR46 were the most productive in the wet season.

In an investigation to find out the source of inheritance of iron toxicity, Abifarin, (1985) crossed four cultivars differing in tolerance to Fe toxicity. F_1 and F_2 were evaluated for tolerance under toxic field conditions. All the F_1s and parents

Suakoko 8 and Gissi 27 were found to be tolerant. Data from the F_2 indicated that tolerance in Gissi 27 was controlled by a recessive gene and that in Suakoko 8 by a dominant gene.

Eighteen cultivars, including fifteen from the International Rice Testing Program were screened by Li *et al.*,(1986) on acid sulfate soil of pH value 3.85 (at 0-15 cm) and 3.07 (40-40 cm), to which N + K or N + K + P + Ca were added. Varietal differences in iron toxicity scored on a 1-9 scale, were evident in the study. It was found that addition of phosphorous (17.6 kg/ha as superphosphate) and Calcium oxide (3000 kg/ha as calcium carbonate) reduced the extent of toxicity. The local variety Guichao yielded significantly more than any of the test cultivars.

Sahrawat *et al.*, (1996) evaluated twenty lowland rice cultivars for tolerance of iron toxicity at an iron-toxic site in Korhogo, Côte d'Ivoire, under irrigated conditions. The cultivars differed in iron-toxicity tolerance. Grain yields varied from 0.10 to 5.04 t/ ha 1and iron toxicity scores, based on the extent of bronzing symptoms on foliage, ranged from 2 to 9 (1 indicates normal growth and nine indicates that most plants are dead or dying). Further evaluation of rice cultivars during 1992-97 showed that among three promising iron-tolerant cultivars, CK 4 was superior to other varieties with respect to grain yield (5.33 t /ha), followed by WITA 1 (4.96 t ha/1) and WITA 3 (4.46 t/ ha) and tolerant check Suakoko 8 (3.80 t/ ha).

Nipah *et al.*, (1997) conducted a screening for tolerance to iron toxicity on twenty eight genotypes of rice, two landraces of *Oryza glaberrima* and tolerant and susceptible control varieties Suakoko 8 and Bouak 189 at Korghogo, Côte d'Ivoire, on irrigated ultisol lowland containing 343 ppm iron. Plants were assessed at fifteen day intervals and cumulative toxicity was scored. Results revealed that iron toxicity reduced yields and plant height. The *O. glaberrima* landraces had only marginal symptoms and the lowest toxicity scores.

Twelve advanced breeding lines from WARDA were evaluated for yield and iron toxicity tolerance at Edozhigi in Niger State and Ikot Obong in Akwa Ibom State, Nigeria by Okocha and Singh, (1998). At Edozhigi four entries (CK73, CK4, TOX3027-43-1-E3-1-1-1 and TOX3050-46-E3-3-3-3) yielded more than the local standards Faro 35 and Suakoko 8 (both 2556.8 kg/ha). At Ikot Obong, the effect of iron toxicity was more severe as a result of high iron content in the soil water. Highest yields at Ikot Obong were obtained from TOX3118-6-E2-3-2 (1339.5 kg/ha) and Suakoko 8 (1633.5 kg/ha).

In a study by Nath and Borah (1999) to find the effect of application of iron on glycolic acid oxidase and nitrate reductase in rice indicated cultivar differences for tolerance to iron toxicity. *Oryza rufipogon* and *Oryza sativa* cv 229-F41 with higher glycolic acid oxidase and leaf nitrate reductase activities were found to more tolerant to the adverse effects of higher concentration of iron.

Sahrawat and Sika (2002) conducted experiments at an iron-toxic site (Korhogo, Côte d'Ivoire) during the 2000 wet and dry seasons to evaluate the performance of promising *O. sativa* (CK 4, tolerant check; Bouake 189, susceptible check) and *O.glaberrima* (CG 14) cultivars. While CK 4 and Bouake 189 showed typical iron toxicity symptoms in varying degrees, CG 14 plants did not show any iron toxicity symptoms at all as measured by iron toxicity scores. Although CG 14 did not give high grain yields because of its lower harvest index, lodging of the crop, especially under the application of nutrients and shattering of seeds at maturity, the cultivar showed remarkable tolerance for iron toxicity. Research showed that CG 14 has a high tolerance for iron toxicity and remains an obvious choice as a donor for iron tolerance in breeding programs

With the objective to select suitable lowland rice varieties for growing in the iron-toxic soils of Orissa, India, Nayak *et al.,* (2008) evaluated sixty five genotypes for their tolerance to iron in the field by growing them on a typical iron-toxic Haplaquept (pH 5.1; DTPA extractable iron 368 mg/kg) low in organic matter and cation exchange capacity. The results showed that there was a wide range in tolerance to iron toxicity and iron- tolerant rice genotypes irrespective of their growth duration produced higher grain yields than the iron-susceptible cultivars in the respective duration groups. The grain yield of the rice cultivars evaluated ranged from 0.77 to 3.6 t $ha^{-1}$and was influenced by tolerance to iron toxicity and growth duration

2.6.2. Laboratory Screening

Selection for tolerance under field conditions is sometimes difficult due to heterogeneous soil conditions in toxic fields. *In vitro* screening approaches may not be able to substitute conventional breeding,. However, they would be supplementary in manipulating such complex characters. A brief summary of the *in vitro* studies related to iron toxicity tolerance in rice is reviewed below.

Hu *et al.*, (1997) conducted a hydroponic culture experiment with 5 iron-tolerant and 5 iron-sensitive rice lines derived from Azucena × IR64. Results revealed that the peroxidase (POD) activity in the rice shoot was closely correlated with tolerance to iron stress, it being higher in tolerant lines than in sensitive lines. Iron stress significantly increased POD activity in all lines, but this increase was positively correlated with iron concentration in tolerant lines and negatively correlated with iron concentration in sensitive lines.

Wu *et al.*,(1997) conducted a study to find out molecular markers linked to genes underlying seedling tolerance for ferrous iron toxicity. In the study, a double haploid (DH) population consisting of one hundred and twenty three lines (derived from a japonica variety, Azucena and an indica variety, IR64) and 100BC_1F_1 Azucena lines were cultivated hydroponics using two treatments one with excess Fe^{2+}

concentrations of 250 mg/L and a control with standard nutrient solution. Genotypic tolerance was evaluated using an index scale based on degree of leaf bronzing and relative decrease in shoot dry weight. Toxic symptoms were not observed for Azucena and BC_1F_1 plants. In contrast index values for the DH population indicated segregation for tolerance and IR 64 was moderately sensitive. Molecular marker loci associated with variations in index and in relative decrease in shoot dry weight and gene loci for tolerance were detected using 175 markers mapped on all 12 chromosomes by single marker loci and interval mapping.

Tissue tolerance to higher iron concentrations in plants has been considered to be important to iron toxicity tolerance in rice. Wu *et al.,* (1998) conducted an experiment *in vitro* for characterization of tissue tolerance to iron by molecular markers in different lines of rice as continuation of his earlier work. Segregation for leaf bronzing and growth reduction due to Fe^{2+} toxicity was observed in a doubled haploid (DH) population with 135 lines derived from a Fe^{2+} tolerant japonica variety, Azucena, and a sensitive indica variety, IR64 in a solution culture (with 250 ppm Fe at pH 4.5). To better understand the mechanism of tissue tolerance, Leaf Bronzing Index (LBI), total iron concentration in shoot tissue and the enzymes of ascorbate peroxidase (AP), dehydroascorbate reductase (DR) and glutathione reductase (GR), and concentrations of ascorbate (AS) and dehydroascorbate (DHA), which are involved in the ascorbate-specific H_2O_2-scavenging system, were determined for the population under Fe^{2+} stress. The total iron concentrations in the 38 tolerant lines ranged from 1.76 mg Fe/g to 4.12 mg Fe/g and were in a similar range as in the non-tolerant genotype (2.04 – 4.55 mg Fe/ g). Single locus analysis and interval mapping analysis based on one seventy five molecular markers revealed that the interval flanked by RG345 and RZ19 on chromosome one was an important location of gene(s) for Fe^{2+} tolerance. The ascorbate-specific system for scavenging Fe^{2+}-mediated oxygen free radicals may be an important mechanism for tissue Fe^{2+} tolerance. A gene locus with relative small effect on root ability to exclude Fe^{2+} was also detected.

Mendoza *et al.,* (2003) studied genetic variability of tolerance for iron toxicity in different species of *Oryza* and their derivatives. Using seedling-stage screening procedures, one hundred and sixty one genotypes representing twenty-four improved and traditional varieties of *O. sativa,* eighteen *O. glaberrima,* ten *O. rufipogon,* thirteen *O. sativa* × *O. rufipogon* derivatives, and ninety six *O. sativa* × *O. glaberrima* derivatives were screened. Advanced progenies were screened in 300 ppm and 400 ppm iron concentrations under controlled conditions in the phytotron. Seven genotypes of *O. sativa* and three accessions from *O. rufipogon* showed tolerance in 400-ppm concentration, whereas none of the accessions from *O. glaberrima* species was tolerant. Varieties BW267-3, Suakoko 8, IR9884, IR68544-29-2-1-3-1-2, and Azucena showed good levels of tolerance at 400-ppm iron concentration. Three *O. rufipogon* accessions, 105909, 106412, and 106423, were found to be highly tolerant, and these could be good donors for tolerance for iron toxicity. Some of the derivatives of *O. sativa* × *O. glaberrima* were found to have better tolerance for iron toxicity than both parents. Most of the advanced progenies derived from *O. sativa* × *O. rufipogon* screened at 400 ppm iron concentration showed tolerance to moderate tolerance.

Better targeting of varietal improvement requires selection tools improving our understanding of the resistance mechanisms and strategies of rice in the presence of excess iron. A phytotron study was conducted by Asch *et al.,* (2005) to develop a screen for seedling resistance to iron toxicity.. In the study individual plants were subjected to varying levels of iron concentration (0–3000 mg/ L iron supplied as Fe (II)SO_4), stress duration (1–5 days of exposure), vapor-pressure deficit (VPD;1.1 and 1.8 kPa), and seedling age (14 days and 28 days). Genotypes were evaluated based on leaf-bronzing score and tissue concentrations of iron. A clear segregation of the genotypic tolerance spectrum was obtained when scoring twenty eight day old seedlings after three days of exposure to 2000 mg/L ferrous iron in a high-VPD environment. The screen allows selecting genotypes with low leaf-bronzing score as resistant to iron toxicity, and additional analyses of the tissue Fe concentration of those can identify the general adaptation strategy to be utilized in breeding programs.

The influence of high applied ferrous iron concentrations on the growth and mineral composition of the tissue of inter-specific rice, *Oryza sativa* × *Oryza glaberrima*, were studied by Dorlodot *et al.*, (2005). Experiments were performed in hydroponics by applying different ferrous iron concentrations (0, 125, 250, and 500 mg /litre Fe^{2+}) at two different plant ages. Iron toxicity conditions and symptom development were achieved in a hydroculture system provided with a frequent adjustment of pH, oxygen content, associated iron redox state, and iron availability in the nutrient solution. Symptoms (bronzing, as well as reduction in plant growth and survival rate) appeared at and above 250 mg $litre^{-1}$ applied Fe^{2+} after 4 weeks of iron toxicity stress. The hybrid line did not show iron toxicity symptoms at 125 mg $litre^{-1}$ Fe^{2+}, despite an iron concentration in its leaves (3356 mg kg^{-1}) well above the usual critical toxicity concentration in rice (700 mg kg^{-1}). The concentrations of all mineral elements, except iron, were maintained between their critical deficiency and toxicity limits. This property may have contributed to the tolerance to leaf iron concentration of hybrid line at 125 mg $litre^{-1}$ concentration of iron which is generally considered toxic to rice.

In the culture solution methods used to date, a major difficulty has been maintaining an excess level of iron concentration in order to reveal toxicity symptoms. Shimizu *et al.*, (2005) noticed lower temperature in culture solution improved uptake of iron in varieties. By lowering the solution temperature to around 20°C, Iron uptake was increased from a threshhold content of 300 mg/kg of dry weight of shoot for toxic symptom to more than 1000 mg/kg in susceptible and in tolerant cultivars. Concentrations of other related minerals in the plant tissue, i.e., potassium (K) and phosphorus (P) were not affected by the low solution temperature itself but by iron content, which can be inferred on the basis of their response curves to the excess concentration of iron. Using the proposed screening method, it is possible to obtain reproducible results in screening a large number of plants or breeding lines.

Agar nutrient solution technique was evaluated by Wang *et al.*, (2008) as an alternative screening tool for iron toxicity and zinc deficiency. Agar was dissolved in boiling water and mixed with nutrient solution to achieve a final agar concentration of 0.1% (w/v). Zinc deficiency was induced by supplying Zn at a low concentration (0.1×10^{-3} μmol L^{-1}), while Fe toxicity was induced by supplying excess Fe^{2+} (200 mg L^{-1}). Symptoms of Zn deficiency and Fe toxicity developed more rapidly in ANS compared with conventional nutrient solutions (CNS) because of the development of Zn depletion zones as a result of the reduced convection in the viscous agar medium and far less ferrous iron precipitation. Genotypic comparisons showed that the tolerance rankings obtained in ANS were very similar to the field tolerance rankings, whereas this was not the case in CNS.

Marsisa *et al.*, 2009 assessed genotypes under iron stress to a develop a protocol for genotypes. The experimental design was completely randomized, using a triple factorial scheme 2 x 5 x 6 (time x dose x genotype). Shoot length and nine days under stress were favorable for genotype discrimination under iron stress. The genotypes BR IRGA 409 and BRS AGRISUL were, respectively, the most sensitive and tolerant genotypes to iron stress. According to the genotype performance, hydroponics can be recommended as an efficient cultivation technique for the selection of iron stress-tolerant rice genotypes.

Two indica rice (*Oryza sativa* L.) cultivars, viz. 'Swarna' and 'Kalinga III' were compared for their response to iron (Fe) stress by Panda *et al.*, (2012). The cultivars were raised with four Fe levels viz. 0.05, 1, 5, 10 mg L^{-1} in hydroponic culture. Plant growth, soluble protein, chlorophyll content and phytoferritin of leaves increased significantly with increase in Fe concentration up to 5 mg L^{-1}, but decreased at 10 mg L^{-1}. In contrast, lipid peroxidation, decreased up to 5 mg L^{-1} then increased at 10 mg L^{-}

^{1}. However, at 10 mg L^{-1} of Fe these parameters were more adversely affected in 'Swarna' than 'Kalinga III'. Iron stress may, lead to secondary metallic ion stresses and under such situations cultivars like 'Kalinga III' will perform better than 'Swarna'.

To analyze the genetic factors for excess iron accumulation under K or P deficiency, a set of seedlings in F_3 and F_8 generations from an *Oryza sativa* cross between a japonica cultivar 'Gimbozu_ and an indica cultivar 'Kasalath_ were raised and exposed to nutritional stresses in a short period under nutritional solutions by Shimizu *et al.*,(2009). Quantitative trait loci (QTL) for the iron accumulation and related mineral contents in each plant were analyzed with composite interval mapping. QTLs for the Fe, P and Mg content in shoots were compared in the maps of F_3 and F_8. The QTLs for the Fe content in shoots varied in three types of nutritional conditions, but consistently indicated two overlapping regions on chromosome 3 and 4. The obtained QTLs were cross-checked with those reported before. Some of these QTLs were indicative of iron excluding the power of the root, which was expressed under reduced P content in solution.

Classification of rice genotypes based on their mechanisms of adaptation to iron toxicity was done by Engel *et al.,* (2012). It was found that, while the use of resistant genotypes is the most promising approach to address the problem, the stress appears to differentially affect rice plants as a function of plant age, climatic conditions, stress intensity and duration, and the prevailing adaptation mechanism. Twenty one contrasting six week-old rice genotypes were compared regarding their response (symptom score, biomass, Fe concentrations and uptake) to a 6 d iron pulse of 1500 mg L^{-1} Fe(II). Eight selected genotypes were further compared at different stress intensities (0, 500, 1000, and 1500 mg L^{-1} Fe(II) and at different developmental stages (4-, 6-, and 8-week-old plants). Based on Fe-induced biomass reduction and leaf-bronzing score, the tested spectrum was grouped in resistant and sensitive genotypes. Linking bronzing scores to leaf iron concentrations allowed further differentiation into includer and excluder types. Iron precipitation on roots and organ-specific iron partitioning permitted to classify the adaptation strategies into root exclusion, stem and leaf sheath retention, and leaf blade tissue tolerance. The effectiveness of these strategies differed with stress intensity and developmental stage. The reported findings improve the understanding of Fe-stress response and provide a basis for future genotype selection or breeding for enhancing Fe-toxicity resistance in rice.

Elec *et al.,* (2013) established a high-throughput screening technique using nutrient solution culture for identifying iron toxicity tolerant genotypes. Varying levels of iron, pH, and chelators in Yoshida nutrient solution culture were tested to maintain sufficient ferrous iron concentration over time to optimize the severity of iron toxicity stress for distinguishing between tolerant (Azucena) and sensitive (IR64) genotype. Optimized nutrient solution conditions were 300 mg L^{-1} iron supplied as ferrous iron at pH 4.0 with a 1:2 molar ratio of Fe:EDTA, which maintained sufficient ferrous iron stress over 5 days. This screening technique can be used in plant breeding programs as a high-throughput technique to identify genotypes tolerant to Fe toxicity.

The resistance mechanisms and strategies of rice in the presence of an excess of ferrous iron formed the objective of the experiment by Nyamangyoku and Bertin in 2013. Cultivated African rice (*O. glaberrima* Steud) was generally less sensitive to stress than cultivated Asian rice (*O. sativa* L.). A wide range of cultivars of both cultivated rice species and their interspecific hybrids were experimented under two levels of Fe^{2+} (0 and 250 mg L^{-1} supplied as FeSO4) during 28 days in hydroponic conditions in greenhouse. Leaf dry weight, root organic matter, leaf bronzing index, leaf and root Fe concentration, leaf and root mineral concentration and reduction in leaf and root growth were determined. Leaf iron concentration and the level of bronzing correlated positively and highly significantly. Both parameters correlated negatively and highly significantly with leaf dry weight, thus showing that efficient regulation of leaf iron concentration play a primordial role in resistance to ferrous iron toxicity. Results indicated that in experimental conditions, that iron coating must be considered as a symptom of sensitivity to ferrous iron toxicity rather than as a mechanism of resistance. Obvious differences were found between cultivars, especially discriminating the *glaberrima's* from the remaining ones. The *glaberrima's* produced high biomass, both under control and treated conditions. They may thus be considered as ferrous-iron resistant mainly because of avoidance mechanism.

Yue-Ping *et al.*, 2013 conducted an experiment to find out the effect of potassium on organic acid metabolism of iron sensitive and iron resistant rice cultivars. It was found that excessive iron concentration (250 mg l^{-1}) significantly inhibited the growth of both Fe-sensitive cultivar IIyou838 and Fe-resistant cultivar Xieyou9308, including the shoot and root lengths, root and shoot fresh weights, and dry weight . The results indicated that potassium can alleviate iron toxicity to a certain degree. Under iron toxicity, changes in plant height, root length, biomass, organic acid contents and enzyme activities of IIyou838 were greater than those of Xieyou 9308, showing its sensitivity to iron toxicity.

Materials & Methods

III. MATERIALS AND METHODS

The present investigation was conducted in Kerala Agricultural University (KAU) during 2012-2013. The study was carried out as two major experiments at two different locations, both experiencing humid tropical climate. Hybridization programme (Experiment I) and laboratory screening for iron toxicity tolerance [Experiment II (b)] were conducted in the Department of Plant Breeding and Genetics, College of Horticulture, Kerala Agricultural University (KAU), Vellanikkara P.O., Thrissur 680 656, located 40 m above MSL at $10^0 31'$ N latitude and $76^0 13'$ E longitude. Field screening for iron toxicity tolerance [Experiment II (a)] was located at Vth block (identified as iron toxic land) of Regional Agricultural Research Station, KAU, Pattambi, Palakkad located at 10°48'40"N latitude and 76°11'35"E longitude

3.1 Experimental Material

The material for the present study comprised of nine varieties procured from 1) Regional Agricultural Research Station (RARS), KAU, Pattambi, Palakkad 2) Rice Research Station (RRS), Moncompu, Thekkekara P.O., Alappuzha and 3). Directorate of Rice Research (DRR), Hyderabad. Six varieties including four released from KAU served as the male parents in the present study. All the three female parents used in the study are reported to be iron toxicity tolerant rice varieties. The details of the parental varieties in the study are given in Table 7.

3.2 Methods

The research programme comprised of hybridization (Experiment 1) of three female parents (Lines) with six male parents in an Line x Tester mating design during *kharif* 2012 followed by screening of resultant hybrids and parents for iron toxicity tolerance both under field [Experiment 2 (a)] and laboratory [Experiment 2 (b)] conditions during *rabi* 2012-2013.

Table 7. Salient features of parents used in the study

Treatments	Variety	Parentage	Year of release & Institute	Salient features
Lines (Female parent)				
L_1	Mo 19 (Krishnanjana)	Mo1 x Mo 6	1999, RRS, Moncompu	Days to maturity : 105-110 Grain colour:- red
L_2	PTB 53 (Mangala Mahsuri)	Re-selection from Mahsuri for red kernel colour and stress tolerance	1998, RARS, Pattambi	Days to maturity : 140- 145 Grain colour:- red
L_3	PTB 57 (Swetha)	Selection from IET 14735	2002, RARS, Pattambi	Days to maturity *kharif*: 140-145 Days to maturity *rabi*: 135-140 Grain colour:- red
Testers (Male parent)				
T_1	PTB 43 (Swarnaprabha)	Bhavani/ PTB 38	1985, RARS, Pattambi	Days to maturity: 105-110 Grain colour:- red
T_1	PTB 49 (Kairali)	IR 36/ PTB 39	1993, RARS, Pattambi	Days to maturity :110-115 Grain colour:- red
T_3	PTB 39 (Jyothi)	PTB 10/IR 8	1974, RARS, Pattambi	Days to maturity :110-115 Grain colour:- red
T_4	PTB 45 (Matta Triveni)	PTB 35/PTB15	1990, RARS, Pattambi	Days to maturity :100-105 Grain colour:- red
T_5	IR 64	IR 5657-33-2-1/IR 2061-465-1-5-5	1985,IRRI, Philippines	Days to maturity: 117 days Grain colour:- White
T_6	Triguna	Swarnadhan/RP 1579- 38	1997, DRR, Hyderabad	Days to maturity : 120-125 Grain colour:- White
Checks [used in Experiment II (b) only]				
C_1	PTB 56 Varsha	M210/(M210/PTB 28)	2002, RARS, Pattambi	Days to maturity *kharif*:115-120 Days to maturity *rabi*:105-110 Grain colour:- red
C_2	PTB 30 Chuvannamodan	Mass selection from Chuvannamodan a traditional rice variety of Kerala suitable for uplands	1951, RARS, Pattambi	Days to maturity :105-110 Grain colour:- red

3.2.1 Experiment I: Hybridization Programme

A non-replicated crossing block was laid out during June – December, 2012. Staggered sowing of each variety was done at weekly intervals from 14/05/2012 to 25/10/2012 to ensure synchronized flowering between males and females and pollen availability for hybridization. Usual agronomic practices were adopted. Hybrid seeds between the lines and testers were produced by emasculation through clipping method followed by hand pollination.

3.2.1.1 Emasculation

Emasculation of spikelets in female parents was done late in the afternoon (after 3pm). Panicles that have emerged fifty to sixty per cent out of the flag leaf were used for emasculation. The leaf sheath from the panicle was slightly detached to expose the spikelets and for easiness of emasculation. Very young florets from the bottom of the panicle where the height of the anthers is less than half the floret were cut away. Florets likely to open the next day (where the height of the anthers equal or more than half the florets) were selected for emasculation. The top one-third of each selected floret to be emasculated was clipped with scissors to expose the anthers. The anthers were removed with the tip of the forceps prong by pressing them against the side of the floret and lifting out. Butter paper cover bag was placed over. The emasculated panicles were bagged in butter paper bags and its bottom edge folded against the peduncle to hold the bag securely in place. Tagging and labeling of the emasculated panicle was done.

3.2.1.2 Pollination

Although the stigma of emasculated spikelets remains receptive for three to seven days, seed set was maximum when the florets were pollinated on the subsequent day of emasculation. At about 8am, panicles from the desired male parent ready to dehisce were selected. The panicles were enclosed in petridish and top of the petridish gently tapped to release the pollen grains to the petridish. Pollen grains collected in

Panicle selection

Half emerged anthers

Slanting cut

Removing six anthers

Collection of pollen anthers

Pollination

Covering and tagging

Seed set

Harvested seeds

Plate 1: Hybridization

the petridish were then transferred to the stigma with the help of thin camel brush. The pollinated panicles were re-bagged to avoid contamination by foreign pollen. The pollinated spikelets were checked for seed set on the fifth day after hybridization and the bag was removed.

A total of eighteen cross combinations were made and the set seeds were collected separately. Around ninety to hundred hybrid seeds were collected in each cross combination. The cross combinations generated is detailed in Table 8.

Table 8. Designation of genotypes resulting from Line x Tester mating design

Line/ Tester	**Krishnanjana (L_1)**	**Mangala Mahsuri (L_2)**	**Swetha (L_3)**
Swarnaprabha (T_1)	H_1	H_7	H_{13}
Kairali (T_2)	H_2	H_8	H_{14}
Jyothi (T_3)	H_3	H_9	H_{15}
Mattatriveni (T_4)	H_4	H_{10}	H_{16}
IR-64 (T_5)	H_5	H_{11}	H_{17}
Triguna (T_6)	H_6	H_{12}	H_{18}

3.2.2 Experiment II Screening for iron toxicity tolerance

3.2.2.1 Experiment II (a) Field screening

The experiment was laid out in the iron toxic land (Vth block) in RARS, Pattambi, following a Randomised Complete Blocks Design accommodating a total of nine parents and eighteen hybrids in three replications. Each entry was transplanted in a row of 1.8 m length at spacing of 20 cm x 15 cm. Recommended agronomic

Iron toxic field

Field before transplanting

Plate 2: Iron toxic field at RARS, Pattambi before transplanting

practices as per package of practices of Kerala Agricultural University (2011) were followed during crop growth period to raise a good crop. The soil characteristics of the experimental site are enumerated in Table 9.

Table 9. Soil characteristics of the experiment field at RARS, Pattambi

Soil Type	Taxonomic class	pH	EC	Iron content	Manganese content
North central laterites	Oxic tropaquepts	6.38	0.13	1738.2 ppm	17.45 ppm

3.2.2.2 Experiment II (b) Laboratory Screening for iron toxicity tolerance

Laboratory screening was done via hydroponics as advocated by Shimizu *et al.* (2005). The experiment consisted of plastic tray of 10L capacity. Holes were made in polystyrene (thermocol) plate covered at the bottom with nylon net to contain the germinated seeds. They were floated upon the Yoshida's nutrient solution (Yoshida *et al.,* 1976) (Table 10) contained in the plastic tray. Germinated seeds of the parents and hybrids were sown in holes of the polystyrene plate floated on deionised water and maintained for four days which was then replaced with Yoshida's solution.

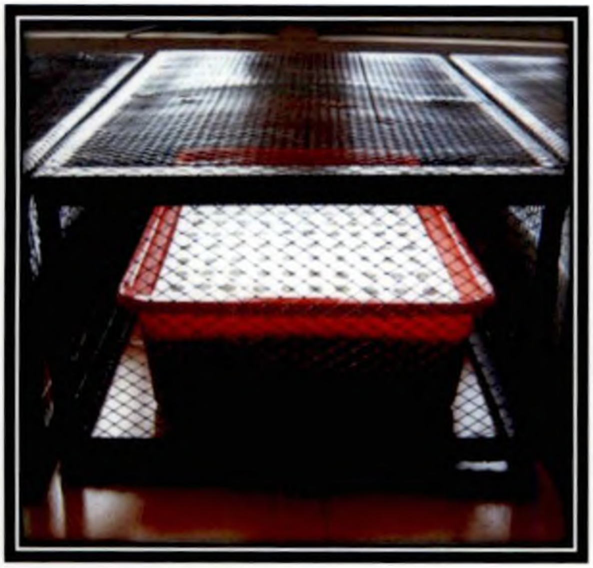
The experimental set up consisted of two sets of hybrids and parents, each set consisting of ten germinated plants per entry being screened. One of the set was cultured on Yoshida's solution alone and served as the control, while, in the other, the iron (Fe) content in the culture solution was enhanced to 600 ppm iron concentration through addition of Fe-EDTA.

Table 10. Nutrient composition of Yoshida's stock solution

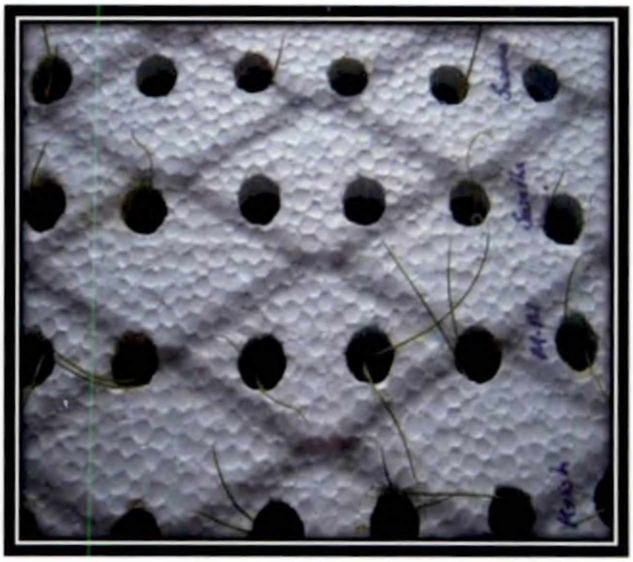
Macronutrients	**Source**	**g /500ml**
N	Ammonium nitrate (NH_4NO_3)	45.700
P	Sodium dihydrogen phosphate (NaH_2PO_4)	17.800
K	Pottassium sulphate (K_2SO_4)	35.700
Ca	Calcium chloride ($CaCl_2.2H_2O$)	58.675
Mg	Magnesium sulphate ($MgSO_4.7H_2O$)	162.00
Micronutrients Stock solution		
Mn	Manganese chloride ($MnCl_3.4H_2O$)	0.750
Mo	Ammonium molybdate 4 hydrate (NH_4 $Mo_7O_{24}.4H_2O$)	0.0375
Zn	Zinc sulphate, 7 hydrate ($ZnSO_4.7H_2O$)	0.0175
B	(Boric acid H_3BO_3)	0.467
Cu	Cupric sulphate, 5 hydrate ($CuSO_4.5H_2O$)	0.0155
Fe	Ferric chloride ($FeCl_3.6H_2O$)	2.310
Citric acid		5.950

Six stock solutions

Yoshidas culturing solution 10 l



Hydroponics set up



Germinated seedlings in Hydroponics

Plate 3: Laboratory Screening of Parents and F_1s

The stock solutions were prepared as above (Table 10). Twelve millitre from each stock solution was taken and made up to ten litre to serve as the culture solution. The pH of the stock solution was maintained at 5.0 using (0.01M) NaOH and (0.01 M) HCl. Each week the culture solution was renewed and every third day the pH adjusted to 5.5. The culture was maintained for 30 days and observations recorded on the thirtieth day.

3.3 Observations recorded

Following biometric observations enumerated below were recorded in Experiment II.

3.3.1 Experiment II. (a) Field screening for iron toxicity tolerance

Observations were recorded on ten plants chosen at random in each entry

3.3.1.1 At tillering (20 days after transplanting)

3.3.1.1.1 Iron adsorbed on root surface (mg kg^{-1})

Iron adsorbed on the root surface was measured by uprooting two plants in each replication with their roots intact. The root zone was washed thoroughly with deionised water taking care not to dislodge the iron plaque. The roots were then immersed in 25 ml of 0.01 M Calcium chloride. Iron content in the Calcium chloride solution was later analysed for iron content using Perkin- Elmer AAS (Piper 1966).

3.3.1.1.2 Iron content in the root (mg kg^{-1})

The roots were properly dried at 60^{O} Celsius for seventy-two hours and later diacid digestion was done ($2HNO_3$:$1HClO_4$) followed by filtration. Filterate was collected and analysed for iron content using Perkin- Elmer AAS (Piper 1966).

3.3.1.1.3 Manganese content in the root (mg kg^{-1})

The roots were properly dried at 60^{O} Celsius for seventy-two hours and later diacid digestion was done ($2HNO_3$:$1HClO_4$) followed by filtration. Filterate was collected and analysed for manganese content using Perkin- Elmer AAS (Piper 1966).

3.3.1.1.4 Total number of roots

The total number of roots including dead and fresh roots in each uprooted plant was count after washing the root zone thoroughly.

3.3.1.1.5 Number of fresh roots

The number of freshly emerged roots in each uprooted plant was counted.

3.3.1.1.6 Dry weight of roots

The roots were properly dried at 60°Celsius for seventy two hours and their weights were taken.

3.3.1.2 At flowering

3.3.1.2.1 Days to 50 % flowering

Actual number of days from sowing to ear emergence in fifty per cent of the plants was recorded as time of heading.

3.3.1.2.2 Iron content in 3rd leaf from tip (mg kg^{-1})

The third leaf from the tip of ten plants were collected in each entry and oven dried at 60^{O} Celsius for seventy-two hours and later diacid digestion was done ($2HNO_3$:$1HClO_4$) followed by filtration. Filterate was collected and analysed for iron content using Perkin- Elmer AAS (Piper 1966).

3.3.1.2.3 Manganese content in 3^{rd} leaf from tip (mg kg^{-1})

The third leaf from the tip of ten plants were collected in each entry and oven dried at 60^O Celsius for seventy-two hours and later diacid digestion was done ($2HNO_3$:$1HClO_4$) followed by filtration. Filterate was collected and analysed for manganese content using Perkin- Elmer AAS (Piper 1966).

3.3.1.2.4 Iron content in youngest fully open mature leaf (mg kg^{-1})

Ten leaves (youngest fully open mature leaf) from each entry is collected oven dried at 60^O Celsius for seventy-two hours and later diacid digestion was done ($2HNO_3$:$1HClO_4$) followed by filtration. Filterate was collected and analysed for iron content using Perkin- Elmer AAS (Piper 1966).

3.3.1.2.5 Manganese content in youngest fully open mature leaf (mg kg^{-1})

Ten leaves (youngest fully open mature leaf) from each entry is collected oven dried at 60^O Celsius for seventy-two hours and later diacid digestion was done ($2HNO_3$:$1HClO_4$) followed by filtration. Filterate was collected and analysed for manganese content using Perkin- Elmer AAS (Piper 1966).

3.3.1.2.6 Iron content in oldest leaf (mg kg^{-1})

Ten leaves (oldest leaves) from each entry is collected oven dried at 60^O Celsius for seventy-two hours and later diacid digestion was done ($2HNO_3$:$1HClO_4$) followed by filtration. Filterate was collected and analysed for iron content using Perkin- Elmer AAS (Piper 1966).

3.3.1.2.7 Manganese content in oldest leaf (mg kg^{-1})

Ten leaves (oldest leaves) from each entry is collected oven dried at 60^O Celsius for seventy-two hours and later diacid digestion was done ($2HNO_3$:$1HClO_4$) followed by filtration. Filterate was collected and analysed for manganese content using Perkin- Elmer AAS (Piper 1966).

3.3.1.2.8 Visual scoring for iron-toxicity symptoms (IRRI, 1996)

Scoring for iron toxicity symptoms in the hybrids and parents was done (at fifty per cent flowering stage) using the visual scoring system for iron toxicity according to Standard Evaluation Scale (IRRI, 1996) as detailed in Table 11.

Table 11.Visual scoring for iron-toxicity symptoms (IRRI, 1996)

Scale	Description	Category
1	Growth and tillering near normal	Highly resistant
2	Growth and tillering near normal; reddish-brown spots of orange discoloration on tips of old leaves	Resistant
3	Growth and tillering near normal; older leaves reddish-brown, purple or orange yellow	Moderately resistant
5	Growth and tillering delayed; many leaves discolored	Moderately susceptible
7	Growth and tillering ceased; most leaves discoloured or dead	Susceptible
9	Almost all plants dead or drying	Highly susceptible

3.3.1.3 At maturity

Observations were recorded on ten plants in each entry.

3.3.1.3.1 Plant height (cm)

Measured from the ground level to the tip of the flag leaf at maturity and expressed in centimeter.

3.3.1.3.2 Culm length (cm)

Measured from the ground level to the base of the panicle at maturity and expressed in centimeter.

3.3.1.3.3 Total tillers

The total number of grain bearing and non-bearing tillers were counted at maturity.

3.3.1.3.4 Productive tillers

The total numbers of grain bearing tillers per plant were counted at maturity.

3.3.1.3.5 Panicle length (cm)

Length of main axis of panicle measured from the panicle base to the tip was measured and expressed in centimeter.

3.3.1.3.6 Spikelets/panicle

Number of spikelets/panicle was counted on three randomly selected panicles from each of the ten representative plants at maturity and the average computed.

3.3.1.3.7 Grains /panicle

Number of filled grains/panicle was counted at maturity on three randomly selected panicles from each of the ten representative plants at maturity and the average computed.

3.3.1.3.8 Seed set per cent

The total number of filled and shrivelled spikelets in the primary panicle in each plant was counted. The seed set was computed as the ratio of filled grains to the total number of spikelets (Filled and shrivelled) and expressed as per cent over as follows

$$\text{Seed set (\%)} = \frac{\text{Number of well filled spikelets}}{\text{Filled + (Ill filled spikelets)}} \times 100$$

3.3.1.3.9 1000 grain weight (g)

Random sample of 1000 well-developed, whole grains, dried to 13 per cent moisture content from each entry was weighed after harvest and the average computed and expressed in grams.

3.3.1.3.10 Root length (cm)

Measured from the base of the root to the tip of the longest root and expressed in centimeters.

3.3.1.3.11 Shoot weight (g)

At harvest each from ten representative plants is uprooted and shoot and root separated, oven dried and dry weight is taken separately for shoot and expressed in grams.

3.3.1.3.12 Root weight (g)

Root weight of each entry is taken after oven dried and expressed in grams

3.3.1.3.13 Grain yield/ plant

Total grain yield from ten representative plants was weighed and the average value expressed in grams.

3.3.1.3.14 Visual scoring for iron-toxicity symptoms (IRRI, 1996)

Visual scoring for iron toxicity symptoms at maturity was recorded according to IRRI, 1996 as enumerated under **3.3.1.2.8**

3.3.2 Experiment II.2 Laboratory screening for iron toxicity tolerance (on 30th day)

Observations on individual plant basis were recorded on thirtieth day after experiment initiation.

3.3.2.1 Shoot length (cm)

Measured from the base of the shoot to the tip of the tallest leaf blade and expressed in centimeters.

3.3.2.2 Root length (cm)

Measured from the base of the root to the tip of the longest root and expressed in centimeters.

3.3.2.3 Total number of roots

The total number of roots including dead and fresh roots in each plant was counted after washing the root zone thoroughly.

3.3.2.4 Number of fresh roots

The number of freshly emerged roots in each plant was counted.

3.3.2.5 Vigour index (SL/RL)

The vigour index was calculated as the ratio of shoot length to root length as follows

Seedling vigour = Shoot length/ Root length

3.3.2.6 Biomass (g)

Biomass of each plant in the entry is taken and expressed in grams.

3.3.2.7 Iron adsorbed on root surface (mg kg^{-1})

The root zone was washed thoroughly with deionised water taking care not to dislodge the iron plaque. The roots were then immersed in 25 ml of 0.01 M Calcium chloride. Iron content in the Calcium chloride solution was later analysed for iron content using Perkin- Elmer AAS (Piper 1966).

3.3.2.8 Visual scoring for iron-toxicity symptoms (IRRI, 1996)

Visual scoring for iron toxicity symptoms was recorded according to IRRI, 1996 as enumerated under **3.3.1.2.8**

3.4 Statistical Analysis

3.4.1 Experiment II. 1 Field screening

3.4.1.1 At tillering and flowering

3.4.1.1.1 Variability studies

3.4.1.1.1.1 Analysis of variance:

The data collected for all the biometrical traits were subjected to an analysis of variance suggested by Panse and Sukatme (1954).

Source	**d.f.**	**Mean square**	**Expected mean squares**
Replication	(r-1)	M_r	$\sigma^2e + g.\ \sigma^2r$
Genotype	(g-1)	M_g	$\sigma^2e + r.\ \sigma^2g$
Error	(r-1)	M_e	σ^2e

Where,

r = number of replications

g = number of genotypes

M_r = replication mean squares

M_g = genotypes mean squares

M_e= error variance

3.4.1.1.1.2 Estimation of genetic parameters:

Phenotypic and Genotypic variances

These were estimated according to the method suggested by Lush (1940).

Genotypic variance (σ^2g) = (M_g - M_e)/r

Phenotypic variance (σ^2p) = $\sigma^2g + \sigma^2e$

Coefficient of variation

The components namely, phenotypic, genotypic and environmental variances were used for estimation of coefficient of variation at both phenotypic and genotypic levels for all the traits were computed by following the formula as suggested by Burton and De vane (1953).

Phenotypic coefficient of variation (PCV)

$$PCV(\%) = \frac{\sigma_p}{\overline{X}} \times 100$$

Genotypic coefficient of variation (GCV)

$$GCV(\%) = \frac{\sigma_g}{\overline{X}} \times 100$$

Where, $\overline{X}$ = grand mean of the trait

σ_P = phenotypic standard deviation

σ_g = genotypic standard deviation

The PCV and GCV were classified as suggested by Sivasubramanian and Madhavamenon (1973) into low (0-10%), moderate (10.1-20%) and high (>20%).

Heritability (h^2)

Heritability (Broad sense) for all the traits were computed by the formula suggested by Lush (1940).

$$h^2 = \frac{\sigma^2 g}{\sigma^2 p} \times 100$$

Where,

h^2 = heritability (broad sense)

σ^2_g = genotypic variance

σ^2_p = phenotypic variance

Heritability was classified as suggested by Johnson *et al.* (1955) in to low (0-30%), moderate (30.1-60%) and high (>60%).

Genetic Advance (GA)

Genetic advance was estimated according to the formula given by Johnson *et al.* (1955).

$$GA = h^2.K.\sigma_p$$

Where,

h^2 = heritability

σp = phenotypic standard deviation

K = standardized selection differential at given intensity and it is 2.06 at 5 per cent intensity of selection.

Genetic gain

Genetic gain = $(GA / \overline{X}) \times 100$

Where, GA = Genetic advance

$\overline{X}$ = General mean

Genetic gain was categorized as suggested by Johnson *et al.*, (1955) as low (0-10%), moderate (10.1-20%) and high (>20%).

3.4.1.1.2 Correlation Analysis

Phenotypic and genotypic correlation coefficients were calculated using the method by Johnson *et al.*, (1955)

Phenotypic correlation coefficients

$$rp\ X.Y = \frac{\sigma p\ (X.Y)}{(\sigma^2 px.\ \sigma^2 py)^{1/2}}$$

Genotypic correlation coefficient

$$rg\ X.Y = \frac{\sigma g\ (X.Y)}{(\sigma^2 gx.\ \sigma^2 gy)^{1/2}}$$

Where,

$\sigma p\ (X.Y)$ = phenotypic covariance between X and Y

$\sigma g\ (X.Y)$ = Genotypic covariance between X and Y

3.4.1.1.3 Path co-efficient analysis

In path coefficient analysis, the genotypic correlation coefficient is partitioned into direct and indirect effects. Path coefficient suggested by Wright (1923) was applied to study the cause and effect relationship of yield and yield attributes. The direct and indirect effects were classified based on the scale given by Lenka and Mishra (1973)

>1.0 – very high

0.3-0.99 – High

0.2- 0.29 – Moderate

0.10- 0.19 – Low

0.00- 0.09 - negligible

3.4.1.2 At maturity

3.4.1.2.1 Combining ability analysis

The data for all the biometrical traits were subjected to analysis of variance appropriate for line x tester design as suggested by Kempthrone (1957). The mean squares due to different sources of variation were obtained and the genetic expectations were worked out using the following analysis of variance (Nadarajan and Gunasekaran, 2008)

Analysis of variance for combining ability

Source	**d.f.**	**Mean squares**	**Expected mean squares**
Replication	(r-1)		
Hybrids	(lt-1)		
Lines	(l-1)	MS_1	σe^2+ r(Cov. FS- 2Cov.HS) + rt (Cov. HS)
Testers	(t-1)	MS_2	σe^2+ r(Cov. FS- 2Cov.HS) + rl (Cov. HS)
Lines x testers	(l-1) (t-1)	MS_3	σe^2 + r (Cov. FS – 2Cov.HS)
Error	(r-1) (lt-1)	MS_4	σe^2
Total	(rlt-1)	MS_5	

Where,

r - Number of replications

l - Number of lines

t - Number of testers

Estimation of *gca* and *sca* effects

The *gca* and *sca* effects for each cross were estimated. The analysis was done in the following model (Nadarajan and Gunasekaran, 2008).

$$X_{ijk} = \mu + g_i + g_j + s_{ij} + e_{ijk}$$

Where,

X_{ijk} - Value of the ijkth observation

μ - Population mean

g_i - *gca* effect of the ith line Italics

g_j - *gca* effect of the jth tester

sij - *sca* effect of the ijth hybrid

eijk- error effect associated with ijkth observation

l - number of lines

j - number of testers

k - number of replications

The individual effects of *gca* and *sca* were obtained from the two way table of lines versus testers in which each figure was a total over replications as follows

$\mu = x/rlt$

$g\hat{}_i = x_i/rt - x../rlt$

$g\hat{}_j = x_j/rl - x../rlt$

$s\hat{}ij = x_{ij}/r - x_i/rt - x_j/rl + x../rlt$

The standard errors pertaining to *gca* and *sca* effects were calculated from the square root of the variance effects as indicated below.

a) Standard error effects for lines SE (gi) = $(\sigma e^2/rt)^{1/2}$

b) Standard error effects for testers SE (g_j) = $(\sigma e^2/rl)^{1/2}$

c) Standard error effects for hybrids SE (sij) = $(\sigma e^2/r)^{1/2}$

3.4.1.2.2 Estimation of Heterosis

Magnitude of heterosis was estimated over mid-parent, better parent as well as standard parent (Nadarajan and Gunasekaran, 2008)

Relative Heterosis

The superiority of F_1 over the mid parental value was estimated as:

$$di = \frac{F-MP}{MP} \times 100$$

where,

F – mean value of hybrid

MP – mid parental value

Heterobeltiosis (dii)

Superiority or inferiority of F_1 over better parent was calculated as

$$dii = \frac{F-BP}{BP} \times 100$$

where,

BP – mean value of better parent

Standard heterosis (diii)

Superiority or inferiority of F_1 over standard parent was calculated as

$$diii = \frac{F-SV}{SV} \times 100$$

where,

SV – mean value of the standard variety. For each character best performing tester was used as standard.

Test of significance

Significance of estimates of heterosis was tested at error degrees of freedom as suggested by Turner (1953).

't' for relative heterosis = $\frac{F-MP}{\sqrt{\frac{Me}{r} x\ 3/2}}\ x\ 100$

't' for heterobeltiosis = $\frac{F-BP}{\sqrt{\frac{Me}{r} x\ 2}}\ x\ 100$

't' for standard heterosis = $\frac{F-SV}{\sqrt{\frac{Me}{r} x\ 2}}\ x\ 100$

Where 'M_e' was error variance and 'r' was the number of replication.

3.4.1.2.3 Variability studies

As enumerated under 3.4.1.1.1

3.4.1.2.4 Correlation studies

As enumerated under 3.4.1.1.2

3.4.1.2.5 Path co-efficient analysis

As enumerated under 3.4.1.1.3

3.4.2 Experiment II (b) Laboratory screening for iron toxicity tolerance

3.4.2.1 Anova for factorial design

The data recorded under Experiment II (b) was analyzed using Factorial ANOVA so as to estimate the effect of both variety and varying levels of iron in the solution culture on dependent variables. It allows us to determine if there are interactions between the independent variables or factors considered. The mean squares due to different sources of variation were worked out using the following analysis of variance (Gomez and Gomez 1976).

Source	**d.f.**	**Mean square**	**Expected mean squares**
Replication	(r-1)	M_r	M_r/M_e
Main effect (A)	(a-1)	M_A	M_A/M_e
Main effect (B)	(b-1)	M_B	M_B/M_e
Factor (AB)	(a-1) (b-1)	M_{AB}	M_{AB}/M_e
Error	ab (r-1)	M_e	

3.4.2.2 Pair wise comparison using Least Significant Difference test

The least significant difference (LSD) test is the simplest and the most commonly used procedure for making pair comparisons. The procedure provides for a single LSD value, at a prescribed level of significance, which serves as the boundary between significant and non significant differences between any pair of treatment means. That is, two treatments are declared significantly different at a prescribed level of significance if their difference exceeds the computed LSD value; otherwise they are not significantly different (Gomez and Gomez 1976).

The procedure for applying the LSD test involves these steps:

1) Compute the mean difference between the ith and jth treatment as

$$d_{ij} = x_i - x_j$$

where X_i and X_j are the means of the i^{th} and j^{th} treatments.

2) Compute the LSD value at α level of significance as:

$$LSD_\alpha = (t_\alpha)\ (S_d)$$

where (S_d) is the standard error of the mean difference and (t_α) is the tabular t value at α level of significance and with n= error degrees of freedom.

Results

IV. RESULTS

Three, high yielding varieties of rice exhibiting tolerance to iron toxicity were crossed with six high yielding varieties of short duration in a line x tester mating design. The observation on iron toxicity tolerance and yield attributes influenced by iron toxicity were recorded for parents and hybrids under both field and laboratory conditions. Biometric analysis to assess the variability, association of yield attributes with yield, combining ability and extent of heterosis was done. The results obtained are presented below.

A. Field screening for iron toxicity tolerance

4.1Variability and trait association at tillering and flowering

4.1.1 Analysis of variance

The analysis of variance (Table 12) revealed that there existed significant differences among the genotypes for most of the yield attributes studied with the exceptions being total number of roots and manganese content in oldest leaf (mg kg^{-1}). Very high significant differences between genotypes were observed with respect to iron adsorbed on root surface, iron content in the root, number of fresh roots, days to fifty per cent flowering, iron and manganese content in third leaf from tip, iron and manganese content in youngest fully open mature leaf, iron content in oldest leaf and visual scoring for iron toxicity symptoms.

4.1.2 Mean performance of parents and hybrids at tillering and flowering

Mean performance of parents and hybrids for the various traits at tillering and flowering are given in Table 13 and detailed below.

Table 12. Analysis of variance for yield attributes influenced by iron toxicity at tillering and flowering - I

Source	df	Mean sum of squares						
		Iron adsorbed on root surface (mg kg^{-1})	Iron content in the root (mg kg^{-1})	Manganese content in the root (mg kg^{-1})	Total number of roots	Number of fresh roots	Dry weight of roots (g)	Days to 50% flowering
Replication	2	1052.59	1024.00	11678.25	127.27	5.86	0.005	459.31
Treatment	26	3654.73**	9302995.70**	24633.83*	540.90	411.03**	0.035*	1046.63**
Error	52	506.05	181740.30	13621.25	387.22	116.37	0.017	25.72

*significant at 5% level; **significant at 1% level

Table 12. Analysis of variance for yield attributes influenced by iron toxicity at tillering and flowering – II (contd.)

Source	df	Mean sum of squares						
		Iron content in 3rd leaf from tip (mg kg^{-1})	Manganese content in 3rd leaf from tip (mg kg^{-1})	Iron content in youngest fully open mature leaf (mg kg^{-1})	Manganese content in youngest fully open mature leaf (mg kg^{-1})	Iron content in oldest leaf (mg kg^{-1})	Manganese content in oldest leaf (mg kg^{-1})	Visual scoring for iron toxicity symptoms
Replication	2	54151.00	13040.00	8200.00	26696.00	1466.00	3576.00	0.11
Treatment	26	265646.75**	5045.13**	186459.06**	45079.79**	118712.11**	5533.74	9.88**
Error	52	16208.05	1517.74	2203.06	10130.26	1115.1	3729.74	0.18

*significant at 5% level; **significant at 1% level

Table 13. Mean performance of parents and hybrids for yield and yield attributes at tillering and flowering.

Genotypes	**Iron adsorbed on root surface (mg kg^{-1})**	**Iron content in root (mg kg^{-1})**	**Manganese content in root (mg kg^{-1})**	**Total number of roots**	**Number of fresh roots**	**Dry weight of roots (g)**	**Days to fifty per cent flowering**
Lines							
L_1	**82.45**	**4066.5**	271.08	74.67	54	0.15	**122**
L_2	92.17	4409	**322.92**	**83.33**	**61.67**	**0.15**	131
L_3	**118.61**	**7883.82**	**175.58**	**49.67**	**34.33**	**0.11**	**139.67**
Testers							
T_1	58.19	3068.13	238	65	**46.67**	0.21	92.67
T_2	12.47	4429.13	188.46	70	34.33	0.17	86.67
T_3	10.46	**2498.67**	199.17	71	34.33	0.18	**93.67**
T_4	**6.37**	4429.46	**166.79**	65	28.33	0.21	85
T_5	12.47	**6757.88**	**310.13**	**57**	**20.67**	**0.17**	91
T_6	**120.1**	2545.88	218.58	**93.33**	35	**0.37**	**84.33**
Hybrids							
H_1	16.89	8448.83	236.83	50.67	**12**	**0.08**	**115**
H_2	**14.07**	**2363.96**	231.54	63.67	14.67	0.16	120.33
H_3	36.4	4904.17	290.83	60	20	0.13	132
H_4	68.39	4529.58	186.33	55	22.33	0.14	129.33
H_5	48.48	5047.33	322	65.67	29.33	0.44	118.33
H_6	55.06	2523.96	353.88	**96**	43.67	0.37	124.67
H_7	28.96	4426.83	161.75	80	29	0.27	136.67
H_8	100.18	4199.25	210.67	55	23	0.22	139
H_9	39.56	4048.67	216.71	81.67	39.33	0.18	**145**
H_{10}	51.37	2988.21	233.21	77	38.67	0.21	129
H_{11}	55.96	4176.79	171.96	**45**	19.67	0.21	136.33
H_{12}	22.49	2576.96	249.42	70.33	32.67	**0.54**	118.33
H_{13}	65.28	2739.13	207.08	62.67	25.67	0.29	130.67
H_{14}	**119.93**	**8715.33**	**615.42**	65	27.33	0.1	134
H_{15}	53.67	3000.77	240.13	77	31.5	0.21	132
H_{16}	41.56	4853.92	226.67	85	**46**	0.18	129.67
H_{17}	87.27	4790.33	280.08	61.67	20.33	0.14	133
H_{18}	50.53	4520.75	**158.5**	88.33	30.33	0.13	128.33
SE±m	18.37	348.08	95.29	16.07	8.81	0.11	4.14

Table 13. Mean performance of parents and hybrids for yield and yield attributes at tillering and flowering (contd.).

Genotypes	Iron content in third leaf from tip (mg kg^{-1})	Manganese content in third leaf from tip (mg kg^{-1})	Iron content in youngest fully open mature leaf (mg kg^{-1})	Manganese content in youngest fully open mature leaf (mg kg^{-1})	Iron content in oldest leaf (mg kg^{-1})	Manganese content in oldest leaf (mg kg^{-1})	Visual scoring for iron toxicity
Lines							
L_1	**768.54**	1516.54	**737.88**	**1498.17**	**1000.17**	**1551.96**	5
L_2	**723.71**	**1528.46**	467.83	1364.92	837.21	1526.79	2
L_3	727.46	**1450.08**	**373.13**	**1286.33**	**542.25**	**1482.71**	2.33
Testers							
T_1	762.92	1539.67	**821.67**	**1543.08**	877.04	1558.25	3.33
T_2	**1091.33**	1550.04	806.29	1502.63	877.79	**1532.63**	3
T_3	790	**1555.5**	**673.33**	1526.08	**768.25**	1548	3
T_4	**622.88**	**1535.67**	743.83	1539.71	876.42	**1628.04**	3.33
T_5	810.88	1536.83	687.42	**1500.79**	**1067.46**	1536.46	7
T_6	870	1547.92	800.96	1523.67	897.75	1550.04	6.67
Hybrids							
H_1	403.96	1529.17	**498.96**	1477.54	649.33	1525.79	**7.33**
H_2	391.75	1535	250.08	1514.17	518.63	1556.96	7
H_3	398.38	1541.17	213.13	1544.13	801.63	1557.13	5.33
H_4	631.96	1530.92	217.38	1470.63	850.88	1546.17	5.33
H_5	522.13	**1566.31**	326.56	1556.56	741.54	1545.44	7
H_6	357.96	1563.13	320.79	1519.92	917.33	1571.54	5.33
H_7	**1482.08**	1515.31	276.33	1278.79	563.38	1555.75	3
H_8	407.06	1554.69	344.06	**1811.75**	665.73	**1577.38**	2.33
H_9	289.06	1458.13	212.19	1381.88	849.75	1539.81	2
H_{10}	412.42	1545.21	179.88	1394.83	**938.38**	1547.08	3
H_{11}	341.96	1564.13	326.5	1403.46	520.29	1531.79	5
H_{12}	249.88	1564.25	143.88	1384.46	551	1561.54	5.33
H_{13}	301.21	1534.54	205.92	1354.88	**236.63**	1497.13	2.33
H_{14}	249.08	1463.58	**44.75**	1277	564.75	1522	2
H_{15}	261.42	**1435.04**	50.67	**1216.33**	573.08	1505.88	2
H_{16}	**198.96**	1482.58	198.58	1351.29	555.63	1523.17	3
H_{17}	458.92	1445.63	66.46	1338.04	403.75	**1370.67**	5
H_{18}	375	1466.31	356.44	1408.94	749.23	1536.06	5
SE±m	103.95	31.81	38.32	82.18	27.27	49.86	0.34

4.1.2.1 Iron adsorbed on root surface (mg kg^{-1})

Among all lines, testers and hybrids, this trait varied from 6.37 mg kg^{-1} (T_4) to 120.10 mg kg^{-1} (T_6) with a grand mean of 54.42 mg kg^{-1}. In the parental lines, the mean value for this trait ranged from 82.45 mg kg^{-1} (L_1) to 118.61 mg kg^{-1} (L_3) whereas in testers it ranged from 6.37 mg kg-^{1} (T_4) to 120.10 mg kg-^{1} (T_6). Mean value of hybrids ranged between 14.07 mg kg^{-1} (H_2) and 119.93 mg kg^{-1} (H_{14}).

4.1.2.2 Iron content in root (mg kg^{-1})

Iron content in root varied between 2363.96 mg kg^{-1} (H_2) and 8715.33 mg kg^{-1} (H_{14}). A grand mean of 4405.30 mg $kg^{-1}$was estimated for this trait. Among lines, this attribute varied from 4066.50 mg kg^{-1} (L_1) to 7883.82 mg kg^{-1} (L_3). Among testers it varied from 2498.67 mg kg^{-1} (T_3) to 6757.88 mg kg^{-1} (T_5). In the hybrids it ranged between 2363.96 mg kg^{-1} (H_2) and 8715.33 mg kg^{-1} (H_{14}).

4.1.2.3 Manganese content in root (mg kg^{-1})

Manganese content in root ranged between 158.50 mg kg^{-1} (H_{18}) and 615.42 mg kg^{-1} (H_{14}) among all the genotypes. Grand mean estimated for this trait was 247.54 mg kg^{-1}. In the parental lines this trait varied from 175.88 mg kg^{-1} (L_3) to 322.92 mg kg^{-1} (L_2) while among the testers it was between 166.79 mg kg^{-1} (T_4) and 310.13 mg kg^{-1} (T_5). Among the hybrids it varied between 158.50 mg kg^{-1} (H_{18}) and 615.42 mg kg^{-1} (H_{14}).

4.1.2.4 Total number of roots

Range for this trait varied between 45.00 (H_{11}) and 96.00 (H_6) among all the genotypes. It registered a grand mean of 69.21. Among the lines this trait varied from 49.67 (L_3) to 83.33 (L_2) and among the testers it varied from 57.00 (T_5) to 93.33 (T_6). Among the hybrids the range was between 45.00 (H_{11}) and 96.00 (H_6).

4.1.2.5 Number of fresh roots

Overall range for this trait was between 12.00 (H_1) and 61.67 (L_2). A grand mean of 31.66 was registered for this trait. Among the parental lines this trait varied between 34.33 (L_3) and 61.67 (L_2) where as in the testers it was between 20.67 (T_5) and 46.67 (T_1). In the hybrids this trait ranged between 12.00 (H_1) to 46.00 (H_{16}).

4.1.2.6 Dry weight of roots (g)

Dry weight of roots ranged between 0.08 g (H_1) and 0.54 g (H_{12}) among all the genotypes. Grand mean estimated was 0.21 g. In the lines this trait varied between 0.11 g (L_3) and 0.15 g (L_2) while in the testers it varied from 0.17 g (T_2, T_5) and 0.37 g (T_6). Among the hybrids the range was between 0.08 g (H_1) and 0.54 g (H_{12}).

4.1.2.7 Days to fifty per cent flowering

Days to fifty per cent flowering ranged between 84.33 days (T_6) and 145.00 days (H_9). Grand mean of this trait was 120.65 days. In the parental lines the mean value for this trait ranged from 122.00 days (L_1) to 139.67 days (L_3) whereas in testers it ranged from 84.33 days (T_6) to 93.67 days (T_3). Mean value of hybrids ranged between 115.00 days (H_1) and 145.00 days (H_9).

4.1.2.8 Iron content in third leaf from tip (mg kg^{-1})

This trait ranged between 198.96 mg kg^{-1} (H_{16}) and 1482.08 mg kg^{-1} (H_7) among all the genotypes. Estimated grand mean for this trait was 551.88 mg kg^{-1}. Among lines this trait varied from 723.71 mg kg^{-1} to 768.54 mg kg^{-1} (L_1) while in the testers this was between 622.88 mg kg^{-1} (T_4) and 1091.33 mg kg^{-1} (T_2). Mean value among the hybrids ranged from 198.96 mg kg^{-1} (H_{16}) to 1482.08 mg kg^{-1} (H_7).

4.1.2.9 Manganese content in third leaf from tip (mg kg^{-1})

Estimates for this trait varied between 1435.04 mg kg^{-1} (H_{15}) and 1566.31 mg kg^{-1} (H_5). Grand mean estimated for this trait was 1520.58 mg kg^{-1}. In the lines it varied from 1450.08 mg kg^{-1} (L_3) to 1528.46 mg kg^{-1} (L_2) where as in the testers it ranged from 1535.67 mg kg^{-1} (T_4) to 1555.50 mg kg^{-1} (T_3). Among the hybrids the range was between 1435.04 mg kg^{-1} (H_{15}) and 1566.31 mg kg^{-1} (H_5).

4.1.2.10 Iron content in youngest fully open mature leaf (mg kg^{-1})

Overall range for this trait was between 44.75 mg kg^{-1} (H_{14}) to 821.67 mg kg^{-1} (T_1). A grand mean of 383.14 mg kg^{-1} was estimated for this trait. Among lines this attribute varied from 373.13 mg kg^{-1} (L_3) to 737.88 mg kg^{-1} (L_1). Among testers it varied from 673.33 mg kg^{-1} (T_3) to 821.67 mg kg^{-1} (T_1). In the hybrids it ranged between 44.75 mg kg^{-1} (H_{14}) and 498.96 mg kg^{-1} (H_1).

4.1.2.11 Manganese content in youngest fully open mature leaf (mg kg^{-1})

Manganese content in youngest fully open mature leaf ranged between 1216.33 mg kg^{-1} (H_{15}) and 1811.75 mg kg^{-1} (H_8) among all the genotypes. Grand mean estimated for this trait was 1443.33 mg kg^{-1}. In the parental lines this trait varied from 1286.33 mg kg^{-1} (L_3) to 1498.17 mg kg^{-1} (L_1) while among the testers it was between 1500.79 mg kg^{-1} (T_5) and 1543.08 mg kg^{-1} (T_1). Among the hybrids it varied between 1216.33 mg kg^{-1} (H_{15}) and 1811.75 mg kg^{-1} (H_8).

4.1.2.12 Iron content in oldest leaf (mg kg^{-1})

Iron content in oldest leaf ranged between 236.62 mg kg^{-1} (H_{13}) and 1067.46 mg kg^{-1} (T_5). A grand mean of 718.34 mg kg^{-1}was registered for this trait. Among the parental lines this trait varied between 542.25 mg kg^{-1} (L_3) and 1000.17 mg kg^{-1} (L_1) where as in the testers it was between 768.25 mg kg^{-1} (T_3) and 1067.46 mg kg^{-1} (T_5).

In the hybrids this trait ranged between 236.62 mg kg^{-1} (H_{13}) and 938.38 mg kg^{-1} (H_{10}).

4.1.2.13 Manganese content in oldest leaf (mg kg^{-1})

Among all lines, testers and hybrids, this trait varied from 1370.67 mg kg^{-1} (H_{17}) to 1628.04 mg kg^{-1} (T_4). It estimated a grand mean of 1536.52 mg kg^{-1}. In the parental lines the mean value for this trait ranged from 1482.71 mg kg^{-1} (L_3) to 1551.96 mg kg^{-1} (L_1) whereas in testers it ranged from 1532.63 mg kg-^{1} (T_2) to 1628.04 mg kg-^{1} (T_4). Mean value of hybrids ranged between 1370.67 mg kg^{-1} (H_{17}) and 1577.38 mg kg^{-1} (H_8).

4.1.2.14 Visual scoring for iron toxicity symptoms (mg kg^{-1})

Visual scoring for iron toxicity symptoms ranged from 2.00 (L_2, H_{14}, H_{15}, H_9) to 7.33 (H_1) among all the genotypes. Grand mean estimated was 4.19. In the lines this trait varied between 2.00 (L_2) and 5.00 (L_1) while in the testers it varied from 3.00 (T_2, T_3) and 7.00 (T_5). Among the hybrids the range was between 2.00 (H_{14}, H_{15}, H_9) and 7.33 (H_1).

4.1.3 Variability studies

Variability and genetic parameter estimates for the fourteen yield attributes studied at tillering and flowering are enlisted in Table 14. The results are detailed below.

4.1.3.1 Phenotypic and genotypic coefficient of variation

In general, the phenotypic coefficient of variation (PCV) was higher than the genotypic coefficient of variation (GCV) for all the yield attributes studied.

Table 14. Variability and genetic parameters for yield attributes influenced by iron toxicity at tillering and flowering

Traits	Range		Mean	SEm (±)	Coefficient of variation (%)		Heritability (Broad sense) (%)	Genetic advance	Genetic advance as % of mean
	Minimum	Maximum			PCV	GCV			
Iron adsorbed on root surface (mg kg^{-1})	6.37	120.10	54.42	18.37	72.48	59.53	67.47	54.82	100.74
Iron content in the root (mg kg^{-1})	2363.96	8715.33	4405.30	348.08	40.75	39.58	94.36	3489.21	79.20
Manganese content in the root (mg kg^{-1})	158.5	615.42	247.54	95.29	53.12	24.48	21.23	57.51	23.23
Total number of roots	45.00	96.00	69.21	16.07	30.25	10.34	11.68	5.04	7.28
Number of fresh roots	12.00	61.67	31.66	8.81	46.27	31.30	45.77	13.81	43.62
Dry weight of roots (g)	0.08	0.54	0.21	0.11	70.93	36.55	26.96	0.08	39.40
Days to 50% flowering	84.33	145.00	120.65	4.14	15.86	15.29	92.97	36.64	30.37
Iron content in 3rd leaf from tip (mg kg^{-1})	198.96	1482.08	551.88	103.95	57.11	52.25	83.69	543.40	98.46
Manganese content in 3rd leaf from tip (mg kg^{-1})	1435.04	1566.31	1520.58	31.81	3.41	2.26	43.51	46.52	3.06
Iron content in youngest fully open mature leaf (mg kg^{-1})	44.75	821.67	383.14	38.32	65.83	64.68	96.54	501.61	130.92
Manganese content in youngest fully open mature leaf (mg kg^{-1})	1216.33	1811.75	1443.33	82.18	10.23	7.48	53.48	162.60	11.27
Iron content in oldest leaf (mg kg^{-1})	236.62	1067.46	718.34	27.27	27.95	27.56	97.23	402.18	55.99
Manganese content in oldest leaf (mg kg^{-1})	1370.67	1628.04	1536.52	49.86	4.28	1.60	13.82	18.74	1.22
Visual scoring for iron toxicity symptoms	2.00	7.33	4.19	0.34	44.12	42.98	94.86	3.61	86.23

Phenotypic coefficient of variation ranged from 3.41 per cent to 72.48 per cent, corresponding to the traits manganese content in third leaf from tip and iron adsorbed on root surface. Manganese content in third leaf from tip (3.41 per cent) and oldest leaf (4.28 per cent) recorded low PCV, while days to fifty per cent flowering (15.86 per cent) and manganese content in youngest fully open mature leaf (10.23 per cent) registered moderate values of PCV. All other traits exhibited high PCV.

Genotypic coefficient of variation (GCV) ranged from 1.60 per cent (manganese content in oldest leaf) to 64.68 per cent (iron content in youngest fully open mature leaf). Low estimates of GCV were also observed in manganese content in third leaf from tip (2.26 per cent) and manganese content in youngest fully open mature leaf (7.48 per cent). Days to fifty per cent flowering (15.29 per cent) and total number of roots (10.34 per cent) exhibited moderate GCV, while all other traits registered high GCV estimates.

Difference between PCV and GCV estimated was the maximum for dry weight of roots (34.38 per cent) followed by manganese inside the root (28.64) and total number of roots (19.91). However, the difference between PCV and GCV was low in case of days to fifty per cent flowering (0.57 per cent), iron content in the oldest leaf (0.39 per cent), manganese content in third leaf from tip (1.15 per cent) and iron content in youngest fully opened mature leaf (1.15 per cent).

4.1.3.2 Heritability and genetic advance as per cent of mean

Heritability estimates ranged from 11.68 per cent (total number of roots) to 97.23 per cent (iron content in oldest leaf).Traits manganese content in root (21.23 per cent) and oldest leaf (13.82 per cent), total number of roots (11.68 per cent) and dry weight of roots (26.96 per cent) recorded low estimates of heritability, where as manganese content in third leaf from tip (43.51 per cent) and youngest fully opened mature leaf (53.48 per cent), and fresh number of roots (45.77 per cent) recorded moderate heritability while all other traits exhibited high heritability estimates.

Genetic advance as per cent of mean estimates varied between 1.22 per cent to 130.92 per cent for manganese content in oldest leaf and iron content in youngest fully open mature leaf respectively. Low estimates were also observed for manganese content in third leaf from tip (3.06 per cent) and total number of roots (7.28 per cent) where as moderate estimate was observed for manganese content in youngest fully open mature leaf (11.27 per cent). All other traits recorded high estimates of genetic advance as per cent of mean.

4.1.4 Correlation studies

The inter-relationship between grain yield/plant and yield attributes influenced by iron toxicity where studied by estimating the genotypic and phenotypic correlation coefficients. The results are detailed in Table 15.

4.1.4.1 Association of yield attributes with grain yield/plant (g)

Grain yield/plant recorded significant to high significant positive correlation at phenotypic level and genotypic level with days to fifty per cent flowering ($r_p = 0.476$, $r_g = 0.601$). Significant negative to high significant negative correlation at phenotypic and genotypic level was estimated for iron content in youngest fully open mature leaf (r_p= -0.416, r_g= -0.551), manganese content in youngest fully open mature leaf (r_p =-0.233, r_g = -0.389), iron content in oldest leaf (r_p = -0.274, r_g = -0.363) and visual scoring for iron toxicity symptoms (r_p= -0.260, r_g = -0.327).

A high significant positive correlation was recorded with total number of roots at genotypic level (r_g = 0.291), while it registered a significant to high significant

Table 15. Phenotypic (PCC) and genotypic (GCC) correlation coefficients among grain yield and yield attributes influenced by iron toxicity at tillering and flowering

Traits	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	Y
X_1	1.000	0.191	0.214	-0.090	0.091	-0.181	0.325**	-0.070	-0.120	-0.134	-0.091	-0.142	-0.082	-0.220*	0.103
X_2	0.205	1.000	0.277*	-0.311**	-0.227*	-0.371**	0.157	0.011	-0.280*	-0.055	-0.165	-0.060	-0.157	0.041	-0.099
X_3	0.540**	0.566**	1.000	-0.130	-0.032	0.170	0.088	-0.166	-0.058	-0.175	-0.113	0.038	0.019	-0.015	0.029
X_4	0.270*	-0.847**	0.684**	1.000	0.664**	0.238*	-0.050	0.044	-0.121	0.014	-0.110	0.192	0.096	-0.074	0.110
X_5	0.405**	-0.321**	0.293**	0.657**	1.000	0.134	-0.018	0.115	-0.088	0.187	-0.091	0.317**	0.153	-0.357**	0.070
X_6	0.027	-0.718**	-0.457**	0.574**	0.118	1.000	-0.104	0.023	0.240*	-0.029	0.050	-0.021	0.063	0.144	-0.136
X_7	0.399*	0.163	0.170	-0.136	-0.049	-0.243*	1.000	-0.359**	-0.318**	-0.781**	-0.350**	-0.466**	-0.210	-0.297**	0.476**
X_8	-0.094	0.004	-0.454**	0.154	0.214	-0.075	-0.462**	1.000	0.195	0.568**	0.020	0.314**	0.080	-0.011	-0.210
X_9	-0.518**	-0.451**	-0.221*	-0.073	-0.001	0.850**	-0.562**	0.213	1.000	0.334**	0.494**	0.226*	0.565**	0.288**	-0.164
X_{10}	-0.183	-0.068	-0.396**	0.108	0.342**	-0.052	-0.836**	0.616**	0.496**	1.000	0.386**	0.601**	0.250*	0.173	-0.416**
X_{11}	-0.174	-0.221*	-0.175	-0.294**	-0.174	0.239*	-0.446**	0.120	0.833**	0.580**	1.000	0.349**	0.330**	0.263*	-0.233*
X_{12}	-0.149	-0.059	0.046	0.557**	0.463**	-0.065	-0.496**	0.354**	0.395**	0.616**	0.513**	1.000	0.318**	0.199	-0.274*
X_{13}	-0.884**	-0.450**	-0.520**	0.456**	0.100	0.824**	-0.623**	0.238*	0.693**	0.689**	0.952**	0.925**	1.000	0.020	-0.170
X_{14}	-0.281*	0.036	0.011	-0.279*	-0.502**	0.323**	-0.319**	-0.008	0.488**	0.180	0.415**	0.197	0.161	1.000	-0.260*
Y	0.174	-0.073	0.144	0.291**	0.104	-0.273*	0.601**	-0.213	-0.326**	-0.551**	-0.389**	-0.363**	-0.474**	-0.327**	1.000

* significant at 5% level ; **significant at 1 % level

PCC: Above diagonal; GCC : Below diagonal

X_1- Iron adsorbed on root surface (mg kg^{-1})
X_2- Iron content in root (mg kg^{-1})
X_3- Manganese content in root (mg kg^{-1})
X_4-Total number of roots
X_5-Number of fresh roots
X_6-Dry weight of roots (g)
X_7-Days to fifty percent flowering
X_8-Iron content in 3rd leaf from tip (mg kg^{-1})
X_9-Manganese content in 3rd leaf from tip (mg kg^{-1})
X_{10}- Iron content in youngest fully open mature leaf (mg kg^{-1})
X_{11}-Manganese content in youngest fully open mature leaf (mg kg^{-1})
X_{12}-Iron content in oldest leaf (mg kg^{-1})
X_{13}-Manganese content in oldest leaf (mg kg-^{1})
X_{14}- Visual scoring for iron toxicity symptoms
Y- Grain yield/plant(g)

negative correlation at genotypic level with dry weight of roots (r_g = -0.273), manganese content in third leaf from tip (r_g = -0.326) and oldest leaf (r_g= -0.474).

4.1.4.2 Inter-correlation among yield attributes

4.1.4.2.1 Iron adsorbed on root surface (mg kg^{-1})

Iron adsorbed on root surface exhibited high significant positive correlation at phenotypic and genotypic level with days to fifty per cent flowering (r_p = 0.325, r_g = 0.399) while significant to high significant negative correlation was recorded with visual scoring for iron toxicity symptoms at phenotypic and genotypic level (r_p = -0.220, r_g = -0.281). Significant to high significant positive genotypic correlation was recorded with manganese content in root (r_g = 0.540), total number of roots (r_g = 0.270) and number of fresh roots (r_g = 0.405). Manganese content in third leaf from tip (r_g = -0.518) and oldest leaf (r_g= -0.884) registered a negative high significant correlation at genotypic level.

4.1.4.2.2 Iron content in roots (mg kg^{-1})

Iron content in the root registered significant to high significant positive correlation at phenotypic and genotypic level with manganese content in root (r_p = 0.227, r_g = 0.566), while significant to high significant negative correlation at phenotypic and genotypic level was recorded by total number of roots (r_p = -0.311, r_g = -0.847), number of fresh roots (r_p = -0.227 ,r_g = -0.321), dry weight of roots (r_p= -0.371 and r_g= -0.718), manganese content in third leaf from tip (r_p = -0.280, r_g = -0.451). At genotypic level, this trait exhibited significant to high significant negative correlation with manganese content in youngest fully open mature leaf (r_g= -0.221) and oldest leaf (r_g = -0.450).

4.1.4.2.3 Manganese content in roots (mg kg^{-1})

No significant correlation was exhibited by any of the traits at phenotypic level. At genotypic level, positive high significant correlation was recorded through total number of roots (r_g = 0.684) and number of fresh roots (r_g = 0.293), while negative significant to high significant correlation was estimated with dry weight of roots (r_g = -0.457), iron content in third leaf from tip (r_g = -0.454) and youngest fully open mature leaf (r_g = -0.396), manganese content in third leaf from tip (r_g = -0.221) and oldest leaf (r_g = -0.520).

4.1.4.2.4 Total number of roots

Total number of roots exhibited significant to high significant positive correlation at both phenotypic and genotypic level with number of fresh roots (r_p = 0.664, r_g = 0.657) and dry weight of roots (r_p = 0.238, r_g = 0.574). Positive, significant to high significant correlation at genotypic level was estimated with iron (r_g = 0.557) and manganese (r_g = 0.456) content in the oldest leaf, while negative significant to high significant genotypic correlation was recorded with manganese content in youngest fully open mature leaf (r_g = -0.294) and visual scoring for iron toxicity symptoms (r_g = -0.279).

4.1.4.2.5 Number of fresh roots

Number of fresh roots registered high significant positive correlation at phenotypic and genotypic level with iron content in oldest leaf (r_p = 0.317, r_g = 0.463), while high significant negative correlation at both level was registered with visual scoring for iron toxicity symptoms (r_p = -0.357, r_g = -0.502). A high significant positive correlation at genotypic level was estimated with iron content in youngest fully open mature leaf (r_g = 0.342) while no significant correlation was noticed for this trait at phenotypic level.

4.1.4.2.6 Dry weight of roots (g)

This trait recorded a significant to high significant positive correlation at phenotypic level and genotypic level with manganese content in third leaf from tip ($r_p = 0.240$, $r_g = 0.850$). This trait also registered significant to high significant positive correlation at genotypic level with manganese content in youngest fully open mature leaf ($r_g = 0.239$) and oldest leaf ($r_g = 0.824$) and also with visual scoring for iron toxicity symptoms ($r_g = 0.323$). Significant negative genotypic correlation was registered by days to fifty per cent flowering ($r_g = -0.243$).

4.1.4.2.7 Days to fifty per cent flowering

Days to fifty per cent flowering showed high significant negative correlation at phenotypic and genotypic level with iron content in third leaf from tip ($r_p = -0.359$, $r_g = -0.462$), youngest fully open mature leaf ($r_p = -0.781$, $r_g = -0.836$) and oldest leaf ($r_p = -0.466$, $r_g = -0.496$), manganese content in third leaf from tip ($r_p = -0.318$, $r_g = -0.562$) and youngest fully open mature leaf ($r_p = -0.350$, $r_g = -0.446$) and visual scoring for iron toxicity symptoms ($r_p = -0.297$, $r_g = -0.319$). Besides this, it also exhibited high significant negative correlation at genotypic level with manganese content in the oldest leaf ($r_g = -0.623$).

4.1.4.2.8 Iron content in third leaf from tip (mg kg^{-1})

Iron content in third leaf from tip exhibited high significant positive phenotypic and genotypic correlation with iron content in youngest fully open mature leaf ($r_p = 0.568$, $r_g = 0.616$) and oldest leaf ($r_p = 0.314$, $r_g = 0.354$). Manganese content in oldest leaf ($r_g = 0.238$) registered significant positive genotypic correlation with this trait.

4.1.4.2.9 Manganese content in third leaf from tip (mg kg^{-1})

Manganese content in the third leaf from tip showed significant to high significant positive correlation at phenotypic and genotypic level with iron content in youngest fully open mature leaf ($r_p = 0.334$, $r_g = 0.496$) and oldest leaf ($r_p = 0.226$, $r_g = 0.395$), manganese content in youngest fully open mature leaf ($r_p = 0.494$, $r_g = 0.833$) and oldest leaf ($r_p = 0.565$, $r_g = 0.693$) and visual scoring for iron toxicity symptoms ($r_p = 0.288$, $r_g = 0.488$).

4.1.4.2.10 Iron content in youngest fully open mature leaf (mg kg^{-1})

Iron content in the youngest fully open mature leaf recorded significant to high significant positive phenotypic and genotypic correlation with manganese content in youngest fully open mature leaf ($r_p = 0.386$, $r_g = 0.580$), and iron ($r_p = 0.601$, $r_g = 0.616$) and manganese ($r_p = 0.250$, $r_g = 0.689$) content in oldest leaf.

4.1.4.2.11 Manganese content in youngest fully open mature leaf (mg kg^{-1})

Manganese content in youngest fully open mature leaf showed significant to high significant positive correlation respectively at phenotypic and genotypic level with iron ($r_p = 0.349$, $r_g = 0.513$) and manganese content in oldest leaf ($r_p = 0.330$, $r_g = 0.952$) and visual scoring for iron toxicity symptoms ($r_p = 0.263$, $r_g = 0.415$).

4.1.4.2.12 Iron content in oldest leaf (mg kg^{-1})

Iron content in oldest leaf registered high significant positive phenotypic and genotypic correlation with manganese content in oldest leaf ($r_p = 0.318$, $r_g = 0.925$).

4.1.4.2.13 Manganese content in oldest leaf (mg kg^{-1})

No significant correlation was recorded with any other traits at genotypic and phenotypic level by manganese content in oldest leaf.

4.1.5. Path coefficient analysis

The genotypic correlation coefficients of grain yield/plant with yield attributes influenced by iron toxicity at tillering and flowering was further partitioned into direct and indirect effects. The result obtained is given in Table 16. The residual value of path coefficient analysis was 0.39.

4.1.5.1. Direct effects

The positive direct effect on grain yield/plant ranged from 0.076 (visual scoring for iron toxicity symptoms) to 0.998 (days to fifty per cent flowering). Other attributes that registered high positive direct effect on grain yield/plant included manganese content in root (0.557), iron content in third leaf from tip (0.362) and in youngest fully open mature leaf (0.404). Moderate positive direct effect was registered by total number of roots (0.229) while manganese content in youngest fully open mature leaf registered a low positive direct effect (0.172). Negligible positive direct effects were registered through number of fresh roots (0.099) and manganese content in oldest leaf (0.086) and visual scoring for iron toxicity symptoms (0.076).

The negative direct effect on grain yield/plant ranged between -0.096 (Manganese content in third leaf from tip) to -0.693 (iron content in oldest leaf). Attributes that registered high negative direct effect also include iron adsorbed on root surface (-0.465) and iron content in root (-0.362). The trait, dry weight of roots (-0.206) registered a moderate negative indirect effect.

4.1.5.2 Indirect effects

4.1.5.2.1 Iron adsorbed on root surface (mg kg^{-1})

Positive indirect effect exerted by iron adsorbed on roots ranged from 0.040 (number of fresh roots) to 0.398 (days to fifty per cent flowering). High positive

Table 16. Direct (Diagonal) and indirect effects of yield attributes influenced by iron toxicity at tillering and flowering on grain yield

Traits	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}
X_1	**-0.465**	-0.074	0.301	0.062	0.040	-0.005	0.398	-0.034	0.050	-0.074	-0.030	0.103	-0.076	-0.021
X_2	-0.095	**-0.362**	0.315	-0.194	-0.032	0.149	0.162	0.002	0.043	-0.027	-0.038	0.041	-0.039	0.003
X_3	-0.251	-0.205	**0.557**	0.157	0.029	0.097	0.170	-0.165	0.021	-0.160	-0.030	-0.032	-0.045	0.001
X_4	-0.125	0.306	0.381	**0.229**	0.065	-0.117	-0.136	0.056	0.007	0.044	-0.051	-0.386	0.039	-0.021
X_5	-0.188	0.116	0.163	0.151	**0.099**	-0.024	-0.048	0.078	0.000	0.138	-0.030	-0.321	0.009	-0.038
X_6	-0.012	0.262	-0.261	0.131	0.011	**-0.206**	-0.248	-0.028	-0.082	-0.021	0.042	0.045	0.071	0.024
X_7	-0.186	-0.059	0.095	-0.031	-0.005	0.051	**0.998**	-0.167	0.054	-0.338	-0.077	0.343	-0.053	-0.024
X_8	0.044	-0.002	-0.253	0.035	0.021	0.016	-0.461	**0.362**	-0.020	0.249	0.021	-0.245	0.020	-0.001
X_9	0.240	0.163	-0.122	-0.017	0.000	-0.176	-0.560	0.077	**-0.096**	0.200	0.143	-0.273	0.060	0.037
X_{10}	0.085	0.024	-0.220	0.025	0.034	0.011	-0.835	0.223	-0.048	**0.404**	0.100	-0.427	0.059	0.014
X_{11}	0.081	0.080	-0.098	-0.068	-0.017	-0.050	-0.445	0.043	-0.080	0.234	**0.172**	-0.355	0.082	0.031
X_{12}	0.069	0.021	0.026	0.128	0.046	0.013	-0.495	0.128	-0.038	0.249	0.088	**-0.693**	0.079	0.015
X_{13}	0.410	0.162	-0.289	0.105	0.010	-0.170	-0.620	0.086	-0.067	0.278	0.163	-0.639	**0.086**	0.012
X_{14}	0.131	-0.013	0.006	-0.064	-0.050	-0.067	-0.318	-0.003	-0.047	0.073	0.071	-0.136	0.014	**0.076**

Residual value = 0.39

X_1- Iron adsorbed on root surface (mg kg^{-1})
X_2- Iron content in root (mg kg^{-1})
X_3- Manganese content in root (mg kg^{-1})
X_4-Total number of roots
X_5-Number of fresh roots
X_6-Dry weight of roots (g)
X_7-Days to fifty percent flowering
X_8-Iron content in 3rd leaf from tip (mg kg^{-1})
X_9-Manganese content in 3rd leaf from tip (mg kg^{-1})
X_{10}- Iron content in youngest fully open mature leaf (mg kg^{-1})
X_{11}-Manganese content in youngest fully open mature leaf (mg kg^{-1})
X_{12}-Iron content in oldest leaf (mg kg^{-1})
X_{13}-Manganese content in oldest leaf (mg kg-^{1})
X_{14}- Visual scoring for iron toxicity symptoms

indirect effects were also registered through manganese content in root (0.301). Other attributes which registered positive indirect effects include total number of roots, manganese content in third leaf from tip and iron content in oldest leaf.

Negative indirect effect ranged from -0.005 (dry weight of roots) to -0.076 (manganese content in oldest leaf). Negative indirect effect were also recorded through iron content in root and youngest fully open mature leaf, iron content in third leaf from tip, manganese content in youngest fully open mature leaf and visual scoring for iron toxicity symptoms.

4.1.5.2.2 Iron content in root (mg kg^{-1})

Iron content in root varied from 0.002 (iron content in third leaf from tip) to 0.315 (manganese content in root). Positive indirect effect was also registered through dry weight of roots, days to fifty per cent flowering, manganese content in third leaf from tip, iron content in oldest leaf and visual scoring for iron toxicity symptoms.

Negative indirect effect for this trait varied from -0.027 (iron content in youngest fully open mature leaf) to -0.194 (total number of roots). Other traits through which negative indirect effect were exerted include iron adsorbed on root surface, number of fresh roots, manganese content in youngest fully open mature leaf and oldest leaf.

4.1.5.2.3 Manganese content in root (mg kg^{-1})

Range for positive indirect effect by this trait was from 0.001 (visual scoring for iron toxicity symptoms) to 0.170 (days to fifty per cent flowering). Other traits which recorded positive indirect effect included, total number of roots, number of fresh roots, dry weight of roots, manganese content in third leaf from tip.

Negative indirect effect by this trait varied from -0.030 (manganese content in youngest fully open mature leaf) to -0.251 (iron adsorbed on root surface). Negative indirect effect were also registered by iron content in the root, iron content in third leaf from tip and youngest fully open mature leaf, iron content in oldest leaf and manganese content in oldest leaf .

4.1.5.2.4 Total number of roots

Range for positive indirect effect of this trait was from 0.007 (manganese content in third leaf from tip) to 0.381 (manganese content in roots). High positive indirect effects were registered by manganese content in root and iron content in the root (0.306). Other attributes which registered positive indirect effect include number of fresh roots, iron content in third leaf from tip, iron content in youngest fully open mature leaf and manganese content in oldest leaf.

Negative indirect effect ranged from -0.021 (visual scoring for iron toxicity tolerance) to -0.386 (iron content in oldest leaf). Iron content in oldest leaf registered a high negative indirect effect. Other traits which registered negative indirect effect include iron adsorbed on root surface, dry weight of root, days to fifty per cent flowering and manganese content in youngest fully open mature leaf.

4.1.5.2.5 Number of fresh roots

Number of fresh roots varied from 0.000 (manganese content in third leaf from tip) to 0.163 (manganese content in roots) in the positive indirect effects. Other attributes which registered positive indirect effects were iron content in root, total number of roots, iron content in the third leaf from tip and youngest fully open mature leaf and manganese content in oldest leaf.

Negative indirect effect for this trait ranged from -0.024 (dry weight of roots) to -0.321 (iron content in oldest leaf). Iron content in oldest leaf registered high indirect effect in the negative direction. Traits, iron adsorbed on root surface, days to fifty per cent flowering, manganese content in youngest leaf from tip, and visual scoring for iron toxicity symptoms also registered negative indirect effects.

4.1.5.2.6 Dry weight of roots (g)

Dry weight of roots ranged from 0.011 (number of fresh roots) to 0.262 (iron content in the root) for positive indirect effects. Attributes that registered positive indirect effect also include, total number of roots, manganese content in youngest fully open mature leaf, iron content in oldest leaf, manganese content in oldest leaf and visual scoring for iron toxicity symptoms.

Negative indirect effect by this trait varied from -0.012 (iron adsorbed on root surface) to -0.261 (manganese content in roots). Other traits which recorded negative indirect effect include days to fifty per cent flowering, iron content in third leaf from tip, manganese content in third leaf from tip and iron content in youngest fully open mature leaf.

4.1.5.2.7 Days to fifty per cent flowering

Positive indirect effect of days to fifty per cent flowering varied from 0.051 (dry weight of roots) to 0.343 (iron content in oldest leaf). Iron content in oldest leaf registered high positive indirect effect. Other traits which recorded positive indirect effect were manganese content in root and manganese content in third leaf from tip.

Negative indirect effect for this trait varied from -0.005 (number of fresh roots) to -0.338 (iron content in youngest fully open mature leaf). Traits which registered negative indirect effect also include iron adsorbed on root surface, iron content in the roots, total number of roots, iron content in third leaf from tip, manganese content in youngest fully open mature leaf and oldest leaf and visual scoring for iron toxicity symptoms.

4.1.5.2.8 Iron content in third leaf from tip (mg kg^{-1})

Positive indirect effect by iron content in third leaf varied from 0.016 (dry weight of roots) to 0.249 (iron content in youngest fully open mature leaf). Traits, iron adsorbed on root surface, total number of roots, number of fresh roots, manganese content in youngest fully open mature leaf and manganese content in oldest leaf also registered positive indirect effects.

Negative indirect effect for this trait ranged from -0.001 (visual scoring for iron toxicity symptoms) to -0.461 (days to fifty per cent flowering). Days to fifty per cent flowering registered high negative indirect effect on grain yield/plant through this trait. Other attributes which exhibited negative indirect effect were iron content in root, manganese content in root, manganese content in third leaf from tip and iron content in oldest leaf.

4.1.5.2.9. Manganese content in third leaf from tip (mg kg^{-1})

Manganese content in third leaf from tip varied from 0.000 (number of fresh roots) to 0.240 (iron adsorbed on root surface) for positive indirect effect. Traits, iron content in the root, iron content in third leaf from tip and youngest fully open mature leaf, manganese content in youngest fully open mature leaf and oldest leaf and visual scoring for iron toxicity symptoms, also registered positive indirect effect.

Negative indirect effect of manganese content in third leaf from tip ranged from -0.017 (total number of roots) to -0.560 (days to fifty per cent flowering). Other traits which recorded negative indirect effects were manganese content in root, dry weight of roots and iron content in oldest leaf.

4.1.5.2.10 Iron content in youngest fully open mature leaf (mg kg^{-1})

Positive indirect effect for iron content in youngest fully open mature leaf ranged between 0.011 (dry weight of roots) to 0.223 (iron content in third leaf from tip). Positive indirect effect were also registered by iron adsorbed on root surface, iron content in root, total number of roots, number of fresh roots, manganese content in youngest fully open mature leaf and oldest leaf and visual scoring for iron toxicity symptoms.

Negative indirect effect for this trait varied from -0.048 (manganese content in third leaf from tip) to -0.835 (days to fifty per cent flowering). Days to fifty per cent flowering and iron content in oldest leaf (0.427) registered high indirect effect in the negative direction. Negative indirect effect was also exerted through manganese content in root.

4.1.5.2.11. Manganese content in youngest fully open mature leaf (mg kg^{-1})

Manganese content in youngest fully open mature leaf varied between 0.031 (visual scoring for iron toxicity tolerance) to 0.234 (iron content in youngest fully open mature leaf) in positive indirect effect. Other characters which exhibited positive indirect effects were iron adsorbed on root surface, iron content in root, iron content in the third leaf from tip and manganese content in oldest leaf.

Negative indirect effect for this trait ranged from -0.017 (number of fresh roots) to -0.445 (days to fifty per cent flowering). Traits, days to fifty per cent flowering and iron content in oldest leaf (-0.355) recorded high indirect effect in the negative direction. Other traits which recorded negative indirect effect were manganese content in the root, total number of roots, dry weight of roots and manganese content in third leaf from tip.

4.1.5.2.12 Iron content in oldest leaf (mg kg^{-1})

Positive indirect effect for this trait ranged from 0.013 (dry weight of roots) to 0.249 (iron content in youngest fully open mature leaf). Positive indirect effect were also registered by iron adsorbed on root surface, iron content in root, manganese content in root, total number of roots, number of fresh roots, iron content in third leaf from tip, manganese content in youngest fully open mature leaf and oldest leaf and visual scoring for iron toxicity symptoms.

Negative indirect effect for iron content in oldest leaf ranged from -0.038 (manganese content in third leaf from tip) to -0.495 (days to fifty per cent flowering). Days to fifty per cent flowering exhibited a high negative indirect effect through this trait. No other traits registered negative indirect effect through this trait.

4.1.5.2.13 Manganese content in oldest leaf (mg kg^{-1})

Positive indirect effect of manganese content in oldest leaf ranged from 0.010 (number of fresh roots) to 0.410 (iron adsorbed on root surface). Iron adsorbed on roots surface registered high positive indirect effect. Other attributes which recorded positive indirect effect were iron content in root, total number of roots, iron content in third leaf from tip and youngest fully open mature leaf, manganese content in youngest fully open mature leaf and visual scoring for iron toxicity symptoms.

Negative indirect effect for this trait ranged between -0.067 (manganese content in third leaf) to -0.639 (iron content in oldest leaf). Besides, iron content in oldest leaf, days to fifty per cent flowering (-0.620) also registered high negative indirect effect. Other traits which recorded negative indirect effect were manganese content in root and dry weight of roots.

4.1.5.2.14 Visual scoring for iron toxicity symptoms

Positive indirect effects for the trait visual scoring for iron toxicity symptoms ranged from 0.006 (manganese content in root) to 0.131 (iron adsorbed on root surface). Positive indirect effect were also registered through iron content in youngest fully open mature leaf, manganese content in youngest fully open mature leaf and manganese content in oldest leaf.

Negative indirect effect for this trait ranged from -0.003 (iron content in third leaf from tip) to -0.318 (days to fifty per cent flowering). Other traits which registered negative indirect effects were iron content in root, total number of roots, number of fresh roots, dry weight of roots and manganese content in third leaf from tip and iron content in oldest leaf.

4.2. Variability and trait association at maturity

4.2.1 Analysis of variance

The analysis of variance (Table17) revealed the presence of high significant differences among the genotypes for yield and yield attributes at maturity. However, significant difference was absent for total tillers/plant and productive tillers/plant.

4.2.2 Mean performance of parents and hybrids at maturity.

Mean performance of parents and hybrids of the traits at maturity is detailed in Table 18 and described below

4.2.2.1 Plant height (cm)

Estimates for this trait ranged between 43.77 cm (T_2) and 115.67 cm (H_{14}). Grand mean estimated was 81.93 cm. Among lines, plant height ranged between 68.43

Table 17. Analysis of variance for yield and yield attributes at maturity-I

Source	df	Mean sum of squares						
		Plant height (cm)	Culm length (cm)	Total tillers/plant	Productive tillers/plant	Panicle length (cm)	Spikelets/ panicle	Grains/panicle
Replication	2	1587.13	1164.91	1.89	0.21	5.90	5.63	210.84
Treatment	26	1418.91**	869.35**	8.97	7.99	12.83**	854.50**	1229.45**
Error	52	138.94	79.77	5.45	5.18	0.38	10.07	49.52

*significant at 5%; **significant at 1%

Table 17. Analysis of variance for yield and yield attributes at maturity-II (contd.).

Source	df	Mean sum of squares						
		Seed set (%)	1000 grain weight (g)	Root length (cm)	Shoot weight (g)	Root weight (g)	Visual scoring for iron toxicity symptoms	Grain yield/ plant (g)
Replication	2	257.83	0.90	1.54	260.62	36.87	0.23	11.06
Treatment	26	332.15**	26.50**	32.09**	45.87**	4.07**	8.67**	80.64**
Error	52	62.33	4.99	6.76	4.73	0.75	0.13	12.18

*significant at 5%; **significant at 1%

Table 18. Mean performance of parents and hybrids for yield and yield attributes at maturity

Genotypes	Plant height (cm)	Culm length (cm)	Total tillers/ plant	Productive tillers/ plant	Panicle length (cm)	Spikelets/ panicle	Grains/ Panicle
Lines							
L_1	**68.43**	**51.63**	9.57	8.53	**15.10**	102.00	**68.20**
L_2	**94.43**	**67.47**	**12.47**	**11.80**	17.48	**101.67**	78.85
L_3	80.87	62.30	**7.53**	**6.33**	**17.63**	**104.77**	**89.62**
Testers							
T_1	**86.90**	**72.03**	**9.63**	**8.40**	**16.53**	**98.15**	**52.98**
T_2	**43.77**	**32.63**	9.87	8.53	14.03	75.32	45.85
T_3	53.30	40.13	10.50	8.80	**13.77**	73.32	44.58
T_4	50.87	36.63	10.27	9.23	13.85	82.65	43.18
T_5	52.63	39.10	**10.90**	**9.83**	14.07	77.32	**38.00**
T_6	51.20	38.67	10.87	9.53	14.70	**61.65**	39.67
Hybrids							
H_1	**56.20**	**43.30**	9.30	7.70	15.92	118.30	76.42
H_2	71.43	55.57	11.93	10.60	16.73	120.17	84.02
H_3	69.13	53.87	8.63	7.13	15.10	95.37	62.98
H_4	67.33	49.17	8.07	6.73	15.28	96.80	65.67
H_5	73.00	56.87	10.67	9.40	**13.47**	**77.45**	**51.27**
H_6	73.90	54.23	11.07	10.20	15.65	102.43	73.25
H_7	108.17	80.00	13.20	**11.57**	**19.98**	109.95	80.75
H_8	108.77	75.57	11.53	10.20	18.90	100.02	74.82
H_9	109.20	75.40	7.37	6.63	19.43	114.37	92.23
H_{10}	110.47	81.67	**13.47**	11.37	18.08	110.72	96.52
H_{11}	106.37	80.97	10.97	9.27	19.32	114.63	93.43
H_{12}	100.77	79.70	**6.80**	**5.77**	19.05	116.33	96.30
H_{13}	88.90	72.60	10.77	8.20	17.43	111.77	85.55
H_{14}	**115.67**	**94.33**	10.00	8.00	18.53	106.88	90.65
H_{15}	93.60	75.20	9.67	9.03	18.82	119.88	96.40
H_{16}	93.57	74.37	12.40	10.57	18.25	**124.00**	**100.18**
H_{17}	95.53	76.10	11.37	10.00	19.33	121.75	99.62
H_{18}	87.77	72.77	8.33	7.17	17.65	102.16	72.70
SEm(±)	9.62	7.29	1.91	1.86	0.50	2.59	5.75

Table 18. Mean performance of parents and hybrids for yield and yield attributes at maturity (contd.).

Genotypes	Seed set (%)	1000 grain weight (g)	Root length (cm)	Shoot weight (g)	Root weight (g)	Visual scoring for iron toxicity symptoms	Grain Yield/ plant (g)
Lines							
L_1	**67.07**	**19.80**	13.13	**9.63**	**3.32**	**5.33**	11.75
L_2	77.72	17.00	**18.83**	12.42	**4.62**	**3.00**	**15.68**
L_3	**85.69**	**15.20**	**11.93**	**13.32**	4.20	**3.00**	**8.58**
Testers							
T_1	53.99	**16.50**	**12.25**	**7.89**	**2.70**	5.00	7.58
T_2	60.92	18.40	**5.32**	5.79	2.02	3.33	7.15
T_3	60.73	16.50	7.13	4.87	1.72	**7.33**	6.62
T_4	52.36	**20.75**	7.54	5.06	2.18	7.00	**8.12**
T_5	**49.13**	17.08	7.62	**4.65**	**1.46**	**7.33**	**6.13**
T_6	**64.63**	17.75	5.44	5.00	1.70	**7.33**	6.21
Hybrids							
H_1	**64.70**	19.00	**7.56**	**6.98**	2.17	**7.33**	11.16
H_2	70.05	19.67	11.29	7.77	2.36	7.00	17.30
H_3	66.04	15.00	9.77	7.10	**1.98**	5.33	6.53
H_4	67.82	13.00	11.44	8.04	2.48	5.00	5.81
H_5	66.12	**8.00**	13.43	7.46	2.91	7.00	**4.15**
H_6	71.61	18.50	15.63	9.24	3.79	5.00	13.90
H_7	73.47	20.00	**16.27**	14.32	4.55	3.00	18.68
H_8	75.09	21.00	15.35	14.88	3.83	3.33	15.96
H_9	80.65	20.50	12.42	15.04	4.48	3.33	12.62
H_{10}	**87.21**	**22.00**	11.25	15.12	4.87	5.33	**24.16**
H_{11}	81.55	19.25	10.86	13.25	3.63	5.33	16.58
H_{12}	82.77	15.50	8.45	15.70	4.18	5.00	8.56
H_{13}	76.65	15.60	13.15	11.46	3.66	**2.00**	10.72
H_{14}	84.80	20.00	10.42	**16.67**	**5.65**	3.00	14.59
H_{15}	80.38	14.33	13.20	12.94	4.31	3.00	12.38
H_{16}	80.77	18.13	12.29	13.29	4.16	3.00	18.73
H_{17}	81.84	19.89	12.35	13.48	4.16	5.00	19.65
H_{18}	71.30	18.00	10.10	13.71	4.54	5.00	10.14
SEm(±)	6.45	1.82	2.12	1.78	0.71	2.85	0.30

cm (L_1) to 94.43 cm (L_2) and among testers the range was between 43.77 cm (T_2) to 86.90 cm (T_1). In the hybrids it ranged from 56.20 cm (H_1) to 115.67 cm (H_{14}).

4.2.2.2 Culm Length (cm)

Among all lines, testers and hybrids, this trait varied from 32.63 cm (T_2) to 94.33 cm (H_{14}). It estimated a grand mean of 62.68 cm. Culm length ranged from 51.63 cm (L_1) to 67.47 cm (L_2) among the lines, while it varied from 32.63 cm (T_2) to 72.03 cm (T_1) in the testers. The range was between 43.30 cm (H_1) to 94.33 cm (H_{14}) in the hybrids.

4.2.2.3 Total tillers/plant

This trait ranged between 6.80 (H_{12}) and 13.47 (H_{10}) among all the genotypes. Estimated grand mean for this trait was 10.26. Number of total tillers varied between 7.53 (L_3) to 12.47 (L_2) among the lines and 9.63 (T_1) to 10.90 (T_5) among the testers. Among hybrids the range was between 6.80 (H_{12}) to 13.47 (H_{10})

4.2.2.4 Productive tillers/plant

Productive tillers/plant ranged between 5.77 (H_{12}) and 11.80 (L_2) among all the genotypes. Grand mean estimated was 8.91. Range among the lines for this trait was from 6.33 (L_3) to 11.80 (L_2) and among testers it was from 8.40 (T_1) to 9.83 (T_5). Among the hybrids it ranged from 5.77 (H_{12}) to 11.57 (H_7).

4.2.2.5 Panicle length (cm)

This trait ranged between 13.47 cm (H_5) and 19.98 cm (H_7) among all the genotypes. Estimated grand mean for this trait was 16.82 cm. In the lines, panicle length ranged from 15.10 cm (L_1) to 17.63 cm (L_3) and in the testers it ranged from

16.53 cm (T_1) to 13.77 cm (T_3). Among the hybrids, it varied between 13.47 cm (H_5) to 19.98 cm (H_7).

4.2.2.6 Spikelets/panicle

Overall range for this trait was between 61.65 (T_6) and 124.00 (H_{16}). Grand mean estimated was 101.47. Range of spikelets/panicle among the lines was from 101.67 (L_2) to 104.77 (L_3) while among the testers it was from 61.65 (T_6) to 98.15 (T_1). Among the hybrids it ranged from 77.45 (H_5) to 124.00 (H_{16}).

4.2.2.7 Grains/panicle

Among all lines, testers and hybrids, this trait varied from 38.00 (T_5) to 100.18 (H_{16}). It estimated a grand mean of 73.84. Grains/panicle ranged from 68.20 (L_1) to 89.62 (L_3) among lines and from 38.00 (T_5) to 52.98 (T_1) among testers. Among the hybrids it ranged from 51.27 (H_5) to 100.18 (H_{16}).

4.2.2.8 Seed set (%)

Range for this trait varied between 49.13 per cent (T_5) and 87.21 per cent (H_{10}) among all the genotypes. It registered a grand mean of 71.67 per cent. Lowest seed set per cent among the lines was for L_1 (67.07 per cent) and the highest was for L_3 (85.69 per cent). In the testers it varied between 49.13 per cent (T_5) and 64.63 per cent (T_6). Among the hybrids seed set per cent ranged from 64.70 per cent (H_1) to 87.21 per cent (H_{10}).

4.2.2.9 Thousand grain weight (g)

Estimates for thousand grain weight ranged between 8.00 g (H_5) and 22.00 g (H_{10}) among all the genotypes. Estimated grand mean for this trait was 17.64 g. Thousand grain weight ranged between 15.20 g (L_3) to 19.80 g (L_1) among the lines and 16.50 g (T_1) to 20.75 g (T_4) among the testers. Among the hybrids it varied between 8.00 g (H_5) to 22.00 g (H_{10}).

4.2.2.10 Root length (cm)

Root length ranged between 5.32 cm (T_2) and 18.83 cm (L_2) among all the genotypes. Grand mean estimated was 11.27 cm. Root length recorded a minimum of 11.93 cm (L_3) and a maximum of 18.83 cm (L_2) among the lines. It ranged between 5.32 cm (T_2) to 12.25 cm (T_1) among the testers. For the hybrids it varied between 7.56 cm (H_5) to 16.27 cm (H_7)

4.2.2.11 Shoot weight (g)

Shoot weight varied between 4.65 g (T_5) and 16.67 (H_{14}) among all the genotypes. It registered a grand mean of 10.56 g. Shoot weight was recorded the least for L_1 (9.63 g) and the greatest for L_3 (13.32 g) among the lines. In the testers it varied from 4.65 g (T_5) to 7.89 g (T_1). Among the hybrids it ranged from 6.98 g (H_1) to 16.67 g (H_{14}).

4.2.2.12 Root weight (g)

Overall range for this trait was between 1.46 g (T_5) and 5.65 g (H_{14}). Grand mean estimated was 3.39 g. In the lines it ranged from 3.32 g (L_1) to 4.62 g (L_2) and in the testers it ranged from 1.46 g (T_5) to 2.70 g (T_1). Among hybrids root weight varied between 1.98 g (H_3) to 5.65 g (H_{14}).

4.2.2.13 Visual scoring for iron toxicity symptoms

Visual scoring for iron toxicity symptoms ranged between 2.00 (H_{13}) and 7.33 (T_3, T_5, T_6, H_1) among all the genotypes. Grand mean estimated was 4.88. Visual scoring for iron toxicity symptoms varied between 3.00 (L_2 and L_3) to 5.33 (L_1)

among lines and 3.33 (T_2) to 7.33 (T_3, T_5, T_6) among testers. Among hybrids it varied between 2.00 (H_{13}) to 7.33 (H_1)

4.2.2.14. Grain yield/plant (g)

Grain yield/plant ranged between 4.15 g (H_6) and 24.16 g (H_{10}) among all the genotypes. It estimated a grand mean of 11.83 g. In the lines, grain yield/ plant ranged from 8.58 g (L_3) to 15.68 g (L_2) and in the testers it ranged from 6.13 g (T_5) to 8.12 g (T_4). In the hybrids it ranged from 4.15 g (H_5) to 24.16 g (H_{10}).

4.2.3 Variability studies

Mean, range, genotypic and phenotypic coefficients of variation, genetic parameters such as heritability, genetic advance, genetic advance as per cent of mean were estimated for grain yield/plant and thirteen yield attributes at maturity. The results are enumerated in Table 19 and detailed below.

4.2.3.1 Phenotypic and genotypic coefficient of variation

The phenotypic coefficient of variation (PCV) was higher than the genotypic coefficient of variation (GCV) for all the traits under study in general.

Phenotypic coefficient of variation ranged between 12.65 per cent and 50.00 per cent corresponding to the traits panicle length and grain yield/plant. Moderate PCV estimates were also recorded for spikelets/panicle (16.83 per cent), seed set per cent (17.22 per cent) and thousand grain weight (19.76 per cent). High PCV was recorded for all other traits.

The genotypic coefficient of variation ranged from 10.55 per cent (total tillers/plant) to 40.37 per cent (grain yield/plant). Moderate estimates of GCV were also observed for productive tillers/plant (10.87 per cent), panicle length (12.12 per

Table 19. Variability and genetic parameters for yield and yield attributes at maturity

Traits	Range		Mean	SEm (±)	Coefficient of variation (%)		Heritability (Broad sense) (%)	Genetic advance	Genetic advance as % of mean
	Minimum	Maximum			PCV	GCV			
Plant height (cm)	43.77	115.67	81.93	9.62	29.03	25.21	75.40	36.96	45.11
Culm Length (cm)	32.63	94.33	62.68	7.29	29.55	25.88	76.70	29.28	46.71
Total tillers / plant	6.80	13.47	10.26	1.91	25.08	10.55	17.70	0.94	9.16
Productive tillers /plant	5.77	11.80	8.91	1.86	27.77	10.87	15.30	0.78	8.75
Panicle Length (cm)	13.47	19.98	16.82	0.50	12.65	12.12	91.70	4.02	23.90
Spikelets/ panicle	61.65	124.00	101.47	2.59	16.83	16.53	96.50	33.96	33.47
Grains/panicle	38.00	100.18	73.84	5.75	28.50	26.86	88.80	38.50	52.14
Seed set (%)	49.13	87.21	71.67	6.45	17.22	13.23	59.10	15.01	20.94
1000 grain weight (g)	8.00	22.00	17.64	1.82	19.76	15.18	59.00	4.24	24.04
Root length (cm)	5.32	18.83	11.27	2.12	34.59	25.77	55.50	4.46	39.57
Shoot weight (g)	4.65	16.67	10.56	1.78	40.67	35.07	74.40	6.58	62.31
Root weight (g)	1.46	5.65	3.39	0.71	40.13	31.00	59.70	1.67	49.26
Visual scoring for iron toxicity symptoms	2.00	7.33	4.88	0.30	35.39	34.60	95.60	3.40	69.67
Grain yield/ plant (g)	4.15	24.16	11.83	2.85	50.00	40.37	65.20	7.95	67.20

cent), spikelets/panicle (16.53 per cent), seed set per cent (13.23 per cent) and thousand grain weight (15.18 per cent). All other traits registered high GCV estimates.

The difference between PCV and GCV was the minimum in case of spikelets/ panicle (0.30 per cent) followed by panicle length (0.53 per cent), while the maximum difference was recorded for productive tillers/plant (16.90 per cent) followed by total tillers/plant (14.53 per cent).

4.2.3.2. Heritability and genetic advance

Heritability for the traits ranged from 15.30 per cent (productive tillers/plant) to 96.50 per cent (spikelets per panicle). Low heritability was also registered by total tillers/plant (17.70 per cent) besides productive tillers/plant. Moderate heritability was estimated for seed set per cent (59.10 per cent), thousand grain weight (59.00 per cent), root length (55.50 per cent) and root weight (59.70 per cent). All other traits registered high heritability.

Genetic advance as per cent of mean varied between 8.75 per cent (productive tillers/ plant) to 69.67 per cent (visual scoring for iron toxicity symptom). Low estimate was also observed for total tillers/plant (9.16 per cent) while all other traits recorded high estimates of genetic advance as per cent of mean.

4.2.4. Correlation studies

Genotypic and phenotypic correlation coefficients were calculated for all the possible combinations among grain yield/plant and the thirteen yield attributes at maturity influenced by iron toxicity. The results are tabulated in Table 20.

Table 20. Phenotypic (PCC) and genotypic (GCC) correlation coefficients among grain yield and yield attributes at maturity

Traits	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	Y
X_1	**1.000**	0.971**	0.106	0.084	0.787**	0.605**	0.694**	0.617**	0.182	0.582**	0.809**	0.742**	-0.592**	0.547**
X_2	0.981**	**1.000**	0.087	0.065	0.780**	0.628**	0.699**	0.602**	0.125	0.533**	0.808**	0.745**	-0.582**	0.519**
X_3	0.241*	0.167	**1.000**	0.950**	0.025	0.008	0.007	-0.011	0.180	0.240*	0.112	0.207	0.013	0.640**
X_4	0.186	0.057	1.019**	**1.000**	0.009	-0.010	-0.035	-0.069	0.139	0.277*	0.092	0.194	0.032	0.625**
X_5	0.979**	0.958**	0.175	0.147	**1.000**	0.759**	0.825**	0.689**	0.323**	0.371**	0.805**	0.664**	-0.607**	0.598**
X_6	0.716**	0.737**	0.050	-0.004	0.812**	**1.000**	0.871**	0.546**	0.230*	0.385**	0.620**	0.522**	-0.447**	0.583**
X_7	0.856**	0.864**	0.094	0.042	0.896**	0.951**	**1.000**	0.882**	0.235*	0.365**	0.753**	0.670**	-0.546**	0.644**
X_8	0.925**	0.915**	0.123	0.084	0.885**	0.791**	0.939**	**1.000**	0.191	0.306**	0.691**	0.645**	-0.520**	0.545**
X_9	0.305**	0.224*	0.628**	0.685**	0.401**	0.310**	0.247*	0.116	**1.000**	-0.050	0.206	0.198	-0.063	0.576**
X_{10}	0.621**	0.549**	0.536**	0.676**	0.567**	0.519**	0.540**	0.549**	-0.016	**1.000**	0.368**	0.445**	-0.475**	0.375**
X_{11}	1.029**	1.002**	-0.117	-0.177	0.983**	0.758**	0.927**	1.029**	0.332**	0.640**	**1.000**	0.906**	-0.618**	0.573**
X_{12}	0.994**	0.983**	-0.063	-0.082	0.920**	0.726**	0.895**	1.010**	0.278*	0.741**	0.980**	**1.000**	-0.581**	0.582**
X_{13}	-0.638**	-0.627**	-0.004	0.045	-0.648**	-0.463**	-0.584**	-0.671**	-0.097	-0.600**	-0.731**	-0.783**	**1.000**	-0.296**
Y	0.761**	0.700**	0.687**	0.643**	0.778**	0.755**	0.782**	0.715**	0.706**	0.580**	0.702**	0.694**	-0.389**	**1.000**

* significant at 5% level ; **significant at 1 % level

PCC: Above diagonal; **GCC** : Below diagonal

X_1- Plant height (cm)
X_2- Culm length (cm)
X_3- Total tillers/plant
X_4- Productive tillers/plant
X_5- Panicle length

X_6- Spikelets/panicle
X_7- Grains/panicle
X_8- Seed set (%)
X_9- 1000 grain weight (g)
X_{10}- Root length (cm)

X_{11}- Shoot weight (g)
X_{12}- Root weight (g)
X_{13}- Visual scoring for iron toxicity symptoms
Y- Grain yield/plant (g)

4.2.4.1 Association of yield attributes with grain yield/plant (g)

Grain yield/plant (g) recorded a high significant negative correlation with visual scoring for iron toxicity symptoms at phenotypic and genotypic level (r_p= -0.296, rg= -0.389). It also recorded a high significant positive correlation at phenotypic and genotypic level with all other traits.

4.2.4.2 Inter-correlation among yield attributes

4.2.4.2.1 Plant height (cm)

Plant height recorded high significant positive correlation at phenotypic and genotypic level respectively with culm length (r_p = 0.971, r_g = 0.981), panicle length (r_p = 0.787, r_g = 0.979), spikelets/panicle (r_p = 0.605, r_g = 0.716), grains/panicle (r_p = 0.694, r_g = 0.856), seed set per cent (r_p = 0.617, r_g = 0.925), root length (r_p = 0.582, r_g= 0.621), shoot weight (r_p = 0.809, r_g = 1.029) and root weight (r_p = 0.742, r_g = 0.994). It recorded high significant negative correlation phenotypic level and genotypic level with visual scoring for iron toxicity symptoms (r_p = -0.592, r_g = -0.638). It also recorded high to very high genotypic correlation with total number of tillers/plant (r_g = 0.241) and thousand grain weight (r_g = 0.305)

4.2.4.2.2 Culm length (cm)

Culm length registered high significant positive correlation at phenotypic level and genotypic level with panicle length (r_p = 0.780, r_g = 0.958), spikelets/ panicle (r_p = 0.628, r_g = 0.737), grains/ panicle (r_p = 0.699, r_g = 0.864), seed set per cent (r_p = 0.602, r_g = 0.915), root length (r_p = 0.533, r_g= 0.549), shoot weight (r_p = 0.808, r_g= 1.002) and root weight (r_p = 0.745, r_g = 0.983). High significant negative correlation at phenotypic and genotypic level was registered between this attribute and visual scoring for iron toxicity symptoms (r_p = -0.582, r_g = -0.627).

4.2.4.2.3 Total tillers/plant

Total tillers/plant showed significant to high significant positive correlation at phenotypic and genotypic level with productive tillers/plant ($r_p = 0.950$, $r_g = 1.019$) and root length ($r_p = 0.240$, $r_g = 0.536$). It also recorded high significant positive correlation at genotypic level with thousand grain weight ($r_g = 0.628$).

4.2.4.2.4 Productive tillers/plant

Productive tillers/plant recorded significant to high significant positive correlation at phenotypic and genotypic level with root length ($r_p = 0.277$, $r_g = 0.676$). It also recorded high significant positive genotypic correlation with thousand grain weight ($r_g = 0.685$).

4.2.4.2.5 Panicle length (cm)

Panicle length registered high significant positive correlation at phenotypic level and genotypic level with spikelets/panicle ($r_p = 0.759$, $r_g = 0.812$), grains/panicle ($r_p = 0.825$, $r_g = 0.896$), seed set per cent ($r_p = 0.689$, $r_g = 0.885$), thousand grain weight ($r_p = 0.323$, $r_g = 0.401$), root length ($r_p = 0.371$, $r_g = 0.567$), shoot weight ($r_p = 0.805$, $r_g = 0.983$) and root weight ($r_p = 0.664$, $r_g = 0.920$). It also registered high significant negative correlation at phenotypic level and genotypic level with visual scoring for iron toxicity symptoms ($r_p = -0.607$, $r_g = -0.648$).

4.2.4.2.6 Spikelets/panicle

Spikelets/panicle recorded significant to high significant positive correlation at phenotypic level and genotypic level with grains/panicle ($r_p = 0.871$, $r_g = 0.951$), seed set per cent ($r_p = 0.546$, $r_g = 0.791$), thousand grain weight ($r_p = 0.230$, $r_g = 0.310$), root length ($r_p = 0.385$, $r_g = 0.519$), shoot weight ($r_p = 0.620$, $r_g = 0.758$) and root weight ($r_p = 0.522$, $r_g = 0.726$). It also registered high significant negative correlation with visual scoring for iron toxicity symptoms at phenotypic and genotypic level ($r_p = -0.447$, $r_g = -0.463$).

4.2.4.2.7 Grains/panicle

Grains/panicle showed significant to high significant positive correlation at phenotypic level and genotypic level with seed set per cent ($r_p = 0.882$, $r_g = 0.939$), thousand grain weight ($r_p = 0.235$, $r_g = 0.247$), root length ($r_p = 0.365$, $r_g = 0.540$), shoot weight ($r_p = 0.753$, $r_g = 0.927$) and root weight ($r_p = 0.670$, $r_g = 0.895$). It also recorded high significant negative correlation with visual scoring at phenotypic and genotypic level ($r_p = -0.546$, $r_g = -0.584$).

4.2.4.2.8 Seed set (%)

Seed set per cent recorded high significant positive correlation at phenotypic and genotypic level with root length ($r_p = 0.306$, $r_g = 0.549$), shoot weight ($r_p = 0.691$, $r_g = 1.029$) and root weight ($r_p = 0.645$, $r_g = 1.010$). It also registered high significant negative correlation with visual scoring for iron toxicity symptoms at phenotypic and genotypic level ($r_p = -0.520$, $r_g = -0.671$).

4.2.4.2.9 Thousand grain weight (g)

Thousand grain weight recorded high significant positive correlation at genotypic level with shoot weight ($r_g = 0.332$), while it registered significant positive genotypic correlation with root weight ($r_g = 0.278$).

4.2.4.2.10 Root length (cm)

Root length showed high significant positive correlation at phenotypic level and genotypic level with shoot weight ($r_p = 0.368$, $r_g = 0.640$) and root weight ($r_p = 0.445$, $r_g = 0.741$).It also recorded high significant negative correlation with visual scoring at phenotypic and genotypic level with visual scoring for iron toxicity symptoms (r_p = -0.475, r_g = -0.600).

4.2.4.2.11 Shoot weight (g)

Shoot weight registered high significant positive correlation at phenotypic and genotypic level with root weight (r_p = 0.906, r_g = 0.980) while it recorded high significant negative correlation at phenotypic and genotypic level with visual scoring for iron toxicity symptoms (r_p = -0.618, r_g = -0.731).

4.2.4.2.12 Root weight (g)

Root weight registered a high significant negative correlation at phenotypic and genotypic level with visual scoring for iron toxicity symptoms (r_p = -0.581, r_g = -0.783)

4.2.5 Path co-efficient analysis

The genotypic correlation coefficient of grain yield with yield attributes at maturity was further partitioned into direct and indirect effects. The results are detailed in Table 21. A residual value of 0.06 was recorded in this analysis.

4.2.5.1 Direct effects

Positive direct effect ranged from 0.015 (plant height) to 6.071 (root weight). Very high positive direct effect were exhibited by root weight, productive tillers/plant (1.458) and panicle length (3.153) while high positive direct effect was exhibited by seed set per cent (0.429). Grains/panicle (0.205) and visual scoring for iron toxicity effects (0.267) registered moderate positive direct effect while plant height (0.015) recorded negligible positive direct effect.

Table 21. Direct (Diagonal) and indirect effects of yield attributes at maturity on grain yield

Traits	X_1	X_3	X_4	X_5	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}
X_1	**0.015**	-0.222	0.271	3.086	0.176	0.397	-0.081	-0.972	-7.776	6.037	-0.170
X_3	0.004	**-0.923**	1.486	0.553	0.019	0.053	-0.166	-0.839	0.884	-0.382	-0.001
X_4	0.003	-0.940	**1.458**	0.463	0.009	0.036	-0.182	-1.059	1.340	-0.496	0.012
X_5	0.015	-0.162	0.214	**3.153**	0.184	0.380	-0.106	-0.888	-7.428	5.589	-0.173
X_7	0.013	-0.087	0.061	2.825	**0.205**	0.403	-0.066	-0.846	-7.007	5.436	-0.156
X_8	0.014	-0.114	0.123	2.791	0.193	**0.429**	-0.031	-0.860	-7.780	6.129	-0.179
X_9	0.005	-0.579	0.999	1.265	0.051	0.050	**-0.265**	0.025	-2.508	1.690	-0.026
X_{10}	0.009	-0.494	0.986	1.788	0.111	0.235	0.004	**-1.566**	-4.836	4.503	-0.160
X_{11}	0.016	0.108	-0.258	3.099	0.190	0.441	-0.088	-1.002	**-7.558**	5.950	-0.195
X_{12}	0.015	0.058	-0.119	2.902	0.184	0.433	-0.074	-1.162	-7.406	**6.071**	-0.209
X_{13}	-0.010	0.004	0.066	-2.042	-0.120	-0.288	0.026	0.939	5.524	-4.754	**0.267**

Residual effect = 0.06

X_1- Plant height (cm)
X_3- Total tillers/plant
X_4- Productive tillers/plant
X_5- Panicle length
X_7- Grains/panicle
X_8 - Seed set (%)
X_9 - 1000 grain weight (g)
X_{10} - Root length (cm)
X_{11} - Shoot weight (g)
X_{12} - Root weight (g)
X_{13} - Visual scoring for iron toxicity symptoms

Negative direct effect ranged from -0.265 (thousand grain weight) to - 7.558 (shoot weight). Very high negative direct effects were recorded by shoot weight and root length (-1.566). Total tillers/plant (-0.923) registered a high direct effect in the negative direction while thousand grain weight registered moderate negative direct effect.

4.2.5.2 Indirect effects

4.2.5.2.1 Plant height (cm)

Positive indirect effect through plant height varied between 0.176 (grains/panicle) and 6.037 (root weight). Very high positive indirect effect was registered by panicle length (3.086) besides root weight while high positive indirect effect was registered by seed set per cent (0.397). Other attribute which registered positive indirect effect was productive tillers/plant.

Negative indirect effect for this character ranged from -0.081(thousand grain weight) to -7.776 (shoot weight). Shoot weight registered very high indirect effect in the negative direction while root length recorded a high negative indirect effect of 0.972. Negative indirect effect were also registered through total tillers/plant and visual scoring for iron toxicity symptoms.

4.2.5.2.2 Total tillers/plant

Positive indirect effect for total tillers/plant varied from 0.004 (plant height) to 1.486 (productive tillers/plant). Productive tillers registered a very high positive indirect effect while shoot weight (0.884) and panicle length (0.553) registered high positive indirect effect. Other attributes through which positive indirect effect exhibited were grains/panicle and seed set per cent.

Negative indirect effect for this trait ranged from -0.001 (visual scoring for iron toxicity symptoms) to -0.839 (root length). High negative indirect effects were registered through root length and root weight (-0.382). Negative indirect effect was also recorded through thousand grain weight.

4.2.5.2.3 Productive tillers/plant

Positive indirect effect for productive tillers/plant ranged between 0.003 (plant height) and 1.340 (shoot weight). Shoot weight recorded a very high positive indirect effect while panicle length recorded a high positive indirect effect (0.463). Positive indirect effects were also exhibited through grains/panicle, seed set per cent, and visual scoring for iron toxicity symptoms.

Negative indirect effect ranged from -0.182 (grain weight) to 1.059 (root length). Root length registered a very high indirect effect while total tillers/plant (-0.940) and root weight (-0.496) recorded high indirect effect in the negative direction.

4.2.5.2.4 Panicle length (cm)

Positive indirect effect for panicle length ranged from 0.015 (plant height) to 5.589 (root weight). Very high positive indirect effect was registered by root weight while high positive indirect effect was registered with seed set per cent (0.380). Other attributes which registered positive indirect effect were productive tillers/plant and grains/panicle.

Negative indirect effect ranged from -0.106 (thousand grain weight) to -7.428 (shoot weight). Shoot weight registered very high negative indirect effect while root length (0.888) registered a high negative indirect effect. Negative indirect effects were also exerted through total tillers/plant and visual scoring for iron toxicity symptoms.

4.2.5.2.5 Grains/panicle

Range for grains per panicle in positive indirect effect was between 0.013 (plant height) and 5.436 (root weight). Besides root weight, panicle length (2.825) also recorded very high positive indirect effect while seed set per cent registered a high positive indirect effect (0.403). Positive indirect effect was also registered through productive tillers/plant.

Negative indirect effect for this trait ranged from -0.066 (thousand grain weight) to -7.007 (shoot weight). Shoot weight registered very high negative indirect effect while high indirect effect in the negative direction was exhibited through root length (-0.846). Negative indirect effect were also registered through total tillers/plant and visual scoring for iron toxicity symptoms.

4.2.5.2.6 Seed set (%)

Positive indirect effect for this trait ranged from 0.014 (plant height) to 6.129 (root weight). Root weight and panicle length (2.791) registered very high positive indirect effect. Other attributes through which positive indirect effect exerted were productive tillers/plant, and grains/panicle.

Negative indirect effect for seed set per cent ranged from -0.031 (thousand grain weight) to -7.780 (shoot weight). Shoot weight registered very high indirect effect in the negative direction while root length (-0.860) registered high indirect effect in the negative direction. Other attributes which registered negative indirect effect were total tillers/plant and visual scoring for iron toxicity symptoms.

4.2.5.2.7 Thousand grain weight (g)

Positive indirect for the trait thousand grain weight varied from 0.005 (plant height) to 1.690 (root weight). Root weight, panicle length (1.265) registered very high positive indirect effect while productive tillers/plant (0.999) registered high positive indirect effect. Traits, grains/panicle, seed set per cent, root length also registered positive indirect effect.

Negative indirect effect for this trait ranged from -0.026 (visual scoring for iron toxicity symptoms) to -2.508 (shoot weight). Shoot weight registered very high negative indirect effect while total tillers/plant (-0.579) registered high negative indirect effect. No other traits registered negative indirect effect.

4.2.5.2.8 Root length (cm)

Positive indirect effect ranged from 0.004 (grain weight) to 4.503 (root weight). Root weight, panicle length (1.788) registered very high positive indirect effect while productive tillers/plant (0.986) registered high positive indirect effect. Other attributes which registered positive indirect effect were plant height, grains/panicle and seed set per cent.

Negative indirect effect ranged from -0.160 (visual scoring for iron toxicity symptoms) to 4.836 (shoot weight). Very high indirect effect in the negative direction was registered by shoot weight while total tillers/plant (-0.494) registered high negative indirect effect. No other traits registered negative indirect effect through this trait.

4.2.5.2.9 Shoot weight (g)

Positive indirect effect for this trait varied between 0.016 (plant height) to 5.950 (root weight). Root weight and panicle length (3.099) registered very high positive indirect effect while seed set per cent registered a high positive indirect effect (0.441). Other attributes through which positive indirect effect were registered include total tillers/plant and grains/panicle.

Negative indirect effect for this trait ranged from -0.008 (thousand grain weight) to -1.002 (root length). Other attributes through which negative indirect effect exhibited were, productive tillers/plant and visual scoring for iron toxicity symptoms.

4.2.5.2.10 Root weight (g)

Positive indirect effect for root weight ranged between 0.015 (plant height) to 2.902 (panicle length). Panicle length registered a very high positive indirect effect while seed set per cent registered a high positive indirect effect (0.433). Other attributes through which positive indirect effect exerted were total tillers/plant and grains/panicle.

Negative indirect effect through this trait ranged from -0.074 (thousand grain weight) to -7.406 (shoot weight). Shoot weight and root length (-1.162) registered very high indirect effect in the negative direction. Other attributes through which negative indirect effect exhibited were productive tillers/plant and visual scoring for iron toxicity symptoms.

4.2.5.2.11 Visual scoring for iron toxicity symptoms

Positive indirect effect for this trait ranged from 0.004 (total tillers/plant) to 5.524 (shoot weight). Shoot weight recorded very high indirect effect while root length (0.939) recorded high indirect effect in the positive direction. Other attributes through which positive indirect effect exerted include productive tillers/plant and thousand grain weight.

Negative indirect effect ranged from -0.010 (plant height) to -4.754 (root weight). Root weight and panicle length (-2.042) recorded very high negative indirect effect. Grains/panicle and seed set per cent also registered negative indirect effect through this trait.

4.3 Studies on combining ability

4.3.1. Analysis of variance

The estimate of variance due to general and specific combining ability in the line x tester analysis for yield and yield attributes observed at maturity are elaborated in Table 22.

Hybrids and lines registered significant variation among themselves for plant height, culm length, panicle length, grains/panicle, seed set per cent, shoot weight, root weight and visual scoring for iron toxicity symptoms. Significant differences among hybrids were also evident for spikelets/panicle, thousand grain weight, root length, and grain yield/plant in hybrids. The testers did not vary among themselves for yield and yield attributes. The line x tester interaction was significant for productive tillers, panicle length, spikelets/panicle, grains/panicle, thousand grain weight, root length, visual scoring for iron toxicity symptoms and grain yield/plant.

Combining ability variance showed that the specific combining ability (SCA) variance was higher than general combining ability (GCA) variance for total tillers, productive tillers, spikelets/panicle, grains/panicle, thousand grain weight, root length, visual scoring for iron toxicity symptoms and grain yield per plant. The absolute ratio of GCA variance to SCA variance ranged from 0.04: 1 for spikelets/panicle to 101.71: 1 for seed set (%).

4.3.2 Combining ability effects

The general combining ability effects (*gca*) of lines and testers and specific combining ability effects (*sca*) of hybrids for yield and yield attributes observed at maturity are given in Table 23 and Table 24 respectively.

Table 22. Analysis of variance for combining ability for yield and yield attributes -I

Source	d f	Mean sum of squares						
		Plant height (cm)	Culm length (cm)	Total tillers/plant	Productive tillers/ plant	Panicle length (cm)	Spikelets /panicle	Grains/ panicle
Hybrids	17	980.13**	570.57**	11.21	9.24	10.22**	414.39**	599.16**
Lines	2	7149.29**	4081.24**	1.86	1.17	71.12**	772.02	2660.18*
Testers	5	204.01	101.30	15.06	8.12	0.91	81.34	58.48
Line x Tester	10	134.36	103.06	11.16	11.41*	2.70**	509.40**	457.30**
Error	34	99.22	60.31	5.98	5.05	0.37	6.65	52.51
σ^2 gca		262.39	147.27	-0.20	-0.50	2.47	-6.13	66.82
σ^2 sca		11.71	14.25	1.73	2.12	0.78	167.58	134.93
σ^2 gca/ σ^2 sca		22.41	10.34	-0.12	-0.24	3.16	-0.04	0.50

*significant at 5% level; **significant at 1% level

Table 22. Analysis of variance for combining ability for yield and yield attributes –II (contd.)

Source	d f	Mean sum of squares						
		Seed set (%)	1000 grain weight (g)	Root length (cm)	Shoot weight (g)	Root weight (g)	Visual scoring for iron toxicity symptoms	Grain yield/ plant (g)
Hybrids	17	150.32**	36.25**	16.56**	33.29**	3.07**	7.34**	85.21**
Lines	2	864.66**	78.66	3.78	250.72**	17.89**	32.72**	189.79
Testers	5	48.47	21.34	1.42	6.55	0.65	4.21	52.75
Line x Tester	10	58.38	35.23**	26.69**	3.18	1.32	3.83**	80.52**
Error	34	57.50	4.39	5.67	4.32	0.79	0.11	15.50
σ^2 gca		29.50	1.09	-1.78	9.29	0.59	1.08	3.02
σ^2 sca		0.29	10.28	7.01	-0.38	0.18	1.24	21.67
σ^2 gca/ σ^2 sca		101.71	0.11	-0.25	-24.46	3.27	0.87	0.14

*significant at 5% level; **significant at 1% level

Table 23. Estimates of general combining ability effects (*gca*) for yield and yield attributes

	PH(cm)	CL (cm)	TT	PT	PL (cm)	S/P	G/P	SS	GW (g)	RL (cm)	SW (g)	RW (g)	VS	GY (g)
Lines														
L_1	-22.04**	-17.37**	-0.36	-0.24	-2.25**	-7.30**	-14.00**	-7.99**	-2.10**	-0.44	-4.26**	-1.15**	1.50**	-3.61**
L_2	16.75**	9.35**	0.25	0.27	1.52**	1.95**	6.08**	4.41**	2.08**	0.48	2.70**	0.49**	-0.39**	2.67**
L_3	5.30**	8.02**	0.11	-0.04	0.73**	5.35**	7.92**	3.58**	0.03	-0.04	1.56**	0.65**	-1.11**	0.95
SE ± Lines	1.57	1.22	0.38	0.35	0.10	0.41	1.14	1.19	0.33	0.37	0.33	0.14	0.05	0.62
Testers														
T_1	-6.12*	-4.24*	0.78	0.29	0.17	4.28**	-2.03	-4.11*	0.57	0.37	-1.10*	-0.30	-0.50**	0.10
T_2	8.08**	5.62**	0.85	0.74	0.45**	-0.03	0.23	0.94	2.59**	0.40	1.08*	0.19	-0.17*	2.53*
T_3	0.10	-1.38	-1.75**	-1.26*	0.18	0.82	0.94	-0.02	-1.02	-0.16	-0.33	-0.17	-0.72**	-2.91**
T_4	-0.09	-1.14	1.00	0.69	-0.40*	1.45*	4.52*	2.89	0.08	-0.30	0.13	0.08	-0.17*	2.81**
T_5	1.09	1.77	0.69	0.69	-0.24	-4.44**	-1.49	0.79	-1.92**	0.26	-0.63	-0.19	1.17**	0.04
T_6	-3.06	-0.64	-1.57*	-1.15*	-0.16	-2.08**	-2.18	-0.48	-0.30	-0.56	0.86*	0.41	0.39**	-2.55*
SE ± Testers	2.47	1.93	0.61	0.56	0.15	0.64	1.80	1.88	0.52	0.59	0.52	0.22	0.08	0.98

*significant at 5% level; **significant at 1% level

Table 24. Estimates of specific combining ability effects (*sca*) for yield and yield attributes

Hybrids	PH(cm)	CL (cm)	TT	PT	PL	S/P	G/P	SS	GW	RL	SW	RW	VS	GY
H_1	-6.18	-4.63	-1.43	-1.22	0.39	12.26**	9.51**	1.08	2.90**	-4.33**	0.32	-0.14	1.72**	1.26
H_2	-5.15	-2.22	1.14	1.24	0.93**	18.45**	14.85**	1.39	1.55*	-0.62	-1.08	-0.44	1.06**	4.97**
H_3	0.53	3.08	0.44	-0.23	-0.44*	-7.20**	-6.89*	-1.66	0.49	-1.59	-0.34	-0.47	-0.06	-0.36
H_4	-1.08	-1.86	-2.88**	-2.59**	0.33	-6.40**	-7.79**	-2.79	-2.61**	0.22	0.15	-0.21	-0.94**	-6.81**
H_5	3.41	2.93	0.03	0.08	-1.66**	-19.86**	-16.17**	-2.40	-5.61**	1.65	0.32	0.49	-0.28*	-5.70
H_6	8.46*	2.70	2.70**	2.72**	0.45*	2.76**	6.50*	4.37	3.27**	4.67**	0.62	0.77*	-1.50**	6.64**
H_7	7.00	5.35	1.86*	2.14*	0.69**	-5.34**	-6.23*	-2.54	-0.28	3.46**	0.71	0.59	-0.72**	2.49
H_8	-6.60	-8.94**	0.13	0.33	-0.68**	-10.95**	-14.42**	-5.97*	-1.30	2.52**	-0.92	-0.61	-0.72**	-2.66
H_9	1.81	-2.10	-1.44	-1.24	0.13	2.55**	2.28	0.55	1.81*	0.15	0.65	0.39	-0.17	-0.56
H_{10}	3.26	3.92	1.91*	1.54	-0.64**	-1.74	2.98	4.20	2.21**	-0.89	0.28	0.54	1.28**	5.25**
H_{11}	-2.01	0.31	-0.28	-0.56	0.42	8.07**	5.92*	0.64	1.46	-1.83*	-0.84	-0.43	-0.06	0.45
H_{12}	-3.46	1.45	-2.18*	-2.21**	0.08	7.41**	9.47	3.13	-3.91**	-3.42**	0.12	-0.49	0.39**	-4.97**
H_{13}	-0.82	-0.72	-0.44	-0.92	-1.07**	-6.93**	-3.27	1.47	-2.63**	0.87	-1.03	-0.45	-1.00**	-3.74*
H_{14}	11.75**	11.15**	-1.27	-1.56	-0.25	-7.49**	-0.43	4.58	-0.25	-1.90*	2.00**	1.05**	0.33**	-2.31
H_{15}	-2.34	-0.98	1.00	1.47	0.31	4.66**	4.61	1.11	-2.31**	1.44	-0.32	0.07	0.22	0.92
H_{16}	-2.19	-2.06	0.97	1.05	0.32	8.14**	4.81	-1.41	0.39	0.67	-0.43	-0.33	-0.33**	1.55
H_{17}	-1.40	-3.24	0.25	0.48	1.23**	11.79**	10.26*	1.76	4.15**	0.18	0.51	-0.06	0.33**	5.25**
H_{18}	-5.01	-4.16	-0.51	-0.51	-0.53*	-10.17**	-15.97*	-7.51	0.64	-1.26	-0.74	-0.28	1.11**	-1.67
SE	3.50	2.73	0.86	0.79	0.21	0.91	2.55	2.66	0.74	0.84	0.73	0.31	0.12	1.38

*significant at 5% level; **significant at 1% level

4.3.2.1 Plant height (cm)

The *gca* effects of parents ranged from -22.04 (L_1) to 16.75 (L_2) among lines. All the lines showed significant *gca* except L_1 which showed negative significance with an estimate of -22.04. The range was between -6.12 (T_1) and 8.08 (T_2) for testers. Two testers (T_1) and (T_2) with corresponding values -6.12 and 8.08, exhibited significant *gca* effects.

The *sca* effect among hybrids varied from -6.60 (H_8) to 11.75 (H_{14}). Among hybrids H_6 and H_{14} with estimates 8.46 and 11.75 respectively showed positive significance for *sca* effects.

4.3.2.2 Culm length (cm)

The *gca* effects among lines ranged from -17.37 (L_1) to 9.35 (L_2) and all of them recorded significance. Testers varied from -4.24 (T_1) to 5.62 (T_2) with the testers, T_1 (-4.24) and T_2 (5.62) registering significant *gca* effects.

The *sca* effects of hybrids varied from -8.94 (H_8) to 11.15 (H_{14}). Two hybrids namely H_8 (-8.94) and H_{14} (11.15) recorded significant *sca* effect.

4.3.2.3 Total tillers/plant

Among parents *gca* effect for lines was the minimum for L_1 (-0.36) and maximum for L_2 (0.25) and none among the lines registered significant *gca* effect. It varied between -1.75 (T_3) and 1.00 (T_4) for testers. Two testers T_3 (-1.75) and T_6 (-1.57) recorded significant negative *gca* effect.

The *sca* effect varied from -2.88 (H_4) to 2.70 (H_6). Five hybrids recorded significant *sca* effect.

4.3.2.4 Productive tillers/ plant

The *gca* effects for productive tillers ranged from -0.24 (L_1) to 0.27 (L_2) among the lines, with none of them exhibiting significance for *gca* effect. Among testers it varied between -1.26 (T_3) to 0.74 (T_2). Two testers T_3 (-1.26) and T_6 (-1.15) registered significant negative *gca* effect.

Among hybrids the *sca* effect varied between -2.59 (H_4) and 2.72 (H_6). Four among the eighteen hybrids recorded significance for *sca* effect.

4.3.2.5 Panicle length(cm)

Among lines, the *gca* effects ranged from -2.25 (L_1) to 1.52 (L_2) with all of them exhibiting significance. In testers it ranged from -0.40 (T_4) to 0.45 (T_2) with two of them registering significance for *gca viz.*T_2 (0.45) and T_4 (-0.40).

The *sca* effect for hybrids ranged between -1.66 (H_5) to 1.23 (H_{17}). Ten hybrids recorded significant *sca* effect.

4.3.2.6 Spikelets/panicle

The *gca* effects among parents varied from -7.30 (L_1) to 5.35 (L_3) for lines with all of them showing significance. The *gca* effect varied from -4.44 (T_5) to 4.28 (T_1) for testers. Four testers registered significant *gca* effect.

Among hybrids *sca* effect ranged from -19.86 (H_5) to 18.45 (H_2). Except, H_{10} (-1.74), all hybrids, recorded significant *sca* effect.

4.3.2.7 Grains/panicle

The *gca* effects among lines ranged between -14.00 (L_1) and 7.92 (L_3) with all of them exhibiting significance. Among testers *gca* effect ranged from -2.18 (T_6) to 4.52 (T_4). Among the testers, T_4 (4.52) recorded significant *gca* effect.

The *sca* effect ranged between -16.17 (H_5) and 14.85 (H_2). Eleven hybrids registered significant *sca* effect for this trait.

4.3.2.8 Seed set (%)

Among the parents the *gca* effect for lines varied between -7.99 (L_1) and 4.41 (L_2) with all of them registering significance. In testers it varied between -4.11(T_1) and 2.89 (T_4). Tester T_1 (-4.11) recorded significant *gca* effect.

The *sca* effect among hybrids ranged from -7.51 (H_{18}) to 4.58 (H_{14}). The hybrid H_8 registered significance for *sca* effect.

4.3.2.9 Thousand grain weight (g)

The *gca* effect for parents varied between -2.10 (L_1) and 2.08 (L_2) for lines. Among lines, L_1 (-2.10) and L_2 (2.08) registered significance for *gca* effect. It varied from -1.92 (T_5) to 2.59 (T_2) for testers. Testers T_2 (2.59) and T_5 (-1.92) recorded significant *gca* effects.

The *sca* effect among hybrids ranged between -5.61 (H_5) and 4.15 (H_{17}). Eleven hybrids recorded significant *sca* effect for this trait.

4.3.2.10 Root Length (cm)

Among the lines *gca* effect for this trait varied from -0.44 (L_1) to 0.48 (L_2) and among testers it varied from -0.56 (T_6) to 0.40 (T_2). None among the parents registered significance for *gca* effect.

Among the hybrids *sca* effect ranged between -4.33 (H_1) and 4.67 (H_6). Seven hybrids recorded significant *sca* effect for root length.

4.3.2.11 Shoot weight (g)

The minimum *gca* effect among lines was recorded by L_1 (-4.26) and the maximum by L_2 (2.70) with all of them registering significant *gca* effect. Among testers the minimum *gca* effect was observed for T_1 (-1.10) and the maximum by T_2 (1.08). Three testers T_1 (-1.10), T_2 (1.08) and T_6 (0.86) showed significance for *gca* effect.

Among hybrids *sca* effect ranged between -1.08 (H_2) to 2.00 (H_{14}). Hybrid, H_{14} (2.00) showed significant *sca* effect for this trait.

4.3.2.12 Root weight (g)

The *gca* effect for parents for this trait, lied between -1.15 (L_1) and 0.65 (L_3) among lines. All the lines registered significant *gca* effect. It varied from -0.30 (T_1) to 0.41 (T_6) among testers. None of the testers registered significance for *gca* effect.

The hybrids showed a range of -0.61 (H_8) to 1.05 (H_{14}) for *sca* effect. Hybrids, H_6 (0.77) and H_{14} (1.05) recorded significant *sca* effect.

4.3.2.13 Visual Scoring for iron toxicity symptoms

Among parents the *gca* effect ranged from -1.11 (L_3) to 1.50 (L_1) for lines and varied from -0.72 (T_3) to 1.17 (T_5) for testers. All the parents recorded significant *gca* effect for this trait.

The *sca* effect varied from -1.50 (H_6) to 1.72 (H_1). Fourteen hybrids registered significance for *sca*.

4.3.2.14 Grain yield/plant (g)

The range of *gca* effect for this character was between -3.61 (L_1) and 2.67 (L_2) among the lines. Lines L_1 (-3.61) and L_2 (2.67) recorded significant *gca* effect. It ranged between -2.91(T_3) and 2.81 (T_4) among the testers. Four testers registered significant *gca* effect.

Hybrids recorded a range of -6.81 (H_4) to 6.64 (H_6) for *sca* effect. Six hybrids registered significance for the *sca* effect.

4.4 Studies on heterosis

Estimates of expression of relative heterosis (d_i), heterobeltiosis (d_{ii}) and standard heterosis (d_{iii}) presented in Table 25, Table 26, Table 27 and Table 28 and are detailed below.

4.4.1 Days to fifty per cent flowering

All hybrids registered significant positive relative heterosis for this trait. The values ranged from 7.14 (H_1) to 29.08 (H_9) for relative heterosis. Fifteen hybrids recorded significant heterobeltiosis of which nine among them being negatively significant. The values varied between -9.67 (H_{12}) and 10.69 (H_9). All hybrids recorded significant positive standard heterosis. Lowest standard heterosis for this trait was recorded in H_1 (22.77) and highest in H_9 (54.80). Fifteen hybrids recorded significance for all the three types of heterosis.

4.4.2 Plant height (cm)

The relative heterosis for this trait ranged from -27.64 (H_1) to 85.61 (H_{14}).). Eleven hybrids showed significant positive relative heterosis, in which H_1 registered significant negative relative heterosis. Heterobeltiosis varied from -35.33 (H_1) to 43.03 (H_{14}). Only two hybrids recorded significant heterobeltiosis in which H_1 registered negative significance. Thirteen hybrids recorded positive significance for standard heterosis which varied from 5.44 (H_1) to 117.01 (H_{14}). H_1 and H_{14} recorded significance for all three types of heterosis.

4.4.3 Culm length (cm)

Relative heterosis for culm length ranged between -29.97 (H_1) and 98.74 (H_{14}). Twelve hybrids recorded significant relative heterosis of which H_1 registered negative significance. Heterobeltiosis varied from -39.89 (H_1) to 51.42 (H_{14}) .Two hybrids were significant for heterobeltiosis among which H_1 registered negative significance. Lowest standard heterosis was noted for 7.98 (H_1) and highest was recorded for 135.25 (H_{14}). Fourteen hybrids recorded positive significance for standard heterosis for this trait. All three types of heterosis were significant for (H_{14}).

4.4.4 Total tillers/ plant

Lowest relative heterosis of this trait among hybrids was recorded for H_{12} (-41.71) and highest for H_{16} (39.33). Only three hybrids recorded significant relative heterosis among which H_{16} alone recorded positive significance. Heterobeltiosis ranged from -45.45 (H_{12}) to 20.95 (H_2) with only two hybrids showing significance in

Table 25. Relative heterosis, heterobeltiosis and standard heterosis (%) for yield and yield attributes - I

Hybrids	Days to 50 % flowering			Plant height (cm)			Culm length (cm)			Total tillers/plant		
	di	dii	diii	di	dii	diii	di	dii	diii	di	dii	Diii
H_{1}	7.14**	-5.74**	22.77**	-27.64*	-35.33**	5.44**	-29.97**	-39.89**	7.98	-3.13	-3.46	-11.43
H_{2}	15.33**	-1.37	28.46**	27.33	4.38	34.02	31.88*	7.62	38.57*	22.81	20.95	13.65
H_{3}	22.41**	8.20**	40.92**	13.58	1.02	29.71*	17.40	4.33	34.33	-13.95	-17.78	-17.78
H_{4}	24.96**	6.01**	38.07**	12.88	-1.61	26.33**	11.40	-4.78	22.61	-18.66	-21.43	-23.17
H_{5}	11.11**	-3.01*	26.33**	20.59	6.67	36.96	25.35	10.14	41.81**	4.23	-2.14	1.59
H_{6}	20.85**	2.19	33.09**	23.54	7.99	38.65	20.12	5.04	35.25	8.32	1.84	5.40
H_{7}	22.21**	4.33**	45.91**	19.30*	14.54	102.94**	14.70	11.06	99.50**	19.46	5.88	25.71
H_{8}	27.72**	6.11**	48.39**	57.40**	15.18	104.07**	50.98**	12.01	88.45**	3.28	-7.49	9.84
H_{9}	29.08**	10.69**	54.80**	47.83**	15.64	104.88**	40.15**	11.76	88.03**	-35.85*	-40.91**	-29.84
H_{10}	19.44**	-1.53	37.72**	52.05**	16.98	107.25**	56.90**	21.05	103.66**	18.48	8.02	28.25
H_{11}	22.82**	4.07**	45.54**	44.65**	12.64	99.56**	51.95**	20.01	101.91**	-6.13	-12.03	4.44
H_{12}	9.91**	-9.67**	26.33**	38.38**	6.71	89.06**	50.19**	18.13	98.75**	-41.71**	-45.45**	-35.24
H_{13}	12.48**	-6.44**	39.50**	5.98	2.30	66.79	8.09	0.79	81.05**	25.44	11.76	2.54
H_{14}	18.41**	-4.06**	43.06**	85.61**	43.03**	117.01**	98.74**	51.42**	135.25**	14.94	1.35	-4.76
H_{15}	13.14**	-5.49**	40.92**	39.53**	15.75	75.61*	46.83**	20.71	87.53**	7.21	-7.94	-7.94
H_{16}	15.43**	-7.16**	38.43**	42.05**	15.70	75.55*	50.34**	19.37	85.45**	39.33*	20.78	18.10
H_{17}	15.32**	-4.78**	41.99**	43.12**	18.14	79.24**	50.10**	22.15	89.78**	23.33	4.28	8.25
H_{18}	14.58**	-8.12**	37.00**	32.91*	8.53	64.67	44.14**	16.80	81.46**	-9.42	-23.31	-20.63
SE ±	1.44	1.66	1.66	8.33	9.62	9.62	6.32	7.29	7.29	1.65	1.91	1.91

*significant at 5% level, **significant at 1% level

Table 26. Relative heterosis, heterobeltiosis and standard heterosis (%) for yield and yield attributes - II

Hybrids	Productive tillers /plant			Panicle length (cm)			Spikelets / panicle			Grains / panicle		
	di	dii	diii	di	dii	diii	di	dii	diii	di	dii	diii
H_1	-9.06	-9.77	-12.50	0.63	-3.73	15.73**	18.21**	15.98**	61.35**	26.12**	12.05	71.40**
H_2	24.22	24.22	20.45	14.87**	10.82**	21.71**	35.54**	17.81**	63.90**	47.33**	23.19**	88.45**
H_3	-17.69	-18.94	-18.94	4.62	0.00	9.76**	8.79**	-6.50*	30.08**	11.69	-7.65	41.27**
H_4	-24.20	-27.08	-23.48	5.58	1.21	11.10**	4.85	-5.10*	32.03**	17.91	-3.71	47.29**
H_5	2.36	-4.41	6.82	-7.66*	-10.82**	-2.20	-13.62**	-24.07**	5.64	-3.45	-24.83**	14.99
H_6	12.92	6.99	15.91	5.03	3.64	13.78**	25.19**	0.42	39.71**	35.82**	7.40	64.30**
H_7	14.52	-1.98	31.44	17.49**	14.3**	45.49**	10.05**	8.15**	49.97**	22.50**	2.41	81.12**
H_8	0.33	-13.56	15.91	19.94**	8.10**	37.56**	13.02**	-1.62	36.42**	19.99*	-5.12	67.81**
H_9	-35.60*	-43.79**	-24.62	24.37**	11.15**	41.46**	30.72**	12.49**	55.99**	49.45**	16.97*	106.88**
H_{10}	8.08	-3.67	29.17	15.43**	3.43	31.58**	20.14**	8.90**	51.01**	58.18**	22.41**	116.49**
H_{11}	-14.33	-21.47	5.30	22.45**	10.49**	40.61**	28.09**	12.75**	56.35**	59.92**	18.50*	109.57**
H_{12}	-45.94**	-51.13**	-34.47	18.38**	8.96**	38.66**	42.46**	14.43**	58.67**	62.51**	22.13**	116.00**
H_{13}	11.31	-2.38	-6.82	2.05	-1.13	26.83**	10.16**	6.68**	52.44**	19.98**	-4.54	91.89**
H_{14}	7.62	-6.25	-9.09	17.05**	5.10	34.88**	18.70**	2.02	45.78**	33.83**	1.15	103.33**
H_{15}	19.38	2.65	2.65	19.89**	6.74*	36.99**	34.64**	14.43**	63.51**	43.66**	7.56	116.23**
H_{16}	35.76	14.44	20.08	15.93**	3.50	32.80**	32.33**	18.36**	69.13**	50.87**	11.78	124.71**
H_{17}	23.71	1.69	13.64	21.98**	9.64**	40.73**	33.73**	16.21**	66.07**	56.11**	11.15	123.44**
H_{18}	-9.66	-24.83	-18.56	9.18**	0.09	28.41**	22.78**	-2.48	39.35**	12.46	-18.88**	63.07**
SE ±	1.61	1.86	1.86	0.43	0.50	0.50	2.24	2.59	2.59	4.98	5.75	5.75

*significant at 5% level, **significant at 1% level

Table 27. Relative heterosis, heterobeltiosis and standard heterosis (%) for yield and yield attributes - III

Hybrids	Seed set (%)			1000 grain weight (g)			Root length (cm)			Shoot weight (g)		
	di	dii	diii	di	dii	diii	di	dii	diii	di	dii	diii
H_1	6.88	-3.54	6.53	4.68	-4.04	15.15	-40.46**	-42.45*	5.99*	-20.30	-27.50	43.28
H_2	9.47	4.45	15.35	2.97	-0.67	19.19	22.36	-14.01	58.36	0.77	-19.34	59.42
H_3	3.35	-1.53	8.75	-17.36	-24.24*	-9.09	-3.60	-25.63	36.96	-2.13	-26.31	45.65
H_4	13.58	1.12	11.68	-35.88**	-37.35**	-21.21	10.75	-12.84	60.51*	9.44	-16.55	64.94
H_5	13.81	-1.42	8.87	-56.62**	-59.60**	-51.52**	29.43	2.25	88.30**	4.46	-22.54	53.10
H_6	8.75	6.77	17.92	-1.46	-6.57	12.12	68.32**	19.03	119.21**	26.30	-4.08	89.58*
H_7	11.57	-5.46	20.98	19.4*	17.65	21.21	4.67	-13.61	128.14**	40.99**	15.28	193.86**
H_8	8.32	-3.38	23.64*	18.64*	14.13	27.27*	27.12	-18.47	115.31**	63.41**	19.76	205.29**
H_9	16.50	3.77	32.80**	22.39*	20.59	24.24*	-4.33	-34.05**	74.15*	73.91**	21.07	208.62**
H_{10}	34.09**	12.22	43.60**	16.56	6.02	33.33**	-14.66	-40.25**	57.78	73.02**	21.73	210.31**
H_{11}	28.59**	4.94	34.28**	12.96	12.68	16.67	-17.89	-42.34**	52.27	55.22**	6.68	171.94**
H_{12}	16.30*	6.51	36.30**	-10.79	-12.68	-6.06	-30.34	-55.1**	18.57	80.21**	26.36	222.12**
H_{13}	9.75	-10.55	26.22	-1.58	-5.45	-5.45	8.79	7.35	84.49**	8.03	-13.99	135.10**
H_{14}	15.69*	-1.03	39.64**	19.05*	3.20	21.21	20.75	-12.68	46.10	74.45**	25.12	242.00**
H_{15}	9.78	-6.20	32.35**	-9.57	-1.52	-13.13	38.47	10.61	85.07**	42.24*	-2.86	165.52**
H_{16}	17.01*	-5.75	32.99**	0.88	0.16	9.90	26.27	3.03	72.38*	44.59**	-0.26	172.64**
H_{17}	21.41*	-4.49	34.76**	23.21*	3.75	20.54	26.42	3.56	73.28*	49.94**	1.16	176.50**
H_{18}	-5.14	-16.80*	17.40	9.26	1.52	9.09	16.30	-15.33	41.67	49.62**	2.88	181.21**
SE ±	5.58	6.45	6.45	1.58	1.82	1.82	1.84	2.12	2.12	1.54	1.78	1.78

*significant at 5% level, **significant at 1% level

Table 28. Relative heterosis, heterobeltiosis and standard heterosis (%) for yield and yield attributes - IV

Hybrids	Root weight (g)			Visual scoring for iron toxicity symptoms			Grain yield/ plant (g)		
	Di	dii	diii	di	Dii	diii	di	dii	diii
H_1	-27.92	-34.69	26.10	41.94**	37.50**	0.05	15.47	-5.02	72.79
H_2	-11.50	-28.82	37.44	61.54**	31.25**	-4.50	83.03**	47.22*	170.71**
H_3	-21.57	-40.47	14.94	-15.79**	-27.27**	-27.24**	-28.93	-44.44	4.16
H_4	-9.90	-25.40	44.03	-18.92**	-28.57**	-31.79**	-41.53	-50.56*	-11.16
H_5	21.84	-12.31	69.32	10.53*	-4.55	-4.50	-53.61*	-64.71**	-40.41
H_6	50.71*	13.97	120.06**	-21.05**	-31.82**	-31.79**	54.78	18.26	113.64*
H_7	24.39	-1.48	164.52**	-25.00**	-40.00**	-59.07**	60.56**	19.09	188.72**
H_8	15.36	-17.07	122.66**	5.26	0.00	-54.52**	39.77	1.77	147.69**
H_9	41.32*	-3.02	160.39**	-35.48**	-54.55**	-54.52**	13.19	-19.51	93.85*
H_{10}	43.45*	5.56	183.41**	6.67	-23.81**	-27.24**	102.96**	54.04**	273.04**
H_{11}	19.48	-21.38	111.09**	3.23	-27.27**	-27.24**	52.06*	5.76	157.60**
H_{12}	32.17	-9.56	142.81**	-3.23	-31.82**	-31.79**	-21.75	-45.39*	33.04
H_{13}	6.15	-12.88	112.97**	-50.00**	-60.00**	-72.71**	32.64	24.90	69.14
H_{14}	81.46**	34.35*	228.43**	-5.26	-10.00	-59.07**	85.43**	69.99*	124.17**
H_{15}	45.63*	2.61	150.83**	-41.94**	-59.09**	-59.07**	62.79	44.18	92.92*
H_{16}	30.45	-0.98	142.05**	-40.00**	-57.14**	-59.07**	124.27**	118.24**	196.69**
H_{17}	46.83*	-1.10	141.76**	-3.23	-31.82**	-31.79**	167.13**	128.97**	206.22**
H_{18}	53.73*	7.98	163.95**	-3.23	-31.82**	-31.79**	37.19	18.19	44.95
SE ±	0.61	0.71	0.71	0.26	0.30	0.30	2.47	2.85	2.85

*significant at 5% level, **significant at 1% level

the negative direction. Standard heterosis ranged from -35.24 (H_{12}) to 28.25 (H_{10}). None of the hybrids showed significant standard heterosis.

4.4.5 Productive tillers/plant

Only two hybrids showed significance for relative heterosis and heterobeltiosis which was registered in the negative direction, while none of them were significant for standard heterosis for productive tillers. The values ranged from -45.94 (H_{12}) to 35.76 (H_{16}), -51.13 (H_{12}) to 24.22 (H_2) and -34.47 (H_{12}) to 31.44 (H_7) for relative heterosis, heterobeltiosis and standard heterosis respectively.

4.4.6 Panicle length (cm)

Thirteen, nine and seventeen hybrids among eighteen hybrids recorded significance for relative heterosis, heterobeltiosis and standard heterosis respectively for panicle length. Hybrid, H_5 registered significant negative relative heterosis and heterobeltiosis. Relative heterosis value ranged between -7.66 (H_5) and 24.37 (H_9), while heterobeltiosis varied from -10.82 (H_5) to 14.30 (H_7). Standard heterosis value lied between -2.20 (H_5) and 45.49 (H_7) among the hybrids. Eight hybrids registered significance for all types of heterosis.

4.4.7 Spikelets/ panicle

All hybrids except H_4 exhibited significant relative heterosis for this trait, which ranged from -13.62 (H_5) to 42.46 (H_{12}). H_5 alone registered significant relative heterosis in the negative direction. Fourteen hybrids recorded significant heterobeltiosis among which H_5 registered negative significance. Heterobeltiosis value varied from -24.07 (H_5) to 18.36 (H_{16}). Except (H_5) all hybrids recorded significant standard heterosis. Lowest standard heterosis for this trait was recorded for 5.64 (H_5) and highest for 69.13 (H_{16}). Twelve hybrids recorded significant for all the three types of heterosis.

4.4.8 Grains/panicle

Relative heterosis ranged from -3.45 (H_5) to 62.51 (H_{12}). Fourteen hybrids showed significant relative heterosis, while seven hybrids had significant heterobeltiosis. H_5 registered negative significant heterobeltiosis. Heterobeltiosis varied from -24.83 (H_5) to 23.19 (H_2). All except (H_5) had significant standard heterosis which varied from 14.99 (H_5) to 124.71 (H_{16}). Five hybrids recorded significance for all, relative heterosis, heterobeltiosis and standard heterosis.

4.4.9 Seed set (%)

Lowest relative heterosis for this trait was recorded for -5.41 (H_{18}) while highest was for 34.09 (H_{10}) Six hybrids registered significance for relative heterosis for this trait. Only one hybrid H_{18} recorded significant heterobeltiosis which was in the negative direction and it ranged from -16.80 (H_{18}) to 12.22 (H_{10}). Nine hybrids recorded significant standard heterosis which varied from 6.53 (H_1) to 43.60 (H_{10}).

4.4.10 Thousand grain weight (g)

Seven, three and four among the hybrids recorded significance for relative heterosis, heterobeltiosis and standard heterosis for this trait respectively. Relative heterosis ranged between -56.62 (H_5) and 23.21 (H_{17}). Heterobeltiosis varied between -59.60 (H_5) and 20.59 (H_9) while standard heterosis was between -51.52 (H_5) and 33.33 (H_{10}). H_5 was negatively significant for all three types of heterosis, while H_4 registered negative significance for relative heterosis and heterobeltiosis.

4.4.11 Root length (cm)

Relative heterosis was recorded the lowest for -40.46 (H_1) and highest for 68.32 (H_6). Only two hybrids registered significant relative heterosis for this trait of which H_1 registered negative significance. Five hybrids recorded negative significant heterobeltiosis which ranged from -55.10 (H_{12}) to 19.03 (H_6). All hybrids reported positive values for standard heterosis which varied from 5.99 (H_1) to 128.14 (H_7). Eleven hybrids registered significant standard heterosis for this trait. H_1 reported significant negative relative heterosis and heterobeltiosis and significant positive standard heterosis.

4.4.12 Shoot weight (g)

Eleven hybrids recorded significant positive relative heterosis which ranged between -20.30 (H_1) to 80.21 (H_{12}). Heterobeltioisis varied from -27.50 (H_1) to 26.36 (H_{12}). None of the hybrids registered significant heterobeltiosis, while thirteen hybrids showed significant positive standard heterosis for this trait. Standard heterosis ranged between 43.28 (H_1) to 242.00 (H_{14}).

4.4.13 Root weight (g)

Hybrid, H_{14} registered positive significance for all the three types of heterosis. Seven hybrids reported significant relative heterosis which ranged from -27.92 (H_1) to 81.46 (H_{14}). Only one hybrid recorded significant heterobeltiosis while thirteen hybrids registered significant standard heterosis. Lowest heterobeltiosis was for H_3 (-40.47) and highest for H_{14} (34.35). Standard heterosis varied from 14.94 (H_3) to 228.43 (H_{14}).

4.4.14 Visual scoring for iron toxicity symptoms

Relative heterosis for visual scoring ranged from -50.00 (H_{13}) to 61.54 (H_2) and heterobeltiosis varied from -60.00 (H_{13}) to 37.50 (H_1). In standard heterosis lowest was reported for H_{13} (-72.71) and highest for H_1 (0.05). Eleven hybrids registered significance for relative heterosis of which eight hybrids recorded significance in the negative direction. Fifteen hybrids registered significant heterobeltiosis among which thirteen hybrids were negatively significant. Among the hybrids fifteen of them registered negative standard heterosis and all of them were negative except (H_1).

4.4.15. Grain yield/plant (g)

Five hybrids recorded significance for all the three types of heterosis for grain yield. Eight hybrids registered significance for relative heterosis. Similarly eight hybrids registered significant heterobeltiosis. H_5 registered negative significance for relative heterosis and heterobeltiosis. Eleven hybrids were significant for standard heterosis. The values ranged from -53.61 (H_5) to 167.13 (H_{17}) and -64.71 (H_5) to 128.97 (H_{17}) for relative heterosis and heterobeltiosis respectively. Standard heterosis varied from -40.41 (H_5) to 273.04 (H_{10}).

B. Laboratory screening for iron toxicity tolerance

4.5 Influence of genotypes and varying iron levels on yield attributes

4. 5. 1. Analysis of variance

The yield attributes observed at different iron levels in rice genotypes comprising of lines, testers, hybrids and two check varieties were subjected to analysis of variance. The result is given in Table 29.

High significant mean squares of genotypes (Factor A) revealed the existence of significant differences among the genotypes for all the yield attributes studied. High significant mean squares of iron levels (Factor B) revealed that the yield attributes varied significantly at different levels of iron. Results revealed significant interaction effects of genotype x iron levels for all yield attributes studied. This indicated that among genotypes, the variations in yield attributes were significantly different at varying iron levels.

Table 29. Analysis of variance for yield attributes in laboratory screening for iron toxicity tolerance (30 DAS)

Source	df	Shoot length (cm)	Root length (cm)	Total number of roots	Number of fresh roots	Vigour index	Biomass (g)	Iron adsorbed on root surface (mg kg^{-1})	Visual scoring for iron toxicity symptoms
Factor A (Genotypes)	28	73.067**	9.050**	10.469**	0.973**	8.579**	0.032**	111.445**	7.770**
Factor B(Iron level)	1	37.570**	37.666**	11.172**	1.838**	54.608**	0.193**	37537.913**	541.887**
Factor AB(Genotypes x Iron level)	28	11.425**	11.588**	1.583**	0.400**	8.504**	0.004**	108.667**	6.177**
Error	58	1.456	0.358	0.274	0.094	0.457	0.000	4.194	0.557
CV		9.770	12.790	11.940	39.990	20.030	8.540	10.920	16.820
SE (AB)		0.853	0.423	0.371	0.217	0.478	0.008	1.448	0.528
CD		2.413	1.197	1.048	0.614	1.352	0.021	4.095	1.493

**significant at 1% level

DAS: days after sowing

4.5.2 Influence of genotypes on yield attributes

The performance of individual rice genotypes averaged over varying levels of iron concentration on the yield attributes is detailed in Table 30 and described below.

4.5.2.1 Shoot length (cm)

Shoot length varied from 5.84 cm to 23.00 cm. Maximum shoot length was observed in check genotype C_2 (23.00 cm). It was found superior to all other genotypes for this attribute. The next best genotypes were testers T_1 (18.11 cm), T_2 (17.96 cm) followed by lines L_1 (17.16 cm), L_2 (17.13 cm).These genotypes were found to be on par with each other with respect to this attribute. The least estimate for shoot length was recorded in H_5 (5.84 cm). It was found to be on par with H_1, H_2 and H_4.

4.5.2.2 Root length (cm)

Root length ranged between 1.79 cm and 7.77 cm. Maximum root length was recorded in line L_1 (7.77 cm) followed by hybrid H_{15} (6.81 cm). L_1 was found to be superior to all other varieties for this attribute while H_{15} was found to be on par with T_3 (6.15 cm), H_{10} (6.64 cm), and C_1 (6.25). Minimum root length was recorded in hybrid H_{16} (1.79 cm). H_{16} was found to be on par with H_5, H_{14} and H_{18}.

4.5.2.3 Total number of roots

Total number of roots ranged from 2.10 (H_5) to 8.10 (L_1). Line L_1 was found to be superior to all other genotypes for this attribute. H_5 was found to be on par with H_1, H_2, H_8, H_9, H_{10}.

Table 30. Performance of rice genotypes averaged over different levels of iron in laboratory screening for iron toxicity tolerance (30 DAS)

Genotypes	Shoot length (cm)	Root length (cm)	Total number of roots	Number of fresh roots	Vigour index	Biomass (g)	Iron adsorbed on root surface (ppm)	Visual scoring for iron toxicity symptoms
Lines								
L_1	17.16^{bc}	7.77^{a}	8.10^{a}	2.15^{a}	2.22^{ghijkl}	0.229^{c}	20.81^{ab}	1.80^{i}
L_2	17.13^{bc}	4.38^{hijk}	5.20^{def}	0.90^{cdefgh}	4.23^{cde}	0.199^{cd}	22.26^{ab}	3.70^{fgh}
L_3	15.65^{cde}	4.58^{ghij}	6.35^{bc}	1.40^{bc}	3.64^{def}	0.128^{fghi}	22.85^{ab}	3.52^{gh}
Testers								
T_1	18.11^{b}	5.53^{defg}	6.95^{b}	0.90^{cdefgh}	3.28^{efg}	0.049^{jk}	22.68^{ab}	5.18^{abcde}
T_2	17.96^{b}	5.39^{defg}	6.75^{b}	0.90^{cdefgh}	3.69^{def}	0.079^{hijk}	20.99^{ab}	3.57^{gh}
T_3	16.35^{bcd}	6.15^{bcde}	5.90^{cd}	1.10^{cdef}	2.69^{fghijk}	0.179^{de}	22.11^{ab}	2.94^{h}
T_4	15.09^{de}	5.44^{defg}	6.40^{bc}	1.35^{bcd}	2.87^{fghij}	0.054^{jk}	23.14^{ab}	4.90^{abcdef}
T_5	9.93^{hijk}	3.67^{jkl}	6.35^{bc}	0.45^{hij}	2.62^{fghijk}	0.048^{jk}	11.74^{de}	5.30^{abcd}
T_6	14.50^{def}	3.48^{klm}	5.05^{ef}	0.60^{fghij}	5.23^{bc}	0.298^{b}	20.93^{ab}	1.70^{i}
Hybrids								
H_1	6.19^{m}	2.76^{lmn}	2.60^{jkl}	0.35^{ij}	2.42^{ghijkl}	0.056^{jk}	13.78^{cd}	6.00^{a}
H_2	7.44^{lm}	5.34^{defgh}	2.90^{jkl}	0.30^{ij}	1.62^{kl}	0.049^{jk}	20.91^{ab}	5.10^{abcde}
H_3	8.33^{jkl}	4.25^{ijk}	3.85^{ghi}	1.75^{ab}	2.08^{hijkl}	0.048^{jk}	3.72^{f}	5.15^{abcde}
H_4	7.32^{lm}	5.36^{defgh}	3.40^{hij}	0.50^{hij}	2.17^{ghijkl}	0.056^{jk}	10.22^{e}	4.00^{efgh}
H_5	5.84^{m}	2.62^{mno}	2.10^{l}	0.30^{ij}	2.32^{ghijkl}	0.046^{k}	10.24^{e}	5.25^{abcde}
H_6	8.09^{kl}	5.83^{cdef}	4.05g^{h}	0.55^{ghij}	1.39^{l}	0.056^{jk}	21.02^{ab}	5.05^{abcde}
H_7	11.21^{gh}	4.57^{ghij}	3.40^{hij}	0.50^{hij}	2.81^{fghij}	0.077^{ijk}	22.57^{ab}	5.48^{abc}
H_8	9.75^{hijk}	5.25^{efgh}	2.75^{jkl}	0.75^{efghi}	1.94^{ijkl}	0.080^{hijk}	15.59^{c}	5.75^{a}
H_9	8.83^{ijkl}	3.69^{kl}	2.90^{jkl}	0.15^{j}	2.80^{fghij}	0.082^{hijk}	10.64^{de}	5.70^{ab}
H_{10}	8.15^{kl}	6.64^{bc}	2.20^{kl}	0.20^{j}	2.71^{fghijk}	0.082^{hijk}	11.66^{de}	5.03^{abcde}
H_{11}	13.69^{ef}	2.39^{no}	3.25^{hij}	0.45^{hij}	7.02^{a}	0.123^{fghi}	22.65^{ab}	5.63^{ab}
H_{12}	13.80^{ef}	5.03^{fghi}	3.80^{ghi}	0.60^{fghij}	5.28^{bc}	0.201^{cd}	21.53^{ab}	4.13^{defgh}
H_{13}	10.75^{hi}	5.10^{fghi}	3.45^{hij}	0.45^{hij}	3.22^{efgh}	0.131^{efgh}	20.83^{ab}	5.63^{ab}
H_{14}	12.70^{fg}	2.72^{lmno}	3.25^{hij}	0.30^{ij}	5.48^{b}	0.088^{hijk}	21.66^{ab}	5.75^{a}
H_{15}	10.25^{hij}	6.81^{b}	5.05^{ef}	0.90^{cdefgh}	1.76^{jkl}	0.150^{efg}	21.15^{ab}	4.45^{bcdefg}
H_{16}	10.29^{hij}	1.79^{o}	3.00^{ijk}	0.20^{j}	6.74^{a}	0.050^{jk}	20.70^{ab}	5.72^{ab}
H_{17}	15.35^{cde}	5.15^{fghi}	5.15^{def}	1.25^{cde}	3.07^{fghi}	0.154^{def}	23.80^{a}	4.31^{cdefg}
H_{18}	9.86^{hijk}	2.30^{no}	3.15^{ij}	0.65^{fghij}	4.38^{cd}	0.101^{ghij}	20.20^{b}	5.08^{abcde}
C_1	15.50^{cde}	6.25^{bcd}	5.50^{de}	1.30^{bcd}	3.67^{def}	0.356^{a}	20.23^{b}	1.33^{i}
C_2	23.00^{a}	5.65^{def}	4.50^{fg}	1.05^{cdefg}	4.49^{bcd}	0.343^{a}	23.27^{ab}	1.55^{i}

Means in each column with at least one letter in common are not significantly different at 1% level of probability

DAS: days after sowing

4.5.2.4 Number of fresh roots

This trait varied from 0.15 to 2.15. Number of fresh roots was registered the maximum by L_1 (2.15) and it was on par with H_3 and superior to all other genotypes. Minimum value for this trait was registered by H_9 (0.15) and it was on par with T_5, T_6 and all the hybrids except H_3, H_8, H_{15} and H_{17}.

4.5.2.5 Vigour index (SL/RL)

Vigour index varied between 1.38 and 7.02. H_{11} (7.02) recorded the highest vigour index and it was on par with H_{16} (6.74). H_6 recorded the least value (1.39) and it was on par with L_1, H_1, H_2, H_3, H_4, H_5, H_6, H_8 and H_{15}.

4.5.2.6 Biomass (g)

The range for biomass was from 0.046 g to 0.356 g. C_1 (0.356 g) registered the highest biomass and was found to be on par with C_2 and superior from all others. H_5 (0.046 g) recorded least biomass and it was on par with the testers, *viz.* T_1, T_2, T_3, T_4, T_5 and all the hybrids except H_{11} H_{12}, H_{13}, H_{15}, H_{17} and H_{18}.

4.5.2.7 Iron adsorbed on root surface (mg kg^{-1})

Iron adsorbed on root surface varied between 3.72 mg kg^{-1} to 23.80 mg kg^{-1}. Maximum value for this trait was recorded by H_{17} (23.80 mg kg^{-1}) and it was on par with all the parents except T_5 and also with the check C_2. Among hybrids, it was on par with H_2, H_6, H_7, H_{11}, H_{12}, H_{13}, H_{14}, H_{15}, H_{16}. Minimum value for this trait was recorded by H_3 (3.72 mg kg^{-1}) and it was found to be inferior to all other genotypes.

4.5.2.8 Visual scoring for iron toxicity symptoms

This trait ranged from 1.33 to 6.00. Lowest value for visual scoring was registered by check C_1 (1.33) and it was found to be on par with C_2 (1.55), L_1 (1.80) and T_6 (1.70). Maximum value was registered by H_1 (6.00) which was on par with T_1, T_4, T_5, H_2, H_3, H_5, H_6, H_7, H_8, H_9, H_{10}, H_{11}, H_{13}, H_{14}, H_{16} and H_{18}.

4.5.3 Influence of iron levels on yield attributes

Comparison of yield attributes at different levels of iron (0 ppm and 600 ppm iron) is given in Table 31.

4.5.3.1 Shoot length (cm)

Shoot length of seedlings (12.92 cm) in control (0 ppm iron) was found to be superior to that at 600 ppm of iron (11.78 cm).

4.5.3.2 Root length (cm)

Root length at 600 ppm (5.25 cm) was superior to that in control (4.11 cm).

4.5.3.3 Total number of roots

Total number of roots recorded a value of 4.70 at 0 ppm which was found to be superior to that produced at 600 ppm iron (4.08).

4.5.3.4 Number of fresh roots

Number of fresh roots was found to be superior at 600 ppm level (0.89) to that at 0 ppm (0.64)

4.5.3.5 Vigour index (SL/RL)

Vigour index recorded a value of 4.06 at control level was and found to be superior to that at 600 ppm iron (2.69)

Table 31. Effect of different levels of iron on yield attributes of rice genotypes in laboratory screening for iron toxicity tolerance (30 DAS)

Concentration of iron	Shoot length (cm)	Root length (cm)	Total number of roots	Number of fresh roots	Vigour index	Biomass (g)	Iron adsorbed on root surface (mg kg^{-1})	Visual scoring for iron toxicity symptoms
0 ppm	12.92^{a}	4.11^{b}	4.70^{a}	0.64^{b}	4.06^{a}	0.164^{a}	0.77^{b}	2.29^{b}
600 ppm	11.78^{b}	5.25^{a}	4.08^{b}	0.89^{a}	2.69^{b}	0.083^{b}	36.74^{a}	6.60^{a}

Means in each column with at least one letter in common are not significantly different at 1% level of probability

DAS: days after sowing

4.5.3.6 Biomass

Biomass production at 0 ppm iron (0.164 g) was found to be superior to that at 600 ppm iron (0.083 g).

4.5.3.7 Iron adsorbed on root surface (mg kg^{-1})

Iron adsorbed on root surface registered a very high value at 600 ppm iron (36.74 mg kg^{-1}) which was superior to that adsorbed at 0 ppm iron (0.77 mg kg^{-1}).

4.5.3.8 Visual scoring for iron toxicity symptoms

Visual scoring for iron toxicity symptoms at control level registered a low value of 2.28 and distinctly varying from that at 600 ppm (6.60).

4.5.4 Influence of genotype x iron interaction on yield attributes

The interaction effects of genotype x iron levels on yield attributes of rice genotypes are given in Table 32 and Table 33 and. the results enumerated below

4.5.4.1 Shoot length (cm)

Shoot length varied between 8.00 cm (H_8 and H_{10}) and 23.45 cm (C_1) at 0 ppm iron. It ranged between 4.03 cm (H_5) to 22.55 cm (C_2) at 600 ppm. Over the two levels of iron (0ppm and 600 ppm) shoot length varied from 4.03 cm (H_5) at 600 ppm iron to 23.45 cm in check variety C_2 at 0 ppm.

Shoot length of C_2 at 0 ppm was on par with its performance at 600 ppm (22.55 cm). Hybrid H_1 (4.67 cm), H_4 (6.00 cm) and tester T_5 (5.60 cm) also recorded very low values of shoot length and were on par with minimum value of H_5 at 600 ppm.

Table 32. Genotype x Iron interaction effect on yield attributes in laboratory screening for iron toxicity tolerance (30 DAS) –I

Genotypes	Shoot length (cm)		Root length (cm)		Total number of roots		Number of fresh roots	
	0 ppm	600 ppm	0 ppm	600 ppm	0 ppm	600 ppm	0 ppm	600 ppm
Lines								
L_1	$15.45^{efghijk}$	18.86^{cd}	8.10^{cd}	7.43^{cdef}	9.30^{a}	6.90^{cd}	2.00^{bc}	2.30^{b}
L_2	17.90^{de}	$16.35^{defghij}$	3.35^{pqrstu}	5.40^{hijklm}	6.20^{defg}	$4.20^{klmnopqrs}$	0.80^{efghi}	1.00^{defgh}
L_3	14.15^{ijklmn}	17.15^{defgh}	3.30^{qrstu}	5.85^{ghijkl}	6.70^{cde}	6.00^{defgh}	1.10^{defg}	1.70^{bcd}
Testers								
T_1	$15.40^{efghijk}$	20.83^{bc}	4.80^{klmno}	6.25^{efghij}	8.40^{ab}	5.50^{efghij}	0.80^{efghi}	1.00^{defgh}
T_2	17.28^{defg}	18.64^{cd}	3.70^{nopqrs}	7.07^{defg}	7.50^{bc}	6.00^{defgh}	0.50^{ghi}	1.30^{cdef}
T_3	$14.90f^{ghijklm}$	17.80^{de}	5.60^{hijklm}	6.70^{efgh}	$5.30^{fghijkl}$	6.50^{cdef}	0.60^{fghi}	1.60^{cd}
T_4	$14.50^{ghijklm}$	$15.67^{efghijk}$	4.81^{jklmno}	6.06^{fghijk}	6.90^{cd}	5.90^{defgh}	0.80^{efghi}	1.90^{bc}
T_5	14.25^{ijklmn}	$5.60^{yz[}$	4.90^{jklmno}	2.43^{stuvw}	6.50^{cdef}	6.20^{defg}	0.80^{efghi}	0.10^{i}
T_6	13.70^{jklmno}	$15.30^{efghijkl}$	4.95^{jklmn}	2.00^{uvw}	$5.20^{ghijklm}$	$4.90^{hijklmno}$	0.60^{fghi}	0.60^{fghi}
Hybrids								
H_1	7.71^{uvwxy}	$4.67^{z[}$	3.79^{nopqrs}	1.72^{vw}	3.00^{stuv}	2.20^{uvw}	0.40^{ghi}	0.30^{hi}
H_2	7.88^{uvwxy}	7.00^{wxyz}	3.50^{opqrst}	7.17^{defg}	3.50^{pqrst}	2.30^{tuvw}	0.30^{hi}	0.30^{hi}
H_3	9.67^{rstuvw}	7.00^{wxyz}	3.50^{opqrst}	5.00^{ijklmn}	3.70^{opqrs}	$4.00^{mnopqrs}$	0.50^{ghi}	3.00^{a}
H_4	8.63^{tuvwx}	$6.00^{xyz[}$	2.38^{stuvw}	8.33^{cd}	$4.50^{ijklmnop}$	2.30^{tuvw}	0.30^{hi}	0.70^{fghi}
H_5	7.64^{uvwxy}	$4.03^{[}$	$3.60^{nopqrst}$	1.64^{vw}	3.20^{qrstuv}	1.00^{x}	0.40^{ghi}	0.20^{i}
H_6	9.29^{stuvw}	6.90^{wxyz}	5.86^{ghijkl}	5.80^{ghijkl}	3.70^{opqrs}	$4.40^{ijklmnopq}$	0.30^{hi}	0.80^{efghi}
H_7	10.00^{qrstuv}	$12.42^{lmnopqr}$	2.71^{stuvw}	6.42^{efghi}	3.10^{rstuv}	3.70^{opqrs}	0.30^{hi}	0.70^{fghi}
H_8	8.00^{uvwxy}	11.50^{nopqrs}	6.00^{ghijk}	4.50^{lmnopq}	2.00^{vwx}	3.50^{pqrst}	1.00^{defgh}	0.50^{ghi}
H_9	8.20^{uvwxy}	9.46^{stuvw}	4.76^{klmnop}	2.44^{stuvw}	3.40^{pqrstu}	2.40^{tuvw}	0.20^{i}	0.10^{i}
H_{10}	8.00^{uvwxy}	8.30^{uvwxy}	11.50^{a}	1.78^{vw}	3.00^{stuv}	1.40^{wx}	0.20^{i}	0.20^{i}
H_{11}	$14.39^{hijklmn}$	13.00^{klmnop}	1.44^{vw}	3.33^{qrstu}	3.30^{pqrstu}	3.20^{qrstuv}	0.20^{i}	0.70^{fghi}
H_{12}	$15.35^{efghijk}$	12.25^{mnopqr}	1.75^{vw}	8.30^{cd}	$4.10^{lmnopqrs}$	3.50^{pqrst}	0.60^{fghi}	0.60^{fghi}
H_{13}	$14.00^{ijklmno}$	7.50^{uvwxy}	2.70^{stuvw}	7.50^{cde}	3.40^{pqrtu}	3.50^{pqrst}	0.40^{ghi}	0.50^{ghi}
H_{14}	14.20^{ijklmn}	11.20^{opqrst}	1.85^{vw}	$3.60^{nopqrst}$	3.20^{qrstuv}	3.30^{pqrstu}	0.40^{ghi}	0.20^{i}
H_{15}	$12.75^{klmnopq}$	7.75^{uvwxy}	4.87^{jklmno}	8.75^{bc}	5.80^{defgh}	$4.30^{jklmnopqr}$	1.00^{defgh}	0.80^{efghi}
H_{16}	13.33^{klmno}	7.25^{vwxyz}	1.33^{w}	2.24^{tuvw}	2.30^{tuvw}	3.70^{opqrs}	0.20^{i}	0.20^{i}
H_{17}	17.65^{def}	13.06^{klmnop}	4.55^{lmnopq}	5.75^{ghijkl}	6.50^{cdef}	3.80^{opqrs}	1.50^{cde}	1.00^{defgh}
H_{18}	10.35^{pqrstu}	9.37^{stuvw}	2.55^{stuvw}	2.04^{uvw}	3.30^{pqrstu}	3.00^{stuv}	0.80^{efghi}	0.50^{ghi}
Check - C_1	16.70^{defghi}	$14.30^{hijklmn}$	2.85^{rstuv}	9.65^{b}	5.40^{fghijk}	5.60^{efghi}	1.10^{defg}	1.50^{cde}
Check - C_2	23.45^{a}	22.55^{ab}	4.20^{mnopqr}	7.10^{defg}	3.90^{nopqrs}	$5.10^{ghijklmn}$	0.50^{ghi}	1.60^{cd}

Means in each column with at least one letter in common are not significantly different at 1% level of probability

DAS: days after sowing

Table 33. Genotype x Iron interaction effect on yield attributes in laboratory screening for iron toxicity tolerance (30 DAS) – II (contd.)

Genotypes	Vigour index		Biomass (g)		Iron adsorbed on root surface (mg kg $^{-1}$)		Visual scoring for iron toxicity symptoms	
	0 ppm	600 ppm	0 ppm	600 ppm	0 ppm	600 ppm	0 ppm	600 ppm
Lines								
L_1	$1.91^{ijklmnopq}$	$2.53^{ghijklmnop}$	0.256^{cdef}	0.203^{fghij}	1.48^{h}	40.13^{c}	1.73^{ijk}	1.90^{ijk}
L_2	5.39^{cd}	$3.07^{efghijkl}$	0.224^{fghi}	0.175^{ghijk}	1.14^{h}	43.39^{abc}	2.73^{hijk}	4.73^{g}
L_3	4.30^{cdef}	$2.98^{fghijklm}$	0.143^{jklmno}	0.114^{klmnop}	1.15^{h}	44.54^{abc}	2.20^{ijk}	4.83^{g}
Testers								
T_1	$3.21^{efghijk}$	3.35^{efghij}	0.049^{pqrst}	0.049^{pqrst}	0.88^{h}	44.47^{abc}	2.62^{ijk}	7.73^{abcd}
T_2	4.68^{cde}	$2.70^{fghijklmn}$	0.099^{lmnopq}	0.058^{pqrst}	0.85^{h}	41.12^{bc}	2.63^{ijk}	4.50^{gh}
T_3	$2.67^{fghijklmn}$	$2.71^{fghijklmn}$	0.174^{ghijk}	0.183^{fghijk}	1.29^{h}	42.92^{abc}	3.00^{i}	2.88^{hij}
T_4	$3.15^{efghijkl}$	$2.59^{ghijklmno}$	0.056^{pqrst}	0.051^{pqrst}	0.73^{h}	45.55^{ab}	3.00^{hi}	6.80^{cdef}
T_5	$2.93^{fghijklm}$	$2.30^{hijklmnopq}$	0.073^{opqrst}	0.022^{qrst}	0.95^{h}	22.52^{ef}	1.80^{ijk}	8.80^{a}
T_6	$2.77^{fghijklmn}$	7.69^{b}	0.300^{cde}	0.296^{cde}	1.03^{h}	40.84^{bc}	1.60^{ijk}	1.80^{ijk}
Hybrids								
H_1	$2.04^{ijklmnopq}$	$2.80^{fghijklmn}$	$0.090^{lmnopqrs}$	0.022^{qrst}	0.81^{h}	26.74^{de}	3.00^{hi}	9.00^{a}
H_2	$2.27^{hijklmnopq}$	0.98^{opq}	$0.078^{nopqrst}$	0.020^{rst}	0.55^{h}	41.27^{bc}	2.60^{ijk}	7.60^{abcde}
H_3	$2.77^{fghijklmn}$	1.40^{mnopq}	0.071^{opqrst}	0.024^{qrst}	0.54^{h}	6.90^{g}	1.50^{ijk}	8.80^{a}
H_4	3.62^{efghi}	0.72^{q}	$0.080^{nopqrst}$	0.032^{qrst}	0.57^{h}	19.86^{f}	1.00^{k}	7.00^{bcdef}
H_5	$2.12^{ijklmnopq}$	$2.53^{ghijklmnop}$	$0.078^{nopqrst}$	0.014^{st}	0.61^{h}	19.88^{f}	1.50^{ijk}	9.00^{a}
H_6	$1.58^{klmnopq}$	1.20^{nopq}	$0.092^{lmnopqr}$	0.020^{rst}	0.60^{h}	41.44^{bc}	2.40^{ik}	7.70^{abcde}
H_7	3.68^{efghi}	$1.93^{ijklmnopq}$	0.143^{jklmno}	0.011^{t}	0.62^{h}	44.53^{abc}	2.90^{hij}	8.07^{abc}
H_8	1.33^{mnopq}	$2.55^{ghijklmno}$	0.149^{ijklmn}	0.010^{t}	0.63^{h}	30.56^{d}	3.00^{hi}	8.50^{abc}
H_9	$1.72^{jklmnopq}$	3.88^{defg}	0.150^{ijklmn}	0.013^{st}	0.63^{h}	20.64^{f}	2.40^{ijk}	9.00^{a}
H_{10}	0.70^{q}	4.71^{cde}	0.151^{ijklmn}	0.013^{st}	0.58^{h}	22.73^{ef}	1.05^{jk}	9.00^{a}
H_{11}	10.14^{a}	3.91^{defgh}	0.237^{efgh}	0.010^{t}	0.60^{h}	44.69^{abc}	2.83^{hijk}	8.43^{abc}
H_{12}	9.06^{ab}	1.50^{lmnopq}	0.217^{fghij}	0.185^{fghijk}	0.60^{h}	42.47^{abc}	2.66^{ijk}	5.60^{fg}
H_{13}	5.44^{cd}	1.00^{opq}	0.249^{defg}	0.012^{st}	0.66^{h}	41.01^{bc}	2.57^{ijk}	8.70^{ab}
H_{14}	7.84^{b}	$3.11^{efghijkl}$	0.164^{hijkl}	0.011^{t}	0.55^{h}	42.78^{abc}	2.50^{ijk}	9.00^{a}
H_{15}	$2.62^{ghijklmno}$	0.89^{pq}	0.204^{fghij}	$0.096^{lmnopqr}$	0.55^{h}	41.74^{bc}	2.83^{hijk}	6.07^{defg}
H_{16}	10.21^{a}	3.27^{efghij}	$0.088^{mnopqrst}$	0.011^{t}	0.83^{h}	40.58^{c}	3.00^{hi}	8.43^{abc}
H_{17}	3.87^{defgh}	$2.27^{hijklmnopq}$	0.235^{efgh}	0.072^{opqrst}	0.77^{h}	46.83^{a}	2.60^{ijk}	6.02^{efg}
H_{18}	4.06^{defg}	4.70^{cde}	0.156^{ijklm}	0.046^{pqrst}	0.64^{h}	39.77^{c}	1.90^{ijk}	8.27^{abc}
$Check_1$	5.84^{c}	1.48^{lmnopq}	0.391^{a}	0.321^{bc}	0.62^{h}	39.84^{c}	1.08^{jk}	1.58^{ijk}
$Check_2$	5.80^{c}	$3.19^{efghijk}$	0.373^{ab}	0.313^{bcd}	0.75^{h}	45.80^{ab}	1.43^{ijk}	1.67^{ijk}

Means in each column with at least one letter in common are not significantly different at 1% level of probability

DAS: days after sowing

4.5.4.2 Root length (cm)

Range of root length at 0 ppm was between 1.33 cm (H_{16}) and 11.50 cm (H_{10}). At 600 ppm level this trait ranged between 1.64 cm (H_6) and 9.65 cm (C_1). Over the two levels of iron toxicity the range for this trait was 1.33 cm (H_{16}) to 11.50 cm (H_{10}).

Maximum root length was registered by H_{10} at 0 ppm and it was found to be superior to all other genotypes. The minimum value of H_{16} at control level was on par with H_4, H_7, H_{11}, H_{12}, H_{13}, H_{14} and H_{18} at control level of iron toxicity and T_5, T_6, H_1, H_5, H_9, H_{10}, H_{16} and H_{18} at 600 ppm level of iron toxicity.

4.5.4.3 Total number of roots

Total number of roots varied between 2.00 (H_8) and 9.30 (L_1) at control level while it ranged between 1.00 (H_5) and 6.90 (L_1) at 600 ppm level. Over the two levels of iron concentration this trait ranged between 1.00 and 9.30

Maximum value for total number of roots over two levels was recorded by L_1 (9.30) at 0 ppm iron which was found to be on par with T_1 (8.40) at control level itself. Over the two levels of iron concentration minimum value for total number of roots was recorded by H_5 at 600 ppm level which was on par with H_8 at control level and H_{10} at 600 ppm level.

4.5.4.4 Number of fresh roots

Number of fresh roots ranged from 2.00 (L_1) to 0.20 (H_9, H_{10}, H_{11}, H_{16}) at 0 ppm iron. At 600 ppm level this trait varied from 0.10 (H_9) to 3.00 (H_3). Over the two levels of iron concentration this trait varied between 0.10 and 3.00

H_3 at 600 ppm level recorded maximum number of fresh roots while T_5 (0.10) and H_9 (0.10) at 600 ppm level recorded minimum number of fresh roots. T_5 and H_9 at 600 ppm level was on par with almost all genotypes at control level except L_1 (2.00),

L_3 (1.10), H_{10} (1.00) and H_{17}. At 600 ppm level they were on par with all the hybrids except H_{17} (1.00) and T_6 (0.60).

4.5.4.5 Vigour index (SL/RL)

At control level, vigour index varied between 0.70 (H_{10}) and 10.21 (H_{16}). At 600 ppm iron, this trait varied from 0.72 (H_4) to 7.69 (T_6). Over the two levels it varied from 0.70 (H_{10}) and 10.21 (H_{16}).

Over the two levels vigour index was recorded the highest by H_{16} (10.21) at control level which was on par with H_{11} (10.14) and H_{12} (9.06) at control level. Least vigour index was recorded by H_{10} (0.70) at control level which was on par with L_1, H_1, H_2, H_5, H_6, H_8 and H_9 at control level and T_5, H_2, H_3, H_4, H_6,H_7, H_{12}, H_{13},H_{15},H_{17} and C_1 at 600 ppm level.

4.5.4.6 Biomass (g)

Biomass ranged between 0.049 g (T_1) to 0.391 g (C_1) at 0 ppm iron. At 600 ppm iron this trait varied from 0.100 (H_8) to 0.321 (C_1). Over all the range was between 0.100 g to 0.391 g.

Over the two iron concentration level, C_1 (0.391g) at control level showed the highest mean performance which was on par with C_2 (0.373g) at control level itself. Lowest mean performance occurred at 600 ppm for H_{11} (0.010 g) and H_8 (0.010 g). They were on par with T_1, T_4, T_5 among parents at control level and H_2. H_3, H_4, H_5, H_{16} among hybrids at control level. Lowest mean performance were also on par with T_1, T_2, T_4, T_5 among parents at 600 ppm and with all the hybrids except H_{12}, H_{15} at 600 ppm level.

4.5.4.7 Iron adsorbed on roots (mg kg^{-1})

This trait varied from 0.54 mg kg^{-1} (H_3) to 1.29 mg kg^{-1} (T_3) in control. At 600 ppm iron, this trait ranged between 6.90 mg kg^{-1} (H_3) to 46.83 mg kg^{-1} (H_{17}). At both levels of iron concentrations, this trait varied from 0.54 mg kg^{-1} to 46.83 mg kg^{-1}.

Over the two iron concentration level highest mean performance was recorded by H_{17} (46.83 mg kg-^{1}) at 600 ppm level and it was on par with L_2, L_3, T_1, T_3, T_4 among parents and H_7, H_{11}, H_{12}, H_{14} among hybrids and C_2 at 600 ppm. All the genotypes at control level were on par with the least mean which was recorded by H_3 (0.54 mg kg^{-1}).

4.5.4.8 Visual scoring for iron toxicity symptoms

In control (0 ppm iron), this trait varied between 1.00 (H_4) to 3.00 (T_3, T_4, H_1, H_8 and H_{16}). At 600 ppm level this trait varied from 1.58 (C_1) to 9.00 (H_1, H_5, H_{14}). Overall the range was between 1.00 and 9.00

Over the two concentration of iron levels, least mean performance for this trait was by H_4 (1.00) at control level and it was on par with all other genotypes at control level except T_3,T_4, H_1, H_8 and H_{16}.

This trait was recorded the highest (9.00) by H_1, H_5, H_9, H_{10}, H_{14} at 600 ppm level. They were on par with T_5, H_2, H_3, H_6, H_7, H_8, H_{11}, H_{13}, H_{16} and H_{18} at 600 ppm level.

4.5.5 Correlation studies

4.5.5.1 Correlation among yield attributes and iron toxicity tolerance at 0 ppm iron

The Pearson's correlation among yield attributes at control is given in Table 34.

Table 34. Correlation among yield attributes at control level of iron in laboratory screening for iron toxicity tolerance (30 DAS)

Traits	Shoot length (cm)	Root length (cm)	Total number of roots	Number of fresh roots	Vigour index	Biomass (g)	Iron adsorbed on root surface (mg kg^{-1})	Visual scoring for iron toxicity symptoms
Shoot length (cm)	1.000							
Root length (cm)	-0.125	1.000						
Total number of roots	0.527**	0.231	1.000					
Number of fresh roots	0.356**	0.240	0.645**	1.000				
Vigour index	0.456**	-0.701**	-0.141	-0.150	1.000			
Biomass (g)	0.565**	-0.014	0.058	0.291*	0.285*	1.000		
Iron adsorbed on root surface (mg kg^{-1})	0.390**	0.255	0.593**	0.425**	-0.121	0.157	1.000	
Visual score for iron toxicity symptoms	0.005	-0.247	-0.032	-0.076	0.188	-0.183	0.031	1.000

*significant at 5% level, **significant at 1% level DAS: days after sowing

4.5.5.1.1 Association of visual scoring for iron toxicity symptoms with yield attributes

At 0 ppm iron (Control), none of the yield attributes exhibited significant correlation with visual scoring for iron toxicity symptoms.

4.5.5.1.2 Inter-correlation among yield attributes at 0 ppm iron

High significant positive correlation existed between shoot length and total number of roots (0.527), number of fresh roots (0.356), vigour index (0.465), biomass (0.565) and iron adsorbed on root surface (0.390).Root length exhibited high significant negative correlation with vigour index (-0.701).Total number of roots registered high significant positive correlation with number of fresh roots (0.645) and iron adsorbed on root surface (0.593). Number of fresh roots recorded significant to high significant positive correlation with iron adsorbed on roots (0.425) and biomass (0.291). Vigour index recorded positive significant correlation with biomass.

4.5.5.2 Correlation among yield attributes and iron toxicity tolerance at 600 ppm of iron

Correlation among yield attributes traits at 600 ppm of iron toxicity are detailed in Table 35.

4.5.5.2.1 Association of visual scoring for iron toxicity symptoms with yield attributes

At 600 ppm of iron concentration, visual scoring for iron toxicity symptoms recorded high significant negative correlation with shoot length (-0.697), root length (-0.498), total number of roots (-0.612), number of fresh roots (-0.462), biomass (-0.912) and iron adsorbed on root surface (-0.445).

Table 35. Correlation among yield attributes at 600 ppm iron in laboratory screening for iron toxicity tolerance (30 DAS)

Traits	Shoot length (cm)	Root length (cm)	Total number of roots	Number of fresh roots	Vigour index	Biomass (g)	Iron adsorbed on root surface (mg kg^{-1})	Visual scoring for iron toxicity symptoms
Shoot length (cm)	1.000							
Root length (cm)	0.369**	1.000						
Total number of roots	0.669**	0.400**	1.000					
Number of fresh roots	0.490**	0.440**	0.601**	1.000				
Vigour index	0.292*	-0.656**	0.010	-0.175	1.000			
Biomass (g)	0.612**	0.387**	0.502**	0.393**	0.219	1.000		
Iron adsorbed on root surface (mg kg^{-1})	0.590**	0.367**	0.410**	0.034	0.095	0.353**	1.000	
Visual score for iron toxicity symptoms	-0.697**	-0.498**	-0.612**	-0.462**	-0.141	-0.912**	-0.445**	1.000

*significant at 5% level, **significant at 1% level

DAS: days after sowing

4.5.5.2.2 Inter-correlation among yield attributes

Shoot length exhibited significant to high significant positive correlation with all the yield attributes studied. Root length (cm) also recorded high significant correlation with all the other yield attributes under study. However, its correlation was negative with respect to vigour index (-0.656). Positive and high significant correlation was registered between total number of roots and number of fresh roots (0.601), biomass (0.502) and iron adsorbed on root surface (0.410). Number of fresh roots recorded positive highly significant correlation with biomass (0.393). Biomass registered high significant positive correlation with iron adsorbed on root surface (0.353).

Discussion

V. DISCUSSION

Rice, (*Oryza sativa* L.), is the mainstay of more than half of humanity. Increasing food security inevitably warrants increase in production and productivity of rice. However, apart from the socio-economic factors that limit area expansion and rice production, abiotic stresses *viz.*, salinity, iron toxicity, soil acidity etc., lower the crop yield in the rice belts, the world over. Iron (Fe^{2+}) toxicity in soil is a widespread problem for rice (*Oryza sativa* L.) cultivation in India, especially in areas experiencing high rainfall and soil acidity such as Kerala, Orissa, West Bengal and Andaman Islands. A slump of 10% to 100% in productivity may occur depending on the iron (Fe^{2+}) concentration and the tolerance of the cultivar used. To correct the effects of the toxicity, harnessing the inter-varietal differences in iron toxicity tolerance in rice is much more practical and feasible than resorting to digging ditches around the fields, repeated washing of field after accumulation of water, use of lime, dolomite or chalk. Hence, it is imperative to evolve varieties with high production potential and tolerance to iron toxicity.

Variability is the basis for any crop improvement programme. This variability encompasses both existing variability and those from attempts at creating variability. Plant breeding approaches aim at exploiting the spectrum of variation for identification and selection of superior genotypes. Assessment of genetic variance and parameters *viz.*, heritability and genetic advance, elucidation of trait association with yield, combining ability and expression of heterosis is of immense importance in the selection process for crop improvement.

Considering the above, in the present study, three high yielding varieties of rice exhibiting tolerance to iron toxicity were hybridized with six high yielding varieties of short duration in a line x tester mating design. Screening of parents and hybrids for tolerance to iron toxicity was done under both field and laboratory conditions. The observation on yield and yield attributes recorded were analyzed and the results obtained are discussed here under.

Experiment II (A). Field screening for iron toxicity tolerance

5.1 Variability and genetic parameters

Analysis of variance in parents and hybrids revealed existence of significant differences among the genotypes for most of the yield attributes studied. However, variability among genotypes was low with respect to total number of roots, manganese content in old leaf, total tillers/plant and productive tillers/plant.

5.1.1 Mean performance of parents and hybrids

Response to selection could be expected from progeny H_{13} (PTB 57/PTB 43) which exhibited least mean value for visual scoring for iron toxicity symptom at both flowering and maturing. According to IRRI, (1996) H_{13} had recorded 'Resistance' reaction to iron toxicity indicating high tolerance to iron toxicity.

Hybrids H_7 (PTB 53/PTB 43), H_8 (PTB 53/PTB 49), H_9 (PTB 53/PTB 39), H_{14} (PTB 57/PTB 49), H_{15} (PTB 57/PTB 39), and H_{16} (PTB 57/PTB 45) exhibited moderate resistance to iron toxicity at both flowering and maturity. Hence these could be exploited further in breeding programmes aimed at imparting tolerance to iron toxicity.

Hybrids H_{10} (PTB 53/PTB 45) and H_{17} (PTB 57/IR64) with higher mean grain yield/plant but moderate susceptibility to iron toxicity holds promise but attempts need to be made to improve their tolerance to iron toxicity. The next best yielders H_{16} and H_7 exhibiting moderate resistance to iron toxicity holds promise and could be used for simultaneous improvement of these traits. These can also serve as the source to

Parents and F_1s during tillering stage

Iron toxicity symptoms at tillering stage

Plate 4: Field screening of Parents and F_1s

develop breeding material in which selection can be exercised in succeeding generation.

5.1. 2 Phenotypic and genotypic coefficient of variation

Coefficient of variation provides a relative measure of variance among different traits. In general, the estimates of PCV were higher than GCV indicating the effect of environment on yield and yield attributes. The difference between the PCV and GCV estimates were low in case of days to fifty per cent flowering, iron content in oldest leaf, panicle length and spikelets/panicle indicating predominance of genetic factors controlling variability in these traits *i.e.*, these attributes are less influenced by environment (Figure 1 and Figure 2).

Grain yield/plant and tolerance to iron toxicity (recorded as visual scoring for iron toxicity symptoms), at flowering as well as at maturity, recorded high PCV and GCV estimates, indicating presence of ample variability among the genotypes for these traits and the possibility of improvement through simple selection. Sabesan *et al.,* (2009), Karthikeyan *et al.,* (2010), Jayasudha and Sharma (2010), Fiyaz *et al.,* (2011) also reported high PCV and GCV in case of grain yield/plant.

High PCV and GCV estimates were recorded for attributes, iron adsorbed on root surface, iron and manganese content in root, number of fresh roots, dry weight of roots, iron content in the third leaf from tip, youngest fully open mature leaf and oldest leaf at tillering and flowering and plant height, culm length, grains/panicle, root length, root and shoot weight at maturity. High PCV and GCV estimates in plant height were also reported by Pal *et al.,* (2010). Similar findings in case of grains/panicle were reported by Karim *et al.,* (2007), Sabesan *et al.,* (2009), Akhtar *et al.,* (2011), Idrisl *et al.,* (2012).

Figure 1: Comparison of Phenotypic Coefficient of Variation and Genotypic Coefficient of Variation at tillering and flowering

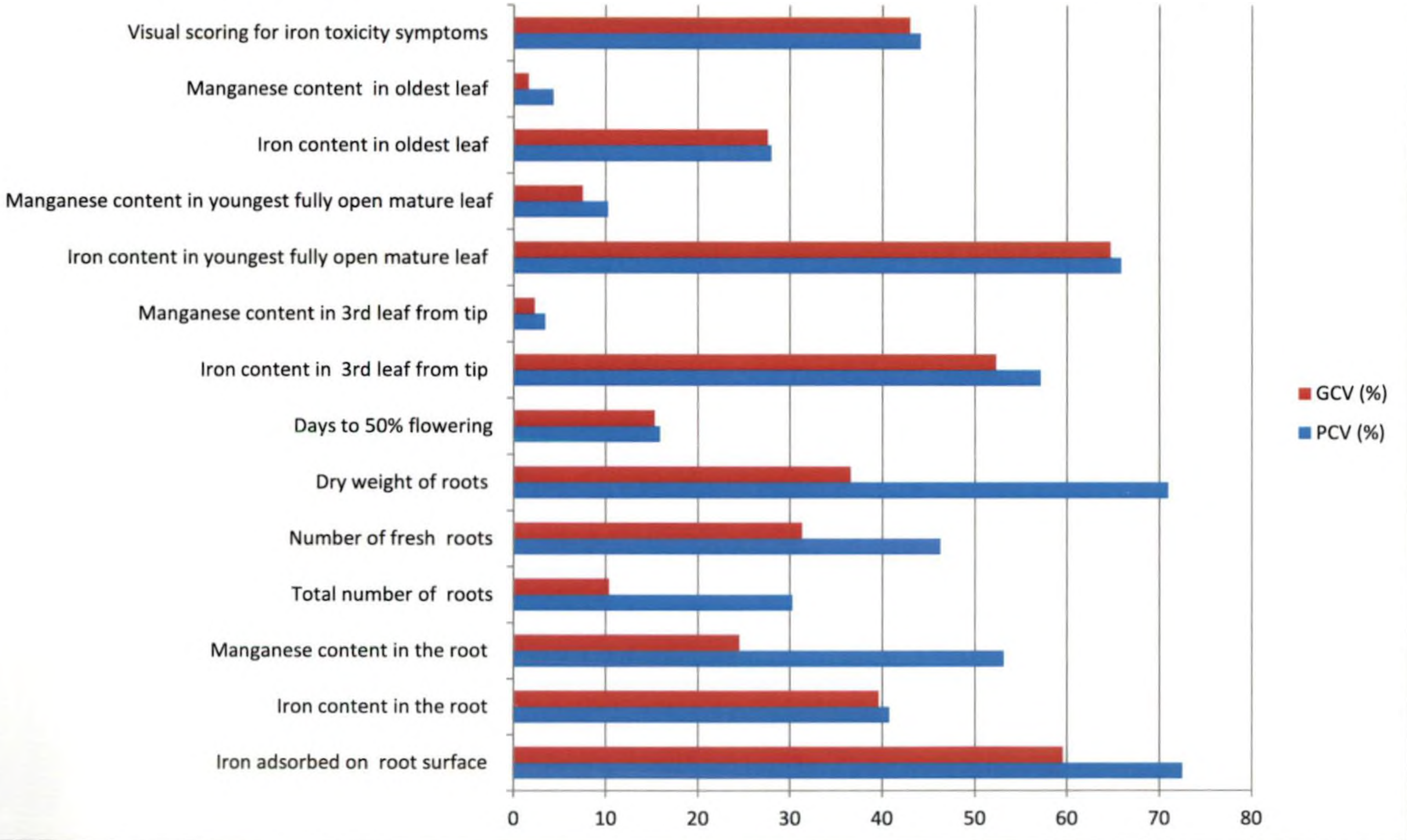
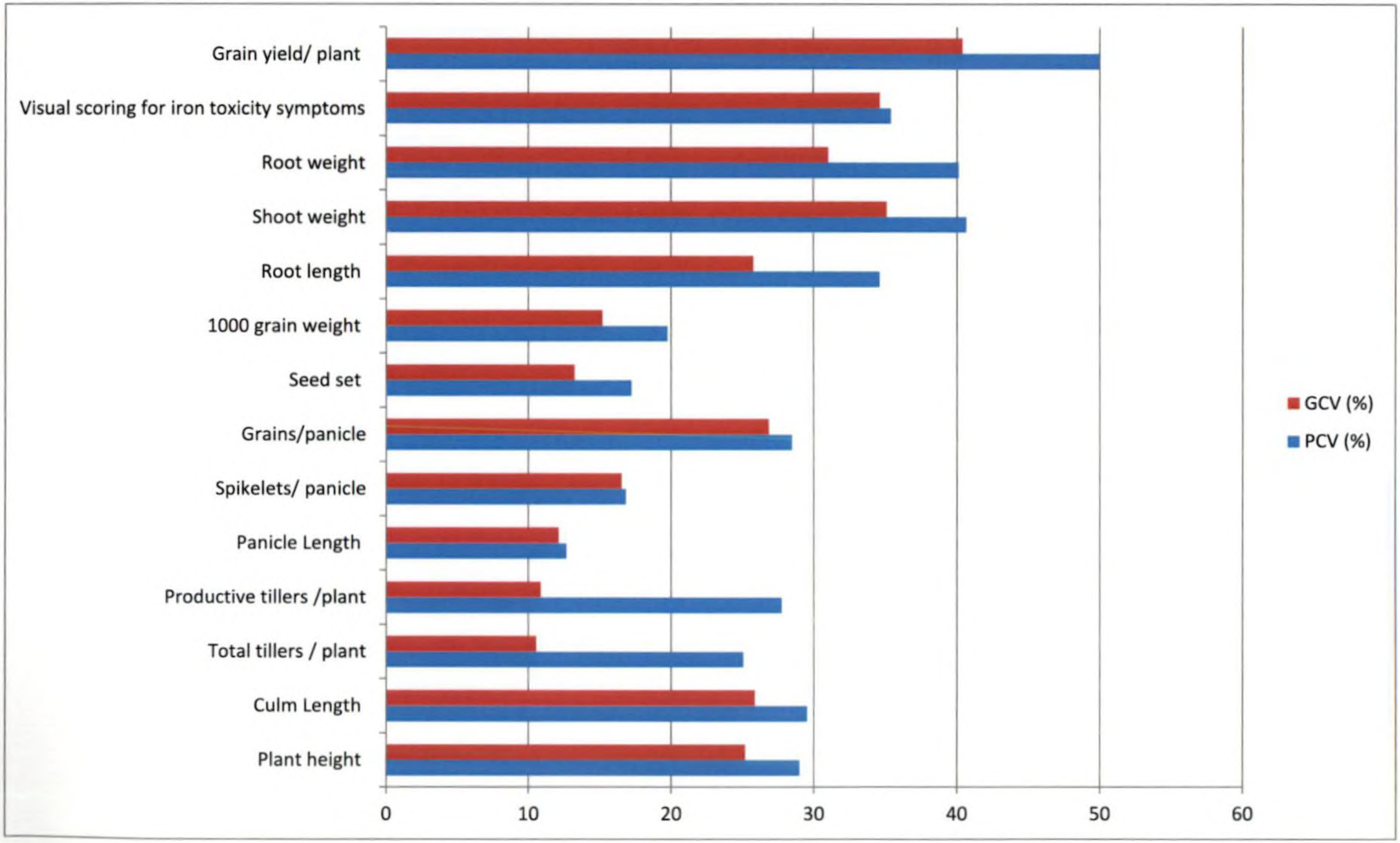


Figure 2: Comparision of Phenotypic coefficient of variation and Genotypic coefficient of variation at maturity



Moderate PCV and GCV were observed for days to fifty per cent flowering, panicle length spikelets/panicle, seed set per cent and thousand grain weight. Similar findings were reported by Karthikeyan *et al.,* (2010), for days to fifty per cent flowering while the findings of Karthikeyan *et al.,* (2010) and Bhadru *et al.,* (2012) are in concurrent in case of thousand grain weight. Jayasudha and Sharma (2010) had reported similar findings for panicle length.

5.1.3 Heritability

The amount of genetic variation considered alone will not be of much use to the breeder unless supplemented with the information on heritability estimate which is a measure of the heritable portion of the total variation. Heritability plays an important role in deciding the suitability and strategy for selection of a character. High heritability indicates high scope of genetic improvement of these characters through selection.

Grain yield/plant at maturity and visual scoring for iron toxicity tolerance at both flowering and maturity recorded high heritability, indicating that selection would be effective in improving these traits. Findings of, Karthikeyan *et al.,* (2010), Fiyaz *et al.,* (2011), Jayasudha and Sharma (2010), Quatadah *et al.,* (2012) also reported high heritability in case of grain yield/plant.

High heritability was also observed for iron adsorbed on root surface, iron content in root, third leaf from tip, youngest fully open mature leaf and oldest leaf, days to fifty per cent flowering at tillering and flowering and plant height, culm length, panicle length, spikelets/panicle, grains/panicle and shoot weight at maturity. Similar findings in case of days to fifty per cent flowering were also reported by Fiyaz *et al.,* (2011) and Singh *et al.,* (2011). High heritability values for plant height were also reported by Akhtar *et al.,* (2011), Fiyaz *et al.,* (2011), Quatadeh *et al.,* (2012).

The findings of Kumar *et al.*, (2012) also suggested high heritability values of panicle length, grains/panicle similar to the findings in the present study.

At tillering and flowering moderate heritability estimates were observed for number of fresh roots, manganese content in third leaf from tip and youngest fully open mature leaf. Similarly, seed set per cent, thousand grain weight, root length and root weight at maturity registered moderate heritability reflecting possibility of only moderate progress in these traits through selection. Fiyaz *et al.*, (2011), Bhadru *et al.*, (2012) had also reported moderate heritability for thousand grain weight.

It has been suggested by Burton and Devane (1953) that the GCV along with heritability estimate could provide a better picture of the amount of advance to be expected by phenotypic selection. According to Singh *et al.*, (2005), high GCV and high heritability indicate effectiveness of selection based on these traits. The obtained results point that most of the attributes studied are mostly governed by additive gene action and suggests possibility of developing superior genotypes with yield.

5.1.4 Genetic advance

Though high heritability indicates the effectiveness of selection on the basis of phenotypic performance, it cannot point out the amount of the genetic progress that can be made from selecting the best individuals. Alternatively, estimates of genetic advance can serve as an indication in this regard. Since genetic advance is dependent on phenotypic variability and heritability in addition to selection intensity, according to Johnson *et al.*, 1955, the heritability estimates in conjunction with genetic advance will be more effective and reliable in predicting the response to selection.

Grain yield/plant and visual scoring for iron toxicity at tillering and flowering, and maturity had also registered high genetic advance as per cent of mean, indicating that gain in grain yield/plant and tolerance to iron toxicity could be expected if judicious selection is exercised. Fiyaz *et al.*, (2011) also reported high genetic advance for grain yield/plant.

High genetic advance as per cent of mean was recorded for attributes iron adsorbed on root surface, iron content in root, iron content in third leaf from tip, in youngest fully open mature leaf, and in oldest leaf. Although improvement of these traits individually may seem to have no direct relevance on yield, being inter-related to various yield components, they gain utmost importance in breeding varieties with high yielding and tolerance to iron toxicity.

Plant height, culm length, panicle length, spikelets/panicle, grains/panicle, seed set per cent, thousand grain weight, root length, shoot and root weight at maturity recorded high genetic advance. Similar results for plant height were obtained by Singh *et al.*, (2011), for spikelets/panicle by Quatadah *et al.*, (2012), for grains/panicle by Kumar *et al.*, (2012) and Bhadru *et al.*, (2012). High genetic advance as per cent of mean for thousand grain weight were also reported by Fiyaz *et al.*, (2011) and Bhadru *et al.*, (2012).

High estimates of heritability along with genetic advance as per cent of mean was evident for the traits, iron adsorbed on root surface, iron content in root, days to fifty per cent flowering, iron content in third leaf from tip, youngest fully open mature leaf, oldest leaf and visual scoring for iron toxicity symptoms at tillering and flowering and plant height, culm length, panicle length, spikelets/ panicle, grains/panicle, shoot weight , visual scoring for iron toxicity symptoms and grain yield/plant at maturity. Similar findings in case of plant height were also reported by Sabesan *et al.*, (2009), Karthikeyan *et al.*, (2010), Pal *et al.*, (2010), Jayasudha and Sharma (2010) and Singh *et al.*, (2011). High heritability in conjunction with high genetic advance in case of spikelets/panicle were also reported by Fiyaz *et al.*, (2011), Singh *et al.*, (2011), and Quatadah *et al.*, (2012). Sabesan *et al.*, (2009) and Kumar *et* *al.*, (2012) also reported high heritability along with high genetic advance for grains/panicle. High heritability along with high genetic advance in case of grain yield/plant was also reported by Karthikeyan *et al.*, (2010) and Fiyaz *et al.*; (2011). Akhtar *et al.*, (2011), Quatadah *et al.*, (2012) suggests that values of high heritability coupled with high genetic advance as per cent of mean indicates that substantial improvement in the expression of characters over base population can be expected through selection. Simple selection would be effective in improvement of these traits.

Moderate heritability estimates along with high genetic advance as per cent of mean were observed for traits, number of fresh roots, seed set per cent, thousand grain weight, root length and root weight implying influence of both additive and non-additive gene action on expression of these traits. Hence improvement of these traits could be attained by following recurrent or reciprocal recurrent selection to exploit both additive and non-additive genetic components.

5.2 Trait association studies

Tolerance to iron toxicity and grain yield/plant are complex traits resulting from interaction of many yield attributes. Being highly influenced by environment, selection based on knowledge of association between the dependent variables and their component traits could accentuate the progress in breeding efforts. Trait association studies could also provide information on the predictor variables on which selection of superior genotypes could be based. Hence, the present study was undertaken to know the inter-relation among different yield contributing characters and their association with grain yield/plant.

5.2.1 Correlation analysis at tillering and flowering

In general, genotypic correlation coefficients (GCC) were higher than phenotypic correlation coefficients (PCC) indicating the predominant role of genetic background rather than environmental effect for association between yield and yield attributes. Gomez and Rangasamy (2002) also reported that phenotypic correlation coefficient value is lessened due to the significant interaction of environment.

In the present investigation, at tillering and flowering, only total number of roots and days to fifty per cent flowering recorded positive and high significant correlation with grain yield/plant. Similar results was observed for days to fifty per cent flowering by Basavaraja *et al.,* (2011), Fiyaz *et al.,* (2011), and Rangare *et al.,* (2012). The above traits registered a negative inter correlation with visual scoring for iron toxicity indicating that susceptibility reaction sets in with decrease in total roots and duration.

In addition to pointing out that flowering is delayed under toxic conditions, the study also pointed out that, tolerance to iron toxicity at tillering and flowering phase increased with an increase in amount of iron adsorbed on root surface, number total number of roots and number of fresh roots. Delay in flowering under iron toxic situation was also reported by Mandal *et al.,* (2004). Iron excluded at the root level to avoid damage to the shoot tissue was considered as an avoidance mechanism by rice plants (Nozoe, *et al.,* 2008), which was reflected at the negative significant correlation with visual scoring for iron toxicity symptoms. Fageria *et al.,* (2008) also reported increased number of roots and fresh roots under iron toxic situations in rice plants.

High degree of negative association was also observed between yield and dry weight of roots, manganese content in third leaf, youngest fully open mature leaf and oldest leaf, iron content in the youngest fully open mature leaf and oldest leaf. However, the traits dry weight of roots, manganese content in third leaf and youngest fully open mature leaf recorded a positive relationship with visual scoring for iron toxicity. Thus, it becomes evident that negative selection for traits dry weight of roots, manganese content in third leaf and youngest fully open mature leaf will lead to simultaneous improvement of grain yield/plant and tolerance to iron toxicity.

As expected the inter-correlations between iron content in the youngest fully open mature leaf and iron content in the oldest leaf was significant and positive. Similar trend was observed with respect to iron content in the third leaf from tip and youngest fully open mature leaf and iron content oldest leaf. However, in general, the study indicated that the amount of iron in the photosynthetically active leaves i.e., third leaf from tip and youngest fully open mature leaf was very meager i.e., 2.90 per cent to 33.50 per cent and 0.50 per cent to 33.50 per cent respectively. The result is in concurrence with the reports of Nozoe *et al.,* (2008) who pointed out that although iron was taken up into the rice root, tissue damage was avoided either by compartmentation (immobilization) of active iron in old leaves that consist of photosynthetically less active leaf sheath tissue or exclusion from symplast. However, at tillering and flowering neither did iron content in the youngest fully opened leaf nor that in third leaf from tip register any significant relationship with yield.

Manganese content in the third leaf registered significant positive correlation with iron content in youngest leaf and oldest leaf. According to Lopez- Millian *et al.,* (2004) and Echkhardt *et al.,* (2001) iron transporters can also transport manganese and high positive correlation between iron and manganese exists. Another study by Marschner (1995) reports that manganese moves easily from root to shoot in the xylem sap transpirational stream and the mobility of iron is more regulated.

5.2.2 Path-coefficient analysis at tillering and flowering

Though the estimates of correlation coefficients mostly indicate inter-relationship of different attributes, they do not furnish information on the cause and effect. The actual contribution of an attribute and its influence through other traits could be arrived at only by way of partitioning the genotypic correlation coefficients into direct and indirect effects by path coefficient analysis. This will be very much helpful in imparting due weightage to important yield attributes under selection process.

The path coefficient analysis at tillering and flowering revealed that high positive direct effect on yield was contributed by days to fifty per cent flowering, manganese content in root, iron content in third leaf from tip and in youngest fully open mature leaf. Incidentally, days to fifty per cent flowering had recorded a high positive correlation with yield. This pointed out that selection based on days to fifty per cent flowering may lead to increased yield under iron toxic condition.

A negative inter correlation between days to flowering and visual scoring for iron toxicity symptoms was observed. Visual scoring for iron toxicity had registered a negligible positive direct effect on yield but a high significant negative correlation with yield. This negative effect on grain yield/plant due to susceptibility to iron toxicity was also made possible *via* its high negative indirect effect through days to fifty per cent flowering emphasizing the importance of days to flowering on yield and tolerance to iron toxicity.

Days to fifty per cent flowering exercised high positive indirect effect on yield through iron content in oldest leaf and high negative indirect effect through iron content in youngest fully open mature leaf and vice-versa. High negative indirect effect of iron toxicity on grain yield/plant for most of the traits was through days to fifty per cent flowering and iron content in oldest leaf. Traits iron adsorbed on roots, iron and manganese content in the third leaf from tip, iron and manganese content in the youngest fully open mature leaf and iron and manganese content in the oldest leaf registered high negative indirect effect through days to fifty per cent flowering. This points out that days to fifty per cent flowering is a very useful predictor variable for both grain yield/plant and tolerance to iron toxicity.

Attributes that registered high negative direct effects on yield were iron content in oldest leaf followed by iron adsorbed on root surface and iron content in root. Dry weight of roots registered a moderate negative direct effect o yield. High negative effect on yield by total number of roots, number of fresh roots, iron and manganese content in the youngest fully open mature leaf and manganese content in the oldest leaf was made possible through iron content in the oldest leaf. The total number of roots exercised high positive indirect effect on yield through iron content in the roots and high negative indirect effect through iron content in oldest leaf.

Correlation studies in conjunction with path coefficient analysis for the traits at tillering and flowering indicated that days to fifty per cent flowering exercised a positive influence on yield while iron content in old leaf had a negative impact. Hence emphasis on these traits in appropriate direction during selection for yield will be rewarding. Positive correlation and positive direct effect of days to fifty per cent flowering on yield were also reported by Basavaraja *et al.,* (2011) and Fiyaz *et al.,* (2011).

5.2.3 Correlation analysis at maturity

Existence of high significant correlation between grain yield/plant and yield attributes was observed at maturity. As, at tillering and flowering, visual scoring for iron toxicity symptoms (susceptibility to iron toxicity), registered a high significant negative correlation with grain yield/plant at maturity indicating that improvement in tolerance may lead to increase in yield.

The yield attributes *viz.*, plant height, culm length, number of total tillers/plant and productive tillers/plant, panicle length, spikelets/panicle, grains/panicle, seed set per cent, thousand grain weight, root length, weight of shoot and root recorded positive correlation with grain yield/plant under iron toxic conditions. Positive correlation of grain yield/plant with plant height, total tillers/plant, productive tillers/plant, panicle length, spikelets/panicle, grains/panicle, thousand grain weight were also reported by Bhadru *et al.,* (2011), Rangare *et al.,* (2012) and Idrisl *et al.,* (2012).

As the study encompasses the reaction of iron toxicity, the inter-correlation of visual scoring with grain yield/plant components is of special interest. It was noticed that there occurs a decrease in plant height, culm length, panicle length, spikelets/panicle and grains/panicle, seed set per cent, root length, shoot and root weight with increase in susceptibility to iron toxicity as evident from the negative correlation of these traits with visual scoring. These traits had registered a positive correlation with yield. Hence, result emphasizes an improvement in plant height, culm length, panicle length, spikelets/panicle and grains/panicle, seed set per cent, root length, shoot and root weight can simultaneously improve grain yield/plant and tolerance to iron toxicity.

The inter-relationship among yield components under iron toxic condition was almost similar to that observed by many earlier workers under non-toxic conditions. Plant height was found to be positively and significantly associated with culm length, total tillers/plant, panicle length, spikelets/panicle, grains/panicle, seed set per cent, thousand grain weight, root length, shoot weight and root weight. Similar positive inter correlation of plant height with yield components were reported by many workers. Positive inter correlation of plant height with panicle length, spikelets/panicle, grains/panicle, were also reported by Girolkar *et al.,* (2008), with thousand grain weight by Fiyaz *et al.,* (2011), with root length by Akhtar *et al.,* (2011), with root weight by Vinothin *et al.,* (2008).

Total tillers/plant registered high positive inter correlation with productive tillers/plant, thousand grain weight and root length. Jayasudha *et al.,* (2010) also reported positive inter correlation between total tillers/plant with productive tillers/plant and panicle length. Positive inter correlation of plant height spikelets/panicle were reported by Basavaraja *et al.,* (2011) and with thousand grain weight similar findings were obtained by Akhtar *et al.,* (2011). Productive tillers/plant registered high significant positive correlation with thousand grain weight which is in conformity with Vinothin *et al.*, (2008), and also with root length.

Panicle length also registered a high significant genotypic correlation with spikelets/panicle, grains/panicle, seed set per cent, thousand grain weight, root length, shoot weight and root weight. Positive inter correlation of panicle length with spikelets/panicle were also reported by Rangare *et al.*, (2012) and Fiyaz *et al.*, (2011). Positive inter correlation with grains/panicle and thousand grain weight were reported by Bastian *et al.*, (2008), Bhadru *et al.*, (2011) and Chandra *et al.*, (2009).

Spikelets/panicle with yield components revealed positive high significant association with grains/panicle, seed set per cent, thousand grain weight, root length, shoot weight and root weight. Positive inter correlation of spikelets/panicle with grains/panicle were also reported by Girolkar *et al.*, (2008) and with thousand grain weight were reported by Chandra *et al.*, (2009) and Fiyaz *et al.*, (2011).

Positive inter-correlation of grains/panicle with thousand grain weight and root weight were reported by Vinothin *et al.*, (2008). Seed set per cent and thousand grain weight registered positive inter -correlation with shoot weight and root weight. Positive and high significant inter-correlation of root length and root weight as observed in the study is in concomitance with the findings of Vinothin *et al.*, (2008).

5.2.4 Path-coefficient analysis at maturity

The path coefficient analysis involving yield components recorded at maturity revealed that very high to high positive direct effect on grain yield/plant was exerted by root weight followed by panicle length, productive tillers/plant and seed set per cent indicating their importance in determining this yield. The results also revealed that the maximum positive indirect effects on yield of all traits except number of total tillers/plant, productive tillers/plant and visual scoring for iron toxicity tolerance was through root weight. Very high to high positive indirect effect of all traits on yield studied at maturity except visual scoring for iron toxicity tolerance was also made possible through panicle length.

Visual scoring for iron toxicity had registered a high negative indirect effect on yield *via* root weight, panicle length and a moderate indirect effect through seed set per cent. Hence, an increase in root weight, panicle length and seed set per cent may be given importance while aiming for improved yield as well as decreasing susceptibility to iron toxicity. Selection may be made in the positive direction for these traits to improve grain yield/plant as well as tolerance to iron toxicity. It also indicated that an increase in visual scoring for iron toxicity i.e., an increase in susceptibility to iron toxicity is not always an indication of decrease in yield unless there is a decrease in panicle length and root weight.

Positive direct effect of productive tillers/plant and panicle length on grain yield/plant was also reported by Rajamadhan *et al.,* (2011) and Rangare *et al.,* (2012). The high positive indirect effect of thousand grain weight on yield through productive tillers/plant, panicle length and root weight as observed in the study is in agreement with the findings of Vinothin *et al.,* (2008). Positive indirect effect of plant height and panicle length *via* root weight was also reported by Vinothin *et al.,* (2008).

Grains/panicle was found to exert moderate positive direct effect on yield. Girolker *et al.,* (2008) and Tandelkar *et al.,* (2008) also reported positive direct effect of grains/panicle on grain yield/plant.

High negative direct effect on grain yield/plant was exerted through shoot weight followed by root length and total tillers/plant although these traits had exhibited high significant positive correlation with yield. Results also pointed out that the high to very high negative indirect effect on yield for most traits except, number of total tillers/plant, productive tillers/plant and visual scoring for iron toxicity tolerance was *via* shoot weight followed by root length. The high positive correlation of both shoot weight and root length was made possible through root weight and panicle length. Therefore, the traits shoot weight and root length cannot not be used as reliable predictor variable to improve yield. An improvement of these traits may not result in increased yield unless accompanied by an increase in panicle length and root weight.

Negative indirect effect of thousand grain weight on yield through total tillers/plant and shoot weight observed in the present study corroborates the findings of Tandelkar *et al.,* (2008). Positive indirect effect of total tillers/plant on grain yield/plant *via* productive tillers/plant and panicle length were also reported by Basavaraja *et al.,* (2011). Rajamadhan *et al.,* (2011) had recorded positive indirect effect of productive tillers/plant through plant height, panicle length, grains/panicle. Similar to the findings of this study, Rajamadhan *et al.,* (2011) and Vinothin *et al.,* (2008) also revealed that grains/panicle exerted a positive indirect effect through plant height, productive tillers/plant, panicle length, seed set per cent, shoot weight and root weight, while registering negative indirect effect on yield through total tillers/plant, grain weight, root length and shoot weight

Visual scoring for iron toxicity or increased susceptibility had registered very high positive indirect effect on yield through root length and shoot weight. These traits had registered a negative correlation with visual scoring for iron toxicity. Hence, results emphasizes that changes in root length and shoot weight that may occur under iron toxic conditions may not be a reliable predictor of improved tolerance to iron toxicity. Vinothin *et al.,* (2008) and Chandra *et al.,* (2009) had reported negative indirect effect of thousand grain weight *via* shoot weight.

Majority of traits had recorded high negative indirect effect on yield through root length and shoot weight. In addition, thousand grain weight registered high negative indirect effect and root length exerted high positive indirect effect on yield through total tillers/plant and productive tillers/plant. Positive indirect effect of total tillers/plant on grain yield/plant via productive tillers/plant and panicle length were also reported by Basavaraja *et al.,* (2011). Rajamadhan *et al.,* (2011) had recorded positive indirect effect of productive tillers/plant through plant height, panicle length, grains/panicle. Similar to the findings of this study, Rajamadhan *et al.,* (2011) and Vinothin *et al.,* (2008) also revealed that grains/panicle exerted a positive indirect effect through plant height, productive tillers/plant, panicle length, seed set per cent, shoot weight and root weight, while registering negative indirect effect on yield.

Correlation studies in conjunction with path coefficient analysis for the traits at maturity under iron toxic conditions indicated that yield and tolerance to iron toxicity was highly and positively influenced by panicle length, root weight and seed set per cent. These traits had registered significant positive correlation with yield and negative inter correlation with visual scoring for iron toxicity besides registering a high to very high positive direct effect on yield. Most of the other characters had exerted moderate, high to very high positive indirect effect through them. Hence emphasis on panicle length, root weight and seed set per cent in selection for yield will lead to a simultaneous increase in tolerance to iron toxicity.

5.3 Studies on combining ability

Selection of parents on the basis of phenotypic performance alone is not a sound procedure since phenotypically superior lines may yield poor recombination. Combining ability analysis provides information on additive and non-additive variances and combining ability effects, which are crucial in the choice of parents and crosses in a hybridization programme. The choice of parents would be all the more effective if based on combining ability test and mean performance (Tiwari *et al.,* 2011). Therefore, the parents were evaluated based on their mean performance along with their *gca* effects in the present study. Information on *sca* effects is associated with interaction effects which may be due to dominance and epistatic components that are non fixable in nature and hence worthwhile for commercial exploitation as hybrids. A high level of heterosis along with mean performance as well as specific combining ability of the crosses is required for breeding strategies based on hybrid production (Rahimi *et al.,* 2010). An attempt has also been made in the present study to evaluate the hybrids based on their heterosis, mean performance and *sca* effects.

5.3.1 Analysis of variances

The analysis of variance for combining ability revealed that the hybrids differed significantly from each other except for number of total tillers/plant and productive tillers/plant.

Higher and significant mean squares for lines compared to testers and higher SCA variance over GCA variance for spikelets/panicle, grains/panicle, thousand grain weight, root length, visual scoring for iron toxicity symptoms and grain yield/plant indicated greater contribution of lines than the testers to higher *sca* effects. Results indicated the presence of significant variability among lines x testers for number of productive tillers/plant, panicle length, spikelets/panicle, grains/panicle, thousand grain weight, root length, reaction to iron toxicity and grain yield/plant (Fig. 3 to Fig. 16).Apportioning of combining ability variance into fixable and non-fixable variances indicated that both additive and non-additive gene action played a significant role in controlling the expression of the characters studied.

The magnitude of SCA variances was higher than GCA variances for visual scoring for iron toxicity symptoms and grain yield/plant indicating pre-ponderance of non-additive gene action i.e., dominance and epistatic gene action in the inheritance of these traits. Higher SCA variances than GCA variance were also noticed for traits spikelets/ panicle, grains/ panicle, thousand grain weight, root length. Non-additive gene action is the heritable and non-fixable portion of genetic variance contributed by the dominance and epistatic gene action. Latha *et al.,* (2013), have reported pre-

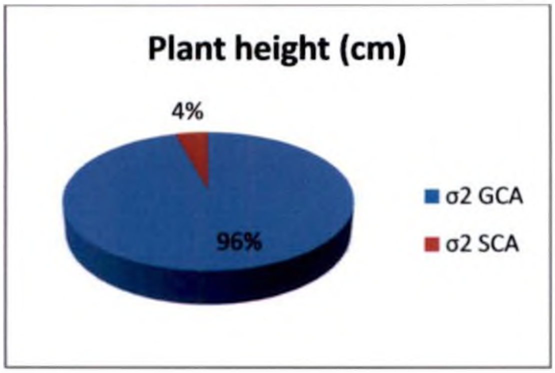


Figure 3: GCA and SCA for Plant height

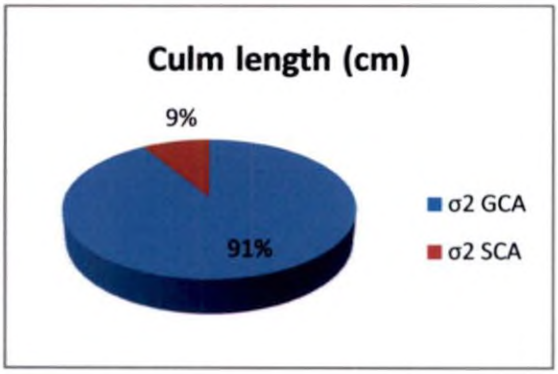


Figure 4: GCA and SCA for Culm length

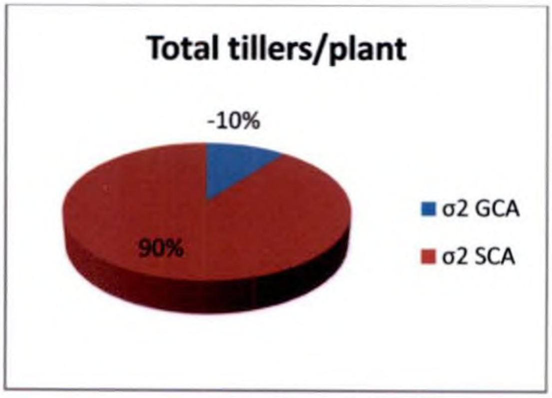


Figure 5: GCA and SCA for Total tillers/plant

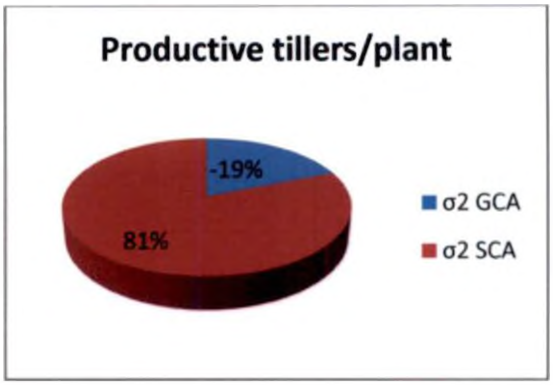


Figure 6: GCA and SCA for Productive tillers/plant

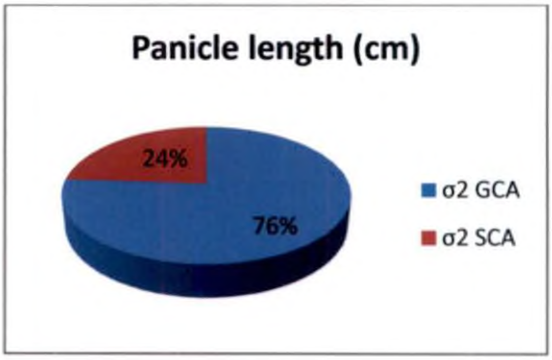


Figure 7: GCA and SCA for Panicle length

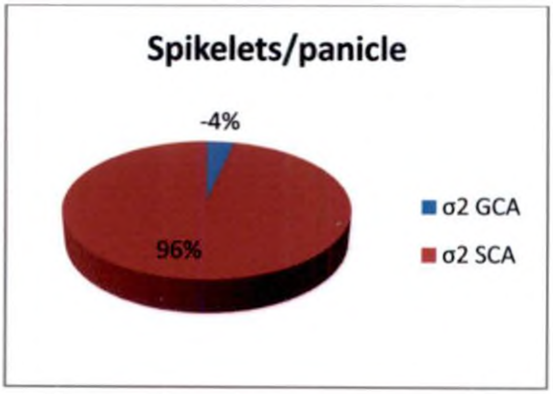


Figure 8: GCA and SCA for Spikelets/panicle

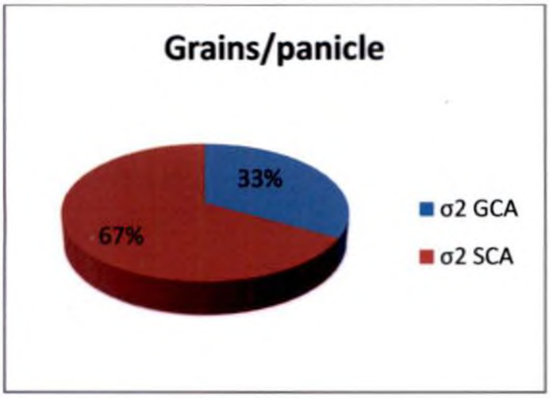


Figure 9: GCA and SCA for Grains/panicle

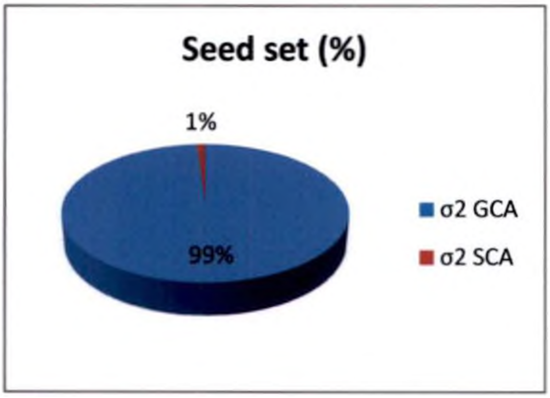


Figure 10: GCA and SCA for Seed set (%)

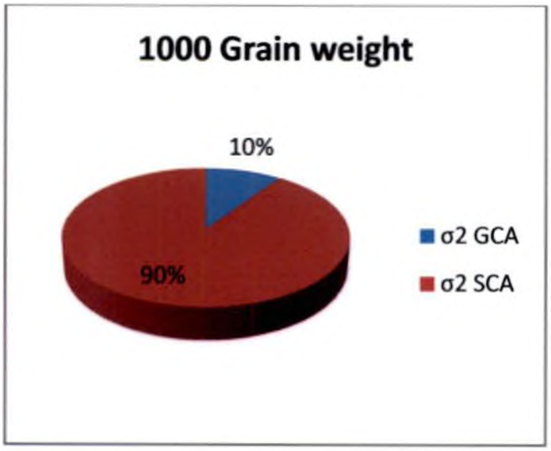


Figure 11: GCA and SCA for 1000 Grain weight

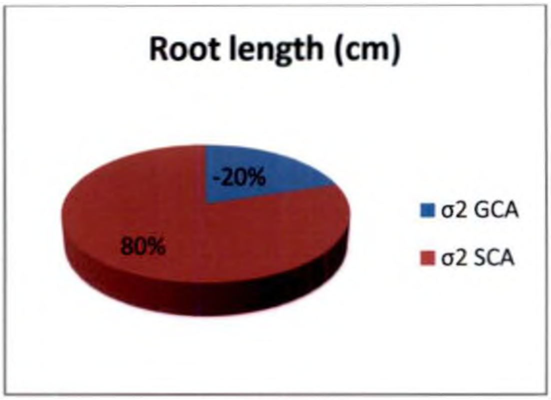


Figure 12: GCA and SCA for Root length

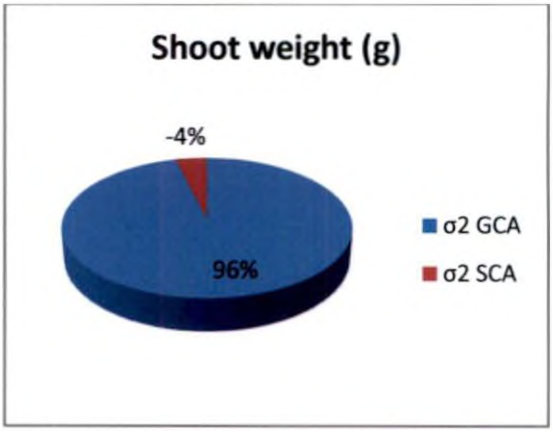


Figure 13: GCA and SCA for Shoot weight

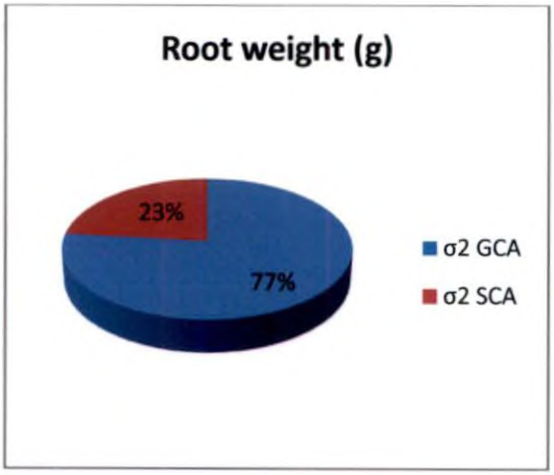


Figure 14: GCA and SCA for Root weight

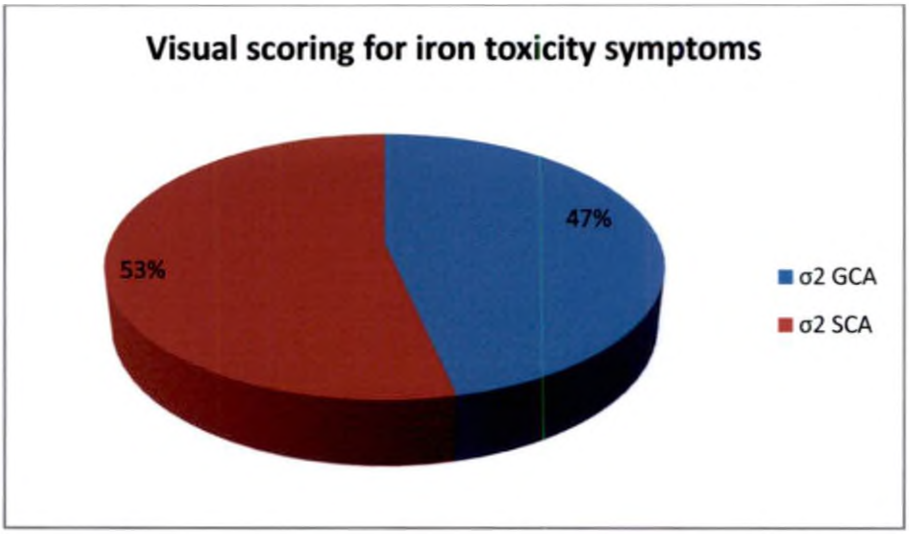


Figure 15: GCA and SCA for Visual scoring for iron toxicity symptoms

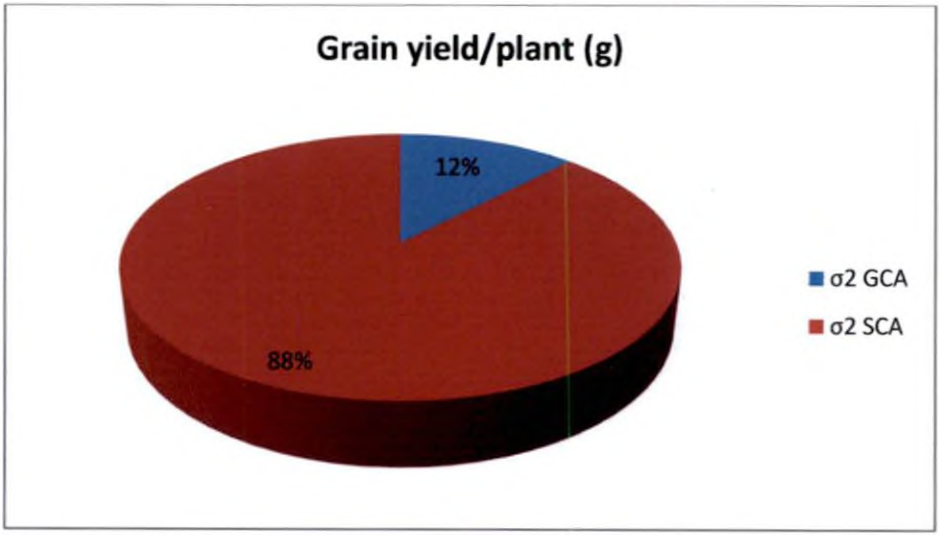


Figure 16: GCA and SCA for Grain yield/plant

ponderance of non-additive gene action in expression of grain yield/plant and its components.

Higher estimates of GCA variance over SCA variance for plant height, culm length, panicle length, seed set per cent, shoot weight and root weight pointed to preponderance of additive gene action. Additive gene action is the heritable and fixable portion of genetic variance contributed by the additive gene action. These results are in agreement with the findings of Kumar *et al.,* (2009) and Adarsha, (2011).

5.3.2 Evaluation of parents

5.3.2.1 Evaluation of parents based on mean performance

Scoring of parents based on the mean performance for the yield, tolerance to iron toxicity and yield attributes were done (Table 36). High estimates of yield and yield attributes were considered advantageous while high estimates for visual scoring for iron toxicity tolerance was considered disadvantageous.

Assuming 'm' as the mean performance of parents for a yield attribute and's' as the standard error difference of mean based on analysis of variance, three classes namely i) varietal mean falling above 'm + s' and ii) varietal mean falling between m-s and m+s and iii) varietal mean falling below m –s were formed with respective scores equal to +1, 0 and -1. In case of visual scoring for iron toxicity tolerance score assigned for the three classes i, ii and iii were -1, 0 and +1 respectively. The status of a parent was high if the scores of a particular character was +1, moderate and low if the score equaled,0 and -1 respectively (Thirumeni, 1998). Considering mean performance of parents with respect to grain yield/plant alone, parental lines L_2 (PTB 53) and L_1 (Mo 19) out-yielded all other parents whereas in case of tolerance to iron toxicity, tester T_2 (PTB 49) along with lines L_2 and L_3 (PTB 57) exhibited moderate resistance.

Table 36. Scoring of parents based on mean performance (x)

Genotypes	PH (cm)	CL (cm)	TT	PT	PL (cm)	S/P	G/P	SS	GW (g)	RL (cm)	SW (g)	RW (g)	VS	GY/P (g)	Total Score
Lines															
L_1	0	-1	0	-1	0	1	1	0	1	1	1	0	0	1	4
L_2	1	1	1	1	1	1	1	1	0	1	1	1	0	1	12
L_3	1	1	-1	-1	1	1	1	1	-1	0	1	1	0	0	5
Testers															
T_1	1	1	0	0	1	1	0	-1	0	1	0	0	0	-1	3
T_2	-1	-1	0	0	-1	-1	-1	0	0	-1	-1	0	0	-1	-8
T_3	-1	-1	0	0	-1	-1	-1	0	0	-1	-1	-1	0	-1	-9
T_4	-1	-1	0	0	-1	-1	-1	-1	1	-1	-1	0	0	0	-7
T_5	-1	-1	0	0	-1	-1	-1	-1	0	-1	-1	-1	0	-1	-10
T_6	-1	-1	0	0	-1	-1	-1	0	0	-1	-1	-1	0	-1	-9

Line L_2 followed by L_3 are adjudged the best based on mean performance for yield, tolerance to iron toxicity and yield attributes. Hence, these could be utilized for further breeding programmes for improvement of yield and yield attributes.

5.3.2.2 Evaluation of parents based *gca* effects

The parents were characterized for their ability to transmit desirable genes to their progenies. Information regarding general combing ability effects of parents is of prime importance as it helps in successful prediction of genetic potential of individuals to yield desirable progenies in segregating populations.

To get a better picture about the general combining ability effects, parents were scored based on their *gca* effects (Table 37) and were categorized into three general combiner groups. Only those that exhibited significant *gca* effects for each trait were taken into account as non significant parents are statistically not different from zero. The parents with positive significance were given a score of +1 (high) and those with negative significant *gca* effects scored as -1 (low) and those with other than the above two cases were categorized into average (moderate) combiners, except in case of visual scoring for iron toxicity tolerance. The score obtained for each character were summed up to judge the combining ability status of the parent. The parents were considered as good combiners, if the total score was more than +1, bad combiners if the sum of the scores were -1 or lesser and medium combiners if the total score equaled zero (Murthy and Kulkarni, 1996)

Line L_2 (PTB 53), testers T_2 (PTB 49) and T_4 (PTB45) proved to be good combiner for grain yield/plant. Lines L_2, L_3 (PTB 57), testers T_1 (PTB 43), T_2, T_3 (PTB 39) and T_4 proved to be good combiners for tolerance to iron toxicity.

Table 37. Scoring of parents based on *gca* effects

Genotypes	PH (cm)	CL (cm)	TT	PT	PL (cm)	S/P	G/P	SS	GW (g)	RL (cm)	SW (g)	RW (g)	VS	GY/P (g)	Total score
Lines															
L_1	-1	-1			-1	-1	-1	-1	-1		-1	-1	-1	-1	-11
L_2	1	1			1	1	1	1	1		1	1	1	1	11
L_3	1	1			1	1	1	1			1	1	1		9
Testers															
T_1	-1	-1				1		-1			-1		1		-2
T_2	1	1			1				1		1		1	1	7
T_3			-1	-1									1	-1	-2
T_4					-1	1	1						1	1	3
T_5						-1			-1				-1		-3
T_6			-1	-1		-1					1		-1	-1	-4

Based on the scoring of the estimates of general combining ability effects for all the yield and yield attributes, Line L_2 was the best general combiner followed by line L_3, testers T_2 and T_4.

5.3.2.3 Evaluation of parents based on mean performance and *gca* effects

The potential of a genotype could be adjudged by comparing both the mean performance and combining ability effects (Table 38). Based on mean performance and *gca* effects for yield alone, L_2 (PTB 53) and L_1 (Mo 19) proved to be the promising whereas parents L_2, L_3 (PTB 57), T_1 (PTB 43), T_2 (PTB 49), T_3 (PTB 39) and T_4 (PTB 45) were found promising for tolerance to iron toxicity.

Scoring based on both the *gca* effects and their mean performance for all the yield and yield attributes revealed that line L_2 followed by line L_3 were most promising parents. This ranking of parents based on mean performance and *gca* effects revealed good parallelism between mean performance and *gca* effect as evident from L_2 and L_3. This observation is in contrast to the findings of Thirumeni (1998). Hybridization involving parents L_2 and L_3 would therefore assumed to be result in more desirable and superior recombinants for yield, tolerance to iron toxicity and other yield attributes.

5.3.3 Evaluation of hybrids

Information on specific combining ability effects is associated with interaction effects which may be due to dominance and epistatic components of variations that are non-fixable in nature and hence worth-while for commercial exploitation as hybrids.

5.3.3.1 Evaluation based on mean performance of hybrids

As done in case of parents, the hybrids were scored based on their mean performance for yield and yield attributes (Table 39).

Table 38. Scoring of parents based on *gca* effects and mean performance

Genotypes	PH (cm)		CL (cm)		TT		PT		PL (cm)		S/P		G/P		SS	
	gca	x	*gca*	x	*gca*	x	*gca*	x	*gca*	x	*gca*	x	*gca*	x	*gca*	x
Lines																
L_1	-1	0	-1	-1		0		-1	-1	0	-1	1	-1	1	-1	0
L_2	1	1	1	1		1		1	1	1	1	1	1	1	1	1
L_3	1	1	1	1		-1		-1	1	1	1	1	1	1	1	1
Testers																
T_1	-1	1	-1	1		0		0		1	1	1		0	-1	-1
T_2	1	-1	1	-1		0		0	1	-1		-1		-1		0
T_3		-1		-1	-1	0	-1	0		-1		-1		-1		0
T_4		-1		-1		0		0	-1	-1	1	-1	1	-1		-1
T_5		-1		-1		0		0		-1	-1	-1		-1		-1
T_6		-1		-1	-1	0	-1	0		-1	-1	-1		-1		0

Table 38. Scoring of parents based on *gca* effects and mean performance (contd.).

Genotypes	GW (g)		RL (cm)		SW (g)		RW (g)		VS		GY/P (g)		Total score		Final score
	gca	x	*gca*	x	*gca*	x	*gca*	x	*gca*	x	*gca*	x	*gca*	x	(*gca*+x)
Lines															
L_1	-1	1		1	-1	1	-1	0	-1	0	-1	1	-11	4	-7
L_2	1	0		1	1	1	1	1	1	0	1	1	11	12	23
L_3		-1		0	1	1	1	1	1	0		0	9	5	14
Testers															
T_1		0		1	-1	0		0	1	0		-1	-2	3	1
T_2	1	0		-1	1	-1		0	1	0	1	-1	7	-8	-1
T_3		0		-1		-1		-1	1	0	-1	-1	-2	-9	-11
T_4		1		-1		-1		0	1	0	1	0	3	-7	-4
T_5	-1	0		-1		-1		-1	-1	0		-1	-3	-10	-13
T_6		0		-1	1	-1		-1	-1	0	-1	-1	-4	-9	-13

Table 39. Scoring of hybrids based on mean performance (x)

	PH (cm)	CL (cm)	TT	PT	PL (cm)	S/P	G/P	SS	GW (g)	RL (cm)	SW (g)	RW (g)	VS	GY/P (g)	Total score
H_1	-1	-1	0	0	-1	1	-1	-1	0	-1	-1	-1	0	-1	-8
H_2	-1	-1	0	0	-1	1	0	0	1	0	-1	-1	0	1	-2
H_3	-1	-1	0	0	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-11
H_4	-1	-1	-1	-1	-1	-1	-1	-1	-1	0	-1	-1	0	-1	-12
H_5	-1	-1	0	0	-1	-1	-1	-1	-1	0	-1	-1	0	-1	-10
H_6	-1	-1	0	0	-1	-1	-1	0	0	1	-1	0	0	1	-4
H_7	1	1	1	1	1	0	0	0	1	1	1	0	0	1	9
H_8	1	0	0	0	1	-1	-1	0	1	1	1	0	0	1	4
H_9	1	0	-1	0	1	1	1	0	1	0	1	1	0	-1	5
H_{10}	1	1	1	1	0	0	1	1	1	0	1	1	0	1	10
H_{11}	1	1	0	0	1	1	1	0	0	0	0	0	0	1	6
H_{12}	1	1	-1	-1	1	1	1	1	-1	-1	1	0	0	-1	2
H_{13}	0	0	0	0	0	1	0	0	-1	0	0	0	0	-1	-1
H_{14}	1	1	0	0	1	0	1	1	1	0	1	1	0	1	9
H_{15}	0	0	0	0	1	1	1	0	-1	0	0	0	0	-1	1
H_{16}	0	0	1	0	1	1	1	0	0	0	0	0	0	1	5
H_{17}	0	0	0	0	1	1	1	0	1	0	0	0	0	1	5
H_{18}	0	0	-1	0	0	-1	-1	0	0	0	0	1	0	-1	-3

Hybrids H_{10} (PTB 53/PTB 45), H_{17} (PTB 57/IR64), H_{16} (PTB 57/PTB 45), H_7 (PTB 53/PTB 43), H_2 (Mo 19/PTB 49), H_{11} (PTB 53/IR64), H_8 (PTB 53/PTB 49), H_{14} (PTB 57/PTB 49), and H_6 (Mo 19/Triguna) recorded high grain yield/plant. Hybrid H_{13} (PTB 57/PTB 43) (Resistant) scored the least for visual scoring for iron toxicity symptoms and hybrids H_7, H_8, H_9 (PTB 53/PTB 39), H_{14}, H_{15} (PTB 57/PTB 39), and H_{16} recorded moderate resistance to iron toxicity.

Based on mean performance for yield, tolerance to iron toxicity and yield attributes, among hybrids, H_{10} ranked first followed by H_7 and H_{14}. Hybrids H_{11}, H_9, H_{16} and H_{17} were also found promising. Gilbert, 1958 suggested that parents with good performance would result in good hybrids which were reflected in case of all the above hybrids. These had both or at least one parent with good mean performance.

5.3.3.2 Evaluation of hybrids based on *sca* effect

The *sca* effects of hybrids were evaluated similar to the *gca* effects (Table 40). The *sca* effects are attributed to the combination of positive favorable genes from different parents or might be due linkage of genes in repulsion phase. According to Sprague and Tatum (1942) the *sca* effects are due to non additive gene action.

Hybrid H_4 (Mo 19/PTB 45), H_5 (Mo 19/IR64), H_6 (Mo 19/Triguna), H_7 (PTB 53/PTB 43), H_8 (PTB 53/PTB 49), H_{13} (PTB 57/PTB 43) and H_{16} (PTB 57/PTB 45) recorded significant *sca* in the desired direction for tolerance to iron toxicity. However, significant *sca* in the desired direction for grain yield/plant was exhibited by H_2 (Mo 19/PTB 49), H_6 (Mo 19/Triguna), H_{10} (PTB 53/PTB 45) and H_{17} (PTB 57/IR64). Only hybrid H_6 recorded significant *sca* effect for both tolerance to iron toxicity and grain yield/plant. Scoring of the hybrids based on *sca* effects for yield and other yield attributes revealed that H_6 was the best followed by hybrids H_2, H_{17}, H_7, H_9 (PTB 53/PTB 39), H_{16}, H_{10} and H_{11} (PTB 53/IR64).

Table 40. Scoring of hybrids based on *sca* effect

	PH (cm)	CL (cm)	TT	PT	PL (cm)	S/P	G/P	SS	GW (g)	RL (cm)	SW (g)	RW (g)	VS	GY/P (g)	Total score
H_1						1	1		1	-1			-1		1
H_2					1	1	1		1				-1	1	4
H_3					-1	-1	-1								-3
H_4			-1	-1		-1	-1		-1				1	-1	-5
H_5					-1	-1	-1		-1				1		-3
H_6	1		1	1	1	1	1		1	1		1	1	1	11
H_7			1	1	1	-1	-1			1			1		3
H_8		-1			-1	-1	-1	-1		1			1		-3
H_9						1			1						2
H_{10}			1		-1				1				-1	1	1
H_{11}						1	1			-1					1
H_{12}			-1	-1		1			-1	-1			-1	-1	-5
H_{13}					-1	-1			-1				1	-1	-3
H_{14}	1	1				-1				-1	1	1	-1		1
H_{15}						1			-1						0
H_{16}						1							1		2
H_{17}					1	1	1		1				-1	1	4
H_{18}					-1	-1	-1						-1		-4

These results indicate that the possibility of combining yield with tolerance to iron toxicity can be attempted by resorting to combination breeding approaches. This approach will help produce desirable segregants in the subsequent generations as suggested by Shanthi *et al.*, (2011).

It was evident that crosses exhibiting high *sca* effects did not always involve parents with high *gca* effect. The best hybrid H_6 was a low/moderate cross-combination. It did not score high for grain yield/plant but had scored high for tolerance to iron toxicity. Patil *et al.*, (2011) suggested that crosses resulted from average/poor or poor/average could be exploited for getting desirable recombinants from the segregating population.

Similarly, crosses exhibiting significant desirable *sca* effects for various traits involved all possible combinations viz., good x good, average x average, average x poor, poor x good, poor x average and poor x poor combing parents. It may be suggested that inter-allelic interaction were important for these traits. Similar results have been reported by Sharma and Mani (2008) and Hijam and Sarkar, (2013). This was also in conformity with the findings of Saidaih *et al.*, (2011) who opined that the high yield potential of cross combinations with high/low *gca* effects was attributed to interactions between positive alleles from good combiner and negative alleles from poor combiner.

5.3.3.3 Based on mean performance and *sca* effect

The total score of mean performance and *sca* effect for yield and yield attributes (Table 41) revealed that hybrid H_7 (PTB 53/PTB 43) followed by H_{10} (PTB 53/PTB 45), H_{14} (PTB 57/PTB 49), H_{17} (PTB 57/IR64), H_6 (Mo 19/Triguna), H_9 (PTB 53/PTB 39) and H_{16} (PTB 57/PTB 45) were the best. There was no exact correspondence between mean performance and *sca* effects in these hybrids. Therefore the study indicated that the *sca* effect may not always lead to correct choice of hybrid

Table 41. Scoring of hybrids based on *sca* and mean performance (x)

	PH (cm)		CL (cm)		TT		PT		PL (cm)		S/P		G/P		SS		GW (g)	
	sca	x	*sca*	x	*sca*	x	*sca*	x	*sca*	x	*sca*	x	*sca*	x	*sca*	x	*sca*	x
H_1		-1		-1		0		0		-1	1	1	1	-1		-1	1	0
H_2		-1		-1		0		0	1	-1	1	1	1	0		0	1	1
H_3		-1		-1		0		0	-1	-1	-1	-1	-1	-1		-1		-1
H_4		-1		-1	-1	-1	-1	-1		-1	-1	-1	-1	-1		-1	-1	-1
H_5		-1		-1		0		0	-1	-1	-1	-1	-1	-1		-1	-1	-1
H_6	1	-1		-1	1	0	1	0	1	-1	1	-1	1	-1		0	1	0
H_7		1		1	1	1	1	1	1	1	-1	0	-1	0		0		1
H_8		1	-1	0		0		0	-1	1	-1	-1	-1	-1	-1	0		1
H_9		1		0		-1		0		1	1	1		1		0	1	1
H_{10}		1		1	1	1		1	-1	0		0		1		1	1	1
H_{11}		1		1		0		0		1	1	1	1	1		0		0
H_{12}		1		1	-1	-1	-1	-1		1	1	1		1		1	-1	-1
H_{13}		0		0		0		0	-1	0	-1	1		0		0	-1	-1
H_{14}	1	1	1	1		0		0		1	-1	0		1		1		1
H_{15}		0		0		0		0		1	1	1		1		0	-1	-1
H_{16}		0		0		1		0		1	1	1		1		0		0
H_{17}		0		0		0		0	1	1	1	1	1	1		0	1	1
H_{18}		0		0		-1		0	-1	0	-1	-1	-1	-1		0		0

Table 41. Scoring of hybrids based on *sca* and mean performance (x) (contd..)

	RL (cm)		SW (g)		RW (g)		VS		GY/P (g)		Total *sca* score	Total mean (x) score	Final score (*sca* +x)
	sca	x	*sca*	x	*sca*	x	*sca*	x	*sca*	x			
H_1	-1	-1		-1		-1	-1	0		-1	1	-8	-7
H_2		0		-1		-1	-1	0	1	1	4	-2	2
H_3		-1		-1		-1		0		-1	-3	-11	-14
H_4		0		-1		-1	1	0	-1	-1	-5	-12	-17
H_5		0		-1		-1	1	0		-1	-3	-10	-13
H_6	1	1		-1	1	0	1	0	1	1	11	-4	7
H_7	1	1		1		0	1	0		1	3	9	12
H_8	1	1		1		0	1	0		1	-3	4	1
H_9		0		1		1		0		-1	2	5	7
H_{10}		0		1		1	-1	0	1	1	1	10	11
H_{11}	-1	0		0		0		0		1	1	6	7
H_{12}	-1	-1		1		0	-1	0	-1	-1	-5	2	-3
H_{13}		0		0		0	1	0	-1	-1	-3	-1	-4
H_{14}	-1	0	1	1	1	1	-1	0		1	1	9	10
H_{15}		0		0		0		0		-1	0	1	1
H_{16}		0		0		0	1	0		1	2	5	7
H_{17}		0		0		0	-1	0	1	1	4	5	9
H_{18}		0		0		1	-1	0		-1	-4	-3	-7

combinations. The result is in conformity of the findings of Bastian, (1999) who opined that such non-concordance between mean performance and *sca* effects of good progenies hybrid may be due to non-additive gene action.

The top ranking hybrids involved parents with either, good mean performance, good *gca* effects or both. According to Raghavaiah and Joshi (1986), the combination of parents with high *gca* effects will be useful in the improvement of autogamous plants. According to them for improvement of self pollinated crops like rice, *sca* of a particular cross will be useful if it is accompanied by high *gca* of respective parents.

Best ranked hybrid H_7, recorded high mean estimates for grain yield/plant and significant *sca* for visual scoring for iron toxicity in the desired direction. Hybrid H_{10} ranked first with respect to grain yield/plant and possessed significant *sca* for the same and moderate score for visual scoring. These two hybrids may be grown in successive generations following pedigree method of selection to generate elite lines with stable yield under iron toxic environment.

5.4 Studies on heterosis

5.4.1 Heterosis

Utilization of heterosis is important for maximization of yield as well as tolerance to iron toxicity. Gene action and combining ability in relation to information on heterosis determines whether heterosis is fixable or predictable Tiwari *et al.*, (2011) (Fig. 17 to Fig. 19).

Hybrids, H_3 (Mo 19/PTB 39), H_4 (Mo 19/PTB 45), H_6 (Mo 19/Triguna), H_7 (PTB 53/PTB 43), H_9 (PTB 53/PTB 39), H_{13} (PTB 57/PTB 43), H_{15} (PTB 57/PTB 39) and H_{16} (PTB 57/PTB 45) exhibited significant heterosis, heterobeltiosis and standard heterosis for tolerance to iron toxicity. Hybrids, H_2 (Mo 19/PTB 49), H_{10} (PTB

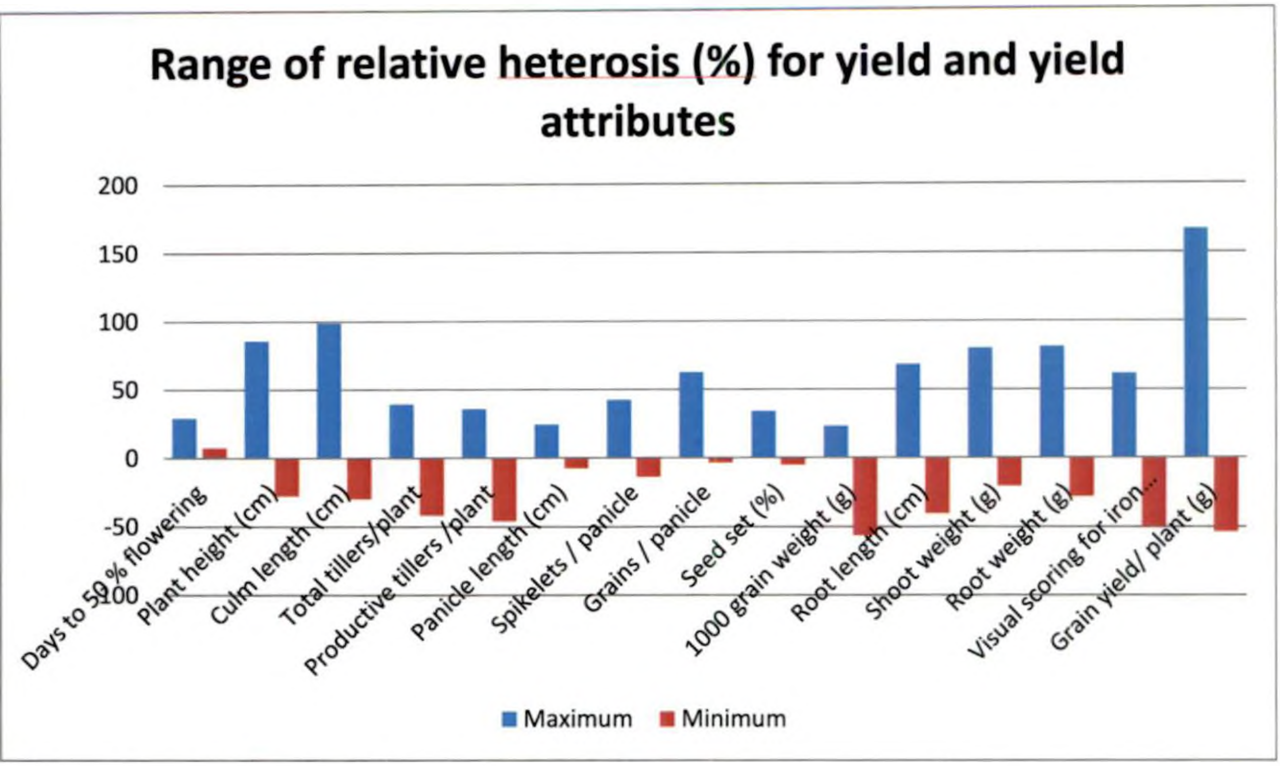


Figure 17: Range of relative heterosis (%) for yield and yield attributes

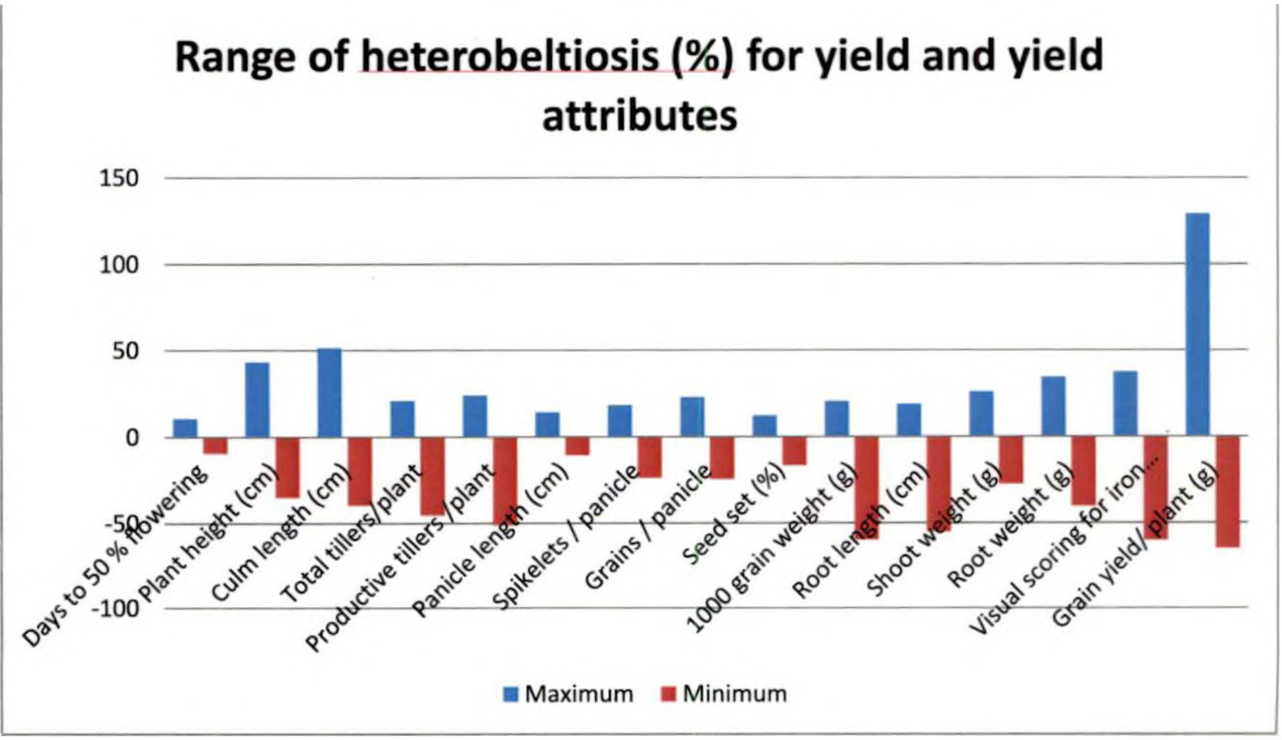


Figure 18: Range of heterobeltiosis (%) for yield and yield attributes

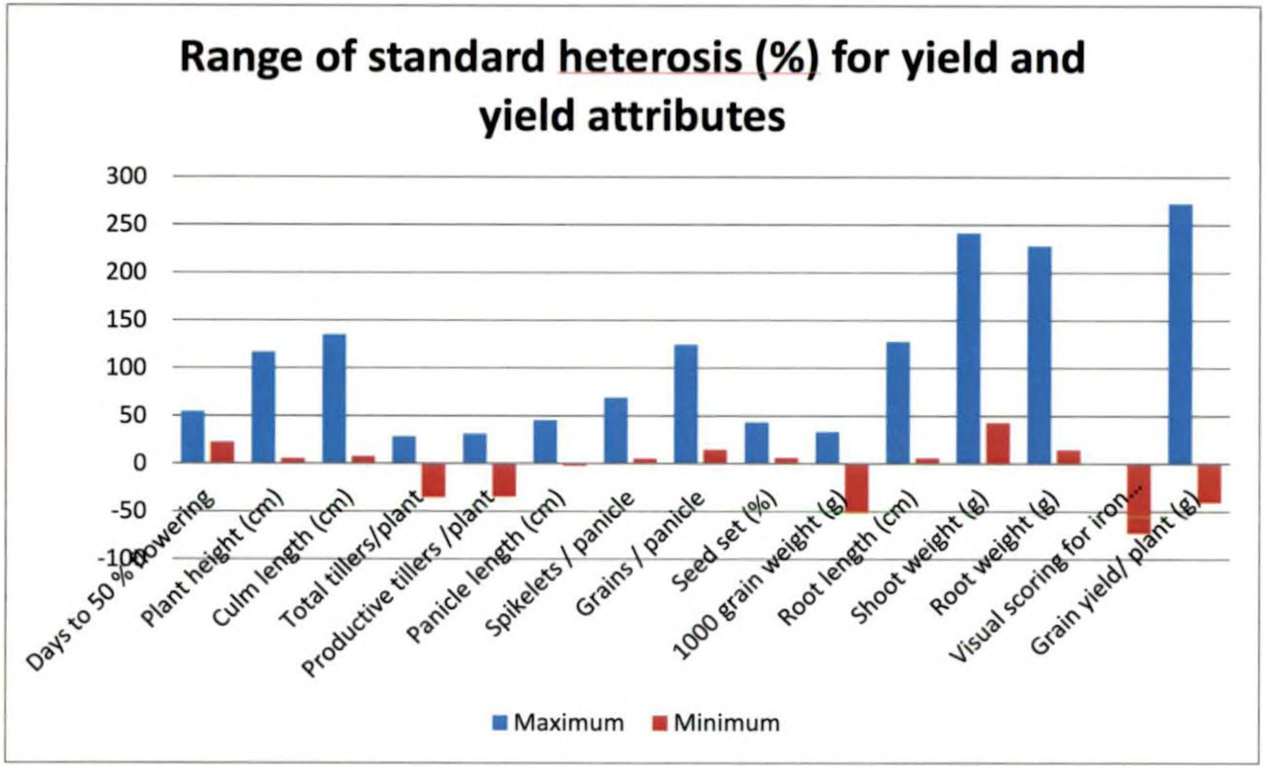


Figure 19: Range of standard heterosis (%) for yield and yield attributes

53/PTB 45), H_{14} (PTB 57/PTB 49), H_{16} and H_{17} (PTB 57/IR64) exhibited significant heterosis, heterobeltiosis and standard heterosis for grain yield/plant. Results revealed that hybrids H_{16}, H_{10}, H_9 and H_7 were found to be good heterotic cross-combinations for yield and yield attributes. These could be exploited for its yield potential and toxicity to iron tolerance to obtain desirable segregants in future breeding programme.

Study revealed that not all crosses with high heterotic effect exhibited significant *sca* effects. There were crosses with high heterosis and low *sca* effect and vice versa. This showed inconsistent relationship between heterosis and *sca* effects. The study revealed that the *sca* effects may not always lead to correct choice of hybrid combination. Hence the selection of hybrids based on high mean performance and heterotic expression would be more useful than that based on *sca* effects alone as reported by Pethani and Kapoor (1984).

5.4.2 Heterosis and mean performance

Heterosis for grain yield/plant along with its component is very important consideration in heterosis breeding. In the study the per cent heterosis (magnitude) varied from trait to trait and cross to cross and none of the cross combination recorded significant heterosis for all the traits simultaneously. Heterosis along with mean performance gives a better picture on the hybrids to be selected.

The hybrids were ranked (Table 42) modifying the method devised by Arunachalam and Bandyopadhyay (1984) to delineate the parental divergence. The norm (y) for each trait was derived by averaging the mean performance of all the hybrids exhibiting positive heterosis for the respective trait. The proportion of traits (p) for which a particular hybrid exhibited mean performance $\geq$ the respective 'y' was calculated. The hybrids were ranked (a) in serratum in ascending order of the value of 'p'

Table 42 Ranking of hybrids based on mean performance and relative heterosis (di), heterobeltiosis (dii), standard heterosis (diii)

	Relative heterosis (di)					Heterobeltiosis (dii)					Standard heterosis (diii)					Total Score (i+ii+iii)	Final rank
Cross	‘p’	Rank based on ‘p’ (‘a’)	‘q’	Rank based on ‘q’ (‘b’)	Score(s) [‘a’+‘b] (i)	‘p’	Rank based on ‘p’ (‘a’)	‘q’	Rank based on ‘q’ (‘b’)	Score(s) [‘a’+‘b’] (ii)	‘p’	Rank based on ‘p’ (‘a’)	‘q’	Rank based on ‘q’ (‘b’)	Score(s) [‘a’+‘b’] (iii)		
H_1	0.33	3	0.00	1	4	0.27	2	0.13	3	5	0.27	2	0.00	1	3	12	14
H_2	0.40	4	0.40	5	9	0.40	4	0.40	7	11	0.40	4	0.20	3	7	27	10
H_3	0.27	2	0.07	2	4	0.20	1	0.07	2	3	0.20	1	0.07	2	3	10	15
H_4	0.20	1	0.07	2	3	0.20	1	0.07	2	3	0.20	1	0.07	2	3	9	16
H_5	0.20	1	0.07	2	3	0.20	1	0.00	1	2	0.20	1	0.07	2	3	8	17
H_6	0.27	2	0.27	4	6	0.27	2	0.20	4	6	0.33	3	0.33	4	7	19	13
H_7	0.67	7	0.47	6	13	0.67	7	0.40	7	14	0.80	9	0.80	10	19	46	2
H_8	0.67	7	0.47	7	14	0.53	6	0.27	5	11	0.73	8	0.67	9	17	42	5
H_9	0.60	6	0.67	9	15	0.53	6	0.53	9	15	0.60	6	0.60	8	14	44	3
H_{10}	0.53	5	0.73	10	15	0.60	7	0.47	8	15	0.53	5	0.67	9	14	44	3
H_{11}	0.53	5	0.53	8	13	0.53	6	0.33	6	12	0.53	5	0.53	7	12	37	7
H_{12}	0.33	3	0.47	7	10	0.33	3	0.40	7	10	0.40	4	0.40	5	9	29	9
H_{13}	0.40	4	0.13	3	7	0.33	3	0.20	4	7	0.40	4	0.47	6	10	24	12
H_{14}	0.60	6	0.67	9	15	0.53	6	0.33	6	12	0.60	6	0.60	8	14	41	6
H_{15}	0.53	5	0.67	9	14	0.33	3	0.27	5	8	0.53	5	0.60	8	13	35	8
H_{16}	0.60	6	0.80	11	17	0.47	5	0.53	9	14	0.67	7	0.80	10	17	48	1
H_{17}	0.53	6	0.87	12	18	0.47	5	0.33	6	11	0.60	6	0.60	8	14	43	4
H_{18}	1.07	8	0.27	4	12	0.33	3	0.13	3	6	0.40	4	0.33	4	8	26	11

Similarly, a norm (k) for each trait was calculated by averaging the heterosis value all the hybrids showing positive heterosis. The proportion of traits (q) for which a particular hybrid exhibited heterosis value $\geq$ to the respective 'k' was arrived at. The hybrids were ranked (b) in serratum in ascending order of the value of 'q'.

The above procedure was followed for all three heterosis estimates *viz.*, relative heterosis, heterobeltiosis and standard heterosis. The total score for each hybrid was derived from their respective values of 'a' and 'b'. The hybrids with the highest final score was ranked the best.

Based on scoring the heterosis estimates and mean performance for yield and yield attributes, hybrid H_{16} was found to be good heterotic cross-combination. Hybrids H_7 (PTB 53/PTB 43), H_9 (PTB 53/PTB 39) and H_{10} (PTB 53/PTB 45), H_{17} (PTB 57/IR64), H_8 (PTB 53/PTB 49), H_{14} (PTB 57/PTB 49), H_{11} (PTB 53/IR64) and H_{15} (PTB 57/PTB 39) were also found to be promising.

5.4.3 Heterosis, mean performance and *sca*

For practical value, a variety or hybrid with good yield potential combining various yield attributes in the desirable range is useful. In the present investigation an attempt has also been made to choose hybrid combinations for high order of expression for all the three parameters *viz.*, heterosis, *sca* and mean performance (Table 43).

Based on the scoring the estimates of heterosis, *sca* and mean performance for yield and yield attributes, hybrids H_7 (PTB 53/PTB 43), H_{10} (PTB 53/PTB 45) and H_{16} (PTB 57/PTB 45) ranked the best. Hybrids H_{17} (PTB 57/IR64) followed by H_{14} (PTB 57/PTB 49) and H_9 (PTB 53/PTB 39) were also found promising. Hence these crosses could be exploited for their yield potential and yield attributes to obtain desirable segregants in further breeding programmes. The results also indicated that the best

Table 43. Ranking of hybrids based on scoring of heterosis, *sca* and mean

	Score		Total score	Final rank
Entry	Heterosis	*sca* + mean	Heterosis + *sca* +mean	
H_1	12	-7	5	12
H_2	27	2	29	8
H_3	10	-14	-4	13
H_4	9	-17	-8	15
H_5	8	-13	-5	14
H_6	19	7	26	9
H_7	46	12	58	1
H_8	42	1	43	6
H_9	44	7	51	4
H_{10}	44	11	55	2
H_{11}	37	7	44	5
H_{12}	29	-3	26	9
H_{13}	24	-4	20	10
H_{14}	41	10	51	4
H_{15}	35	1	36	7
H_{16}	48	7	55	2
H_{17}	43	9	52	3
H_{18}	26	-7	19	11

cross-combinations identified involved both or at least one good combiner for yield and yield components.

Experiment II (B). Laboratory screening for iron toxicity tolerance

Yield losses associated with iron (Fe^{2+}) toxicity in field experiments depends on rice cultivar, prevailing iron toxicity levels and crop management strategies. In addition to these factors, manifestation of toxicity symptoms and yield loss in iron-toxic sites are also influenced by unknown site factors. As uniform control on iron toxicity cannot be exercised in iron-toxic sites field experiments, a laboratory screening of parents and hybrids under study was carried out to quantify the effects of iron toxicity on yield attributes and to investigate the range of tolerance to this stress. Plant reactions to Fe^{2+} can be detected and measured in laboratory tests based on different traits, where differences in plantlets can indicate tolerant and sensitive genotypes (Ferreira , 1997). The purpose of this study was to evaluate the performance of rice genotypes comprising of parental lines, testers, hybrids and check varieties in response to iron toxicity in hydroponic culture and also to assess the viability of this technique as an auxiliary tool in rice breeding programs for iron stress tolerance.

5.5 Influence of genotypes and varying iron levels on yield attributes

5.5.1 Influence of genotypes on yield attributes

High significant mean squares of genotypes revealed that wide variability existed among the parents, hybrids and check varieties under study for all the yield attributes studied.

Check C_1 (PTB 56), C_2 (PTB 30) and parental line L_1 (Mo 19) and tester T_6 (Triguna) were adjudged superior to other genotypes with respect to tolerance to iron toxicity and most other traits studied. Hybrids H_1 (Mo 19/PTB 43), H_2 (Mo 19/PTB

49), H_5 (Mo 19/IR64), H_{16} (PTB 57/PTB 45) were poor performers for most attributes studied in addition to exhibiting susceptibility to iron toxicity. Considering the performance of the genotypes for various attributes, Line L_1 was found the best. Parental line $L_1$was found superior to all other genotypes with respect to attributes root length, total number of tillers and number of fresh roots. It also exhibited the least score for iron toxicity tolerance.

5.5.2 Influence of iron levels on yield attributes

Significant mean squares of iron levels on yield attributes indicated that the expression of all the yield attributes studied where distinct at increased iron toxicity level 600 ppm over control.

Shoot length, total number of roots, vigour index (SL/RL) and biomass was found to be drastically reduced at 600 ppm compared to control indicating that an increase in iron level negatively affects these traits. Fageria *et al.,* (2008), reported that iron toxicity disorder may be expressed as reduced plant height, reduced tillering, leaf discolouration and reduced root growth. The study pointed out that with an increase in concentration of iron (600 ppm), an increase in root length, number of fresh roots, iron adsorbed on root surface and visual scoring for iron toxicity tolerance (susceptibility to iron toxicity) was observed. Toxic levels of iron are reported to cause stunting of growth especially through reduction in both shoot and root length, and biomass. A study by Wang *et al.,* (2013) revealed that excessive Fe^{2+} significantly inhibited the growth of both Fe-sensitive cultivar and Fe-resistant cultivar, including the shoot, root and shoot fresh weights, and dry weight. However the finding of the present study with respect to root length under excessive Fe^{2+} is in contrast to that of Wang *et al.,* (2013). Crestani *et al.,* (2009) reported that higher iron concentrations reduced root development and lead to shorter and thicker roots with less branching, i.e., reduced formation of secondary roots.

The results pointed that an increase in root length and number of fresh roots at higher concentrations of iron was accompanied by a decrease in biomass in few genotypes which points to possible existence of a lean and lanky unhealthy root system.

5.5.3 Influence of genotype x iron interaction on yield attributes

Significant interaction effects of genotypes x iron levels for all traits indicated that the performance of genotypes varied with varying iron levels.

The per cent change in expression of the attributes between the two iron levels (600 and 0 ppm) over that at 0 ppm iron (Table 44) indicated that the rate of change was negligible in few genotypes while it was substantial in others. A negligible change in expression of traits in few genotypes may point out that these were least affected by toxic levels of iron in the growth medium compared to the others. Alternatively, a change in trait expression may indicate the attempt or capacity of the genotype to adapt and overcome the excessive iron stress condition (Fig. 20 to Fig. 27)

Root and shoot length were reported in the literature as traits used to test rice genotype response to Fe^{2+} in nutrient solution (Ferreira, 1997). Majority of the genotypes studied recorded a decrease in shoot length at higher iron level compared to 0 ppm. The per cent change in shoot length was the least in C_2 (PTB 30) and hybrid H_{10} (PTB 53/PTB 45). The change in shoot length in line L_2 (PTB 53), testers T_2 (PTB 49), T_4 (PTB 45), T_6 (Triguna), hybrids H_{11} (PTB 53/IR64) and H_{18} (PTB 57/Triguna) was also low compared to the heavy stunting observed in tester T_5 (IR 64) and hybrids H_5 (Mo 19/IR64), H_{13} (PTB 57/PTB 43), H_{15} (PTB 57/PTB 39) and H_{16} (PTB 57/PTB 45).

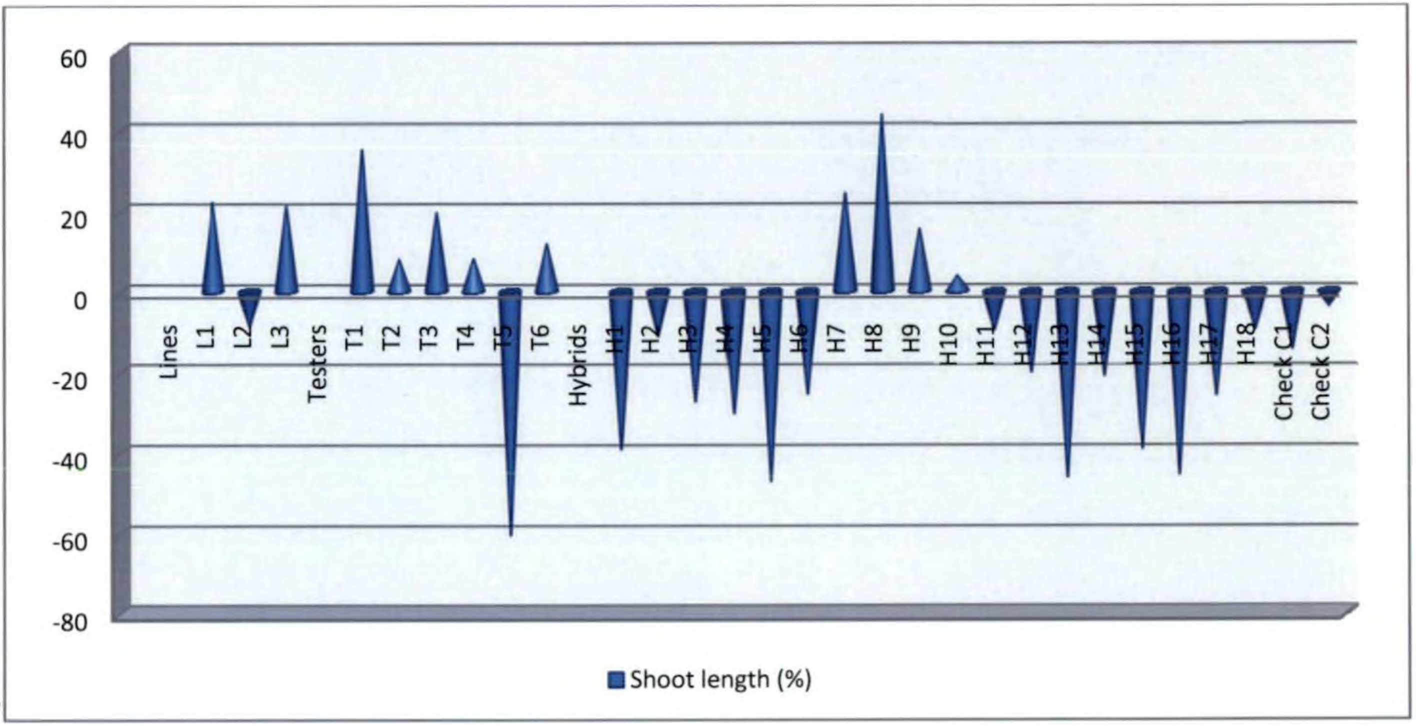


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Figure 20: Per cent change in shoot length between iron levels (0 and 600 ppm)

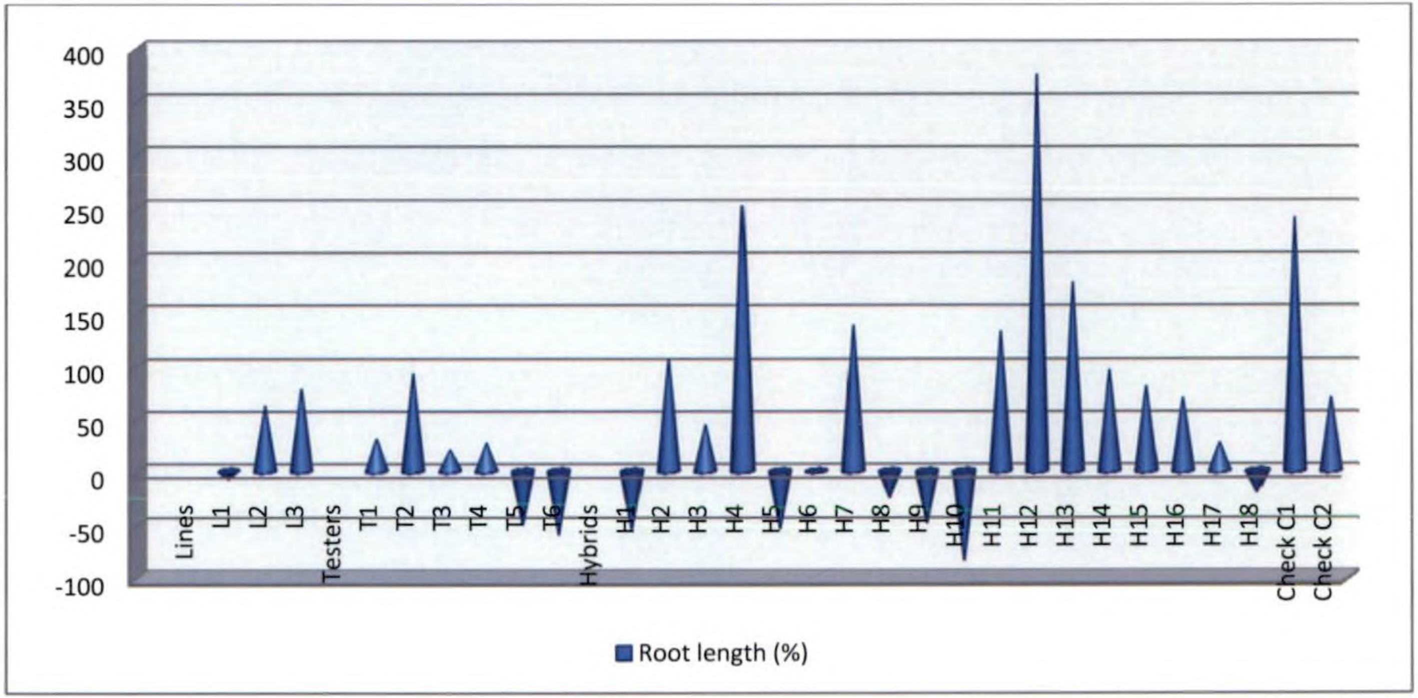


Figure 21: Per cent change in root length between iron levels (0 and 600 ppm)

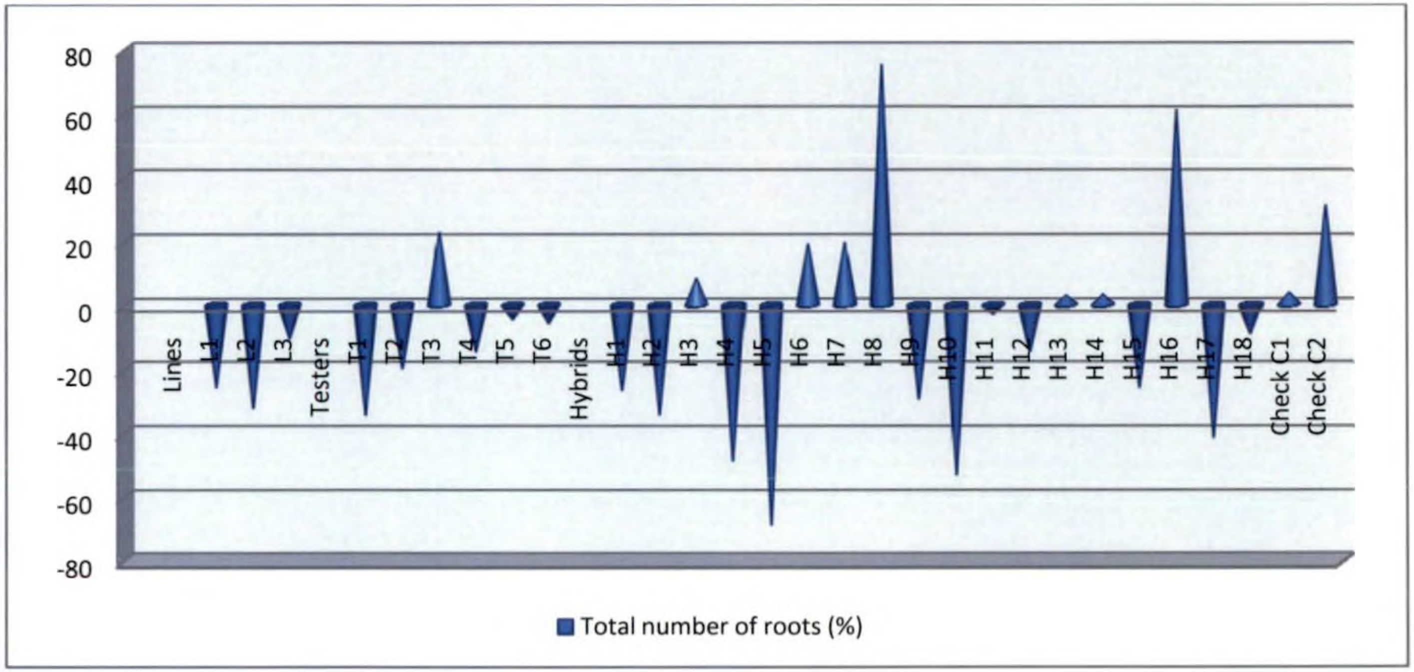


Figure 22: Per cent change in total number of roots between iron levels (0 and 600 ppm)

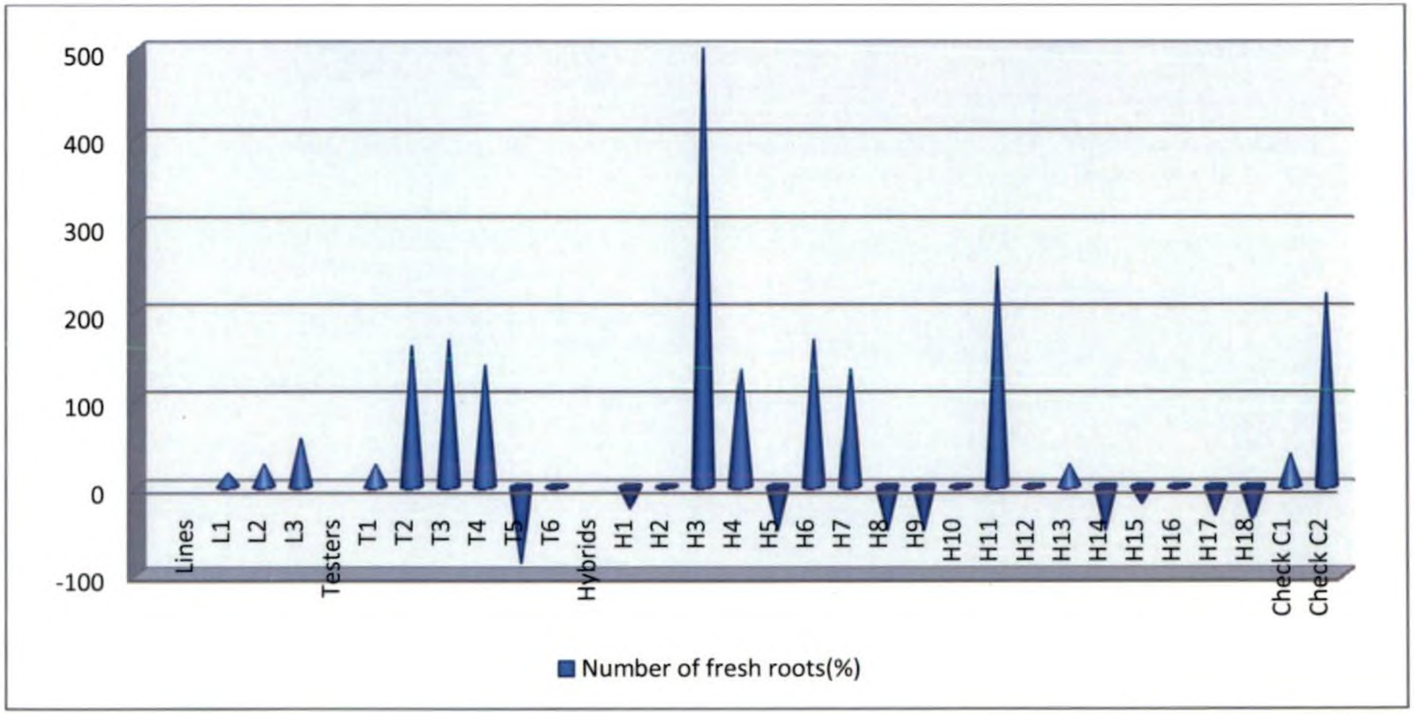


Figure 23; Per cent change in number of fresh roots between iron levels (0 and 600 ppm)

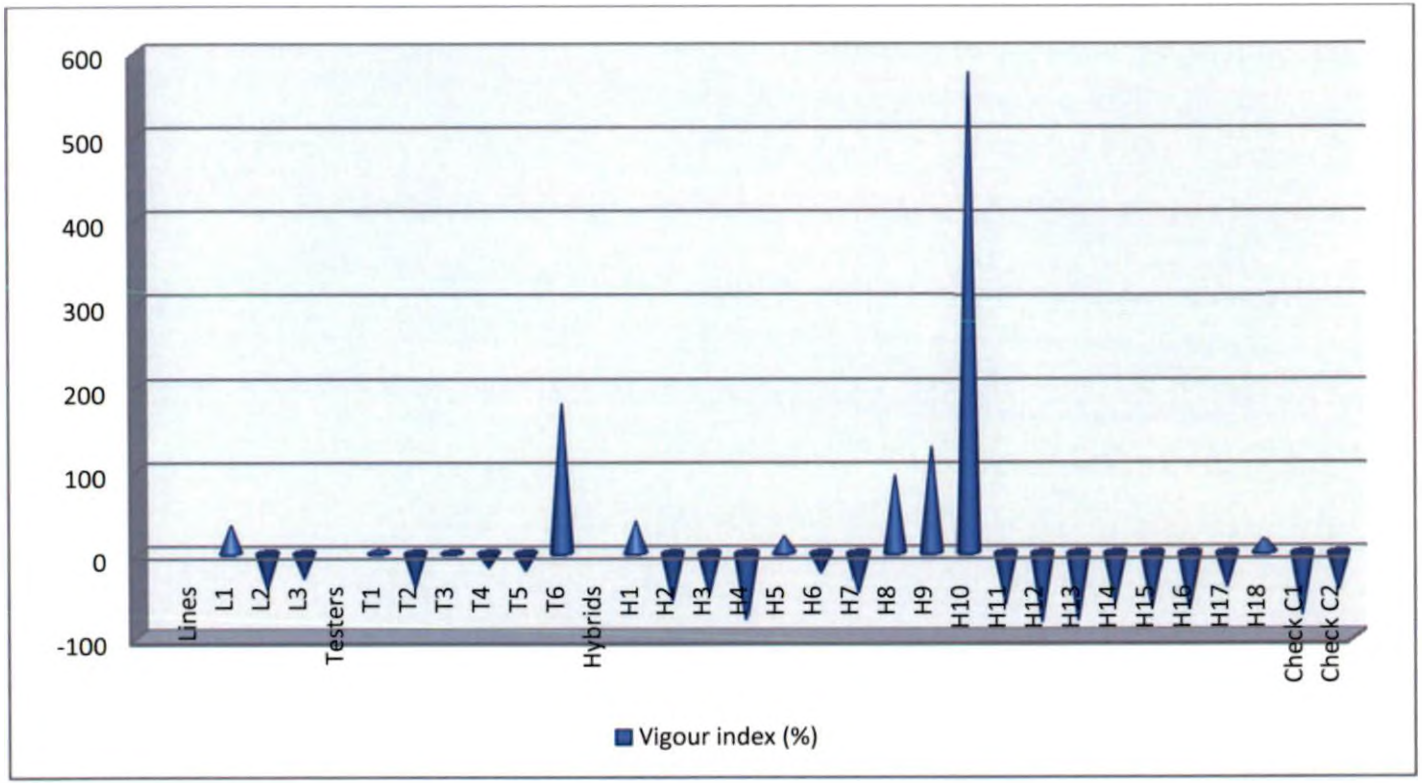


Figure 24: Per cent change in vigour index between iron levels (0 and 600 ppm)

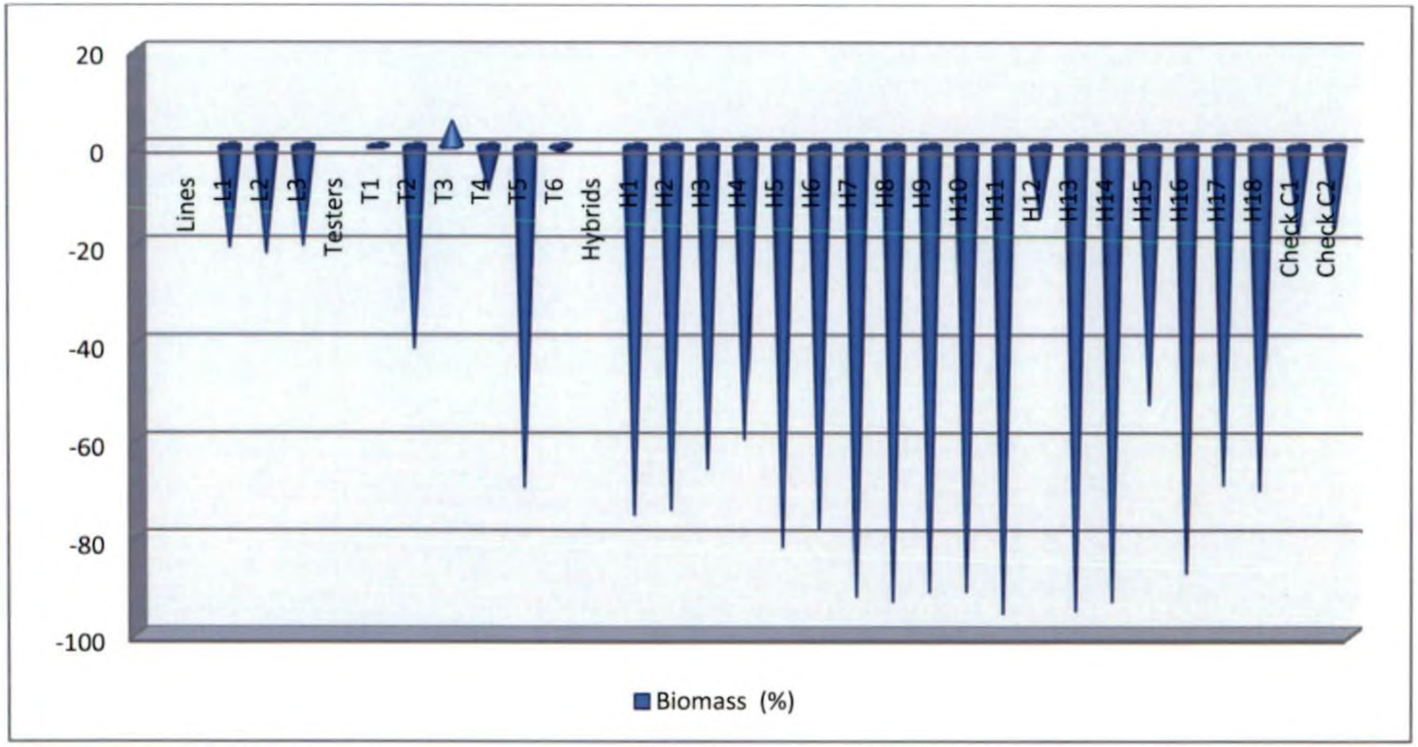


Figure 25: Per cent change in biomass between iron levels (0 and 600 ppm)

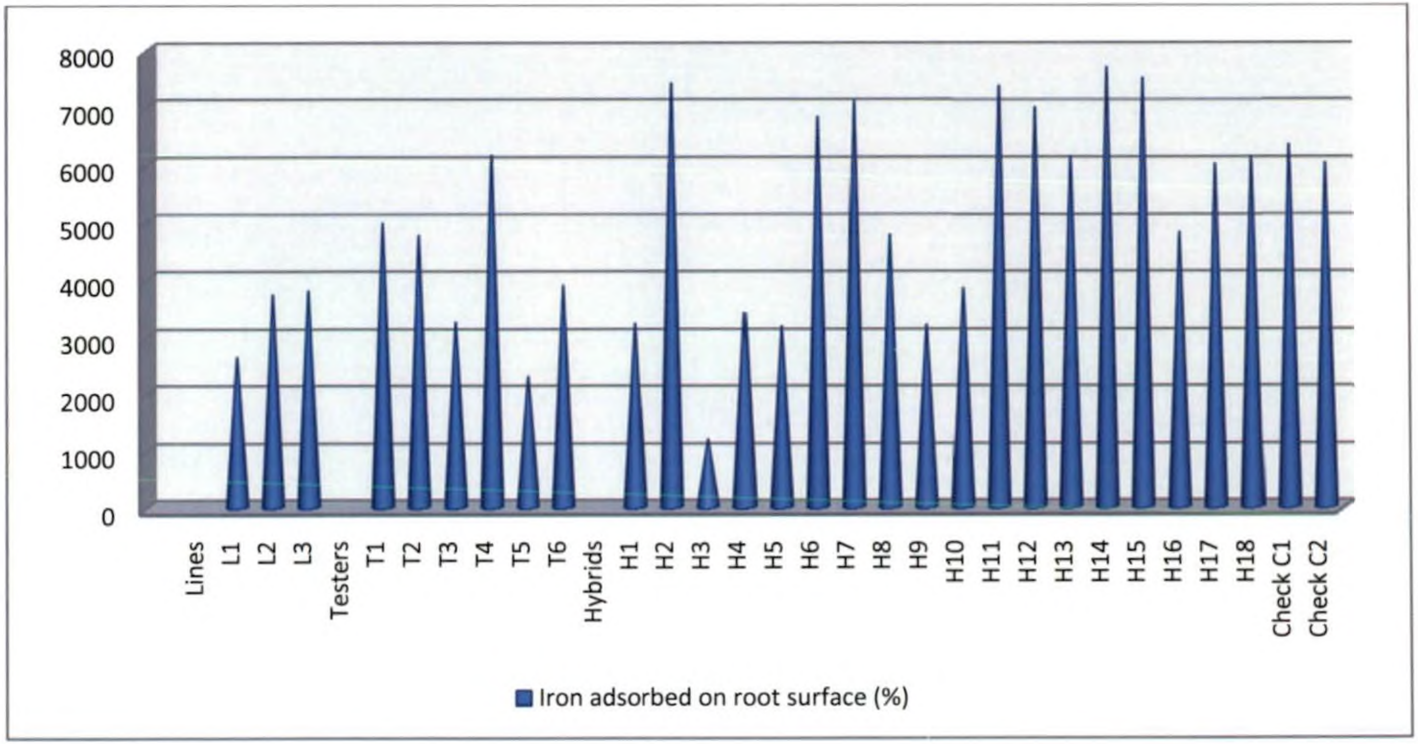


Figure 26: Per cent change in iron adsorbed on root surface between iron levels (0 and 600 ppm)

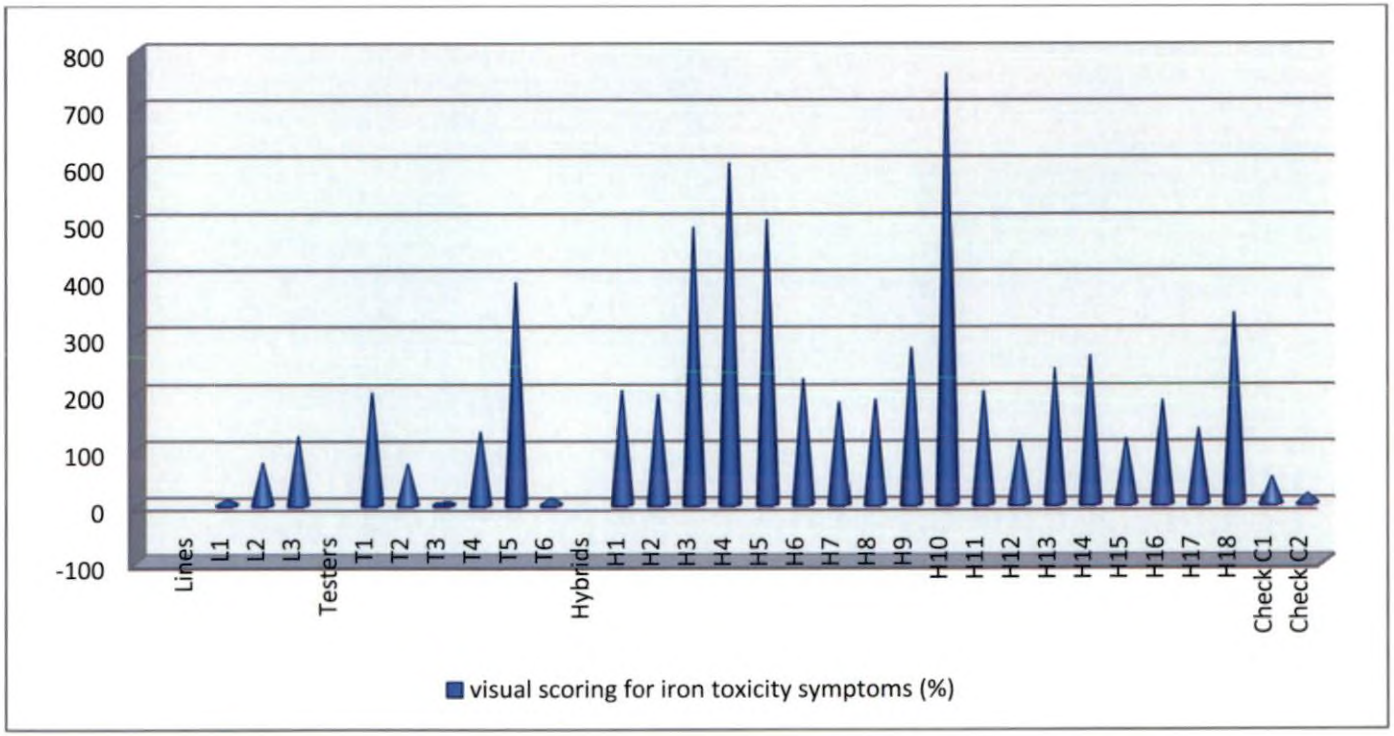


Figure 27: Per cent change in visual scoring for iron toxicity symptoms between iron levels (0 and 600 ppm)

Table 44. Per cent difference between varietal responses to iron at 600 ppm, over 0 ppm

Genotypes	Shoot length	Root length	Total number of roots	Number of fresh roots	Vigour index	Biomass	Iron adsorbed on root surface	Visual scoring for iron toxicity symptoms
Lines								
L_1	22.1	-8.3	-25.8	15.0	32.5	-20.7	2611.5	9.8
L_2	-8.7	61.2	-32.3	25.0	-43.0	-21.9	3706.1	73.3
L_3	21.2	77.3	-10.4	54.5	-30.7	-20.3	3773.0	119.5
Testers								
T_1	35.3	30.2	-34.5	25.0	4.4	0.0	4953.4	195.0
T_2	7.9	91.1	-20.0	160.0	-41.3	-41.4	4737.6	71.1
T_3	19.5	19.6	22.6	166.7	1.5	5.2	3227.1	-4.0
T_4	8.1	26.0	-14.5	137.5	-17.8	-8.9	6139.7	126.7
T_5	-60.7	-50.4	-4.6	-87.5	-21.5	-69.9	2270.5	388.9
T_6	11.7	-59.6	-5.8	0.0	177.6	-1.3	3865.0	12.5
Hybrids								
H_1	-39.4	-54.6	-26.7	-25.0	37.3	-75.6	3201.2	200.0
H_2	-11.2	104.9	-34.3	0.0	-56.8	-74.4	7403.6	192.3
H_3	-27.6	42.9	8.1	500.0	-49.5	-66.2	1177.8	486.7
H_4	-30.5	250.0	-48.9	133.3	-80.1	-60.0	3384.2	600.0
H_5	-47.3	-54.4	-68.8	-50.0	19.3	-82.1	3159.0	500.0
H_6	-25.7	-1.0	18.9	166.7	-24.1	-78.3	6806.7	220.8
H_7	24.2	136.9	19.4	133.3	-47.6	-92.3	7082.3	178.3
H_8	43.8	-25.0	75.0	-50.0	91.7	-93.3	4750.8	183.3
H_9	15.4	-48.7	-29.4	-50.0	125.6	-91.3	3176.2	275.0
H_{10}	3.8	-84.5	-53.3	0.0	572.9	-91.4	3819.0	757.1
H_{11}	-9.7	131.3	-3.0	250.0	-61.4	-95.8	7348.3	197.9
H_{12}	-20.2	374.3	-14.6	0.0	-83.4	-14.7	6978.3	110.5
H_{13}	-46.4	177.8	2.9	25.0	-81.6	-95.2	6113.6	238.5
H_{14}	-21.1	94.6	3.1	-50.0	-60.3	-93.3	7678.2	260.0
H_{15}	-39.2	79.7	-25.9	-20.0	-66.0	-52.9	7489.1	114.5
H_{16}	-45.6	68.4	60.9	0.0	-68.0	-87.5	4789.2	181.0
H_{17}	-26.0	26.4	-41.5	-33.3	-41.3	-69.4	5981.8	131.5
H_{18}	-9.5	-20.0	-9.1	-37.5	15.8	-70.5	6114.1	335.3
Check C_1	-14.4	238.6	3.7	36.4	-74.7	-17.9	6325.8	46.3
Check C_2	-3.8	69.0	30.8	220.0	-45.0	-16.9	6006.7	16.8

In contrast to change in shoot length, most genotypes recorded an increase in root length at higher iron level compared to 0 ppm. The change was negligible in hybrid H_6 (Mo 19/Triguna) and line L_1 (Mo 19). The change in Tester T_3 (PB 39) and hybrid H_{18} (PTB 57/Triguna) was also low. The per cent increase in root length was substantial in Hybrid H_{12} (PTB 53/Triguna) followed by H_4 (Mo 19/PTB 45) and C_2 (PTB 30). Heavy stunting of roots was evident in genotypes, H_{10} (PTB 53/PTB 45), T_6 (Triguna), H_5 (Mo 19/IR64), H_1 (Mo 19/PTB 43) and T_5 (IR 64). Increase in root length may be an adaptation for these genotypes under iron stress situation. It is in contrast to the findings of Fageria *et al.,* (2008) who reported iron toxicity disorder may result in reduced root growth.

There was a decrease in total number of roots in most genotypes, though an increase was observed in few. Negligible change in total number of roots was observed in genotypes H_{11} (PTB 53/IR64), H_{13} (PTB 57/PTB 43), H_{14} (PTB 57/PTB 49), C_1 (PTB 56), T_5 (IR 64), T_6 (Triguna), H_3 (Mo 19/PTB 39) and H_{18} (PTB 57/Triguna). Heavy decrease in total number of roots was observed in H_5 (Mo 19/IR64) followed by H_{10} (PTB 53/PTB 45), H_4 (Mo 19/PTB 45), and H_{17} (PTB 57/IR64). An increase in number of roots may be considered as an attempt to negate the stress situation. The per cent increase in total roots was substantial in H_8 (PTB 53/PTB 49) followed by H_{16} (PTB 57/PTB 45), C_2 (PTB 30) and T_3 (PTB 39).

The roots of rice plants affected by iron toxicity become scanty coarse, short and blunted and dark brown in colour resulting early senescence of roots (Sahrawat, 2004). Production of large number of fresh roots is a favourable adaptation mechanism of plant to make up for the loss of active roots due to iron toxicity. In the present study, the number of fresh roots in most genotypes increased with increased iron levels. Check C_1 (PTB 30), tester T_3 (PTB 39) and hybrid H_3 (Mo 19/PTB 39) registered the maximum increase in number of fresh roots at excessive iron levels.

Severe reduction in number of fresh roots was observed in tester T_5 (IR64), hybrids H_9 (PTB 53/PTB 39), H_{14} (PTB 57/PTB 49) and H_5 (Mo 19/IR64).

The biomass decreased with increase in iron levels invariably in all genotypes. Nyamangyoku and Bertin (2013) found that the tolerant varieties produce high biomass in both control and toxicity solution. The poor growth of genotypes under excessive iron levels have been reported by several workers. Hybrids, H_5 (Mo 19/IR64), H_7 (PTB 53/PTB 43), H_8 (PTB 53/PTB 49), H_9 (PTB 53/PTB 39), H_{10} (PTB 53/PTB 45), H_{11} (PTB 53/IR64), H_{13} (PTB 57/PTB 43), H_{14} (PTB 57/PTB 49), and H_{16} (PTB 57/PTB 45) were the most affected. Tester T_1 (PTB 43), T_6 (Triguna), T_3 (PTB 39), T_4 (PTB 45) recorded least reduction in biomass at toxic levels of iron. Hybrids H_{12} and all the three parental lines (L_1; Mo 19, L_2; PTB 53 and L_3; PTB 57) and the two check varieties C_1 (PTB 56) and C_2 (PTB 30) also recorded negligible reduction in biomass.

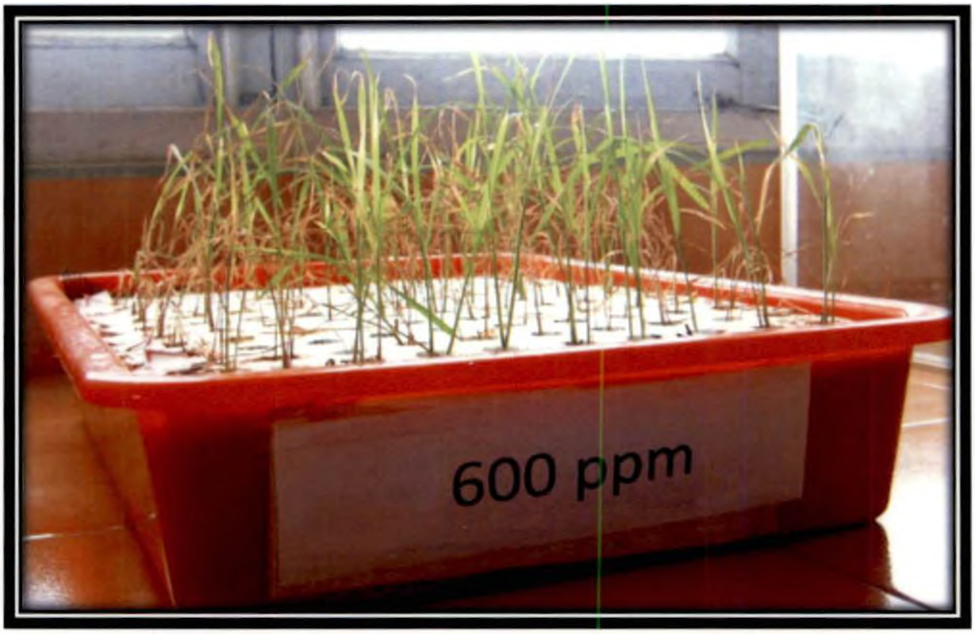
The adsorption of iron on root surface increased in all genotypes with excessive levels of iron. Hybrid H_{14} (PTB 57/PTB 49) followed by H_{11} (PTB 53/IR64), H_{15} (PTB 57/PTB 39), H_2 (Mo 19/PTB 49) and tester T_4 (PTB 45) excluded the highest amount of iron at the root surface. Higher adsorbed iron is an indication of iron exclusion mechanism operating in the plant system. Exclusion of Fe^{2+} in soil solution at the root level to avoid damage to the shoot tissue (rhizospheric oxidation and root Fe^{2+} selectivity) had been reported as exclusion/avoidance mechanism by Nozoe *et al.,* (2008). Nyamangyoku and Bertin (2013) opined that the iron coating must be considered as a symptom of sensitivity to ferrous iron toxicity rather than as a mechanism of resistance.

Bronzing scale is a classic parameter to evaluate cultivars to the sensitivity for ferrous toxicity. The susceptibility of varieties to iron toxicity increased with higher levels of iron as evident from the higher scores for iron toxicity symptoms. However, the per cent change in symptom was negligible which may be an indication of lower susceptibility of these genotypes to varying levels of iron. Parental line L_3 (PTB 57) was the least affected by the change in iron level followed by Line L_1 (Mo 19), tester T_6 (Triguna) and check C_2 (PTB 30). Check C_1 (PTB 56), tester T_2 (PTB 49) and line L_2 (PTB 53) were also found to be less affected by increased iron levels. Tester T_5 (IR64) and hybrids H_{10} (PTB 53/PTB 45) followed by H_5 (Mo 19/IR64), H_4 (Mo 19/PTB 45) and H_3 (Mo 19/PTB 39) were perceptibly affected by increased iron levels as evident from the per cent increase in score for iron toxicity over control (0 ppm).

Considering the performance of the genotypes at varying levels of iron, it can be concluded that, the performance of check variety C_2 (PTB 30; Chuvannamodan) was least affected by higher levels of iron. Among parents, tester T_6 (Triguna) and T_3 (PTB 39; Jyothi) and L_1 (Mo 19; Krishnanjana) were also found to be less affected by varying levels of iron. The results substantiates the performance of variety PTB 39;Jyothy (T_3) which is one of the most popular high yielding variety of Kerala grown under different agro-ecosytems with soils of varying iron toxic levels. Incidentally, Mo 19;Krishnanjana (L_1) is an iron toxicity tolerant high yielding rice variety of Kerala recommended for the kari soils (acid sulphate soils belt with high iron content) while Triguna is the national check variety for iron toxicity screening trials (Rajan and Prameela 2004). Hybrids H_{14} (PTB 57/PTB 49) and H_{18} (PTB 57/Triguna) and testers T_4 (PTB 45; Matta Triveni) and T_2 (PTB 49; Kairali) also showed promise under excessive iron levels.

Results indicated that genotypes H_5 (Mo 19/IR64), T_5 (IR 64), H_{10} (PTB 53/PTB 45) and H_{13} (PTB 57/PTB 43) were highly susceptible to iron toxicity. The results confirm the reports that, IR64 is susceptible to iron toxicity. It has been used as the susceptible check in screening studies by earlier workers (Nozoe *et al.,* 2008, Guerta and Kirk, 2002). The poor performance of H_5 (Mo 19/IR64) is in conformity of the results of the field screening trials in which it was found to be the lowest yielder of grains/panicle. However, H_{10} (PTB 53/PTB 45) recorded the highest grain yield/plant

Reaction of Genotypes at control



Reaction of genotypes at 600 ppm of iron concentration

Plate 5: Genotypes at different levels of iron concentration

PTB 30 at control and 600 ppm

Triguna at control and 600 ppm

PTB 39 at control and 600 ppm

Mo 19 at control and 600 ppm

Plate 6 : Performance of genotypes tolerant to iron toxicity at varying levels of iron

Score1-H_4 at control

Score 3-H_1 at control

Score 5.60- H_{12} at 600 ppm

Score7- H_4 at 600 ppm

Score9- H_{14} at 600 ppm

Plate 7: Visual scoring for iron toxicity

in the field screening while H_{13} (PTB 57/PTB 43) though an average yielder recorded the least score for iron toxicity tolerance.

This contrast in performance under field conditions may be due to many physiological tolerance mechanisms operating in the plant systems, soil conditions and factors which need further study. Within tolerant varieties of rice, Nozoe *et al.*, 2008 reported several mechanisms *viz.*, oxidation of Fe^{2+} at the root surface (iron oxidizing power), exclusion of Fe^{2+} at the root surface (iron excluding power), retention of Fe^{2+} in the root tissue (iron retaining power), leaf tissue tolerance to excess amounts of Fe^{2+}, to be relevant in coping with excess iron concentrations. These may be the reasons for high response of tolerant genotypes compared to others in iron toxic situations. Compared to field conditions, performance of hybrids were poor and parents were better under laboratory conditions. A suggestion for this contrast performance of genotypes under laboratory and field conditions may be the interaction of other nutrients in field due to dynamic soil conditions, which play an important role not only in reducing the effect of iron toxicity but also in the expression of iron tolerance by various rice cultivars (Sahrawat 2004). Deficiencies of P, K, Ca, Mg, and manganese (Mn) decrease the iron-excluding power of rice roots and can affect the rice plant's tolerance of iron toxicity (Sahrawat 2004).

A comparison of results of laboratory and field screening also emphasizes the existence of strong negative correlation between tolerance to iron toxicity and grain yield/plant.

These points out that simple selection will not be successful in developing varieties with both high yield and tolerance. Breeding efforts that help combine tolerance to iron toxicity and yield potential from different sources and identification of desirable progenies in the segregating generation would be beneficial.

5.5.4 Correlation studies among yield attributes and iron toxicity tolerance at control

Correlation studies facilitate the assessment of the chance for mutual improvement of two traits. Simple correlation indicates broadly the type of association that exists between various attributes. Pearson's correlation among the yield attributes and iron toxicity tolerance in the laboratory studies revealed that no significant correlation existed between the attributes and visual score for iron toxicity symptoms as expected under absence of toxic levels of iron.

Under non toxic levels of iron, high significant positive inter correlation existed between shoot length and total number of roots, number of fresh roots, vigour index (SL/RL), biomass and iron adsorbed on root surface. Root length exhibited high significant negative correlation with vigour index (SL/RL). Total number of roots registered high significant positive correlation with number of fresh roots and iron adsorbed on root surface. Number of fresh roots recorded significant positive correlation with iron adsorbed on roots and biomass. Vigour index (SL/RL) recorded positive significant correlation with biomass.

5.5.5 Correlation studies among yield attributes and iron toxicity tolerance at 600 ppm of iron

At toxic levels of iron (600 ppm) high significant negative correlation was evident between yield attributes *viz.,* shoot length, root length, total number of roots, number of fresh roots, biomass and iron adsorbed on root surface with visual score for iron toxicity symptoms recorded indicating that plant growth is drastically affected when iron level reaches 600ppm. The degree of leaf bronzing has been suggested as a good measure of the degree of iron toxicity (IRRI,1965)

Inter-correlation among yield attributes reveals the inter-dependency of these characters at iron toxic situation. Shoot length and root length exhibited significant to high significant positive correlation with all the yield attributes studied. However, inter correlation with root length was negative with respect to vigour index (SL/RL). Positive and high significant inter correlation was registered between total number of roots and number of fresh roots, biomass and iron adsorbed on root surface. Number of fresh roots recorded positive highly significant correlation with biomass. Biomass registered high significant positive correlation with iron adsorbed on root surface. A positive association between traits warrants the simultaneous improvement of the both the traits while restricting selection to any one of the traits. However, a negative relationship necessitates equal weightage to be given on both the traits (Rajamadhan *et al.*, 2011).

The study revealed that existence of high significant negative correlation between yield and susceptibility to iron toxicity (visual scoring for iron toxicity tolerance). Several yield attributes that registered a negative relationship with susceptibility to iron toxicity had exhibited a positive association with yield. Hence, selection based on these attributes can lead to improvement in tolerance to iron toxicity as well as yield.

FUTURE LINE OF WORK

Very less number of works has been done in the breeding aspect regarding iron toxicity tolerance in rice in Kerala conditions. More studies to confirm the genetic and physiological mechanisms acting in tolerant varieties need to be undertaken for developing tolerant varieties against iron toxicity. Efforts should be directed for the following future studies

1) Days to fifty per cent flowering, panicle length, seed set per cent and root weight could be used as predictor variables under iron toxic field conditions to improve yield.

2) Promising parents PTB 53 (L_2; Mangala Mahsuri), and PTB 57 (L_3; Swetha) from field studies may be further used in breeding programmes aiming to impart iron toxicity tolerance in rice and improve yield.

3) Attempts to identify promising segregants with high yield and tolerance to iron toxicity from these cross-combinations PTB 53/PTB 43(H_7), PTB 53/PTB 45(H_{10}), and PTB 57/PTB 45 (H_{16}) may prove fruitful.

4) Check varieties PTB 56 (C_1; Varsha) and PTB 30 (C_2; Chuvannamodan) which had performed high under laboratory conditions may be evaluated in field to confirm their tolerance.

5) Molecular studies including QTL mapping using molecular markers for iron toxicity tolerant gene aid in further advance of the conventional breeding programmes with regard to iron toxicity tolerance

Summary

VI. Summary

The present study 'Combining ability for tolerance to iron toxicity in rice (*Oryza sativa* L.)' was carried out at Kerala Agricultural University (KAU), Vellanikkara during 2012-2013. Three iron toxicity tolerant lines [L_1: Mo 19 (Krishnanjana), L_2: PTB 53 (Mangala Mahsuri), L_3: PTB 57 (Swetha)], six testers [T_1: PTB 43 (Swarnaprabha), T_2: PTB 49 (Kairali), T_3: PTB 39 (Jyothy), T_4: PTB 45 (Matta Triveni), T_5: IR 64 and T_6: Triguna] and the resultant eighteen hybrids generated through line x tester mating design (Experiment I) constituted the study material. The performance of hybrids and parents was evaluated under both field and laboratory conditions. Field screening for iron toxicity tolerance [Experiment II (a)] was done at Regional Agricultural Research Station, KAU, Pattambi, while, laboratory screening for iron toxicity tolerance [Experiment II (b)] was conducted in the Department of Plant Breeding and Genetics, College of Horticulture, KAU, Vellanikkara, Thrissur.

The study envisaged the assessment of the extent of variability and genetic parameters for yield and yield attributes, understanding the degree and extent of association between grain yield and its contributing characters with special emphasis on iron toxicity tolerance. In addition to the above, the programme also aimed at identifying potential parents and superior cross-combinations for yield and tolerance to iron toxicity through estimation of heterosis and combining ability.

The salient findings of the study are summarized below:

Field screening for tolerance to iron toxicity iron toxicity tolerance

Variability studies

1) Wide variability was found to exist among parents and hybrids for yield and most yield attributes studied indicating ample scope for improvement of the traits through selection.

2) High PCV and GCV estimates were recorded for grain yield, tolerance to iron toxicity and attributes *viz.*, iron adsorbed on root surface, iron and manganese content in root, number of fresh roots, dry weight of roots at flowering, iron content in the third leaf from tip, youngest fully open mature leaf and oldest leaf, plant height, culm length, grains/panicle, root length, root and shoot weight at maturity. This indicated presence of ample variability among genotypes for these traits and the possibility of improvement through selection.

3) High heritability coupled with high genetic advance as per cent of mean indicating additive gene action were observed for grain yield, visual scoring for iron toxicity, iron adsorbed on root surface, iron content in root, iron content in third leaf from tip, youngest fully open mature leaf, oldest leaf, days to fifty per cent flowering, plant height, culm length, panicle length, spikelets/panicle, grains/panicle and shoot weight. High heritability coupled with high genetic advance as per cent of mean indicates that substantial improvement in the expression of characters over base population can be expected through selection. Simple selection would be effective in improvement of these traits.

4) Moderate heritability estimates along with high genetic advance as per cent of mean were observed for traits, number of fresh roots, seed set per cent, thousand grain weight, root length and root weight, implying influence of both additive and non-additive gene action on expression of these traits. Improvement of these traits could be attained by following recurrent or reciprocal recurrent selection to exploit both additive and non-additive genetic components.

Trait association studies

1) Total number of roots, days to fifty per cent flowering recorded positive and high significant correlation with grain yield/plant besides registering a significant negative inter correlation with visual scoring for iron toxicity symptoms indicating the chance of mutual development of yield and tolerance to iron toxicity tolerance among the observed traits at tillering and flowering. Fresh number of roots also had registered a negative significant inter correlation with visual scoring for iron toxicity symptoms

2) At tillering and flowering, high degree of negative association was observed between grain yield/plant and dry weight of roots, manganese content in third leaf, youngest fully open mature leaf and oldest leaf, iron content in the youngest fully open mature leaf and oldest leaf, and visual scoring for iron toxicity tolerance indicating negative selection to be emphasized in case of these traits to improve yield. Among them dry weight of roots, manganese content in the third leaf and youngest fully open mature leaf had also registered significant positive inter correlation with visual scoring for iron toxicity which warrants negative selection to improve grain yield/plant and tolerance to iron toxicity together.

3) High positive direct effect on yield was contributed by days to fifty per cent flowering, manganese content in root, iron content in third leaf from tip and in youngest fully open mature leaf. Among these only days to fifty per cent flowering had recorded a high positive correlation with yield indicating that days to fifty per cent flowering can be a reliable indicator for yield improvement

4) Visual scoring for iron toxicity registered a negligible positive direct effect on yield but a high significant negative correlation with yield. The negative effect

of visual scoring for iron toxicity on grain yield was also made possible *via* its high negative indirect effect through days to fifty per cent flowering.

5) Correlation analysis along with path analysis emphasized the importance of days to fifty per cent flowering at tillering and flowering as predictor variable for increased yield and tolerance to iron toxicity.

6) Among the observed characters at maturity all had registered significant positive correlation with grain yield/plant except for visual scoring for iron toxicity symptoms. A negative correlation of visual scoring for iron toxicity symptoms indicated an increase in score affects the yield.

7) Except, total tillers/plant, productive tillers/plant and thousand grain weight all others among the observed characters had also registered significant negative inter correlation with visual scoring for iron toxicity symptoms indicating the chance of mutual development for grain yield/plant and tolerance to iron toxicity together.

8) Path analysis for the characters studied at maturity indicated very high to high positive direct effect on grain yield/plant was exerted by root weight followed by panicle length, productive tillers/plant and seed set per cent. Besides that most of the other characters had exerted their moderate, high to very high indirect effect through them. Very high to high negative indirect effect was exerted by shoot weight followed by root weight and most of the characters had exerted their negative indirect effects through them.

9) Correlation analysis in conjunction with path analysis for the characters at maturity indicated, root weight, panicle length and seed set per cent had registered significant positive correlation with yield and negative inter correlation with visual scoring for iron toxicity besides registering a high to

very high positive direct effect on yield. More over most of the other characters had exerted moderate, high to very high positive indirect effect through them. Hence, panicle length, root weight and seed set per cent in selection for yield will lead to a simultaneous increase in tolerance to iron toxicity.

Studies on combining ability

1) Analysis of variance for combining ability revealed that the hybrids differed significantly from each for all traits except number of total tillers and productive tillers per plant.

2) Higher and significant mean squares for lines compared to testers and higher SCA variance over GCA variance indicating pre-ponderance of non-additive gene action was noticed for spikelets/panicle, grains/panicle, thousand grain weight, root length, visual scoring for iron toxicity symptoms and grain yield/plant. This also indicated greater contribution of lines to higher *sca* effects than the testers in the expression of these traits.

3) Higher estimates of GCA variance over SCA variance indicative of preponderance of additive gene action was evident in case of plant height, culm length, panicle length, seed set per cent, shoot weight and root weight at maturity.

4) From mean performance studies among parents, it was evident that L_2 (PTB 53) and L_1 (Mo 19) out-yielded all others. In case of tolerance to iron toxicity, tester T_2 (PTB 49) along with lines L_2 and L_3 (PTB 57) exhibited moderate resistance. Scoring based on mean performance for all the yield and yield attributes revealed that Line L_2 followed by L_3 was the best parents.

5) Results from the *gca* effects of parents indicated L_2 (PTB 53), T_2 (PTB 49) and T_4 (PTB 45) to be good combiners for grain yield while L_2, L_3 (PTB 57), T_1 (PTB 43), T_2, T_3 (PTB 39) and T_4 proved to be good combiners for tolerance to iron toxicity. Scoring of the *gca* effects for all the yield and yield attributes revealed that Line L_2 was the best general combiner followed by line L_3, testers T_2 and T_4.

6) Evaluation of parents for yield alone based on both mean performance and *gca* effects revealed L_2 (PTB 53) and L_1 (Mo 19) to be promising, while, parents L_2, L_3 (PTB 57), T_1 (PTB 43), T_2 (PTB 49), T_3 (PTB 39) and T_4 (PTB 45) were found promising for tolerance to iron toxicity. Scoring of the *gca* effects and mean estimates of all the yield and yield attributes revealed that, Line L_2 followed by line L_3 were the most promising parents.

7) Evaluation of hybrids based on mean performance indicated the hybrids H_{10} (PTB 53/PTB 45), H_{17} (PTB 57/IR64), H_{16} (PTB 57/PTB 45), H_7 (PTB 53/PTB 43), H_2 (Mo 19/PTB 49), H_{11} (PTB 53/IR64), H_8 (PTB 53/PTB 49), H_{14} (PTB 57/PTB 49), and H_6 (Mo 19/Triguna) performed better than others for yield alone. H_{13} (PTB 57/PTB 43) (Resistant) scored the least for visual scoring for iron toxicity symptoms and hybrids H_7, H_8, H_9 (PTB 53/PTB 39), H_{14}, H_{15} (PTB 57/PTB 39), and H_{16} recorded moderate resistance to iron toxicity, but did not rank in the scoring scheme. Considering mean performance of hybrids for both reaction to iron toxicity and grain yield H_{16}, H_7 and H_{14} can be adjudged the better specific combinations. Scoring based on mean performance for all the yield and yield attributes indicated H_{10} was the best hybrid followed by H_7 and H_{14}.

8) Specific combining ability studies in the cross combinations generated indicated H_2 (Mo 19/PTB 49), H_6 (Mo 19/Triguna), H_{10} (PTB 53/PTB 45) and

H_{17} (PTB 57/IR64) to record significant *sca* effect for grain yield/plant. Hybrid H_4 (Mo 19/PTB 45), H_5 (Mo 19/IR64), H_6, H_7 (PTB 53/PTB 43), H_8 (PTB 53/PTB 49), H_{13} (PTB 57/PTB 43) and H_{16} (PTB 57/PTB 45) recorded significant *sca* in the desired direction for tolerance to iron toxicity. Scoring of the hybrids based on *sca* effects for all the yield and other yield attributes revealed that H_6 was the best followed by hybrids H_2, H_{17}, H_7 (PTB 53/PTB 43), H_9 (PTB 53/PTB 39), H_{16}, H_{10} and H_{11} (PTB 53/IR64) . There was no exact correspondence between mean performance and *sca* effects in these hybrids.

9) Ranking of hybrids based on both mean performance and *sca* effect for yield and yield attributes revealed that hybrid H_7 (PTB 53/PTB 43) followed by H_{10} (PTB 53/PTB 45), H_{14} (PTB 57/PTB 49), H_{17} (PTB 57/IR64), H_6 (Mo 19/Triguna), H_9 (PTB 53/PTB 39) and H_{16} (PTB 57/PTB 45) were the best. H_7, recorded high mean estimates for grain yield/plant and significant *sca* for visual scoring for iron toxicity in the desired direction. Hybrid H_{10} ranked first with respect to grain yield and possessed significant *sca* for the same and moderate score for visual scoring.

Studies on Heterosis

1) Hybrids H_2 (Mo 19/PTB 49) , H_{10} (PTB 53/PTB 45), H_{14} (PTB 57/PTB 49), H_{16} (PTB 57/PTB 45) and H_{17} exhibited significant heterosis, heterobeltiosis and standard heterosis for grain yield whereas hybrids, H_3 (Mo 19/PTB 39), H_4 (Mo 19/PTB 45), H_6 (Mo 19/Triguna), H_7 (PTB 53/PTB 43), H_9 (PTB 53/PTB 39), H_{13} (PTB 57/PTB 43), H_{15} (PTB 57/PTB 39) and H_{16} exhibited significant heterosis, heterobeltiosis and standard heterosis for tolerance to iron toxicity. Results revealed that hybrids H_{16}, H_{10}, H_9 and H_7 were the good heterotic cross-combinations for yield and yield attributes.

2) Based on the heterosis estimates and mean performance for yield and yield attributes, hybrid H_{16} was found to be the best heterotic cross-combination. Hybrids H_7 (PTB 53/PTB 43), H_9 (PTB 53/PTB 39) and H_{10} (PTB 53/PTB 45), H_{17} (PTB 57/IR64), H_8 (PTB 53/PTB 49), H_{14} (PTB 57/PTB 49), H_{11} (PTB 53/IR64) and H_{15} (PTB 57/PTB 39) were also found to be promising.

3) Based on the scoring of estimates of heterosis, *sca* and mean performance for yield and yield attributes, hybrids H_7 (PTB 53/PTB 43), H_{10} (PTB 53/PTB 45) and H_{16} (PTB 57/PTB 45) ranked the best. Hybrids H_{17} (PTB 57/IR64) followed by H_{14} (PTB 57/PTB 49) and H_9 (PTB 53/PTB 39) were also found promising.

Experiment II (b). Laboratory screening for iron toxicity tolerance

1) Performance of the genotypes (30th day after sowing) in the laboratory screening revealed that, Line L_1 (Mo 19) was the best irrespective of iron levels. Parental line L_1, was found superior to all other genotypes with respect to attributes root length, total number of tillers, number of fresh roots and tolerance to iron toxicity. Parental line L_1, tester T_6 (Triguna), check varieties C_1 (PTB 56) and C_2 (PTB 30) registered the least score for iron toxicity tolerance.

2) A drastic reduction in shoot length, total number of roots, vigour index (SL/RL) and biomass was found to occur at 600 ppm, while, root length, number of fresh roots, iron adsorbed on root surface and visual scoring for iron toxicity tolerance (susceptibility to iron toxicity) was found to increase with increase in iron level.

3) Performance of the genotypes at varying levels of iron, revealed that check variety C_2 (PTB 30) was least affected by higher levels of iron. Among parents, tester T_6 (Triguna) and T_3 (PTB 39) and line L_1 (Mo 19) were also found to be less affected by varying levels of iron.

4) Thirty days after sowing, at toxic levels of iron (600 ppm), high significant negative correlation was evident between attributes *viz.,* shoot length, root length, total number of roots, number of fresh roots, biomass and iron adsorbed on root surface with visual scoring for iron toxicity symptoms recorded indicating that plant growth is drastically affected when iron level reaches 600ppm.

The study revealed that susceptibility to iron toxicity negatively affected performance of genotypes. Existence of wide variability among genotypes for yield, tolerance to iron toxicity and other yield attributes as evident in the study indicate ample scope for improvement of yield as well as tolerance through concerted breeding programmes.

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COMBINING ABILITY FOR TOLERANCE TO IRON TOXICITY IN RICE (*Oryza sativa* L.)

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Three lines tolerant to iron toxicity [L_1: Mo 19 (Krishnanjana), L_2: PTB 53 (Mangala Mahsuri) and L_3: PTB 57 (Swetha)] were crossed to six high yielding testers [T_1: PTB 43 (Swarnaprabha), T_2: PTB 49 (Kairali), T_3: PTB 39 (Jyothy), T_4: PTB 45 (Matta Triveni), T_5: IR 64 and T_6: Triguna] in a line x tester mating design resulting in eighteen hybrid combinations. Observations taken on yield and yield attributes were statistically analysed to deduce the nature and extent of variability and association among yield and yield attributes, estimate the genetic parameters, assess the combining ability effects and quantify the magnitude of heterosis in hybrid.

Wide variability was found to exist among parents and hybrids for yield and most yield attributes studied indicating ample scope for improvement through selection. Variability among genotypes was low with respect to total number of roots, manganese content in old leaf, total tillers/plant and productive tillers/plant. High heritability coupled with high genetic advance as per cent of mean were observed for grain yield, visual scoring for iron toxicity, iron adsorbed on root surface, iron content in root, iron content in third leaf from tip, youngest fully open mature leaf, oldest leaf, days to fifty per cent flowering, plant height, culm length, panicle length, spikelets/panicle, grains/panicle and shoot weight indicating that substantial improvement in the expression of these attributes over base population can be expected through selection.

Results emphasized that an improvement in days to fifty per cent flowering at tillering and flowering, panicle length, seed set per cent and root weight at maturity are reliable predictor variables for increased yield and tolerance to iron toxicity. Negative selection for traits *viz.,* dry weight of roots, manganese content in third leaf and youngest fully open mature leaf at tillering and flowering,

may also lead to simultaneous improvement of grain yield and tolerance to iron toxicity.

Higher estimates of GCA variance over SCA variance indicative of preponderance of additive gene action was evident in case of plant height, culm length, panicle length, seed set per cent, shoot weight and root weight at maturity. Pre-ponderance of non-additive gene action indicated by higher SCA variances than GCA variances was registered for traits spikelets/panicle, grains/panicle, thousand grain weight, root length, visual scoring for iron toxicity symptoms and grain yield.

Evaluation of parents for yield alone based on both mean performance and *gca* effects revealed L_2 (PTB 53) and L_1 (Mo 19) to be promising, while, parents L_2 (PTB 53), L_3 (PTB 57), T_1 (PTB 43), T_2 (PTB 49), T_3 (PTB 39) and T_4 (PTB 45) were found promising for tolerance to iron toxicity. Scoring of the *gca* effects and mean estimates for all the yield and yield attributes revealed that, line L_2 (PTB 53) followed by line L_3 (PTB 57) were the most promising parents. Hybrid H_{13} (PTB 57/PTB 43) was found to exhibit 'Resistance' reaction to iron toxicity indicating high tolerance to iron toxicity whereas hybrids H_{10} (PTB 53/PTB 45) and H_{17} (PTB 57/IR 64) with high mean grain yield were found to be moderately susceptible to iron toxicity. Based on the scoring of estimates of heterosis, *sca* and mean performance for yield and yield attributes, hybrids, H_7 (PTB 53/PTB 43), H_{10} (PTB 53/PTB 45) and H_{16} (PTB 57/PTB 45) ranked the best. Hence, attempts to identify promising segregants with high yield and tolerance to iron toxicity from these cross-combinations may prove fruitful.

Performance of the genotypes (30th day after sowing) in the laboratory screening revealed that, a drastic reduction in shoot length, total number of roots, vigour index (SL/RL) and biomass was found to occur at 600 ppm, while, root length, number of fresh roots, iron adsorbed on root surface and visual scoring for iron toxicity tolerance (susceptibility to iron toxicity) was found to increase with increase in iron level. Parental line L_3 (PTB 57) was the least affected perceptibly by the change in iron level followed by Line L_1 (Mo 19), tester T_6 (Triguna) and check C_2 (PTB 30). Considering the performance of the genotypes for all the attributes at varying levels of iron, it was revealed that check variety C_2 (PTB 30) was least affected by higher levels of iron. Among parents, tester T_6 (Triguna) and T_3 (PTB 39) and line L_1 (Mo 19) were also found to be less affected by varying levels of iron.

Ample variability among genotypes for yield, tolerance to iron toxicity and other yield attributes as evident in the study indicate ample scope for isolation of superior genotypes through concerted breeding programmes.