GENETIC ARCHITECTURE OF GRAIN IRON AND ZINC DENSITIES AND THEIR ASSOCIATION WITH AGRONOMIC TRAITS IN PEARL MILLET

(*Pennisetum glaucum* (L.) R. Br.)

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M.Sc. (Ag.)

DOCTOR OF PHILOSOPHY IN AGRICULTURE

(GENETICS AND PLANT BREEDING)

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BY
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M.Sc. (Ag.)

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2014

DECLARATION

I, **ANAND KANATTI**, hereby declare that the thesis entitled **"GENETIC ARCHITECTURE OF GRAIN IRON AND ZINC DENSITIES AND THEIR ASSOCIATION WITH AGRONOMIC TRAITS IN PEARL MILLET (*Pennisetum glaucum* (L.) R. Br.)"** submitted to the **Professor Jayashankar Telangana State Agricultural University** for the degree of **DOCTOR OF PHILOSOPHY IN AGRICULTURE** is the result of original research work done by me. I also declare that no material contained in this thesis has been published earlier in any manner.

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Date: **I. D. No. RAD/10-17**

CERTIFICATE

Mr. **ANAND KANATTI** has satisfactorily prosecuted the course of research and that thesis entitled **"GENETIC ARCHITECTURE OF GRAIN IRON AND ZINC DENSITIES AND THEIR ASSOCIATION WITH AGRONOMIC TRAITS IN PEARL MILLET (*Pennisetum glaucum* (L.) R. Br.)"** submitted is the result of original research and is of sufficiently high standard to warrant its presentation to the examination. I also certify that neither the thesis nor its part thereof has been previously submitted by him for a degree of any University.

Date:

(K.RADHIKA)
Chairperson

CERTIFICATE

This is to certify that the thesis entitled **"GENETIC ARCHITECTURE OF GRAIN IRON AND ZINC DENSITIES AND THEIR ASSOCIATION WITH AGRONOMIC TRAITS IN PEARL MILLET (*Pennisetum glaucum* (L.) R. Br.)"** submitted in partial fulfillment of the requirements for the degree of 'Doctor of Philosophy in Agriculture' of the Professor Jayashankar Telangana State Agricultural University, Hyderabad is a record of the bonafide original research work carried out by Mr. **ANAND KANATTI** under our guidance and supervision.

No part of the thesis has been submitted by the student for any other degree or diploma. The published part and all assistance and help received during the course of the investigations have been duly acknowledged by the author of the thesis.

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Place: ***Hyderabad***

Date: ***(Anand Kanatti)***

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LIST OF SYMBOLS AND ABBREVIATIONS

%	:	Per cent
$<$	:	Less than
$>$	:	Greater than
$\leq$	:	Less than or equals to
$\geq$	:	More than or equals to
σ^2	:	Variance
$\sum$	:	Summation
AAS	:	Atomic Absorption Spectrophotometry
AICPMIP	:	All India Co-ordinated Pearl Millet Improvement Project
ANOVA	:	Analysis of variance
B-line	:	Maintainer line
cm	:	centimeter
CGIAR	:	Consultative Group on International Agricultural Research
CV	:	Coefficient of Variation
d	:	days
DTPA	:	Diethylene Triamine Penta Acetic acid
et al.	:	and others
F_1	:	First filial generation
Fe	:	Iron
GCA	:	General Combining Ability variance
gca	:	General Combining Ability effects
ha	:	hectares
ICMA	:	ICRISAT Millet A-line
ICMB	:	ICRISAT Millet B-line
ICTP	:	ICRISAT Togo Patancheru
ICMR	:	ICRISAT Millet Restorer
ICMV	:	ICRISAT Millet Variety
ICP-OES	:	Inductively Coupled Plasma Optical Emission Spectrometry
ICRISAT	:	International Crops Research Institute for Semi-Arid Tropics
i.e.	:	that is
IPC	:	ICRISAT Pollinator Collection
kcal	:	Kilo Calories

LIST OF SYMBOLS AND ABBREVIATIONS (Cont.)

kg ha^{-1}	:	Kilograms per hectare
m	:	meter
mg kg^{-1}	:	Milligram per kilogram
ml	:	Milliliter
No.	:	number
OPVs	:	Open Pollinated Varieties
$plot^{-1}$	:	per plot
PRP	:	Potential Restorer Parent
r	:	Correlation coefficient
R-line	:	Restorer line
Raj	:	Rajasthan
RBD	:	Randomized Block Design
SCA	:	Specific Combining Ability variance
sca	:	Specific Combining Ability effects
SEm	:	Standard error mean
t ha^{-1}	:	tons per hectare
viz.,	:	Namely
WHO	:	World Health Organization
XRF	:	X-ray Fluorescence Spectrometry
Zn	:	Zinc

Abstract

NAME OF THE AUTHOR	:	**ANAND KANATTI**
TITLE OF THE THESIS	:	**"GENETIC ARCHITECTURE OF GRAIN IRON AND ZINC DENSITIES AND THEIR ASSOCIATION WITH AGRONOMIC TRAITS IN PEARL MILLET (*Pennisetum glaucum* (L.) R. Br.)"**
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ABSTRACT

Micronutrient malnutrition resulting from dietary deficiency of one or more micronutrients has been recognized as a serious human health problem worldwide. The most striking of these are iron (Fe) and zinc (Zn) deficiencies that rank 9^{th} and 11^{th}, respectively, among the top 20 health risk factors contributing to global burden of disease. Biofortification is a cost-effective and sustainable agricultural strategy to address the micronutrient deficiencies of resource-poor and majority of malnourished populations. In a recent initiative of HarvestPlus Challenge Program of the CGIAR at ICRISAT, research is underway to improve Fe and Zn densities in pearl millet. The main objective of the research reported herein was to study the genetics of Fe and Zn densities and their association with grain yield with a view to enhance breeding efficiency and devise effective breeding strategies for the development of improved cultivars with elevated levels of these micronutrients.

A line × tester study involving 196 hybrids derived from crosses between 14 B-lines and 14 R-lines, and 28 respective parental lines showed predominantly additive gene action for both micronutrients as reflected in high predictability ratio (0.90 for Fe and 0.91 for Zn), no better-parent heterosis, mostly non-significant mid-parent heterosis, and highly significant and high positive correlation between mid-parental values and hybrids performance *per se* (r=0.79 for Fe and 0.80 for Zn). Study of intra-population variability in two OPVs (ICTP 8203 and ICMV 221) also showed predominantly additive genetic variation for these micronutrients, with σ^2_A 5.6 times higher than σ^2_D for Fe density and 4.7 times higher for Zn density in ICTP 8203, while 1.9 times higher for Fe density and 5.3 times higher for Zn density in ICMV 221. These results would imply that intra-population improvement for Fe and Zn densities would be highly effective, while to breed hybrids with high Fe and Zn densities would require that the same genes or genomic regions for high levels of these traits should be incorporated into both parental lines of the hybrids. Line × tester study of inbred lines showed highly significant and high positive correlation between parental performance

per se and their general combining ability (*gca*) effects (r=0.86 for Fe and r=0.85 for Zn). A similar pattern was found in topcross studies of two sets of inbred lines crossed with two OPVs, showing highly significant and high positive correlation (r=0.89 for Fe and r=0.88 for Zn in set-1, and r=0.75 for Fe and r=0.84 for Zn in set-2) between performance *per se* of lines and their topcross performance (a measure of *gca*). These results suggest that selection for high *gca* lines can be effectively made based on parental performance *per se*. Both testers were equally effective in selecting high *gca* inbred lines, while *gca* of individual plants (S_0) was highly tester dependent. Thus, early generation testing, at best, can be used to discard low general combiners, and this subject requires further investigation in terms of early generation stage of the material to be tested for *gca*, and the OPV to be used as tester.

Among agronomic traits, predominance of additive genetic variance was observed for 1000-grain weight and days to 50% flowering in line × tester study, while intra-population study showed predominance of additive genetic variance for days to 50% flowering, and predominance of dominance variance for 1000-grain weight. For grain yield, low predictability ratio (0.52), and highly significant and high positive correlation between hybrids performance *per se* and their *sca* effects (r=0.72) and low (although significant) positive correlation between hybrids performance *per se* and mid-parent value (r=0.29) indicated predominance of non-additive genetic control.

In a study of two sets of hybrids, evaluated multi-locationally, the correlation between Fe and Zn density was highly significant and positive. In both sets, Fe as well as Zn densities had moderate to low negative correlations with grain yield, plant height, panicle length and days to 50% flowering. However, these negative correlations were not always significant, and were highly influenced by environmental factors. For instance, the correlation of grain yield with Fe density varied from -0.50 to -0.08 across the environments, and with Zn density it varied from -0.23 to 0.13 across the environments. In inbred × OPV topcross trials also, Fe and Zn densities were highly significantly and positively correlated, but these were not correlated with grain yield, 1000-grain weight and days to 50 % flowering. Thus, negative association of Fe and Zn densities with grain yield in the hybrid trial might have resulted from the involvement of *iniadi* germplasm as a common source of high Fe and Zn densities in both male and female inbred parents, thereby reducing the genetic diversity between the parental lines for traits associated with heterosis for grain yield. Whether this could also be due to natural negative association between genetic factors for these micronutrients on one hand and grain yield on the other merits further studies through selection experiments using genomic tools as the resolution of this issue has a direct bearing on breeding high-yielding hybrids with high levels of Fe and Zn densities in pearl millet.

Introduction

Chapter I

INTRODUCTION

Micronutrient malnutrition arising from dietary deficiency of one or more micronutrients has been recognized as a serious human health problem worldwide. The most striking of these are iron (Fe) and zinc (Zn) deficiencies that rank 9^{th} and 11^{th}, respectively, among the top 20 risk factors contributing to global burden of disease (WHO, 2002). Pharmaceutical supplementation, industrial fortification and dietary diversification are some of the interventions that have been used to address this problem. Notwithstanding the recurring cost, the impact of supplementation and fortification in the developing countries remains limited because of poor infrastructure and delivery system (Stein *et al*., 2005). Dietary diversification raises an issue of diverse food affordability since a sharp increase in food prices will have a large impact on poor households. It also has a problem of consumer acceptance in case dietary diversification calls for including foods which are not a part of conventional diets. Biofortification of staple crops, is a sustainable and cost-effective approach with great promise for improving the nutritional status and health of poor populations in both rural and urban areas of the developing world (Bouis, 2003). Biofortified cultivars of staple crops improved for mineral micronutrients are also readily acceptable to consumers as their adoption does not call for change in dietary habits.

Pearl millet (*Pennisetum glaucum (*L.) R. Br.) is a major warm-season cereal grown on 28 million ha for grain and fodder production in some of the most marginal areas of the arid and semi-arid tropical regions of Asia and Africa. India is the largest producer of this crop with about 9 million ha area and 8.5 million tons of grain production (Yadav *et al*., 2012). In these regions, pearl millet is a major source of dietary energy and mineral micronutrients. For instance, the contribution of pearl millet to the total Fe and Zn intake from all food sources widely varied across rural India, but in parts of Rajasthan, Maharashtra and Gujarat states, it was observed to be contributing 19-63% of the total Fe intake and 16-56% of the total Zn intake from all food sources (Parthasarathy Rao *et al*., 2006). Large genetic variability for Fe and Zn densities observed in the breeding lines, improved populations and germplasm (Velu *et al.*, 2007 and 2008a and Rai *et al.*, 2012) provides good prospects to breed improved pearl millet cultivars with elevated levels of these micronutrients. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), supported by HarvestPlus Challenge Program of the CGIAR, and in partnership with the public and private sector breeding program in India, has undertaken a major initiative to develop high-yielding hybrids with high levels of Fe and Zn densities in pearl millet.

A broad understanding of the patterns of inheritance and its implications in the magnitude and direction of heterosis and relationship among the parental lines and hybrids can make significant contribution to devise effective breeding strategies. Earlier studies based on hybrids and their parental lines have shown that both Fe and Zn densities are predominantly under additive genetic control, there is hardly any better-parent heterosis, and performance *per se* of parental lines is significantly and highly correlated with their general combining ability (GCA) (Velu *et al*., 2011b and Govindaraj *et al*., 2013). These results need to be validated based on studies with different sets of genotypes.

While high positive correlation between performance *per se* of lines and their GCA indicates that lines having below average GCA can be reliably discarded based on their performance *per se*, those with above average performance *per se* need to tested for GCA to select high general combiners. The most economical and practical method to test GCA of lines is to test their performance in topcross hybrids developed by crossing with open-pollinated varieties used as broad-based tester. This raises the issue of tester effect on GCA. Studies in maize have shown significant tester effect on GCA for grain yield (Matzinger, 1953., Rawlings and Thomson, 1962., Lonnquist and Lindsey, 1970., Abel and Pollack, 1991 and Castellanos *et al*., 1998). Tester effect on GCA for Fe and Zn density has not been studied in any crop.

High-yielding and high-Fe/Zn open-pollinated varieties (OPVs) can be further improved for their Fe/Zn density, and can also prove an important source for developing high-Fe/Zn hybrid parents provided these have significant genetic variability for these micronutrients. Large differences among S_1 progenies derived from populations have been shown both for Fe and Zn densities (Velu *et al*., 2007 and Gupta *et al*., 2009). However, the nature of this variability has not been studied, which has implication for intra-population improvement and line development.

While improving the Fe and Zn densities, it is important that genetic gains for these micronutrients do not compromise on grain yield and other agronomic traits.

Earlier studies in pearl millet (Rai *et al*., 2012), wheat (Garvin *et al*., 2006., Morgounov *et al*., 2007., Shi *et al*., 2008 and Zhao *et al*., 2009), sorghum (Reddy *et al*., 2005) and maize (Banziger and Long, 2000) reported significant negative relationship between micronutrients and grain yield. However, there is limited genetic information with respect to the nature and magnitude of relationship of Fe and Zn densities with grain yield and agronomic traits in different genetic material and across different environmental conditions in pearl millet.

Based on the considerations mentioned above, the present study was conducted with the following specific objectives:

- To evaluate the combining ability of designated seed parents and lines with diverse levels of grain iron and zinc densities
- To study the correlation of grain iron and zinc densities with yield and other agronomic traits
- To assess the tester effect on combining ability for grain iron and zinc densities
- To assess intra-population genetic variation for grain iron and zinc densities
- To assess intra-population variability for combining ability for grain iron and zinc densities.

Review of Literature

Chapter II

REVIEW OF LITERATURE

2.1 Pearl millet

Pearl millet (*Pennisetum glaucum* (L.)R. Br.), grown for food, feed and fodder, is cultivated on about 30 million ha in more than 30 countries of 5 continents, namely, Asia, Africa, North America, South America and Australia (Yadav *et al*., 2012a). Pearl millet is grown in the arid and semi-arid tropical regions of Africa (18 million ha) and Asia (10 million ha). In Africa, majority of pearl millet acreage is in Western and Central Africa where it is grown in 17 countries. Niger, Nigeria, Burkina Faso, Mali and Senegal account for nearly 90% of cultivated pealmillet area in Africa. At individual country level, India is the largest producer of this crop with about 9 million ha area and 8.5 million tons of grain production. The major pearl millet growing Indian states of Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana, accounts for >90% acreage of pearl millet.

Pearl millet, a C_4 plant belonging to the family Poaceae, has high photosynthetic efficiency and dry matter production capacity. It is predominantly a cross-pollinated crop with 75-80% outcrossing (Burton, 1980). Pearl millet is better adapted than other cereals to growing areas characterized by dry semi-arid environments. It has highest water use efficiency under water–limiting environments (Zegada-Lizarazu and Iijima, 2005), highest level of tolerance to high-temperatures during reproductive phase (Gupta *et al*., 2015) and high salinity tolerance (Kulkarni *et al*., 2006., Yadav *et al*., 2012a and 2012b). The characteristics like high genetic variability, protogyny and availability of efficient cytoplasmic genetic male sterility system offer great possibilities to exploit heterosis for both grain and fodder yield through hybrid development (Andrews and Kumar, 1992., Rai *et al*., 1999., Rai *et al*., 2001 and Yadav *et al*., 2012a).

Pearl millet is a nutritious and well digested source of calories and proteins for humans. It contains about 12-14% of protein, 5% fat, 67% carbohydrates and 360 K cal energy value 100^{-1} g grains (Ejeta *et al*., 1987 and Khairwal *et al*., 1999). The amino acid profile of pearl millet grain is more balanced than that of normal sorghum or maize, and is comparable to those of wheat, barley and rice. The lysine content of the protein ranges from 1.9 to 3.9 g 100^{-1} g protein (Ejeta *et al*., 1987). The energy value of pearl millet grain is relatively high, arising from its higher oil content relative to maize, wheat or sorghum (Hill and Hanna, 1990). Collins *et al.* (1997) reported that commercial layers given feed containing pearl millet grain had lower omega-6 to omega-3 fatty acid ratio, endowing the eggs with a fatty acid profile more favorable to human health.

Recent studies have shown the presence of a wide range of genetic variability for grain iron (Fe) content (18 to 135 mg kg^{-1}) and zinc (Zn) content (22 to 92 mg kg^{-1}) (Velu *et al*., 2008a and 2008b., Rai *et al*., 2012 and Govindaraj *et al.*, 2013), indicating good prospects for genetic enhancement of Fe and Zn. Furthermore, a biofortified high-Fe pearl millet variety Dhanashakti (ICTP 8203 Fe 10-2), an improved version of ICTP 8203, has been officially released in 2014 for cultivation in India. Dhanashakti has 71 mg kg^{-1} of Fe density (9% more than ICTP 8203) and 2.2 t ha^{-1} grain yield (11% more than ICTP 8203), with no change in Zn density (38-39 mg kg^{-1}) and flowering time (45 days) (ICRISAT, 2013 and 2014). Further, pearl millet is also an excellent forage crop because of its lower hydrocyanic acid content than sorghum. Its green fodder is rich in protein, calcium, phosphorus and other minerals with oxalic acid within safe limit (Yadav *et al*., 2012a).

2.2 Micronutrient malnutrition and alleviating strategies

Micronutrient malnutrition, also known as 'Hidden hunger', has been recognized as a serious human health problem worldwide, as two third of the world's population is at risk of deficiency of one or more micronutrients, the most striking of these being iron (Fe) and zinc (Zn) deficiencies (WHO, 2002 and Stein, 2010). Anemia is a global problem, affecting both developing and developed countries with major consequences for human health as well as social and economic development. It occurs at all stages of the life cycle, but is more prevalent in pregnant women and young children (WHO, 2008). Deficiency of iron and zinc results in poor growth, reduced immunity, fatigue, irritability, weakness, hair loss, wasting of muscles, sterility, morbidity and even death in acute cases (Haas and Brownlie, 2001., Pfeiffer and McClafferty, 2007 and Stein, 2010).

Most of the iron in human body is present in the erythrocytes as haemoglobin, where its main function is to carry oxygen from the lungs to the tissues. Iron is also an important component of various enzyme systems, such as the cytochromes, which are involved in oxidative metabolism. Likewise, zinc is a nutritionally essential mineral needed for catalytic, structural and regulatory functions in the body. Over 300 different enzymes depend on zinc for their ability to catalyze vital chemical reactions (LPI, 2014). The major reason for micronutrient deficiency in the populations of the developing countries is the predominance of non-diversified plant-based diets, which are poor in micronutrients, as compared to the diets rich in meat, vegetables and fruits (FAO, 2004 and Gomez-Galera, *et al*., 2010). Anti-nutritional factors such as phytic acid, fibres and tannins further reduce the bio-availability of these minerals by preventing their absorption in the intestine (White and Broadley, 2005 and Pfeiffer and McClafferty, 2007).

Several interventions have been in vogue to alleviate micronutrient malnutrition: dietary diversification (consumption of meat, fish, vegetables and fruits along with staple foods), supplementation (ingestion of micronutrients in tablet and sachet forms) and food fortification (addition of minerals to processed foods), but long term effectiveness of such interventions depends on continued funding, infrastructure and good distribution network (White and Broadley, 2009). Alternatively, a more efficient, cost-effective and sustainable solution is biofortification. It relies on conventional plant breeding and modern biotechnology to increase the micronutrient density in edible portion of staple crops, and holds great promise for improving the nutritional status and health of poor populations in both rural and urban areas of developing countries (Bouis, 2003., White and Broadley, 2005 and Pfeiffer and McClafferty, 2007).

HarvestPlus Challenge Program of CGIAR was initiated in 2004 with the support from the Bill and Melinda Gates Foundation, the Word Bank and USAID. The focus of this program is on three micronutrients that are widely recognized by the World Health Organization (WHO) as most critical: iron, zinc and vitamin A. Comprehensive biofortification programs are proposed for six staple foods for which feasibility studies have already been completed and which are consumed by majority of the world's poor in Africa, Asia and Latin America: rice, wheat, maize, cassava, common bean and pearl millet. In India, government has initiated several programmes to promote cultivation and consumption of nutrient-rich crops (which includes pearl millet) to reduce malnutrition. The scheme on "Initiative for Nutritional Security through Intensive Millets Promotion (INSIMP)" was initiated in order to promote cultivation and consumption of millet-based food products, of sorghum, pearl millet, finger millet and other small millets, for which India government had allocated Rs. 300 crores in 2011-12 under Rashtriya Krishi Vikas Yojana (RKVY). In India's budget for

2013-14, Rs.200 crores was allocated for Nutri-farms pilot scheme to promote cultivation and setting up of assured supply chains of nutrient-rich varieties of food crops in districts of the county that are most affected by malnutrition. The cereal crops like rice, maize, pearl millet, finger millet and wheat biofortified for specific micronutrients and horticultural crops such as sweet potato and moringa are identified for production of nutri-rich foods under this pilot scheme. The Indian National Food Security Act, 2013 (also Right to Food Act), was signed into law on September 12, 2013, with an aim to provide subsidized food grains to approximately two thirds of India's 1.2 billion people. Under the provisions of the bill, nutri-cereals such as pearl millet, finger millet, sorghum and maize were included in the PDS (Public Distribution System), along with wheat and rice to encourage their production and strengthen the nutritional security.

2.3 Plant factors

Iron and zinc are required for plants in small amount, hence these are known as essential micronutrient elements for plants and are involved in many vital physiological metabolic processes during plant growth and development. The plants ability to acquire and accumulate iron and zinc in grains depends on many interrelated metabolic pathways involved in the uptake of Fe and Zn from soil, their transport to vegetative tissues (stem and leaves) and mobilization and/or remobilization to grains during grain development (Broadley *et al*., 2007 and Ma and Ling, 2009). Each of these processes is governed by several genes and influenced by several factors like environment (soil pH, micronutrient concentrations, moisture level and fertilizer application), genotypes and genotype × environment interaction (Frossard *et al*., 2000., Gregorio, 2002 and Singh *et al*., 2005).

Iron is plentiful in the soil, but mainly in forms not available to plants. Over the normal pH range of 4.0-9.0 in most agricultural soils, total soluble iron is not sufficient to meet plant requirement. Hence plants would obviously have to develop alternative efficient mechanisms to absorb the Fe from soil to meet their optimal requirement; otherwise, crops grown on almost all soils would suffer from Fe deficiency (Lindsay, 1974 and Tisdale *et al*., 1993). Plant genotypes differ in their ability to absorb and translocate Fe, which is a genetically controlled adaptive process, enabling response to Fe deficiency or stress (Tisdale *et al*., 1993 and Marschner, 1995). Iron uptake is dependent on the plant’s ability to reduce Fe^{3+} (Ferric) to Fe^{2+} (Ferrous) and remove it from the complex or chelating compound.

Plants have evolved two strategies to take up Fe from the soil under deficiency condition (Romheld, 1987). Most crops, dicotyledons and monocotyledons except graminaceous plants (grasses) use a reduction-based strategy (Strategy-I), and the grasses such as corn, wheat, rice, pearl millet and sorghum use a chelation-based strategy (strategy-II) (Marschner, 1995). Strategy-I plants excrete protons and reductants from root cells to acidify the soil environment by lowering the pH of the soil and increasing the solubility of Fe^{3+} to enhance Fe^{2+} uptake. Strategy-II plants release small molecular weight compounds known as the mugineic acid (MA) family of phytosiderophores (PS). Phytosiderophores have high affinity for Fe^{3+} and efficiently bind Fe^{3+} in the rizhosphere. Fe^{3+}–PS complexes are then transported into the plant roots *via* a specific transport system (Marschner, 1995 and Frossard *et al.*, 2000) and is more efficient than the reduction strategy (Mori, 1999). Other mechanisms like increase in organic acids, particularly citrate in root sap, adequate transport of Fe from roots to top and less accumulation of P in roots and shoots, even in the presence of relatively high P in growth medium (Tisdale *et al*., 1993) are also found to enhance the uptake of Fe from the soil.

Similar to Fe uptake, the uptake of Zn is also an active process which involves Zn-phytosiderophores (Zn-PS) and this mechanism is found in monocots of graminaceous family but not in dicots (Zhang *et al.*, 1991). The phytosiderophores are produced under deficiency condition (Cakmak *et al*., 1996). Zn and Fe phytosiderophores have similar structural conformation (Iwashita *et al*., 1983), but stability of Fe-PS is much higher (Murakami *et al*., 1989). The efficiency of plant genotypes differs in their quantity and compound composition of phytosiderophores. Singh *et al*. (2002) reported that bread wheat (*Triticum aestivum*) showed more efficiency than durum wheat (*Triticum durum*) in release of phytosiderophores. The compound 2'- deoxy mugineic acid (DMA) is predominant in wheat (Singh *et al*., 2002), while in rice mugenic acid (MA) is found to be predominant (Higuchi *et al*., 1999). According to Dong *et al*. (1995), longer and thinner roots with greater proportion of thinner roots compared to the total root biomass early in growth period were associated with Zn-efficient genotypes.

2.4 Genetic variability and combining ability

2.4.1 Grain Fe and Zn densities

Genetic studies (Table 2.1.) in pearl millet showed Fe and Zn densities predominantly under additive genetic control. This additive genetic nature for both the traits were suggested by higher magnitude of predictability ratio (which indicates proportion of additive variance to that of total genetic variance), highly significant positive correlation observed between mid-parental value and hybrids performance *per se* and no better-parent heterosis; and this genetic nature being consistent across diverse genetic material and different mating schemes (line × tester and diallel) (Velu *et al*., 2011b and Govindaraj *et al*., 2013). Likewise, studies in other cereals, such as rice (Zhang *et al*., 2004) and maize (Gorsline *et al*., 1964., Arnold and Bauman, 1976., Brkic *et al*., 2003., Long *et al*., 2004., Chen *et al*., 2007 and Chakraborti *et al*., 2011) using diallel mating design reported that both micronutrients were largely under additive genetic control. A recent study in sorghum (Ashok Kumar *et al*., 2013) reported the predominance of dominance variance governing Fe density in two sets of diallel crosses.

Few studies reported reciprocal differences or maternal effects on grain Fe and Zn densities. Chakraborti *et al*. (2011) reported significant reciprocal differences in some hybrids of diallel crosses of quality maize genotypes and Ashok Kumar *et al*. (2013) reported significant reciprocal differences in some of the hybrid combinations in sorghum. Velu *et al*. (2011b) did not find any significant reciprocal differences in diallel crosses of pearl millet.

2.4.2 Grain yield and agronomic traits

The underlying genetic mechanism for different agronomic traits of pearl millet has been reported in numerous studies and these were reviewed in detail by Virk (1988) and Khairwal *et al*. (1999). Most estimates obtained using line × tester and diallel designs in inbred lines shown existence of additive, non-additive and epistatic gene action for grain yield, 1000-grain weight and days to 50% flowering. Most of these studies reported predominance of additive gene action for grain weight and days to 50% flowering and non-additive as well as additive and non-additive type of gene action for grain yield. Some of the recent studies of genetics of these traits are reviewed here: for grain yield, Yadav *et al*. (2000) observed predominance of additive genetic control in topcross study of male-sterile lines × populations crosses, while Izge *et al*. (2007) in inbreds diallel crosses and Jethva *et al*. (2011) in line × tester crosses reported the predominance of non-additive genetic variance. For 1000-grain weight, Rasal and Patil (2003) and Jethva *et al*. (2011) reported predominance of non-additive genetic variance in line × tester studies, Velu (2006) and Izge *et al*. (2007) recorded predominance of additive genetic variance in diallel cross study and Govindaraj (2011) reported predominance of additive genetic variance in two sets of inbred parents of line × tester crosses. For days to 50% flowering, Velu (2006) and Izge *et al*. (2007) reported the preponderance of non-additive genetic variance in inbred diallel crosses, Yadav *et al*. (2000) reported additive genetic variance in inbreds × populations top-crosses and Govindaraj (2011) found predominance of additive genetic variance in two sets of line × tester crosses.

2.4.3 Tester effect on combining ability

A successful breeding program geared for heterosis exploitation results in superior lines that are able to transmit the desirable characteristics to the hybrids. Although the performance of the individual crosses is determined, the inbred lines are usually saved or discarded on the basis of the mean performance in several crosses (i.e. general combining ability). This necessitates making and testing of very large number of crosses. To solve this problem, Davis (1927) suggested the use of topcrosses, i.e. crossing lines with open-pollinated varieties as tester to assess the general combining ability. It is generally agreed that these should be broad-based testers. However, the quantum remains regarding the effect of testers on general combining ability.

Studies of tester effect on combining ability for different traits were summarized in Table 2.2. Matzinger (1953) suggested that the type of tester to be used for inbred evaluation depends on objective of study. If objective of study is to determine a replacement for an existing line in a certain combination, specific combining ability is of prime importance and the most appropriate tester is the opposite parent of single cross or double cross or its component inbred lines. On the other hand, if one is interested in attaining high level of general performance before attempting an evaluation in specific combinations, the ranking of lines with respect to general combining ability can be accomplished most economically through the use of a tester having a broad genetic base.

Russell (1961) concluded that the expression of greater genetic differences among test crosses was one of the main features of an ideal tester. Hull (1947) stated that theoretically the most efficient tester would be homozygous recessive at all loci and that homozygosity for the dominance alleles at any locus should be avoided. These conclusions were based on considerations of the constant parent regression method of analysis of single crosses. The regression of performance of offspring on the performance of the variable parents for a particular constant parent was shown to be largest when the gene frequency of the character for the constant parent was zero. The regression was zero when the gene frequency was 1 for complete dominance or at equilibrium gene frequency for overdominance. A strong positive regression would be desirable as this would allow more discrimination among the variable parents.

Smith (1986) concluded that lines with greater frequency of alleles could be identified if a tester with low frequency (or absence) of favourable alleles was used in test crosses, and for trait conditioned by large number of loci showing complete dominance, the correlation between performance *per se* of lines and test cross performance were expected to be less than 0.5, which was due to the masking effect of favourable dominant alleles in the tester. Hallauer *et al*. (1988) suggested that either a homozygous recessive line or a population with low allele frequency for important trait under selection would be an effective tester to use in hybrid breeding program.

2.4.4 Study of intra-population variability using North Carolina mating Design-1

An understanding of type of gene action within the breeding populations is very useful in selection among the base populations as well as in choosing the most efficient breeding scheme for their further improvement. Total genetic variance can be divided theoretically into additive, dominance and epistatic variance. The relative magnitude of these three variances is of important to the plant breeder in order to plan the most effective breeding scheme. Selection within populations would be most effective if the gene action is mainly additive, on the other hand, existence of dominance or epistasis justifies the use of hybrid program.

North Carolina (NC) designs or biparental mating designs were developed to study the genetic variability in random mating populations generated from a cross between two inbred lines (Comstock and Robinson, 1948). This approach was extended by Robinson *et al*. (1955) to study the genetic variance within open-pollinated populations. Synonyms of North Carolina-1 mating design are design-1, nested design, hierarchical design and NCD-1, in which, within each variety, ‘m’ random plants used as male or pollen parents are crossed to ‘f’ randomly selected (4 to 6) female or seed parents. A female plant crossed with a given male parent, shall not be involved in mating with other pollen parent. Consequently, there will be ‘mf’ matings and ‘mf’ progeny families, and a group of progenies having one common male parent is called male group (half-sibs). Comstock and Robinson (1948) suggested grouping progenies into sets by males to increase precision of variance estimates with better control of experimental error. Later, they suggested two alternatives for arranging the progenies in the field, which are replications-within-the-sets and sets-within-replications (Comstock and Robinson, 1952).

The results of genetic studies using biparental mating design (NCD-1) are summarized in Table 2.3. Majority of studies for grain yield in maize concluded the predominance of dominance variance component (El-rouby, 1979., Shashi and Singh,1985., Akanvou *et al*., 1997., Zaffar *et al*., 2001., Pereira and Amaral Junior, 2001 and Badu-Apraku, 2007), while studies by Robinson *et al*. (1955) and Marker and Joshi (2005) concluded that additive genetic variance constituted the major portion of the total genetic variance; Lindsey *et al*. (1962) reported that the varied estimates of additive and dominance components within same variety was influenced by assortative mating. For 100-grain weight, El-rouby *et al*. (1979) reported predominance of dominance variance. On the contrary, higher magnitude of additive genetic variance was reported by Shashi and Singh (1985), Zaffar *et al*. (2001) and Marker and Joshi (2005). Furthemore, for days to 50% flowering high additive genetic variance has been reported by Lindsey *et al*., 1962 and El-rouby *et al*., 1979, while in other studies high proportion of dominance variance has been reported (Zaffar *et al*., 2001 and Badu-Apraku, 2007).

Sprague and Tatum (1942) observed that in previously selected material, the variance for specific combining ability was found to be larger than the variance for general combing ability, while in unselected material, the situation was reverse and the variance for general combining ability was larger. Robinson *et al*. (1955) stated that two possibilities are advanced for reconciling presence of additive genetic variance with ineffective intra-variety selection. The first rests on negative genetic correlation between grain yield and other components of net reproductive capacity. The second envisages the additive genetic variance as arising from loci at which gene action is largely additive and gene frequency is at equilibrium between the forces of mutation and selection; he also noted that epistasis, linkage, and genotype × environment interaction were potential sources of bias mostly on estimate of dominance variance than additive variance.

2.5 Environmental effect on grain micronutrients

Various studies have shown (Table 2.4.) significant effect of genotype by environment interaction (GEI) for grain iron and zinc densities, which lead to changes in ranking of genotypes for their micronutrient densities across the environments. Hence, the assessment of environmental stability of the genotypes for micronutrient densities in grains is important. Studies in pearl millet reported significant GEI across the environments (Gupta *et al*., 2009., Velu *et al*., 2011b and Govindaraj *et al*., 2013). Nevertheless, Gupta *et al*. (2009) reported significant correlation (r = >0.66) for performance of genotypes across the seasons for both Fe and Zn densities. Similarly, Velu *et al*. (2011b) also recorded highly significant correlation for performance of genotypes for Fe (r=0.93) and Zn (r=0.86) densities across the seasons, which indicated high consistency in ranking of genotypes across the environments in spite of recording significant GEI. Oikeh *et al*. (2003) reported significant GEI and the genetic component accounted for 12% and 29% for Fe and Zn, respectively in maize elite genotypes. On contrary, higher proportion of GEI for Zn density than Fe density was reported in maize by Prasanna *et al*. (2011). Studies in wheat by Oury *et al*. (2006) observed significant GEI which was higher in magnitude for Fe than Zn across different years as well as locations. Likewise, Gomez-Becerra *et al*. (2010) found higher environmental influence on grain Fe density than Zn density. Peleg *et al*. (2008) reported significant GEI for both Fe and Zn. However, outstanding accessions were found in both sufficient and limited water availability conditions in wild wheat accessions. These studies implied that the magnitude of sensitivity to environment of grain Fe and Zn densities depends on the type of genetic material, soil and microclimatic conditions.

2.6 Heritability for grain iron and zinc densities

Genetic variation supplemented with the information on heritability would give the measure of heritable portion of the total variation which is important in any crop improvement programme. Heritability in broad sense refers to both additive and non-additive genetic components as a proportion of the total phenotypic variance, while narrow sense heritability refers to only the additive component of total phenotypic variance. Studies on pearl millet found that broad sense (h^2bs) heritability varied from 65.3 to 71.2% for Fe density and 64.8 to 79.7% for Zn density in S_1 genotypes of two open-pollinated varieties (Gupta *et al.*, 2009). Similarly, Velu (2006) observed significant influence of seasonal effect on heritability estimates of grain Fe and Zn densities, with h^2bs 81% and 71% in rainy season and 52% and 44% in summer season for Fe and Zn densities, respectively. In rice, Gregorio *et al*. (2000) reported 43% and 88% narrow sense and broad sense heritability, respectively for Fe density. Likewise, Garcia-oliveira *et al*. (2009) reported 73% and 41% h^2bs for Fe and Zn densities, respectively. In wheat, Joshi *et al*. (2010) reported 37% and 25% h^2bs in elite lines and Gomez-Becerra *et al*. (2010) found 36% and 72% h^2bs in wild accessions for Fe and Zn densities, respectively. Chakraborti *et al*. (2010) reported higher magnitude of h^2bs for both Fe (78% and 73%) and Zn (71% and 76%) in maize.

2.7 Heterosis

2.7.1 Grain Fe and Zn densities

Gene action studies (Table 2.1.) reported higher proportion of additive genetic control for both grain Fe and Zn densities, hence, as expected, very low estimates of heterosis were reported for these traits. In pearl millet, Velu *et al*. (2011b) reported no better-parent heterosis and only four of 90 hybrids with significant positive mid-parent (MP) heterosis for Fe (11.5-19.3%) and Zn (11.8-19.6%) densities, Govindaraj *et al*. (2013) also reported no better-parent (BP) heterosis, and mostly negative significant mid-parent heterosis in two sets of line × tester studies. In another study, MP heterosis for Zn density was significant in 11 of 45 hybrids tested, with positive heterosis (18.8 to 22.4%) in three and negative heterosis (-10.9 to -18.2%) in eight hybrids (Rai *et al*., 2007).

In maize, Chen *et al*. (2007) found non-significant MP heterosis for grain Fe density and significant MP heterosis for ear leaf Fe content, while Chakraborti *et al*. (2009) did not obtain any of the hybrids with significant positive MP and BP heterosis. In another study, Chakraborti *et al*. (2011) concluded that BP heterosis estimates were influenced by environment effect of locations and few hybrids showed positive BP heterosis for Fe and Zn densities. Ashok Kumar *et al*. (2013) reported significant variability for estimates of heterosis for both Fe and Zn densities in hybrids of three different sets of diallel crosses in sorghum, in which MP and BP heterosis, respectively, varied from -26% to 43% and -35% to 30% for Fe density, and -26% to 35% and -31%

to 21% for Zn density. This negative heterosis might be due to the involvement of genes other than those with additive gene action where alleles determining lower Fe and Zn densities are partially dominant. It is also likely that effects of genes acting additively for Fe and Zn densities are influenced by genetic backgrounds, the more so in the negative direction, mimicking low levels of partial dominance.

2.7.2 Grain yield and other agronomic traits

Recent studies on heterosis in pearl millet for grain yield, 1000-grain weight and days to 50% flowering are reviewed here. For grain yield, Yadav (1999) reported positive significant MP heterosis from 37.1% to 184.3% in hybrids of iso-nuclear male sterile lines × diverse pollinators crosses. Later, in another study, Yadav (2006) found that MP heterosis varied from -0.50 to 42.4 in hybrids of land races × elite lines crosses and observed that heterosis for one trait was associated with slightly reduced heterosis for other component traits. Vagadiya *et al*. (2010) observed that 36 of 48 hybrids had significant BP heterosis (-25.9 to 105.7). Likewise, Izge *et al*. (2007) reported that 42 of 45 hybrids had significant positive BP heterosis (-16.9% to 18.59%). Presterl and Weltzien (2003) reported that the MP heterosis for grain yield varied from -14.0% to 30% in population × land races diallel crosses. Yadav and Rai (2011) observed very low MP heterosis (-20.8% to 32.5%) in a study of Indian land races × African elite composite.

For 1000-grain weight, most of the hybrids recorded significant positive MP heterosis (up to 60.41%) and BP heterosis (up to 16.31%) for 1000-grain weight (Arulselvi *et al*., 2006), while Velu (2006) found MP heterosis up to 33% and BP heterosis up to 24% for 1000-grain weight. In another study, Vaghasiya *et al*. (2009) observed positive BP heterosis (41%). Izge *et al*. (2007) recorded heterosis estimates which varied from 1.69% to 114.5%; while, Manga and Dubey (2004) in a diallel study observed that 29 of the 36 hybrids had significant mid-parent heterosis for 1000-grain mass.

MP heterosis estimates for days to 50% flowering varied from -12.9% to 3.6% (Yadav, 1999), while in another study, the MP heterosis varied between -7.33% to 7.48% (Yadav 2006). Similarly, Vagadiya *et al*. (2010) found that BP heterosis varied from -25.63% to 11.59%. Izge *et al*. (2007) reported negative significant BP heterosis (-13.5% to -0.23%).

2.8 Character association

2.8.1 Variability and association between grain Fe and Zn densities

The existence of sufficient variability is prerequisite for effective genetic improvement. The studies on variability for grain Fe and Zn densities in important cereal crops *viz*., pearl millet, sorghum, finger millet, wheat, rice and maize are summarized in Table 2.5. Studies on pearl millet found large variability in the germplasm and breeding material for both Fe and Zn densities; Fe density varied from 18.0 to 135.0 mg kg^{-1} and Zn density from 22.0 to 92.0 mg kg^{-1}. Most of the potential hybrid parents, improved populations and population progenies with high Fe and Zn levels were entirely or largely based on *Iniadi* germplasm (Velu *et al*., 2007 and 2011b., Rai *et al*., 2012., Govindaraj *et al*., 2013 and Rai *et al*., 2014). *Iniadi* refers to early-maturing and large-seeded land races found in adjoining parts of Togo, Ghana, Benin and Burkina Faso (Andrews and Anand Kumar, 1996). Similarly, large variability was observed in sorghum (7.7-132.6 mg kg^{-1} for Fe and 15.1-91.3 mg kg^{-1} for Zn), finger millet (21.7-65.2 mg kg^{-1} for Fe and 16.6-25.3 mg kg^{-1} for Zn), wheat (16.4-88.4 mg kg^{-1} for Fe and 13.5-139.0 mg kg^{-1} for Zn), rice (5.0-67.0 mg kg^{-1} for Fe and 13.0-89.0 mg kg^{-1} for Zn) and maize (9.6-69.1 mg kg^{-1} for Fe and 12.9-57.6 mg $kg^{-1}$for Zn). These results showed good prospects to breed improved cultivars with elevated levels of these micronutrients through conventional breeding approaches.

The high positive significant association between Fe and Zn densities has been reported in pearl millet (Velu *et al*., 2008a and 2008b., Gupta *et al*., 2009., Rai *et al*., 2012 and Govindaraj *et al*., 2013), sorghum (Ashok Kumar *et al*., 2010 and 2013), maize (Oikeh *et al*., 2003 and 2004b), rice (Stangoulis *et al*., 2007 and Anandan *et al*., 2011), wheat (Garvin *et al*., 2006., Peleg *et al*., 2009., Zhang *et al*., 2010 and Velu *et al*., 2011a) and finger millet (Upadhyaya *et al*., 2011). Genomic studies in wheat (Peleg *et al*., 2009 and Singh *et al*., 2010), rice (Stangoulis *et al*., 2007), common bean (Blair *et al*., 2009 and Cichy *et al*., 2009) and pearl millet (Kumar, 2011) have identified common and overlapping Quantitative Trait Loci (QTL) for Fe and Zn densities. The existence of highly significant positive association and predominance of additive genetic control for Fe and Zn densities would be helpful for simultaneous genetic improvement of both the traits.

2.8.2 Association of grain Fe and Zn densities with agronomic traits

Earlier studies (Table 2.6.) in pearl millet (Velu *et al*., 2007, 2008a and 2008b) and wheat (Murphy *et al*., 2008) reported significant positive association of Fe and Zn densities with grain weight, while other studies in pearl millet observed non-significant association grain Fe and Zn densities with grain weight (Gupta *et al*., 2009 and Rai *et al*., 2012). Thus, the enhancement of these micronutrients is possible without compromising on grain weight.

Studies in pearl millet (Rai *et al*., 2012), wheat (Garvin *et al*., 2006., Morgounov *et al*., 2007., Shi *et al*., 2008 and Zhao *et al*., 2009), sorghum (Reddy *et al*., 2005) and maize (Banziger and Long, 2000) reported low to moderate negative relationships between micronutrients and grain yield (but not always significant). This negative relationship could occur if genes that increase mineral density are linked with genes responsible for the traits related to grain yield.

Some of the association studies between iron and days to 50% flowering reported significant negative correlation in pearl millet (Velu *et al.*, 2008a and Rai *et al*., 2012), while both the micronutrients had significant positive association with days to 50% flowering in sorghum (Reddy *et al*., 2010). On the other hand, most studies did not show significant association between micronutrients and days to 50% flowering in pearl millet (Velu *et al*., 2007 and 2008b., Gupta *et al*., 2009 and Rai *et al*., 2012), sorghum (Reddy *et al*., 2005 and Ashok kumar *et al*., 2010) and wheat (Morgounov *et al*., 2007).

Likewise, plant height showed significant positive association with Fe density in sorghum (Reddy *et al*., 2010) and wheat (Hussain *et al.*, 2012) and also significant positive association with Zn density in sorghum (Reddy *et al*., 2005 and Reddy *et al*., 2010) and wheat (Zhao *et al*., 2009), while both nutrients showed significant negative association with plant height in wheat (Margounov *et al*., 2007) and did not show any association with plant height in sorghum (Ashok kumar *et al*., 2010).

2.9 Analytical techniques of grain Fe and Zn densities analysis

Atomic Absorption Spectrophotometry (AAS) and Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) techniques are highly reproducible and widely used methods for precision phenotyping of grain Fe and Zn densities. The studies using these methods are summarized in Table 2.5. However, breeding for micronutrient dense cultivars needs screening large number of genetic material, such as, germplasm lines, elite lines, segregating populations, hybrids etc. and phenotyping for iron and zinc densities of large number of samples though these techniques involves high cost. Hence, advanced, high-throughput, non-destructive and low-cost quantitative techniques like X-ray Fluorescence Spectrometry (XRF) are now being used in several laboratories for initial screening of large genetic material cost-effectively. Those ranking high for XRF value can be further evaluated using either AAS or ICP to obtain precision estimates (Stangoulis, 2010., Rai *et al.*, 2012 and Paltridge *et al*., 2012).

Material and Methods

Chapter III

MATERIAL AND METHODS

The present investigation was carried out principally to study gene effects, combining ability, heterosis, character association, tester influence on combining ability and intra-population genetic variances for grain iron (Fe) and zinc (Zn) densities in pearl millet during the period from February 2011 to June 2013 at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India. All the experiments were conducted in the Alfisol (red precision soils) in the rainy season (June to September) and summer season (February to May) at Patancheru (18°N, 78°E, 545 m above sea level, and 600 km from the sea). The weather data (total rainfall during the crop season, minimum and maximum temperature, relative humidity, total evaporation, solar radiation and bright sunshine hours) for each cropping season for the years 2011, 2012 and 2013 at Patancheru are given in Appendix A.

The present investigation was carried out objective-wise in five separate experiments as mentioned below.

- Assessment of genetic variation and combining ability of inbred lines using line × tester design
- Assessment of association of grain iron and zinc densities with agronomic traits in hybrids
- Study of tester effect on combining ability of inbred lines
- Assessment of intra-population genetic variation using North Carolina mating Design-1(NCD-1)
- Assessment of intra-population variability for combining ability

The details pertaining to generation and evaluation of experimental material (Table 3.1.), and recording and analyses of data carried out are described experiment wise below:

3.1 GENETIC MATERIAL AND EVALUATION

3.1.1 Assessment of genetic variation and combining ability of inbred lines using line × tester design

3.1.1.1 Genetic material

Parental lines of line × tester crosses consisted of 14 maintainer lines (B-lines or female parents), hereafter referred to as "lines"; 14 restorer lines (R-lines or male parents), hereafter referred to as "testers". These parental lines were of diverse parentage (Table 3.2.) with wide range of grain Fe and Zn densities and differed for grain yield and various agronomic traits such as plant height, tillering, panicle size and 1000-grain weight; and were developed at ICRISAT, Patancheru, India.

3.1.1.2 Crossing program

Pearl millet is an outbreeding species, and producing hybrid grains is easy because of protogynous nature of the crop. The panicles of both lines and testers were bagged with 30 cm × 10 cm parchment paper bag when they were about halfway out of the boot leaf to avoid contamination by foreign pollen. Bagging was done every day. At full bloom stage (as detected by protruding white feathery stigma on the panicle), the pollen from testers was collected in a parchment paper bag and dusted on lines by gentle tapping thoroughly in the morning hours between 8.00 to 11.30. Soon after pollination, the panicles of lines were covered with parchment paper bag to avoid foreign pollen contamination and labeled properly. The crossed panicles were left covered with parchment paper bags until harvest, which were harvested, sundried for more than 15 days and threshed to collect hybrid seeds. This crossing program was carried out in 2011 summer season and a total of 196 hybrids were developed and sufficient seeds of each cross was produced for two season evaluation.

3.1.1.3 Field evaluation

Parental lines (28) and their hybrids (196) were evaluated separately in two experiments laid side by side (one for hybrids and other one for inbred lines) (Arunachalam, 1974) in Randomized Complete Block Design (RCBD). The parental trial consisted of 30 entries including two checks (ICTP 8203 and KH 302) and hybrid trial consisted of 200 entries (including two checks, KH 302 and 86M86, repeated twice). All the entries were replicated thrice, and were evaluated for two seasons in 2011 rainy season and 2012 summer season. Plots of each replication were randomized independently using *GenStat* statistical package, and same randomization was used for both the seasons. The seeds of each entry distributed equally to the sowing packets, representing number of rows of each plot size; and then randomized plot numbers were assigned to each plot seed packets and arranged according to planned field layout.

3.1.1.4 Agronomic practices

Sowing was done by tractor-mounted 4-cone planter (7100 US model), with each entry planted in two rows of 2 m length, spaced at 75 cm and 60 cm between rows in rainy and summer seasons, respectively. Overplanted plots were thinned 15 d after planting to single plants, spaced 15 cm apart within each row. A basal dose of 100 kg of diammonium phosphate (18% N and 46% P) was applied at the time of field preparation and 100 kg of urea (46% N) was applied as top dressing within 2 to 4 d after thinning. Trials were irrigated at 7 to 10 d intervals in summer and as needed in rainy season, to ensure no moisture stress. All the recommended agronomic practices were followed for good crop growth.

3.1.1.5 Observations recorded and harvesting

Observations were recorded in both hybrid and parental trials for days to 50% flowering, 1000-grain weight, grain yield and grain Fe and Zn densities, detailed measurement of these traits are given in subheads 3.2. The plots of all the entries were harvested at physiological maturity (85–90 days after planting). During harvest, main panicles of five random plants from each plot were harvested and stored separately in a cloth bag to produce clean grain samples for micronutrient analysis. The remaining panicles of the plot were harvested as a bulk. These panicles were sundried for 10 to 15 days. While threshing, five separately harvested panicles were manually threshed first and approximately 20 g of grains was collected for Fe and Zn analysis, and left over grains from these panicles were added to the bulk grain produced by threshing in a multihead machine thresher. The grain yield including the 20 g sample taken for micronutrient analysis was recorded for each plot and converted to t ha^{-1} for grain yield analysis.

3.1.2 Assessment of association of grain iron and zinc densities with agronomic traits in hybrids

3.1.2.1 Genetic material

The experimental material comprised of F_1 hybrids and were selected from ICRISAT biofortification hybrid breeding program. These hybrids were produced by crossing diverse male sterile lines and restorer lines of pearl millet (Table 3.3. and 3.4.) which were selected based on wide range for Fe and Zn densities, grain yield and various agronomic traits, such as, plant height, panicle size and tillering.

3.1.2.2 Field evaluation

The experimental material included in this study consisted of two hybrid trials (Set-A and Set-B). Set-A consisting of 35 entries (32 hybrids and 3 checks) (Table 3.3.) was evaluated at Patancheru (E1) and at two different locations [Ahmedabad (E2) and Aligarh (E3)] in A-zone of northern India. Set-B consisting of 31 entries (28 hybrids and 3 checks) (Table 3.4.) and was evaluated at Patancheru (E1), and at two different locations [Aurangabad (E4), and Dhule (E5)] in B-zone of peninsular India. Both sets were evaluated in Randomized Complete Block Design (RCBD) with three replications in 2012 rainy season. The plot size was two rows of 4 m length spaced at 75 cm at Patancheru and at 50 cm at other locations, with plant-to-plant spacing of 15 cm within rows at all the locations. All the recommended agronomic practices were followed (as given in 3.1.1.4) for good crop stand.

3.1.2.3 Observations recorded

Observations were recorded on days to 50% flowering, plant height, panicle length, number of panicles plot^{-1}, number of plants plot^{-1}, 1000-grain weight, grain yield, and grain Fe and Zn densities. Detailed measurement of agronomic data and grain micronutrient analysis were given in subheads 3.2. Harvesting was done as given in 3.1.1.5.

3.1.3 Study of tester effect on combining ability of inbred lines

3.1.3.1 Genetic material

All 28 parental lines of line × tester combining ability study were used for topcrossing with broad-based testers to study the tester effect on combining ability. Twenty eight inbred lines (14 B and 14 R-lines) were used as female parents and two open pollinated varieties (OPVs) [Raj 171 (low iron) and ICMR 312 (high iron)] as pollen parents and broad based testers (Table 3.5.). Crossing was done in 2011 rainy season. The pollen from each tester variety was collected separately from 50-100 panicles and mixed thoroughly by shaking before dusting on receptive panicles of inbred lines. This process was continued daily in the morning hours for 10-15 d to cross all inbred lines with both the tester varieties separately. The entire process like bagging and other precautionary measures to avoid contamination from foreign pollen sources during crossing program were undertaken as described in 3.1.1.2. Sufficient seed of 56 topcrosses (28 each with Raj 171 and ICMR 312) was produced for two season evaluation.

3.1.3.2 Field evaluation

The experiment consisted of 28 topcross hybrids, each with Raj 171 and ICMR 312 testers and a check (ICTP 8203). Topcross hybrid trials were randomized separately for Raj 171 and ICMR 312 testers and evaluated during summer 2012 and summer 2013 in RBD with three replications, with a plot size of two rows of 4 m length. Both trials (28 hybrids + 1 check) were laid out side by side as 58 entries experiment in the same field to minimize soil heterogeneity effect. Parents were evaluated separately, with plot size of 1 row of 4 m length, as discussed in 3.1.1.3. All the recommended agronomic practices were followed (as given in 3.1.1.4) for good crop stand.

3.1.3.3 Observations recorded

Observations were recorded for days to 50% flowering, 1000-grain weight, grain yield and grain Fe and Zn densities. Detailed measurement of agronomic data and grain micronutrient analysis are given in subheads 3.2. Harvesting was done as given in 3.1.1.5.

3.1.4 Assessment of intra-population genetic variation using NCD-1

3.1.4.1 Genetic material

Two open pollinated varieties (OPVs) [ICTP 8203 and ICMV 221] (Table 3.5.) were used as the base populations for this study. Progenies for this experiment were produced by North Carolina mating Design-1 (NCD-1) (Comstock and Robinson, 1952 and Robinson *et al*., 1955). From the base population randomly chosen S_0 plants (‘*m*’) were used as pollen parent (males) and each pollen parent was mated with randomly selected S_0 plant (‘*f*’) used as seed parent (female) and a female plant once crossed would not be involved in mating with any other pollen parent. Consequently, there will be *'mf'* matings as well as progeny families. In each population, 40 plants were selected as male parents and each male was mated to randomly selected four different female plants, thus producing totally 160 full-sib progeny families. A group of progenies having one common male parent was grouped as a male group and four such male groups constituted one set, and in each population 10 such sets were constituted. This crossing program was carried out during 2012 summer season. Daily about 4-5 male parents were selected for crossing and it was continued for 10-15 days. All the processes like bagging and other precautionary measures to avoid contamination from foreign pollen were undertaken as described in 3.1.1.2.

3.1.4.2 Field evaluation

Total 160 biparental progenies each of ICTP 8203 and ICMV 221 populations were grouped into 10 sets each. Progenies of each set were replicated thrice (with plot size of one row of 2 m length) and evaluated in replications-in sets (within block RBD) experimental design proposed by Comstock and Robinson (1952) in which each set was evaluated in compact and uniform block for local control of experimental error. All the sets of both populations were accommodated in the same experimental field and evaluated for two seasons in 2012 rainy season and 2013 summer season.

3.1.4.3 Observation recorded

Observations were recorded on days to 50% flowering, 1000-grain weight, and grain Fe and Zn densities. Detailed measurement of these traits are given in subheads 3.2. Harvesting was done as given in 3.1.1.5.

3.1.5 Assessment of intra-population variability for combining ability

3.1.5.1 Genetic material

Two open-pollinated varieties (OPVs) [ICTP 8203 and ICMV 221] were used as the base populations (seed parent), and Raj 171 and ICMR 312 as broad-based testers (pollen parent) (Table 3.5.) for the assessment of intra-population variability for combining ability for grain Fe and Zn densities. Randomly selected S_0 plants from base populations were crossed with both the testers. Each randomly selected S_0 plant was first crossed with one of the testers (ICMR312) when main panicle was receptive and tillers panicle of the same S_0 plant was crossed with another tester (Raj 171). Likewise 60 S_0 plants were crossed with both the testers and totally 120 topcross progenies were developed with each base population during 2012 summer season. The entire operations like bagging and other precautionary measures to avoid contamination from foreign pollen were carried out as per the description given in 3.1.1.2.

3.1.5.2 Field evaluation

Topcross hybrids of ICTP 8203 population were grouped tester-wise. Sixty progenies each with Raj 171 and ICMR 312 testers along with four common checks (ICMV 221, ICMR 312, Raj 171 and ICMH 356) constituting a total of 64 entries for each tester-group were randomized separately and totally 128 entries of both the testers were evaluated in the same field side by side to minimize soil heterogeneity. All the entries of both the trials were replicated thrice in RCBD with a plot size of one row of 2 m length and evaluated for two seasons during 2012 rainy and 2013 summer seasons. Similarly, the topcross progenies of ICMV 221 population were also evaluated using the same four checks. All the recommended agronomic practices were followed (as given in 3.1.1.4) for good crop stand.

3.1.5.3 Observations recorded

Observations were recorded for days to 50% flowering, 1000-grain weight, and grain Fe and Zn densities. Detailed measurements of these traits are given in subheads 3.2. Harvesting was done as given in 3.1.1.5.

3.2 OBSERVATIONS RECORDED

3.2.1 Agronomic observations

3.2.1.1 Days to 50% flowering (days): The number of days taken from sowing to the stigma emergence in main shoots of 50% of plants in a plot was recorded.

3.2.1.2 Plant height (cm): Plant height was measured from stem base to the tip of spike of main tiller, averaged across 5-10 randomly selected plants of each plot and was recorded at the time of harvest.

3.2.1.3 Panicle length (cm): Panicle length was measured from the base to the tip of the main tiller panicle at maturity, averaged across 3-5 randomly selected plants of each plot.

3.2.1.4 Effective tillers plant^{-1}: Number of panicle bearing plants in an individual plot were counted at maturity, and total number of panicles at the harvest time. Total numbers of panicles were divided by total number of plants to estimate number of effective tillers plant^{-1}.

3.2.1.5 1000 grain weight (g): A random sample of 200 grains of each entry from each replication was counted, weighed and multiplied by a factor of five to derive 1000-grain weight.

3.2.1.6 Grain yield (t ha^{-1}): After threshing, grains obtained from all plants of a plot was weighed. Plot yield was converted into t ha^{-1} by using following formula.

$$\text{Yield (t ha}^{-1}) = \frac{\text{Plot yield (kg)} \times 10000}{1000 \times \text{Plot size (m}^2)}$$

3.2.2 Grain micronutrient analysis

3.2.2.1 Grain samples collection

In all the experiments, open-pollinated (OP) grain samples were produced and used to estimate grain Fe and Zn densities expressed in mg kg^{-1}. At the time of harvesting, 5 to10 representative main panicles from each plot were harvested at physiological maturity (85–90 days after planting). The harvested panicles were put directly in a separate cloth bag to avoid soil contamination and dried them in the sun to <12% post-harvest grain moisture content. While threshing, separately harvested panicles were manually threshed first and approximately 20 g of grains was collected for Fe and Zn analysis. Grains were cleaned from glumes, panicle chaff and debris and transferred to new nonmetal fold envelops and stored in cold temperature. Care was taken at each step to avoid contamination of the grains with dust particles and any other extraneous matter (Stangoulis and Sison, 2008).

3.2.2.2 Analysis of grain iron and zinc densities

Grain Fe and Zn densities were analyzed at the Charles Renard Analytical Laboratory, ICRISAT, Patancheru, India following the method described by Wheal *et al*. (2011). The ground samples were digested in closed tubes; and Fe and Zn in the digests were analyzed using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES). Briefly, grain samples were finely ground and oven dried at 60°C for 48 h before analyzing them for Fe and Zn densities. Ground sample (0.2 g) was transferred to 25 ml polyprophelene PPT tubes; digestion was initiated by adding 2.0 ml of concentrated nitric acid (HNO_3) and 0.5 ml of 30% hydrogen peroxide (H_20_2). Tubes were vortexed to ensure that entire sample was wetted, and then pre-digested overnight at room temperature. Tubes were vortexed again before placing them into the digestion block and initially heated at 80^{o}C for 1 hour, followed by digesting at 120 ^{o}C for 2 hours. After digestion, the volume of the digest was made to 25 ml using distilled water; and the content was agitated for 1 minute by vortex mixer. The digests were filtered and Fe and Zn densities were determined using ICP-OES.

3.2.3 Soil micronutrient analysis

3.2.3.1 Soil samples collection

At the time of planting of each experiment, four well-spread representative soil samples were collected from the experimental fields from 0-30 cm top layer. The soil samples were air-dried, crushed with a wood mallet and sieved through a 6 mm nylon screen. Precautions were taken to avoid contamination during sampling, drying, crushing and storage. A representative sub-sample of each soil sample was further pulverized with a wooden rolling pin and screened through a 1 mm stainless sieve and used for the laboratory analyses.

3.2.3.2 Analysis of soil iron and zinc contents

The soil Fe and Zn contents were analyzed by DTPA extractable method (Lindsay and Norvell, 1978) at Charles Renard Analytical Laboratory, ICRISAT, Patancheru, and expressed as mg kg^{-1} (ppm). Ten grams of air-dried soil was placed in a 125 ml conical flask and 20 ml of the DTPA extracting solution was added. Each flask was covered with screw cap and placed on a horizontal shaker with a stroke of 8.0 cm and with a speed of 120 cycles min^{-1}. After 2 hours of shaking, the suspensions were filtered by gravity through Whatman no. 42 filter paper. The filtrates were analyzed for Fe and Zn contents using Atomic Absorption Spectrophotometry (AAS). The mean soil Fe and Zn contents varied from 2.7 to 14.0 mg kg^{-1} and from 1.9 to 7.2 mg kg^{-1}, respectively across the experimental fields of ICRISAT, Patancheru (Appendix B.). These Fe and Zn contents in the soil were in the sufficient range for normal plant requirements (2.6 to 4.5 mg kg^{-1} for Fe; 0.6 to 1.0 mg kg^{-1} for Zn) (Tisdale *et al*., 1993 and Sahrawat and Wani, 2013).

3.3 STATISTICAL ANALYSIS

3.3.1 General statistics

3.3.1.1 Mean

Mean value ($\overline{X}$) of each character was determined by dividing the sum of the observed values with the corresponding number of observations.

$$\overline{X} = \frac{\sum_{i=1}^{N} X_i}{N}$$

Where,

X_i - Observation of the i th treatment

N - Total number of observations.

3.3.1.2 Variance (S^2)

Variance was calculated as the average of the squared differences between the individual values and their mean value. It is a measure of variation among families/treatments or replications, etc.

$$S^2 = \frac{1}{n-1}\left[\sum_{i=1}^{n} x_i^2 - \frac{(\sum_{i=1}^{n} x_i)^2}{n}\right]$$

Where,

S^2- Sample variance,

n- Number of observations,

X_i - Observation of the i th treatment

3.3.1.3 Standard deviation (SD)

The standard deviation is a measure of dispersion of individual values around the population mean. For data with normal distribution, about 95% individuals will have value within 2 standard deviation of the mean, the other 5% being equally scattered above and below these limits and it is measure of variability regardless of the distribution.

$$\text{Standard deviation (SD)} = \sqrt{\text{Variance}} \text{ or } \sqrt{S^2}$$

Where, S^2- Sample variance

3.3.1.4 Standard error (SE)

The standard error is a measure of the precision of sample mean. To know how widely scattered some measurements are, standard deviation is used and to indicate the uncertainty around the estimate of mean measurement, the standard error of the mean is quoted (Altman and Bland, 2005 and Biau, 2011).

$$\text{SE}=\sqrt{\frac{\text{MSE}}{\text{n}}}\ \ or\ \ \frac{SD}{\sqrt{n}}$$

Where,

SE - Standard error,

MSE - Error mean square,

SD - Standard deviation and

n - Number of observations or sample size.

3.3.1.5 Coefficient of variation (CV)

The coefficient of variation measures the variability in relation to the mean (or average) and is used to compare the relative dispersion in one type of data with the relative dispersion in another type of data. The data to be compared may be in the same units, in different units, with the same mean or with different means. The CV indicates the degree of precision in the particular experiment when estimate using error mean square (MSE) and if CV is estimated using genotypic mean square (MSG), it indicates genetic variability.

$$\text{CVe (\%)} = \frac{\sqrt{\text{MSE}}}{\text{Trait grand mean}} \times 100$$

$$\text{CVg (\%)} = \frac{\sqrt{\text{MSG}}}{\text{Trait grand mean}} \times 100$$

Where, MSE- Error mean square, and MSG- Genotypic mean square

3.3.1.6 Percent variation (%)

Percent variation is a ratio of the absolute variation to the base value, expressed in per cent. An absolute variation is simply the difference between the start (base) value and the new (final) one.

$$\text{Variation (\%)} = \frac{\text{Base value} - \text{Final value}}{\text{Base value}} \times 100$$

3.3.1.7 Least Significant Difference (LSD)

Significance test for pair wise comparison between two genotypes were estimated using Least Significant Difference (LSD) or Critical Difference (CD) values.

$$\text{LSD or CD} = t_{\alpha} \times \text{SEd}$$

$$\text{Standard error of difference (SEd)} = \sqrt{\frac{2\text{MSE}}{\text{rs}}}$$

Where,

MSE - Error mean square,

r, s- Number of replications and seasons, respectively,

t_{α} -Table t value at error degrees of freedom, at 5% or 1% levels (α) of significance.

3.3.2 Assessment of genetic variation and combining ability of inbred lines using line × tester design

3.3.2.1 Analysis of variance (ANOVA)

3.3.2.1.1 ANOVA Model

Data were analyzed using Statistical Analysis Systems (SAS) version 9.2 (SAS Institute, 2004). ANOVA for individual environments (Tables 3.6. and 3.7.) and pooled ANOVA over the two environments (Tables 3.8. and 3.9.) were performed using Generalized Linear Model procedures using random-effects model (Eisenhart, 1947., Kempthorne, 1957., Steel and Torrie, 1980., McIntosh, 1983 and Hallauer *et al.*, 1988). All effects were considered as random in the combined analysis of variance and Satterthwaite's approximation was used to obtain the appropriate degrees of freedom for the synthesized *F*-test (where direct *F*-test is not possible) i.e., for lines and testers *F*-test (Satterthwaite, 1941 and1946).

3.3.2.1.2 Effective (approximate) degrees of freedom

Approximate degrees of freedom for linear combinations of mean squares are calculated using Satterthwaite (1946), approximate degrees of freedom formula as given below:

$$\text{F test} = \frac{(\text{MSr} + \cdots + \text{MSs})}{(\text{MSu} + \cdots + \text{MSv})}$$

$F_{(p,q)}$ -test significance was tested using p and q degrees of freedom which were calculated as:

$$p = \frac{(MSr + \cdots + MSs)^2}{\frac{(MSr)^2}{dfr} + \cdots + \frac{(MSs)^2}{dfs}}$$

$$q = \frac{(MSu + \cdots + MSv)^2}{\frac{(MSu)^2}{dfu} + \cdots + \frac{(MSv)^2}{dfv}}$$

Where, p and q were the effective degrees of freedoms for numerator and denominator factor, respectively,

MSr, MSs, MSv and MSu were the mean sum of squares, and dfr, dfs, dfu and dfv were the degrees freedom for r, s, u and v factors, respectively.

Approximate degrees of freedom for “lines” component in line × tester hybrid trial (Table 3.9.) was calculated using Satterthwaite (1946) as mentioned below:

$$F - \text{test (Lines)} = \frac{M4 + M10}{M6 + M8}$$

F-test significance was tested using p (numerator) and q (denominator) degrees of freedom calculated as

$$p = \frac{(M4 + M10)^2}{\frac{(M4)^2}{l-1} + \frac{(M10)^2}{(l-1)(t-1)(s-1)}}$$

$$q = \frac{(M6 + M8)^2}{\frac{(M6)^2}{(l-1)(t-1)} + \frac{(M8)^2}{(l-1)(s-1)}}$$

Where,

M4, M6, M8, and M10 were mean squares as said in the line × tester hybrids ANOVA Table 3.9.

r, l, t and s were number of replications, lines, testers and seasons, respectively.

3.3.2.2 Estimation of general combining ability (σ^2_{GCA}) and specific combining ability (σ^2_{SCA}) variances

The general combining ability (σ^2_{GCA}) and specific combining ability (σ^2_{SCA}) variances were estimated as per Kaushik *et al*. (1984):

Variances for lines and testers were calculated as mentioned in ANOVA Table 3.9.

Variances due to lines (σ^2_L) = [(M4+M10) - (M6+M8)]/rts

Variances due to testers (σ^2_T) = [(M5+M10) - (M6+M9)]/rls

Variance due to general combining ability (σ^2_{GCA})

$$= \frac{\{(l-1)\sigma^2_L + (t-1)\sigma^2_T\}}{(l+t)-2}$$

Variance due to specific combining ability(σ^2_{SCA})

$$= \sigma^2_{LT} = \frac{(M_{LT} - M_{SLT})}{rs}$$

Where,

σ^2_L - Variance attributed to lines,

σ^2_T - Variance attributed to testers,

σ^2_{LT} -Variance attributed to line × tester interaction component,

M4, M5, M6, M8, M9 and M10 were mean squares due to lines, testers, line × tester, line × environment, tester × environment and line × tester × environment components, respectively,

r, l, t, and s were number of replications, lines, testers and seasons, respectively.

3.3.2.3 Predictability ratio (PR)

Predictability ratio was computed following Baker (1978) as mentioned below:

$$\text{Predictability ratio (PR)} = \frac{2\sigma^2_{GCA}}{(2\sigma^2_{GCA} + \sigma^2_{SCA})}$$

Where,

σ^2_{GCA} and σ^2_{SCA} were variances due to GCA and SCA, respectively.

$(2\sigma^2_{GCA} + \sigma^2_{SCA})$ - Total genetic variance of single cross progenies (F_1) (Griffings, 1956)

Closer the PR to unity better is the predictability of the crosses performance based on GCA effects of their parents, which means predominance of additive genetic variance for that trait.

3.3.2.4 Contribution of line, tester and line × tester to total genotypic variance

The proportionate contribution of lines, testers and their interactions were estimated as indicated below (K N Rai Pers. Comm.)

$$\text{Contribution of lines (l)} = \frac{\sigma^2_l}{\sigma^2_l + \sigma^2_t + \sigma^2_{l\times t}} \times 100$$

$$\text{Contribution of testers (t)} = \frac{\sigma^2_t}{\sigma^2_l + \sigma^2_t + \sigma^2_{l\times t}} \times 100$$

$$\text{Contribution of line} \times \text{tester interaction (l} \times \text{t)} = \frac{\sigma^2_{l\times t}}{\sigma^2_l + \sigma^2_t + \sigma^2_{l\times t}} \times 100$$

Where, σ^2_l, σ^2_t and $\sigma^2_{l\times t}$ were variances due to lines, testers, and line × tester interaction, respectively.

3.3.2.5 Combining ability effects

3.3.2.5.1 Estimation of combining ability effects

The concept of general and specific combining ability was introduced by Sprague and Tatum (1942). Combining ability is the relative ability of a biotype to transmit desirable performance to its crosses. General combining ability (*gca*) is the average performance of a strain in a series of crosses, and the term specific combining ability (*sca*) is used to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of average performance of the lines involved. Schematic representation for estimation of *gca* and *sca* effects is illustrated in Table 3.10.

Mathematical model for combing ability effects is

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

Where,

X_{ijks} - Value of ijksth observation,

μ - population mean,

i - denotes number of lines, i=1 to i=*l*

j - denotes number of testers j=1 to j=*t*

k - denotes number of replications

s - denotes number of seasons

e_{ijks} – error associated with ijksth observation.

GCA effects of female (g_i) = $X_{i.} - X_{..}$

GCA effects of male (g_j) = $X_{.j} - X_{..}$

SCA effects of hybrid (s_{ij}) = $X_{ij} - X_{i.} - X_{.j} + X_{..}$

$X_{i.}$ is the mean of the hybrids with ith female (line) averaged over replications, seasons and males,

$X_{.j}$ is the mean of the hybrids with jth male (tester) averaged over replications, seasons and females,

X_{ij} is the mean of a given hybrid averaged over replications and seasons, and

$X_{..}$ experimental mean

3.3.2.5.2 Standard error estimates of combining ability effects

The standard errors pertaining to *gca* effects of lines and testers, and *sca* effects of hybrids across two environments were estimated as detailed below (Singh and Chaudhary, 1942 and Dabholkar, 1992).

Genotype	Standard Error (SE)	Standard Error Difference (SEd)	't'-test (at error df)
Lines	SE (g_i) = $\sqrt{\frac{MSE}{rst}}$	SEd (g_i-g_l) = $\sqrt{\frac{2MSE}{rst}}$	$t_{lines} = \frac{g_i - 0}{SE(g_i)}$
Testers	SE(g_j) = $\sqrt{\frac{MSE}{rsl}}$	SEd (g_j-g_t) = $\sqrt{\frac{2MSE}{rsl}}$	$t_{testers} = \frac{g_j - 0}{SE(g_j)}$
Hybrids	SE(s_{ij}) = $\sqrt{\frac{MSE}{rs}}$	SEd (s_{ij}-s_{lt}) = $\sqrt{\frac{2MSE}{rs}}$	$t_{hybrids} = \frac{s_{ij} - 0}{SE(s_{ij})}$

Where,

MSE - Error mean sum of square, from ANOVA for line × tester hybrid study across environments, l, t, r and s refers to number of lines, testers, replications and seasons, respectively,

$SE(g_i)$, $SE(g_j)$ and $SE(s_{ij})$ were standard errors due to lines, testers and hybrids, respectively.

SEd (g_i-g_l), SEd (g_j-g_t) and SEd $(s_{ij}-s_{lt})$ were standard errors between *gca* effects between two lines, between two testers and *sca* effects between two hybrids, respectively.

3.3.2.6 Estimates of heterosis

The magnitude of heterosis in hybrids, expressed as percent increase or decrease of a character over mid-parent and better parent, was estimated following Hallauer *et al*. (1988).

3.3.2.6.1 Mid-parent (MP) heterosis

It was estimated as the percent deviation of the mean performance of F_1 over the mean of mid-parental value.

$$\text{MP heterosis (\%)} = \frac{\overline{F_1}-\overline{MP}}{\overline{MP}} \times 100$$

Where, $\overline{F_1}$ - Mean value of the F_1 hybrid,

$\overline{MP}$ - Mean value of the two parents involved in a cross.

3.3.2.6.2 Better parent (BP) heterosis

It was estimated as the percent deviation of the mean performance of F_1 over the better parent (while F_1 value higher than better parent).

$$\text{BP heterosis (\%)} = \frac{\overline{F_1}-\overline{BP}}{\overline{BP}} \times 100$$

Where, $\overline{F_1}$-Mean value of the F_1 hybrid,

$\overline{BP}$ - Mean value of the better parent for a given cross.

3.3.2.6.3 ‘t’-test for significance of heterosis

The significance of mid-parent and better parent heterosis was tested using ‘t’ - test at error degrees of freedom (KN Rai Pers. Comm.)

$$\text{'t' for MP heterosis} = \frac{\overline{F_1}\text{-}\overline{MP}}{\sqrt{(\sigma^2_{e(c)} + {}^1/_2\, \sigma^2_{e(p)})/r}}$$

$$\text{'t' for BP heterosis} = \frac{\overline{F_1}\text{-}\overline{BP}}{\sqrt{(\sigma^2_{e(c)} + \sigma^2_{e(p)})/r}}$$

Where,

$\sigma^2_{e(c)}$ and $\sigma^2_{e(p)}$- Error variances due to crosses and parents, respectively,

r – Number of replications.

3.3.3 Assessment of association of grain iron and zinc densities with agronomic traits

3.3.3.1 Covariance

Covariance was calculated to estimate the relationship between pair of traits. Covariance is always measured between two dimensions. If the covariance was calculated between one dimension and itself, the variance is obtained.

$$\mathrm{cov}(X, Y) = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{n - 1}$$

Where,

$\bar{x}$ - Mean of X variable,

$\bar{y}$ - Mean of Y variable,

n - Number of observations or sample size.

3.3.3.2 Correlation coefficient

The Pearson correlation coefficient was calculated to estimate the linear relationship between pair of traits by the following formula:

$$r_{(XY)} = \frac{COV(X, Y)}{S_X S_Y}$$

$$r(x, y) = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \ \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

Where,

$r_{(X,Y)}$ is the phenotypic correlation between the variables X and Y, COV(X, Y) is the phenotypic covariance of the variables X and Y,

S_X is the sample standard deviation of the random variable X and

S_Y is the sample standard deviation of the random variable Y.

The observed value of correlation coefficient is compared with the tabulated value for n-2 degrees of freedom, where n is number of observations.

$$t = r\sqrt{\frac{n-2}{1-r^2}}$$

r- Correlation coefficient,

n- Total number of observations.

3.3.3.3 Principal Component Analysis (PCA)

Associations among the traits were also determined by Principal Component Analyses (PCA) (Hatcher, 1994) using R version 3.0.2 (R Project for Statistical Computing, http://www.r-project.org/).

3.3.4 Study of tester effect on combining ability of inbred lines

Analyses of variances for both sets of inbred parental topcrosses for individual and across the environments were performed using ANOVA model given in Tables 3.7., 3.9. and 3.11.

3.3.5 Assessment of intra-population genetic variation using NCD-1

Data were analyzed using Statistical Analysis Systems (SAS) version 9.2 (SAS Institute, 2004). ANOVA for individual environments (Table 3.12.) and pooled ANOVA over the two environments (Table 3.13.) were performed using Generalized Linear Model procedures using a random-effects model (Hallauer *et al.*, 1988). Satterthwaite's approximation was used to obtain the appropriate degrees of freedom for the synthesized *F*-test (where direct *F*-test is not possible) (Satterthwaite, 1941 and 1946).

3.3.5.1 Estimates of genetic variance components in individual environment

$$\text{Variance due to males } (\sigma^2_M) = \frac{M3 - M4}{rf} = \frac{1}{4}\sigma^2_A$$

$$\text{Variance due to females } (\sigma^2_F) = \frac{M4 - M5}{r} = \frac{1}{4}\sigma^2_A + \frac{1}{4}\sigma^2_D$$

$$\text{Additive variance } (\sigma^2_A) = 4\sigma^2_M$$

$$\text{Dominance variance } (\sigma^2_{\mathrm{D}}) = 4(\sigma^2_{\mathrm{F}} - \sigma^2_{M})$$

$$\text{Average degree of dominance } (\bar{a}) = \sqrt{\frac{2\sigma^2_{\mathrm{D}}}{\sigma^2_{\mathrm{A}}}}$$

Where,
M3, M4 and M5 were mean squares of males, females within males and error respectively,
r, f – number of replications and females, respectively.

3.3.5.2 Estimates of genetic variance components in multi-environment

$$\text{Variance due to males } (\sigma^2_{\mathrm{M}}) = \frac{\{(\mathrm{M5} + \mathrm{M8}) - (\mathrm{M6} + \mathrm{M7})\}}{\mathrm{erf}} = \frac{1}{4}\sigma^2_{\mathrm{A}}$$

$$\text{Variance due to females } (\sigma^2_{\mathrm{F}}) = \frac{(\mathrm{M6} - \mathrm{M8})}{\mathrm{er}} = \frac{1}{4}\sigma^2_{\mathrm{A}} + \frac{1}{4}\sigma^2_{\mathrm{D}}$$

$$\text{Additive variance } (\sigma^2_{\mathrm{A}}) = 4\sigma^2_{\mathrm{M}}$$

$$\text{Dominance variance } (\sigma^2_{\mathrm{D}}) = 4(\sigma^2_{\mathrm{F}} - \sigma^2_{\mathrm{M}})$$

$$\text{Average degree of dominance } (\bar{a}) = \sqrt{\frac{2\sigma^2_{\mathrm{D}}}{\sigma^2_{\mathrm{A}}}}$$

$$\text{Additive genetic } \times \text{ environments variance } (\sigma^2_{\mathrm{A\times E}}) = 4\sigma^2_{\mathrm{M\times E}}$$

$$\text{Dominance } \times \text{ environments variance } (\sigma^2_{\mathrm{D\times E}}) = 4(\sigma^2_{\mathrm{F\times E}} - \sigma^2_{\mathrm{M\times E}})$$

$$\text{Total genetic variance } (\sigma^2_{\mathrm{G}}) = 4\sigma^2_{\mathrm{F}}$$

$$\text{Genetic } \times \text{ environments variance } (\sigma^2_{\mathrm{G\times E}}) = 4\sigma^2_{\mathrm{F\times E}}$$

Where, M5, M6, M7 and M8 were mean squares of males, females within males, males × environments and females within males × environments, respectively,
e, r, f – number of environments, replications and females, respectively.

3.3.5.3 Estimates of heritability components

Individual environment

$$h^2 = \frac{4\sigma^2_{\mathrm{M}}}{\frac{\sigma^2_{\mathrm{e}}}{r} + 4\sigma^2_{\mathrm{F/M}}}$$

Multi-environments

$$h^2 = \frac{4\sigma^2_{\mathrm{M}}}{\frac{\sigma^2_{\mathrm{e}}}{\mathrm{re}} + \frac{4\sigma^2_{\mathrm{FE/M}}}{\mathrm{e}} + 4\sigma^2_{\mathrm{F/M}}}$$

Where,
σ^2_{M}, $\sigma^2_{F/M}$ and $\sigma^2_{FE/M}$ were variances of males, females within males and females within males × environments, respectively,
e, r – Number of environments and replications, respectively.

Heritability was classified as (Robinson *et al.*, 1949):

Low = 0 to 30%

Moderate= 30-60%

High= > 60%

3.3.6 Assessment of intra-population variability for combining ability

Analyses of variances for both ICTP 8203 and ICMV 221 topcrosses for individual and across the environments were performed using ANOVA model given in Tables 3.7., 3.9. and 3.11.

Results and discussion

Chapter IV

RESULTS AND DISCUSSION

Biofortification is a cost-effective and sustainable agricultural strategy to address the micronutrient deficiencies of resource-poor and majority of malnourished populations. With a view to enhance breeding efficiency for these micronutrients, efforts in this study were made to investigate underlying genetics of grain Fe and Zn densities in pearl millet as this crop forms staple food for poor and marginal farmers of arid and semi-arid tropics regions. Since hybrids and open-pollinated varieties are the two cultivar options in this highly cross-pollinated crop, the nature of genetic variability was studied in the context of heterosis and combining ability. Also for biofortification to be a viable strategy, it is important that genetic improvement of these traits does not compromise, especially on grain yield and grain size. So, study of association among Fe and Zn densities, gain yield and grain size was also undertaken, which can provide valuable insights into the prospects of simultaneous improvement of all these traits. Results of various experiments conducted on these subjects are presented and discussed experiment-wise under the following headings:

4.1 Assessment of genetic variation and combining ability of inbred lines using line × tester design

4.2 Assessment of association of grain iron and zinc densities with agronomic traits in hybrids

4.3 Study of tester effect on combining ability of inbred lines

4.4 Assessment of intra-population genetic variation

4.5 Assessment of intra-population variability for combining ability

4.1 ASSESSMENT OF GENTIC VARIATION AND COMBINING ABILITY OF INBRED LINES USING LINE × TESTER DESIGN

Line × tester mating design produces hybrids, which, if evaluated along with their parental lines, provide useful information, not only on the nature of gene action for trait under investigation, but also on the magnitude and direction of heterosis, and relationship between performance *per se* of parental lines and their general combining ability. For the investigation of these inter-related issues, 14 maintainer lines (B-lines or female parents), hereafter referred to as "lines"; 14 restorer lines (R-lines or male parents), hereafter referred to as "testers"; and 196 hybrids produced by line × tester crosses were included in this study. Parental lines and hybrids were evaluated separately in adjacent blocks for grain iron (Fe) and zinc (Zn) densities, grain yield, 1000-grain weight, and days to 50% flowering.

4.1.1 Variability among parental lines

4.1.1.1 Analysis of variance for parental lines

There were highly significant differences among the parental lines (both females or lines, and males or testers) for all traits in individual environments as well as over the environments, except for days to 50% flowering among both male and female parents, and grain yield among female parents over the environments (Table 4.1.). Male × environment (M × E) as well as female × environment (F × E) interactions also were highly significant for all traits, except for male × environment interaction for grain yield. The contributions of F × E interactions to variability relative to those due to differences among female parents were 15% for Fe density, 13% for Zn density, 30% for 1000-grain weight, and 43% for days to 50% flowering, but it was about 10% higher for grain yield. Similarly, the contributions of M × E interactions to variability relative to those due to differences among male parents were 14% for Fe density, 18% for Zn density, 9% for 1000-grain weight and 71% for days to 50% flowering.

4.1.1.2 Parental lines performance *per se*

4.1.1.2.1 Grain iron and zinc densities

The grain Fe density among the lines (B-lines or female parents) ranged from 24.0 (ICMB 92111) to 71.3 mg kg^{-1}(ICMB 98222) in rainy season, and from 34.3

(ICMB 07999) to 83.1 mg kg^{-1}(ICMB 98222) in summer season (Table 4.2.). Based on the mean performances over the environments, it ranged from 30.3 (ICMB 92111) to 77.2 mg kg^{-1} (ICMB 98222). Amongst the R-lines or testers, the Fe density ranged from 29.0 (IPC 1354) to 75.0 mg kg^{-1}(PRP 2) in rainy season, and from 35.0 (IPC 1354) to 89.2 mg kg^{-1}(PRP 2) in summer season. Based on the mean performances over the environments, the Fe density ranged from 32.0 (IPC 1354) to 82.1 mg kg^{-1}(PRP 2). Averaged over all the parental lines, grain Fe density in the summer season was 54.1 mg kg^{-1}, 20.2% higher than that of rainy season in B-lines; and it was 55.7 mg kg^{-1}, 11.2% higher in R-lines.

The grain Zn density among the B-lines ranged from 22.9 (ICMB 92111) to 39.7 mg kg^{-1} (ICMB 0488) in rainy season, and from 30.3 (ICMB 07999) to 51.6 mg kg^{-1} (ICMB 05555) in summer season. Based on the mean performances over the environments, it varied from 27.4 (ICMB 92111) to 45.3 mg kg^{-1} (ICMB 98222). Amongst the testers, Zn density varied from 19.5 (IPC 1354) to 49.2 mg kg^{-1} (PRP 2) in rainy season, and from 33.8 (PRP 6) to 61.9 mg kg^{-1}(IPC 616) in summer season. Based on the mean performances over the environments, it varied from 29.0 (IPC 1354) to 55.5 mg kg^{-1}(PRP 2). Averaged over all the parental lines, grain Zn density in the summer season was 42.3 mg kg^{-1}, 30.6% higher than that of rainy season in B-lines; and it was 48.2 mg kg^{-1}, 42.2% higher in R-lines.

4.1.1.2.2 Agronomic traits

Thousand grain weight among the B-lines varied from 6.3 (ICMB 92111) to 13.8 g (ICMB 92888) in rainy season, and from 8.5 (ICMB 92111) to 12.8 g (ICMB 93222) in summer season (Table 4.2.). Based on the mean performances over the environments, it varied from 7.4 (ICMB 92111) to 12.9 g (ICMB 97111). Amongst testers, it varied from 6.3 (IPC 390) to 12.1 g (PRP 3) in rainy season, and from 6.6 (PRP 9) to 12.2 g (PRP 4) in summer season. Based on the mean performances over the environments, it varied from 6.9 (PRP 9) to 11.5 g (PRP 3). Averaged over all parental lines, 1000-grain weight in the summer season was 11.1 g, 12% higher than that of rainy season in B-lines; while it was equal in both seasons in R-lines.

The grain yield among B-lines varied from 1.0 (ICMB 04888) to 3.9 t ha^{-1} (ICMB 92888) in rainy seasons, and from 1.2 (ICMB 92888) to 4.3 t ha^{-1} (ICMB 97111) in summer season. Based on the mean performances over the environments, it varied from 1.6 (ICMB 04888) to 3.6 t ha^{-1} (ICMB 97111). Among the testers, grain yield varied from 1.2 (IPC 1178) to 2.6 t ha^{-1} (PRP 4) in rainy season, and from 1.6 (IPC 1354) to 3.4 t ha^{-1}(PRP 4). Based on the mean performances over the environments, it varied from 1.4 (IPC 1354) to 3.0 t ha^{-1} (PRP 4). Averaged over all the parental lines, grain yield in the summer season was 3 t ha^{-1}, 43% higher than that of rainy season in B-lines; and it was 2.6 t ha^{-1}, 46% higher in R-lines.

Days to 50% flowering among B-lines varied from 42 (ICMB 07555) to 49 d (ICMB 93222) in rainy season, and from 49 (ICMB 88004) to 60 d (ICMB 92111) in summer season. Based on the mean performances over the environments, it varied from 46 (ICMB 07555) to 54 d (ICMB 93222). Among the testers, it varied from 44 (PRP 3) to 54 d (PRP 1) in rainy season, and from 54 (IPC 390) to 67 d (IPC 1178) in summer season. Based on the mean performances over the environments, it varied from 49 (PRP 3) to 59 d (IPC 1178. Averaged over all the parental lines, days to 50% flowering in the summer season was 54 d, 20% higher than that of rainy season in B-lines; and it was 59 d, 20% higher in R-lines.

4.1.2 Genetic variance

4.1.2.1 Analysis of variance for combining ability

The differences among hybrids as well as their interactions with environments (H × E) were highly significant for all five traits (Tables 4.3. and 4.4.). However, the contribution of H × E interactions to the variability relative to those due to genetic differences among the hybrids were low for Fe (14%) and Zn (16%) densities, and 1000- grain weight (15%); and higher for days to 50% flowering (34%) and grain yield(41%). Further partitioning of H × E interactions showed that contribution of L × E interactions to the variability relative to those due to line effects were 7% for Fe density, 9% for Zn density, 11% for 1000-grain weight, 18% for days to 50% flowering, and 28% for grain yield. The contribution of T × E interactions to the variability relative to those due to tester effects were 5-6% for both micronutrients and 1000-grain weight, while these were 24% for grain yield and 49% for days to 50% flowering. Furthermore, highly significant and high positive correlations were observed for mean performance of hybrids between two seasons for Fe ($r=0.76$, $p<0.01$), Zn ($r=0.74$, $p<0.01$) and 1000-grain weight ($r=0.79$, $p<0.01$), while these were relatively low for days to 50% flowering ($r=0.56$, $p<0.01$); and lowest for grain yield ($r=0.44$, $p<0.01$).

The contribution of L × T interaction effect to variability relative to those due to line and tester effects combined was only about 20% for Fe and Zn densities, 26% for

1000-grain weight and 22% for days to 50% flowering, while it was about 20% higher for grain yield. It implies that line × tester interaction played major role for grain yield, which is largely under non-additive genetic control. The contribution of L × T × E interaction to variability relative to that due to L × T interaction was 40-60% for both micronutrients, 1000-grain weight, days to 50% flowering and grain yield, which was highly significant for all the traits.

4.1.2.3 Combining ability variance and predictability ratio

The variance due to general combining ability (σ^2_{GCA}) was about 4 to 5 times higher than the variance due to specific combining ability (σ^2_{SCA}) for Fe and Zn densities, and more than twice for 1000-grain weight and days to 50% flowering. For grain yield, σ^2_{GCA} was 50% of that due to σ^2_{SCA} (Tables 4.3. and 4.4. and Fig 4.1.). This led to predictability ratio close to unity for both Fe (0.85 in rainy season, 0.87 in summer season and 0.90 over the environments) and Zn (0.90 in rainy season, 0.85 in summer season and 0.91 over the environments) densities. Compared to these micronutrients, the predictability ratio was slightly lower for 1000-grain weight (0.80 in rainy season, 0.77 in summer season and 0.84 over the environments) and days to 50% flowering (0.77 in rainy season, 0.87 in summer season and 0.83 over the environments), and much lower for grain yield (0.50 in rainy season, 0.42 in summer season and 0.52 over the environments).

Predictability ratio close to unity for both Fe and Zn densities indicated that these traits are predominantly under additive genetic control. Earlier studies in pearl millet (Velu *et al*., 2011b and Govindaraj *et al*., 2013), rice (Zhang *et al*., 2004) and maize (Gorsline *et al*., 1964., Arnold and Bauman, 1976., Brkic *et al*., 2003., Long *et al*., 2004 and Chen *et al*., 2007) were also reported these micronutrients to be largely under additive genetic control. Likewise, several studies in pearl millet have reported predominantly additive genetic variability for 1000-grain weight and days to 50% flowering, and predominantly non-additive genetic variability for grain yield (Khairwal *et al*., 1999 and Izge *et al*., 2007).

4.1.3 Hybrid performance

4.1.3.1 Grain iron and zinc densities

The Fe density among the hybrids varied from 23.6 (ICMB 92111 × PRP 9) to 64.6 mg kg^{-1} (ICMB 98222 × PRP 5), with an average of 40.9 mg kg^{-1} in rainy season; while in summer season it varied from 28.0 (ICMB 92111 × PRP 9) to 73.5 mg kg^{-1}

(ICMB 08222 × PRP 5), with an average of 49.7 mg kg^{-1} (Table 4.2. and Appendix C.). Based on the mean performances over the environments, it varied from 25.8 (ICMB 92111× PRP 9) to 64.5 mg kg^{-1} (ICMB 08222 × PRP 5), with an average of 45.3 mg kg^{-1}. About 90 hybrids in both seasons had higher Fe density over the respective experimental means. Based on the mean performances over the environments, 85 hybrids had higher Fe density over the trial mean. The average Fe density of hybrids was 22% higher in summer season than that of rainy season.

The Zn density among the hybrids varied from 20.2 (ICMB 92111 × PRP 9) to 45.4 mg kg^{-1} (ICMB 04888 × PRP 3), with an average of 30.7 mg kg^{-1} in rainy season; and from 29.6 (ICMB 07999 × PRP 9) to 60.2 mg kg^{-1} (ICMB 93222 × PRP 8), with an average of 43.6 mg kg^{-1} in summer season. Based on the mean performances over the environments, it varied from 25.8 (ICMB 02555 × PRP 9) to 48.2 mg kg^{-1} (ICMB 93222 × PRP 8), with an average of 37.1 mg kg^{-1}. Among the hybrids, 101 hybrids in rainy season and 94 hybrids in summer season had higher Zn density over the respective experimental means. Based on the mean performances over the environments, 96 hybrids had higher Zn density over the trial mean. The average Zn density was 22% higher in summer season than rainy season. Based on mean performance over the environments, 72 hybrids had higher values for both Fe and Zn densities over the trial mean.

4.1.3.2 Agronomic traits

The 1000-grain weight among the hybrids ranged from 8.6 (ICMB 92111 × PRP 9) to 15.5 g (ICMB 05555 × PRP 3), with an average of 12.3 g in rainy season; and from 8.8 (ICMB 02555 × PRP 9) to 13.7 g (ICMB 92888 × PRP 3), with an average of 11.3 g in summer season (Table 4.2. and Appendix C.). Based on the mean performances over the environments, it varied from 8.8 (ICMB 92111 × PRP 9) to 14.3 g (ICMB 88004 × PRP 6), with an average of 11.8 g. About 95 hybrids in both seasons had higher 1000-grain weight over the respective trial means. Based on the mean performances over the environments, 102 hybrids had higher 1000-grain weight over the mean. The average 1000-grain weight was 9% higher in rainy season than summer season.

The grain yield among the hybrids ranged from 2.1 (ICMB 04888 × IPC 616) to 5.4 t ha^{-1} (ICMB 93222 × PRP 6), with an average of 4.2 t ha^{-1} in rainy season; and from 2.5 (ICMB 04888 × IPC 616) to 5.1 t ha^{-1} (ICMB 02555 × PRP 9), with an average of 3.9 t ha^{-1} in summer season (Table 4.2. and Appendix D.). Based on the mean performances over the environments, it varied from 2.3 (ICMB 04888 × IPC 616) to 5.0 t ha^{-1} (ICMB 02555 × PRP 9) with an average of 4.0 t ha^{-1}. Among the hybrids, 103 in rainy season and 88 in summer season had higher grain yield over the respective trial means. Based on the mean performances over the environments, 106 hybrids showed higher grain yield over the mean. The average grain yield was 36% higher in rainy season than summer season.

Days to 50% flowering ranged between 38 (ICMB 97111 × IPC 616) to 47 d (ICMB 07777 × IPC 1178), with an average of 43 d in rainy season; and from 44 (ICMB 88004 × PRP 2) to 60 d (ICMB 93222 × PRP 6), with an average of 53 d in summer season (Table 4.2. and Appendix D.). Based on the mean performances over the environments, it varied from 41 (ICMB 88004 × PRP 2) to 53 d (ICMB 93222 × IPC 1178), with an average of 48 d. The days to 50% flowering of 67 hybrids in rainy season and 86 hybrids in summer season was less than the respective trial means. Based on the mean performances over the environments, 73 hybrids had days to 50% flowering lesser than trial mean. Averaged over all hybrids, days to 50% flowering was 23% hastened in rainy season than summer season.

4.1.4 General combining ability

4.1.4.1 Grain iron and zinc densities

General combining ability (*gca*) effects of lines (B-lines or female parents) for Fe density ranged from -7.5 (ICMB 92111) to 9.0 (ICMB 98222) in rainy season, and from -11.6 (ICMB 92111) to 9.5 (ICMB 05555) in summer season (Table 4.5.). Based on the mean performances over the environments, it varied from -9.5 (ICMB 92111) to 7.6 (ICMB 05555). Amongst the 14 B-lines, based on the mean performances over the environments, six lines had significant positive *gca* effects and most of these had > 55 mg kg^{-1} Fe density; while seven lines had significant negative *gca* effects and most of these had <44 mg kg^{-1} Fe density.

The *gca* effects for Fe density amongst testers varied from -9.3 (PRP 9) to 9.8 (PRP 3) in rainy season, and from -9.2 (PRP 9) to 9.2 (PRP 3) in summer season. Based on the mean performances over the environments, it varied from -9.2 (PRP 9) to 9.5 (PRP 3). Amongst 14 testers, based on mean performances over the environments, seven testers had significant positive *gca* effects and most of these had >56 mg kg^{-1} Fe density; while six testers had significant negative *gca* effects and most of these had < 44 mg kg^{-1} Fe density.

The *gca* effects for Zn density among B-lines ranged from -3.7 (ICMB 97111) to 3.6 (ICMB 98222) in rainy season, and from -5.2 (ICMB 92111) to 4.9 (ICMB 05555) in summer season. Based on the mean performances over the environments, it varied from -4.2 (ICMB 92111) to 3.7 (ICMB 05555). Amongst 14 B-lines, based on the mean performances over the environments, six lines had significant positive *gca* effects and all these lines had ≥40 mg kg^{-1} Zn density; while five lines had significant negative *gca* effects and all these lines had <34 mg kg^{-1}Zn density.

Among the testers, *gca* effects for Zn density varied from -6.8 (PRP 9) to 7.6 (PRP 3) in rainy season, and from -8.9 (PRP 9) to 5.0 (PRP 3) in summer season. Based on the mean performances over the environments, it varied from -7.8 (PRP 9) to 6.2 (PRP 3). Among 14 testers, based on the mean performances over the environments, seven testers had significant positive *gca* effects and most of these had >41 mg kg^{-1}Zn density, while five testers had significant negative *gca* effects and all of these had <36 mg kg^{-1}Zn density.

Among the B-lines, ICMB 05555, ICMB 08222, ICMB 88004 and ICMB 93222; and among the testers PRP 2, PRP 3 and PRP 5 had significant positive *gca* effects in individual environments as well as over the environments for both Fe and Zn densities.

Based on the mean performances over the environments, highly significant and very high positive correlations were observed between performance *per se* of B-lines and their *gca* effects, both for Fe density (r=0.93, p<0.01) and Zn density (r=0.90, p<0.01) (Table 4.5. and Fig 4.2.). Similarly, highly significant and very high positive correlations were observed between performance *per se* of testers and their *gca* effects, both for Fe density (r=0.80, p<0.01) and Zn density (r=0.87, p<0.01). Similar relationships between performance *per se* and *gca* effects for Fe and Zn densities have been reported in an earlier pearl millet study (Govindaraj *et al*., 2013). This indicates that selection for performance *per se* would be highly effective for selection for *gca* effects of both the micronutrients.

4.1.4.2 Agronomic traits

4.1.4.2.1 1000-grain weight

For 1000-grain weight, *gca* effects of B-lines varied from -2.0 (ICMB 92111) to 1.3 (ICMB 05555) in rainy season, and from -1.0 (ICMB 92111) to 0.8 (ICMB 07555) in summer season. Based on the mean performances over the environments, it varied from -1.5 (ICMB 92111) to 1.0 (ICMB 05555) (Table 4.5.). Amongst 14 B-lines, based on the mean performances over the environments, seven lines had significant positive *gca* effects and most of these had ≥10.9 g 1000-grain weight; while six lines had significant negative *gca* effects and most of these had ≤10.2 g 1000-grain weight.

Among the testers, *gca* effects for 1000-grain weight varied from -1.7 (PRP 9) to 1.1 (PRP 3) in rainy season, and from -1.5 (PRP 9) to 0.8 (PRP 4) in summer season. Based on the mean performances over the environments, it varied from -1.6 (PRP 9) to 0.9 (PRP 3). Amongst 14 testers, based on the mean performances over the environments, seven testers had significant positive *gca* effects and most of these had ≥ 9.4 g 1000-grain weight; while five testers had significant negative *gca* effects and most of these had 8.3 g 1000-grain weight.

Based on the mean performances over the environments, among the B-lines, ICMB 88004, ICMB 93222 and ICMB 05555 lines had significant positive *gca* effects for 1000-grain weight as well as for Fe and Zn densities; and among the testers, PRP 3 and PRP 8 had significant positive *gca* effects for 1000-grain weight as well as for Fe and Zn densities. As for Fe and Zn densities, the correlation between performance *per se* and their *gca* effects was significant and positive for grain weight, in both B-lines ($r=0.60$, $p<0.05$) and testers ($r=0.78$, $p<0.01$) (Fig 4.2.).

4.1.4.2.2 Grain yield

Among the B-lines, *gca* effects for grain yield varied from -0.55 (ICMB 08222) to 0.56 (ICMB 93222) in rainy season, and from -0.23 (ICMB 08333) to 0.29 (ICMB 07999) in summer season. Based on the mean performances over the environments, it varied from -0.37 (ICMB 08222) to 0.33 (ICMB 93222) (Table 4.6.). Amongst 14 B-lines, based on the mean performances over the environments, four lines had significant positive *gca* effects and most of these had ≥ 2.3 t ha^{-1} grain yield; while three lines had significant negative *gca* effects and all of these had ≤ 2.3 t ha^{-1} grain yield.

Among the testers, *gca* effects for grain yield varied from -0.52 (PRP 2) to 0.54 (PRP 9) in rainy season, and from -0.39 (PRP 3) to 0.40 (PRP 9) in summer season. Based on the mean performances over the environments, it varied from -0.44 (PRP 3) to 0.47 (PRP 9). Among the 14 testers, based on the mean performances over the environments, five had significant positive *gca* effects and most of these had ≥ 2.4 t ha^{-1} grain yield; while five had significant negative *gca* effects and most of these had ≤ 2.2 t ha^{-1} grain yield.

There were no correlation between performance *per se* and *gca* effects for grain yield in B-lines as well as in testers. It suggests that selection for *gca* effects based on performance *per se* of inbred lines would not be highly effective for grain yield, but high general combiners are as likely to be in high-yielding lines as they are likely to be in average and low-yielding lines.

4.1.4.2.3 Days to 50% flowering

For days to 50% flowering, *gca* effects among B-lines varied from -2.2 (ICMB 88004) to 1.7 (ICMB 93222) in rainy season, and from -5.1 (ICMB 88004) to 3.7 (ICMB 93222) in summer season. Based on mean performances over the environments, it varied from -3.6 (ICMB 88004) to 2.7 (ICMB 93222) (Table 4.6.). Among the 14 B-lines, based on the mean performances over the environments, seven lines had significant positive *gca* effects and most of these had ≥50 d days to 50% flowering; while six lines had significant negative *gca* effects and most of these had ≤ 49 d days to 50% flowering.

Among the testers, *gca* effects for days to 50% flowering varied from -2.0 (PRP 2) to 2.2 (IPC 1178) in rainy season, and from -3.1 (IPC 390) to 3.7 (IPC 1178) in summer season. Based on the mean performances over the environments, it varied from -1.7 (PRP 3) to 2.9 (IPC 1178). Amongst 14 testers, based on the mean performances over the environments, seven testers had significant positive *gca* effects and most of these had ≥ 54 d days to 50% flowering; while seven testers had significant negative *gca* effects and most of these had ≤ 53 d days to 50% flowering. The correlation between *per se* performance and *gca* effects was highly significant and positive for days to 50% flowering both in B-lines ($r=0.77$, $p<0.01$) and testers ($r=0.65$, $p<0.05$) (Fig 4.2.).

Furthermore perusal of parental combinations of 35 high-grain yield and high-Fe hybrids exceeding trial mean for both traits (≥4.1t ha^{-1} grain yield and ≥45 mg kg^{-1} Fe density) (Table 4.7.) showed that both parents of 14 hybrids and at least one parent of 20 hybrids (i.e. total 34 hybrids) had significant positive *gca* effects for Fe density; while both parents of only 5 hybrids and at least one parent of 14 hybrids (i.e. total of 19 hybrids) had significant positive *gca* effects for grain yield. These results imply that to breed high-Fe hybrids at least one parent should have high Fe density with highly significant positive *gca* effect, while to breed high-yielding hybrids, it was not necessarily so.

4.1.5 Specific combining ability

4.1.5.1 Grain iron and zinc densities

Specific combining ability (*sca*) effects of hybrids for Fe density ranged from -11.2 (ICMB 88004 × PRP 5) to 11.1 (ICMB 08333 × IPC 390) in rainy season, and from -9.7 (ICMB 92111 × IPC 1178) to 15.4 (ICMB 98222 × IPC 1178) in summer season (Appendix C.). Based on the mean performances over the environments, it varied from -8.8 (ICMB 98222 × IPC 1354) to 8.4 (ICMB 08333 × IPC 1354), with 28 hybrids having significant positive *sca* effects and 23 hybrids having significant negative *sca* effects.

For Zn density, *sca* effects of hybrids ranged between -7.7 (ICMB 97111 × IPC 843) to 5.6 (ICMB 04888 × PRP 3) in rainy season; and from -6.8 (ICMB 08333 × PRP 3) to 9.7 (ICMB 08222 × PRP 8) in summer season. Based on the mean performances over the environments, it varied from -5.8 (ICMB 97111 × IPC 843) to 5.7 (ICMB 93222 × PRP 8), with 25 hybrids having significant positive *sca* effects and 17 hybrids having significant negative *sca* effects.

There were highly significant and moderate positive correlations between the Fe density of hybrids and their *sca* effects in both the seasons ($r=0.46$ in rainy season, $r=0.49$ in summer season; $p<0.01$), as well as over the environments ($r=0.41$, $p<0.01$). Similar pattern was observed for Zn density ($r=0.42$ in rainy season, $r=0.53$ in summer season and $r=0.42$ over the environments; $p<0.01$).

4.1.5.2 Agronomic traits

Estimates of *sca* effects for 1000-grain weight ranged between -1.9 (ICMB 05555 × PRP 5) to 1.8 (ICMB 97111 × PRP 1) in rainy season, and -1.5 (ICMB 92888 × IPC 390) to 1.7 (ICMB 88004 × PRP 6) in summer season (Appendix C.). Based on the mean performances over the environments, it varied from -1.7 (ICMB 92888 × IPC

390) to 1.4 (ICMB 97111 × PRP 1), with 37 hybrids having significant positive *sca* effects and 40 hybrids having significant negative *sca* effects.

Specific combining ability effects for grain yield varied from -1.82 (ICMB 97111 × IPC 843) to 0.93 (ICMB 07777 × IPC 843) in rainy season, and from -1.36 (ICMB 04888 × IPC 616) to 0.88 (ICMB 07555 × IPC 843) in summer season (Appendix D.). Based on the mean performances over the environments it varied from -1.60 (ICMB 04888 × IPC 616) to 0.77 (ICMB 07777 × IPC 843), with 28 hybrids each having significant positive and significant negative *sca* effects.

For days to 50% flowering, *sca* effects ranged from -2.5 (ICMB 97111 × IPC 616) to 3.2 (ICMB 97111 × PRP 3) in rainy season, and from -4.6 (ICMB 88004 × PRP 2) to 3.1 (ICMB 92888 × PRP 2) in summer season. Based on the mean performances over the environments, it varied from -2.5 (ICMB 88004 ×PRP 2) to 3.1 (ICMB 97111 × PRP 3), with 38 hybrids having significant positive *sca* effects and 39 hybrids having significant negative *sca* effects.

The correlation between performance *per se* of hybrids and their *sca* effects was highly significant and moderate positive both for 1000-grain weight ($r=0.48$ in rainy season, $r=0.53$ in summer season and $r=0.45$ over the environments; $p<0.01$), and days to 50% flowering ($r=0.53$ in rainy season, $r=0.41$ in summer season, and $r=0.42$ over the environments; $p<0.01$); while it was much higher for grain yield ($r=0.73$ in rainy season, $r=0.82$ in summer season, and $r=0.74$ over the environments; $p<0.01$). These results provided further support to the conclusions based on combining ability variances that grain yield is largely under non-additive genetic control.

4.1.6 Heterosis

4.1.6.1 Grain iron and zinc densities

There was no significant better-parent (BP) heterosis for Fe density, except for two hybrids, ICMB 02555 × IPC 1354, ICMB 08333 × IPC 1354, showing respectively, 38.7% and 23.2% heterosis but only in the summer season. The mid-parent (MP) heterosis for Fe density ranged from -37.1 % (ICMB 08333 × PRP 9) to 32.5% (ICMB 92111 × IPC 1178) in rainy season, and from -37.5% (ICMB 98222 × PRP 9) to 54.0% (ICMB 02555 × IPC 1354) in summer season (Appendix E.). Based on the mean performance over the environments, it varied from -36.5% (ICMB 98222 × PRP 9) to 23.4% (ICMB 02555 × IPC 1354). Seventeen hybrids had significant positive MP heterosis and 78 hybrids had significant negative MP heterosis in rainy season, while three hybrids had significant positive MP heterosis and 76 hybrids had significant negative MP heterosis in summer season. Based on the mean performances over the environments, three hybrids had significant positive MP heterosis and 59 hybrids had significant negative MP heterosis.

Four hybrids in summer season and two hybrids over the environments showed better-parent heterosis for Zn density. MP heterosis varied from -33.9% (ICMB 04888 × PRP 9) to 19.8% (ICMB 05555 × PRP 8) in rainy season, and from -25.1% (ICMB 08222 × PRP 2) to 25.0% (ICMB 07777 × IPC 390) in summer season. Based on the mean performances over the environments, it varied from -25.2% (ICMB 98222 × PRP 9) to 22.6% (ICMB 93222 × PRP 8). Seven hybrids had significant positive MP heterosis, and 77 hybrids had significant negative MP heterosis in rainy season; while 16 hybrids had significant positive MP heterosis, and 36 hybrids had significant negative MP heterosis in summer season. Based on the mean performances over the environments, six hybrids had significant positive MP heterosis and 39 hybrids had significant negative MP heterosis.

Averaged over two environments, top 5% (10) of the high-Fe hybrids had 60.2-64.5 mg kg^{-1} Fe density; and parental lines of these hybrids had 46.1-77.2 mg kg^{-1} Fe density (Table 4.8.). The perusal of parental combinations of these high-Fe hybrids showed that both parents in 9 hybrids and one parent in one hybrid had highly significant positive *gca* effect, with at least one of the parents having high Fe density (≥ 58.6 mg kg^{-1}). In contrast, all the 5% (10) bottom-Fe hybrids had ≤ 32.8 mg kg^{-1} Fe density. In the parental pair of these hybrids, both parents in 9 hybrids and one of the parents in one hybrid had highly significant negative *gca*, and most of the parents had <45 mg kg^{-1} Fe density. Similarly for Zn density, the top 5% (10) high-Zn hybrids had 46.2-48.2 mg kg^{-1} Zn density and the parental lines of these hybrids had 37.8 - 49.6 mg kg^{-1} Zn density. The perusal of parental combination of these hybrids showed that both the parents of all the ten hybrids had significant positive *gca* effects and either of the parents were with high Zn density (≥40.7 mg kg^{-1}). Conversely, 5% (10) bottom-Zn hybrids had low range of Zn density (25.8-38.1 mg kg^{-1}) and both parents in nine hybrids and one parent in one hybrid had highly significant negative *gca* effect.

There was highly significant and high positive correlation between hybrids performance *per se* and mid-parent value for Fe density (r=0.75 in rainy season, r=0.71 summer season and r=0.79 over the environments; $p<0.01$), and also for Zn density (r=0.77 in rainy season, r=0.70 in summer season and r=0.80 over the environments; p<

0.01) (Fig 4.3.). This provides further support for the conclusion that Fe and Zn densities were largely under additive genetic control. Similar results in pearl millet have been reported in earlier studies (Velu *et al*., 2011b and Govindaraj *et al*., 2013). While the predominance of additive gene action would make recurrent selection for intra-population improvement and open–pollinated variety (OPV) development highly effective, the development of hybrids with high Fe and Zn densities would require that the same genes for these traits are incorporated into both parental lines of the hybrids.

About 30% of the hybrids, however, had significant mid-parent heterosis for Fe density and 23% hybrids had mid-parent heterosis for Zn density, which is not unexpected as significant, albeit low, variability among the hybrids attributable to σ^2_{SCA} had been observed for both the micronutrients. Most of these mid-parent heterosis values were in the negative direction, indicating the involvement of genes other than those with additive gene action where alleles determining lower Fe and Zn densities are partially dominant. It is also likely that effects of genes acting additively for Fe and Zn densities are influenced by genetic backgrounds, the more so in the negative direction, mimicking low levels of partial dominance. *Iniadi* germplasm so far has been found to be the best source of high Fe and Zn densities in pearl millet (Velu *et al*., 2011b., Rai *et al*. 2012 and Govindaraj *et al*., 2013). Thus, taking into consideration the additive gene action, if the same source is used to introgress the genes responsible for Fe and Zn densities in both parental lines, it is likely to reduce the genetic diversity between B-lines (and consequently A-lines) and R-lines for other traits, which would potentially lead to reduction in heterosis for grain yield and other traits of agronomic and economic importance, which are predominantly under non-additive genetic effects. Genomic selection approach for selective introgression of genes for Fe and Zn densities in parental lines without disrupting the diversity between them for grain yield other agronomic traits can play a major role in breeding high-yielding hybrids with high levels of Fe and Zn densities.

4.1.6.2 Agronomic traits

For 1000-grain weight, amongst 196 hybrids, significant BP heterosis was observed in 140 hybrids in rainy season, 42 hybrids in summer season and 111 hybrids based on the mean of both seasons (Appendix F.). Heterosis over BP varied from 0.1% (ICMB 07777 × PRP 3) to 67.1% (ICMB 07777 × PRP 8) in rainy season, from 0.2% (ICMB 07777 × PRP 6) to 29.2% (ICMB 04888 × IPC 1354) in summer season, and from 0.2% (ICMB 92888 × PRP 1) to 47% (ICMB 07777 × PRP 8) over the environments; with an average value of 25.2% in rainy season, 8.4% in summer season and 15% over the environments. Similarly, significant MP heterosis was observed in 184 hybrids in rainy season, 148 hybrids in summer season, and 180 hybrids based on the mean of both seasons. MP heterosis varied from 0.1% (ICMB 92888 × IPC 843) to 82.8% (ICMB 07777 × PRP 8) in rainy season, from 0.2% (ICMB 02555 × PRP 4) to 48.8% (ICMB 04888 × IPC 1354) in summer season, and from 1.5% (ICMB 02555 × PRP 3) to 59.5% (ICMB 04888 × PRP 8) over the environments; with an average value of 33.3% in rainy season, 14.0% in summer season and 22.9% over the environments.

For grain yield, amongst 196 hybrids, significant BP heterosis was observed in 185 hybrids in rainy season, 109 hybrids in summer season, and 178 hybrids based on the mean of both the seasons (Appendix F.). Heterosis over BP ranged from 2.5% (ICMB 92888 × IPC 390) to 298.5% (ICMB 08333 × IPC 1178) in rainy season, from 0.3% (ICMB 97111 × PRP 8) to 133.9% (ICMB 92888 × IPC 1354) in summer season and from 2.3% (ICMB 02555 × PRP 3) to 141.9% (ICMB 04888 × IPC 1178) over the environments; with an average of 90.4% in rainy season, 30.1% in summer season, and 54.3% over the environments. Similarly, significant MP heterosis was observed in 195 hybrids in rainy season, 167 hybrids in summer season, and 195 hybrids based on the mean of both seasons. Heterosis over MP ranged from 11.6% (ICMB 97111 × IPC 843) to 321.1% (ICMB 08333 × IPC 1178) in rainy season, from 0.3% (ICMB 08333 × PRP 4) to 160.4% (ICMB 92888 × IPC 1354) in summer season, and from 15.6% (ICMB 97111 × IPC 843) to 160.0% (ICMB 04888 × PRP 9) over the environments; with an average of 122.2% in rainy season, 42.6% in summer season and 71.9% over the environments.

For days to 50% flowering, none of the hybrids showed significant BP-heterosis in individual environments as well as over the environments. Out of 196 hybrids, significant MP heterosis was observed in 186 hybrids in rainy season, 175 hybrids in summer season and 186 hybrids over the environments (Appendix E.). MP heterosis for days to 50% flowering varied from -22.1% (ICMB 88004 × PRP 9) to 0.8% (ICMB 08333 × IPC 1178) with an average of -8.2% in rainy season, from -19.4% (ICMB 88004 × PRP 2) to 2.1% (ICMB 07999 × IPC 1178) with an average of -6.6% in summer season, and from -18.6% (ICMB 88004 × PRP 9) to 0.5% (ICMB 98222 × IPC 1178) with an average of -7.3% over the environments.

There was highly significant and moderate to high positive correlation between hybrid performance *per se* and mid-parent value for days to 50% flowering (r=0.45 in rainy season, r=0.77 in summer season and r=0.65 over the environments; p<0.01), and for 1000-grain weight (r=0.52 in rainy season, r=0.59 in summer season, and r=0.61 over the environments; p<0.01); while for grain yield it was low but significant positive in rainy season (r=0.26, p<0.01) and over the environments (r=0.29, p<0.01).

High predictability ratio (≥0.83) and highly significant and high positive correlation between the mid-parental values and hybrid performance (r≥0.61) provided further support to the observation of predominantly additive genetic control for 1000-grain weight and days to 50% flowering (Fig 4.4.). In contrast, relatively lower predictability ratio of 0.52 and significant, though low, correlation between the mid-parental values and hybrid performance (r=0.23, p<0.01) was indicative of predominantly non-additive genetic control for grain yield. The relative importance of additive and non-additive variation for these traits were also reflected in heterosis patterns as no better-parent heterosis was observed and there were highly significant and moderate correlations between hybrids performance *per se* and *sca* effects for days to 50% flowering (r≥0.41); and 56% of the hybrids had significant better-parent heterosis with highly significant but moderate correlation between the hybrid performance *per se* and *sca* for 1000-grain weight (r≥0.45). For grain yield, 91% hybrids showed significant better-parent heterosis, and there was highly significant and high positive correlation between the performance of hybrids *per se* and their *sca* (r=0.74, p<0.01).

4.1.7 Character association

There was highly significant and high positive correlation between Fe and Zn densities in individual environments as well as over the environments both in the parental lines and hybrids, ranging from 0.84 to 0.90 (p<0.01) (Table 4.9.). In parental trial, grain Fe and Zn densities did not show any significant association with 1000-grain weight, grain yield and days to 50% flowering in individual environments as well as over the environments. Thousand grain weight showed significant positive association with grain yield in rainy season (r=0.64, p<0.01), summer season (r=0.47, p<0.05) as well as over the environments (r=0.58, p<0.01), while it had significant negative association with days to 50% flowering in rainy season (r=-0.52, p<0.01), summer season (r=-0.53, p<0.01) and over the environments (r=-0.63, p<0.01). Grain yield showed significant negative association with days to 50% flowering only in summer season (r=-0.37, p<0.05).

In hybrid trial, both iron and zinc densities showed significant, but low negative correlation with grain yield, varying from r=-0.29 to -0.23 ($p<0.01$) in individual and averaged over the environments. Both micronutrients had significant and moderate positive correlation with 1000-grain weight, varying from 0.32 to 0.43 ($P<0.01$) in individual and averaged over the environments. While both micronutrients did not show correlation with days to 50% flowering. Grain yield had significant and very low positive correlation with days to 50% flowering only averaged over the environments ($r=0.14$, $p<0.5$).

Furthermore perusal of 35 high *per se* performing hybrids exceeding the experimental mean both for grain yield (≥4.1t ha^{-1}) and Fe density (≥45 mg kg^{-1}) showed non-significant association between micronutrients (Fe and Zn densities) on one hand and agronomic traits (1000-grain weight, days to 50% flowering and grain yield) on the other (Fig 4.5.). Among these hybrids, significant association was observed only between the Fe density and Zn density ($r=0.72$, $p<0.01$); and between grain yield and days to 50% flowering ($r=0.52$, $p<0.01$). This positive association between grain yield and days to 50% flowering implied that higher yield can be obtained in hybrids of relatively moderate to late maturity, ranging between 43 to 53 d of days to 50% flowering.

Interestingly, highly significant and high positive correlations were observed between the *gca* effect of Fe density and *gca* effect of Zn density in parental lines ($r=0.91$, $p<0.01$), and *sca* effect of Fe and *sca* effect of Zn density in hybrids ($r=0.71$, $p<0.01$) (Table 4.9.). Moderate and highly significant positive correlations were observed between the *gca* effect of 1000-grain weight and Fe density ($r=0.51$, $p<0.01$) and between 1000-grain weight and Zn density ($r=0.54$, $p<0.01$). The *gca* effect of grain yield had significant but moderate negative correlation with Fe density ($r=-0.41$, $p<0.01$), but it was uncorrelated with *gca* effect of Zn density. The *sca* effects of both micronutrients were not correlated with the *sca* effects of either 1000-grain weight or grain yield, but there was highly significant and weak positive correlation between the *sca* effect of 1000-grain weight and grain yield ($r=0.21$, $p<0.01$). Days to 50% flowering *gca* and *sca* effects did not show any significant association with any of the traits.

Highly significant and high positive correlation of *gca* effects of Fe density with the *gca* effects of Zn density, was not unexpected considering that the performance *per se* of the parental lines and their *gca* effects were highly significantly and positively correlated, and there was highly significant and high positive correlation (r=0.88, p<0.01) between the Fe and Zn densities in the parental lines as well as in the hybrids. Similar relationships between these micronutrients have been reported in earlier pearl millet studies (Velu *et al*., 2008a and 2008b., Gupta *et al*., 2009., Rai *et al*., 2012 and Govindaraj *et al*., 2013), and in other cereals, such as sorghum (Ashok Kumar *et al*., 2010 and 2013), maize (Arnold *et al*., 1977 and Oikeh *et al*., 2003 and 2004b), rice (Stangoulis *et al*., 2007 and Anandan *et al*., 2011), wheat (Garvin *et al*., 2006., Peleg *et al*., 2009., Zhang *et al*., 2010 and Velu *et al*., 2011a), and finger millet (Upadhyaya *et al*., 2011). Genomic studies in wheat (Peleg *et al*., 2009 and Singh *et al*., 2010), rice (Stangoulis *et al*., 2007), common bean (Blair *et al*., 2009 and Cichy *et al*., 2009) and pearl millet (Kumar, 2011) have identified common and overlapping Quantitative Trait Loci (QTL) for Fe and Zn densities. Thus, similar patterns for Fe and Zn densities with respect to the nature of genetic variability and heterosis, relationship between the parental lines and their *gca* effects could result from similar physiological processes involved at one or more stages from soil uptake to loading in the grains and tight linkage of some of the genes contributing to the major part of genetic variability for these micronutrients. It would appear that effective simultaneous selection for Fe and Zn densities in pearl millet can be made with respect to all these performance parameters, and application of genomic tools can significantly accelerate this process.

Both Fe and Zn densities were not correlated either with 1000-grain weight or grain yield in the parental lines (Table 4.9.), which indicates that parental lines with high Fe and Zn densities can be developed without compromising on grain size and grain yield. In hybrids, however, Fe and Zn densities had highly significant and moderate positive correlations with 1000-grain weight. While some of the earlier studies in pearl millet (Velu *et al*., 2007, 2008a and 2008b) have reported significant positive association of Fe and Zn densities with 1000-grain weight, other studies have reported no correlations of Fe and Zn densities with 1000-grain weight (Gupta *et al*., 2009 and Rai *et al*., 2012). This indicated that high Fe and Zn densities could be easily combined with large grain size. The Fe and Zn densities had highly significant though weak negative correlations with grain yield. Earlier studies in pearl millet hybrids (Rai *et al*., 2012), wheat (Garvin *et al*., 2006., Morgounov *et al*., 2007., Shi *et al*., 2008 and Zhao *et al*., 2009), sorghum (Reddy *et al*., 2005) and Maize (Banziger and Long, 2000) reported significant negative relationship between micronutrients and yield. In the present study, however, these correlations were weak enough in the magnitude, indicating that if these were the results of adverse genetic associations, high-yielding hybrids with high Fe and Zn densities can be bred by making selection for these traits in larger segregating populations and progenies as compared to those used for breeding for grain yield alone. These weak negative relationships resulting from dilution effects, however, cannot be ruled out and, therefore, this subject merits further investigation.

4.2 ASSESSMENT OF ASSOCIATION OF GRAIN IRON AND ZINC DENSITIES WITH AGRONOMIC TRAITS IN HYBRIDS

Development of pearl millet cultivars with high levels of grain iron (Fe) and zinc (Zn) density can make significant contribution to reducing widespread deficiencies of these micronutrients in populations heavily dependent on staple cereals for their dietary energy and nutritional requirements. It is imperative that breeding of such cultivars must not compromise on grain yield and farmer-preferred traits. With this view, the present investigation was focused to examine the association of grain Fe and Zn densities with grain yield and other agronomic traits (days to 50% flowering, 1000-grain weight, effective number of tillers, plant height and panicle length) in two sets of pearl millet hybrids evaluated in multilocational trials. The experimental material included in this study consisted of two sets of hybrids, hereafter referred to as Set-A and Set-B. Set-A consisted of 32 hybrids and set-B consisted of 28 hybrids.

4.2.1 Analysis of variance and variability among traits

Analysis of variance showed highly significant differences among the hybrids for all traits in individual environments (Table 4.10.) as well as over the environments (Table 4.11.) in both hybrid sets. Also, hybrids (H) × environments (E) interaction effect was significant for all traits across the environments in both the sets, except for 1000-grain weight and panicle length in set-B. The variability due to H × E interaction effect relative to genotype effect due to hybrids was 38% and 35% for iron density and 70% and 68% for zinc density in set-A and set-B, respectively. Similar results of greater G × E interaction for Zn density than Fe density have been reported in maize (Prasanna *et al*., 2011). This may apparently imply greater sensitivity and differential response of hybrids for Zn than Fe density to changes in the soil and climatic conditions. This could also be due to proportionately larger differences among the hybrids for Fe density than for Zn density. For instance, about two-fold differences among the hybrids were observed for Fe density in all the environments in both sets of hybrids, with the widest range of 38-75 mg kg^{-1} (E1) in set-A hybrids and 33-74 mg kg^{-1} (E5) in set-B hybrids (Table 4.12.). In comparison, the differences among the hybrids were much smaller for Zn density in each environment in both sets of hybrids, with widest range of 27-46 mg kg^{-1} (E2) in set-A hybrids and 32-52 mg kg^{-1} (E5) in set-B hybrids (Table 4.12. and Appendices G and I).

The contribution of H x E interaction to variability for grain yield relative to those due to differences among the hybrids was 52% in set-A, and much higher (101%) in set-B. While grain yield differences among the hybrids were two-to-three-fold with the widest range of 1.11-3.82 t ha^{-1} (E2) in set-A, these were less than two-fold with the widest range of 2.35-6.03 t ha^{-1} (E4) in set-B (Table 4.12.). The contribution of H × E interaction to variability relative to those due to differences among hybrids for 1000-grain weight was 32% in set-A and 22% in set-B. The 1000-grain weight differences among the hybrids were generally 1.5 to 1.8-fold in both sets of hybrids, with the widest range of 9-16 g (E2) in set-A and 11-20 g (E1) in set-B. The contribution of H × E interaction to variability relative to those due to differences among the hybrids was lowest (13-15%) for days to 50% flowering. For plant height, these were similar to those observed for Fe density in both sets of hybrids (35%), while these varied from 48% in set-A to 60% in set-B for effective tillers; and from 47% in set-A to 7% in set-B for panicle length. The widest range among the hybrids for days to 50% flowering was 40-58 days (E2) in set-A and 38-48 days (E1) in set-B. For plant height, the widest range was 160-252 cm (E2) in set-A and 182-251 cm (E4) in set-B, while for panicle length, the widest range was 15-24 cm (E2) in set-A and 16-29 cm (E1) in set-B (Table 4.12. and Appendices G, H, I and J).

4.2.2 Association of grain iron and zinc densities with agronomic traits

Based on mean performance across the environments, there was highly significant and high positive association between Fe and Zn density in both sets of hybrids (r=0.60 in set-A and 0.62 in set-B; p<0.01), and this trend was consistent across the environments, with the correlation coefficient varying from 0.49 (E3) to 0.63 (E2) in set-A, and from 0.52 (E1) to 0.65 (E5) in set-B (Table 4.13.). Similar relationships between these micronutrients have been reported in earlier studies on pearl millet (Velu *et al*., 2007, 2008a and 2008b., Gupta *et al*., 2009., Rai *et al*., 2012, 2013 and 2014 and Govindaraj *et al*., 2013), and in other cereals, such as sorghum (Ashok Kumar *et al*., 2010 and 2013), maize (Oikeh *et al*., 2003 and 2004b), rice (Stangoulis *et al*., 2007 and Anandan *et al*., 2011), wheat (Garvin *et al*., 2006., Peleg *et al*., 2009., Zhang *et al*., 2010 and Velu *et al*., 2011a), and finger millet (Upadhyaya *et al*., 2011). These positive associations between Fe and Zn densities may likely result from common and overlapping Quantitative Trait Loci (QTL) as reported in wheat (Peleg *et al*., 2009 and Singh *et al*., 2010), rice (Stangoulis *et al*., 2007), common bean (Cichy *et al*., 2009 and

Blair *et al*., 2009) and pearl millet (Kumar, 2011) implying that simultaneous selection for both micronutrients is likely to be highly effective.

Based on the mean performance over the environments, Fe density had highly significant and moderate negative correlation with grain yield in both sets of hybrids (r=-0.50 in set-A; P<0.01and r=-0.43 in set-B; P<0.05). However, it varied from -0.47 (E1) to -0.24 (E3) across the environments in set-A, and from -0.50 (E1) to -0.08 (E5) in set-B, and was not always significant (Table 4.13.). The correlation between Zn density and grain yield was also negative, except in one environment (E3) in set-A, but was smaller in magnitude compared to the association between Fe density and grain yield, and it was non-significant in all the cases. Such patterns of relationships of Fe and Zn densities with grain yield are not unexpected considering the high positive correlation between Fe and Zn densities and larger G × E interaction effect relative to genotypic effect for Zn density than for Fe density. Earlier studies in pearl millet (Rai *et al*., 2012), wheat (Garvin *et al*., 2006., Morgounov *et al*. 2007., Shi *et al*. 2008 and Zhao *et al*. 2009), sorghum (Reddy *et al*., 2005) and Maize (Banziger and Long, 2000) also reported significant negative relationship between these micronutrients and grain yield.

Almost all the ICRISAT-bred breeding lines and hybrids parents having high Fe and Zn densities are largely or entirely based on *iniadi* germplasm in their parentage (Velu *et al.*, 2007 and 2008b and Rai *et al*., 2012). Further, it has been found that both these micronutrients are predominantly under additive genetic control with no better-parent heterosis (Velu *et al*., 2011b and Govindaraj *et al*., 2013). This would imply that hybrids with high Fe and Zn densities would have both parents high in these micronutrients and such parents are likely to have largely *iniadi* germplasm in their parentage. Therefore, though high in Fe and Zn densities, there is likely to be reduction in genetic diversity between parents for traits and physiological functions related to heterosis for grain yield, which is predominantly under non-additive genetic control (Khairwal *et al*., 1999). Conversely, hybrids with average and low Fe and Zn densities would have less of the *iniadi* germplasm in the parentage of parental lines and hence probability of greater diversity and consequently greater heterosis for traits related to high grain yield. This would call for application of genomic tools for selective introgression of only those genes and genomic regions from *iniadi* germplasm into the parental lines which are associated with high Fe and Zn densities to ensure that diversity for traits related to heterosis for grain yield is not reduced. Such an approach would enhance the probability of combining high grain yield with high Fe and Zn densities in hybrids.

Iron density and 1000-grain weight did not show any significant association and this relationship was consistent across the environments in both set-A and set-B. Likewise, Zn density showed significant association with 1000-grain weight only in E3 ($r=0.35$, $p<0.01$) in set-A, while in set-B it ranged between 0.36 (E5) to 0.44 (E1) and was significant in E1 ($r=0.44$, $p<0.05$), E4 ($r=0.38$, $p<0.05$) and across the environments ($r=0.42$, $p<0.05$). Similar results have been reported in earlier pearl millet studies (Gupta *et al*., 2009 and Rai *et al*., 2012). There was no association between grain yield and 1000-grain weight in both the sets. This non-significant or significant positive association of 1000-grain weight with both micronutrients implies that higher grain Fe and Zn densities are not necessarily related to small grain size, and in general, hybrids with higher micronutrient (Fe and Zn) densities also had greater grain weight. Thus, the enhancement of micronutrients would not affect 1000-grain weight of the genotypes. This relationship could be more advantageous for selecting simultaneously or independently for the combination of bold grain and high micronutrient traits during genetic improvement program.

Iron density showed negative association with days to 50% flowering. Averaged over the environments, it was significant only in set-A ($r=-0.45$, $p<0.01$). Across the environments, it was significant in E1 ($r=-0.49$, $p<0.01$) and E2 ($r=-0.46$, $p<0.01$) in set-A and in E1 ($r=-0.57$, $p<0.01$) in set-B. The association of Zn density with days to 50% flowering ranged from -0.37 (E4) to 0.32 (E3) in both the sets and was significant and negative only in E4 ($r=-0.37$, $p<0.05$) in set-B. Earlier studies also reported significant negative association between Fe density and days to 50% flowering in pearl millet (Velu *et al.*, 2008a and Rai *et al*., 2012), while Reddy *et al*., (2010) found that both the micronutrients had significant positive association with days to 50% flowering in sorghum, and most studies did not show significant association between micronutrients and days to 50% flowering in pearl millet (Velu *et al*., 2007 and 2008b., Gupta *et al*., 2009 and Rai *et al*., 2012), sorghum (Reddy *et al*., 2005 and Ashok kumar *et al*., 2010) and wheat (Morgounov *et al*., 2007).

Both Fe and Zn densities showed lower negative correlation with plant height. Fe density had significant negative association only in set-A ($r=-0.37$, $p<0.05$, in E2) and for Zn density correlation, varying from -0.23 (E2) to 0.46 (E3), while it was significant and positive only in E3 ($r=0.46$, $p<0.01$). Similarly, based on mean performance over the environments, Fe density had significant negative association with panicle length in set-B ($r=-0.48$, $p<0.01$), while, it was significant and negative in E2 ($r=-0.51$, $p<0.01$) in set-A, and in E1 ($r=-0.61$, $p<0.01$) in set-B. The correlation coefficient between Zn density and panicle length ranged from -0.37 (E1) to 0.13 (E3) and it was significant and negative only in E1 ($r=-0.37$, $p<0.05$) of set-B.

It suggests that association between micronutrients and plant height varied in both positive and negative directions with lower magnitude. Thus, selection for high Fe and Zn densities in required plant height is possible. Earlier studies reported significant positive association between Fe density and plant height in sorghum (Reddy *et al*., 2010) and wheat (Hussain *et al.*, 2012); and between Zn density and plant height in sorghum (Reddy *et al*., 2005 and Reddy *et al*., 2010) and wheat (Zhao *et al*., 2009). Some earlier reports also indicated that both micronutrients had significant negative association with plant height in wheat (Margounov *et al*., 2007) and did not show any association with plant height in sorghum (Ashok kumar *et al*., 2010). While effective number of tillers did not show any significant relationship with Fe and Zn densities in both the sets, except in environment E2, where it had significantly positive, but low, association with both micronutrient densities ($r=0.39$ with Fe, $r=0.35$ with Zn; $p<0.05$). Thus, selection of micronutrient-dense hybrids can be effective with varying tillering characteristics.

Based on the mean performance over the environments, grain yield had significant positive association with days to 50% flowering ($r=0.73$ in set-A, $r=0.63$ in set-B; $p<0.01$), with plant height ($r=0.72$ in set-A, $r=0.55$ in set-B; $p<0.01$) and with panicle length ($r=0.46$ in set-A, $r=0.59$ in set-B, $p<0.01$). This trend was largely consistent in individual environments also. For days to 50% flowering it was significant and positive in all the environments in set-A, and only in E4 ($r=0.70$, $p<0.01$) in set-B; for plant height, it was significant and positive in all the environments in both the sets except for E5 in set-B; and for panicle length, it was significant in E1 and E2 environments in set-A and E1 and E4 environments in set-B. Similarly, over the environments, days to 50% flowering had significant positive association with plant height ($r=0.81$ in set-A, $r=0.59$ in set-B, $p<0.01$) and panicle length ($r=0.42$, $p<0.05$ in set-A; $r=0.62$, $p<0.01$ in set-B); and this trend was also consistent in all the individual environments in both the sets, varying from 0.45 (E5) to 0.83 (E2) with plant height and from 0.38 (E2) to 0.69 (E1 in set-B) with panicle length. Averaged over the environments, there was highly significant and positive correlation between plant height and panicle length in set-A (r=0.61) varying from 0.43 (E1) to 0.56 (E2 and E3).

4.2.3 Principal component analysis (PCA)

Based on mean performance over the environments, principal component analysis showed (Fig 4.6. and 4.7.) that the first two principal components (PCs) accounting for 62.6% of the total variability in set-A with PC1 (45.0%) and PC2 (17.6%); and 61.3% of the total variability in set-B with PC1 (40.5%) and PC2 (20.8%). Furthermore, both PCA graphs (Fig 4.6. and 4.7.) demonstrated consistency in grouping of the traits. The Fe and Zn densities and 1000-grain weight formed one group (G1), while grain yield, panicle length, plant height and days to 50% flowering formed another group (G2) in both the sets, and these traits within each group had significant positive association among themselves. The effective tiller number was either not associated with both the groups in set-A or had significant negative association with G2 traits in set-B. Both Fe and Zn densities had either significant positive or non-significant association with 1000-grain weight. Grain yield and other agronomic traits (*viz*., plant height, panicle length and days to 50% flowering) showed low to moderate negative association with both the micronutrients.

From this study it could be suggested that, hybrids with high Fe and Zn densities can be developed without compromising on grain weight, while selecting for high Fe and Zn densities with high grain yield, large number of parental combinations or large segregating population has to be screened than that for yield alone. However, results of this study do not provide any clear cut indications if days to 50% flowering, panicle length and plant height, owing to their positive relationships with grain yield, may have any bearing on the negative correlation observed between grain yield on one hand, and Fe and Zn densities on the other. These issues of Fe and Zn associations with grain yield and other traits merit further investigations, and must be resolved through selection experiments in segregating populations, with the application of genomic tools providing further insights.

4.3 STUDY OF TESTER EFFECT ON COMBINING ABILITY OF INBRED LINES

Performance of inbred lines *per se* does not always provide an entirely adequate measure of their values in hybrid combinations. Development of simple and cost-effective methods to assess the combining ability of new lines has been a major problem in the development of new hybrids (Matzinger, 1953). One way to study the combining ability of a set of lines is to cross them in all possible combinations or with another set of inbred lines. Number of hybrids to be produced and evaluated, following this method, becomes increasingly expensive as the number of lines involved increases. Davis (1927) suggested the use of topcrosses to assess the combining ability of the lines by crossing them with open-pollinated varieties. Testers may affect topcross performance of lines, and hence they differ in their discriminating ability for selecting general combiners. Therefore, there is a need to understand tester influence on general combining ability. This study was carried to determine the relative efficiency of two open-pollinated varieties (Raj 171 and ICMR 312) used as testers in determining general combining ability of two sets of inbred lines (14 B-lines and 14 R-lines) for Fe and Zn densities, grain yield, 1000-grain weight and days to 50% flowering.

4.3.1 Analysis of variance

4.3.1.1 Inbred parents

There were highly significant differences among B-lines (Table 4.14.) and R-lines (Table 4.15.) in individual environments as well as over the environments for all five traits. B-line × environment (B × E) interactions were also significant except for grain yield. The contribution of B × E interactions to the variability relative to those due to genotypic differences among B-lines were 15% for Fe, 32% for Zn, 35% for 1000-grain weight and 3% for days to 50% flowering. R-line × environment (R × E) interactions were significant only for Zn density and 1000-grain weight, and the contribution of these interactions to the variability relative to those due to genotypic differences among R-lines were very low for these traits (8% for Zn density and 5% for 1000-grain weight).

4.3.1.2 Topcross hybrids

There were highly significant differences among B-line × Raj 171 topcrosses (TC1) for all the traits, except for grain yield in individual environments as well as over the environments (Table 4.14.). The TC1 × E interactions were significant only for Zn density and days to 50% flowering, and the contribution of these interactions to the variability relative to those due to differences among the genotypes (TC1 topcrosses) were 33% and 20%, respectively. There were significant differences among B-line × ICMR 312 topcrosses (TC2) for Fe density, 1000-grain weight and days to 50% flowering in individual environments as well as over the environments, while for Zn density these were significant in both seasons and for grain yield only in 2013 summer season. The TC2 × E interactions were significant for Zn density, 1000-grain weight and days to 50% flowering, and the contribution of these interactions to the variability relative to those due to differences among the genotypes (TC2 topcrosses) were 63%, 19% and 23%, respectively.

Highly significant differences were also observed among R-line × Raj 171 (TC3) and R-line × ICMR 312 topcrosses (TC4) for all the traits in individual environments and over the environments, except for grain yield over the environments (Table 4.15.). The TC3 × E and TC4 × E interactions were significant only for grain yield and days to 50% flowering, and the contribution of these interactions to the variability relative to those due to differences among the genotypes (TC3 and TC4 topcrosses) were 46% and 62% for grain yield and 24% and 12% for days to 50% flowering, respectively.

Topcrosses with both the testers considered together showed significant differences for all the traits among B-lines topcrosses (TB) in individual environments and over the environments (Table 4.16.). B-line topcrosses × environment (TB × E) interactions were significant for all the traits, and the contribution of these interactions to the variability relative to those due to genotypic differences among B-line topcrosses (TB) were low for Fe (19%), 1000-grain weight (11%) and days to 50% flowering (21%), and higher for Zn density (43%) and grain yield (58%). Further partitioning of TB × E interactions showed that B-line × environment (BL × E) interactions were significant for 1000-grain weight, grain yield and days to 50% flowering; and the contribution of these interactions relative to those due to B-line effects, respectively, were 16% for 1000-grain weight, 62% for grain yield, and 18% for days to 50% flowering.

For topcrosses of both the testers considered together, significant variability was observed among R-line topcrosses (TR) for all the traits in individual environments as well as over the environments (Table 4.17.). The R-line topcrosses × environment (TR

× E) interactions were significant for grain yield and days to 50% flowering, and contribution of these interactions to the variability relative to those due to genotypic differences among R-line topcrosses (TR) were 55% and 17%, respectively. Further partitioning of TR × E interactions showed that R-lines × environment (RL × E) interactions were significant for 1000-grain weight, grain yield and days to 50% flowering, and contribution of these interactions to the variability relative to those due R-line effects were 10%, 59% and 14%, respectively.

Pooled over the environments, BL × T interactions were significant for all traits among B-line topcrosses (TB), except for Zn density (Table 4.16.). These significant BL × T interaction effects suggest that testers differed in their ranking of inbred lines based on the performance of their topcrosses. However, the contribution of these interactions to the variability relative to those due to differences among the topcrosses averaged over both testers (i.e. BL effects) were 21% for Fe density, 27% for Zn density, 46% for 1000-grain weight, 9% for days to 50% flowering and 81% for grain yield among TB topcrosses. Similarly, averaged over the environments RL × T interactions were significant for all the traits among R-line topcrosses (TR) (Table 4.17.). The contribution of these interactions to the variability relative to those due to differences among the topcrosses averaged over both testers (i.e. RL effects) were 10-13% for Fe and Zn densities, 1000-grain weight and days to 50% flowering and 21% for grain yield among TR topcrosses. This suggests that contribution of BL × T and RL × T interactions to the variability was very low for Fe and Zn densities, 1000-grain weight and days to 50% flowering, implying high consistency of ranking of topcross hybrids with these two testers. For grain yield, these interactions were higher in both TB and TR topcrosses, suggesting inconsistent ranking of inbred lines for their topcross performances with these two testers. A similar trend was observed in individual environments. The BL × T × E interaction was significant only for Zn density and the contribution of this interaction to the variability relative to that due to BL × T interaction was 85%. The RL × T × E interaction was significant only for Fe density and contribution of this interaction relative to that due to RL × T interaction was 55%.

4.3.2 Variability among parental lines and their topcrosses

4.3.2.1 Inbred parental performance *per se*

Based on the mean performances over the environments, Fe density varied from 36.9 (ICMB 07999) to 81.3 mg kg^{-1} (ICMB 93222) in B-lines, and from 37.2 (IPC 1354) to 89.0 mg kg^{-1} (PRP 2) in R-lines; while Zn density varied from 36.9 (ICMB

07777) to 60.2 mg kg^{-1} (ICMB 05555) in B-lines and from 37.6 (IPC 1354) to 70.6 mg kg^{-1} (IPC 616) in R-lines (Table 4.18.). Similarly, grain yield varied from 1.3 (ICMB 92888) to 3.7 t ha^{-1} (ICMB 97111) in B-lines, and from 1.4 (IPC 1354) to 3.1 t ha^{-1} (PRP 4) in R-lines. Thousand grain weight varied from 8.8 (ICMB 92111) to 12.8 g (ICMB 92888) in B-lines, and from 6.4 (PRP 9) to 11.9 g (PRP 4) in R-lines; while days to 50% flowering ranged from 47 (ICMB 88004) to 59 d (ICMB 92111) in B-lines, and from 52 (PRP 3) to 63 d (IPC 1178) in R-lines.

4.3.2.2 Topcrosses performance

Based on the mean performances over the environments, Fe density ranged from 37.5 (ICMB 92888 × Raj 171) to 58.9 mg kg^{-1} (ICMB 93222 × Raj 171) with an average of 46.4 mg kg^{-1} in B-line × Raj 171 topcrosses (TC1); and from 42.2 (ICMB 92111 × ICMR 312) to 61.9 mg kg^{-1} (ICMB 08222 × ICMR 312) with an average of 50.9 mg kg^{-1} in B-line × ICMR 312 topcrosses (TC2) (Table 4.19.). The Zn density ranged from 40.4 (ICMB 92888 × Raj 171) to 55.5 mg kg^{-1} (ICMB 93222 × Raj 171) with an average of 46.8 mg kg^{-1} in TC1 topcrosses, and from 41.8 (ICMB 97111 × ICMR 312) to 54.2 mg kg^{-1} (ICMB 08222 × ICMR 312) with an average of 48.7 mg kg^{-1} in TC2 topcrosses. Likewise, Fe density ranged from 35.7 (PRP 9 × Raj 171) to 57.5 mg kg^{-1} (PRP2 × Raj 171) with an average of 45.4 mg kg^{-1} in R-lines × Raj 171 topcrosses (TC3), and from 39.3 (PRP 9 × ICMR 312) to 64.9 mg kg^{-1} (PRP 4 × ICMR 312) with an average of 51.1 mg kg^{-1} in R-lines × ICMR 312 topcross hybrids (TC4). Zn density varied from 38.4 (IPC 390 × Raj 171) to 55.3 mg kg^{-1} (PRP 2 × Raj 171) with an average of 47.3 mg kg^{-1} in TC3 topcrosses, and from 38.3 (PRP 9 × ICMR 312) to 58.4 mg kg^{-1} (PRP 4 × ICMR 312) with an average of 50.2 mg kg^{-1} in TC4 topcrosses.

In topcrosses of B-lines, 1000-grain weight ranged from 10.4 (ICMB 92111 × Raj 171) to 12.8 g (ICMB 07555 × Raj 171) with an average of 11.8 g in TC1 topcrosses, and from 11.8 (ICMB 02555 × ICMR 312) to 14.8 g (ICMB 92888 × ICMR 312) with an average of 13.3 g in TC2 topcrosses (Table 4.19.). Grain yield ranged from 3.0 (ICMB 07777 × Raj 171) to 4.2 t ha^{-1} (ICMB 97111 × Raj 171) with an average of 3.9 t ha^{-1} in TC1 topcrosses, and from 3.7 (ICMB 05555 × ICMR 312) to 4.9 t ha^{-1} (ICMB 07999 × ICMR 312) with an average of 4.3 t ha^{-1} in TC2 topcrosses. Days to 50% flowering varied from 41 (ICMB 88004 × Raj 171) to 51 d (ICMB 93222 × Raj 171) with an average of 47 d in TC1 topcrosses, and from 45 (ICMB 88004 × ICMR 312) to 52 d (ICMB 93222 × ICMR 312) with an average of 49 d in TC2 topcrosses.

In topcrosses of R-lines, 1000-grain weight ranged from 8.7 (IPC 616 × Raj 171) to 11.6 g (PRP 4 × Raj 171) with an average of 10.2 g in TC3 topcrosses, and from 10.6 (IPC 390 × ICMR 312) to 13.5 g (PRP 4 × ICMR 312) with an average of 11.9 g in TC4 topcrosses. Grain yield varied from 3.5 (IPC 1354 × Raj 171) to 4.8 t ha^{-1} (PRP 6 × Raj 171) with an average of 4.1 t ha^{-1} in TC3 topcrosses, and from 3.3 (PRP 8 × ICMR 312) to 4.8 t ha^{-1} (IPC 1178 × ICMR 312) with an average of 4.2 t ha^{-1} in TC4 topcrosses. Days to 50% flowering varied from 47 (PRP 9 × Raj 171) to 54 d (IPC 1178 × Raj 171) with an average of 50 d in TC3 topcrosses, and from 45 (PRP 9 × ICMR 312) to 55 d (IPC 1178 × ICMR 312) with an average of 50 d in TC4 topcrosses.

4.3.3 Relationships between performance *per se* of lines and topcross hybrids

4.3.3.1 Grain iron density

Based on the mean performances over the environments, there was highly significant and high positive correlation between performance *per se* of B-lines and their topcross performance (a measure of general combining ability) for Fe density in both sets of topcrosses, with r=0.78 in TC1 and r=0.84 in TC2 (Table 4.20.). This trend was generally consistent across the environments with r=0.63 and 0.79 for TC1 and r=0.78 and 0.79 for TC2. Averaged over both environments and both testers, the correlation between performance *per se* of B-lines and their topcross became further stronger with r=0.89. Averaged over the environments, the top-ranking six B-lines were 1, 4, 6, 7, 9 and 13 with ≥59 mg kg^{-1} Fe density, and all these lines ranked in the top-ranking six topcrosses of both testers combined together. Except for line 7, the remaining five lines ranked among top-ranking six topcrosses whether with tester Raj 171 or tester ICMR 312. These results showed that selection based on performance *per se* is likely to be highly effective in selecting for high *gca* for Fe density.

There was highly significant and high positive correlation between performance *per se* of R-lines and their topcross in TC3 (r=0.83) and moderate positive correlation in TC4 (r=0.58); and this trend was quite consistent across the environments with r=0.74 and 0.84 in TC3, and r=0.53 and 0.58 in TC4. Averaged over the environments and both testers, the correlation between performance *per se* of R-lines and their topcross performance was 0.75. Averaged over the environments, the top-ranking six R-lines were 16, 17, 18, 19, 24 and 25 with ≥61 mg kg^{-1} Fe density, of which all except one line were also among the six top-ranking topcrosses in each set, and when the mean of both sets of topcrosses were considered together.

Based on the mean performances over the environments, topcrosses performance of B-lines with tester-1 (Raj 171) were highly significantly and positively correlated (r=0.64) with topcross performance with tester-2 (ICMR 312), although the correlation was much higher (r=0.75) in 2012 summer season than in 2013 summer season (r=0.42). Averaged over the environments, from among the B-lines included in six top-ranking topcrosses with tester-1 (TC1), five were included in the six top-ranking topcrosses with tester-2 (TC2). Similarly, topcrosses performance of R-lines with tester-1 (TC3) were also highly significantly and highly positively correlated (r=0.75) with their topcrosses performance with tester-2 (TC4), but this relationship was somewhat inconsistent across the environments (r=0.61 in 2012 summer season and 0.74 in 2013 summer season). Averaged over the environments, from among the R-lines included in six top-ranking topcrosses in TC3, five were included in the six top-ranking topcrosses in TC4. These results showed that top-ranking high general combiners (both B-lines and R-lines) can be selected equally effectively by using any of the two testers.

4.3.3.2 Grain zinc density

Based on the mean performances over the environments, there was highly significant and high positive correlation between performance *per se* of B-lines and their topcross performance for Zn density in both set of topcrosses, with r=0.77 in TC1 and r=0.83 in TC2 (Table 4.21.). This relationship was somewhat inconsistent across the environments, the correlation was higher in 2012 summer season (r=0.70) than in 2013 summer season (r=0.53) in TC1, and it was higher in 2013 summer (r=0.83) than in 2012 summer (r=0.51) in TC2. Averaged over both the environments and both testers, the correlation between performance *per se* of B-lines and their topcrosses became further stronger with r=0.88. Averaged over the environments, the top-ranking six B-lines were 1,4, 6, 7, 9 and 13 with ≥50 mg kg^{-1} Zn density. Except line 6, the remaining five lines ranked in the top-ranking six topcrosses of both the testers combined together as well as with Raj 171 tester (TC1); and except line 7, remaining five lines ranked in the top-ranking six topcrosses with ICMR 312 tester (TC2).

There was highly significant and high positive correlation between performance *per se* of R-lines and their topcross in TC3 (r=0.87) and TC4 (r=0.72). This trend was generally consistent across the environments with r=0.79 and 0.85 in TC3, and r=0.69

and 0.73 in TC4. Averaged over the environments, the top-ranking six R-lines were 16, 17, 19, 24, 25 and 26 with ≥57 mg kg^{-1} Zn density. Except line 17, the remaining five lines ranked in the top-ranking six topcrosses of both testers combined together; while except line 19 in TC3 and lines 17 and 24 in TC4, remaining lines ranked among top-ranking six topcrosses. These results showed that selection based on performance *per se* is likely to be highly effective in selecting for high *gca* for Zn density.

Based on the mean performances over the environments, topcross performance of B-lines with tester-1 (Raj 171) was highly significantly and positively correlated (r=0.62) with topcross performance with tester-2 (ICMR 312), as it was in 2012 summer season (r=0.53). Averaged over the environments, from among the B-lines of six top-ranking topcrosses with tester-1 (TC1), four were included in the top-ranking six topcrosses with tester-2 (TC2). Similarly, the correlation between topcross performance of R-lines with tester-1 (TC3) and tester-2 (TC4) was highly significant and highly positive (r=0.78), and this relationship was highly consistent across the environments with r=0.75 in both seasons. Averaged over the environments, from among the R-lines included in the six top-ranking topcrosses in TC3, four were included in the six top-ranking topcrosses in TC4. These results showed that the top-ranking high general combiners (both B and R lines) can be selected equally effectively by using any of the two testers.

4.3.3.3 1000-grain weight

Based on the mean performances over the environments, there was highly significant and high positive correlation between performance *per se* of B-lines and their topcross performance for 1000-grain weight in both sets of topcrosses, with r=0.74 in TC1 and r=0.71 in TC2 (Table 4.22.). This trend was generally consistent across the environments in TC2 (r=0.67 in both seasons), while it was significant (r=0.73) only in 2013 summer season in TC1. Averaged over both environments and both testers, the correlation between performance *per se* of B-lines and their topcross became further higher with r=0.87. Averaged over the environments, the top-ranking six B-lines were 3, 4, 5, 9,11 and 13 with ≥11.9 g 1000-grain weight. Except lines 11 and 13, the remaining four lines ranked in the top-ranking six topcrosses of both testers combined together as well as in TC2; and except lines 3, 4, and 5, remaining three lines ranked among top-ranking six topcrosses in TC1.

There was highly significant and high positive correlation between performance *per se* of R-lines and their topcrosses in TC3 (r=0.89) and TC4 (r=0.74), and this trend was highly consistent across the environments with r=0.83 and 0.89 in TC3, and r=0.68 and 0.73 in TC4. Averaged over the environments, the top ranking six R-lines were 15, 16, 17, 18, 20 and 21 with ≥8.8 g 1000-grain weight; of which except one line, the remaining five lines were among top-ranking six topcrosses in both the testers combined together as well as in TC4, and all the lines in TC3 were among the six top-ranking topcrosses. These results showed that selection based on performance *per se* is likely to be effective in selecting lines for high *gca* for 1000-grain weight.

Based on the mean performances over the environments, there was no correlation between topcross performance of B-lines with tester-1 (Raj 171) and tester-2 (ICMR 312), and from among the B-lines included in six top-ranking topcrosses with tester-1 (TC1), only three were included in the six top-ranking topcrosses with tester-2 (TC2). The topcross performance of R-lines with tester-1 (TC3) was highly significantly and highly positively correlated (r=0.75) with topcross performance with tester-2 (TC4), and this relationship was consistent across the environments (r=0.72 in 2012 summer season and r=0.74 in 2013 summer season). Averaged over the environments, from among R-lines included in six top-ranking topcrosses in TC3, five were included in the six top-ranking topcrosses in TC4. These results showed that selection of top-ranking high general combiners may be influenced by testers.

4.3.3.4 Grain yield

Grain yield did not show any significant association between performance *per se* of B-lines and R-lines with their topcrosses (Table 4.23.); hence selection of lines based on performance *per se* is as likely to be as effective in selecting for high *gca* as it is not. There was no correlation between topcross performances of B-lines with tester-1 (Raj 171) and tester-2 (ICMR 312); although, from among B-lines involved in six top-ranking topcrosses in TC1, four were included in the six top-ranking topcrosses in TC2. The topcross performance of R-lines with tester-1 (TC3) was highly significantly and positively correlated (r=0.65) with topcross performance with tester-2 (TC4), and this relationship was consistent across the environments (r=0.66 in 2012 summer season and r=0.73 in 2013 summer season). Based on the mean performance over the environments, from among the R-lines involved in six top-ranking topcrosses in TC3, all were included in the six top-ranking topcrosses in TC4. These results showed that selection of top-ranking high general combiners may be ineffective by testers.

4.3.3.5 Days to 50% flowering

Based on the mean performance over the environments, there was highly significant and high positive correlation between performance *per se* of B-lines and their topcross performance for days to 50% flowering in both sets of topcrosses, with r=0.71 in TC1 and r=0.79 in TC2 (Table 4.24.). While this trend was not consistent across the environments with r=0.60 and 0.79 for TC1, it was highly consistent with r=0.72 and 0.73 for TC2. Averaged over both environments and both testers, the correlation between performance *per se* of B-lines and their topcross highly significant and positive with r=0.78. The top-ranking six B-lines were 2, 4, 7, 8, 9 and 13 with ≥52 d days to 50% flowering. Of these, except line 13, the remaining five lines ranked among top-ranking six topcrosses in TC1 as well as in topcrosses of both the testers combined together; while in TC2, except lines 8 and 9, remaining four lines ranked among top-ranking six topcrosses.

There was highly significant and high positive correlation between performance *per se* of R-lines and their topcrosses in TC3 (r=0.71) and TC4 (r=0.69); and this trend was generally inconsistent across the environments with r=0.59 and 0.78 for TC3, and r=0.64 and 0.76 for TC4. Averaged over the environments, the top-ranking six R-lines were 18, 19, 20, 24, 26 and 27 with ≥ 56 d days to 50% flowering. Of these, except lines 19 and 27, the remaining four lines ranked among top-ranking six topcrosses in TC3 as well as in topcrosses of both topcrosses combined together; and except 19, 24 and 27, the remaining lines were ranked among top-ranking six topcrosses in TC4. These results showed that based on performance *per se*, lines can be effectively selected for high *gca* for days to 50% flowering.

The topcrosses performance of B-lines with tester-1 (Raj 171) was highly significantly and positively correlated (r=0.82) with topcross performance with tester-2 (ICMR 312), and this relationship was highly consistent across the environments (r=0.86 in 2012 summer season and r=0.82 in 2013 summer season). Based on the mean performances over the environments, from among the B-lines included in the six top-ranking topcrosses with tester-1 (TC1), three were included in the six top-ranking topcrosses with tester-2 (TC2). Similarly, topcrosses performance of R-lines with tester-1 (TC3) was also highly significantly and highly positively correlated (r=0.88) with their topcrosses performance with tester-2 (TC4), and this relationship was highly consistent across the environments (r=0.85 in 2012 summer season and r=0.83 in 2013 summer season). Averaged over the environments, from among R-lines included in the six top-ranking topcrosses in TC3, five were included in the six top-ranking topcrosses in TC4. These results showed that high general combiners for days to 50% flowering can be effectively selected by using any of the testers.

4.3.4 Association of grain iron and zinc with agronomic traits

Among the topcrosses of B-lines [B-line × Raj 171 (TC1) and B-line × ICMR 312 (TC2)], both Fe and Zn densities did not show any significant correlation with grain yield, 1000-grain weight and days to 50% flowering in individual environments as well as over the environments, except in 2012 summer season, which showed significant negative correlation between Zn density and grain yield ($r=-0.56$, $p<0.05$) (Table 4.25.). Among the topcrosses of R-lines, Fe and Zn densities did not show any significant association with agronomic traits among R-line × Raj 171 (TC3) topcrosses in individual environments as well as over the environments. Among R-line × ICMR 312 (TC4) topcrosses, Fe density showed non-significant correlation with grain yield and days to 50% flowering, and significant positive correlation with 1000-grain weight in 2012 summer season ($r=0.58$, $p<0.05$) and over the environments ($r=0.55$, $p<0.05$); while Zn density showed significant positive correlation with grain yield ($r=0.53$ to 0.56, $p<0.05$) and days to 50% flowering ($r=0.53$ to 0.56, $p<0.05$), and non-significant correlation with 1000-grain weight.

4.4 ASSESSMENT OF INTRA-POPULATION GENETIC VARIATION

Open-pollinated varieties (OPVs) of pearl millet are highly heterogeneous populations with significant variability for most of the quantitative traits. Earlier research identified ICTP 8203 and ICMV 221 as the two promising populations with high levels of both Fe and Zn densities. Also, significant variability for Fe and Zn densities had been observed in both these populations. However, the nature of genetic variability of Fe and Zn densities in these populations has not yet been investigated. An understanding of the nature of genetic variability will have direct bearing on devising effective breeding strategies to further improve these populations for high Fe and Zn densities, and derive inbred lines with higher levels of both micronutrients for use as hybrid parents. North Carolina mating Design-1 (NCD-1) provides direct estimate of additive genetic variance (σ^2_A), which is estimated from source of variation due to males; while this design does not allow direct estimate of dominance variance (σ^2_D), and it is estimated as a part of the genetic variation from source of variation due to females within-males (Comstock and Robinson, 1952 and Robinson *et al*., 1955). In this study, two open pollinated varieties (ICTP 8203 and ICMV 221) were used to estimate the intra-population genetic variances for grain Fe and Zn densities, 1000-grain weight and days to 50% flowering.

4.4.1 Variability within ICTP 8203

There were significant differences among females-in-males-in-sets and among males-in-sets for all the traits in individual environments as well as over the environments (Table 4.26.). While, there were significant females-in-males-in-sets × environment interactions for all the traits, males-in-sets × environment interactions were non-significant. The contribution of females-in-males-in-sets × environment interactions to variability relative to those due to females-in-males-in-sets were 35% for Fe density, 56% for Zn density, 36% for 1000-grain weight and 35% for days to 50% flowering. This indicated that estimates of total genetic variances were confounded with G × E interaction, while additive genetic variance components were not significantly influenced by this interaction component for all the traits.

The Fe density among the progenies ranged from 44.2 (P 4) to 76.9 mg kg^{-1} (P 148) with an average of 58.2 mg kg^{-1} in 2012 rainy season; and from 42.4 (P 118) to

79.6 mg kg^{-1} (P 148) with an average of 57.5 mg kg^{-1} in 2013 summer season (Table 4.27. and Appendix K.). Based on the mean performances over the environments, it varied from 44.0 (P 74) to 78.3 mg kg^{-1} (P 148) with an average of 57.9 mg kg^{-1}. Zn density varied from 24.3 (P 155) to 44.1 mg kg^{-1} (P 8) with an average of 33.6 mg kg^{-1} in rainy season; and from 35.4 (P 117) to 64.3 mg kg^{-1} (P 147) with an average of 52.4 mg kg^{-1} in summer season. Based on the mean performances over environments it varied from 33.0 (P 117) to 51.0 mg kg^{-1} (P 8) with an average of 42.8 mg kg^{-1}.

Thousand grain weight varied from 13.9 (P 30) to 22.3 g (P 3) with an average of 17.7 g in rainy season; and from 12.4 (P 47) to 18.5 g (P 3) with an average of 15.6 g in summer season (Table 4.27. and Appendix K.). Based on the mean performances over both environments it varied from 13.5 (P 157) to 20.4 g (P 3) with an average of 16.6 g. Days to 50% flowering ranged from 38 (P 41) to 48 d (P 157) with an average of 42 d in rainy season; and from 37 (P 5) to 48 d (P 113) with an average of 42 d in summer season. Based on the mean performances over both environments, it varied from 39 (P 33) to 48 d (P 113) with an average of 42 d.

4.4.2 Variability within ICMV 221

There were significant differences among females-in-males-in-sets and among males-in-sets for all the traits in individual environments as well as over the environments, except for days to 50% flowering for which males-in-sets was non-significant over the environments (Table 4.28.). While, males-in-sets × environment interaction was significant only for days to 50% flowering and the contribution of this interaction to variability relative to those due to males-in-sets was 15%. This indicating that estimates of additive variance components were not significantly influenced by environmental variations for Fe and Zn densities and 1000-grain weight. Females-in-males-in-sets × environment interactions were significant for all the traits. The contribution of these interactions to variability relative to those due to the females-in-males-in-sets were 42% for Fe density, 57% for Zn density, 36% for 1000-grain weight and 35% days to 50% flowering, indicating that total genetic variability was significantly confounded with environment interaction.

The Fe density in the progenies varied from 33.4 (P 151) to 71.4 mg kg^{-1} (P 157) with an average of 50.0 mg kg^{-1} in rainy season; and from 40.6 (P 135) to 75.8 mg kg^{-1} (P 157) with an average of 54.2 mg kg^{-1} in summer season (Table 4.27. and Appendix

K.). Based on the mean performances over environments, it varied from 38.3 (P 129) to 73.6 mg kg^{-1} (P 157) with an average of 52.1 mg kg^{-1}. The Zn density varied from 22.5 (P 143) to 37.3 mg kg^{-1} (P 14) with an average of 29.0 mg kg^{-1} in rainy season; and from 37.8 (P 19) to 64.2 mg kg^{-1} (P 108) with an average of 49.8 mg kg^{-1} in summer season. Based on the mean performances over both environments, it varied from 31.3 (P 19) to 48.8 mg kg^{-1} (P 157) with an average of 39.4 mg kg^{-1}.

Thousand grain weight varied from 12.6 (P 98) to 20.5 g (P 54) with an average of 15.9 g in rainy season; and from 11.1 (P 158) to 18.3 g (P 35) with an average of 14.4 g in summer season (Table 4.27. and Appendix K.). Based on the mean performances over environments, it ranged from 12.0 (P 158) to 19.0 g (P 54) with an average of 15.1 g. Days to 50% flowering varied from 38 (P 45) to 46 d (P 135) with an average of 41 d in rainy season; and from 39 (P 35) to 48 d (P 135) with an average of 42 d in summer season. Based on the mean performances over environments, it varied from 39 (P 45) to 47 d (P 135) with an average of 42 d.

4.4.3 Genetic variances and heritability

4.4.3.1 Grain iron and zinc densities

The magnitude of additive genetic variance in ICTP 8203 was much higher than that of dominance variance, when estimated over the environments for both Fe and Zn densities (Table 4.29.). The additive variance was 5.6 times higher for Fe density and 4.7 times higher for Zn density (Fig 4.8.). These estimates of additive genetic variance were not influenced by environmental factors as indicated by non-significant males-in-sets × environment interactions, leading to very low additive × environment variance for both the traits. In contrast, high environmental influence was observed on dominance variance, with the estimates of dominance × environment variance being 2.5 times higher than dominance variance for Fe density, and 12 times higher for Zn density. Dominance × environment interactions variance accounted for 87% and 72% of the variances due to total genotype × environment interaction variances component for Fe and Zn densities, respectively (Fig 4.9.). This implied that estimates of dominance variance were confounded with higher proportion of dominance × environment variance which might have led to higher dominance variance for Fe density in rainy season. Thus, while additive variance for Fe density was 8.6 times higher than the dominance variance in summer season, and it was 6.6 times and 12.2 times higher than that of dominance variance for Zn density in rainy and summer seasons, respectively.

In ICMV 221, the estimates of additive variance, when estimated over the environments were higher than that of dominance variance, being 1.9 times higher for Fe density and 5.3 times higher for Zn density (Table 4.29. and Fig 4.8.). These estimates of additive genetic variances were not influenced by environmental factors as indicated by non-significant males-in-sets × environment interactions, leading to very low additive × environment variance for both the traits. While dominance × environment variance was 2.3 times higher than the dominance variance for Fe density, it was 7.5 times higher than dominance variance for Zn density. For Fe density, the genotype × environment interaction was completely due to dominance × environment variance, hence, the proportion of additive × environment variance was negative or nil; while for Zn density, dominance × environment interaction variance was 85% of that of genotype × environment interaction (Fig 4.9.). This implied that dominance variance component highly varied across the environments, being confounded with higher magnitude of dominance × environment interactions variance. This could have led to 2.4 times higher dominance variance than additive variance for Fe density in the rainy season, and 1.4 times higher estimate in the summer season; and 1.7 times higher estimate for Zn density in the summer season. The additive variance was 2.2 times higher than dominance variance for Zn density, but only in the rainy season.

The greater additive genetic variance transformed into higher narrow-sense heritability for both Fe and Zn densities in ICTP 8203, when estimated over the environments (65% for Fe and 86% for Zn) (Fig 4.10.). Moderate heritability (45%) was observed over the environments for both Fe and Zn densities in ICMV 221. The predominance of additive genetic variance and moderate to high heritability would make recurrent selection for intra-population improvement for Fe and Zn densities, and open-pollinated variety development highly effective. Earlier studies in pearl millet (Velu *et al*., 2011b and Govindaraj *et al*., 2013), rice (Zhang *et al*., 2004) and maize (Gorsline *et al*., 1964., Arnold and Bauman, 1976., Brkic *et al*., 2003., Long *et al*., 2004 and Chen *et al*., 2007) also reported these micronutrients to be largely under additive genetic control. Also, earlier studies on pearl millet (Velu, 2006 and Gupta *et al*., 2009) reported moderate to high estimates of broad-sense heritability, while Velu (2006) noticed significant seasonal effect on heritability estimates for Fe and Zn densities.

4.4.3.2 1000-grain weight

In ICTP 8203, dominance variance was higher than that of additive genetic variance in individual environments (2.4 times higher in rainy season and 1.6 times higher in summer season) as well as over the environments (1.3 times higher) (Table 4.29. and Fig 4.8.). Also, dominance × environment interaction variance component was higher, which accounted for 80% of total genotype × environment interaction variance component. Likewise, in ICMV 221, dominance variance was higher than additive genetic variance in individual environments (1.8 times higher in rainy season and 3.7 times higher summer season) as well as over the environments (4.6 times higher). Dominance × environment interaction component accounted for 62% of that of genotype × environment interaction component indicating large environmental effect. This resulted in low heritability estimates over the environments, in both populations (31% in ICTP 8203 and 13% in ICMV 221). The genetic studies from both the populations suggest largely non-additive genetic control for 1000-grain weight; some of the earlier studies in pearl millet have reported the predominance of non-additive genetic variance in line × tester studies (Rasal and Patil, 2003 and Jethva *et al*., 2011).

4.4.3.3 Days to 50% flowering

In ICTP 8203, additive genetic variance was higher than dominance variance for days to 50% flowering in summer season (3.7 times higher) and over the environments (2.4 times higher), while in rainy season both additive and dominance variances were equal in magnitude (Table 4.29.). The dominance × environment variance accounted for 76% of the total genotype × environment interaction component. Likewise, in ICMV 221, additive genetic variance was higher than dominance variance in individual environments (2.3 times higher in rainy season and 1.2 times higher in summer season) as well as over the environments (2.5 times higher). Dominance × environment interaction component accounted for 69% of total genotype × environment interaction variance. Thus, relatively higher additive genetic variance compared to dominance variance, and relatively lower additive × environment than dominance × environment interaction led to moderate heritability estimates in both populations (55% in ICTP 8203 and 58% in ICMV 221). Earlier studies in pearl millet by Yadav *et al*. (2000) reported the predominance of additive genetic variance for days to 50% flowering in inbreds × populations topcrosses and Govindaraj (2011) found predominance of additive genetic variance in two sets of line × tester crosses.

4.4.4 Correlation among the traits

In individual environments as well as over the environments, significant and positive correlations were observed between Fe and Zn densities among NCD-1 progenies, varying from r=0.50 to 0.78, $p<0.01$ in ICTP 8203 and from r=0.56 to 0.68, $p<0.01$ in ICMV 221 (Table 4.30.). While dominance variance was higher for Fe density, additive variance was higher for Zn density in rainy season; and this inverse variance components between both the micronutrients might have reduced the magnitude of correlation between them in both ICTP 8203 and ICMV 221. Both Fe and Zn densities were not associated with 1000-grain weight and days to 50% flowering. Also, the correlation between days to 50% flowering and 1000-grain weight was non-significant. Significant positive relationships between these micronutrients have been reported in earlier studies on pearl millet (Velu *et al*., 2007, 2008a and 2008b., Gupta *et al*., 2009., Rai *et al*., 2012, 2013 and 2014 and Govindaraj *et al*., 2013), and in other cereals, such as sorghum (Ashok Kumar *et al*., 2010 and 2013), maize (Oikeh *et al*., 2003 and 2004b), rice (Stangoulis *et al*., 2007 and Anandan *et al*., 2011), wheat (Garvin *et al*., 2006., Peleg *et al*., 2009., Zhang *et al*., 2010 and Velu *et al*., 2011a), and finger millet (Upadhyaya *et al*., 2011). These positive associations between Fe and Zn densities may likely result from common and overlapping Quantitative Trait Loci (QTL) as reported in wheat (Peleg *et al*., 2009 and Singh *et al*., 2010), rice (Stangoulis *et al*., 2007), common bean (Cichy *et al*., 2009 and Blair *et al*., 2009) and pearl millet (Kumar, 2011) implying that simultaneous selection for both micronutrients is likely to be highly effective.

4.5 ASSESSMENT OF INTRA-POPULATION VARIABILITY FOR COMBINING ABILITY

Improved open-pollinated varieties (OPVs) serve as valuable germplasm base for deriving parental lines of hybrids. Two OPVs (ICTP 8203 and ICMV 221) had been found among those having highest levels of grain iron (Fe) density. These also had high zinc (Zn) density. This part of present research investigated the variability for combining ability for Fe and Zn densities in these two OPVs, based on the performance of topcross hybrids developed by crossing single plants of ICTP 8203 and ICMV 221 with two broad-based testers (Raj 171 and ICMR 312). The topcrosses of random plants of ICTP 8203 with Raj 171 and ICMR 312 were referred to as "TC1" and "TC2", respectively, while topcrosses of individual plants of ICMV 221 with Raj 171 and ICMR 312 were referred to as "TC3" and "TC4", respectively. The topcross hybrids were evaluated for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight and days to 50% flowering.

4.5.1 Analysis of variance

In ICTP 8203, there were highly significant differences among ICTP 8203 × Raj 171 (TC1) and among ICTP 8203 × ICMR 312 (TC2) topcrosses for all the traits in individual environments as well as over the environments (Table 4.31.). The TC1 × E interactions were significant only for Zn density and days to 50% flowering, and the contribution of these interactions to the variability relative to those due to differences among the genotypes (TC1 topcrosses) were 53% and 31%, respectively. The TC2 × E interactions were significant for Fe density and days to 50% flowering, and the contribution of these interactions to the variability relative to those due to differences among the genotypes (TC2 topcrosses) were 52% and 27%, respectively.

Averaged over both testers, differences among the topcross hybrids of individual plants of ICTP 8203 (i.e. P effects) were highly significant for all the traits in individual environments as well as over the environments (Table 4.32.). The plant × tester (P × T) interactions were also highly significant, except for the Zn density in rainy season and over the environments. The contribution of P × T interactions to variability relative to those due to differences among the topcrosses (i.e. P effects) were about 51% for Fe density, and 28-31% for 1000-grain weight and days to 50% flowering (Fig 4.11.). The topcross × environment (P × E) interactions were significant only for Fe density and days to 50% flowering, and their contribution to variability relative to those due to differences among topcross hybrids were 35% for Fe density and 27% for the days to 50% flowering. P × T × E interaction was significant only for Zn density, contributing 79% of the variability relative to that due to P × T interaction.

In ICMV 221 also, highly significant differences were observed among ICMV 221 × Raj 171 (TC3) and ICMV 221 × ICMR 312 topcrosses (TC4) for all the traits in individual environments and over the environments (Table 4.33.). The TC3 × E and TC4 × E interactions were significant for all the traits, except for 1000-grain weight in TC4 topcrosses; and the contribution of these interactions to the variability relative to those due to differences among the topcrosses were 48% for Fe density, 52% for Zn density, 55% for days to 50% flowering and 40% for 1000-grain weight in TC3; and 41% for Fe density, 40% for Zn density, and 38% for days to 50% flowering in TC4 topcrosses.

Averaged over both testers, differences among the topcross hybrids of individual plants of ICMV 221 (i.e. P effects) were highly significant for all the traits in individual environments as well as over the environments, except for days to 50% flowering over the environments (Table 4.34.). The topcross × tester (P × T) interactions were significant in both seasons for Fe density and days to 50% flowering; in summer season for Zn density; and in rainy season for 1000-grain weight. Over the environments, the P × T interactions were significant only for 1000-grain weight and days to 50% flowering, contributing 50% and 44% to the variability relative to those due to differences among the topcrosses (i.e. P effects) (Fig 4.11.). The topcross × environment (P × E) interactions were highly significant, except for 1000-grain weight, contributing 37%, 40% and 53% of the variability relative to those due to differences among topcross hybrids respectively, for Fe and Zn densities and days to 50% flowering. P × T × E interactions were not significant for any trait.

4.5.2 Variability among topcrosses

4.5.2.1 Grain iron and zinc densities

Based on the mean performances over the environments, Fe density in topcrosses of ICTP 8203 varied from 46.4 (P 27 × Raj 171) to 70.2 mg kg^{-1} (P 13 × Raj 171) with an average of 56.3 mg kg^{-1} among TC1 topcrosses; and from 47.4 (P 54 × ICMR 312) to 64.1 mg kg^{-1} (P 31× ICMR 312) with an average of 55.3 mg kg^{-1} among the TC2 topcrosses (Table 4.35.). Zn density varied from 39.3 (P 36 × Raj 171) to 53.9

mg kg^{-1} (P 35 × Raj 171) with an average of 47.0 mg kg^{-1} among TC1 topcrosses; and from 38.8 (P 33 × ICMR 312) to 52.6 mg kg^{-1} (P 21 × ICMR 312) with an average of 45.1 mg kg^{-1} among TC2 topcrosses. Higher Fe and Zn densities with wider range were observed in topcrosses of Raj 171 tester than in topcrosses of ICMR 312 tester in individual environments as well as over the environments for both Fe and Zn densities.

Likewise, Fe density in topcrosses of ICMV 221 ranged from 38.3 (P 10 × Raj 171) to 65.6 mg kg^{-1} (P 8 × Raj 171) with an average of 50.6 mg kg^{-1} among TC3 topcrosses; and from 40.1 (P 1 × ICMR 312) to 66.7 mg kg^{-1} (P 8 × ICMR 312) with an average of 52.8 mg kg^{-1} among TC4 topcrosses (Table 4.35.). Zn density varied from 33.1 (P 10 × Raj 171) to 52.3 mg kg^{-1} (P 18 × Raj 171) with an average of 44.8 mg kg^{-1} among TC3 topcrosses; and from 35.5 (P 1 × ICMR 312) to 54.0 mg kg^{-1} (P 18 × ICMR 312) with an average of 44.3 mg kg^{-1} among TC4 topcrosses. Mean Fe density was lower and range was larger among topcrosses of Raj 171 tester than in the topcrosses of ICMR 312 in individual environments and over the environments. The mean Zn density was higher and range was wider among topcrosses of Raj 171 tester than in topcrosses of ICMR 312 over the environments.

4.5.2.2 1000-grain weight and days to 50% flowering

Based on the mean performance over the environments, 1000-grain weight in topcrosses of ICTP 8203 varied from 11.7 (P 36 × Raj 171) to 17.2 g (P 21 × Raj 171) with an average of 13.7 g among TC1 topcrosses; and from 13.1 (P 29 × ICMR 312) to 17.2 g (P 25 × ICMR 312) with an average of 15.5 g among TC2 topcrosses (Table 4.35.). Days to 50% flowering varied from 42 (P 33 × Raj 171) to 48 d (P 20 × Raj 171) with an average of 44 d among TC1 topcrosses; and from 41 (P 54 × ICMR 312) to 47 d (P 2 × ICMR 312) with an average of 44 d among TC2 topcrosses. The average 1000-grain weight was lower and the range was wider in topcrosses of Raj 171 tester than in topcrosses of ICMR 312 in individual environments and over the environments. Topcrosses of Raj 171, on an average, flowered later and had wider range than those based on ICMR 312 tester in rainy season as well as over the environments.

Likewise, in topcrosses of ICMV 221, 1000-grain weight varied from 11.2 (P 7 × Raj 171) to 15.5 g (P 8 × Raj 171) with an average of 13.1 g among TC3 topcrosses; and from 10.5 (P 43 × ICMR 312) to 17.4 g (P 4 × ICMR 312) with an average of 14.7 g among TC4 topcrosses (Table 4.35.). Days to 50% flowering ranged from 42 (P 48 ×

Raj 171) to 47 d (P 8 × Raj 171) with an average of 44 d among TC3 topcrosses and from 42 (P 59 × ICMR 312) to 47 d (P 8 × ICMR 312) with an average of 43 d among TC4 topcrosses. The mean 1000-grain weight was lower and range was relatively lesser for topcrosses of Raj 171 tester; while for days to 50% flowering higher mean and lower range was observed for topcrosses of Raj 171 tester than in topcrosses of ICMR 312 in individual environments as well as over the environments.

4.5. Tester effect on topcross hybrid performance

4.5.3.1 Grain iron density

Highly significant P × T interaction, accounting for 51% of the variability relative to those due to differences among the topcrosses (i.e. P effects) (Table 4.32. and Fig 4.11.), implied large tester effects on combining ability for Fe density in ICTP 8203. This was reflected in the low correlation (r=0.33, over the environments) between the topcross performance with tester-1 (TC1) and tester-2 (TC2), which was consistent across the environments (r= 0.39 in rainy season and r=0.25 in summer season). Thus, when 30% (18) of the top-ranking topcrosses were selected based on TC1, topcrosses of only 10 respective plants of ICTP 8203 were included even in 50% top-ranking topcrosses based on TC2 (Table 4.36.). Similarly, when 30% of the top-ranking topcrosses based on TC2 were selected, topcrosses of only 11 respective plants of ICTP 8203 were included even in 50% top-ranking topcrosses based on TC1.

In case of ICMV 221, P × T interaction was not significant, although it accounted for about 30% of the variability relative to those due to differences among the topcrosses (i.e. P effects) (Table 4.34. and Fig 4.11.). This was reflected in higher correlation (r=0.54, over the environments) between the topcross performance with tester-1 (TC3) and tester-2 (TC4) than that observed in topcrosses of ICTP 8203, and it was consistent across the environments (r=0.48 in rainy season and r=0.44 in summer season). Consequently, when 30% (18) of the top-ranking topcrosses were selected in TC3, topcrosses of 15 respective plants of ICMV 221 were included in the 50% of the top-ranking topcrosses of TC4; and when 30% of the top-ranking topcrosses were selected in TC4, topcrosses of 14 respective plants of ICMV 221 were included in the 50% of the top-ranking topcrosses of TC3 (Table 4.36.). These results showed that while any of the two testers could be equally effective in discarding the S_0 derived S_1 progenies with low general combining ability for Fe density in ICMV 221, was not reflected in ICTP 8203.

4.5.3.2 Grain zinc density

In ICTP 8203, P × T interaction was not significant, although it accounted for about 44% of the variability relative to those due to differences among the topcrosses (i.e. P effects) (Table 4.32. and Fig 4.11.), implying the presence of tester effects on combining ability for Zn density. This was reflected in the low correlation between the topcross performance with tester-1 (TC1) and tester-2 (TC2), although it was significant over the environments (r=0.38) and in rainy season (r=0.41). Thus, when 30% (18) of the top-ranking topcrosses were selected based on TC1, topcrosses of only 12 respective plants of ICTP 8203 were included even in 50% top-ranking topcrosses based on TC2 (Table 4.37.). Similarly, when 30% of the top-ranking topcrosses based on tester-2 (TC2) were selected, topcrosses of only 11 respective plants of ICTP 8203 were included even in 50% top-ranking topcrosses based on TC1.

In case of ICMV 221, P × T interaction was not significant, although it accounted for about 20% of the variability relative to those due to differences among the topcrosses (i.e. P effects) (Table 4.34. and Fig 4.11.). This reflected in higher correlation (r=0.69, over the environments) between the topcross performance with tester-1 (TC3) and tester-2 (TC4) than observed in topcrosses of ICTP 8203, and it was consistent across the environments (r=0.54 in rainy season and r=0.61 in summer season). Consequently, when 30% (18) of the top-ranking topcrosses were selected in TC3, topcrosses of 15 respective plants of ICMV 221 were included in 50% of the top-ranking topcrosses of TC4; and when 30% of the top-ranking topcrosses were selected in TC4, topcrosses of 14 respective plants of ICMV 221 were included in the 50% of the top-ranking topcrosses of TC3 (Table 4.37.). These results showed that while any of the two testers could be equally effective in discarding the S_0 derived S_1 progenies with low general combining ability for Zn density in ICMV 221, it was not effective in ICTP 8203.

4.5.3.3 1000-grain weight

There was highly significant P × T interaction, although it accounted for only about 28% of the variability relative to those due to differences among the topcrosses (i.e. P effects), in ICTP 8203 (Table 4.32. and Fig 4.11.). This was reflected in the highly significant correlation (r=0.57 over the environments) between the topcross performance with tester-1 (TC1) and tester-2 (TC2), which was significant in both the seasons (r=0.55 in rainy season and r=0.37 in summer season). Consequently, when

30% (18) of the top-ranking topcrosses were selected in TC1, topcrosses of 13 respective plants of ICTP 8203 were included in the 50% of top-ranking topcrosses of TC2; and when 30% of the top-ranking topcrosses were selected in TC2, topcrosses of 16 respective plants of ICTP 8203 were included in the 50% of the top-ranking topcrosses of TC1 (Table 4.38.).

Highly significant P × T interaction, accounting for 50% of the variability relative to those due to differences among the topcrosses (i.e. P effects) (Table 4.34. and Fig 4.11.), implying large tester effects on combining ability for 1000-grain weight in ICMV 221. This was reflected in the lower correlation (r=0.36, over the environments) between the topcross performance with tester-1 (TC3) and tester-2 (TC4) than that observed in topcrosses of ICTP 8203, and across the environments which was significant only in summer season (r=0.48). Thus, when 30% (18) of the top-ranking topcrosses were selected based on TC3, topcrosses of 13 respective plants of ICMV 221 were included even in 50% top-ranking topcrosses based on TC4 (Table 4.38.). Similarly, when 30% of the top-ranking topcrosses based on TC4 were selected, topcrosses of 15 respective plants of ICMV 221 were included even in 50% top-ranking topcrosses based on TC3. These results showed that either of the two testers can be equally effective in discarding low general combiners for grain yield, in both OPVs.

4.5.3.4 Days to 50% flowering

In ICTP 8203, there was highly significant P × T interaction, although it accounted for only about 31% of the variability relative to those due to differences among the topcrosses (i.e. P effects) (Table 4.32. and Fig 4.11.). This was reflected in the highly significant correlation (r=0.52 over the environments) between the topcross performance with tester-1 (TC1) and tester-2 (TC2), which was consistent across environments (r=0.57 in rainy season and r=0.45 in summer season). Consequently, when 30% (18) of the top-ranking topcrosses were selected in TC1, topcrosses of 12 respective plants of ICTP 8203 were included in 50% of top-ranking topcrosses of TC2; and when 30% of the top-ranking topcrosses were selected in TC2, topcrosses of 14 respective plants of ICTP 8203 were included in 50% of top-ranking topcrosses of TC1 (Table 4.39.).

Highly significant P × T interaction, accounting for 44% of the variability relative to those due to differences among the topcrosses (i.e. P effects) (Table 4.34. and Fig 4.11.), implied large tester effects on combining ability for days to 50% flowering in ICMV 221. This was reflected in the lower correlation (r=0.39, over the environments) between the topcross performance with tester-1 (TC3) and tester-2 (TC4) than that observed in ICTP 8203, across the environments which was significant only in summer season (r=0.56). Thus, when 30% (18) of the top-ranking topcrosses were selected based on TC3, topcrosses of only 13 respective ICMV 221 plants were included even in 50% top-ranking topcrosses based on TC4 (Table 4.39.). Similarly, when 30% of the top-ranking topcrosses based on TC4 were selected, topcrosses of only 12 respective plants of ICMV 221 were included even in 50% top-ranking topcrosses based on TC3. These results showed that discarding low general combiners for days to 50% flowering was to a large extent, tester dependent.

Summary and conclusions

Chapter V

SUMMARY AND CONCLUSIONS

The present research was carried out to understand the genetics of grain Fe and Zn densities and agronomic traits in pearl millet and their inter-relationships, which have a direct bearing on devising effective strategies to breed pearl millet cultivars with elevated levels of Fe and Zn densities. The specific objectives of the research were: to assess genetic variation and combining ability of inbred parental lines, to study association of grain Fe and Zn densities with agronomic traits, examine tester effects on combining ability of inbred parental lines, determine magnitude of genetic variances within open-pollinated populations, and assess the intra-population variability for combining ability. The findings are summarized objective-wise hereunder:

5.1 Assessment of genetic variation and combining ability of inbred lines using line × tester design

Combining ability of 28 parents (14 B-lines and 14 R-lines) was evaluated in line × tester trial during 2011 rainy and 2012 summer seasons. Results showed wide range of variability for all the traits. With 30.3-77.2 mg kg^{-1} Fe density and 27.4-45.3 mg kg-1 Zn density in B-lines; 32.0-82.1 mg kg^{-1} Fe density and 29.0-55.5 mg kg^{-1} Zn density in R-lines; and 25.8-64.5 mg kg^{-1} Fe density and 25.8-48.2 mg kg^{-1} Zn density in hybrids. Among the lines ICMB 05555, ICMB 08222, ICMB 88004 and ICMB 93222; and among the testers PRP 2, PRP 3 and PRP 5 had significant positive *gca* effects in individual environments as well as across the environments for both Fe and Zn densities.

Both Fe and Zn densities had high predictability ratio (0.90 for Fe and 0.91 for Zn), very low contribution of line × tester interaction to variability relative to those due to combined line and tester effects (13% for Fe and 11% for Zn), highly significant positive correlation between mid-parental value and hybrids performance *per se* (r=0.79 for Fe and 0.80 for Zn), and no better-parent heterosis, which showed predominantly additive genetic control for both micronutrients. Similarly, predominance of additive genetic control was also found for 1000-grain weight and days to 50% flowering. On the other hand, low predictability ratio (0.52), higher contribution of line × tester interaction to variability relative to that due to combined line and tester effects (118%), highly significant and high positive correlation between hybrids performance *per se* and their *sca* effects (r=0.72), and low but significant positive correlation between hybrids performance *per se* and mid-parent value (r=0.29) showed the predominance of non-additive genetic control for grain yield.

Hybrids with high levels of Fe and Zn densities had either both the parents or at least one parental line having significant positive general combining ability with high micronutrient density. Thus, to breed hybrids with high Fe and Zn densities would require incorporating these micronutrients in both the parental lines. Furthermore, the highly significant association between performance *per se* and *gca* effects for both Fe (r=0.93 for lines, r=0.80 for testers) and Zn (r=0.90 for lines, r=0.87 for testers) densities indicated that selection for performance *per se* would be effective in simultaneous selection for *gca* effects of both the micronutrients.

There were highly significant and high positive correlations between the Fe and Zn densities both for performance *per se* (r=0.88) and *gca* effects (r=0.91). Fe and Zn densities did not show any significant association with days to 50% flowering in both parents and hybrids; while both micronutrients had highly significant and negative, albeit weak, correlations with grain yield and highly significant and moderate positive correlation with 1000-grain weight in hybrids. These correlations, however, were non-significant in parental lines. This showed that while breeding for high Fe and Zn densities with large grain size will be highly effective, combining high levels of these micronutrients with high grain yield would require growing large breeding populations and progenies than breeding for grain yield alone, to make effective selection for desired combinations.

5.2 Assessment of association of grain iron and zinc densities with agronomic traits in hybrids

Multi-location evaluation (in 2012 rainy season) of two sets of hybrids (set-A with 32 hybrids and set-B with 28 hybrids) with differing genetic composition showed wide range of variability for Fe (45-67 and 44-76 mg kg^{-1}), Zn (25-34 and 32-44 mg kg^{-1}), 1000-grain weight (11-17 and 12-18 g), grain yield (2.0-3.9 and 3.0-4.6 t ha^{-1}), days to 50% flowering (40-53 and 43-52 d) and other traits in set-A and set-B, respectively. Significant hybrid × environment interactions were observed for both the micronutrients and agronomic traits. The contribution of H × E interactions to variability relative to that due to differences among the hybrids were higher for Zn density (68-70%) than Fe density (35-38%). This may apparently imply greater sensitivity and differential response of hybrids for Zn than Fe density to changes in the soil and climatic conditions. This could also be due to proportionately larger differences among the hybrids for Fe density than for Zn density. Among agronomic traits, the contribution of H × E interactions to variability relative to those due to differences among hybrids were higher for grain yield (52-101%), panicle length (7-47%) and effective number of tillers (48 - 60%), and lower (≤35%) for days to 50% flowering, plant height and 1000-grain weight.

There were highly significant and positive correlations between grain Fe and Zn densities, which were consistent across environments in both the hybrid sets (r=0.49 to 0.63 in set-A and r=0.52 to 0.65 in set-B), implying that simultaneous selection for both micronutrients is likely to be highly effective. Iron density and 1000-grain weight did not show any significant association, and Zn density showed both significant and non-significant association with 1000-grain weight (r=0.01 to 0.44), implying simultaneous genetic improvement of both micronutrients in large-seeded background is likely to be effective.

Fe density had moderate to low negative association with grain yield in both sets of hybrids (r=-0.47 to -0.24 in set-A, and r=-0.50 to -0.08 in set-B), but was not always significant. The association between Zn density and grain yield was also negative, but non-significant in all the cases. Such associations might have resulted due to the involvement of *iniadi* germplasm as a common source of high Fe and Zn density in both male and female parents, thereby reducing the genetic diversity between the parental lines for traits associated with heterosis for grain yield. This could also be due to natural negative association between genetic factors for these micronutrients on one hand and grain yield on the other.

Moderate to low negative association of both micronutrients were observed with days to 50% flowering (r=-0.57 to -0.06 with Fe and r=-0.37 to 0.32 with Zn) and panicle length (r=-0.61 to -0.06 with Fe and r=-0.37 to 0.13 with Zn), but were not always significant. Similarly, plant height showed moderate to low negative association with Fe density (r=-0.37 to -0.02), while association with Zn density varied from r=-0.23 to 0.46 and was significant and positive in one environment (r=0.46, $p<0.01$ in E3). Based on the mean performance over the environments, grain yield had significant positive association with days to 50% flowering (r=0.73 in set-A and r=0.63 in set-B; $p<0.01$), plant height (r=0.72 in set-A and r=0.55 in set-B; $p<0.01$) and panicle length (r=0.46 in set-A and r=0.59 in set-B; p<0.01).This trend was consistent in individual environments also. However, results of this study do not provide any clear cut indications if days to 50% flowering, panicle length and plant height, owing to their positive relationships with grain yield, may have any bearing on the negative correlation observed between grain yield on one hand, and Fe and Zn densities on the other. These issues of Fe and Zn associations with grain yield and other traits merit further investigations, and must be resolved through selection experiments in segregating populations, with the application of genomic tools providing further insights.

5.3 Study of tester effect on combining ability of inbred lines

Twenty eight inbreds (14 B and 14 R-lines) were top crossed with two broad-based open-pollinated varieties (Raj 171 and ICMR 312) as testers to study the tester effect on combining ability. Topcrosses along with parents were evaluated during 2012 summer and 2013 summer seasons. Wide range of variability observed for all the traits, with 36.9-81.3 mg kg^{-1} Fe density and 36.9-60.2 mg kg^{-1} Zn density in B-lines; 37.5-58.9 mg kg^{-1} Fe density and 40.4-55.5 mg kg^{-1} Zn density in B-lines × Raj 171; and 42.2-61.9 mg kg^{-1} Fe density and 41.8-54.2 mg kg^{-1} Zn density in B-lines × ICMR 312 crosses. Similarly, 37.2 -89.0 mg kg^{-1} Fe density and 37.6-70.6 mg kg^{-1} Zn density in R-lines; 35.7-57.5 mg kg^{-1} Fe density and 38.4-55.3 mg kg^{-1} Zn density in R-lines × Raj 171; and 39.3-64.9 mg kg^{-1} Fe density and 38.3-58.4 mg kg^{-1} Zn density in R-lines × ICMR 312 crosses.

Pooled over the environments, L × T interactions were significant for all traits among B-line topcrosses (BL × T) as well as R-line topcrosses (RL × T), except for Zn density in B-line topcrosses. For Fe density, there were highly significant and high positive correlations between performance *per se* of B-lines and their topcross performance (a measure of general combining ability) for Fe density with r=0.78 in topcrosses of Raj 171tester (TC1), r=0.84 in topcrosses of ICMR 312 tester (TC2) and r=0.89 averaged over both testers ($\bar{x}1$). From top-ranking six B-lines with ≥59 mg kg^{-1} Fe density, five lines in TC1 and TC2, and all lines in $\bar{x}1$ ranked in the top-ranking six topcrosses. Similarly highly significant and positive correlations were observed between performance *per se* of R-lines and their topcrosses with r=0.83 in topcrosses of Raj 171 tester (TC3), r=0.58 in topcrosses of ICMR 312 tester (TC4) and r=0.75 averaged over both testers ($\bar{x}2$). From among the top-ranking six R-lines with ≥61 mg kg^{-1} Fe density, all except one line were among the six top-ranking topcrosses of TC3, TC4 and

$\bar{x}2$.These results showed that selection based on performance *per se* is likely to be highly effective in selecting for high *gca* for Fe density. Topcrosses performance of B-lines with tester-1 (TC1) were highly significantly and positively correlated (r=0.64) with topcross performance with tester-2 (TC2). From among the B-lines included in six top-ranking topcrosses with tester-1 (TC1), five were included in the six top-ranking topcrosses with tester-2. Similarly, topcrosses performance of R-lines with tester-1 (TC3) were highly significantly and highly positively correlated (r=0.75) with their topcrosses performance with tester-2 (TC4). From among the R-lines included in six top-ranking topcrosses in TC3, five were included in the six top-ranking topcrosses in TC4. These results showed that top-ranking high general combiners (both B-lines and R-lines) for Fe density can be selected equally effectively by using any of the two testers.

Highly significant and high positive correlations were observed between performance *per se* of B-lines and their topcross performance for Zn density in topcrosses of TC1 (r=0.77), TC2 (r=0.83) and $\bar{x}1$ (r=0.88). From among the top-ranking six B-lines, five lines included in the top-ranking six topcrosses of TC1, TC2 and $\bar{x}1$. There was highly significant and high positive correlation between performance *per se* of R-lines and their topcross in TC3 (r=0.87), TC4 (r=0.72) and $\bar{x}2$ (r=0.84). From among the top-ranking six R-lines, five lines included in the top-ranking six topcrosses of $\bar{x}2$ and TC3, and four lines ranked among top-ranking six topcrosses in TC4. There was significant correlation between TC1 and TC2 (r=0.62), and between TC3 and TC4 (r=0.78). From among the B-line of six top-ranking topcrosses in TC1, four were included in the top-ranking six topcrosses in TC2; from among the R-lines included in the six top-ranking topcrosses in TC3, four were included in the six top-ranking topcrosses in TC4. These results showed that the top-ranking high general combiners (both B and R lines) for Zn density can be selected equally effectively by using any of the two testers.

For 1000-grain weight, there was highly significant and high positive correlation between performance *per se* of B-lines and their topcross performance in topcrosses of TC1 (r=0.74), TC2 (r=0.71) and $\bar{x}1$ (r=0.87); and also between performance *per se* of R-lines and their topcrosses in TC3 (r=0.89), TC4 (r=0.74) and $\bar{x}2$ (r=0.87). There was no correlation between TC1 and TC2, while the topcross performance of R-lines with tester-1 (TC3) was highly significantly and highly positively correlated (r=0.75) with topcross performance with tester-2 (TC4). From among R-lines included in six top-ranking topcrosses in TC3, five were included in the six top-ranking topcrosses in TC4. These results showed that selection of top-ranking high general combiners for 1000-grain weight may be influenced by testers.

Grain yield did not show any significant association between performance *per se* of B-lines and R-lines with their topcrosses; hence selection of top-ranking high general combiners may be ineffective on the basis of performance *per se* of line. The topcross performance of R-lines with tester-1 (TC3) was highly significantly and positively correlated (r=0.65) with topcross performance with tester-2 (TC4). From among the R-lines involved in six top-ranking topcrosses in TC3, all were included in the six top-ranking topcrosses in TC4.

There was highly significant and high positive correlation between performance *per se* of B-lines and their topcross performance for days to 50% flowering in topcrosses of TC1 (r=0.71), TC2 (r=0.79) and $\bar{x}1$ (r=0.78); and also between performance *per se* of R-lines and their topcross in TC3 (r=0.71), TC4 (r=0.69) and $\bar{x}2$ (r=0.78). There was significant positive correlation between TC1 and TC2 (r=0.82), and between TC3 and TC4 (r=0.88). From among the B-lines included in the six top-ranking topcrosses in TC1, three were included in the six top-ranking topcrosses in TC2; and from among R-line included in the six top-ranking topcrosses in TC3, five were included in the six top-ranking topcrosses in TC4. These results showed that high general combiners for days to 50% flowering may not be always effectively selected by using different testers.

5.4 Assessment of intra-population genetic variation

Two open-pollinated varieties (ICTP 8203 and ICMV 221) were used to examine intra-population genetic variance for grain Fe and Zn densities, 1000-grain weight and days to 50% flowering. In each population, 160 progenies were developed through North Carolina mating Design-1(NCD-1) and evaluated during 2012 rainy and 2013 summer seasons. Significant variability was observed for all the traits, with Fe density varying from 44.0 to 78.3 and 38.3 to 73.6 mg kg^{-1}, and Zn density from 33.0 to 51.0 and 31.3 to 48.8 mg kg^{-1} among the progenies of ICTP 8203 and ICMV 221, respectively.

The magnitude of additive genetic variance (σ^2_A) was 5.6 times higher than that of dominance variance (σ^2_D) for Fe density and 4.7 times higher for Zn density in ICTP 8203; while it was 1.9 times higher for Fe density and 5.3 times higher for Zn density in

ICMV 221. The estimates of additive × environment variances ($\sigma^2_{A\times E}$) were lower than that of σ^2_A and were non-significant for both the micronutrients in both the populations. The estimates of dominance × environment variances ($\sigma^2_{D\times E}$) for Fe density were 2.5 and 2.3 times higher and for Zn density, 12 and 7.5 times higher than that of σ^2_D in ICTP 8203 and ICMV 221, respectively. These higher estimates of $\sigma^2_{D\times E}$ might have got confounded with σ^2_D leading to higher estimates. The greater additive genetic variance transformed into higher narrow-sense heritability for both Fe and Zn densities in ICTP 8203 (65% for Fe and 86% for Zn), and moderate heritability (45%) for both Fe and Zn densities in ICMV 221. There were highly significant and positive correlations between Fe and Zn densities (r=0.69 in ICTP 8203, r=0.63 in ICMV 221). These findings indicated that predominance of additive gene action for Fe and Zn densities would make recurrent selection for intra-population improvement and open–pollinated variety development highly effective, and highly significant positive correlation of both micronutrients would be helpful in their simultaneous improvement.

Thousand grain weight had 1.3 and 4.5 times higher σ^2_D than that of σ^2_A in ICTP 8203 and ICMV 221, respectively. The estimates of σ^2_D were higher than that of $\sigma^2_{D\times E}$. However, the $\sigma^2_{D\times E}$ accounted for 80% and 62% of the total G × E interaction variance in ICTP 8203 and ICMV 221, respectively, and low to moderate estimate of heritability (31% in ICTP 8203, 13% ICMV 221). For days to 50% flowering σ^2_A was 2.4 times higher than σ^2_D in both the populations, and $\sigma^2_{D\times E}$ contributed 76% of variability relative to that due to G × E variance in ICTP 8203 and 69% in ICMV 221. Heritability was high in both the populations (55% in ICTP 8203 and 58% in ICMV 221). Both 1000-grain weight and days to 50% flowering did not show any significant association with Fe and Zn densities in both the populations.

5.5 Assessment of intra-population variability for combining ability

Randomly selected 60 S_0 plants each from two base populations (ICTP 8203 and ICMV 221) were top-crossed with two testers (Raj 171 and ICMR 312) to assess intra-population variability for combining ability, and these topcrosses were evaluated during 2012 rainy and 2013 summer seasons. Wide range of variability was observed for all traits. Fe density varied from 46.4 to 70.2 mg kg^{-1} in ICTP 8203 × Raj 171 (TC1) and from 47.4 to 64.1 mg kg^{-1} ICTP 8203 × ICMR 312 (TC2) topcrosses; and Zn density varied from 39.3 to 53.9 mg kg^{-1} in TC1 and from 38.8 to 52.6 mg kg^{-1} in TC2 topcrosses. Similarly, Fe density varied from 38.3 to 65.6 mg kg^{-1} in ICMV 221 × Raj

171 (TC3) and from 40.1 to 66.7 mg kg^{-1} ICMV 221 × ICMR 312 (TC4) topcrosses; and Zn density varied from 33.1 to 52.3 mg kg^{-1} in TC3 and 35.5 to 54.0 mg kg^{-1} in TC4 topcrosses.

Highly significant P × T interaction, accounting for 51% of the variability relative to those due to differences among the topcrosses averaged over both testers (i.e. P effects) implied large tester effects on combining ability for Fe density in ICTP 8203. This was reflected in the low correlation (r=0.33) between the topcross performance with tester-1 (TC1) and tester-2 (TC2). Thus, when 30% (18) of the top-ranking topcrosses were selected based on TC1, topcrosses of only 10 respective plants of ICTP 8203 were included even in 50% top-ranking topcrosses based on TC2. Similarly, when 30% of the top-ranking topcrosses based on TC2 were selected, topcrosses of only 11 respective plants of ICTP 8203 were included even in 50% top-ranking topcrosses based on TC1. In case of ICMV 221, P × T interaction was not significant, although it accounted for about 30% of the variability relative to those due to differences among the topcrosses (i.e. P effects). This was reflected in higher correlation (r=0.54,) between the topcross performance with tester-1 (TC3) and tester-2 (TC4) than observed in topcrosses of ICTP 8203. Consequently, when 30% (18) of the top-ranking topcrosses were selected in TC3, topcrosses of 15 respective plants of ICMV 221 were included in the 50% of the top-ranking topcrosses of TC4; and when 30% of the top-ranking topcrosses were selected in TC4, topcrosses of 14 respective plants of ICMV 221 were included in the 50% of the top-ranking topcrosses of TC3. These results showed that while any of the two testers could be equally effective in discarding the S_0-derived S_1 progenies with low general combining ability for Fe density in ICMV 221, it was not so in case of ICTP 8203.

For Zn density, P × T interaction was not significant, although it accounted for about 44% of the variability relative to those due to differences among the topcrosses (i.e. P effects) in ICTP 8203. This was reflected in the low correlation (r=0.38) between the topcross performance with tester-1 (TC1) and tester-2 (TC2). Thus, when 30% (18) of the top-ranking topcrosses were selected based on TC1, topcrosses of only 12 respective plants of ICTP 8203 were included even in 50% top-ranking topcrosses based on TC2. Similarly, when 30% of the top-ranking topcrosses based on tester-2 (TC2) were selected, topcrosses of only 11 respective plants of ICTP 8203 were included even in 50% top-ranking topcrosses based on TC1. In case of ICMV 221, P × T interaction was not significant, although it accounted for about 20% of the variability relative to those due to differences among the topcrosses (i.e. P effects). This was reflected in higher correlation (r=0.69) between the topcross performance with tester-1 (TC3) and tester-2 (TC4) than observed in topcrosses of ICTP 8203. Consequently, when 30% (18) of the top-ranking topcrosses were selected in TC3, topcrosses of 15 respective plants of ICMV 221 were included in 50% of the top-ranking topcrosses of TC4; and when 30% of the top-ranking topcrosses were selected in TC4, topcrosses of 14 respective plants of ICMV 221 were included in the 50% of the top-ranking topcrosses of TC3. These results showed that while any of the two testers could be equally effective in discarding the S_0-derived S_1 progenies with low general combining ability for Zn density in ICMV 221, it was not so in case of ICTP 8203.

For 1000-grain weight, there was highly significant P × T interaction, although it accounted for only about 28% of the variability relative to those due to differences among the topcrosses (i.e. P effects) in ICTP 8203. This was reflected in the highly significant correlation (r=0.57) between the topcross performance with tester-1 (TC1) and tester-2 (TC2). Highly significant P × T interaction, accounting for 50% of the variability relative to those due to differences among the topcrosses (i.e. P effects), implied large tester effects on combining ability in ICMV 221. This was reflected in the lower correlation (r=0.36) between the topcross performance with tester-1 (TC3) and tester-2 (TC4) than observed in topcrosses of ICTP 8203. These results showed that either of the two testers can be equally effective in discarding low general combiners for grain yield in both OPVs.

For days to 50% flowering, there was highly significant P × T interaction, although it accounted for only about 31% of the variability relative to those due to differences among the topcrosses (i.e. P effects) in ICTP 8203. This was reflected in the highly significant correlation (r=0.52) between the topcross performance with tester-1 (TC1) and tester-2 (TC2). Highly significant P × T interaction, accounting for 44% of the variability relative to those due to differences among the topcrosses (i.e. P effects), implied large tester effects on combining ability for days to 50% flowering in ICMV 221. This was reflected in the lower correlation (r=0.39) between the topcross performance with tester-1 (TC3) and tester-2 (TC4) than observed in ICTP 8203. These results showed that discarding low general combiners for days to 50% flowering was to a large extent, tester dependent.

Future line of work

Predominantly additive genetic control of grain iron (Fe) and zinc (Zn) densities, and highly significant and very high positive correlation between the two, implies that there are good prospects for simultaneous genetic enhancement of both micronutrients in open-pollinated varieties (OPVs). The validity of these finding needs to be tested by conducting selection for higher Fe and Zn densities in OPVs to develop their improved versions with higher Fe and Zn densities. While the two OPV (broad-based) testers used in this study were equally effective in selecting for high general combining inbred lines (as reflected in their topcross hybrid performance) both for Fe and Zn densities, these could, at best, be effective only in discarding low general combiners when used for early generation testing. Further research using different OPV testers would provide greater insight into tester effect on early generation testing for general combining ability. The negative correlation of Fe and Zn densities with grain yield in hybrid trials, but not in the inbred × OPV topcross trial, showed the need to test, through actual selection experiments in well-designed populations, whether such patterns are dependent on the type of materials used in the study or do they reflect a natural association as a biological feature of pearl millet. Almost all the high-Fe materials are largely or entirely based on *iniadi* germplasm, which is a common source of high Fe and Zn densities in both male and female parents. This would lead to high Fe densities in the hybrids derived from them, but use of common source for Fe and Zn densities might lead to reduction in diversity among lines for traits related to heterosis for grain yield, and consequently lower hybrid grain yields. In such a case, genes and genomic regions responsible for high Fe and Zn densities should be identified to facilitate their selective introgression into potential hybrid parents, without reducing the diversity among breeding lines for traits related to heterosis for grain yield.

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Tables

Table 2.1. Gene action studies for grain iron (Fe) and zinc (Zn) densities

Sl. No.	Mating design	Trial size	Analytical technique	Trait	Proportion of GCA and SCA	Predominant gene action	Author
	PEARL MLLET (*Pennisetum glaucum* (L.) R.Br.)						
1.	Diallel	10 parents = 90 F_1	AAS	Fe and Zn	GCA>SCA	Additive	Velu *et al* . (2011b)
2.	Line × tester	8B × 9R =72 F_1	AAS	Fe and Zn	GCA>SCA	Additive	Govindaraj *et al* . (2013)
		16B × 12R = 192 F_1	AAS	Fe and Zn	GCA>SCA	Additive	
	SORGHUM (*Sorghum bicolor* (L.) Moench)						
1.	Diallel	5 inbreds= 19 F_1	AAS	Fe	SCA>GCA	Non-additive	Ashok kumar *et al* . (2013)
				Zn	SCA ≥ GCA	Additive	
		6 inbreds= 28 F_1		Fe	-	Non-additive	
		4 parents = 12 F_1		Zn	-	Additive	
	RICE (*Oryza sativa* L.)						
1.	Diallel	7 parents=42 F1	AAS	Fe and Zn	-	Additive	Zhang *et al* . (2004)
	MAIZE (*Zea mays* L.)						
1.	Diallel	9 inbreds =35 F_1	AAS	Fe and Zn	-	Additive	Gorsline *et al.* (1964)
2.	Diallel	6 inbreds= 15 F_1	AAS	Fe and Zn	GCA>SCA	Additive	Arnold and Bauman (1976)
3.	Diallel	8 inbreds =28 F_1	ICP	Fe and Zn	GCA>SCA	Additive	Brkic *et al.* (2003)
4.	Diallel	14 inbreds=91 F_1	ICP	Fe and Zn	GCA>SCA	Additive	Long *et al.* (2004)
5.	Diallel	9 inbreds =36 F_1	AAS	Fe and Zn	GCA>SCA	Additive	Chen *et al.* (2007)
6.	Diallel	7 inbreds =42 F_1	AAS	Fe and Zn	GCA>SCA	Additive	Chakraborti *et al.* (2011)

Table 2.2. Studies of tester effect on combining ability for different traits

Sl.No.	Crop	Test material	Testers	Trait	Best tester	Inference	Reference
1.	Maize	8 inbred lines	14 testers: 2-double cross hybrids, 4 single cross hybrids and 8 inbred lines	Grain yield	Tester type varied with the objective of study	Inbreds tester was suitable for SCA variance study while broad based tester for GCA genetic component sudy.	Matzinger (1953)
2.	Maize	116 S_1 each from 3-populations	2 testers: High and low yielding testers	Grain yield	Low yielding tester	Lines selected based on low yielding tester top-crosses performance showed higher variability and higher grain yield.	Lonnquist and Lindsey (1970)
3.	Sunflower	10 randomly selected inbreds	3 testers: 2 inbreds and their single cross	Grain yield and oil content	All three	Result was consistent with all three testers for top 40% high performing genotypes.	Miller *et al*. (1980)
4.	Maize	19 S_4 progenies	4 testers: OPV; inbred line; single cross and three way cross hybrids.	Grain yield and component traits	Inbreds	Narrow genetic base and less frequency of favourable alleles is the best tester characteristic.	Ali and Tepora (1986)
5.	Maize	34 unadapted accessions	8 testers: 2-synthetic populations; 2-single crosses and 4-inbreds	Grain yield and component traits	Inbreds	To discover un-adopted accessions with favorable alleles require at least two divergent testers that contain an inherently high level of favorable alleles.	Abel and Pollack (1991)
6.	Maize	21 germplasm lines with different levels of inbreeding	7 testers: 5 single crosses,1 synthetic cultivar and 1inbred line	Grain yield and component traits	Single crosses	Single cross testers were suitable for early testing of threeway and double cross hybrids for yield improvement	Castellanos *et al*. (1998)
7.	Maize	36 S_2 progenies of composite (Popcorn)	3 testers: single cross and three way cross hybrids; composite (36 S_2 derived from this composite)	Yield and popping expanssion	Three way cross hybrid	Unrelated testers released greater variability and had greater disrciminating ability.	Pinto *et al*. (2004)

Table 2.3. Genetic studies using North Carolina mating Design-1 (NCD-1) for different traits

Sl. No.	Crop	Genetic Material	Mating Design	Experimental Size	Trait	Genetic Variance	Author
1.	Maize	Three open pollinated varieties	NCD-1	64 M × 4 F=256	Grain yield and days to flowering	Additive > Dominance	Robinson *et al*. (1955)
2.	Maize	Two open pollinated varieties	NCD-1	52 M ×4 F= 208, 64 M × 4 F=256	Grain yield and ear number	Additive and dominance variences, varied with assortative mating	Lindsey *et al*. (1962)
					Days to 50% flowering	Additive > Dominance	
3.	Maize	Open-pollinated variety	NCD-1	125 M × 4 F=500	Grain yield, days to silk and 100- kernel weight	Dominance > Additive	El-rouby *et al*. (1979)
4.	Maize	Composite variety	NCD-1	48 M × 4 F=192	Grain yield 100-kernel weight	Dominance > Additive Additive > Dominance	Shashi and Singh (1985)
5.	Maize	Open-pollinated population	NCD-1	80 M × 4 F=320	Grain yield	Dominance > Additive	Akanvou *et al*. (1997)
6.	Maize	Composite variety	NCD-1	64 M × 4 F=256	Grain yield and days to silk	Dominance > Additive	Zaffar *et al*. (2001)
					Test weight	Additive > Dominance	
7.	Maize	Open-pollinated variety	NCD-1	100 M × 4 F=100	Days to 50% silk	Additive > Dominance	Pereira and Amaral Junior, (2001)
					Grain yield	Dominance > Additive	
8.	Potato	Tetrasomic potato	NCD-1	20 M× 5 F=100	Tuber yield	Additive > Dominance	Ortiz and Golmirzaie (2002)
			NCD-2	16 M × 4 F=64		Dominance > Additive	
9.	Maize	Composite variety	NCD-1	64 M × 4 F=256	Grain yield per plant and 100-grain weight	Additive > Dominance	Marker and Joshi (2005)
10.	Cauliflower	F_2 generation of intervarietal cross	NCD-1	4 M × 4 F=16	Harvest index	Additive > Dominance	Kanwar and Korla (2004)
					Net curd weight and other component traits	Dominance > Additive	
11.	Maize	Open-pollinated variety	NCD-1	75 M × 4 F=300	Grain yield	Dominance > Additive	Badu-Apraku (2007)
					Days to 50% anthesis	Additive > Dominance	

M- Male parents; F- Female parents within each male parent.

Table 2.4. Genotype by environment interaction studies for grain iron (Fe) and zinc (Zn) densities

Sl. No.	Crop	Entries	Genetic material details	Number of Envioronments	Heritability (%) Fe	Heritability (%) Zn	Genotype × environment interaction (GEI)	Author
1.	Pearl millet	30 and 24	S_1 progenies from two populations	2 Seasons	65.3-71.2	64.8-79.7	Significant GEI and highly significant correlation beteween *per se* performance of genotypes in both the environments for Fe (r=0.66) and Zn (r=0.67)	Gupta *et al*. (2009)
2.	Pearl millet	90	Hybrids of diallel cross	2 Seasons	-	-	Significant GEI and highly significant correlation beteween *per se* performance of inbreds in both environments for Fe (r=0.93) and Zn (r=0.86)	Velu *et al*. (2011b)
3.	Pearl millet	72 and 192	two sets of hybrids from line ×tester crosses	2 Seasons	-	-	Significant GEI, hybrids × environments proportion was 19% and 15-30% of that of hybrids for Fe and Zn densities, respectively.	Govindaraj *et al*. (2013)
4.	Rice	85	Near isogenic lines	2 years	72.8	40.6	Significacnt GEI for both Fe and Zn densities	Garcia-oliveira *et al*. (2009)
5.	Rice	10	Commercial genotypes	8-environments	-	-	Significant GEI for Fe density, proportion of G × E was 3 times (19.6%) higher than that of genotypes effect (5.6%)	Suwarto and Nasrullah (2011)
6.	Wheat	22	Wild emmer wheat accessions	Water sufficient and water limited conditions	-	-	Significant G × E interation for both Fe and Zn; and found outstanding accessions under both conditions	Peleg *et al*. (2008)
7.	Wheat	20	Elite lines	10-environments	37	25	Significant GEI, higher environmental influence on Zn than Fe density.	Joshi *et al*. (2010)
8.	Wheat	19	wild emmer wheat accessions	5 locations	36.0	72.0	Significant GEI, magnitude was higher for Fe than Zn density	Gomez-Becerra *et al*. (2010)
9.	Maize	49	Elite late maturing tropical genotypes	3-Locations	-	-	Significant GEI, while genetic component acounted was 12% and 29% for Fe and Zn, respectivley	Oikeh *et al*. (2003)
10.	Maize	30	Diverse genotypes	3-Seasons	-	-	Significant GEI; higher GEI for Fe (58.37%) than Zn (31.77%) density	Prasanna *et al*. (2011)

Table 2.5. Studies on variability and correlation for iron (Fe) and zinc (Zn) densities in different crops

Sl.No.	No. of Entries	Genetic materials details	Density range: Iron (mg kg^{-1})	Density range: Zinc (mg kg^{-1})	Correaltion coefficient	Analytical Technique	Author
PEARL MLLET (*Pennisetum glaucum* (L.) R.Br.)							
1.	120	Hybrids, populations, inbred lines and germplasm accesions	30.1-75.7(45.5)	24.5-64.8(43.9)	0.84**	AAS	Velu *et al*. (2007)
2.	52	Hybrids	46.9-85.0 (63.7)	36.4-69.9 (47.3)	0.65**	AAS	Velu *et al*. (2008a)
3.	68	Improved populations developed by ICRISAT and NARS partners in India and Africa	42.0-79.9 (55.0)	27.2-50.2(38.0)	0.84**	AAS	Velu *et al*. (2008b)
4.	54	30 S_1 from PVGGP-6	29.9-77.2(46.7)	30.7-63.0(44.6)	0.82**	AAS	Gupta *et al*. (2009)
		24 S_1 from IAC-ISC-TCP-1	(37.0)	(37.2)	0.80**		
5.	100	90 F_1 and 10 Inbred lines	34.1-75.8	26.4-52.9	-	AAS	Velu *et al*. (2011b)
6.	796	Advanced breeding lines, population progenies and hybrids	18.0-135.0	22.0-92.0	0.49** to 0.71**	ICP, XRF, NIRS	Rai *et al*. (2012)
7.	160	S_0 (40 entries each from ICTP 8203, JBV3, AIMP 92901, ICMR312)	30.0-122.0	32.0-92.0	0.63** to 0.87**	ICP	Govindaraj *et al*. (2012)
	160	S_1 (40 entries each from ICTP 8203, JBV3, AIMP 92901 and ICMR312)	37.0-133.0	38.0-91.0	0.43** to 0.82**		
8.	309	24 B lines, 21 R lines	34.0 - 102.0	34.0- 84.0	0.86** to 0.90**	AAS	Govindaraj *et al*. (2013)
		264 F_1	30.0 - 80.0	31.0-70.0	0.75** to 0.84**		
SORGHUM [*Sorghum bicolor* (L.) Moench]							
1.	84	Diverse B and R lines, yellow endosperm, high lysine and waxy lines, germplasm and varieties	20.1-37.0 (28.0)	13.4-31.0 (19.0)	0.55**	ICP	Reddy *et al*. (2005)
2.	76	Farmers varieties of northern Benin	30.0-113.0 (59.0)	11.0-44.0 (24.0)	0.17	ICP	Kayode *et al*. (2006)
3.	20	Commercial sorghum cultivars developed in India by private and public sectors	29.8-44.2 (38.8)	22.2-32.9 (27.2)	0.85**	AAS	Ashok Kumar *et al*. (2010)
4.	1394	Germplasm core collection	7.7-132.6 (42.3)	15.1-91.3 (33.5)	0.60**	AAS	Reddy *et al*. (2010)
5.	14	Widely grown varieties of Malawi, Tanzania and Zambia	28.0-63.0 (44.0)	23.0-55.0 (33.0)	0.49**	ICP	Ng'uni *et al*. (2012)
6.	74	59 F_1, 15 inbreds	28.7 - 47.8	21.5 - 55.5	Positive Sig.	AAS	Ashok kumar *et al*. (2013)

Table 2.5. (Cont.)

Sl.No.	Entries	Genetic materials details	Concentration Range: Iron (mg kg^{-1})	Concentration Range: Zinc (mg kg^{-1})	Correaltion coefficient	Analytical Technique	Author
		FINGER MILLET (*Eleusine coracana*)					
1.	622	Gerplasm core collection	21.7-65.2	16.6-25.3	0.28*	AAS	Upadhyaya *et al*. (2011)
		WHEAT (*Triticum aestivum* L.)					
1.	14	US hard red winter varieties from production eras spanning more than a century	24.0-42.8	16.0-33.9	0.55** to 0.71**	ICP	Garvin *et al*. (2006)
2.	243	Bread wheat genotypes-landraces, elite lines, modern cultivars	18.0-88.4	14.0-43.0	0.30** to 0.53**	AAS	Oury *et al*. (2006)
3.	66	Spring and winter common genotypes of central asian breeding program	25.0-56.0 (38.0)	20.0-39.0 (28.0)	0.79**	ICP	Morgounov *et al*. (2007)
4.	119	Doubled haploid population of Hanxuan10 × Lumai 14	-	25.9-50.5 (33.9)	-	ICP	Shi *et al*. (2008)
5.	22	Emmer wheat accessions Dry Condition Wet condition	 52.0-80.0 (68.0) 48-88 (67)	 69.0-139.0 (103.0) 71.0-133.0 (102.0)	 0.57** 0.77**	ICP	Peleg *et al*. (2008)
6.	63	Spring wheat cultivars (56 historical + 7 modern)	28.7-52.2	23.0-43.0	-0.23**	ICP	Murphy *et al*. (2008)
7.	31	Wheat grass (*Thinopyrum elongatum*) x Bread wheat - F_5 lines	42.0-52.6 (46.8)	26.7-35.0 (31.2)	0.58**	ICP	Murphy *et al*. (2009)
8.	150	Diverse origin bread wheat lines	28.8-50.8 (38.2)	13.5-34.5 (21.4)	0.29**	ICP	Zhao *et al*. (2009)
9.	19	Wild emmer wheat accesions	27.0-86.0	39.0-115.0	0.50**	ICP	Gomez-Becerra *et al*. (2010)
10.	73	Wild emmer wheat accesions	16.4-69.8	37.0-112.6	0.40** to 0.67**	ICP	Chatzav *et al*. (2010)
11.	600	Germplasm core collection	26.3-68.8 (39.7)	16.9-60.8 (30.4)	0.81**	ICP	Velu *et al*. (2011a)
12.	40	Wheat cutivars released in Pakistan during last 5 decades	32.0-46.0(38.0)	24.0-36.0(29.0)	0.39*	AAS	Hussain *et al*. (2012)
		RICE (*Oryza sativa* L.)					
1.	90	Australian brown rice	5.0-67.0 (13.0)	13.0-21.0 (16.0)	0.31**	ICP	Marr *et al*. (1995)
2.	1138	Brown rice	6.3-24.4 (12.2)	13.5-58.4 (25.4)	-	ICP	Gregorio *et al*. (2000)
3.	91	6 Black pericarp, 1 white pericarp aromatic rice genotype 42 F_1 progenies 42 F_2 progenies	35.2 -51.2 (44.7) 37.0-52.0 (45.0) 32.2 -54.3 (44.6)	53.0 - 88.9 (65.8) 53.5 - 83.7 (67.0) 52.7 - 89.0 (68.8)	-	AAS	Zhang *et al*. (2004)

Table 2.5. (Cont.)

Sl.No.	Entries	Genetic materials details	Concentration Range Iron (mg kg^{-1})	Zinc (mg kg^{-1})	Correaltion coefficient	Analytical Technique	Author
4.	85	NILs of Teqing × *Oryza rufipogon*	4.9-20.0 (9.6)	13.3-60.1 (27.1)	-0.08 to 0.22*	ICP	Garcia-oliveira *et al*. (2009)
5.	46	Cultivated *indica* and *japonica* rice varieties and germplasm acessions	4.8-22.7(11.3)	14.0-41.7(24.2)	0.71**	AAS	Chandel *et al*. (2010)
	MAIZE (*Zea mays* L.)						
1.	60	B14 x B37 (normal × opaque-2) Segregating (Normal) Segregating (Opaque-2) Homozygous opaque-2 population	 (15.6) (17.7) (23.3)	 (19.4) (23.9) (27.8)	 0.41** 0.52** 0.54**	-	Arnold *et al*. (1977)
2.	1814	Improved genotype and land races (13 trials in Zimbambe and Mexico)	9.6 - 63.2	12.9 - 57.6	-	-	Banziger and Long (2000)
3.	28	28 F_1's of diallel cross	13.6-30.3(21.3)	16.0-23.6(20.2)	0.69**	ICP	Brkic *et al*. (2003)
4.	49	Elite late maturing tropical genotypes	16.8-24.4 (19.7)	16.5-24.6 (20.2)	0.71**	ICP	Oikeh *et al*. (2003)
5.	14	Southern african white grained inbred lines	15.9-28.1 (20.6)	18.2-29.8 (22.9)	0.56* to 0.72**	ICP	Long *et al*. (2004)
6.	36	Diallel direct crosses Grain Fe concentration Ear leaf Fe contration	 45.9-69.1 (53.2) 287.0-653.0 (501.0)	-	-	AAS	Chen *et al*. (2007)
7.	294	F_4 progenies of cross between B84 x Os6-2	16.6 -33.6 (24.2)	16.4 -28.6 (21.7)	0.11	ICP	Simic *et al*. (2009)
8.	224	RIL derived from B73 × Mo17	10.0 - 30.0	-	0.44**	ICP	Lung'aho *et al*. (2011)
9.	42	42 F_1 of QPM diallel cross	12.0-38.5	17.6-49.1	0.43** to 0.64**	AAS	Chakraborti *et al*. (2011)
10.	30	Diverse genotypes	11.3-60.1	14.1-53.0	Non-Significant	AAS	Prasanna *et al*. (2011)

AAS-Atomic Absorption Spetrophotometry; ICP-Inductive Coupled Plasma Spectrometry; XRF-X-Ray Fluorescence spectrometry;
Value in the parantheses is average/mean; *, **- Significant at the 0.05, 0.01 probability levels, respectively.

Table 2.6. Studies on association of grain iron (Fe) and zinc (Zn) densities with 1000-grain weight (GW), grain yield (GY), days to flowering (DF) and plant height (PH)

Sl. No.	Entries	Type of Entries	Plot Size	Trait	GW	GY	DF	PH	Author
	PEARL MLLET (*Pennisetum glaucum* (L.) R.Br.)								
1.	120	Hybrids, populations, inbred lines and germplasm accessions	4rows × 4 m	**Fe**	0.80**	-	-	-	Velu *et al.* (2007)
				Zn	0.85**				
2.	52	Hybrids	2rows × 4 m	**Fe**	0.34*	-	-0.35*	-	Velu *et al.* (2008a)
				Zn	0.35*		-0.22		
3.	259	68 Populations	2rows × 4 m	**Fe**	0.56**	-	-0.29	-	Velu *et al.* (2008b)
				Zn	0.46**		-0.28		
		50 S_1 of ICTP 8203 and 47 S_1 each of CGP, GGP, PVGGP6 populations	1 row × 4 m	**Fe**	0.25 to 0.36*	-	-0.22 to -0.08		
				Zn	0.19 to 0.31*		-0.31 to 0.17		
4.	54	30 S_1 from PVGGP-6 and 24 S_1 from IAC-ISC-TCP-1	3rows × 2 m	**Fe**	0.2 and 0.27	-0.02 and 0.16	-0.20 and 0.40*	-	Gupta *et al.* (2009)
				Zn	0.14 and 0.33	-0.01 and -0.10	-0.17 and 0.26		
5.	178	Hybrids	1 row × 4 m	**Fe**	-0.15 to 0.32	-0.58** to -0.13	-0.59** to -0.05	-	Rai *et al.* (2012)
				Zn	-0.05 to 0.29	-0.32 to 0.17	-0.22 to 0.34		
	SORGHUM [*Sorghum bicolor* (L.) Moench]								
1.	84	Diverse B and R lines, yellow endosperm, high lysine and waxy lines, germplasm and varieties	4rows × 4 m	**Fe**	-0.18	-0.32**	0.18	-0.02	Reddy *et al.* (2005)
				Zn	-0.11	-0.54**	0.12	0.30**	
2.	76	Farmers varieties of northern Benin	-	**Fe**	-0.42**	-	-	-	Kayode *et al.* (2006)
				Zn	0.09				
3.	20	Commercial sorghum cultivars developed in India by private and public sectors	4rows × 2 m	**Fe**	0.28	0.02	0.09	-0.04	Ashok kumar *et al.* (2010)
				Zn	0.22	-0.05	0.16	0.22	
4.	1394	Germplasm core collection	1row × 2 m	**Fe**	-0.13**	-0.16**	0.09**	0.22**	Reddy *et al.* (2010)
				Zn	-0.14**	-0.20**	0.21**	0.38**	
5.	14	Widely grown varieties of Malawi, Tanzania and Zambia	-	**Fe**	-0.33	-	-	-	Ng'uni *et al.* (2012)
				Zn	-0.38*				
	FINGER MILLET (*Eleusine coracana*)								
1.	622	Germplasm core collection	-	**Fe**	-	0.03	-	-	Upadhyaya *et al.* (2011)
				Zn		0.05			

Table 2.6. (Cont.)

Sl. No.	Entries	Type of Entries	Plot Size	Trait	GW	GY	DF	PH	Author
	WHEAT (*Triticum aestivum* L.)								
1.	14	US hard red winter varieties from production eras spanning more than a century	6 rows × 3.3 m	**Fe** **Zn**	-	NS NS	-	-	Garvin *et al.* (2006)
2.	68	Bread wheat genotypes-landraces elite lines, modern cultivars	7 m^2	**Fe** **Zn**	-	-0.51 -0.67	-	-	Oury *et al*. (2006)
3.	25	Spring genotypes of central Asian national breeding program	-	**Fe** **Zn**	-0.26 -0.37	-0.41* -0.64**	0.05 -0.13	-0.60** -0.62**	Morgounov *et al*. (2007)
4.	119	Doubled haploid population of Hanxuan10 × Lumai 14	Per plant basis	**Fe** **Zn**	-	- -0.40*	-	-	Shi *et al*. (2008)
5.	63	Spring wheat cultivars (56 historical + 7 modern)	7 rows × 2.5 m	**Fe** **Zn**	-0.04 0.27**	0.05 -0.06	-	-	Murphy *et al*. (2008)
6.	31	Wheat grass(*Thinopyrum elongatum*) × bread wheat -F_5 lines	4-7 rows × 2.5 m	**Fe** **Zn**	0.47 0.11	0.04 -0.16	-	-	Murphy *et al*. (2009)
7.	150	Diverse bread wheat lines	6 rows × 2 m	**Fe** **Zn**	0.19* -0.05	-0.15 -0.44**	-	0.13 0.28**	Zhao *et al*. (2009)
8.	73	Wild emmer wheat accessions	1 row × 0.4 m	**Fe** **Zn**		0.16 to 0.55** 0.25* to 0.28*	-	-	Chatzav *et al*. (2010)
9.	40	Wheat cultivars released in Pakistan during last 5 decades	6 rows × 5 m	**Fe** **Zn**	-0.29 -0.44**	-0.26 -0.49**	-	0.40** 0.13	Hussain *et al*. (2012)
	MAIZE (*Zea mays* L.)								
1.	60	Segregating populations of B14 × B37	-	**Fe** **Zn**	-0.20 to -0.16 -019 to -012	-	-	-	Arnold *et al.* (1977)
2.	90	Improved genotypes and land races	-	**Fe** **Zn**	-	-0.60* to 0.16 -0.44* to -0.15	-	-	Banziger and Long (2000)
3.	28	F_1 progenies	8 m^2	**Fe** **Zn**	-	-0.37 -0.24	-	-	Brkic *et al*. (2003)
4.	294	F_4 progenies of B84 × Os6-2	1 row × 6 m	**Fe** **Zn**	-	-0.02 to 0.02 -0.02 to 0.02	-	-	Simic *et al*. (2009)
5.	41	Inbred lines	1 row	**Fe** **Zn**	-0.05 -0.09	-0.25* 0.17	0.01 -0.27*	-0.17 0.89**	Chakraborti *et al*. (2009)
6.	224	RIL of B73 x Mo17	-	**Fe** **Zn**	-0.12 -0.05	-	-	-	Lung'aho *et al*. (2011)

*,**- Significant at the 0.05, 0.01 probability levels, respectively; NS- Non-significant.

Table 3.1. Objective-wise summary of genetic material, crossing and evaluation seasons and experimental size used in different studies*

S. No.	Objective	Genetic material	Crossing and evaluation details					Evaluation details					
								Trials	Number of Entries			Plot size	Rep
			S11	R11	S12	R12	S13		Geno types	Checks	Total		
1	Assessment of genetic variation and combining ability of inbred lines by line × tester design	14 B lines (Lines), 14 R lines (Testers)	C RP 8A	E RP 5A	E RP 4C	-	-	L×T hybrids	196	2 (twice)	200	2r×2m	3
						-	-	L×T Parents	28	2	30		
2	Assessment of association of grain iron and zinc densities with agronomic traits	Diverse hybrids from ICRISAT biofortification hybrid breeding program	-	-	-	3 Loc	-	Set-A	32	3	35	2r×4m	3
				-	-	3 Loc	-	Set-B	28	3	31		
3	Study of tester effect on combining ability	28 inbreds of 1st trial and 2 OPV testers (Raj 171 and ICMR 312)	-	C RP 5A	E RP 4C	-	E RP 3B	Topcross hybrids	56	2	58	2r×4m	3
						-		Inbreds	28	2	30	2r×2m	3
4	Assessment of intra-population genetic variation by NCD-1	Base populations- ICTP 8203 and ICMV 221	-	-	C RP 7B	E RP 10B	E RP 8A	ICTP NCD-1	160	-	160	1r×2m	3
				-				ICMV NCD-1	160	-	160		
5	Assessment of intra-population variability for combining ability	Base populations - ICTP 8203 and ICMV 221, Testers- Raj 171 and ICMR 312	-	-	C RP 7B	E RP 10B	E RP 8A	ICTP- Raj Topcross	60	4	64	1r×2m	3
								ICTP-ICMR Topcross	60	4	64		
								ICMV-Raj Topcross	60	4	64		
				-				ICMV -ICMR Topcross	60	4	64		

*RP- Red Precision soils; RP 5A, 8A, 3B, 7B, 10B, 4C- field experimental sites at ICRISAT Patancheru; C- Crossing; E- Evaluation;
Row spacing – 60 cm (in summer season) and 75 cm (in rainy season) and 10-15 cm between plants;
3 Loc-both set-A and B were evaluated in 3- different locations (E1-Patancheru, E2-Ahmadabad, E3-Aligarh, E4-Aurangabad, E5-Dhule) in 2012 rainy season;
R11 and R12- Rainy season of year 2011 and 2012, respectively; S11, S12 and S13- Summer seasons of year 2011, 2012 and 2013, respectively; Rep-Replications; r-Rows, m-Meter.

Table 3.2. Parentage of inbred lines used in combining ability study by line × tester design

ID[a]	Lines/Testers [b]	Parentage [c]
		Lines
1	ICMB 88004	Togo-11-5-2 selection
2	ICMB 92111	(81B× 843B)-11-1-1-B
3	ICMB 92888	(843B× ICMPS 900-9-3-2-2)-41-2-6-2-2
4	ICMB 93222	(26B× 834B)-11-2-B-B
5	ICMB 97111	HTBC-48-B-1-1-1-1
6	ICMB 98222	ARD-288-1-10-1-2(RM)-5
7	ICMB 02555	ICMV 87901-175-2-3-2-B-1
8	ICMB 04888	[(843B× ICTP 8202-161-5)-20-3-B-B-3× B-lines bulk]-2-B-1-3
9	ICMB 05555	[(BSECBPT/91-39× SPF3/S91-116)-15-2-1-4-4× B-lines bulk]-1-B-4-1
10	ICMB 07555	[(843B× ICTP 8202-161-5)-20-3-B-B-3× B-lines bulk]-2-B-1
11	ICMB 07777	{ICMB 99555× [(78-7088/3/SER3 AD//B282/(3/4 EB)× PBLN/S95-359)-19-5-B-B]}-13-2-B-B-B-B
12	ICMB 07999	(HTBC-48-B-1-1-1-5× B-line bulk)-25-1-B-B
13	ICMB 08222	[78-7088/3/SER3 AD//B282/(3/4)EB× PBLN/S95-359]-19-2-B-1-B-B-3
14	ICMB 08333	[ICMB 97444× (843B× 405B)-4]-1-2-B-B-B
		Testers
15	PRP 1	(EERC-HS-29)-B-12-4-1-1
16	PRP 2	(EERC-HS-34)-B-7-2-3-2
17	PRP 3	LaGrap C2-S1-38-2-1-1-1
18	PRP 4	(MC 94 C2-S1-3-2-2-2-1-3-B-B× SDMV 90031 S1-93-3-1-1-3-2-B-2)-B-23-2-2
19	PRP 5	AIMP 92901 S1-15-1-2-3-B-2-B-25-1-1
20	PRP 6	(MC 94 C2-S1-3-2-2-2-1-3-B-B× AIMP 92901 S1-488-2-1-1-4-B-B)-B-8-3-1-3-B-B
21	PRP 7	Jakhrana × SRC II S2-215-3-2-1-B-3
22	PRP 8	(ICMS 7704-S1-127-5-1 × RCB-2 Tall)-B-19-3-2-1-1-1-B
23	PRP 9	MRC S1-9-2-2-B-B-4-B-B
24	IPC 616	[J 260-1× 700557-1-4-10-5-1]-1-2-1-3
25	IPC 843	[(J 834× 700516)]-1-4-4-2-4
26	IPC 1178	(A 836× J 1798-32-2-2)-5-1-1
27	IPC 1354	EICP 8103-5 (Duplicate 001349)
28	IPC 390	(F4FC 1498-1-1-3× J 104)-11-2-1-1

[a] ID- 1-14 lines (B lines) and 15-28 testers (R lines);
[b] PRP-Potential Restorer Parent; ICMB- ICRISAT Millet B-line; IPC- ICRISAT Pollinator Collection.
[c] ICMPS- ICRISAT Millet Pollinator for Smut resistance; HTBC- High-Tillering B-Composite; ARD- Appa Rao, Rai and Djaney; ICMV- ICRISAT Millet Variety; ICTP- ICRISAT Togo Patancheru; BSECBPT- Bold-Seeded Early Composite Best Population Progeny Trial; EB- Ex-Bornu; SPF_3- Seed Parent F_3 Progeny; PBLN-Potential B-line Nursery; EERC- Extra-Early Restorer Composite; LaGrap- Large Grain Population; MC- Medium Composite; SDMV SADCC Millet Variety; AIMP-Aurangabad ICRISAT Millet Population; ICMS- ICRISAT Millet Synthetic; MRC-Mandor Restorer Composite; EICP- Elite ICRISAT Pollinator.

Table 3.3. Pedigree of hybrids used in set-A of association study

ID	B-line		Pollinator
1	ICMA 02333 A4	x	SDMV 90031-S1-11-1-1-1-B-1-B
2	ICMA 96333 A1	x	ICMS 8511 S1-17-2-1-1-4-1-B-3-2-3-B-B
3	ICMA 99444 A4	x	HHVBC tall (C1) S1-33-3-1-1-2-2-2-B-B
4	ICMA 04222 A4	x	(EERC-HS-6)-B-12-1-1-2-B
5	ICMA 93222 A1	x	(EERC-HS-6)-B-12-1-1-2-B
6	ICMA 97444 A1	x	AIMP 92901 S1-520-1-2-3-2-B-B-B-B-2-B
7	ICMA 97222 A1	x	MRC HS-130-2-2-1-B-B-3-B-B-B-1-3-1
8	ICMA 94111 A1	x	AIMP 92901 S1-296-2-1-1-3-B-1-3-B-2
9	ICMA 863 A1	x	(EERC-HS-29)-B-12-4-1-1
10	ICMA 96333 A1	x	(ICMS 7704-S1-127-5-1 × RCB-2 Tall)-B-19-3-3-1-B-1
11	ICMA 96333 A1	x	(IPC 337 ×SDMV 90031-S1-84-1-1-1-1)-2-1-5-P1-1
12	ICMA 97444 A1	x	AIMP 92901 S1-15-1-2-3-B-2-B-25-1-1
13	ICMA 03666 A1	x	ICMR 312 S1-3-2-1-2-2-B-2-1-1
14	ICMA 863 A1	x	[(IPC 1617×SDMV 90031-S1-84-1-1-1-1)×AIMP 92901 S1-296-2-1-1-3-B-1]-3-1-1-4-3
15	ICMA 04222 A4	x	JBV 3 S1 -237-1-3-3-1-B
16	ICMA 96333 A1	x	AIMP 92901 S1-296-2-1-1-3-1-B-3-B-1
17	ICMA 05444 A1	x	AIMP 92901 S1-296-2-1-1-1-B-B-B-B-1
18	ICMA 05444 A1	x	LaGrap C2-S1-38-2-1-1-1
19	ICMA 94333 A1	x	ICMV 96490-S1-15-1-2-3-2
20	ICMA 97444 A1	x	LaGrap C2-S1-52-1-2-1-3
21	ICMA 98222 A1	x	LaGrap C2-S1-96-2-2-1-3
22	ICMA 94333 A1	x	MC 94 C2-S1-3-1-1-4-2-1-B-B-B-B-B
23	ICMA 00222 A1	x	ICMR 312 S1-59-1-5
24	ICMA 02444 A5	x	ICTP 8203 S1 - 26
25	ICMA 04222 A4	x	ICTP 8203 S1-341-B-B-7-1
26	ICMA 02333 A4	x	ICTP 8203 S1-67-B-B-1-1
27	ICMA 03999 A4	x	CGP S1-15
28	ICMA 02333 A4	x	IP No. 13901-3-1
29	ICMA 04999 A1	x	IP No. 8969-1
30	ICMA 02333 A4	x	IP No. 17580-1
31	ICMA 06444 A1	x	(ICMB 04888 x ICMB 02333)-3-1-3-1
32	ICMA 03999 A4	x	{[((MC 94 S1-34-1-B x HHVBC)-16-2-1) × (IP 19626-4-2-3)]-B-28-2-2-3-1-2xICMR 312 S1-3-2-3-2-1-1-B-B-B-B}-B-8
	Checks		
33	Pioneer		86M86
34	Bayer		9444
35	ICRISAT		ICTP 8203

Table 3.4. Pedigree of hybrids used in set-B of association study

ID	A-line		Pollinator
1	ICMA 02333 A4	×	ICMR 312 S1-8-1-1-1-1-B-B-B-1-B (ICMR 08222)
2	ICMA 863 A1	×	ICMR 312 S1-8-1-1-1-1-B-B-B-1-B-B-B
3	ICMA 98222 A1	×	ICMR 312 S1-8-1-1-1-1-B-B-B-1-B
4	ICMA 863 A1	×	ICMR 312 S1-3-2-1-2-2-B
5	ICMA 04777 A4	×	AIMP 92901 S1-520-1-2-3-2-B-B-B-B-2-B
6	ICMA 863 A1	×	MC 94 C2-S1-3-1-1-2-4-B-B-3-B-1
7	ICMA 98222 A1	×	(MC 94 C2-S1-3-2-2-2-1-3-B-B x ICMR 312 S1-3-2-3-2-1-1-B-B)-B-30-3-2
8	ICMA 863 A1	×	(MC 94 C2-S1-3-2-2-2-1-3-B-B x ICMR 312 S1-3-2-3-2-1-1-B-B)-B-22-1-1
9	ICMA 08222 A1	×	MRC S1-156-1-1-1-B-3-B-B-B-8-1-1
10	ICMA 08222 A1	×	LaGrap C2-S1-14-1-2-3-3-2
11	ICMA 05333 A4	×	{((MC 94 S1-34-1-B × HHVBC)-16-2-1) × (IP 19626-4-2-3)]-B-28-3-1-2-2}×{MRC HS 225-3-5-2-B-B-B-B}-B-4-2-1
12	ICMA 05333 A4	×	ICMV 96490-S1-15-1-2-1-1
13	ICMA 02777 A4	×	(MC 94 C2-S1-3-2-2-2-1-3-B-B x ICMR 312 S1-3-2-3-2-1-1-B-B)-B-13-2-2
14	ICMA 02444 A5	×	ICMV 221 S1 - 123
15	ICMA 02333 A4	×	ICMV 221 S1 - 366
16	ICMA 863 A1	×	ICMR 312 S1-59-2-4
17	ICMA 863 A1	×	ICTP 8203 S1-254-B-B-7-1
18	ICMA 863 A1	×	CGP S1-67-1
19	ICMA 06111 A4	×	(ICMB 04888 x ICMB 98222)-10-2-4-3
20	ICMA 02333 A4	×	AIMP 92901 S1-296-2-1-1-3-1-B-3-B
21	ICMA 02333 A4	×	{[((MC 94 S1-34-1-B x HHVBC)-16-2-1) × (IP 19626-4-2-3)]-B-18-2-3-2-2-BxICMR 312 S1-3-2-3-2-1-1-B-B-B-B}-B-9
22	ICMA 05333 A4	×	{[((MC 94 S1-34-1-B x HHVBC)-16-2-1) × (IP 19626-4-2-3)]-B-18-2-3-2-2-BxICMR 312 S1-3-2-3-2-1-1-B-B-B-B}-B-14
23	ICMA 05333 A4	×	{[((MC 94 S1-34-1-B x HHVBC)-16-2-1) × (IP 19626-4-2-3)]-B-18-2-3-2-2-BxICMR 312 S1-3-2-3-2-1-1-B-B-B-B}-B-15
24	ICMA 02333 A4	×	{[((MC 94 S1-34-1-B x HHVBC)-16-2-1) × (IP 19626-4-2-3)]-B-28-2-2-3-1-2xAIMP 92901 S1-296-2-1-1-3-B-1-6-B-B}-B-1
25	ICMA 01444 A4	×	{[((MC 94 S1-34-1-B x HHVBC)-16-2-1) × (IP 19626-4-2-3)]-B-28-2-2-3-1-2xAIMP 92901 S1-296-2-1-1-3-B-1-6-B-B}-B-3
26	ICMA 02333 A4	×	{[((MC 94 S1-34-1-B x HHVBC)-16-2-1) × (IP 19626-4-2-3)]-B-28-2-2-3-1-2xAIMP 92901 S1-296-2-1-1-3-B-1-6-B-B}-B-7
27	ICMA 02333 A4	×	{[((MC 94 S1-34-1-B x HHVBC)-16-2-1) × (IP 19626-4-2-3)]-B-28-2-2-3-1-2xICMR 312 S1-3-2-1-2-2}-B-17
28	ICMA 02333 A4	×	{[((MC 94 S1-34-1-B x HHVBC)-16-2-1) × (IP 19626-4-2-3)]-B-28-2-2-3-1-2xAIMP 92901 S1-296-2-1-1-2-2}-B-6
	Checks		
29	Pioneer		86M86
30	Mahyco		MRB 2210
31	ICRISAT		ICTP 8203

Table 3.5. Pedigree of populations used in studies on assessment of intra-population genetic variation and variability for combining ability

ID	Population	Pedigree
		Base populations
1	ICTP 8203	ICTP 8203 (PI 537113) is an early-maturing, dark gray and large-seeded, open-pollinated, high-yielding variety developed by random mating of five S_2 progenies selected from an Iniadi landrace, originating from northern Togo, at ICRISAT, Patancheru, India (Rai *et al*., 1990).
2	ICMV 221	Bred by random mating 124 selected S_1 progenies of Bold Seeded Early Composite (BSEC) drought trial (Witcombe *et al*., 1997).
		Tester populations
3	ICMR 312	BSEC TCP2 C3. It was developed at ICRISAT by mass selection in BSEC with further progeny testing to improve its male fertility restoration ability and resistance to downy mildew (*Sclerospora graminicola* (Sacc. Schroet.). It is pollen parent of a topcross hybrid ICMH 312 which was developed at ICRISAT and was released in 1993 for cultivation in peninsular India (Witcombe *et al*., 1996).
4	Raj 171	Raj 171 is a medium-maturing, open-pollinated cultivar developed by random mating of eight S_1 progenies from an inter-varietal composite selected at ICRISAT, Patancheru, India (Christinck *et al*., 1990).

Table 3.6. Analysis of variance model for line × tester parental trial for individual environment

Source of Variation	Degrees of freedom	Mean Squares	Expected Mean Squares	F-test	Variance components
Replication (R)	r-1	M1	$\sigma^2_e + g\sigma^2_R$	M1/M6	
Genotype (G)	g-1	M2	$\sigma^2_e + r\sigma^2_G$	M2/M6	$\sigma^2_G = (M2-M6)/r$
Females (F)	f-1	M3	$\sigma^2_e + r\sigma^2_F$	M3/M6	$\sigma^2_F = (M3-M6)/r$
Males (M)	m-1	M4	$\sigma^2_e + r\sigma^2_M$	M4/M6	$\sigma^2_M = (M4-M6)/r$
F vs M	1	M5	$(SS_G - SS_F - SS_M)$	M5/M6	
Error	(g-1) (r-1)	M6	σ^2_e		

Where, $\sigma^2_{F,}$ $\sigma^2_{M\,,}$ $\sigma^2_{G,}$ σ^2_R and σ^2_{e} - refer to the variance estimates of females, males, genotypes (or parents), replications and error, respectively;

Table 3.7. Analysis of variance model for line × tester hybrid trial for individual environment

Source of Variation	Degrees of freedom	Mean Square	Expected Mean Squares	F test	Variance Components
Replication (R)	r-1	M1	$\sigma^2_e+g\sigma^2_R$	M1/M6	
Genotype (G)	g-1	M2	$\sigma^2_e+r\sigma^2_G$	M2/M6	σ^2_G= (M2-M6)/r
Lines(L)	l-1	M3	$\sigma^2_e+r\sigma^2_{LT}+rt\sigma^2_L$	M3/M5	σ^2_L= (M3-M5)/rt
Testers(T)	t-1	M4	$\sigma^2_e+r\sigma^2_{LT}+rl\sigma^2_T$	M4/M5	σ^2_T=(M4-M5)/rl
L × T	(l-1)(t-1)	M5	$\sigma^2_e+r\sigma^2_{LT}$	M5/M6	σ^2_{LT} =(M5-M6)/r
Error	(r-1)(g-1)	M6			

Where, σ^2_L, σ^2_T, σ^2_{LT}, σ^2_G, and σ^2_e - refer to the variance estimates of lines, testers, line × tester, genotype (or hybrids) and error, respectively.

Table 3.8. Analysis of variance model for line × tester parental trial repeated over environments (Random effects model or Model-II)

Source of Variation	Degrees of freedom	Mean Squares	Expected Mean Squares	F-test	Variance components
Season (S)	s-1	M1	$\sigma^2_e + r\sigma^2_{G\times S} + rg\sigma^2_S$	M1/M7	
Replication/S	(r-1) s	M2	$\sigma^2_e + g\sigma^2_{R(S)}$	M2/M11	
Genotype (G)	g-1	M3	$\sigma^2_e + r\sigma^2_{GS} + rs\sigma^2_G$	M3/M7	σ^2_G = (M3-M7)/rs
Females (F)	f-1	M4	$\sigma^2_e + r\sigma^2_{FS} + rs\sigma^2_F$	M4/M8	σ^2_F = (M4-M8)/rs
Males (M)	m-1	M5	$\sigma^2_e + r\sigma^2_{MS} + rs\sigma^2_M$	M5/M9	σ^2_M = (M5-M9)/rs
F vs M	1	M6	$(SS_G - SS_F - SS_M)$	M6/M7	
G × S	(g-1)(s-1)	M7	$\sigma^2_e + r\sigma^2_{GS}$	M7/M11	σ^2_{GS}=(M7-M11)/r
F ×S	(f-1) (s-1)	M8	$\sigma^2_e + r\sigma^2_{FS}$	M8/M11	σ^2_{FS}=(M8-M11)/r
M×S	(m-1) (s-1)	M9	$\sigma^2_e + r\sigma^2_{MS}$	M8/M11	σ^2_{MS}=(M9-M11)/r
(F vs M) × S	1	M10	$(SS_{GS} - SS_{FS} - SS_{MS})$	M10/M11	
Pooled error	(g-1)(r-1) s	M11	σ^2_e		

Where, σ^2_F, σ^2_M, σ^2_G, σ^2_{FS}, σ^2_{MS}, σ^2_{GS}, $\sigma^2_{R(S)}$ and σ^2_e - refer to the variance estimates of females, males, genotypes (or parents), females × seasons, males × seasons, genotypes × seasons, replications within seasons and error, respectively.

Table 3.9. Analysis of variance model for line × tester hybrid trial repeated over environments (Random effects model or Model-II)

Source of Variation	Degrees of freedom	Mean Square	Expected Mean Squares	F test	Variance Components
Season (S)	s-1	M1	$\sigma^2_e+r\sigma^2_{GS}+rg\sigma^2_S$	M1/M7	
Replication/S	(r-1) s	M2	$\sigma^2_e+g\sigma^2_{R(S)}$	M2/M11	
Genotype (G)	g-1	M3	$\sigma^2_e+r\sigma^2_{GS}+rs\sigma^2_G$	M3/M7	σ^2_G= (M3-M7)/rs
Lines(L)	l-1	M4	$\sigma^2_e+r\sigma^2_{LTS}+rs\sigma^2_{LT}+rt\sigma^2_{LS}+rts\sigma^2_L$	(M4+M10)/(M6+M8)	σ^2_L= [(M4+M10)-(M6+M8)]/rts
Testers(T)	t-1	M5	$\sigma^2_e+r\sigma^2_{LTS}+rs\sigma^2_{LT}+rl\sigma^2_{TS}+rls\sigma^2_T$	(M5+M10)/(M6+M9)	σ^2_T=[(M5+M10)-(M6+M9)]/rls
L × T	(l-1)(t-1)	M6	$\sigma^2_e+r\sigma^2_{LTS}+rs\sigma^2_{LT}$	M6/M10	σ^2_{LT} =(M6-M10)/rs
Genotype × Season	(g-1)(s-1)	M7	$\sigma^2_e+r\sigma^2_{GS}$	M7/M11	σ^2_{GS}=(M7-M11)/r
L×S	(l-1) (s-1)	M8	$\sigma^2_e+r\sigma^2_{LTS}+rt\sigma^2_{LS}$	M8/M10	
T × S	(t-1) (s-1)	M9	$\sigma^2_e+r\sigma^2_{LTS}+rl\sigma^2_{TS}$	M9/M10	
L × T × S	(l-1)(t-1) (s-1)	M10	$\sigma^2_e+r\sigma^2_{LTS}$	M10/M11	
Pooled error	(g-1)(r-1) s	M11	σ^2_e		

Where, σ^2_L, σ^2_T, σ^2_{LT}, σ^2_G, σ^2_{LS}, σ^2_{TS}, σ^2_{LTS}, σ^2_{GS}, $\sigma^2_{R(S)}$ and σ^2_e - refer to the variance estimates of lines, testers, line × tester, genotype (or hybrids), lines × seasons, testers × seasons, lines × testers × seasons, genotypes × seasons, replications within seasons and error, respectively.

Table 3.10. Schematic representation of arrangement of crosses (hybrid values) to estimate general combining ability (*gca*) and specific combining ability (*sca*) effects across two environments for a given trait

Lines / Testers	1	2	3	. .	j	. .	*t*	Line Means	Lines *gca* effect (g_i)	Hybrids *sca* effect
1	X_{11}	X_{12}	X_{13}	. .	X_{1j}	. .	X_{1t}	$\mathbf{X_{1.}}$	$X_{1.} - X_{..}$	$X_{1j}= X_{1j}-X_{1.}-X_{.j}+X_{..}$
2	X_{21}	X_{22}	X_{23}	. .	X_{2j}	. .	X_{2t}	$\mathbf{X_{2.}}$	$X_{2.} - X_{..}$	$X_{2j}= X_{2j}-X_{2.}-X_{.j}+X_{..}$
.	.	.	.	. .	.	. .	.	.	.	.
.	.	.	.	. .	.	. .	.	.	.	.
i	X_{i1}	X_{i2}	X_{i3}	. .	X_{ij}	. .	X_{it}	$\mathbf{X_{i.}}$	$X_{i.} - X_{..}$	$X_{ij}=X_{ij}-X_{i.}-X_{.j}+X_{..}$
.	.	.	.	. .	.	. .	.	.	.	.
.	.	.	.	. .	.	. .	.	.	.	.
l	X_{l1}	X_{l2}	X_{l3}	. .	X_{lj}	. .	X_{lt}	$\mathbf{X_{l.}}$	$X_{l.} - X_{..}$	$X_{lj}= X_{lj}- X_{l.}-X_{.j}+X_{..}$
Tester Means	$\mathbf{X_{.1}}$	$\mathbf{X_{.2}}$	$\mathbf{X_{.3}}$	**. .**	$\mathbf{X_{.j}}$	**. .**	$\mathbf{X_{.t}}$	$\mathbf{X_{..}}$		
Testers *gca* effect (g_j)	$X_{.1}-X_{..}$	$X_{.2}-X_{..}$	$X_{.3}-X_{..}$	. .	$X_{.j}-X_{..}$	. .	$X_{.t}-X_{..}$			

Where,

i - denotes number of lines, i=1 to i=*l*,

j - denotes number of testers, j=1 to j=*t*,

$X_{i.}$ - is the mean of the hybrids with i^{th} female (line) averaged over replications, seasons and males,

$X_{.j}$ - is the mean of the hybrids with j^{th} male (tester) averaged over replications, seasons and females,

X_{ij} - is the mean of a given hybrid averaged over replications and seasons, and

$X_{..}$ - experimental mean

Table 3.11. Analysis of variance model for topcrosses for individual environments and repeated over the environments

Individual environment

Source of Variation	**Degrees of freedom**	**Mean Squares**	**Expected Mean Squares**	**F-test**	**Variance components**
Replication (R)	r-1	M1	$\sigma^2_e + g\sigma^2_R$	M1/M3	
Genotype (G)	g-1	M2	$\sigma^2_e + r\sigma^2_G$	M2/M3	σ^2_G = (M2-M3)/r
Error	(g-1) (r-1)	M3	σ^2_e		

Repeated over the environments

Source of Variation	**Degrees of freedom**	**Mean Squares**	**Expected Mean Squares**	**F-test**	**Variance components**
Season (S)	s-1	M1	$\sigma^2_e + r\sigma^2_{GS} + rg\sigma^2_S$	M1/M4	
Replication/S	(r-1) s	M2	$\sigma^2_e + g\sigma^2_{R(S)}$	M2/M5	
Genotype (G)	g-1	M3	$\sigma^2_e + r\sigma^2_{GS} + rs\sigma^2_G$	M3/M4	σ^2_G = (M3-M4)/rs
G × S	(g-1)(s-1)	M4	$\sigma^2_e + r\sigma^2_{GS}$	M4/M5	σ^2_{GS}=(M4-M5)/r
Pooled error	(g-1)(r-1) s	M5	σ^2_e		

Where, $\sigma^2_{R,}$ $\sigma^2_{G,}$ $\sigma^2_{GS,}$ $\sigma^2_{R(S)}$ and σ^2_e - refer to the variance estimates of replications, genotypes, genotypes × seasons, replications within seasons and error, respectively.

Table 3.12. Analysis of variance model for North Carolina mating Design-1 (NCD-1) for replications-in-sets experimental design pooled over sets in one environment

Source of Variation	Degrees of freedom	Mean Squares	Expected Mean Squares	F-test	Variance components
Sets	s-1	M1	$\sigma^2_e + rmf\sigma^2_S$	M1/M5	
Replication/sets	s(r-1)	M2	$\sigma^2_e + mf\sigma^2_R$	M2/M5	
Males/sets	s(m-1)	M3	$\sigma^2_e + r\sigma^2_{F/M} + rf\sigma^2_M$	M3/M4	$\sigma^2_M = (M3-M4)/rf = \frac{1}{4}\sigma^2_A$
Females/males/sets	sm(f-1)	M4	$\sigma^2_e + r\sigma^2_{F/M}$	M4/M5	$\sigma^2_{F/M} = (M4-M5)/r = \frac{1}{4}\sigma^2_A + \frac{1}{4}\sigma^2_D$
Pooled error	s(mf-1)(r-1)	M5	σ^2_e		
Total	srmf-1				

Where, σ^2_M, $\sigma^2_{F/M}$, σ^2_S, σ^2_R and σ^2_e - refer to the variance estimates of males, females within males, sets, replications and error, respectively.

Table 3.13. Analysis of variance model for North Carolina mating Design-1 (NCD-1) for replications-in-sets experimental design pooled over sets and repeated over environments

Source of Variation	Degrees of freedom	Mean Squares	Expected Mean Squares	F-test	Variance components
Environment (E)	e-1	M1	$\sigma^2_e + rmf\sigma^2_E$	M1/M9	
Replication/S/E	se(r-1)	M2	$\sigma^2_e + mf\sigma^2_{R/E}$	M2/M9	
Sets (S)	s-1	M3	$\sigma^2_e + rmf\sigma^2_{SE} + rmfe\sigma^2_S$	M3/M4	
S×E	(s-1)(e-1)	M4	$\sigma^2_e + rmf\sigma^2_{SE}$	M4/M9	
Males/S	s(m-1)	M5	$\sigma^2_e + r\sigma^2_{EF/M} + rf\sigma^2_{EM} + er\sigma^2_{F/M} + erf\sigma^2_M$	(M5+M8)/(M6+M7)	σ^2_M = {(M5+M8)-(M6+M7)}/erf
Females/males/S	ms(f-1)	M6	$\sigma^2_e + r\sigma^2_{EF/M} + er\sigma^2_{F/M}$	M6/M8	$\sigma^2_{F/M}$ = (M6-M8)/re
Males/S × E	s(m-1)(e-1)	M7	$\sigma^2_e + r\sigma^2_{EF/M} + rf\sigma^2_{EM}$	M7/M8	σ^2_{EM}=(M7-M8)/rf
Females/males/S ×E	ms(f-1) (e-1)	M8	$\sigma^2_e + r\sigma^2_{EF/M}$	M8/M9	$\sigma^2_{EF/M}$=(M8-M9)/r
Pooled error	es (r-1) (mf-1)	M9	σ^2_e		
Total	esrmf-1				

Where, σ^2_M, $\sigma^2_{F/M}$, σ^2_S, σ^2_{EM}, $\sigma^2_{EF/M}$, σ^2_{SE}, $\sigma^2_{R/E}$, σ^2_E and σ^2_e - refer to the variance estimates of males, females within males, sets, males × environments, females within males × environments, sets × environments, replications in sets within environments, environments and error, respectively.

Table 4.1. Mean square for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), grain yield (GY) and days to 50% flowering (DF) in the parental lines used in line × tester study of pearl millet, 2011 rainy and 2012 summer seasons, Patancheru

Source of variation	df †	Mean square														
		Fe (mg kg^{-1})			Zn (mg kg^{-1})			GW(g)			GY (t ha^{-1})			DF (d)		
		P	R11	S12	P	R11	S12	P	R11	S12	P	R11	S12	P	R11	S12
Environment (E)	1	4017.42**			6002.45**			16.45*			28.07**			3819.05**		
Replication /E	4(2)	243.54**	99.68*	387.40**	11.17	1.81	20.52	0.17	0.28	0.06	0.58**	0.32	0.85**	0.90	1.58	0.23
Parent (P)	27	958.12**	413.42**	675.78**	324.70**	141.87**	235.00**	18.36**	11.02**	10.70**	1.56	1.26**	1.33**	57.37**	26.19**	49.62**
Female (F)	13	988.05**	408.44**	728.43**	222.28**	88.65**	163.58**	13.78*	13.54**	4.42**	1.74	1.94**	1.74**	31.52	10.74**	34.18**
Male (M)	13	1001.01**	450.09**	674.24**	410.10**	202.27**	276.76**	14.98**	7.38**	9.07**	1.14**	0.63**	0.73**	33.15	24.40**	32.26**
F vs M	1	11.73	1.45	11.35	545.90**	48.53*	620.58**	121.68**	25.58**	113.53**	4.48*	0.61*	3.80**	708.48**	250.30**	476.19**
P× E	27	137.43**			56.84**			3.20**			1.03**			18.44**		
F × E	13	148.72**			29.94*			4.20**			1.89**			13.40**		
M × E	13	136.12**			74.46**			1.33**			0.21			23.51**		
F vs M × E	1	7.46			177.19**			14.44**			0.37			18.01**		
Error	108 (54)	25.60	20.77	30.60	13.40	8.82	18.07	0.41	0.48	0.34	0.14	0.15	0.13	1.13	1.23	1.03

† Values in parentheses indicate individual environment degrees of freedom;

P-Pooled across the environments; R11-2011 rainy season; S12-2012 summer season ;

*,** -Significant at the 0.05, 0.01 probability levels, respectively.

Table 4.2. Mean, range and coefficient of variation (CV) for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), days to 50% flowering (DF) and grain yield (GY) of parental lines and their hybrids included in line × tester study of pearl millet, 2011 rainy and 2012 summer seasons, Patancheru

Trait	ENV	B-line				R-line				Hybrid			
		Min	Max	Mean	CV(%)	Min	Max	Mean	CV(%)	Min	Max	Mean	CV(%)
Fe (mg kg^{-1})	P	30.3	77.2	49.6	10.3	32.0	82.1	49.9	10.3	25.8	64.5	45.3	11.9
	R11	24.0	71.3	45.0	9.6	29.0	75.0	44.9	10.7	23.6	64.6	40.9	11.3
	S12	34.3	83.1	54.1	10.6	35.0	89.2	55.7	9.9	28.0	73.5	49.7	12.3
Zn (mg kg^{-1})	P	27.4	45.3	37.3	10.6	29.0	55.5	40.7	8.2	25.8	48.2	37.1	10.5
	R11	22.9	39.7	32.4	6.8	19.5	49.2	33.9	10.4	20.2	45.4	30.7	9.7
	S12	30.3	51.6	42.3	12.1	33.8	61.9	48.2	6.4	29.6	60.2	43.6	10.6
GW(g)	P	7.4	12.9	10.5	6.7	6.9	11.5	8.8	6.2	8.8	14.3	11.8	5.4
	R11	6.3	13.8	9.9	7.6	6.3	12.1	8.8	6.9	8.6	15.5	12.3	5.2
	S12	8.5	12.8	11.1	5.9	6.6	12.2	8.8	5.5	8.8	13.7	11.3	5.2
GY (t ha^{-1})	P	1.6	3.6	2.5	13.0	1.4	3.0	2.2	18.6	2.3	5.0	4.0	12.5
	R11	1.0	3.9	2.1	13.4	1.2	2.6	1.8	25.0	2.1	5.4	4.2	16.1
	S12	1.2	4.3	3.0	12.0	1.6	3.4	2.6	13.9	2.5	5.1	3.9	13.8
DF (d)	P	46	54	50	1.5	49	59	54	2.4	41	53	48	2.4
	R11	42	49	45	1.8	44	54	49	2.7	38	47	43	2.4
	S12	49	60	54	1.3	54	67	59	2.1	44	60	53	2.4

ENV- Environments; R11-2011 rainy season; S12-2012 summer season; P-Pooled across the environments

Table 4.3. Mean square of line × tester pearl millet hybrids, and genetic components for grain iron (Fe) and zinc (Zn) densities and 1000-grain weight (GW), 2011 rainy and 2012 summer seasons, Patancheru

Source of variation	df †	Mean square								
		Fe (mg kg^{-1})			Zn (mg kg^{-1})			GW (g)		
		P	R11	S12	P	R11	S12	P	R11	S12
Environment (E)	1	22524.46**			48885.46**			313.22**		
Replication / E	4 (2)	62.60	75.80*	49.40	858.30**	14.91	1701.70**	9.08**	6.97**	11.18**
Hybrid (H)	195 (195)	401.68**	208.96**	248.32**	164.66**	76.62**	114.01**	7.69**	5.89**	2.92**
Line (L)	13 (13)	2574.95**	1027.38**	1724.54**	720.86**	298.40**	484.46**	48.63**	39.25**	14.64**
Tester (T)	13 (13)	2470.59**	1447.57**	1134.49**	1324.98**	643.74**	756.55**	42.95**	28.49**	16.50**
(L×T)	169 (169)	77.03**	50.92**	67.25**	32.94**	15.93**	36.43**	1.82**	1.59**	0.96**
H × E	195	55.37**			26.20**			1.12**		
L × E	13	174.76**			62.25**			5.27**		
T ×E	13	111.91**			72.91**			2.05**		
L ×T × E	169	41.61**			19.73**			0.73**		
Error	780 (390)	29.45	21.50	37.50	15.09	8.87	21.40	0.37	0.40	0.34
Genetic components										
σ^2_{GCA}		27.90	28.25	32.43	11.20	10.84	13.91	0.49	0.77	0.35
σ^2_{SCA}		5.90	9.81	9.92	2.20	2.35	5.01	0.18	0.40	0.21
PR= $(2\sigma^2 gca)/(2\sigma^2 gca + \sigma^2 sca)$		0.90	0.85	0.87	0.91	0.90	0.85	0.84	0.80	0.77
% contribution of line σ^2_L		45.03	35.37	52.71	31.15	28.29	32.87	43.41	46.50	36.51
% contibtion of σ^2_T		43.18	50.15	34.28	57.82	62.04	52.19	38.30	33.61	41.26
% contribution of $\sigma^2_{L\times T}$		11.78	14.48	13.01	11.03	9.66	14.93	18.30	19.89	22.22

† Values in parentheses indicate individual environment degrees of freedom;

P- Pooled across the environments; R11-2011 rainy season; S12-2012 summer season ;

*,**-Significant at the 0.05, 0.01 probability levels, respectively; PR-Predictability ratio;

σ^2_{SCA} - Variance attributed to general combining ability; σ^2_{GCA}-Variance attributed to specific combining ability;

σ^2_L , σ^2_T , $\sigma^2_{L \times T}$ - Proportion of contribution of line, tester and line × tester variances to the total genetic variance, respectively.

Table 4.4. Mean square of line × tester pearl millet hybrids and genetic components for grain yield (GY) and days to 50% flowering (DF), 2011 rainy and 2012 summer seasons, Patancheru

Source of variation	df [†]	Mean square					
		GY (t ha^{-1})[‡]			DF (d)		
		P	R11	S12	P	R11	S12
Environment (E)	1	25.12**			27740.53**		
Replication / E	4 (2)	19.26**	0.61	37.92**	149.30**	76.57**	222.04**
Hybrid (H)	195 (195)	1.15**	0.96**	0.66**	27.20**	9.86**	26.52**
Line (L)	13 (13)	3.27**	3.25**	0.96**	191.42**	52.78**	173.45**
Tester (T)	13 (13)	4.66**	3.46**	2.32**	142.20**	54.06**	158.47**
(L×T)	169 (169)	0.72**	0.60**	0.51**	5.73**	3.16**	5.09**
H × E	195	0.47**			9.17**		
L × E	13	0.93**			34.77**		
T ×E	13	1.12**			70.24**		
L ×T × E	169	0.38**			2.50**		
Error	780 (390)	0.25	0.20	0.29	1.37	1.05	1.68
Genetic components							
σ^2_{GCA}		0.03	0.07	0.03	1.32	1.20	3.83
σ^2_{SCA}		0.06	0.13	0.07	0.54	0.70	1.14
PR= $(2\sigma^2 gca)/(2\sigma^2 gca + \sigma^2 sca)$		0.52	0.50	0.42	0.83	0.77	0.87
% contribution of line σ^2_L		21.52	25.80	11.63	48.49	38.54	45.65
% contibtion of σ^2_T		31.45	27.62	35.27	35.93	39.50	41.67
% contribution of $\sigma^2_{L\times T}$		47.03	46.58	53.10	15.58	21.96	12.67

[†] Values in parentheses indicate individual environment degrees of freedom;

P- Pooled across the environments; R11-2011 rainy season; S12-2012 summer season ;

*,**-Significant at the 0.05, 0.01 probability levels, respectively; PR-Predictability ratio;

σ^2_{SCA} -Variance attributed to general combining ability; σ^2_{GCA}-Variance attributed to specific combining ability;

σ^2_L , σ^2_T , $\sigma^2_{L \times T}$ - Proportion of contribution of line, tester and line × tester variances to the total genetic variance, respectively.

Table 4.5. Performance *per se* (mean) of parental lines and their general combining ability (*gca*) effects for grain iron (Fe) and zinc (Zn) densities and 1000-grain weight (GW) in line × tester study of pearl millet, 2011 rainy and 2012 summer seasons, Patancheru

ID [a]	Fe (mg kg^{-1})						Zn(mg kg^{-1})						GW (g)					
	P		R11		S12		P		R11		S12		P		R11		S12	
	Mean	*gca*	Mean	*gca*	Mean	*gca*	Mean	*gca*	Mean	*gca*	Mean	*gca*	Mean	*gca*	Mean	*gca*	Mean	*gca*
Line																		
1	52.6	4.1 **	49.3	4.4 **	56.0	3.8 **	40.0	2.5 **	37.3	1.9 **	42.8	3.1 **	11.0	0.6 **	11.1	0.7 **	10.9	0.4 **
2	30.3	-9.5 **	24.0	-7.5 **	36.5	-11.6 **	27.4	-4.2 **	22.9	-3.3 **	31.9	-5.2 **	7.4	-1.5 **	6.3	-2.0 **	8.5	-1.0 **
3	39.1	-4.8 **	36.9	-3.3 **	41.2	-6.4 **	33.2	-2.9 **	28.4	-2.6 **	38.0	-3.4 **	12.8	0.4 **	13.8	0.3 **	11.9	0.5 **
4	58.6	4.8 **	49.0	4.2 **	68.3	5.4 **	40.9	3.6 **	33.6	3.3 **	48.2	3.9 **	11.4	0.5 **	10.0	0.7 **	12.8	0.2 *
5	39.1	-5.1 **	32.9	-5.0 **	45.4	-5.3 **	30.6	-4.0 **	24.9	-3.7 **	36.2	-4.4 **	12.9	0.1	13.3	0.1	12.6	0.0
6	77.2	7.3 **	71.3	9.0 **	83.1	5.5 **	45.3	2.4 **	39.5	3.6 **	51.0	1.1	10.2	-0.3 **	10.0	-0.3 **	10.4	-0.4 **
7	43.9	0.8	44.0	-1.3 *	43.8	2.8 **	37.1	0.1	31.6	-1.2 **	42.7	1.5 *	10.3	-0.7 **	10.7	-0.7 **	9.9	-0.8 **
8	55.3	1.8 *	50.0	0.8	60.7	2.9 **	45.0	1.6 **	39.7	1.6 **	50.2	1.9 **	9.2	0.7 **	8.3	0.6 **	10.2	0.7 **
9	63.2	7.6 **	53.4	5.5 **	72.9	9.5 **	44.0	3.7 **	36.3	2.4 **	51.6	4.9 **	11.2	1.0 **	10.0	1.3 **	12.4	0.7 **
10	51.1	-1.8 *	44.4	-3.3 **	55.6	-0.3	40.0	0.5	34.1	-0.8 *	46.0	1.7 *	10.9	0.9 **	9.9	0.9 **	11.9	0.8 **
11	43.7	-3.4 **	45.7	-3.2 **	41.6	-3.4 **	32.7	-3.7 **	31.9	-3.4 **	33.5	-3.9 **	8.5	-0.6 **	6.3	-0.8 **	10.6	-0.4 **
12	32.1	-6.6 **	30.0	-5.1 **	34.3	-8.2 **	27.6	-2.6 **	24.9	-1.7 **	30.3	-3.5 **	11.0	-0.4 **	10.5	-0.5 **	11.5	-0.3 **
13	59.8	6.4 **	45.5	5.2 **	74.1	7.8 **	40.7	2.5 **	32.2	2.6 **	49.2	2.4 **	10.8	0.5 **	9.8	0.9 **	11.8	0.1
14	48.5	-1.6 *	53.3	-0.6	43.8	-2.5 **	38.2	0.6	36.4	1.3 **	40.1	0.0	9.6	-1.0 **	8.5	-1.3 **	10.3	-0.6 **
Tester																		
15	43.2	-1.4 *	41.4	-0.4	45.0	-2.4 **	41.7	2.1 **	38.1	2.5 **	45.3	1.7 **	9.4	0.7 **	9.1	0.8 **	9.7	0.6 **
16	82.1	6.4 **	75.0	8.1 **	89.2	4.6 **	55.5	3.1 **	49.2	4.2 **	61.7	2.1 **	8.8	-0.3 **	8.8	-0.5 **	8.7	0.0
17	63.9	9.5 **	59.0	9.8 **	68.8	9.2 **	49.5	6.2 **	45.3	7.6 **	53.7	5.0 **	11.5	0.9 **	12.1	1.1 **	11.0	0.7 **
18	52.1	3.9 **	47.0	5.4 **	57.1	2.4 **	41.5	0.5	33.3	0.8 *	49.8	0.2	11.2	0.7 **	10.3	0.7 **	12.2	0.8 **
19	57.1	5.6 **	53.8	5.3 **	60.4	6.0 **	46.0	3.8 **	40.9	2.9 **	51.1	4.7 **	8.5	0.1	8.3	0.0	8.8	0.1
20	41.6	-2.5 **	47.8	-0.5	35.4	-4.5 **	33.3	-2.9 **	32.8	-2.5 **	33.8	-3.3 **	11.0	0.6 **	11.3	0.8 **	10.8	0.4 **
21	40.0	-2.2 **	34.1	-2.4 **	45.8	-2.0 *	35.6	-1.2 *	28.2	-0.7	43.0	-1.8 **	10.0	0.2 *	9.6	0.2 *	10.4	0.1
22	46.1	1.7 *	37.1	0.4	59.7	3.1 **	37.8	1.8 **	28.1	0.0	52.2	3.6 **	7.6	0.3 **	7.7	0.4 **	7.5	0.3 **
23	43.1	-9.2 **	38.4	-9.3 **	47.7	-9.2 **	31.5	-7.8 **	26.7	-6.8 **	36.3	-8.9 **	6.9	-1.6 **	7.3	-1.7 **	6.6	-1.5 **
24	56.3	1.8 *	43.1	1.5 *	76.0	2.3 **	44.8	0.2	33.4	0.0	61.9	0.6	7.0	-0.8 **	7.4	-0.8 **	6.8	-0.9 **
25	57.8	1.1 *	52.1	0.3	63.4	1.9 *	49.6	2.8 **	39.4	2.2 **	59.9	3.3 **	8.3	-0.2 *	8.5	-0.2 *	8.1	-0.2 **
26	44.4	-0.5	40.0	-2.1 **	48.9	1.1	44.4	1.8 **	35.5	0.0	53.3	3.5 **	7.5	-0.1	7.8	0.0	7.2	-0.1
27	32.0	-7.5 **	29.0	-9.0 **	35.0	-6.1 **	29.0	-5.0 **	19.5	-5.2 **	38.5	-4.8 **	8.0	0.4 **	8.6	0.5 **	7.5	0.3 **
28	39.0	-6.6 **	31.2	-7.2 **	46.8	-6.1 **	29.4	-5.1 **	24.6	-4.9 **	34.2	-5.4 **	7.2	-0.9 **	6.3	-1.3 **	8.1	-0.6 **
SE (mean, *gca*)	2.60	0.59	2.63	0.71	3.19	0.94	1.49	0.42	1.71	0.46	2.45	0.71	0.26	0.07	0.40	0.10	0.34	0.71
r (line, *gca*)		0.93		0.86		0.87		0.90		0.79		0.89		0.60		0.47		0.64
r(tester, *gca*)		0.80		0.83		0.73		0.87		0.88		0.78		0.78		0.79		0.74

[a]1-28 -ID of inbred lines detailed in the table 3.2.; r-Correlation coefficient between mean and *gca*; SE-Standard error; *, **- significant at the 0.05, 0.01 probability levels, respectively; P-Pooled across the environments; R11-2011 rainy season; S12-2012 summer season.

Table 4.6. Performance *per se* (mean) of parental lines and their general combining ability (*gca*) effects for grain yield (GY) and days to 50% flowering (DF) in line × tester study of pearl millet, 2011 rainy and 2012 summer seasons, Patancheru

ID[a]	GY (t ha^{-1})						DF (d)					
	P		**R11**		**S12**		**P**		**R11**		**S12**	
	Mean	*gca*	Mean	*gca*	Mean	*gca*	Mean	*gca*	Mean	*gca*	Mean	*gca*
Line												
1	2.9	-0.03	2.5	0.02	3.2	-0.08	48	-3.6**	47	-2.2**	49	-5.1**
2	2.2	0.12*	2.0	0.09	2.4	0.15*	54	2.1**	47	1.4**	60	2.7**
3	2.3	0.04	3.9	0.18**	1.2	-0.10	48	0.2*	44	0.5**	51	-0.1
4	3.1	0.33**	3.0	0.56**	3.2	0.11	54	2.7**	49	1.7**	59	3.7**
5	3.6	0.01	2.9	0.02	4.3	0.01	48	-0.8**	44	-1.1**	51	-0.5*
6	2.6	-0.08	2.3	-0.17**	2.9	0.01	49	0.3*	47	0.9**	51	-0.4*
7	3.2	0.05	2.9	-0.04	3.6	0.14*	51	0.9**	45	0.3	57	1.6**
8	1.6	-0.23**	1.0	-0.33**	2.2	-0.12	50	0.8**	45	1.0**	56	0.6**
9	2.0	0.01	1.6	0.14*	2.4	-0.11	51	0.3**	46	0.7**	56	-0.1
10	2.3	0.15*	1.5	0.17**	3.1	0.13	46	-1.4**	42	-1.2**	50	-1.7**
11	2.4	-0.05	1.4	-0.08	3.4	-0.01	49	-0.2*	46	0.0	52	-0.5*
12	2.8	0.29**	2.0	0.29**	3.7	0.29**	50	-0.1	44	-0.9**	55	0.7**
13	2.2	-0.37**	1.3	-0.55**	3.0	-0.19*	51	-0.4**	47	-0.4*	55	-0.4*
14	2.3	-0.26**	1.1	-0.28**	3.5	-0.23**	49	-0.7**	43	-0.8**	55	-0.6**
Tester												
15	2.6	0.22**	2.2	0.25**	3.0	0.19*	57	0.6**	54	1.4**	59	-0.2
16	1.8	-0.20**	1.3	-0.52**	2.3	0.12	53	-0.8**	47	-2.0**	59	0.4*
17	2.2	-0.44**	1.8	-0.48**	2.6	-0.39**	49	-1.7**	44	-1.0**	55	-2.4**
18	3.0	-0.01	2.6	-0.07	3.4	0.06	54	1.2**	47	0.1	60	2.3**
19	2.4	0.04	2.2	0.10	2.7	-0.03	55	0.7**	49	0.6**	61	0.7**
20	2.4	0.24**	1.9	0.23**	3.0	0.26**	54	1.1**	46	0.0	61	2.1**
21	2.6	0.10*	2.3	0.02	2.9	0.18*	51	-0.5**	46	-0.8**	57	-0.3
22	2.3	-0.07	2.1	0.05	2.5	-0.20**	53	-1.0**	49	-0.1	57	-1.8**
23	2.0	0.47**	1.5	0.54**	2.5	0.40**	56	-1.6**	53	-1.0**	59	-2.2**
24	1.8	0.05	1.7	-0.01	2.0	0.12	54	-0.6**	47	-1.3**	61	0.3
25	2.7	-0.11*	2.4	-0.02	2.9	-0.19**	53	0.3**	50	1.1**	56	-0.4*
26	1.7	0.14**	1.2	0.21**	2.0	0.07	59	2.9**	51	2.2**	67	3.7**
27	1.4	-0.30**	1.3	-0.30**	1.6	-0.30**	56	0.6**	50	0.3*	62	0.9**
28	2.1	-0.14**	1.3	0.00	3.0	-0.28**	53	-1.4**	51	0.3*	54	-3.1**
SE (mean, *gca*)	0.15	0.05	0.22	0.07	0.25	0.08	0.43	0.13	0.64	0.16	0.58	0.20
r (lines, *gca*)		0.47		0.55		0.30		0.77		0.51		0.84
r (testers, *gca*)		0.22		0.15		0.18		0.65		0.55		0.85

[a]1-28 -ID of inbred lines detailed in the table 3.2.; r-Correlation coefficient between mean and *gca*; SE-Standard error; *, **- Significant at the 0.05, 0.01 probability levels, respectively; P-Pooled across the environments; R11-2011 rainy season; S12-2012 summer season.

Table 4.7. Mean performance of hybrids and their parental lines, and *gca* effects of parental lines for high *per se* performing hybrids over trial mean across the environments (2011 rainy and 2012 summer seasons) for both grain yield (≥4.1 t ha^{-1}) and Fe density (≥46 mg kg^{-1}) in line × tester study, Patancheru

Sl. No.	Hybrid[a]			Performance *per se*					*gca* effects			
									Fe (mg kg^{-1})		GY (t ha^{-1})	
	P1		P2	Fe (mg kg^{-1})	Zn (mg kg^{-1})	GW (g)	GY (t ha^{-1})	DF (d)	P1	P2	P1	P2
1	4	×	15	48.0	43.0	12.6	5.0	52	4.8**	-1.4**	0.33**	0.22**
2	4	×	19	58.0	43.0	11.8	4.9	52	4.8**	5.6**	0.33**	0.04
3	4	×	20	50.0	36.0	13.0	4.8	53	4.8**	-2.5**	0.33**	0.24**
4	9	×	20	47.0	36.0	13.5	4.5	50	7.6**	-2.5**	0.01	0.24**
5	6	×	24	55.0	41.0	10.1	4.5	48	7.3**	1.8**	-0.08	0.05
6	4	×	24	52.0	42.0	11.2	4.5	50	4.8**	1.8**	0.33**	0.05
7	11	×	18	48.0	32.0	12.2	4.5	48	-3.4**	3.9**	-0.05	-0.01
8	9	×	24	55.0	40.0	11.9	4.5	47	7.6**	1.8**	0.01	0.05
9	4	×	18	51.0	41.0	13.3	4.5	52	4.8**	3.9**	0.33**	-0.01
10	4	×	26	48.0	39.0	12.0	4.4	53	4.8**	-0.5	0.33**	0.14**
11	3	×	16	55.0	43.0	12.5	4.4	50	-4.8**	6.4**	0.04	-0.2**
12	4	×	21	46.0	39.0	12.0	4.4	50	4.8**	-2.2**	0.33**	0.1*
13	6	×	15	49.0	41.0	11.9	4.4	49	7.3**	-1.4**	-0.08	0.22**
14	7	×	22	47.0	37.0	11.0	4.4	49	0.8	1.7**	0.05	-0.07
15	9	×	21	57.0	45.0	13.7	4.4	47	7.6**	-2.2**	0.01	0.1*
16	13	×	15	47.0	41.0	13.4	4.3	48	6.4**	-1.4**	-0.37**	0.22**
17	4	×	16	59.0	46.0	12.8	4.3	50	4.8**	6.4**	0.33**	-0.2**
18	10	×	15	47.0	45.0	12.9	4.2	47	-1.8**	-1.4**	0.15**	0.22**
19	14	×	19	48.0	39.0	10.9	4.2	49	-1.6**	5.6**	-0.26**	0.04
20	9	×	25	53.0	44.0	12.4	4.2	49	7.6**	1.1*	0.01	-0.11*
21	5	×	19	46.0	35.0	12.2	4.2	48	-5.1**	5.6**	0.01	0.04
22	9	×	22	61.0	45.0	12.8	4.2	48	7.6**	1.7**	0.01	-0.07
23	1	×	22	55.0	44.0	12.1	4.2	43	4.1**	1.7**	-0.03	-0.07
24	1	×	21	46.0	38.0	12.5	4.2	45	4.1**	-2.2**	-0.03	0.1*
25	1	×	19	48.0	40.0	13.3	4.2	45	4.1**	5.6**	-0.03	0.04
26	8	×	20	50.0	37.0	13.3	4.2	48	1.8**	-2.5**	-0.23**	0.24**
27	2	×	16	48.0	36.0	10.2	4.1	49	-9.5**	6.4**	0.12*	-0.2**
28	7	×	24	47.0	38.0	10.5	4.1	50	0.8	1.8**	0.05	0.05
29	6	×	25	60.0	46.0	11.3	4.1	50	7.3**	1.1*	-0.08	-0.11*
30	1	×	25	59.0	47.0	12.1	4.1	46	4.1**	1.1*	-0.03	-0.11*
31	13	×	20	46.0	34.0	13.4	4.1	50	6.4**	-2.5**	-0.37**	0.24**
32	1	×	24	56.0	38.0	11.3	4.1	44	4.1**	1.8**	-0.03	0.05
33	9	×	26	52.0	43.0	12.9	4.1	50	7.6**	-0.5	0.01	0.14**
34	8	×	21	46.0	39.0	12.4	4.1	48	1.8**	-2.2**	-0.23**	0.1*
35	8	×	19	57.0	46.0	12.9	4.1	50	1.8**	5.6**	-0.23**	0.04
	Min			46.0	32.0	10.1	4.1	43				
	Max			61.0	47.0	13.7	5.0	53				
	Mean			51.3	40.5	12.2	4.3	49				

[a]1-28 -ID of inbred lines detailed in the table 3.2.;

*,** - Significant at the 0.05, 0.01 probability levels, respectively; Fe, Zn- Iron and Zn densities; DF- Days to 50% flowering; GY-Grain yield; GW- 1000-grain weight

Table 4.8. Mean performance of hybrids and their parental lines, and *gca* effects of parental lines for grain iron (Fe) and zinc (Zn) densities for 5% top and 5% bottom ranking hybrids in line × tester study of pearl millet, 2011 rainy and 2012 summer seasons, Patancheru

Fe (mg kg^{-1})								Zn (mg kg^{-1})							
Hybrid[a]			Performance *per se* [b]			*gca* [c]		Hybrid[a]			Performance *per se* [b]			*gca* [c]	
P_1		P_2	F_1	P_1	P_2	P_1	P_2	P_1		P_2	F_1	P_1	P_2	P_1	P_2
Top 5% hybrids															
13	×	19	64.5	59.8	57.1	6.4^{**}	5.6^{**}	4	×	22	48.2	40.9	37.8	3.6^{**}	1.8^{**}
6	×	19	63.8	77.2	57.1	7.3^{**}	5.6^{**}	13	×	19	48.1	40.7	46.0	2.5^{**}	3.8^{**}
6	×	17	63.3	77.2	63.9	7.3^{**}	9.5^{**}	8	×	17	47.9	45.0	49.5	1.6^{**}	6.2^{**}
13	×	17	63.1	59.8	63.9	6.4^{**}	9.5^{**}	1	×	25	46.9	40.0	49.6	2.5^{**}	2.8^{**}
9	×	17	61.3	63.2	63.9	7.6^{**}	9.5^{**}	13	×	22	46.8	40.7	37.8	2.5^{**}	1.8^{**}
9	×	22	61.2	63.2	46.1	7.6^{**}	1.7^{**}	9	×	17	46.7	44.0	49.5	3.7^{**}	6.2^{**}
6	×	18	61.2	77.2	52.1	7.3^{**}	3.9^{**}	13	×	17	46.5	40.7	49.5	2.5^{**}	6.2^{**}
4	×	17	61.1	58.6	63.9	4.8^{**}	9.5^{**}	6	×	17	46.5	45.3	49.5	2.4^{**}	6.2^{**}
13	×	18	60.9	59.8	52.1	6.4^{**}	3.9^{**}	4	×	17	46.4	40.9	49.5	3.6^{**}	6.2^{**}
6	×	25	60.2	77.2	57.8	7.3^{**}	1.1^{*}	6	×	25	46.2	45.3	49.6	2.4^{**}	2.8^{**}
Bottom 5% hybrids															
5	×	23	32.8	39.1	43.1	-5.1^{**}	-9.2^{**}	5	×	28	28.1	30.6	29.4	-4.0^{**}	-5.1^{**}
2	×	20	31.8	30.3	41.6	-9.5^{**}	-2.5^{**}	5	×	27	27.8	30.6	29.0	-4.0^{**}	-5.0^{**}
14	×	23	31.7	48.5	43.1	-1.6^{**}	-9.2^{**}	3	×	23	27.5	33.2	31.5	-2.9^{**}	-7.8^{**}
10	×	28	30.7	51.1	39.0	-1.8^{**}	-6.6^{**}	11	×	23	27.4	32.7	31.5	-3.7^{**}	-7.8^{**}
2	×	28	30.6	30.3	39.0	-9.5^{**}	-6.6^{**}	2	×	28	27.2	27.4	29.4	-4.2^{**}	-5.1^{**}
3	×	27	30.5	39.1	32.0	-4.8^{**}	-7.5^{**}	12	×	23	26.8	27.6	31.5	-2.6^{**}	-7.8^{**}
2	×	27	30.5	30.3	32.0	-9.5^{**}	-7.5^{**}	3	×	27	26.7	33.2	29.0	-2.9^{**}	-5.0^{**}
12	×	27	29.7	32.1	32.0	-6.6^{**}	-7.5^{**}	5	×	23	26.2	30.6	31.5	-4.0^{**}	-7.8^{**}
2	×	22	29.2	30.3	46.1	-9.5^{**}	1.7^{**}	2	×	23	25.9	27.4	31.5	-4.2^{**}	-7.8^{**}
2	×	23	25.8	30.3	43.1	-9.5^{**}	-9.2^{**}	7	×	23	25.8	37.1	31.5	0.1	-7.8^{**}

[a]1-28 -ID of inbred lines detailed in the table 3.2.; [b] Mean performance at two environments (2011 rainy season and 2012 summer season); [c] *gca* -General combining ability effects;
*,** -Significant at the 0.05, 0.01 probability levels, respectively.

Table 4.9. Correlation among grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), grain yield (GY) and days to 50% flowering (DF) in parents (below the diagonal) and hybrids (above the diagonal) in line × tester study of pearl millet, 2011 rainy and 2012 summer seasons, Patancheru

Season	Trait	Fe (mg kg^{-1})	Zn (mg kg^{-1})	GW(g)	GY (t ha^{-1})	DF (d)
P	Fe	1	0.88** (0.71**)	0.42** (0.003)	-0.29** (-0.13)	-0.03 (0.04)
	Zn	0.88** (0.91**)[a]	1	0.43 **(-0.02)	-0.26** (-0.14)	0.06 (0.11)
	GW	0.11 (0.51**)	0.002 (0.54**)	1	-0.05 (-0.21)	-0.03 (-0.15)
	GY	-0.11 (-0.41*)	-0.18 (-0.35)	0.58** (0.21**)	1	0.14* (-0.09)
	DF	-0.11 (-0.05)	0.09 (0.05)	-0.63** (0.003)	-0.35 (0.27)	1
R11	Fe	1	0.85**	0.38**	-0.26**	-0.08
	Zn	0.90**	1	0.39**	-0.23**	0.01
	GW	0.14	0.10	1	0.06	-0.03
	GY	-0.10	-0.13	0.64**	1	0.11
	DF	-0.14	-0.07	-0.52**	-0.13	1
S12	Fe	1	0.86**	0.32**	-0.25**	-0.02
	Zn	0.84**	1	0.34**	-0.29**	0.07
	GW	0.04	-0.19	1	-0.10	-0.03
	GY	-0.15	-0.31	0.47*	1	0.12
	DF	-0.06	0.23	-0.53**	-0.37*	1

[a] Values outside the parentheses are phenotypic correlations for performance *per se*; values within the parentheses are correlations between *gca* effects in parents and between *sca* effects in hybrids;

P- Pooled across the seasons; R11- 2011 rainy season; S12- 2012 summer season;

*,** -Significant at the 0.05, 0.01 probability levels, respectively.

Table 4.10. Mean square for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), grain yield (GY), days to 50% flowering (DF), plant height (PH), panicle length (PL) and effective tillers (ET) for individual environments among set-A and set-B hybrids of pearl millet, 2012 rainy season

Trait	Source of variation	Set-A				Set-B			
		Mean square				Mean square			
		df	E1	E2	E3	df	E1	E4	E5
Fe ($mg\ kg^{-1}$)	Replication	2	22.5	291.6 **	159.0 **	2	6.7	72.4	109.9
	Genotype	31	162.7 **	168.9 **	211.7 **	27	142.1 **	213.3 **	156.1 **
	Error	62	15.2	33.9	26.1	54	20.9	42.6	54.2
Zn ($mg\ kg^{-1}$)	Replication	2	9.1	19.6	60.0 **	2	54.4 **	163.0 **	0.5
	Genotype	31	25.8	61.7 **	15.3 **	27	47.2 **	44.2 **	58.2 **
	Error	62	10.1	27.2	2.7	54	7.7	20.5	18.5
GW (g)	Replication	2	0.9	0.6	3.7 *	2	0.3	5.0	18.8 **
	Genotype	31	11.0 **	9.5 **	8.2 **	27	17.3 **	16.6 **	9.3 **
	Error	62	1.4	1.5	1.0	54	2.5	2.5	3.4
GY ($t\ ha^{-1}$)	Replication	2	0.29	0.69 **	0.90	2	0.44	0.26	0.29
	Genotype	31	0.55 **	1.56 **	0.84 **	27	0.62 **	2.15 **	0.58 *
	Error	62	0.16	0.12	0.31	54	0.14	0.34	0.30
DF (d)	Replication	2	1.5	2.5 *	5.5	2	0.2	1.9	5.6
	Genotype	31	14.7 **	47.3 **	33.5 **	27	17.1 **	10.1 **	18.2 **
	Error	62	0.9	0.7	2.0	54	0.5	1.8	2.2
PH (cm)	Replication	2	211.2	188.3	25.2	2	53.9	12.6	125.9
	Genotype	31	282.8 **	1772.0 **	1136.3 **	27	241.7 **	903.0 **	739.2 **
	Error	62	96.1	197.7	48.1	54	80.4	53.4	138.9
PL (cm)	Replication	2	2.7	22.0 **	4.0	2	1.3	2.4	0.2
	Genotype	31	5.9 **	15.4 **	12.3 **	27	35.2 **	26.1 **	23.2 **
	Error	62	1.7	2.6	1.8	54	4.1	2.3	2.9
ET (no.)	Replication	2	0.16 *	0.10	0.08	2	0.05	0.36	0.01
	Genotype	31	0.19 **	0.09 **	0.07 **	27	0.09 **	0.27 **	0.03
	Error	62	0.05	0.04	0.03	54	0.02	0.09	0.02

*,** - Significance at the 0.05, 0.01 levels of significance, respectively;

E1 -Patancheru (common location for Trial-A and B); E2-Ahmedabad; E3-Aligarh; E4-Aurangabad; E5-Dhule.

Table 4.11. Mean square across the locations for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), grain yield (GY), days to 50% flowering (DF), plant height (PH), panicle length (PL) and effective tillers (ET) among set-A and set-B hybrids of pearl millet, 2012 rainy season

Hybrid	Source of variation	df	Fe (mg kg^{-1})	Zn (mg kg^{-1})	GW (g)	GY (t ha^{-1})	DF (d)	PH (cm)	PL (cm)	ET (no.)
Set-A	Environment (E)	2	3907.58 **	4420.36 **	678.73 **	27.12 **	896.36 **	28292.64 **	412.31 **	2.07 **
	Replication/E	6	157.66 **	29.58 *	1.70	0.63 **	3.20 *	141.55	9.57 **	0.11 **
	Hybrid (H)	31	394.69 **	60.34 **	21.75 **	1.94 **	82.76 **	2355.18 **	22.97 **	0.24 **
	H × E	62	74.33 **	21.21 **	3.51 **	0.51 **	6.38 **	417.96 **	5.37 **	0.06 *
	Error	186	25.07	13.32	1.29	0.20	1.20	113.97	2.07	0.04
Set-B	Environment (E)	2	4839.95 **	2184.99 **	82.35 **	28.92 **	1458.21 **	43191.57 **	280.36 **	1.65 **
	Replication /E	6	63.02	72.64 **	8.04 *	0.33	2.54	64.11	1.30	0.14 **
	Hybrid	27	386.06 **	89.04 **	35.51 **	1.67 *	40.05 **	1395.65 **	78.73 **	0.24 **
	H × E	54	67.13 **	30.30 **	3.85	0.84 **	2.66 **	244.12 **	2.86	0.07 **
	Error	162	39.11	15.55	2.78	0.26	1.52	90.91	3.09	0.04

*, **- Significant at the 0.05, 0.01probability levels, respectively

Table 4.12. Mean, range and coefficient of varition (CV) for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), grain yield (GY), days to 50% flowering (DF), plant height (PH), panicle length (PL) and effective tillers (ET) among set-A and set-B hybrids, 2012 rainy season

Set-A	E1					E2					E3					AA				
Trait	Min	Max	Mean	FD	CV	Min	Max	Mean	FD	CV	Min	Max	Mean	FD	CV	Min	Max	Mean	FD	CV
Fe (mg kg^{-1})	38	75	55	1.97	7.0	36	66	49	1.85	11.9	48	84	62	1.75	8.3	45	67	55	1.48	9.0
Zn (mg kg^{-1})	24	37	31	1.51	10.3	27	46	35	1.72	14.8	18	28	22	1.58	7.4	25	34	29	1.39	12.5
GW (g)	13	20	17	1.56	7.0	9	16	12	1.67	10.1	10	15	12	1.55	8.3	11	17	14	1.54	8.3
GY (t ha^{-1})	2.66	4.29	3.42	1.61	11.9	1.11	3.82	2.41	3.43	14.1	2.20	4.15	3.21	1.88	17.4	2.02	3.94	3.02	1.95	14.7
DF (d)	37	46	42	1.26	2.3	40	58	48	1.47	1.7	39	54	45	1.36	3.1	40	53	45	1.32	2.4
PH (cm)	155	197	177	1.27	5.5	160	252	209	1.57	6.7	163	238	203	1.46	3.4	163	226	196	1.39	5.4
PL (cm)	16	21	18	1.34	7.2	15	24	21	1.59	7.7	19	26	23	1.41	6.0	17	22	21	1.31	7.0
ET (no.)	1.13	2.07	1.53	1.84	14.2	0.91	1.63	1.24	1.79	15.1	1.02	1.54	1.31	1.51	12.6	1.04	1.70	1.36	1.64	14.0

Set-B	E1					E4					E5					AB				
Trait	Min	Max	Mean	FD	CV	Min	Max	Mean	FD	CV	Min	Max	Mean	FD	CV	Min	Max	Mean	FD	CV
Fe (mg kg^{-1})	46	73	59	1.59	7.8	49	89	73	1.82	8.9	33	74	61	2.28	12.0	44	76	64	1.72	9.7
Zn (mg kg^{-1})	25	39	32	1.55	8.6	33	48	41	1.48	11.1	32	52	41	1.63	10.5	32	44	38	1.39	10.4
GW (g)	11	20	16	1.77	9.2	11	19	15	1.73	10.2	11	17	14	1.58	13.1	12	18	15	1.55	11.0
GY (t ha^{-1})	2.62	4.57	3.55	1.74	10.5	2.35	6.03	4.65	2.57	12.6	2.75	4.37	3.73	1.59	14.8	3.04	4.64	3.98	1.53	12.9
DF (d)	38	48	43	1.28	1.7	48	55	52	1.15	2.6	44	53	49	1.21	3.1	43	52	48	1.19	2.6
PH (cm)	172	207	188	1.20	4.8	182	251	221	1.38	3.3	205	260	232	1.27	5.1	186	234	214	1.26	4.5
PL (cm)	16	29	22	1.87	9.4	20	32	25	1.63	6.1	20	33	25	1.63	6.8	19	31	24	1.69	7.4
ET (no.)	0.83	1.83	1.23	2.20	12.7	1.04	2.35	1.47	2.26	20.6	1.08	1.47	1.23	1.36	10.3	1.11	1.87	1.31	1.69	16.0

FC- Fold difference; E1 -Patancheru (common location for Trial-A and B); E2-Ahmedabad;E3-Aligarh; E4-Aurangabad; E5-Dhule; AA-Across the environments of hybrid set-A; AB- Across the environments of hybrid set-B.

Table 4.13. Correlation coefficients among grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), grain yield (GY), days to 50% flowering (DF), plant height (PH), panicle length (PL) and effective tillers (ET) in individual and across the environments of set-A (below diagonal) and set-B (above diagonal) hybrids of pearl millet, 2012 rainy season

		Fe ($mg\ kg^{-1}$)	**Zn ($mg\ kg^{-1}$)**	**GW (g)**	**GY ($t\ ha^{-1}$)**	**DF (d)**	**PH (cm)**	**PL (cm)**	**ET (no.)**	
E1	Fe	**1**	0.52**	-0.16	-0.50**	-0.57**	-0.27	-0.61**	0.19	E1
	Zn	0.51**	**1**	0.44*	-0.23	-0.32	0.19	-0.37*	0.09	
	GW	0.25	0.21	**1**	0.23	-0.19	0.27	-0.12	0.15	
	GY	-0.47**	-0.19	-0.27	**1**	0.31	0.52**	0.41*	0.01	
	DF	-0.49**	-0.19	-0.27	0.80**	**1**	0.46*	0.69**	-0.55**	
	PH	-0.02	0.06	-0.19	0.52**	0.52**	**1**	0.26	-0.32	
	PL	-0.26	-0.21	-0.35*	0.53**	0.41*	0.43*	**1**	-0.26	
	ET	-0.09	-0.03	0.24	-0.31	-0.34	-0.48**	-0.30	**1**	
E2	Fe	**1**	0.61**	-0.04	-0.25	-0.10	-0.11	-0.28	-0.23	E4
	Zn	0.63**	**1**	0.38*	-0.18	-0.37*	-0.14	-0.23	0.34	
	GW	-0.08	0.01	**1**	0.14	-0.27	0.24	0.02	0.34	
	GY	-0.36*	-0.23	0.20	**1**	0.70**	0.62**	0.65**	-0.09	
	DF	-0.46**	-0.33	0.44*	0.74**	**1**	0.64**	0.58**	-0.64**	
	PH	-0.37*	-0.23	0.44*	0.78**	0.83**	**1**	0.26	-0.28	
	PL	-0.51**	-0.30	0.27	0.39*	0.38*	0.56**	**1**	-0.29	
	ET	0.39*	0.35*	-0.36*	-0.41*	-0.67**	-0.63**	-0.54**	**1**	
E3	Fe	**1**	0.65**	0.09	-0.08	-0.06	-0.03	-0.34	-0.25	E5
	Zn	0.49**	**1**	0.36	-0.10	-0.10	0.05	-0.04	-0.12	
	GW	0.20	0.35*	**1**	0.11	-0.36	0.29	-0.23	0.21	
	GY	-0.24	0.13	0.15	**1**	0.22	0.26	0.06	0.25	
	DF	-0.19	0.32	-0.16	0.37*	**1**	0.45*	0.43*	-0.28	
	PH	-0.05	0.46**	0.02	0.50**	0.82**	**1**	0.01	-0.12	
	PL	-0.06	0.13	-0.14	0.24	0.42*	0.56**	**1**	-0.03	
	ET	0.00	-0.02	-0.01	0.16	-0.31	-0.23	-0.28	**1**	
AA	Fe	**1**	0.62**	-0.09	-0.43*	-0.25	-0.19	-0.48**	-0.03	AB
	Zn	0.60**	**1**	0.42*	-0.25	-0.35	0.04	-0.30	0.35	
	GW	0.10	0.12	**1**	0.08	-0.30	0.26	-0.11	0.34	
	GY	-0.50**	-0.15	0.01	**1**	0.63**	0.55**	0.59**	-0.08	
	DF	-0.45**	-0.16	0.04	0.73**	**1**	0.59**	0.62**	-0.61**	
	PH	-0.29	-0.06	0.09	0.72**	0.81**	**1**	0.15	-0.27	
	PL	-0.34	-0.26	0.00	0.46**	0.42*	0.61**	**1**	-0.26	
	ET	0.11	0.10	-0.07	-0.24	-0.48**	-0.46**	-0.39*	**1**	

E1- Patancheru; E2-Ahmadabad; E3-Aligarh; E4-Aurangabad; E5-Dhule; AA-Across the environments of hybrids set-A; AB-Across the environments of set-B;
*,**- Significant at the 0.05, 0.01 probability levels, respectively.

Table 4.14. Mean square for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), grain yield (GY) and days to 50% flowering (DF) among B-lines and their topcrosses, 2012 summer and 2013 summer seasons, Patancheru

		Mean square														
		Fe (mg kg^{-1})			Zn (mg kg^{-1})			GW (g)			GY (t ha^{-1})			DF (d)		
Source	df [†]	P	S12	S13	P	S12	S13	P	S12	S13	P	S12	S13	P	S12	S13
Environment (E)	1	506.33			2106.65**			13.0*			19.52**			829.71**		
Replication/ E	4 (2)	96.97**	191.11**	2.83	62.12	15.1	109.13	0.38	0.38	0.37	0.13	0.18	0.08	0.92	0.67	1.17
B-lines (B)	13	1416.82**	728.43**	896.76**	398.08*	163.58**	363.82**	7.28*	4.34**	5.48**	1.92**	1.74*	0.65*	69.71**	34.18**	37.38**
B × E	13	208.44**			128.79**			2.54**			0.26			1.84**		
Error	52 (26)	26.27	32.84	18.84	44.0	26.24	62.46	0.61	0.47	0.76	0.19	0.13	0.27	0.57	0.46	0.68
Environment (E)	1	15.23			758.37**			12.03**			1.77**			911.68**		
Replication /E	4 (2)	8.73	3.47	13.99	40.95*	56.9**	25	0.14	0.17	0.12	0.79*	0.96**	0.62	4.64*	3.17	6.12**
Raj 171 topcross (TC1)	13	230.42**	146.54**	133.82**	122.5*	67.95**	96.41**	2.72**	1.1**	2.01**	0.55	0.3	0.63	36.98**	33.88**	11.06**
TC1 × E	13	40.07			40.2**			0.41			0.35			7.5**		
Error	52 (26)	25.14	21.27	29.57	14.93	7.57	24.03	0.43	0.33	0.55	0.22	0.14	0.33	1.48	1.99	0.86
Environment (E)	1	14.7			1437.42**			29.62**			16.95**			1440.27**		
Replication /E	4 (2)	14.39	7.92	20.87	18.37	29.48*	7.26	0.91	0.2	1.63	0.31	0.4	0.22	2.63	4.1	1.16
ICMR 312 topcross (TC2)	13	199.52**	99.45**	147.46**	63.16	31.57**	71.24**	4.7**	2.72**	2.86**	0.73	0.48	0.56*	18.62**	13.12**	9.82**
TC2 × E	13	48.44			39.76**			0.91*			0.32			4.29**		
Error	52 (26)	26.13	21.6	30.83	14.7	8.59	21.06	0.42	0.16	0.69	0.19	0.28	0.10	1.46	2.20	0.70

[†] Values in parentheses indicate individual environment degrees of freedom;

P-Pooled across the environments; S12-2012 summer season; S13-2013 summer season ;

*,**- Significant at the 0.05,0.01 probability levels, respectively.

Table 4.15. Mean square for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), grain yield (GY) and days to 50% flowering (DF) among R-lines and their topcrosses in pearl millet, 2012 summer and 2013 summer seasons, Patancheru

		Mean square														
		Fe (mg kg^{-1})			Zn (mg kg^{-1})			GW (g)			GY (t ha^{-1})			DF (d)		
Source	**df** †	**P**	**S12**	**S13**	**P**	**S12**	**S13**	**P**	**S12**	**S13**	**P**	**S12**	**S13**	**P**	**S12**	**S13**
Environment (E)	1	1411.48**			2030.46**			0.39			12.49**			906.86**		
Replication/ E	4 (2)	99.33*	182.53**	16.13	17.67	19.39	15.95	0.12	0.1	0.15	0.63**	0.8**	0.47	0.46	0.64	0.29
R-line (R)	13	1208.89**	542.07**	714.93**	750.47**	276.76**	534.55**	17.3**	9.07**	9.07**	1.13**	0.73**	0.49**	51.16**	32.26**	21.87**
R × E	13	34.18			60.18**			0.84**			0.09			2.96		
Error	52 (26)	33	27.93	37.86	15.67	9.56	21.78	0.25	0.23	0.26	0.14	0.13	0.16	1.78	1.59	1.98
Environment (E)	1	77.77			1291.72**			6.82**			2.81*			1428.93**		
Replication /E	4 (2)	49.83	82.29*	17.37	34.26*	59.54**	8.98	0.44	0.33	0.56	1.14**	1.44**	0.84*	2.06	2.67	1.46
Raj 171 topcross (TC3)	13	280.66**	158.62**	141.54**	173.76**	82.27**	99.19**	4.21**	1.39**	3.26**	0.75	0.31*	0.79**	17.52**	11.55**	10.45**
TC3 × E	13	22.89			8.87			0.45			0.35*			4.23**		
Error	52 (26)	19.95	15.77	24.3	12.32	5.36	19.55	0.3	0.18	0.42	0.17	0.14	0.2	0.95	1.1	0.78
Environment (E)	1	75.22			1959.43**			24.85**			5.63*			1725.07**		
Replication /E	4 (2)	11.59	12.1	11.07	12.94	21.47	4.42	0.71	0.53	0.89	0.88**	0.71**	1.05**	1.33	1.36	1.3
ICMR 312 topcross (TC4)	13	350.36**	195.62**	191.94**	207.08**	86.24**	130.58**	3.72**	1.49**	2.69**	1.1	0.45**	1.34**	35.42**	26.43**	13.09**
TC4 × E	13	42.29			10.95			0.46			0.68**			4.07**		
Error	52 (26)	24.94	31.89	18	10.3	8.58	12.09	0.41	0.4	0.42	0.12	0.13	0.12	0.89	1	0.77

† Values in parentheses indicate individual environment degrees of freedom;

P-Pooled across the environments; S12- 2012 summer season; S13- 2013 summer season ;

*,**- Significant at the 0.05, 0.01 probability levels, respectively.

Table 4.16. Mean square (both testers considered together) for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), grain yield (GY) and days to 50% flowering (DF) among B-line topcrosses in pearl millet, 2012 summer and 2013 summer seasons, Patancheru

		Mean square														
		Fe (mg kg^{-1})			Zn (mg kg^{-1})			GW (g)			GY (t ha^{-1})			DF (d)		
Source	**df †**	**P**	**S12**	**S13**	**P**	**S12**	**S13**	**P**	**S12**	**S13**	**P**	**S12**	**S13**	**P**	**S12**	**S13**
Environment (E)	1	0.004			2155.12**			38.13**			14.21**			2323.98**		
Replication /E	4 (2)	14.96	10.85	19.08	42.82*	80.54**	5.11	0.4	0.1	0.71	0.44	0.1	0.77*	5.47**	4.87	6.08**
B-line topcross hybrids (TB)	27	231.61**	127.09**	155.69**	92.27**	48.28**	84.62**	6.65**	2.95**	4.4**	0.79*	0.72**	0.57**	30.16**	26.2**	10.63**
B-Line (BL)	13	358.63**	214.76**	206.41**	147.51*	74.41**	120.46**	4.94	2.39**	3.24**	0.69	0.3	0.83**	50.88**	41.6**	18.88**
Tester (T)	1	717.12*	248.6**	481.98**	97.12	9.68	111.74*	77.21*	29.94**	47.77**	5.02	9.21**	0.06	90.51	96.43**	14.85**
BL × T	13	75.78**	31.31	72.73*	39.61	25.11**	47.79*	2.25**	1.43**	1.25*	0.56**	0.49*	0.32	4.76*	5.4**	1.95*
TB × E	27	44.53**			40.09**			0.7*			0.45**			6.24**		
BL × E	13	55.66			46.57			0.76*			0.43*			8.93**		
T × E	1	25.78			31.51			1.76*			3.6**			15.01*		
BL × T × E	13	32.04			33.79**			0.43			0.24			2.53		
Error	112 (56)	24.96	20.64	29.65	14.88	8.0	22.61	0.43	0.24	0.64	0.23	0.25	0.2	1.49	2.1	0.79

† Values in parentheses indicate individual environment degrees of freedom;

P-Pooled across the environments; S12-2012 summer season; S13- 2013 summer season ;

*,**- Significant at the 0.05,0.01 probability levels, respectively.

Table 4.17. Mean square (both testers considered together) for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), grain yield (GY) and days to 50% flowering (DF) among R-line topcrosses in pearl millet, 2012 summer and 2013 summer seasons, Patancheru

		Mean square														
		Fe (mg kg^{-1})			Zn (mg kg^{-1})			GW (g)			GY (t ha^{-1})			DF (d)		
Source	**df** †	**P**	**S12**	**S13**	**P**	**S12**	**S13**	**P**	**S12**	**S13**	**P**	**S12**	**S13**	**P**	**S12**	**S13**
Environment (E)	1	155.45*			3216.5**			28.85**			8.19**			3147.03**		
Replication /E	4 (2)	44.9	75.85*	13.96	39.08**	69.99**	8.16	0.23	0.4	0.05	1.43**	1.83**	1.02**	3.08*	3.87*	2.3
R-line topcross hybrids (TR)	27	353.49**	199.04**	181.57**	195.58**	84.25**	120.4**	8.46**	3.1**	5.86**	0.91*	0.4**	1.02**	25.69**	18.83**	11.32**
R-Line (RL)	13	546.5**	286.25**	280.84**	338.54**	147.51**	197.84**	6.9**	2.47**	5.01**	1.52	0.62**	1.8**	48.18**	33.83**	21.44**
Tester (T)	1	1378.27**	697.46**	680.95**	355.1	84.25**	302.74**	126.07	46.35**	81.93**	0.61	0.89*	0.03	7.16	14.58**	0.01
RL × T	13	73.48*	70.74**	46.05*	40.6**	21.0**	30.63*	0.91**	0.4	0.72	0.32**	0.13	0.31	4.63**	4.15**	1.98**
TR × E	27	31.45			10.86			0.54			0.5**			4.26**		
RL × E	13	26.9			9.69			0.65**			0.9**			6.81**		
T × E	1	0.01			35.73			2.84**			0.29			7.16*		
RL × T × E	13	40.54*			10.63			0.24			0.12			1.51		
Error	112 (56)	22.2	23.48	20.89	11.19	7.12	15.41	0.38	0.3	0.46	0.16	0.14	0.19	0.89	1.02	0.76

† Values in parentheses indicate individual environment degrees of freedom;

P- Pooled across environments; S12- 2012 summer season; S13- 2013 summer season;

*,**- Significant at the 0.05,0.01 probability levels, respectively.

Table 4.18. Mean, range and coefficient of variation (CV) for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), grain yield (GY) and days to 50% flowering (DF) of inbred parents of pearl millet, 2012 summer and 2013 summer seasons, Patancheru

		Inbred performance *per se*							
		B-line				**R-line**			
Trait	ENV	Min	Max	Mean	CV(%)	Min	Max	Mean	CV(%)
Fe (mg kg^{-1})	P	36.9	81.3	56.4	9.2	37.2	89.0	59.6	9.6
	S12	34.3	83.1	54.1	10.6	35.0	84.7	55.3	9.6
	S13	39.5	94.2	59.2	7.4	39.3	93.7	63.9	9.6
Zn (mg kg^{-1})	P	36.9	60.2	47.3	14.1	37.6	70.6	53.2	7.5
	S12	30.3	51.6	42.3	12.2	33.8	61.9	48.2	6.4
	S13	36.4	68.8	52.5	15.2	36.7	79.4	58.3	8.0
GW (g)	P	8.8	12.8	11.5	6.8	6.4	11.9	8.9	5.6
	S12	8.5	12.8	11.1	6.2	6.6	12.2	8.8	5.5
	S13	9.2	13.7	11.9	7.3	6.2	12.2	8.9	5.8
GY (t ha^{-1})	P	1.3	3.7	2.5	17.5	1.4	3.1	2.2	17.2
	S12	1.2	4.3	3.0	12.1	1.6	3.4	2.6	14.1
	S13	1.4	2.8	2.0	26.1	1.0	2.7	1.8	21.9
DF (d)	P	47	59	51	1.5	52	63	56	2.4
	S12	49	60	54	1.3	54	67	59	2.1
	S13	44	57	48	1.7	48	59	52	2.7

ENV- Environments; P-Pooled across the seasons; S12- 2012 summer season; S13- 2013 summer season; SD-Standar deviation.

Table 4.19. Mean, range and coefficient of variation (CV) for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), grain yield (GY) and days to 50% flowering (DF) of B and R-line topcross hybrids of pearl millet, 2012 summer and 2013 summer seasons, Patancheru

B-line topcross hybrids											
		Raj 171 (TC1)					ICMR 312 (TC2)				
Trait	ENV	Min	Max	Mean	Range	CV (%)	Min	Max	Mean	Range	CV (%)
Fe (mg kg^{-1})	P	37.5	58.9	46.4	21.4	10.9	42.2	61.9	50.9	19.7	8.8
	S12	36.9	57.7	47.0	20.8	9.8	41.6	60.4	50.5	18.8	7.9
	S13	34.7	60.1	46.1	25.4	11.8	41.6	63.4	51.3	21.8	9.7
Zn (mg kg^{-1})	P	40.4	55.5	46.8	15.2	8.0	41.8	54.2	48.7	12.4	7.2
	S12	36.3	52.0	43.9	15.7	6.0	37.1	49.7	44.5	12.6	5.1
	S13	41.8	62.2	50.4	20.5	10.0	45.4	62.2	52.9	16.8	8.3
GW (g)	P	10.4	12.8	11.8	2.4	5.5	11.8	14.8	13.3	2.9	4.1
	S12	10.6	12.8	11.5	2.2	5.0	11.0	14.0	12.7	3.0	3.4
	S13	10.2	13.3	12.3	3.1	6.0	12.1	15.6	13.9	3.5	4.7
GY (t ha^{-1})	P	3.0	4.2	3.9	1.2	12.1	3.7	4.9	4.3	1.2	9.6
	S12	3.4	4.5	4.0	1.1	9.4	4.1	5.3	4.7	1.2	7.9
	S13	2.7	4.4	3.8	1.7	15.2	3.2	4.4	3.8	1.2	11.8
DF (d)	P	40.5	51.2	47.2	10.7	2.6	44.5	51.7	48.5	7.2	2.0
	S12	41.7	55.3	50.5	13.7	2.8	48.0	55.7	52.6	7.7	2.0
	S13	39.3	47.0	43.3	7.7	2.2	41.0	47.7	44.3	6.7	2.0

R-line topcross hybrids											
		Raj 171 (TC3)					ICMR 312 (TC4)				
Trait	ENV	Min	Max	Mean	Range	CV (%)	Min	Max	Mean	Range	CV (%)
Fe (mg kg^{-1})	P	35.7	57.5	45.4	21.8	11.4	39.3	64.9	51.1	25.6	9.8
	S12	33.2	57.9	44.3	24.6	10.6	38.4	62.0	50.2	23.6	11.3
	S13	36.1	57.1	46.3	21.1	12.1	39.9	68.0	52.1	28.1	8.2
Zn (mg kg^{-1})	P	38.4	55.3	47.3	16.9	8.2	38.3	58.4	50.2	20.1	6.4
	S12	35.4	51.5	43.4	16.0	0.8	33.0	50.8	45.4	17.9	6.5
	S13	40.8	59.1	51.3	18.3	9.0	43.6	66.0	55.2	22.4	6.3
GW (g)	P	8.7	11.6	10.2	2.9	6.4	10.6	13.5	11.9	2.9	5.4
	S12	8.8	11.4	9.9	2.6	4.0	10.6	12.9	11.4	2.3	5.6
	S13	8.6	11.8	10.5	3.2	7.9	10.6	14.2	12.5	3.6	5.2
GY (t ha^{-1})	P	3.5	4.8	4.1	1.3	10.8	3.3	4.8	4.2	1.6	8.4
	S12	3.9	5.2	4.2	1.3	12.4	3.5	4.9	4.4	1.4	8.0
	S13	2.8	4.5	3.9	1.7	8.3	2.4	4.8	3.9	2.4	8.8
DF (d)	P	47.3	54.0	49.6	6.7	2.4	45.0	54.8	50.1	9.8	1.9
	S12	50.7	57.7	53.7	7.0	2.7	48.3	59.3	54.6	11.0	1.8
	S13	43.0	50.3	45.4	7.3	1.9	41.7	50.3	45.4	8.7	1.9

ENV- environments; P-Pooled across the seasons; S12- 2012 summer season; S13- 2013 summer season.

Table 4.20. Performance *per se* and rankings of B-lines (B) and R-lines (R) and their topcross hybrids for grain iron (Fe) density, 2012 and 2013 summer seasons, Patancheru

Fe (mg kg^{-1})																			
B-line										R-line									
		Per se				Ranks						*Per se*				Ranks			
ID	B-line	B	TC1	TC2	$\bar{x}1$	B	TC1	TC2	$\bar{x}1$	ID	R-line	R	TC3	TC4	$\bar{x}2$	R	TC3	TC4	$\bar{x}2$
Pooled over the environments																			
4	ICMB 93222	81	59	60	60	1	1	2	1	16	PRP 2	89	57	57	57	1	1	4	2
13	ICMB 08222	78	51	62	56	2	4	1	2	24	IPC 616	85	52	51	52	2	4	7	4
9	ICMB 05555	77	52	54	53	3	3	4	4	17	PRP 3	73	53	56	54	3	3	5	3
6	ICMB 98222	76	47	55	51	4	6	3	5	25	IPC 843	67	47	51	49	4	5	8	7
1	ICMB 88004	59	56	53	55	5	2	5	3	19	PRP 5	66	43	59	51	5	8	2	6
7	ICMB 02555	58	46	52	49	6	8	7	6	18	PRP 4	61	56	65	60	6	2	1	1
8	ICMB 04888	54	46	48	47	7	7	9	8	22	PRP 8	60	45	57	51	7	6	3	5
10	ICMB 07555	54	49	47	48	8	5	11	7	26	IPC 1178	57	44	51	47	8	7	9	9
5	ICMB 97111	46	42	43	43	9	11	13	13	21	PRP 7	52	43	54	48	9	9	6	8
14	ICMB 08333	45	39	50	44	10	12	8	12	23	PRP 9	50	36	39	37	10	14	14	14
3	ICMB 92888	44	37	52	45	11	14	6	10	28	IPC 390	48	42	40	41	11	10	13	12
11	ICMB 07777	41	45	46	46	12	9	12	9	15	PRP 1	47	41	48	45	12	12	10	10
2	ICMB 92111	40	38	42	40	13	13	14	14	20	PRP 6	42	42	47	44	13	11	11	11
12	ICMB 07999	37	42	47	45	14	10	10	11	27	IPC 1354	37	36	41	38	14	13	12	13
	SE±	2.1	2.0	2.1	2.0						SE±	2.4	1.8	2.0	1.9				
	r1 (B, TCs)		0.78	0.84	0.89						r4 (R, TCs)		0.83	0.58	0.75				
	r2 (TC1, TC2)		0.64								r5 (TC3, TC4)		0.75						
2012 summer season (S12)																			
6	ICMB 98222	83	52	59	55	1	6	2	3	16	PRP 2	85	58	53	56	1	1	6	3
13	ICMB 08222	74	55	60	58	2	3	1	2	24	IPC 616	76	51	49	50	2	3	8	4
9	ICMB 05555	73	52	53	53	3	5	5	4	17	PRP 3	69	50	62	56	3	4	1	2
4	ICMB 93222	68	58	58	58	4	1	3	1	25	IPC 843	63	44	52	48	4	6	7	8
8	ICMB 04888	61	45	50	47	5	8	7	9	19	PRP 5	60	40	59	50	5	11	3	5
1	ICMB 88004	56	56	49	52	6	2	9	5	22	PRP 8	60	42	56	49	6	9	4	6
10	ICMB 07555	56	53	48	51	7	4	10	6	18	PRP 4	57	56	62	59	7	2	2	1
5	ICMB 97111	45	39	42	40	8	12	14	13	26	IPC 1178	49	43	49	46	8	7	9	9
14	ICMB 08333	44	45	53	49	9	7	4	7	23	PRP 9	48	33	38	36	9	14	14	14
7	ICMB 02555	44	44	51	48	10	9	6	8	28	IPC 390	47	45	41	43	10	5	12	10
11	ICMB 07777	42	43	47	45	11	10	11	10	21	PRP 7	46	43	54	49	11	8	5	7
3	ICMB 92888	41	38	45	42	12	13	12	12	15	PRP 1	45	40	43	42	12	12	11	12
2	ICMB 92111	37	37	43	40	13	14	13	14	20	PRP 6	35	41	44	42	13	10	10	11
12	ICMB 07999	34	41	49	45	14	11	8	11	27	IPC 1354	35	33	40	36	14	13	13	13
	SE±	3.3	2.7	2.7	2.6						SE±	3.1	2.3	3.3	2.8				
	r1 (B, TCs)		0.79	0.78	0.84						r4 (R, TCs)		0.74	0.58	0.73				
	r2 (TC1, TC2)		0.75								r5 (TC3, TC4)		0.61						
2013 summer season (S13)																			
4	ICMB 93222	94	60	62	61	1	1	2	1	24	IPC 616	94	53	53	53	1	4	5	4
13	ICMB 08222	85	47	63	55	2	6	1	3	16	PRP 2	92	57	62	59	2	1	2	2
9	ICMB 05555	82	51	54	53	3	3	5	4	17	PRP 3	78	55	50	53	3	3	10	5
7	ICMB 02555	72	47	53	50	4	5	6	5	25	IPC 843	71	49	50	50	4	5	11	7
6	ICMB 98222	69	43	52	47	5	11	7	8	19	PRP 5	71	45	59	52	5	7	3	6
1	ICMB 88004	63	57	57	57	6	2	4	2	18	PRP 4	66	56	68	62	6	2	1	1
10	ICMB 07555	52	45	46	46	7	8	10	9	26	IPC 1178	65	44	52	48	7	8	7	8
8	ICMB 04888	48	49	46	48	8	4	9	7	22	PRP 8	60	48	59	53	8	6	4	3
3	ICMB 92888	47	36	60	48	9	13	3	6	21	PRP 7	59	42	53	47	9	11	6	9
5	ICMB 97111	47	45	45	45	10	9	12	11	23	PRP 9	51	38	40	39	10	13	13	13
14	ICMB 08333	45	35	47	41	11	14	8	13	20	PRP 6	49	43	51	47	11	9	9	11
2	ICMB 92111	43	40	42	41	12	12	14	14	28	IPC 390	49	36	40	38	12	14	14	14
11	ICMB 07777	41	46	45	46	13	7	11	10	15	PRP 1	49	42	52	47	13	10	8	10
12	ICMB 07999	39	44	45	44	14	10	13	12	27	IPC 1354	39	38	41	40	14	12	12	12
	SE±	2.5	3.1	3.2	3.1						SE±	3.6	2.8	2.5	2.6				
	r1 (B, TCs)		0.63	0.79	0.84						r4 (R, TCs)		0.84	0.53	0.72				
	r2 (TC1, TC2)		0.42								r5 (TC3, TC4)		0.74						
	r3 (S12, S13)			0.70	0.62						r3 (S12, S13)			0.83	0.78				

SE- Standard error; TC1, TC3- topcrosses with Raj 171 tester; TC2,TC3- topcrosses with ICMR 312 ; $\bar{x}1$- Average of TC1 and TC2; $\bar{x}2$- Average of TC3 and TC4; r1- correlation of B with TC1, TC2 and $\bar{x}1$; r2- Correlation between TC1 and TC2; r3-correlation correlation between S12 and S13 seasons; r4- correlation of R with TC3, TC4 and $\bar{x}2$; r5-correlation between TC3 and TC4; $r(0.05) \geq 0.53$; $r(0.01) \geq 0.66$

Table 4.21. Performance *per se* and rankings of B-lines (B) and R-lines (R) and their topcross hybrids for grain zinc (Zn) density, 2012 and 2013 summer seasons, Patancheru

Zn (mg kg^{-1})																			
B-line										R-line									
		Per se				Ranks						*Per se*				Ranks			
ID	B-line	B	TC1	TC2	$\bar{x}1$	B	TC1	TC2	$\bar{x}1$	ID	R-line	R	TC3	TC4	$\bar{x}2$	R	TC3	TC4	$\bar{x}2$
Pooled over the environments																			
9	ICMB 05555	60	50	52	51	1	3	3	4	24	IPC 616	71	52	51	52	1	5	8	5
4	ICMB 93222	58	56	53	54	2	1	2	1	16	PRP 2	69	55	54	54	2	1	6	2
13	ICMB 08222	57	49	54	52	3	6	1	3	26	IPC 1178	65	50	54	52	3	6	4	4
7	ICMB 02555	54	50	48	49	4	5	7	6	25	IPC 843	63	52	54	53	4	4	5	3
6	ICMB 98222	53	48	50	49	5	7	5	7	19	PRP 5	60	48	56	52	5	7	2	6
1	ICMB 88004	50	54	51	53	6	2	4	2	17	PRP 3	57	53	48	50	6	3	10	7
10	ICMB 07555	48	50	48	49	7	4	9	5	22	PRP 8	55	45	55	50	7	10	3	8
8	ICMB 04888	43	43	47	45	8	12	11	9	18	PRP 4	54	54	58	56	8	2	1	1
3	ICMB 92888	43	40	48	44	9	14	8	12	15	PRP 1	50	47	52	50	9	8	7	9
14	ICMB 08333	43	44	49	46	10	10	6	8	21	PRP 7	46	46	50	48	10	9	9	10
2	ICMB 92111	40	41	48	44	11	13	10	13	20	PRP 6	41	44	47	46	11	11	11	11
5	ICMB 97111	39	44	42	43	12	9	14	14	23	PRP 9	39	39	38	39	12	13	14	14
12	ICMB 07999	37	43	46	44	13	11	12	11	28	IPC 390	38	38	42	40	13	14	13	13
11	ICMB 07777	37	45	45	45	14	8	13	10	27	IPC 1354	38	40	43	42	14	12	12	12
	SE±	2.7	1.6	1.6	1.6						SE±	1.6	1.4	1.3	1.4				
	r1 (B, TCs)		0.77	0.83	0.88						r4 (R, TCs)		0.87	0.72	0.84				
	r2 (TC1, TC2)		0.62								r5 (TC3, TC4)		0.78						
2012 summer season (S12)																			
9	ICMB 05555	52	49	47	48	1	3	3	4	24	IPC 616	62	46	46	46	1	6	9	6
6	ICMB 98222	51	45	50	48	2	6	1	3	16	PRP 2	62	51	48	50	2	1	6	2
8	ICMB 04888	50	40	45	42	3	10	8	8	25	IPC 843	60	48	51	49	3	3	1	3
13	ICMB 08222	49	48	46	47	4	4	6	5	17	PRP 3	54	47	44	45	4	4	10	8
4	ICMB 93222	48	52	48	50	5	1	2	1	26	IPC 1178	53	46	50	48	5	5	4	4
10	ICMB 07555	46	50	46	48	6	2	4	2	22	PRP 8	52	39	49	44	6	11	5	10
1	ICMB 88004	43	46	44	45	7	5	9	7	19	PRP 5	51	44	50	47	7	8	3	5
7	ICMB 02555	43	43	40	42	8	8	13	11	18	PRP 4	50	51	51	51	8	2	2	1
14	ICMB 08333	40	45	46	46	9	7	7	6	15	PRP 1	45	45	47	46	9	7	8	7
3	ICMB 92888	38	39	41	40	10	13	12	13	21	PRP 7	43	42	47	44	10	9	7	9
5	ICMB 97111	36	40	37	39	11	11	14	14	27	IPC 1354	38	36	40	38	11	13	12	12
11	ICMB 07777	34	39	44	42	12	12	10	10	23	PRP 9	36	35	33	34	12	14	14	14
2	ICMB 92111	32	36	46	41	13	14	5	12	28	IPC 390	34	37	39	38	13	12	13	13
12	ICMB 07999	30	41	43	42	14	9	11	9	20	PRP 6	34	40	42	41	14	10	11	11
	SE±	3.0	1.6	1.7	1.6						SE±	1.8	1.3	1.7	1.5				
	r1 (B, TCs)		0.70	0.51	0.71						r4 (R, TCs)		0.79	0.73	0.81				
	r2 (TC1, TC2)		0.53								r5 (TC3, TC4)		0.75						
2013 summer season (S13)																			
9	ICMB 05555	69	53	57	55	1	4	4	5	24	IPC 616	79	58	57	57	1	3	7	3
4	ICMB 93222	67	59	58	59	2	2	2	2	26	IPC 1178	77	53	59	56	2	6	5	6
7	ICMB 02555	66	56	56	56	3	3	5	3	16	PRP 2	76	59	62	60	3	1	2	2
13	ICMB 08222	66	50	62	56	4	8	1	4	19	PRP 5	68	51	61	56	4	7	3	5
1	ICMB 88004	57	62	58	60	5	1	3	1	25	IPC 843	66	57	57	57	5	4	8	4
6	ICMB 98222	55	50	51	50	6	9	8	8	17	PRP 3	63	59	52	55	6	2	10	8
3	ICMB 92888	51	43	55	49	7	13	6	9	18	PRP 4	58	56	66	61	7	5	1	1
10	ICMB 07555	50	51	50	50	8	6	11	7	22	PRP 8	57	51	60	56	8	8	4	7
2	ICMB 92111	48	45	49	47	9	12	12	14	15	PRP 1	54	50	58	54	9	9	6	9
14	ICMB 08333	45	42	53	47	10	14	7	12	21	PRP 7	49	49	54	52	10	10	9	10
12	ICMB 07999	43	46	50	48	11	11	9	11	20	PRP 6	48	49	52	50	11	11	11	11
5	ICMB 97111	41	48	46	47	12	10	13	13	23	PRP 9	43	43	44	43	12	13	14	13
11	ICMB 07777	40	51	45	48	13	7	14	10	28	IPC 390	42	41	45	43	13	14	13	14
8	ICMB 04888	36	52	50	51	14	5	10	6	27	IPC 1354	37	43	47	45	14	12	12	12
	SE±	4.6	2.8	2.6	2.8						SE±	2.7	2.6	2.0	2.3				
	r1 (B, TCs)		0.53	0.83	0.79						r4 (R, TCs)		0.85	0.69	0.82				
	r2 (TC1, TC2)		0.42								r5 (TC3, TC4)		0.75						
	r3 (S12, S13)		1	0.25							r3 (S12, S13)		0.91	0.92					

SE- Standard error; TC1, TC3- topcrosses with Raj 171 tester; TC2,TC3- topcrosses with ICMR 312 ; $\bar{x}1$- Average of TC1 and TC2; $\bar{x}2$- Average of TC3 and TC4; r1- correlation of B with TC1, TC2 and $\bar{x}1$; r2- Correlation between TC1 and TC2; r3-correlation correlation between S12 and S13 seasons; r4- correlation of R with TC3, TC4 and $\bar{x}2$; r5-correlation between TC3 and TC4; r(0.05) ≥ 0.53; r(0.01)≥0.66

Table 4.22. Performance *per se* and rankings of B-lines (B) and R-lines (R) and their topcross hybrids for 1000-grain weight (GW), 2012 and 2013 summer seasons, Patancheru

GW (mg kg^{-1})																			
B-line										R-line									
		Per se				Ranks						*Per se*				Ranks			
ID	B-line	B	TC1	TC2	x̄1	B	TC1	TC2	x̄1	ID	R-line	R	TC3	TC4	x̄2	R	TC3	TC4	x̄2
Pooled over the environments																			
3	ICMB 92888	13	12	15	13	1	8	1	1	18	PRP 4	12	12	14	13	1	1	1	1
9	ICMB 05555	13	12	14	13	2	6	3	4	20	PRP 6	12	11	13	12	2	3	3	3
5	ICMB 97111	12	12	15	13	3	7	2	2	17	PRP 3	11	11	13	12	3	2	2	2
4	ICMB 93222	12	12	14	13	4	11	4	6	21	PRP 7	10	10	12	11	4	6	5	7
13	ICMB 08222	12	12	13	13	5	3	7	8	15	PRP 1	10	11	12	11	5	5	10	6
11	ICMB 07777	12	13	13	13	6	2	10	7	16	PRP 2	9	11	12	11	6	4	6	4
8	ICMB 04888	12	12	14	13	7	4	5	5	19	PRP 5	9	10	12	11	7	9	7	8
12	ICMB 07999	12	12	12	12	8	5	12	10	27	IPC 1354	8	10	12	11	8	7	4	5
10	ICMB 07555	12	13	14	13	9	1	6	3	28	IPC 390	8	10	11	10	9	10	14	12
1	ICMB 88004	12	12	13	12	10	9	9	9	25	IPC 843	8	10	11	11	10	8	12	10
14	ICMB 08333	11	11	13	12	11	12	8	11	26	IPC 1178	7	9	12	11	11	12	9	11
6	ICMB 98222	10	12	12	12	12	10	13	12	22	PRP 8	7	10	12	11	12	11	8	9
7	ICMB 02555	10	11	12	11	13	13	14	14	24	IPC 616	7	9	11	10	13	14	11	14
2	ICMB 92111	9	10	13	12	14	14	11	13	23	PRP 9	6	9	11	10	14	13	13	13
	SE±	0.3	0.3	0.3	0.3					SE±		0.2	0.2	0.3	0.3				
	r1 (B, TCs)		0.74	0.71	0.87					r4 (R, TCs)			0.89	0.74	0.87				
	r2 (TC1, TC2)		0.37							r5 (TC3, TC4)			0.75						
2012 summer season (S12)																			
4	ICMB 93222	13	11	14	12	1	10	4	5	18	PRP 4	12	11	13	12	1	1	1	1
5	ICMB 97111	12	11	14	13	2	9	2	4	17	PRP 3	11	11	12	12	2	2	2	2
9	ICMB 05555	12	11	14	13	3	7	3	3	20	PRP 6	11	10	12	11	3	4	5	3
3	ICMB 92888	12	12	14	13	4	6	1	2	21	PRP 7	10	10	11	11	4	9	7	9
10	ICMB 07555	12	13	13	13	5	1	5	1	15	PRP 1	10	10	11	11	5	3	10	8
13	ICMB 08222	12	12	12	12	6	4	8	7	19	PRP 5	9	10	12	11	6	7	6	7
12	ICMB 07999	12	12	12	12	7	5	11	9	16	PRP 2	9	10	11	11	7	5	8	5
1	ICMB 88004	11	11	12	12	8	8	7	10	25	IPC 843	8	10	11	10	8	8	11	10
11	ICMB 07777	11	12	12	12	9	2	10	8	28	IPC 390	8	10	11	10	9	10	13	11
6	ICMB 98222	10	11	11	11	10	11	14	14	22	PRP 8	8	10	12	11	10	11	4	6
14	ICMB 08333	10	11	12	11	11	12	12	12	27	IPC 1354	7	10	12	11	11	6	3	4
8	ICMB 04888	10	12	12	12	12	3	9	6	26	IPC 1178	7	9	11	10	12	13	9	12
7	ICMB 02555	10	11	12	11	13	14	13	13	24	IPC 616	7	9	11	10	13	14	14	14
2	ICMB 92111	9	11	13	12	14	13	6	11	23	PRP 9	7	9	11	10	14	12	12	13
	SE±	0.4	0.3	0.2	0.3					SE±		0.3	0.2	0.4	0.3				
	r1 (B, TCs)		0.42	0.67	0.71					r4 (R, TCs)			0.89	0.68	0.84				
	r2 (TC1, TC2)		0.28							r5 (TC3, TC4)			0.72						
2013 summer season (S13)																			
3	ICMB 92888	14	12	16	14	1	8	1	3	20	PRP 6	12	12	14	13	1	2	3	3
8	ICMB 04888	13	13	15	14	2	2	3	1	18	PRP 4	12	12	14	13	2	1	1	1
11	ICMB 07777	13	13	13	13	3	1	9	5	15	PRP 1	11	11	12	12	3	5	7	7
9	ICMB 05555	13	13	14	13	4	3	5	4	17	PRP 3	10	12	14	13	4	4	2	2
1	ICMB 88004	12	12	13	13	5	11	10	12	21	PRP 7	10	11	13	12	5	6	6	6
13	ICMB 08222	12	13	14	13	6	6	7	7	16	PRP 2	9	12	13	12	6	3	4	4
5	ICMB 97111	12	13	15	14	7	5	2	2	27	IPC 1354	9	11	13	12	7	7	5	5
14	ICMB 08333	12	12	14	13	8	12	6	9	19	PRP 5	8	10	12	11	8	9	9	8
12	ICMB 07999	12	13	13	13	9	7	13	10	28	IPC 390	8	10	11	10	9	10	14	13
10	ICMB 07555	12	13	14	13	10	4	8	6	25	IPC 843	8	10	12	11	10	8	12	9
4	ICMB 93222	11	12	14	13	11	10	4	8	24	IPC 616	8	9	12	10	11	14	10	12
7	ICMB 02555	10	11	12	12	12	13	14	14	26	IPC 1178	8	10	12	11	12	12	8	10
6	ICMB 98222	10	12	13	13	13	9	12	11	22	PRP 8	7	10	12	11	13	11	11	11
2	ICMB 92111	9	10	13	12	14	14	11	13	23	PRP 9	6	9	12	10	14	13	13	14
	SE±	0.5	0.4	0.5	0.5					SE±		0.3	0.4	0.4	0.4				
	r1 (B, TCs)		0.73	0.67	0.82					r4 (R, TCs)			0.83	0.73	0.84				
	r2 (TC1, TC2)		0.46							r5 (TC3, TC4)			0.74						
	r3 (S12, S13)		1	0.68						r3 (S12, S13)			0.88	0.81					

SE- Standard error; TC1, TC3- topcrosses with Raj 171 tester; TC2,TC3- topcrosses with ICMR 312 ; x̄1- Average of TC1 and TC2; x̄2- Average of TC3 and TC4; r1- correlation of B with TC1, TC2 and x̄1; r2- Correlation between TC1 and TC2; r3-correlation correlation between S12 and S13 seasons; r4- correlation of R with TC3, TC4 and x̄2; r5-correlation between TC3 and TC4; r(0.05) ≥ 0.53; r(0.01)≥0.66

Table 4.23. Performance *per se* and rankings of B-lines (B) and R-lines (R) and their topcross hybrids for grain yield (GY), 2012 and 2013 summer seasons, Patancheru

GY (mg kg^{-1})																			
B-line										R-line									
		Per se				Ranks						*Per se*				Ranks			
ID	B-line	B	TC1	TC2	$\bar{x}_1$	B	TC1	TC2	$\bar{x}_1$	ID	R-line	R	TC3	TC4	$\bar{x}_2$	R	TC3	TC4	$\bar{x}_2$
Pooled over the environments																			
5	ICMB 97111	4	4	5	4	1	1	4	2	18	PRP 4	3	4	4	4	1	5	5	5
7	ICMB 02555	3	4	5	4	2	9	2	4	20	PRP 6	3	5	4	5	2	1	4	1
12	ICMB 07999	3	4	5	4	3	8	1	1	21	PRP 7	3	4	4	4	3	8	13	12
14	ICMB 08333	3	4	4	4	4	4	9	6	28	IPC 390	3	4	4	4	4	7	10	8
1	ICMB 88004	3	4	4	4	5	10	8	7	15	PRP 1	2	4	5	5	5	2	2	2
11	ICMB 07777	3	3	4	4	6	14	10	14	19	PRP 5	2	4	4	4	6	4	6	4
4	ICMB 93222	3	4	5	4	7	3	5	3	25	IPC 843	2	4	4	4	7	11	7	7
10	ICMB 07555	2	4	4	4	8	11	13	13	22	PRP 8	2	4	3	4	8	12	14	14
6	ICMB 98222	2	4	4	4	9	5	12	11	23	PRP 9	2	4	4	4	9	6	3	6
13	ICMB 08222	2	4	4	4	10	2	7	5	17	PRP 3	2	4	4	4	10	10	11	11
2	ICMB 92111	2	4	5	4	11	13	3	8	16	PRP 2	2	4	4	4	11	13	8	10
9	ICMB 05555	2	4	4	4	12	6	14	12	24	IPC 616	2	4	4	4	12	9	9	9
8	ICMB 04888	2	4	4	4	13	12	6	9	26	IPC 1178	1	4	5	5	13	3	1	3
3	ICMB 92888	1	4	4	4	14	7	11	10	27	IPC 1354	1	3	4	4	14	14	12	13
	SE±	0.2	0.2	0.2	0.2					SE±		0.2	0.2	0.1	0.2				
	r1 (B, TCs)		0.12	0.44	0.40					r4 (R, TCs)			0.42	0.04	0.23				
	r2 (TC1, TC2)		0.06							r5 (TC3, TC4)			0.65						
2012 summer season (S12)																			
5	ICMB 97111	4	4	5	5	1	8	4	5	18	PRP 4	3	4	4	4	1	7	11	9
12	ICMB 07999	4	4	5	5	2	5	2	1	28	IPC 390	3	4	4	4	2	10	13	13
7	ICMB 02555	4	4	5	5	3	11	1	4	15	PRP 1	3	4	5	5	3	3	3	3
14	ICMB 08333	4	4	4	4	4	10	14	14	20	PRP 6	3	5	5	5	4	1	1	1
11	ICMB 07777	3	3	5	4	5	14	9	13	21	PRP 7	3	4	4	4	5	13	14	14
4	ICMB 93222	3	4	5	5	6	7	5	6	25	IPC 843	3	4	4	4	6	12	9	10
1	ICMB 88004	3	4	5	4	7	9	6	7	19	PRP 5	3	4	5	4	7	6	7	6
10	ICMB 07555	3	4	4	4	8	3	12	10	17	PRP 3	3	4	5	5	8	4	5	4
13	ICMB 08222	3	4	5	5	9	6	3	2	23	PRP 9	3	4	5	5	9	5	4	5
6	ICMB 98222	3	5	4	4	10	1	11	8	22	PRP 8	2	4	4	4	10	9	12	11
2	ICMB 92111	2	4	5	4	11	12	8	9	16	PRP 2	2	4	4	4	11	14	10	12
9	ICMB 05555	2	4	4	4	12	4	13	11	24	IPC 616	2	4	4	4	12	11	8	8
8	ICMB 04888	2	4	5	4	13	13	7	12	26	IPC 1178	2	4	5	5	13	2	2	2
3	ICMB 92888	1	4	5	5	14	2	10	3	27	IPC 1354	2	4	5	4	14	8	6	7
	SE±	0.2	0.2	0.3	0.3					SE±		0.2	0.2	0.2	0.2				
	r1 (B, TCs)		-0.22	0.29	0.11					r4 (R, TCs)			0.13	-0.30	-0.11				
	r2 (TC1, TC2)		-0.25							r5 (TC3, TC4)			0.66						
2013 Summer season (S13)																			
7	ICMB 02555	3	4	4	4	1	5	7	6	18	PRP 4	3	4	5	4	1	4	3	3
12	ICMB 07999	3	4	4	4	2	9	2	5	21	PRP 7	2	4	4	4	2	7	11	9
5	ICMB 97111	3	4	4	4	3	1	5	2	20	PRP 6	2	4	4	4	3	3	9	5
1	ICMB 88004	3	4	4	4	4	7	8	9	19	PRP 5	2	5	4	4	4	1	7	4
14	ICMB 08333	2	4	4	4	5	2	3	1	28	IPC 390	2	4	4	4	5	8	5	7
11	ICMB 07777	2	3	3	3	6	14	11	14	22	PRP 8	2	3	2	3	6	12	14	14
4	ICMB 93222	2	4	4	4	7	4	4	3	15	PRP 1	2	4	5	5	7	2	2	1
10	ICMB 07555	2	3	3	3	8	11	12	12	25	IPC 843	2	4	4	4	8	9	4	8
6	ICMB 98222	2	4	3	4	9	10	10	11	23	PRP 9	2	4	4	4	9	6	6	6
2	ICMB 92111	2	3	4	4	10	13	1	8	16	PRP 2	2	4	4	4	10	11	8	10
9	ICMB 05555	2	4	3	4	11	8	13	10	17	PRP 3	2	3	3	3	11	13	12	12
3	ICMB 92888	1	3	3	3	12	12	14	13	24	IPC 616	1	4	4	4	12	10	10	11
13	ICMB 08222	1	4	4	4	13	3	9	7	27	IPC 1354	1	3	3	3	13	14	13	13
8	ICMB 04888	1	4	4	4	14	6	6	4	26	IPC 1178	1	4	5	5	14	5	1	2
	SE±	0.3	0.30	0.2	0.3					SE±		0.2	0.3	0.2	0.3				
	r1 (B, TCs)		0.20	0.30	0.29					r4 (R, TCs)			0.46	0.15	0.31				
	r2 (TC1, TC2)		0.43							r5 (TC3, TC4)			0.73						
	r3 (S12, S13)			0.17	0.42					r3 (S12, S13)				0.41	0.27				

SE- Standard error; TC1, TC3- topcrosses with Raj 171 tester; TC2,TC3- topcrosses with ICMR 312 ; $\bar{x}_1$- Average of TC1 and TC2; $\bar{x}_2$- Average of TC3 and TC4; r1- correlation of B with TC1, TC2 and $\bar{x}_1$; r2- Correlation between TC1 and TC2; r3-correlation correlation between S12 and S13 seasons; r4- correlation of R with TC3, TC4 and $\bar{x}_2$; r5-correlation between TC3 and TC4; r(0.05) ≥ 0.53; r(0.01)≥0.66

Table 4.24. Performance *per se* and rankings of B-lines (B) and R-lines (R) and their topcross hybrids for days to 50% flowering (DF), 2012 and 2013 summer seasons, Patancheru

DF (mg kg^{-1})																			
B-line										R-line									
		Per se				Ranks						*Per se*				Ranks			
ID	B-line	B	TC1	TC2	$\bar{x}1$	B	TC1	TC2	$\bar{x}1$	ID	R-line	R	TC3	TC4	$\bar{x}2$	R	TC3	TC4	$\bar{x}2$
Pooled over the environments																			
2	ICMB 92111	59	49	50	50	1	4	3	2	26	IPC 1178	63	54	55	54	1	1	1	1
4	ICMB 93222	56	51	52	51	2	1	1	1	27	IPC 1354	58	49	51	50	2	8	8	7
7	ICMB 02555	53	50	49	49	3	2	6	3	18	PRP 4	58	51	52	52	3	2	2	2
13	ICMB 08222	53	46	50	48	4	10	4	8	19	PRP 5	57	48	50	49	4	13	10	10
9	ICMB 05555	52	49	49	49	5	5	7	6	20	PRP 6	57	51	52	51	5	3	3	3
8	ICMB 04888	52	50	48	49	6	3	9	5	24	IPC 616	56	50	51	51	6	5	7	5
12	ICMB 07999	52	47	51	49	7	7	2	4	15	PRP 1	56	49	51	50	7	9	6	8
14	ICMB 08333	51	46	48	47	8	12	11	11	16	PRP 2	56	50	51	51	8	4	4	4
11	ICMB 07777	49	47	49	48	9	9	5	9	23	PRP 9	55	47	45	46	9	14	14	14
5	ICMB 97111	48	48	49	48	10	6	8	7	22	PRP 8	55	49	48	49	10	10	11	11
6	ICMB 98222	48	47	48	47	11	8	10	10	21	PRP 7	53	50	51	50	11	6	5	6
3	ICMB 92888	48	45	46	46	12	13	13	13	25	IPC 843	53	49	50	50	12	7	9	9
10	ICMB 07555	47	46	47	47	13	11	12	12	28	IPC 390	52	49	48	48	13	11	12	12
1	ICMB 88004	47	41	45	43	14	14	14	14	17	PRP 3	52	48	47	47	14	12	13	13
	SE±	0.3	0.5	0.5	0.5						SE±	0.6	0.4	0.4	0.4				
	r1 (B, TCs)		0.71	0.79	0.78						r4 (R, TCs)		0.71	0.69	0.72				
	r2 (TC1, TC2)		0.82								r5 (TC3, TC4)		0.88						
2012 summer season (S12)																			
2	ICMB 92111	60	53	55	54	1	3	2	3	26	IPC 1178	67	58	59	59	1	1	1	1
4	ICMB 93222	59	55	56	56	2	1	1	1	27	IPC 1354	62	54	56	55	2	7	6	6
7	ICMB 02555	57	54	53	54	3	2	6	2	19	PRP 5	61	52	55	54	3	11	9	10
8	ICMB 04888	56	52	54	53	4	6	4	5	20	PRP 6	61	55	56	56	4	4	4	4
9	ICMB 05555	56	52	53	53	5	7	7	6	24	IPC 616	61	55	56	56	5	5	5	5
13	ICMB 08222	55	49	53	51	6	11	9	11	18	PRP 4	60	56	56	56	6	2	3	3
14	ICMB 08333	55	48	52	50	7	13	12	12	15	PRP 1	59	53	55	54	7	8	7	8
12	ICMB 07999	55	50	54	52	8	10	3	9	16	PRP 2	59	54	55	55	8	6	8	7
11	ICMB 07777	52	51	53	52	9	8	8	7	23	PRP 9	59	51	48	50	9	14	14	14
3	ICMB 92888	51	48	49	48	10	12	13	13	22	PRP 8	57	52	51	52	10	12	12	13
6	ICMB 98222	51	52	53	53	11	4	5	4	21	PRP 7	57	56	57	56	11	3	2	2
5	ICMB 97111	51	52	52	52	12	5	11	8	25	IPC 843	56	53	55	54	12	10	10	9
10	ICMB 07555	50	50	52	51	13	9	10	10	17	PRP 3	55	53	51	52	13	9	13	11
1	ICMB 88004	49	42	48	45	14	14	14	14	28	IPC 390	54	51	52	52	14	13	11	12
	SE±	0.4	0.8	0.9	0.8						SE±	0.7	0.6	0.6	0.6				
	r1 (B, TCs)		0.60	0.72	0.67						r4 (R, TCs)		0.59	0.64	0.64				
	r2 (TC1, TC2)		0.86								r5 (TC3, TC4)		0.85						
2013 summer season (S13)																			
2	ICMB 92111	57	45	46	46	1	3	3	2	26	IPC 1178	59	50	50	50	1	1	1	1
4	ICMB 93222	52	47	48	47	2	1	1	1	18	PRP 4	56	47	47	47	2	3	2	2
7	ICMB 02555	50	45	44	45	3	2	7	4	27	IPC 1354	55	45	45	45	3	9	9	9
13	ICMB 08222	50	44	46	45	4	7	2	3	19	PRP 5	53	44	45	44	4	12	11	12
9	ICMB 05555	49	45	44	44	5	4	8	6	20	PRP 6	53	47	47	47	5	4	3	3
12	ICMB 07999	49	44	46	45	6	5	4	5	15	PRP 1	52	45	46	46	6	8	4	5
8	ICMB 04888	48	43	43	43	7	9	11	10	22	PRP 8	52	46	45	46	7	5	7	6
14	ICMB 08333	47	44	44	44	8	6	10	8	16	PRP 2	52	47	46	46	8	2	5	4
11	ICMB 07777	46	42	45	43	9	11	6	9	24	IPC 616	52	46	45	46	9	6	8	7
5	ICMB 97111	45	43	45	44	10	8	5	7	23	PRP 9	52	44	42	43	10	11	14	14
6	ICMB 98222	45	42	42	42	11	10	13	12	25	IPC 843	50	46	45	45	11	7	10	8
3	ICMB 92888	45	42	44	43	12	12	9	11	28	IPC 390	50	45	44	44	12	10	12	10
10	ICMB 07555	44	41	42	42	13	13	12	13	21	PRP 7	49	43	45	44	13	14	6	11
1	ICMB 88004	44	39	41	40	14	14	14	14	17	PRP 3	48	43	42	43	14	13	13	13
	SE±	0.5	0.5	0.5	0.5						SE±	0.8	0.5	0.5	0.5				
	r1 (B, TCs)		0.79	0.73	0.80						r4 (R, TCs)		0.78	0.76	0.80				
	r2 (TC1, TC2)		0.82								r5 (TC3, TC4)		0.83						
	r3 (S12, S13)			0.76	0.63						r3 (S12, S13)			0.61	0.84				

SE- Standard error; TC1, TC3- topcrosses with Raj 171 tester; TC2,TC3- topcrosses with ICMR 312 ; $\bar{x}1$- Average of TC1 and TC2; $\bar{x}2$- Average of TC3 and TC4; r1- correlation of B with TC1, TC2 and $\bar{x}1$; r2- Correlation between TC1 and TC2; r3-correlation correlation between S12 and S13 seasons; r4- correlation of R with TC3, TC4 and $\bar{x}2$; r5-correlation between TC3 and TC4; r(0.05) ≥ 0.53; r(0.01)≥0.66

Table 4.25. Association of grain iron (Fe) and zinc (Zn) densities with grain yield (GY), 1000-grain weight (GW) and days to 50% flowering (DF) among topcrosses of B-line and R-line, 2012 summer and 2013 summer seasons, Patancheru

Inbred	Topcross	Trait	Fe (mg kg^{-1})			Zn (mg kg^{-1})		
			P	**S12**	**S13**	**P**	**S12**	**S13**
B-line	B-line × Raj 171 (TC1)	GY	0.17	0.26	0.19	0.26	0.39	0.14
		GW	0.26	0.24	0.24	0.12	0.21	0.07
		DF	-0.02	-0.12	0.10	-0.07	-0.01	-0.03
	B-line × ICMR 312 (TC2)	GY	-0.17	-0.13	-0.36	-0.23	-0.56*	-0.14
		GW	-0.01	-0.36	0.19	-0.09	-0.28	-0.03
		DF	0.06	0.29	0.15	0.03	0.35	0.16
R-line	R-line × Raj 171 (TC3)	GY	-0.17	-0.27	-0.13	0.40	0.50	0.27
		GW	0.42	0.39	0.37	0.36	0.40	0.30
		DF	0.29	0.36	0.18	0.40	0.50	0.27
	R-line × ICMR 312 (TC4)	GY	-0.14	-0.35	0.11	0.56*	0.55*	0.53*
		GW	0.55*	0.58*	0.52	0.33	0.23	0.41
		DF	0.26	0.08	0.40	0.56*	0.55*	0.53*

P- Pooled across environments; S12- 2012 summer season; S13- 2013 summer season; r (0.05) ≥ 0.53; r (0.01)≥ 0.66

Table 4.26. Mean square for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW) and days to 50% flowering among progenies of ICTP 8203 derived through North Carolina mating Design-1 (NCD-1), 2012 rainy and 2013 summer seasons, Patancheru

Source of variation	df [†]	Mean square											
		Fe (mg kg^{-1})			Zn (mg kg^{-1})			GW(g)			DF (d)		
		P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13
Environment	1	76.6 *			82116.2 **			1024.54 **			23.15 **		
Replication in sets in environment	40 (20)	179.0 **	210.2 **	147.7 **	110.6 **	58.5 **	162.6 **	2.21 **	2.32	2.11 *	2.54 *	3.39 **	1.68
Sets	9	683.3 **	304.2 **	485.6 **	142.9	96.1 **	215.2 **	16.85 **	6.53 **	13.44 **	66.22 **	36.25 **	39.69 **
Sets × environment	9	119.8 **			175.6 **			3.12 *			9.79 **		
Males in sets	30	409.1 **	194.9 **	267.7 **	172.6 **	48.1 **	154.3 **	18.04 **	13.40 **	7.59 **	22.06 *	13.24 **	13.90 **
Females in males in sets	120	124.3 **	87.2 **	79.9 **	48.2 **	20.7 **	53.7 **	6.09 **	5.52 **	2.72 **	9.76 **	6.88 **	6.42 **
Males in sets × environment	30	52.6			35.5			2.92			5.08		
Females in males in sets × environment	120	43.3 **			27.0 **			2.14 **			3.53 **		
Error	600 (300)	25.6	23.7	27.6	19.4	12.8	26.5	1.33	1.48	1.18	1.58	1.72	1.44

[†] Values in parentheses indicate individual environment degrees of freedom;

P-Pooled across environments; R12-2012 rainy season; S13-2013 summer season ;

*,** - Significant at the 0.05, 0.01 probability levels, respectively.

Table 4.27. Mean, range and coefficient of variation (CV) for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW) and days to 50% flowering (DF) among the NCD-1 progenies of ICTP 8203 and ICMV 221, 2012 rainy and 2013 summer seasons, Patancheru

		ICTP 8203				ICMV 221			
		Min	Max	Mean	CV (%)	Min	Max	Mean	CV (%)
Fe (mg kg^{-1})	P	44.0	78.3	57.9	8.7	38.3	73.6	52.1	10.2
	R12	44.2	76.9	58.2	8.4	33.4	71.4	50.0	11.1
	S13	42.4	79.6	57.5	9.1	40.6	75.8	54.2	9.4
Zn (mg kg^{-1})	P	33.0	51.0	42.8	10.3	31.3	48.8	39.4	9.7
	R12	24.3	44.1	33.6	10.7	22.5	37.3	29.0	11.1
	S13	35.4	64.3	52.4	9.8	37.8	64.2	49.8	8.8
GW (g)	P	13.5	20.4	16.6	3.0	12.0	19.0	15.1	2.8
	R12	13.9	22.3	17.7	3.1	12.6	20.5	15.9	2.6
	S13	12.4	18.5	15.6	2.9	11.1	18.3	14.4	3.1
DF (d)	P	39	48	42	6.9	39	47	42	8.5
	R12	38	48	42	6.9	38	46	41	8.9
	S13	37	48	42	7.0	39	48	42	7.9

P-Pooled across environments; R12-2012 rainy season; S13-2013 summer season ;

Table 4.28. Mean square for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW) and days to 50% flowering (DF) among progenies of ICMV 221 derived through North Carolina mating Design-1 (NCD-1), 2012 rainy and 2013 summer seasons, Patancheru

Source of variation	df †	Mean square											
		Fe (mg kg^{-1})			Zn (mg kg^{-1})			GW (g)			DF (d)		
		P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13
Environment	1	3964.7 **			103082.3 **			575.4 **			141.1 **		
Replication in sets in environment	40 (20)	211.8 **	132.9 **	290.6 **	314.0 **	50.1 **	578.0 **	1.8	2.2	1.4	1.8	2.0 *	1.5
Sets	9	663.3 *	612.9 **	205.7 **	68.4	40.7 **	105.4 **	24.6 *	20.4 **	10.1 **	36.7	17.8 **	33.3 **
Sets × environment	9	159.4 **			78.0 **			5.9 **			14.4 **		
Males in sets	30	345.9 **	183.8 *	212.5 **	140.1 **	50.8 **	129.9 **	16.9 **	12.9 **	6.6 **	13.6	6.3 **	12.3 *
Females in males in sets	120	140.8 **	101.6 **	96.2 **	53.5 **	21.1 **	63.3 **	5.8 **	4.9 **	3.0 **	7.8 **	3.2 **	7.4 **
Males in sets × environment	30	48.6			40.4			2.6			5.0 *		
Females in males in sets × environment	120	58.7 **			30.7 *			2.1 *			2.8 **		
Error	600 (300)	28.3	31.0	25.8	14.7	10.4	19.0	1.6	2.0	1.3	1.4	1.1	1.7

† Values in parentheses indicate individual environment degrees of freedom;

P-Pooled across environments; R12-2012 rainy season; S13-2013 summer season ;

*,** - Significant at the 0.05, 0.01 probability levels, respectively.

Table 4.29. Variance components and heritability for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW) and days to 50% flowering (DF) among NCD-1 progenies of ICTP 8203 and ICMV 221, 2012 rainy and 2013 summer seasons, Patancheru

ICTP 8203								
Trait		σ^2_A	σ^2_D	σ^2_G	$\sigma^2_{A\times E}$	$\sigma^2_{D\times E}$	$\sigma^2_{G\times E}$	h^2_{ns}(%)
Fe (mg kg^{-1})	P	45.91	8.16	54.06	3.12	20.43	23.55	65
	R12	35.91	48.75	84.66				39
	S13	62.58	7.28	69.86				79
Zn (mg kg^{-1})	P	19.31	-5.16	14.15	2.85	7.26	10.11	86
	R12	9.14	1.39	10.53				62
	S13	33.54	2.74	36.28				74
GW (g)	P	1.79	2.36	4.15	0.51	2.09	2.61	31
	R12	2.12	4.77	6.89				28
	S13	2.49	4.15	6.64				35
DF (d)	P	1.86	0.77	2.63	0.26	0.83	1.09	55
	R12	2.63	2.75	5.38				45
	S13	1.62	0.44	2.06				66
ICMV 221								
Fe (mg kg^{-1})	P	35.87	18.88	54.75	-3.38	43.84	40.46	45
	R12	27.39	66.84	94.24				26
	S13	38.76	55.16	93.92				38
Zn (mg kg^{-1})	P	12.82	2.4	15.21	3.23	18.06	21.29	45
	R12	9.89	4.39	14.28				56
	S13	22.21	36.84	59.05				34
GW (g)	P	0.6	2.74	3.34	0.72	1.16	1.88	13
	R12	1.01	1.84	2.85				31
	S13	1.63	5.96	7.59				20
DF (d)	P	1.77	0.72	2.50	0.17	0.38	0.55	58
	R12	2.67	1.18	3.86				59
	S13	1.21	1.03	2.23				45

P-Pooled across environments; R12-2012 rainy season; S13-2013 summer season ; σ^2_A- Additive genetic variance; σ^2_D- Dominance variance; σ^2_G- Total genetic variance; $\sigma^2_{A\times E}$ – Additive × environments variance; $\sigma^2_{D\times E}$ – Dominance × environments variance; h^2_{ns}- Narrow-sense heritability;

Table 4.30. Correlation among grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW) and days to 50% flowering (DF) for NCD-1 progenies of ICTP 8203 (below diagonal) and ICMV 221 (above diagonal), 2012 rainy and 2013 summer seasons, Patancheru

Environment	Trait	Fe (mg kg^{-1})	Zn (mg kg^{-1})	GW (g)	DF (d)
P	**Fe**	1	0.63**	0.12	0.01
	Zn	0.69**	1	0.15	0.05
	GW	0.03	0.10	1	-0.23
	DF	0.05	0.00	-0.22	1
R12	**Fe**	1	0.56**	0.06	-0.04
	Zn	0.5**	1	0.21	0.05
	GW	0.13	0.13	1	-0.11
	DF	0.04	0.05	-0.22	1
S13	**Fe**	1	0.68**	0.14	0.06
	Zn	0.78**	1	0.14	0.06
	GW	-0.04	0.01	1	-0.24
	DF	0.06	0.07	-0.19	1

P- Pooled across environments; R12- 2012 rainy season; S13 - 2013 summer season ;
*,** - Significant at the 0.05, 0.01 probability levels, respectively.

Table 4.31. Mean square for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW) and days to 50% flowering (DF) for topcrosses of S_0 plants of ICTP 8203, 2012 rainy and 2013 summer seasons, Patancheru

		Mean square											
		Fe (mg kg^{-1})			Zn (mg kg^{-1})			GW (g)			DF (d)		
Source	df †	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13
Environment (E)	1	1925.81**			46660.12**			217.16**			211.6**		
Replication /E	4 (2)	29.90	48.11	11.70	110.61**	104.00**	117.22**	1.13	2.25	0.01	2.17	0.82	3.52
ICTP 8203 (P) × Raj 171 topcrosses (TC1)	59	153.67**	78.07**	120.40**	62.83**	27.20**	68.57**	5.74**	4.24**	3.03**	10.38**	5.13**	8.51**
TC1 × E	59	44.98			32.96**			1.54			3.26**		
Error	236 (118)	33.75	32.07	35.44	19.55	15.76	23.38	1.21	1.26	1.16	1.70	1.56	1.84
Environment (E)	1	857.13**			43489.71**			183.40**			340.28**		
Replication /E	4(2)	731.47**	72.39	1390.54**	191.8**	323.18**	60.42*	2.25	1.61	2.89	5.69**	6.51**	4.87*
ICTP 8203 (P) × ICMR 312 topcrosses (TC2)	59	94.27**	53.44**	88.28**	44.02**	23.39**	39.57**	5.89**	4.10**	3.38**	10.15**	6.29**	6.56**
TC2 × E	59	49.00**			19.24			1.59			2.71**		
Error	236 (118)	24.26	25.9	22.53	15.63	13.79	17.55	1.22	1.47	0.97	1.35	1.19	1.50

† Values in parentheses indicate individual environment degrees of freedom;

P-Pooled across environments; R12- 2012 rainy season; S13- 2013 summer season ;

*,** - Significant at the 0.05, 0.01 probability levels, respectively

Table 4.32. Mean square (both testers considered together) for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW) and days to 50% flowering (DF) for topcrosses of S_0 plants of ICTP 8203, 2012 rainy and 2013 summer seasons, Patancheru

		Mean square											
		Fe (mg kg^{-1})			Zn (mg kg^{-1})			GW (g)			DF (d)		
Source	**df** [†]	**P**	**R12**	**S13**	**P**	**R12**	**S13**	**P**	**R12**	**S13**	**P**	**R12**	**S13**
Environment (E)	1	2695.58**			90151.67**			399.84**			544.27**		
Replication /E	4 (2)	392.61**	4.96	780.25**	259.44**	354.73**	164.15**	2.27	3.26	1.28	6.70**	5.68*	7.72**
ICTP 8203 topcross (H1)	119	125.09**	65.26**	105.95**	57.28**	26.58**	56.49**	10.80**	6.48**	5.87**	11.03**	6.35**	7.70**
Plant (P)	59	164.86*	90.67**	131.78**	74.35**	35.75**	65.01**	9.12**	6.49**	4.40**	15.62**	8.97**	10.91**
Tester (T)	1	182.78	6.61	270.56**	517.23*	177.98**	353.02**	598.87**	279.14**	320.45**	101.25	82.18**	26.68**
P × T	59	84.45**	40.84*	78.66**	32.56	14.84	43.22**	2.51**	1.86*	2.01**	4.91**	2.45**	4.17**
H1 × E	119	47.12**			25.99**			1.56*			3.02**		
P × E	59	58.08**			26.65			1.78			4.26**		
T × E	1	98.21			15.95			0.71			7.61*		
P × T × E	59	35.79			25.57*			1.35			1.71		
Error	476(238)	31.95	29.71	34.26	17.83	15.26	20.45	1.21	1.36	1.07	1.52	1.38	1.67

[†] Values in parentheses indicate individual environment degrees of freedom;

P-Pooled across environments; R12- 2012 rainy season; S13- 2013 summer season ;

*,** -Significant at the 0.05, 0.01 probability levels, respectively.

Table 4.33. Mean square for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW) and days to 50% flowering (DF) for topcrosses of S_0 plants of ICMV 221, 2012 rainy and 2013 summer seasons, Patancheru

		Mean square											
		Fe (mg kg^{-1})			Zn (mg kg^{-1})			GW (g)			DF (d)		
Source	df[†]	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13
Environment (E)	1	1126.16**			46577.59**			126.98**			14.4		
Replication /E	4 (2)	23.46	12.78	34.14	210.18**	64.59**	355.77**	2.37	2.70	2.04	6.22**	8.62**	3.82
ICMV 221 (P) × Raj 171 topcrosses (TC3)	59	171.77**	61.97**	193.37**	96.97**	26.89**	120.58**	4.08**	3.66**	2.04**	7.11*	3.75**	7.28**
TC3 × E	59	81.58**			50.57**			1.61*			3.92**		
Error	236 (118)	39.93	27.58	52.50	20.36	13.37	27.40	1.06	1.18	0.94	1.63	1.94	1.31

Environment (E)	1	5233.26**			65511.01**			28.84*			241.74**		
Replication /E	4 (2)	446.7**	563.47**	329.93**	182.34**	171.67**	193.00**	28.37**	55.49**	1.25	8.11**	14.27**	1.94
ICMV 221 (P) × ICMR 312 topcrosses (TC4)	59	165.67**	67.50**	165.48**	86.56**	23.02**	98.13**	11.72**	13.95**	3.02**	6.81**	2.89**	6.5**
TC4 × E	59	68.27*			34.75*			5.26			2.59*		
Error	236 (118)	44.06	18.27	70.06	22.52	11.92	33.20	4.29	7.47	1.10	1.82	1.61	2.03

[†] Values in parentheses indicate individual environment degrees of freedom;

P-Pooled across environments; R12- 2012 rainy season; S13- 2013 summer season ;

*,**- Significant at the 0.05, 0.01 probability levels, respectively.

Table 4.34. Mean square (both testers considered together) for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW) and days to 50% flowering (DF) for topcrosses of S_0 plants of ICMV 221, 2012 rainy and 2013 summer seasons, Patancheru

		Mean square											
		Fe (mg kg^{-1})			Zn (mg kg^{-1})			GW (g)			DF (d)		
Source	**df** †	**P**	**R12**	**S13**	**P**	**R12**	**S13**	**P**	**R12**	**S13**	**P**	**R12**	**S13**
Environment (E)	1	5574.54**			111278.10**			138.45**			187.07**		
Replication /E	4 (2)	242.39**	372.80**	111.97	374.28**	221.95**	526.62**	13.25**	24.51**	1.99	12.4**	19.97**	4.83
ICMV 221 topcross hybrid (H2)	119	175.09**	64.24**	191.83**	91.33**	29.85**	110.40**	11.83**	10.04**	5.34**	7.64**	4.61**	6.84**
Plant (P)	59	260.19**	96.06**	259.33**	153.31**	38.42**	176.36**	10.42**	10.22**	3.72**	9.65	4.08**	10.71**
Tester (T)	1	957.07	5.92	1697.07**	41.31	607.34**	239.35**	475.55	155.70**	336.95**	87.50	156.03**	0.54
P × T	59	77.43	33.41*	99.46**	30.07	11.49	42.33*	5.24*	7.39**	1.32	4.27**	2.57*	3.06**
H2 × E	119	80.54**			49.01**			3.55*			3.81**		
P × E	59	95.01**			61.44**			3.45			5.14**		
T × E	1	756.63**			803.84**			17.47*			69.07**		
P × T × E	59	55.42			24.02			3.37			1.36	1.79	1.67
Error	476 (238)	43.57	24.44	62.94	21.41	12.66	30.23	2.80	4.58	1.02	1.73		

† Values in parentheses indicate individual environment degrees of freedom;

P-Pooled across environments; R12- 2012 rainy season; S13- 2013 summer season ;

*,** -Significant at the 0.05, 0.01 probability levels, respectively.

Table 4.35. Mean, range and coefficient of variation (CV) for grain iron (Fe), zinc (Zn) densities, 1000-grain weight (GW) and days to 50% flowering (DF) among topcrosses of S_0 plants of ICTP 8203 (TC1 and TC2) and ICMV 221 (TC3 and TC4), 2012 rainy and 2013 summer seasons, Patancheru

		ICTP 8203									
		TC1 (Raj 171 tester)					TC2 (ICMR 312 tester)				
Trait	ENV	Min	Max	Mean	Range	CV(%)	Min	Max	Mean	Range	CV(%)
Fe (mg kg^{-1})	P	46.4	70.2	56.3	23.79	10.3	47.4	64.1	55.3	16.69	8.9
	R12	44.4	66.6	54.0	22.14	10.5	45.7	63.3	53.7	17.61	9.5
	S13	46.1	73.8	58.7	27.72	10.1	44.6	68.0	56.9	23.34	8.3
Zn (mg kg^{-1})	P	39.3	53.9	47.0	14.63	9.4	38.8	52.6	45.1	13.81	8.8
	R12	30.2	44.7	35.6	14.51	11.2	29.1	43.4	34.2	14.30	10.9
	S13	48.1	68.6	58.4	20.56	8.3	48.3	62.9	56.4	14.62	7.4
GW (g)	P	11.7	17.2	13.7	5.45	8.0	13.1	17.2	15.5	4.04	7.1
	R12	11.9	18.1	14.5	6.13	7.8	13.6	18.3	16.2	4.63	7.5
	S13	11.0	16.3	12.9	5.23	8.3	12.1	17.7	14.8	5.63	6.7
DF (d)	P	42	48	44	6.00	2.9	41	47	44	6.67	2.7
	R12	41	48	44	6.67	2.9	40	47	43	7.00	2.6
	S13	41	49	45	8.33	3.0	42	49	45	7.00	2.7
		ICMV 221									
		TC3 (Raj 171 tester)					TC4 (ICMR 312 tester)				
Trait	ENV	Min	Max	Mean	Range	CV(%)	Min	Max	Mean	Range	CV(%)
Fe (mg kg^{-1})	P	38.3	65.6	50.6	27.3	12.5	40.1	66.7	52.8	26.6	12.6
	R12	35.4	64.0	48.8	28.6	10.8	40.2	61.8	49.1	21.5	8.7
	S13	29.2	76.6	52.3	47.4	13.8	40.0	74.5	56.7	34.5	14.8
Zn (mg kg^{-1})	P	33.1	52.3	44.8	19.2	10.1	35.5	54.0	44.3	18.5	10.7
	R12	26.9	38.6	33.4	11.7	10.9	23.7	36.7	30.8	13.0	11.2
	S13	36.9	69.6	56.2	32.7	9.3	47.2	74.5	57.9	27.3	10.0
GW (g)	P	11.2	15.5	13.1	4.3	7.9	10.5	17.4	14.7	6.9	14.0
	R12	11.6	16.6	13.7	5.0	7.9	8.5	17.8	15.0	9.3	18.2
	S13	10.8	14.9	12.5	4.1	7.7	12.1	17.6	14.5	5.6	7.3
DF (d)	P	42	47	44	4.8	2.9	42	47	43	5.8	3.1
	R12	41	46	44	5.0	3.2	41	46	42	5.3	3.0
	S13	42	48	44	6.3	2.6	42	48	44	6.7	3.2

ENV- Environments; P-Pooled across environments; R12- 2012 rainy season; S13- 2013 summer season

Table 4.36. Performance *per se* and rankings of topcrosses of S_0 plants of ICTP 8203 and ICMV 221 for grain iron (Fe) density, 2012 rainy and 2013 summer seasons, Patancheru

Fe (mg kg^{-1})

ICTP 8203

Top cross	P Mean TC1	P Mean TC2	P Rank TC1	P Rank TC2	Top cross	R12 Mean TC1	R12 Mean TC2	R12 Rank TC1	R12 Rank TC2	Top cross	S13 Mean TC1	S13 Mean TC2	S13 Rank TC1	S13 Rank TC2
P 13	70.2	55.5	**1**	**31**	P 13	66.6	54.8	**1**	**25**	P 13	73.8	56.2	**1**	**35**
P 29	66.0	53.6	**2**	**40**	P 41	63.9	57.6	**2**	**10**	P 35	72.3	65.1	**2**	**4**
P 35	65.3	60.7	**3**	**6**	P 53	62.7	58.4	**3**	**8**	P 48	71.3	60.3	**3**	**19**
P 48	64.7	57.9	**4**	**18**	P 34	61.7	62.7	**4**	**3**	P 29	70.5	60.5	**4**	**18**
P 4	64.0	60.3	**5**	**8**	P 29	61.5	46.7	**5**	**59**	P 21	70.0	58.1	**5**	**27**
P 21	63.1	57.1	**6**	**21**	P 28	61.2	55.8	**6**	**19**	P 4	67.7	64.5	**6**	**7**
P 24	62.5	55.0	**7**	**33**	P 24	61.0	58.3	**7**	**9**	P 30	67.3	62.8	**7**	**13**
P 34	62.4	63.3	**8**	**2**	P 4	60.3	56.2	**8**	**17**	P 9	66.4	68.0	**8**	**1**
P 41	62.4	60.5	**9**	**7**	P 42	60.2	54.7	**9**	**27**	P 50	65.7	64.0	**9**	**9**
P 9	62.2	59.7	**10**	**11**	P 5	60.2	63.3	**10**	**2**	P 12	64.2	49.9	**10**	**52**
P 45	60.6	50.0	**11**	**53**	P 19	58.6	50.5	**11**	**46**	P 24	64.0	51.7	**11**	**46**
P 19	60.5	50.8	**12**	**51**	P 45	58.5	50.6	**12**	**45**	P 34	63.2	64.2	**12**	**8**
P 53	60.1	55.8	**13**	**29**	P 35	58.3	56.3	**13**	**13**	P 39	62.8	61.6	**13**	**14**
P 42	60.1	56.7	**14**	**23**	P 48	58.0	55.5	**14**	**21**	P 26	62.7	53.6	**14**	**42**
P 39	59.5	57.4	**15**	**20**	P 9	57.9	54.2	**15**	**29**	P 45	62.7	49.4	**15**	**55**
P 12	59.2	51.6	**16**	**46**	P 33	57.5	53.7	**16**	**30**	P 55	62.6	49.6	**16**	**54**
P 26	59.1	54.6	**17**	**34**	P 37	57.2	53.2	**17**	**31**	P 19	62.5	51.2	**17**	**47**
P 37	59.0	54.2	**18**	**35**	P 7	57.2	48.4	**18**	**55**	P 14	62.3	60.8	**18**	**17**
P 49	58.4	60.2	**19**	**9**	P 38	57.2	57.2	**19**	**12**	P 23	62.1	53.8	**19**	**41**
P 38	58.4	61.1	**20**	**4**	P 39	56.2	53.2	**20**	**32**	P 3	61.7	56.7	**20**	**33**
P 7	58.3	53.8	**21**	**38**	P 21	56.2	56.2	**21**	**16**	P 49	61.2	59.0	**21**	**23**
P 50	58.2	58.2	**22**	**17**	P 12	55.8	53.2	**22**	**33**	P 10	61.1	53.5	**22**	**43**
P 55	58.2	49.7	**23**	**55**	P 18	55.7	58.5	**23**	**7**	P 41	60.8	63.4	**23**	**12**
P 5	58.1	58.7	**24**	**16**	P 49	55.6	61.5	**24**	**4**	P 37	60.8	55.2	**24**	**38**
P 3	57.8	56.3	**25**	**26**	P 26	55.4	55.3	**25**	**24**	P 42	59.9	58.7	**25**	**25**
P 30	57.7	59.2	**26**	**12**	P 16	55.3	55.5	**26**	**22**	P 38	59.6	64.9	**26**	**5**
P 33	57.6	51.5	**27**	**47**	P 25	55.1	57.3	**27**	**11**	P 7	59.3	59.1	**27**	**22**
P 16	57.1	56.6	**28**	**24**	P 6	54.4	56.3	**28**	**15**	P 16	58.9	57.6	**28**	**29**
P 23	57.0	52.4	**29**	**42**	P 1	54.1	60.5	**29**	**5**	P 25	58.7	50.2	**29**	**49**
P 25	56.9	53.8	**30**	**39**	P 3	54.0	56.0	**30**	**18**	P 31	58.4	64.9	**30**	**6**
P 28	56.6	56.8	**31**	**22**	P 15	53.8	49.0	**31**	**53**	P 33	57.7	48.3	**31**	**58**
P 18	56.5	61.0	**32**	**5**	P 52	53.7	59.9	**32**	**6**	P 53	57.5	53.2	**32**	**44**

ICMV 221

Top cross	P Mean TC3	P Mean TC4	P Rank TC3	P Rank TC4	Top cross	R12 Mean TC3	R12 Mean TC4	R12 Rank TC3	R12 Rank TC4	Top cross	S13 Mean TC3	S13 Mean TC4	S13 Rank TC3	S13 Rank TC4
P 8	65.6	66.7	**1**	**1**	P 21	64.0	51.9	**1**	**12**	P 8	76.6	74.5	**1**	**1**
P 21	62.2	55.6	**2**	**18**	P 43	58.1	61.8	**2**	**1**	P 18	73.6	70.6	**2**	**4**
P 6	62.1	53.1	**3**	**30**	P 24	55.6	51.6	**3**	**16**	P 6	72.4	60.0	**3**	**17**
P 18	61.4	60.5	**4**	**6**	P 28	54.8	49.8	**4**	**24**	P 14	61.1	50.9	**4**	**46**
P 47	57.0	49.1	**5**	**47**	P 8	54.6	59.0	**5**	**3**	P 47	61.1	52.8	**5**	**41**
P 24	56.6	57.3	**6**	**10**	P 4	53.9	59.6	**6**	**2**	P 53	60.5	55.4	**6**	**33**
P 41	56.4	57.5	**7**	**8**	P 35	53.0	50.0	**7**	**23**	P 50	60.4	58.9	**7**	**24**
P 50	56.1	56.6	**8**	**14**	P 47	52.9	45.4	**8**	**48**	P 41	60.2	56.3	**8**	**30**
P 30	55.9	57.1	**9**	**12**	P 41	52.5	58.7	**9**	**4**	P 30	59.9	63.7	**9**	**10**
P 35	55.5	54.6	**10**	**20**	P 22	52.4	42.9	**10**	**53**	P 21	59.7	59.3	**10**	**20**
P 43	55.4	56.8	**11**	**13**	P 34	52.4	49.1	**11**	**26**	P 48	59.6	60.0	**11**	**16**
P 53	55.4	51.3	**12**	**34**	P 46	52.0	46.6	**12**	**46**	P 20	59.1	69.8	**12**	**5**
P 20	54.8	61.2	**13**	**5**	P 26	51.9	48.7	**13**	**29**	P 35	58.0	59.2	**13**	**21**
P 51	54.8	61.7	**14**	**3**	P 51	51.9	57.6	**14**	**5**	P 51	57.7	65.7	**14**	**7**
P 14	53.5	47.6	**15**	**54**	P 50	51.8	54.3	**15**	**9**	P 24	57.5	63.0	**15**	**12**
P 12	53.3	60.0	**16**	**7**	P 6	51.8	46.3	**16**	**47**	P 39	56.6	59.4	**16**	**19**
P 4	53.3	66.0	**17**	**2**	P 30	51.8	50.5	**17**	**18**	P 12	56.0	63.0	**17**	**11**
P 48	52.8	54.0	**18**	**25**	P 29	51.3	44.0	**18**	**51**	P 55	55.4	50.4	**18**	**48**
P 52	52.2	48.3	**19**	**52**	P 40	51.2	51.8	**19**	**15**	P 33	55.3	51.3	**19**	**45**
P 39	52.0	54.5	**20**	**21**	P 52	50.7	47.7	**20**	**37**	P 2	54.6	68.1	**20**	**6**
P 49	51.9	53.5	**21**	**27**	P 12	50.7	57.0	**21**	**6**	P 25	54.4	52.6	**21**	**42**
P 2	51.8	56.2	**22**	**15**	P 20	50.6	52.6	**22**	**10**	P 52	54.4	48.8	**22**	**55**
P 55	51.8	48.9	**23**	**48**	P 53	50.4	47.2	**23**	**43**	P 49	53.8	59.1	**23**	**22**
P 46	51.8	50.9	**24**	**36**	P 7	50.1	49.0	**24**	**28**	P 19	53.7	55.8	**24**	**32**
P 33	51.8	50.7	**25**	**37**	P 49	50.1	48.0	**25**	**36**	P 13	53.0	59.7	**25**	**18**
P 26	51.6	55.1	**26**	**19**	P 31	49.9	49.0	**26**	**27**	P 43	52.8	51.9	**26**	**43**
P 34	51.4	61.4	**27**	**4**	P 38	49.5	48.2	**27**	**34**	P 4	52.7	72.5	**27**	**3**
P 40	51.0	54.1	**28**	**24**	P 57	49.3	51.5	**28**	**17**	P 5	52.1	49.4	**28**	**51**
P 22	50.9	44.3	**29**	**58**	P 18	49.2	50.4	**29**	**20**	P 44	52.0	50.6	**29**	**47**
P 19	50.7	49.2	**30**	**46**	P 2	49.1	48.4	**30**	**31**	P 46	51.5	55.3	**30**	**34**
P 7	50.4	50.3	**31**	**40**	P 56	48.7	48.3	**31**	**33**	P 26	51.2	61.5	**31**	**15**
P 29	50.1	53.3	**32**	**29**	P 60	48.6	54.3	**32**	**8**	P 60	51.0	53.1	**32**	**38**

Table 4.36. (Cont.)

Fe (mg kg^{-1})

ICTP 8203

Top cross	P Mean TC1	P Mean TC2	P Rank TC1	P Rank TC2	Top cross	R12 Mean TC1	R12 Mean TC2	R12 Rank TC1	R12 Rank TC2	Top cross	S13 Mean TC1	S13 Mean TC2	S13 Rank TC1	S13 Rank TC2
P 14	56.1	55.8	**33**	**30**	P 55	53.7	49.9	**33**	**48**	P 8	57.5	52.4	**33**	**45**
P 15	55.1	49.8	**34**	**54**	P 47	52.9	52.7	**34**	**36**	P 18	57.3	63.4	**34**	**11**
P 10	54.9	51.3	**35**	**48**	P 22	52.7	45.7	**35**	**60**	P 15	56.5	50.6	**35**	**48**
P 31	54.8	64.1	**36**	**1**	P 8	52.0	51.7	**36**	**40**	P 5	55.9	54.0	**36**	**40**
P 8	54.7	52.1	**37**	**45**	P 23	51.9	51.1	**37**	**42**	P 60	55.9	49.4	**37**	**56**
P 1	53.8	58.9	**38**	**14**	P 31	51.2	63.3	**38**	**1**	P 2	55.8	44.6	**38**	**60**
P 11	53.2	57.4	**39**	**19**	P 58	51.0	52.4	**39**	**38**	P 11	55.6	65.7	**39**	**2**
P 52	53.2	61.5	**40**	**3**	P 11	50.8	49.2	**40**	**51**	P 43	55.4	55.7	**40**	**37**
P 58	53.0	55.4	**41**	**32**	P 59	50.7	52.1	**41**	**39**	P 44	55.0	48.9	**41**	**57**
P 43	53.0	51.2	**42**	**50**	P 50	50.6	52.4	**42**	**37**	P 58	55.0	58.4	**42**	**26**
P 59	52.7	54.1	**43**	**36**	P 43	50.5	46.8	**43**	**58**	P 59	54.7	56.1	**43**	**36**
P 47	52.6	55.8	**44**	**28**	P 20	50.3	51.3	**44**	**41**	P 56	54.0	61.4	**44**	**16**
P 60	52.1	49.6	**45**	**57**	P 14	49.8	50.7	**45**	**44**	P 1	53.6	57.2	**45**	**31**
P 22	51.8	51.2	**46**	**49**	P 46	49.8	49.8	**46**	**49**	P 32	53.4	59.9	**46**	**20**
P 32	51.5	53.9	**47**	**37**	P 17	49.7	52.8	**47**	**35**	P 17	53.4	59.6	**47**	**21**
P 17	51.5	56.2	**48**	**27**	P 32	49.6	47.9	**48**	**56**	P 57	53.2	56.3	**48**	**34**
P 57	51.4	52.3	**49**	**43**	P 57	49.6	48.4	**49**	**54**	P 52	52.6	63.9	**49**	**10**
P 20	51.3	52.7	**50**	**41**	P 40	48.9	54.7	**50**	**26**	P 20	52.3	54.0	**50**	**39**
P 6	51.2	58.9	**51**	**13**	P 10	48.7	49.1	**51**	**52**	P 47	52.2	58.9	**51**	**24**
P 46	50.7	49.7	**52**	**56**	P 36	48.5	50.9	**52**	**43**	P 28	51.9	57.8	**52**	**28**
P 40	50.2	60.2	**53**	**10**	P 60	48.2	49.9	**53**	**47**	P 46	51.7	49.7	**53**	**53**
P 2	50.1	49.6	**54**	**58**	P 30	48.0	55.6	**54**	**20**	P 40	51.6	65.6	**54**	**3**
P 56	50.0	58.8	**55**	**15**	P 51	47.8	55.4	**55**	**23**	P 22	50.9	56.7	**55**	**32**
P 44	49.8	49.1	**56**	**59**	P 54	47.5	47.8	**56**	**57**	P 36	50.7	50.1	**56**	**50**
P 36	49.6	50.5	**57**	**52**	P 27	46.7	54.2	**57**	**28**	P 54	49.8	47.0	**57**	**59**
P 51	48.7	56.4	**58**	**25**	P 56	46.0	56.3	**58**	**14**	P 51	49.6	57.3	**58**	**30**
P 54	48.6	47.4	**59**	**60**	P 44	44.6	49.4	**59**	**50**	P 6	48.0	61.5	**59**	**15**
P 27	46.4	52.1	**60**	**44**	P 2	44.4	52.9	**60**	**34**	P 27	46.1	49.9	**60**	**51**
SE±	2.4	2.0				3.3	2.9				3.4	2.7		
r_1		**0.33**					**0.39**					**0.25**		
r_2											**0.56**	**0.35**		

ICMV 221

Top cross	P Mean TC3	P Mean TC4	P Rank TC3	P Rank TC4	Top cross	R12 Mean TC3	R12 Mean TC4	R12 Rank TC3	R12 Rank TC4	Top cross	S13 Mean TC3	S13 Mean TC4	S13 Rank TC3	S13 Rank TC4
P 44	50.0	47.9	**33**	**53**	P 33	48.2	50.2	**33**	**21**	P 40	50.7	56.4	**33**	**28**
P 57	50.0	54.3	**34**	**23**	P 11	48.2	47.5	**34**	**39**	P 57	50.7	57.1	**34**	**26**
P 28	49.9	48.5	**35**	**50**	P 55	48.2	47.5	**35**	**40**	P 7	50.6	51.6	**35**	**44**
P 60	49.8	53.7	**36**	**26**	P 44	48.0	45.2	**36**	**49**	P 34	50.4	73.6	**36**	**2**
P 25	49.6	53.5	**37**	**28**	P 15	47.9	51.9	**37**	**13**	P 17	50.3	52.8	**37**	**39**
P 56	48.8	51.4	**38**	**33**	P 19	47.7	42.6	**38**	**54**	P 45	50.2	45.8	**38**	**57**
P 38	48.7	48.6	**39**	**49**	P 39	47.5	49.5	**39**	**25**	P 3	50.1	49.8	**39**	**50**
P 45	48.2	47.1	**40**	**55**	P 10	47.4	42.0	**40**	**57**	P 22	49.5	45.8	**40**	**58**
P 3	47.8	50.0	**41**	**42**	P 54	47.3	48.4	**41**	**32**	P 27	49.3	49.1	**41**	**52**
P 13	47.6	51.1	**42**	**35**	P 32	46.7	47.5	**42**	**41**	P 58	49.0	49.1	**42**	**54**
P 5	47.5	45.2	**43**	**56**	P 45	46.1	48.5	**43**	**30**	P 56	49.0	54.4	**43**	**35**
P 58	47.5	45.1	**44**	**57**	P 48	45.9	48.1	**44**	**35**	P 29	48.9	62.7	**44**	**13**
P 27	47.1	49.8	**45**	**43**	P 58	45.9	41.2	**45**	**58**	P 9	48.1	59.1	**45**	**23**
P 15	46.8	54.5	**46**	**22**	P 14	45.8	44.4	**46**	**50**	P 38	47.9	49.1	**46**	**53**
P 31	46.4	57.4	**47**	**9**	P 3	45.4	50.1	**47**	**22**	P 37	47.4	54.4	**47**	**36**
P 9	46.2	55.7	**48**	**17**	P 42	45.3	46.8	**48**	**45**	P 23	46.8	62.6	**48**	**14**
P 17	46.1	48.3	**49**	**51**	P 27	45.0	50.4	**49**	**19**	P 15	45.8	57.1	**49**	**27**
P 37	45.7	50.7	**50**	**38**	P 59	44.9	47.4	**50**	**42**	P 59	45.2	52.8	**50**	**40**
P 54	45.4	49.2	**51**	**45**	P 25	44.8	54.4	**51**	**7**	P 28	45.0	47.3	**51**	**56**
P 59	45.1	50.1	**52**	**41**	P 9	44.3	52.4	**52**	**11**	P 16	43.8	56.4	**52**	**29**
P 32	45.0	52.4	**53**	**31**	P 37	43.9	47.0	**53**	**44**	P 36	43.7	56.1	**53**	**31**
P 23	45.0	57.2	**54**	**11**	P 23	43.2	51.8	**54**	**14**	P 54	43.4	50.1	**54**	**49**
P 42	43.5	56.0	**55**	**16**	P 5	42.9	41.0	**55**	**59**	P 32	43.4	57.4	**55**	**25**
P 11	43.4	50.6	**56**	**39**	P 36	42.5	42.5	**56**	**55**	P 31	42.8	65.7	**56**	**8**
P 36	43.1	49.3	**57**	**44**	P 13	42.2	42.5	**57**	**56**	P 42	41.7	65.2	**57**	**9**
P 1	41.4	40.1	**58**	**60**	P 17	41.9	43.8	**58**	**52**	P 1	41.7	40.0	**58**	**60**
P 16	39.6	52.0	**59**	**32**	P 1	41.2	40.2	**59**	**60**	P 11	38.6	53.6	**59**	**37**
P 10	38.3	43.2	**60**	**59**	P 16	35.4	47.5	**60**	**38**	P 10	29.2	44.4	**60**	**59**
SE±	2.6	2.7				3.0	2.5				4.2	4.8		
r_1		**0.54**					**0.48**					**0.44**		
r_2											**0.42**	**0.46**		

P-Pooled across environments; R12- 2012 rainy season; S13- 2013 summer season; TC1, TC3- topcrosses with Raj 171 tester; TC2, TC4- Topcrosses with ICMR 312 tester; r_1- correlation between TC1 and TC2; r2- correlation between R12 and S13; r(0.05) ≥ 0.25 ; r(0.01) ≥ 0.33

Table 4.37. Performance *per se* and rankings of topcrosses of S_0 plants of ICTP 8203 and ICMV 221 for grain zinc (Zn) density, 2012 rainy and 2013 summer seasons, Patancheru

Zn (mg kg^{-1}) — ICTP 8203

Top cross	P Mean TC1	P Mean TC2	P Rank TC1	P Rank TC2	Top cross	R12 Mean TC1	R12 Mean TC2	R12 Rank TC1	R12 Rank TC2	Top cross	S13 Mean TC1	S13 Mean TC2	S13 Rank TC1	S13 Rank TC2
P 35	53.9	50.1	1	2	P 41	44.7	37.5	1	8	P 48	68.6	57.2	1	24
P 13	53.8	44.2	2	38	P 13	43.1	34.6	2	30	P 39	68.2	60.5	2	14
P 39	53.0	49.8	3	3	P 5	41.0	37.5	3	7	P 35	67.9	62.9	3	1
P 48	52.5	46.0	4	23	P 34	41.0	34.9	4	25	P 24	64.8	54.2	4	41
P 24	51.8	44.7	5	35	P 35	39.9	37.3	5	9	P 13	64.6	53.8	5	45
P 21	50.8	52.6	6	1	P 21	39.8	43.4	6	1	P 14	64.5	61.9	6	5
P 26	50.8	44.0	7	39	P 12	39.1	33.5	7	35	P 23	64.1	52.4	7	52
P 5	50.7	47.6	8	11	P 4	39.1	33.3	8	38	P 50	63.9	61.9	8	3
P 23	50.4	43.3	9	42	P 24	38.8	35.2	9	19	P 53	63.5	55.5	9	33
P 3	50.3	45.4	10	29	P 26	38.4	35.8	10	15	P 26	63.1	56.2	10	30
P 53	50.2	46.2	11	20	P 45	38.1	33.0	11	40	P 12	62.8	57.3	11	23
P 42	50.1	45.9	12	24	P 3	38.0	35.3	12	18	P 10	62.7	54.7	12	39
P 4	50.1	47.3	13	14	P 42	38.0	37.1	13	10	P 3	62.5	55.5	13	34
P 41	49.9	47.9	14	9	P 6	38.0	33.5	14	36	P 42	62.2	59.0	14	17
P 45	49.7	42.3	15	49	P 39	37.7	39.0	15	3	P 55	61.9	52.9	15	50
P 12	48.6	45.4	16	28	P 28	37.5	35.2	16	20	P 21	61.8	61.9	16	4
P 14	48.6	47.2	17	15	P 1	37.4	36.2	17	12	P 49	61.7	61.5	17	7
P 15	48.5	44.5	18	36	P 38	37.1	35.0	18	23	P 19	61.4	52.7	18	51
P 34	48.4	45.0	19	32	P 15	36.9	34.8	19	27	P 45	61.4	51.6	19	56
P 9	48.3	45.2	20	31	P 53	36.8	36.9	20	11	P 4	61.1	61.3	20	8
P 49	48.2	49.6	21	5	P 23	36.7	34.3	21	32	P 5	60.5	57.6	21	22
P 10	47.8	43.3	22	43	P 48	36.4	34.7	22	28	P 25	60.2	50.7	22	57
P 38	47.8	47.8	23	10	P 9	36.4	34.8	23	26	P 15	60.2	54.1	23	43
P 55	47.5	41.8	24	53	P 47	36.0	35.0	24	22	P 9	60.2	60.7	24	11
P 19	47.5	42.6	25	47	P 32	36.0	34.4	25	31	P 44	60.1	52.1	25	55
P 50	47.5	47.5	26	12	P 37	35.9	31.4	26	49	P 31	59.4	61.2	26	9
P 32	47.4	45.7	27	27	P 18	35.9	36.0	27	13	P 32	58.9	57.0	27	27
P 47	47.0	45.4	28	30	P 59	35.5	33.8	28	33	P 7	58.6	61.0	28	10
P 18	46.9	48.8	29	6	P 8	35.4	31.4	29	50	P 58	58.6	53.3	29	49
P 7	46.8	46.5	30	19	P 7	35.1	32.0	30	45	P 30	58.4	53.9	30	44
P 28	46.8	46.7	31	16	P 29	35.0	30.6	31	57	P 38	58.4	60.6	31	13
P 25	46.4	42.9	32	46	P 2	35.0	33.7	32	34	P 16	58.2	59.1	32	16

Zn (mg kg^{-1}) — ICMV 221

Top cross	P Mean TC3	P Mean TC4	P Rank TC3	P Rank TC4	Top cross	R12 Mean TC3	R12 Mean TC4	R12 Rank TC3	R12 Rank TC4	Top cross	S13 Mean TC3	S13 Mean TC4	S13 Rank TC3	S13 Rank TC4
P 18	52.3	54.0	1	1	P 26	38.6	32.8	1	17	P 18	69.6	74.5	1	1
P 50	51.9	47.9	2	9	P 12	38.1	35.3	2	4	P 50	68.5	61.9	2	12
P 8	51.7	53.9	3	2	P 49	38.0	29.2	3	43	P 6	67.4	58.5	3	24
P 35	50.9	45.6	4	19	P 8	37.7	36.2	4	2	P 8	65.7	71.6	4	2
P 6	50.1	44.0	5	35	P 22	37.6	27.3	5	57	P 35	65.1	57.3	5	34
P 41	50.0	46.0	6	16	P 4	37.6	35.2	6	5	P 41	64.9	56.4	6	38
P 49	49.8	46.5	7	13	P 43	37.5	33.6	7	11	P 53	64.0	57.4	7	33
P 47	49.5	46.6	8	11	P 15	37.1	32.2	8	18	P 55	63.5	62.4	8	9
P 55	49.4	46.6	9	12	P 24	36.7	29.2	9	44	P 47	63.2	61.7	9	13
P 12	49.0	50.2	10	5	P 35	36.6	34.0	10	8	P 30	62.3	69.1	10	4
P 30	48.9	52.9	11	3	P 37	36.3	33.1	11	14	P 48	62.2	64.5	11	7
P 48	48.8	48.2	12	7	P 31	36.1	33.0	12	16	P 33	61.9	54.7	12	43
P 33	48.4	42.3	13	45	P 47	35.8	31.6	13	22	P 14	61.7	62.0	13	11
P 53	48.4	45.2	14	21	P 56	35.8	29.4	14	39	P 49	61.6	63.9	14	8
P 29	48.2	51.7	15	4	P 29	35.7	33.3	15	13	P 57	60.7	57.2	15	35
P 43	48.0	44.9	16	26	P 48	35.5	31.8	16	21	P 29	60.7	70.1	16	3
P 26	47.7	45.0	17	25	P 30	35.4	36.7	17	1	P 12	59.8	65.0	17	5
P 57	47.6	44.3	18	33	P 50	35.3	33.9	18	9	P 25	59.8	61.4	18	15
P 56	46.9	43.3	19	39	P 55	35.3	30.9	19	30	P 52	59.5	52.6	19	50
P 14	46.6	44.9	20	27	P 41	35.2	35.5	20	3	P 5	58.7	56.0	20	41
P 4	46.6	48.3	21	6	P 40	35.1	29.4	21	40	P 43	58.4	56.3	21	39
P 45	46.5	40.2	22	52	P 32	35.1	30.2	22	35	P 45	58.4	51.9	22	52
P 20	46.2	45.2	23	23	P 21	34.9	28.8	23	47	P 19	58.4	59.2	23	22
P 24	46.2	43.5	24	37	P 18	34.9	33.5	24	12	P 56	58.0	57.2	24	36
P 25	46.0	48.0	25	8	P 33	34.9	29.9	25	37	P 46	57.9	61.1	25	17
P 19	45.7	44.4	26	31	P 20	34.6	28.8	26	48	P 20	57.8	61.5	26	14
P 46	45.3	46.2	27	15	P 45	34.6	28.4	27	49	P 44	57.0	53.6	27	45
P 5	45.1	41.7	28	48	P 11	34.5	30.6	28	33	P 26	56.7	57.2	28	37
P 15	45.1	45.1	29	24	P 57	34.4	31.3	29	24	P 17	56.3	59.2	29	23
P 21	44.7	39.8	30	53	P 54	33.8	31.5	30	23	P 2	55.7	64.8	30	6
P 51	44.0	42.3	31	44	P 39	33.4	31.2	31	26	P 4	55.6	61.4	31	16
P 32	43.8	45.4	32	20	P 19	33.0	29.6	32	38	P 24	55.6	57.8	32	31

Table 4.37. (Cont.)

Zn (mg kg^{-1})

ICTP 8203

Top cross	P Mean TC1	P Mean TC2	P Rank TC1	P Rank TC2	Top cross	R12 Mean TC1	R12 Mean TC2	R12 Rank TC1	R12 Rank TC2	Top cross	S13 Mean TC1	S13 Mean TC2	S13 Rank TC1	S13 Rank TC2
P 29	46.3	43.8	33	40	P 33	35.0	31.5	33	48	P 47	58.0	55.7	33	32
P 44	46.0	42.1	34	52	P 49	34.7	37.7	34	6	P 18	58.0	61.6	34	6
P 31	46.0	49.7	35	4	P 60	34.5	31.2	35	51	P 29	57.5	57.0	35	26
P 33	46.0	38.8	36	60	P 43	34.5	31.0	36	52	P 43	57.1	54.9	36	38
P 16	46.0	47.4	37	13	P 11	34.3	33.0	37	41	P 33	57.0	49.7	37	58
P 58	45.9	41.2	38	58	P 20	34.3	29.2	38	59	P 57	56.7	56.4	38	29
P 43	45.8	43.0	39	45	P 51	34.1	39.1	39	2	P 60	56.3	52.2	39	53
P 59	45.6	44.8	40	33	P 57	34.1	36.0	40	14	P 11	56.1	59.4	40	15
P 8	45.5	42.6	41	48	P 16	33.8	35.7	41	16	P 28	56.1	58.2	41	20
P 60	45.4	41.7	42	55	P 19	33.6	32.5	42	43	P 52	56.0	55.3	42	35
P 57	45.4	46.2	43	21	P 22	33.6	29.3	43	58	P 34	55.8	55.1	43	37
P 11	45.2	46.2	44	22	P 17	33.5	31.8	44	47	P 59	55.8	55.8	44	31
P 30	45.1	44.8	45	34	P 58	33.2	29.1	45	60	P 8	55.6	53.7	45	47
P 37	45.1	39.8	46	59	P 40	33.2	30.9	46	53	P 41	55.1	58.3	46	19
P 1	45.0	46.5	47	18	P 55	33.2	30.7	47	56	P 51	55.0	54.1	47	42
P 51	44.6	46.6	48	17	P 10	33.0	31.9	48	46	P 37	54.3	48.3	48	60
P 2	44.5	45.9	49	25	P 14	32.6	32.6	49	42	P 17	54.2	57.1	49	25
P 52	44.1	43.1	50	44	P 31	32.6	38.1	50	5	P 2	54.0	58.0	50	21
P 20	44.0	41.7	51	56	P 46	32.6	33.3	51	37	P 20	53.7	54.2	51	40
P 17	43.9	44.4	52	37	P 25	32.5	35.1	52	21	P 1	52.6	56.9	52	28
P 6	43.0	47.9	53	8	P 52	32.2	34.9	53	24	P 54	52.5	53.5	53	48
P 40	42.7	45.8	54	26	P 56	32.2	38.7	54	4	P 56	52.4	58.9	54	18
P 56	42.3	48.8	55	7	P 44	31.9	32.1	55	44	P 40	52.3	60.7	55	12
P 54	42.1	42.2	56	51	P 30	31.8	35.7	56	17	P 22	50.7	55.3	56	36
P 22	42.1	42.3	57	50	P 27	31.8	34.6	57	29	P 27	50.5	48.9	57	59
P 46	41.4	43.5	58	41	P 54	31.8	30.8	58	55	P 46	50.2	53.8	58	46
P 27	41.2	41.8	59	54	P 50	31.2	33.1	59	39	P 36	48.3	52.1	59	54
P 36	39.3	41.5	60	57	P 36	30.2	30.8	60	54	P 6	48.1	62.4	60	2
SE±	1.8	1.6				2.3	2.1				2.8	2.4		
r_1		0.38					0.41					0.21		
r_2											0.35	0.41		

ICMV 221

Top cross	P Mean TC3	P Mean TC4	P Rank TC3	P Rank TC4	Top cross	R12 Mean TC3	R12 Mean TC4	R12 Rank TC3	R12 Rank TC4	Top cross	S13 Mean TC3	S13 Mean TC4	S13 Rank TC3	S13 Rank TC4
P 2	43.6	42.8	33	41	P 6	32.9	29.4	33	41	P 51	55.5	53.4	33	47
P 31	43.6	43.1	34	40	P 53	32.8	33.1	34	15	P 60	55.3	58.2	34	28
P 37	43.6	44.1	35	34	P 28	32.7	34.8	35	6	P 27	55.1	62.3	35	10
P 44	43.5	41.9	36	47	P 46	32.7	31.2	36	29	P 9	54.7	60.7	36	18
P 60	43.4	45.9	37	17	P 51	32.4	31.3	37	25	P 3	54.6	49.8	37	56
P 22	43.1	38.1	38	58	P 59	32.3	30.3	38	34	P 21	54.5	50.8	38	54
P 9	43.1	46.3	39	14	P 25	32.3	34.6	39	7	P 7	54.4	58.3	39	27
P 28	43.1	47.2	40	10	P 52	31.8	28.9	40	46	P 28	53.4	59.6	40	20
P 39	43.0	42.5	41	43	P 2	31.5	28.2	41	50	P 34	53.3	59.3	41	21
P 27	42.9	45.8	42	18	P 5	31.5	27.4	42	54	P 15	53.1	58.0	42	29
P 52	42.8	40.8	43	51	P 14	31.5	27.9	43	52	P 38	52.7	47.3	43	59
P 17	42.8	45.2	44	22	P 9	31.5	31.9	44	19	P 36	52.6	57.9	44	30
P 7	42.7	44.8	45	28	P 38	31.5	27.6	45	53	P 13	52.6	52.6	45	51
P 3	42.4	40.8	46	50	P 60	31.4	33.7	46	10	P 39	52.6	53.8	46	44
P 34	42.3	43.3	47	38	P 34	31.2	27.4	47	55	P 32	52.4	60.6	47	19
P 38	42.1	37.4	48	59	P 7	31.1	31.2	48	28	P 42	51.5	53.5	48	46
P 40	41.7	41.2	49	49	P 27	30.7	29.3	49	42	P 31	51.0	53.3	49	48
P 59	41.0	44.4	50	32	P 58	30.5	28.1	50	51	P 37	50.8	55.2	50	42
P 42	40.9	42.1	51	46	P 42	30.3	30.8	51	31	P 59	49.7	58.4	51	26
P 36	40.9	42.6	52	42	P 3	30.2	31.9	52	20	P 16	49.6	56.3	52	40
P 11	40.8	44.5	53	30	P 44	30.0	30.1	53	36	P 1	49.3	47.2	53	60
P 13	39.7	38.8	54	56	P 17	29.3	31.2	54	27	P 22	48.7	48.9	54	57
P 54	39.4	44.5	55	29	P 10	29.2	29.0	55	45	P 40	48.4	53.1	55	49
P 16	38.8	43.5	56	36	P 36	29.2	27.3	56	56	P 11	47.2	58.5	56	25
P 1	38.4	35.5	57	60	P 16	27.9	30.8	57	32	P 23	47.1	51.2	57	53
P 58	37.5	39.1	58	54	P 23	27.6	26.4	58	58	P 54	45.0	57.5	58	32
P 23	37.3	38.8	59	55	P 1	27.4	23.7	59	60	P 58	44.5	50.1	59	55
P 10	33.1	38.1	60	57	P 13	26.9	25.1	60	59	P 10	36.9	47.3	60	58
SE±	1.8	1.9				2.1	2.0				3.0	3.3		
r_1		0.69					0.54					0.61		
r_2											0.41	0.54		

P-Pooled across environments; R12- 2012 rainy season; S13- 2013 summer season; TC1, TC3- topcrosses with Raj 171 tester; TC2, TC4- Topcrosses with ICMR 312 tester; r_1- correlation between TC1 and TC2; r2- correlation between R12 and S13; r(0.05) ≥ 0.25 ; r(0.01) ≥ 0.33

Table 4.38. Performance *per se* and rankings of topcrosses of S_0 plants of ICTP 8203 and ICMV 221 for 1000-grain weight (GW), 2012 rainy and 2013 summer seasons, Patancheru

GW (g)

Top cross	ICTP 8203 – P Mean		Rank		Top cross	ICTP 8203 – R12 Mean		Rank		Top cross	ICTP 8203 – S13 Mean		Rank		Top cross	ICMV 221 – P Mean		Rank		Top cross	ICMV 221 – R12 Mean		Rank		Top cross	ICMV 221 – S13 Mean		Rank	
	TC1	TC2	TC1	TC2		TC1	TC2	TC1	TC2		TC1	TC2	TC1	TC2		TC3	TC4	TC3	TC4		TC3	TC4	TC3	TC4		TC3	TC4	TC3	TC4
P 21	17.2	16.8	1	4	P 21	18.1	17.8	1	4	P 21	16.3	15.9	1	10	P 8	15.5	16.0	1	9	P 8	16.6	17.1	1	6	P 58	14.9	16.2	1	2
P 52	15.6	16.6	2	8	P 52	17.4	18.3	2	1	P 19	15.4	15.0	2	25	P 58	14.8	17.0	2	2	P 30	15.6	17.2	2	5	P 36	14.5	15.8	2	6
P 19	15.4	16.1	3	21	P 33	16.2	16.0	3	36	P 17	15.3	14.8	3	32	P 48	14.6	15.2	3	24	P 48	15.5	15.1	3	33	P 8	14.4	14.9	3	21
P 50	15.4	16.4	4	13	P 50	16.1	17.2	4	17	P 50	14.7	15.7	4	12	P 47	14.0	15.5	4	22	P 11	15.4	16.7	4	14	P 20	13.7	15.3	4	12
P 17	15.3	15.2	5	40	P 12	16.0	15.7	5	38	P 2	14.6	15.6	5	13	P 30	14.0	15.9	5	10	P 26	15.1	16.4	5	18	P 48	13.7	15.4	5	11
P 33	15.1	16.8	6	3	P 47	16.0	16.6	6	28	P 30	14.4	14.9	6	30	P 11	13.9	16.4	6	4	P 60	15.1	17.6	6	2	P 46	13.5	16.1	6	4
P 47	14.8	15.4	7	36	P 53	16.0	17.2	7	16	P 33	14.1	17.7	7	1	P 13	13.9	15.7	7	16	P 24	15.1	16.9	7	10	P 57	13.4	14.8	7	25
P 12	14.7	14.9	8	42	P 37	15.9	17.3	8	12	P 4	14.0	15.9	8	8	P 57	13.8	15.8	8	15	P 21	15.0	15.0	8	36	P 13	13.3	14.6	8	28
P 29	14.7	13.1	9	60	P 29	15.5	14.2	9	58	P 29	13.8	12.1	9	60	P 29	13.8	16.2	9	7	P 47	14.9	16.7	9	13	P 27	13.3	14.4	9	32
P 59	14.6	15.9	10	27	P 19	15.5	17.2	10	14	P 59	13.8	15.0	10	24	P 38	13.8	14.5	10	38	P 15	14.8	15.7	10	27	P 47	13.2	14.2	10	37
P 4	14.5	16.7	11	6	P 26	15.4	16.1	11	35	P 52	13.8	15.0	11	28	P 24	13.8	15.4	11	23	P 58	14.8	17.8	11	1	P 38	13.2	14.5	11	31
P 26	14.5	15.6	12	31	P 45	15.4	16.6	12	30	P 47	13.6	14.3	12	43	P 26	13.7	15.8	12	13	P 43	14.8	8.5	12	60	P 45	13.1	15.4	12	9
P 45	14.4	16.5	13	11	P 32	15.3	17.6	13	5	P 55	13.6	16.0	13	7	P 50	13.7	14.3	13	42	P 29	14.7	16.7	13	15	P 40	13.1	13.5	13	50
P 30	14.4	16.0	14	25	P 10	15.3	17.4	14	10	P 26	13.5	15.1	14	22	P 21	13.7	14.9	14	33	P 35	14.6	16.5	14	16	P 32	13.0	14.8	14	23
P 23	14.3	16.3	15	17	P 59	15.3	16.8	15	23	P 45	13.5	16.4	15	4	P 46	13.7	16.0	15	8	P 50	14.4	15.2	15	32	P 50	13.0	13.4	15	51
P 53	14.3	16.8	16	5	P 17	15.3	15.7	16	40	P 12	13.4	14.2	16	45	P 15	13.7	15.1	16	25	P 13	14.4	16.9	16	11	P 39	13.0	15.0	16	18
P 32	14.2	16.3	17	18	P 23	15.3	15.8	17	37	P 23	13.3	16.9	17	2	P 45	13.7	12.9	17	55	P 32	14.3	17.0	17	8	P 53	12.9	14.3	17	34
P 5	14.1	16.5	18	9	P 5	15.3	17.1	18	18	P 6	13.3	15.4	18	16	P 27	13.7	14.9	18	32	P 38	14.3	14.5	18	45	P 23	12.9	15.0	18	16
P 55	14.0	16.3	19	16	P 4	15.1	17.4	19	11	P 14	13.3	14.6	19	37	P 32	13.7	15.9	19	12	P 45	14.3	10.4	19	55	P 4	12.9	17.6	19	1
P 6	14.0	14.9	20	43	P 18	14.9	18.0	20	2	P 32	13.2	15.0	20	27	P 35	13.7	15.6	20	18	P 22	14.3	14.9	20	38	P 29	12.8	15.8	20	5
P 18	13.9	16.6	21	7	P 25	14.8	17.6	21	6	P 16	13.1	15.2	21	20	P 20	13.7	15.6	21	19	P 57	14.3	16.9	21	12	P 35	12.8	14.8	21	24
P 16	13.9	16.4	22	15	P 1	14.8	17.6	22	7	P 43	13.1	15.0	22	26	P 60	13.6	16.4	22	5	P 2	14.2	15.5	22	30	P 3	12.8	15.1	22	15
P 37	13.8	16.0	23	24	P 3	14.7	15.3	23	47	P 44	13.0	15.1	23	21	P 36	13.6	16.6	23	3	P 52	14.2	9.5	23	59	P 25	12.7	14.6	23	27
P 2	13.8	16.4	24	14	P 16	14.6	17.6	24	8	P 5	13.0	15.9	24	9	P 52	13.6	11.4	24	57	P 34	14.2	17.5	24	3	P 6	12.7	13.8	24	45
P 14	13.7	15.6	25	32	P 6	14.6	14.5	25	55	P 18	12.9	15.2	25	19	P 43	13.4	10.5	25	60	P 27	14.1	15.4	25	31	P 33	12.6	15.4	25	7
P 10	13.7	16.9	26	2	P 41	14.6	16.7	26	24	P 35	12.9	14.0	26	49	P 39	13.4	15.7	26	17	P 46	14.0	16.0	26	21	P 52	12.6	13.3	26	53
P 60	13.7	15.4	27	37	P 56	14.6	18.0	27	3	P 27	12.8	15.1	27	23	P 23	13.3	15.0	27	28	P 39	13.8	16.4	27	19	P 15	12.6	14.5	27	29
P 35	13.7	15.3	28	38	P 24	14.6	17.5	28	9	P 9	12.8	14.5	28	39	P 4	13.3	17.4	28	1	P 23	13.8	14.9	28	37	P 30	12.5	14.6	28	26
P 41	13.7	15.7	29	29	P 60	14.6	15.5	29	43	P 60	12.8	15.3	29	17	P 53	13.2	14.0	29	46	P 42	13.8	9.5	29	58	P 59	12.5	15.4	29	10
P 1	13.6	16.5	30	10	P 31	14.5	14.9	30	52	P 40	12.8	15.7	30	11	P 3	13.2	12.6	30	56	P 59	13.8	16.5	30	17	P 55	12.5	13.5	30	48
P 25	13.6	17.2	31	1	P 15	14.5	16.9	31	20	P 34	12.8	14.2	31	44	P 59	13.1	15.9	31	11	P 4	13.7	17.1	31	7	P 21	12.5	14.8	31	22
P 43	13.6	15.2	32	41	P 55	14.5	16.7	32	25	P 41	12.7	14.6	32	35	P 25	13.1	15.0	32	26	P 18	13.6	14.6	32	44	P 24	12.5	13.9	32	44

Table 4.38. (Cont.)

GW (g)

ICTP 8203

Top cross	P Mean TC1	P Mean TC2	P Rank TC1	P Rank TC2	Top cross	R12 Mean TC1	R12 Mean TC2	R12 Rank TC1	R12 Rank TC2	Top cross	S13 Mean TC1	S13 Mean TC2	S13 Rank TC1	S13 Rank TC2
P 24	13.5	16.0	**33**	**23**	P 35	14.4	16.7	**33**	**26**	P 28	12.7	14.8	**33**	**33**
P 34	13.5	15.6	**34**	**33**	P 30	14.3	17.0	**34**	**19**	P 13	12.7	12.7	**34**	**59**
P 31	13.5	14.4	**35**	**50**	P 34	14.3	16.9	**35**	**21**	P 53	12.6	16.4	**35**	**5**
P 56	13.5	16.5	**36**	**12**	P 14	14.2	16.6	**36**	**29**	P 51	12.6	15.5	**36**	**14**
P 28	13.4	15.6	**37**	**30**	P 28	14.2	16.5	**37**	**32**	P 54	12.5	14.1	**37**	**47**
P 9	13.4	14.9	**38**	**47**	P 54	14.2	16.5	**38**	**33**	P 31	12.4	13.9	**38**	**51**
P 40	13.4	16.1	**39**	**22**	P 40	14.1	16.5	**39**	**34**	P 24	12.4	14.6	**39**	**36**
P 3	13.3	14.7	**40**	**48**	P 9	14.1	15.3	**40**	**46**	P 1	12.4	15.4	**40**	**15**
P 54	13.3	15.3	**41**	**39**	P 43	14.0	15.5	**41**	**44**	P 38	12.4	14.0	**41**	**48**
P 51	13.3	16.2	**42**	**19**	P 51	14.0	16.8	**42**	**22**	P 56	12.4	14.9	**42**	**29**
P 15	13.2	15.9	**43**	**26**	P 46	13.8	14.8	**43**	**53**	P 49	12.3	14.6	**43**	**38**
P 27	13.2	16.1	**44**	**20**	P 49	13.8	15.2	**44**	**48**	P 39	12.3	15.2	**44**	**18**
P 44	13.2	15.9	**45**	**28**	P 8	13.8	16.5	**45**	**31**	P 48	12.3	13.8	**45**	**53**
P 49	13.1	14.9	**46**	**45**	P 39	13.6	15.7	**46**	**39**	P 25	12.3	16.7	**46**	**3**
P 39	13.0	15.5	**47**	**35**	P 42	13.6	15.5	**47**	**42**	P 22	12.2	12.7	**47**	**58**
P 42	12.8	14.9	**48**	**44**	P 7	13.6	14.6	**48**	**54**	P 10	12.1	16.4	**48**	**6**
P 8	12.8	15.5	**49**	**34**	P 27	13.5	17.2	**49**	**15**	P 58	12.1	13.4	**49**	**56**
P 7	12.7	14.2	**50**	**53**	P 57	13.5	14.9	**50**	**51**	P 42	12.1	14.3	**50**	**42**
P 13	12.7	14.1	**51**	**55**	P 44	13.3	16.6	**51**	**27**	P 3	12.0	14.2	**51**	**46**
P 48	12.6	14.1	**52**	**54**	P 58	13.0	15.2	**52**	**49**	P 20	12.0	13.7	**52**	**54**
P 57	12.6	14.3	**53**	**52**	P 22	13.0	13.6	**53**	**60**	P 7	11.9	13.8	**53**	**52**
P 22	12.6	13.2	**54**	**59**	P 48	13.0	14.5	**54**	**56**	P 15	11.9	14.9	**54**	**31**
P 58	12.5	14.3	**55**	**51**	P 2	12.9	17.3	**55**	**13**	P 8	11.8	14.4	**55**	**40**
P 46	12.4	13.8	**56**	**57**	P 13	12.7	15.6	**56**	**41**	P 37	11.8	14.7	**56**	**34**
P 20	12.3	14.4	**57**	**49**	P 11	12.7	15.4	**57**	**45**	P 57	11.8	13.6	**57**	**55**
P 38	12.3	14.1	**58**	**56**	P 20	12.6	15.0	**58**	**50**	P 11	11.7	14.3	**58**	**41**
P 11	12.2	14.9	**59**	**46**	P 38	12.1	14.2	**59**	**57**	P 36	11.5	13.9	**59**	**50**
P 36	11.7	13.8	**60**	**58**	P 36	11.9	13.7	**60**	**59**	P 46	11.0	12.9	**60**	**57**
SE±	0.5	0.5				0.7	0.7				0.6	0.6		
r_1		**0.57**					**0.55**					**0.37**		
r_2											**0.59**	**0.58**		

ICMV 221

Top cross	P Mean TC3	P Mean TC4	P Rank TC3	P Rank TC4	Top cross	R12 Mean TC3	R12 Mean TC4	R12 Rank TC3	R12 Rank TC4	Top cross	S13 Mean TC3	S13 Mean TC4	S13 Rank TC3	S13 Rank TC4
P 34	13.1	16.2	**33**	**6**	P 41	13.6	14.8	**33**	**42**	P 10	12.4	15.0	**33**	**20**
P 42	13.1	11.2	**34**	**59**	P 20	13.6	15.9	**34**	**23**	P 44	12.4	13.2	**34**	**55**
P 2	13.0	14.9	**35**	**30**	P 3	13.6	10.1	**35**	**56**	P 42	12.4	12.8	**35**	**58**
P 18	12.9	14.3	**36**	**41**	P 53	13.6	13.7	**36**	**51**	P 19	12.4	14.1	**36**	**39**
P 12	12.7	14.0	**37**	**47**	P 1	13.5	13.1	**37**	**54**	P 26	12.4	15.2	**37**	**13**
P 33	12.7	15.5	**38**	**21**	P 25	13.5	15.5	**38**	**29**	P 11	12.3	16.2	**38**	**3**
P 41	12.7	13.9	**39**	**49**	P 56	13.4	16.3	**39**	**20**	P 12	12.3	13.2	**39**	**56**
P 1	12.7	13.8	**40**	**50**	P 5	13.4	13.6	**40**	**52**	P 49	12.3	13.5	**40**	**49**
P 49	12.7	14.1	**41**	**44**	P 14	13.2	15.0	**41**	**34**	P 60	12.2	15.2	**41**	**14**
P 14	12.6	15.0	**42**	**27**	P 12	13.1	14.9	**42**	**40**	P 16	12.1	14.1	**42**	**38**
P 56	12.6	15.8	**43**	**14**	P 49	13.1	14.7	**43**	**43**	P 14	12.1	15.0	**43**	**19**
P 40	12.6	14.7	**44**	**35**	P 33	12.9	15.7	**44**	**28**	P 18	12.1	14.0	**44**	**41**
P 10	12.6	14.7	**45**	**34**	P 37	12.8	15.7	**45**	**26**	P 43	12.1	12.5	**45**	**59**
P 22	12.6	14.4	**46**	**39**	P 10	12.8	14.5	**46**	**47**	P 34	12.0	15.0	**46**	**17**
P 5	12.6	13.7	**47**	**51**	P 9	12.8	13.3	**47**	**53**	P 9	11.9	13.8	**47**	**46**
P 44	12.5	11.4	**48**	**58**	P 36	12.7	17.4	**48**	**4**	P 56	11.9	15.4	**48**	**8**
P 9	12.3	13.5	**49**	**53**	P 44	12.7	9.6	**49**	**57**	P 1	11.9	14.5	**49**	**30**
P 6	12.3	14.2	**50**	**43**	P 31	12.6	14.1	**50**	**48**	P 2	11.9	14.4	**50**	**33**
P 16	12.3	15.5	**51**	**20**	P 16	12.4	16.9	**51**	**9**	P 5	11.8	13.9	**51**	**43**
P 19	12.2	14.0	**52**	**48**	P 51	12.3	14.8	**52**	**41**	P 41	11.8	13.1	**52**	**57**
P 31	12.1	13.7	**53**	**52**	P 17	12.3	15.0	**53**	**35**	P 31	11.7	13.3	**53**	**52**
P 55	12.1	14.6	**54**	**36**	P 40	12.2	15.9	**54**	**22**	P 28	11.4	12.1	**54**	**60**
P 37	12.1	15.0	**55**	**29**	P 19	12.1	13.9	**55**	**50**	P 37	11.3	14.2	**55**	**36**
P 17	11.8	14.4	**56**	**40**	P 28	12.0	14.1	**56**	**49**	P 51	11.2	14.3	**56**	**35**
P 51	11.8	14.5	**57**	**37**	P 6	12.0	14.5	**57**	**46**	P 17	11.2	13.8	**57**	**47**
P 28	11.7	13.1	**58**	**54**	P 54	11.9	15.8	**58**	**24**	P 54	11.2	14.1	**58**	**40**
P 54	11.5	14.9	**59**	**31**	P 55	11.7	15.7	**59**	**25**	P 22	10.9	13.9	**59**	**42**
P 7	11.2	14.1	**60**	**45**	P 7	11.6	14.9	**60**	**39**	P 7	10.8	13.3	**60**	**54**
SE±	0.4	0.9				0.6	1.6				0.6	0.6		
r_1		**0.36**					**0.20**					**0.48**		
r_2											**0.45**	**0.50**		

P-Pooled across environments; R12- 2012 rainy season; S13- 2013 summer season; TC1, TC3- topcrosses with Raj 171 tester; TC2, TC4- Topcrosses with ICMR 312 tester; r_1- correlation between TC1 and TC2; r2- correlation between R12 and S13; r(0.05) ≥ 0.25 ; r(0.01) ≥ 0.33

Table 4.39. Performance *per se* and rankings of topcrosses of S_0 plants of ICTP 8203 and ICMV 221 for days to 50% flowering (DF), 2012 rainy and 2013 summer seasons, Patancheru

DF (d)

ICTP 8203

Top cross	P				Top cross	R12				Top cross	S13			
	Mean		Rank			Mean		Rank			Mean		Rank	
	TC1	TC2	TC1	TC2		TC1	TC2	TC1	TC2		TC1	TC2	TC1	TC2
P 2	47.7	47.3	**1**	**1**	P 2	47.7	46.7	**1**	**1**	P 20	49.3	45.3	**1**	**20**
P 20	47.7	44.0	**2**	**20**	P 20	46.0	42.7	**2**	**27**	P 41	49.0	46.7	**2**	**5**
P 41	47.2	45.7	**3**	**4**	P 1	45.7	44.3	**3**	**8**	P 7	48.7	44.0	**3**	**38**
P 8	46.5	42.3	**4**	**52**	P 27	45.7	44.3	**4**	**12**	P 8	48.0	44.0	**4**	**39**
P 14	46.3	44.2	**5**	**17**	P 21	45.3	46.3	**5**	**2**	P 14	48.0	47.0	**5**	**3**
P 16	46.2	46.5	**6**	**2**	P 23	45.3	44.3	**6**	**10**	P 2	47.7	48.0	**6**	**2**
P 27	46.2	44.3	**7**	**15**	P 24	45.3	42.3	**7**	**34**	P 12	47.3	44.3	**7**	**31**
P 23	46.0	45.3	**8**	**8**	P 41	45.3	44.7	**8**	**6**	P 16	47.3	48.7	**8**	**1**
P 1	45.8	45.3	**9**	**7**	P 8	45.0	40.7	**9**	**57**	P 15	46.7	45.3	**9**	**19**
P 7	45.7	42.7	**10**	**48**	P 16	45.0	44.3	**10**	**9**	P 23	46.7	46.3	**10**	**8**
P 24	45.5	43.2	**11**	**39**	P 26	45.0	44.3	**11**	**11**	P 27	46.7	44.3	**11**	**32**
P 42	45.5	45.5	**12**	**6**	P 42	45.0	44.7	**12**	**7**	P 32	46.7	46.0	**12**	**11**
P 12	45.3	43.0	**13**	**45**	P 52	45.0	43.7	**13**	**14**	P 11	46.3	45.0	**13**	**23**
P 32	45.3	44.7	**14**	**14**	P 3	44.7	42.3	**14**	**32**	P 25	46.3	44.0	**14**	**41**
P 56	45.3	44.8	**15**	**13**	P 13	44.7	41.7	**15**	**45**	P 1	46.0	46.3	**15**	**6**
P 57	45.3	43.5	**16**	**34**	P 14	44.7	41.3	**16**	**51**	P 10	46.0	42.7	**16**	**55**
P 43	45.2	43.7	**17**	**26**	P 56	44.7	43.3	**17**	**21**	P 42	46.0	46.3	**17**	**9**
P 52	45.2	43.5	**18**	**33**	P 57	44.7	43.7	**18**	**15**	P 43	46.0	44.7	**18**	**30**
P 15	45.0	43.5	**19**	**28**	P 30	44.3	43.3	**19**	**18**	P 48	46.0	45.7	**19**	**15**
P 3	44.8	43.8	**20**	**24**	P 43	44.3	42.7	**20**	**30**	P 53	46.0	44.3	**20**	**37**
P 10	44.8	42.3	**21**	**53**	P 9	44.0	42.0	**21**	**39**	P 56	46.0	46.3	**21**	**10**
P 21	44.8	46.3	**22**	**3**	P 32	44.0	43.3	**22**	**20**	P 57	46.0	43.3	**22**	**50**
P 25	44.8	42.7	**23**	**50**	P 10	43.7	42.0	**23**	**40**	P 22	45.7	44.7	**23**	**29**
P 26	44.8	45.0	**24**	**10**	P 34	43.7	43.7	**24**	**13**	P 24	45.7	44.0	**24**	**40**
P 9	44.7	42.5	**25**	**51**	P 35	43.7	43.0	**25**	**22**	P 9	45.3	43.0	**25**	**51**
P 11	44.7	43.3	**26**	**35**	P 36	43.7	43.0	**26**	**23**	P 17	45.3	45.7	**26**	**13**
P 53	44.7	44.8	**27**	**12**	P 37	43.7	41.7	**27**	**47**	P 34	45.3	47.0	**27**	**4**
P 34	44.5	45.3	**28**	**9**	P 39	43.7	45.0	**28**	**4**	P 40	45.3	43.7	**28**	**48**
P 30	44.3	43.8	**29**	**25**	P 44	43.7	43.0	**29**	**24**	P 52	45.3	43.3	**29**	**49**
P 4	44.2	42.0	**30**	**55**	P 46	43.7	42.0	**30**	**41**	P 3	45.0	45.3	**30**	**17**
P 17	44.2	44.2	**31**	**18**	P 4	43.3	42.0	**31**	**38**	P 4	45.0	42.0	**31**	**57**
P 22	44.2	44.0	**32**	**21**	P 12	43.3	41.7	**32**	**44**	P 49	45.0	45.0	**32**	**28**

ICMV 221

Top cross	P				Top cross	R12				Top cross	S13			
	Mean		Rank			Mean		Rank			Mean		Rank	
	TC3	TC4	TC3	TC4		TC3	TC4	TC3	TC4		TC3	TC4	TC3	TC4
P 8	46.7	47.3	**1**	**1**	P 8	46.3	46.3	**1**	**1**	P 17	48.0	47.3	**1**	**3**
P 17	46.2	44.7	**2**	**5**	P 26	45.3	42.3	**2**	**26**	P 13	47.7	46.3	**2**	**4**
P 18	45.8	43.8	**3**	**12**	P 38	45.3	42.7	**3**	**19**	P 8	47.0	48.3	**3**	**2**
P 6	45.7	42.5	**4**	**45**	P 40	45.3	41.3	**4**	**55**	P 18	47.0	45.7	**4**	**7**
P 13	45.7	43.8	**5**	**11**	P 45	45.3	43.0	**5**	**12**	P 32	47.0	44.7	**5**	**19**
P 45	45.7	43.5	**6**	**22**	P 6	45.0	41.7	**6**	**44**	P 11	46.7	45.3	**6**	**10**
P 11	45.5	44.0	**7**	**9**	P 12	45.0	42.7	**7**	**16**	P 60	46.7	45.0	**7**	**15**
P 32	45.2	43.5	**8**	**20**	P 15	45.0	43.7	**8**	**6**	P 6	46.3	43.3	**8**	**37**
P 54	45.2	42.2	**9**	**53**	P 33	45.0	43.3	**9**	**10**	P 45	46.0	44.0	**9**	**28**
P 60	45.2	43.8	**10**	**15**	P 18	44.7	42.0	**10**	**37**	P 3	45.7	44.3	**10**	**20**
P 38	45.0	43.0	**11**	**32**	P 20	44.7	42.3	**11**	**23**	P 37	45.7	45.3	**11**	**12**
P 22	44.8	43.0	**12**	**31**	P 22	44.7	41.3	**12**	**53**	P 54	45.7	42.0	**12**	**58**
P 19	44.7	43.0	**13**	**30**	P 34	44.7	43.3	**13**	**11**	P 41	45.3	43.7	**13**	**33**
P 52	44.7	43.3	**14**	**27**	P 43	44.7	42.7	**14**	**20**	P 52	45.3	43.7	**14**	**35**
P 3	44.5	44.2	**15**	**8**	P 54	44.7	42.3	**15**	**32**	P 2	45.0	48.3	**15**	**1**
P 34	44.5	44.5	**16**	**6**	P 10	44.3	42.0	**16**	**35**	P 19	45.0	44.0	**16**	**26**
P 41	44.5	42.7	**17**	**42**	P 11	44.3	42.7	**17**	**15**	P 22	45.0	44.7	**17**	**18**
P 43	44.5	43.5	**18**	**21**	P 17	44.3	42.0	**18**	**36**	P 23	44.7	43.3	**18**	**40**
P 23	44.3	42.8	**19**	**36**	P 19	44.3	42.0	**19**	**38**	P 38	44.7	43.3	**19**	**42**
P 26	44.3	42.2	**20**	**52**	P 39	44.3	41.7	**20**	**49**	P 42	44.7	43.3	**20**	**43**
P 50	44.3	42.5	**21**	**46**	P 53	44.3	43.7	**21**	**8**	P 50	44.7	42.7	**21**	**51**
P 2	44.2	46.7	**22**	**2**	P 55	44.3	41.0	**22**	**60**	P 5	44.3	44.7	**22**	**16**
P 5	44.2	43.2	**23**	**28**	P 5	44.0	41.7	**23**	**43**	P 14	44.3	44.7	**23**	**17**
P 31	44.2	44.8	**24**	**4**	P 7	44.0	41.7	**24**	**45**	P 31	44.3	46.0	**24**	**6**
P 40	44.2	41.8	**25**	**58**	P 23	44.0	42.3	**25**	**25**	P 34	44.3	45.7	**25**	**8**
P 12	44.0	42.8	**26**	**34**	P 28	44.0	41.3	**26**	**54**	P 43	44.3	44.3	**26**	**23**
P 37	44.0	43.7	**27**	**18**	P 31	44.0	43.7	**27**	**7**	P 21	44.0	43.3	**27**	**39**
P 42	44.0	42.8	**28**	**38**	P 36	44.0	41.7	**28**	**48**	P 27	44.0	46.0	**28**	**5**
P 53	44.0	44.3	**29**	**7**	P 50	44.0	42.3	**29**	**31**	P 7	43.7	43.0	**29**	**46**
P 55	44.0	42.5	**30**	**47**	P 51	44.0	42.0	**30**	**42**	P 9	43.7	44.3	**30**	**21**
P 7	43.8	42.3	**31**	**49**	P 52	44.0	43.0	**31**	**13**	P 28	43.7	42.7	**31**	**50**
P 14	43.8	43.7	**32**	**16**	P 58	44.0	44.0	**32**	**5**	P 30	43.7	44.3	**32**	**22**

Table 4.39. (Cont.)

DF (d)

ICTP 8203

Top cross	P Mean TC1	P Mean TC2	P Rank TC1	P Rank TC2	Top cross	R12 Mean TC1	R12 Mean TC2	R12 Rank TC1	R12 Rank TC2	Top cross	S13 Mean TC1	S13 Mean TC2	S13 Rank TC1	S13 Rank TC2
P 36	44.2	43.5	33	31	P 15	43.3	41.7	33	46	P 59	45.0	45.3	33	22
P 39	44.2	45.5	34	5	P 25	43.3	41.3	34	52	P 5	44.7	45.3	34	18
P 46	44.2	43.2	35	40	P 31	43.3	43.3	35	19	P 26	44.7	45.7	35	14
P 59	44.2	44.0	36	23	P 38	43.3	41.7	36	48	P 31	44.7	45.3	36	21
P 31	44.0	44.3	37	16	P 51	43.3	42.3	37	36	P 36	44.7	44.0	37	42
P 37	44.0	43.3	38	36	P 53	43.3	45.3	38	3	P 39	44.7	46.0	38	12
P 40	44.0	43.0	39	46	P 59	43.3	42.7	39	31	P 46	44.7	44.3	39	36
P 13	43.8	42.7	40	49	P 60	43.3	42.0	40	42	P 6	44.3	43.7	40	45
P 35	43.8	44.0	41	22	P 6	43.0	42.3	41	33	P 21	44.3	46.3	41	7
P 6	43.7	43.0	42	44	P 11	43.0	41.7	42	43	P 30	44.3	44.3	42	34
P 44	43.7	43.7	43	27	P 17	43.0	42.7	43	26	P 37	44.3	45.0	43	26
P 49	43.7	43.2	44	41	P 7	42.7	41.3	44	50	P 55	44.3	42.0	44	58
P 5	43.5	44.0	45	19	P 22	42.7	43.3	45	17	P 18	44.0	43.7	45	47
P 48	43.5	43.5	46	32	P 40	42.7	42.3	46	35	P 29	44.0	44.3	46	33
P 55	43.5	41.0	47	59	P 45	42.7	41.0	47	55	P 35	44.0	45.0	47	25
P 60	43.5	42.0	48	56	P 55	42.7	40.0	48	59	P 44	43.7	44.3	48	35
P 18	43.2	43.5	49	29	P 58	42.7	42.3	49	37	P 47	43.7	45.0	49	27
P 38	43.2	42.3	50	54	P 5	42.3	42.7	50	25	P 54	43.7	41.7	50	60
P 51	43.2	43.2	51	42	P 18	42.3	43.3	51	16	P 60	43.7	42.0	51	59
P 45	43.0	41.7	52	58	P 33	42.3	42.7	52	29	P 45	43.3	42.3	52	56
P 47	43.0	43.3	53	37	P 47	42.3	41.7	53	49	P 58	43.3	44.0	53	44
P 58	43.0	43.2	54	43	P 49	42.3	41.3	54	54	P 13	43.0	43.7	54	46
P 29	42.7	43.5	55	30	P 50	42.3	41.0	55	56	P 38	43.0	43.0	55	54
P 50	42.7	43.3	56	38	P 28	42.0	44.7	56	5	P 50	43.0	45.7	56	16
P 54	42.5	40.7	57	60	P 19	41.3	40.3	57	58	P 51	43.0	44.0	57	43
P 28	42.3	44.8	58	11	P 29	41.3	42.7	58	28	P 19	42.7	43.0	58	52
P 19	42.0	41.7	59	57	P 54	41.3	39.7	59	60	P 28	42.7	45.0	59	24
P 33	41.7	42.8	60	47	P 48	41.0	41.3	60	53	P 33	41.0	43.0	60	53
SE±	0.5	0.5				0.7	0.6				0.8	0.7		
r_1		0.52					0.57					0.45		
r_2											0.54	0.58		

ICMV 221

Top cross	P Mean TC3	P Mean TC4	P Rank TC3	P Rank TC4	Top cross	R12 Mean TC3	R12 Mean TC4	R12 Rank TC3	R12 Rank TC4	Top cross	S13 Mean TC3	S13 Mean TC4	S13 Rank TC3	S13 Rank TC4
P 20	43.8	43.7	33	17	P 13	43.7	41.3	33	52	P 53	43.7	45.0	33	14
P 28	43.8	42.0	34	54	P 41	43.7	41.7	34	50	P 55	43.7	44.0	34	31
P 39	43.8	42.0	35	56	P 60	43.7	42.7	35	22	P 4	43.3	44.0	35	25
P 33	43.7	42.7	36	41	P 1	43.3	42.0	36	34	P 16	43.3	45.3	36	11
P 51	43.7	43.0	37	33	P 2	43.3	45.0	37	2	P 24	43.3	43.3	37	41
P 27	43.5	45.0	38	3	P 3	43.3	44.0	38	3	P 26	43.3	42.0	38	56
P 36	43.5	42.0	39	55	P 14	43.3	42.7	39	17	P 29	43.3	44.0	39	27
P 10	43.3	42.3	40	50	P 16	43.3	42.7	40	18	P 39	43.3	42.3	40	53
P 15	43.3	43.5	41	19	P 29	43.3	41.7	41	47	P 51	43.3	44.0	41	30
P 16	43.3	44.0	42	10	P 32	43.3	42.3	42	28	P 12	43.0	43.0	42	47
P 29	43.3	42.8	43	37	P 42	43.3	42.3	43	29	P 20	43.0	45.0	43	13
P 58	43.3	43.8	44	14	P 44	43.3	41.3	44	56	P 25	43.0	43.7	44	32
P 9	43.2	43.0	45	29	P 46	43.3	42.3	45	30	P 35	43.0	45.7	45	9
P 44	43.2	41.8	46	59	P 27	43.0	44.0	46	4	P 36	43.0	42.3	46	52
P 1	42.8	41.8	47	57	P 57	43.0	41.7	47	51	P 40	43.0	42.3	47	54
P 21	42.8	42.8	48	35	P 9	42.7	41.7	48	46	P 44	43.0	42.3	48	55
P 24	42.8	43.3	49	25	P 25	42.7	41.0	49	59	P 47	43.0	44.0	49	29
P 25	42.8	42.3	50	51	P 49	42.7	42.0	50	41	P 56	42.7	43.0	50	48
P 30	42.8	43.3	51	26	P 56	42.7	42.3	51	33	P 58	42.7	43.7	51	36
P 46	42.8	42.8	52	39	P 24	42.3	43.3	52	9	P 1	42.3	41.7	52	59
P 56	42.7	42.7	53	44	P 37	42.3	42.0	53	40	P 10	42.3	42.7	53	49
P 57	42.5	42.5	54	48	P 59	42.3	41.3	54	58	P 33	42.3	42.0	54	57
P 4	42.3	43.3	55	24	P 30	42.0	42.3	55	27	P 46	42.3	43.3	55	44
P 35	42.3	43.8	56	13	P 21	41.7	42.3	56	24	P 48	42.3	44.3	56	24
P 49	42.3	42.8	57	40	P 35	41.7	42.0	57	39	P 49	42.0	43.7	57	34
P 47	42.2	42.7	58	43	P 4	41.3	42.7	58	14	P 57	42.0	43.3	58	45
P 59	42.2	41.5	59	60	P 47	41.3	41.3	59	57	P 59	42.0	41.7	59	60
P 48	41.8	43.5	60	23	P 48	41.3	42.7	60	21	P 15	41.7	43.3	60	38
SE±	0.5	0.6				0.8	0.7				0.7	0.8		
r_1		0.39					0.23					0.56		
r_2											0.31	0.49		

P-Pooled across environments; R12- 2012 rainy season; S13- 2013 summer season; TC1, TC3- topcrosses with Raj 171 tester; TC2, TC4- Topcrosses with ICMR 312 tester; r_1- correlation between TC1 and TC2; r2- correlation between R12 and S13; r(0.05) ≥ 0.25 ; r(0.01) ≥ 0.33

Illustrations

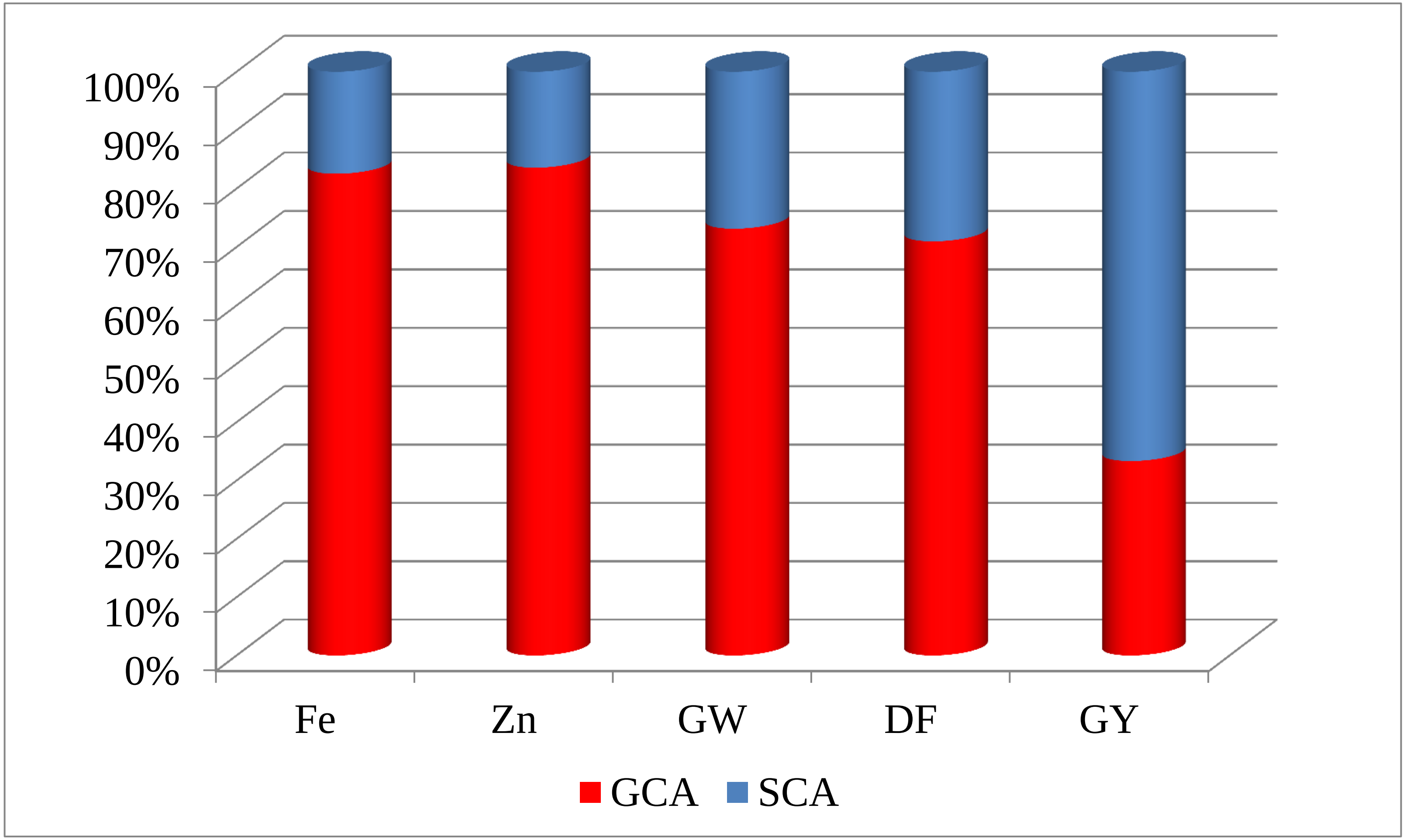

Figure 4.1. Relative proportions of general combining ability (GCA) and specific combining ability (SCA) variances for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), days to 50% flowering (DF) and grain yield (GY) in line × tester study, averaged over environments (2011 rainy and 2012 summer seasons), Patancheru

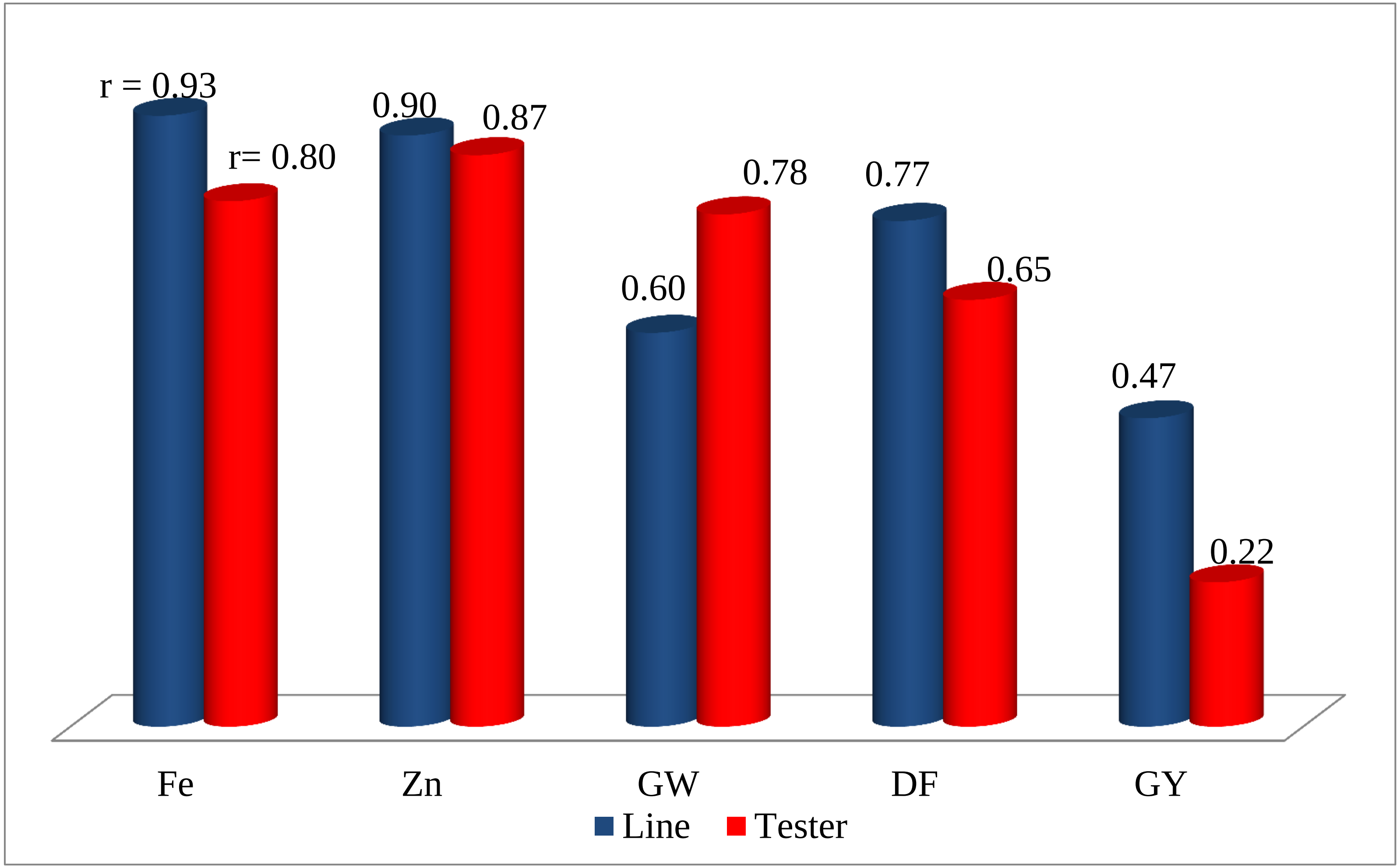

Figure 4.2. Relationship between parental performance *per se* and their *gca* effects (r) for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), days to 50% flowering (DF) and grain yield (GY) in line × tester study, averaged over environments (2011 rainy and 2012 summer seasons), Patancheru

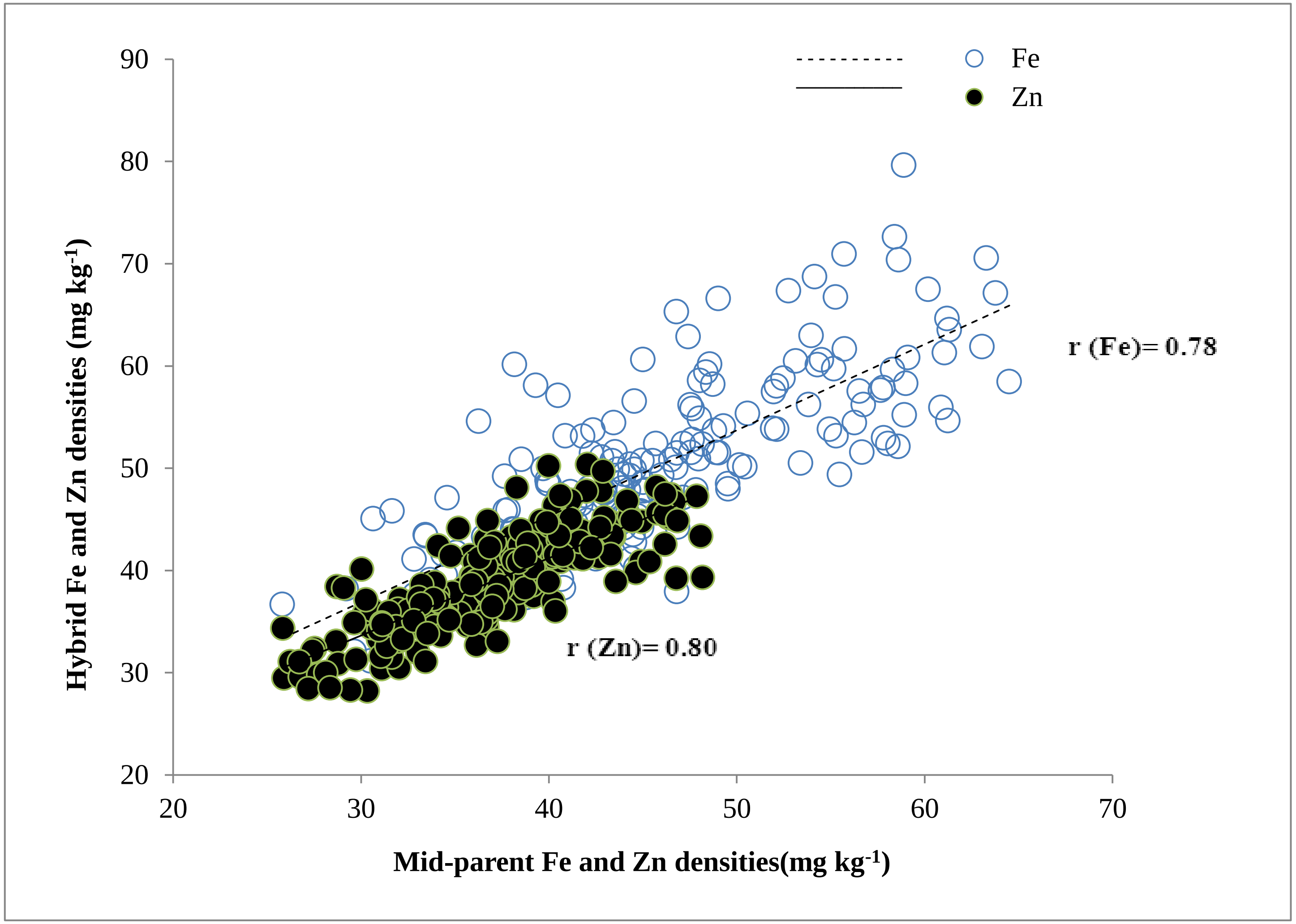

Figure 4.3. Relationship between mid-parental and hybrid values for grain iron (Fe) and zinc (Zn) densities in line × tester study, averaged over environments (2011 rainy and 2012 summer seasons), Patancheru

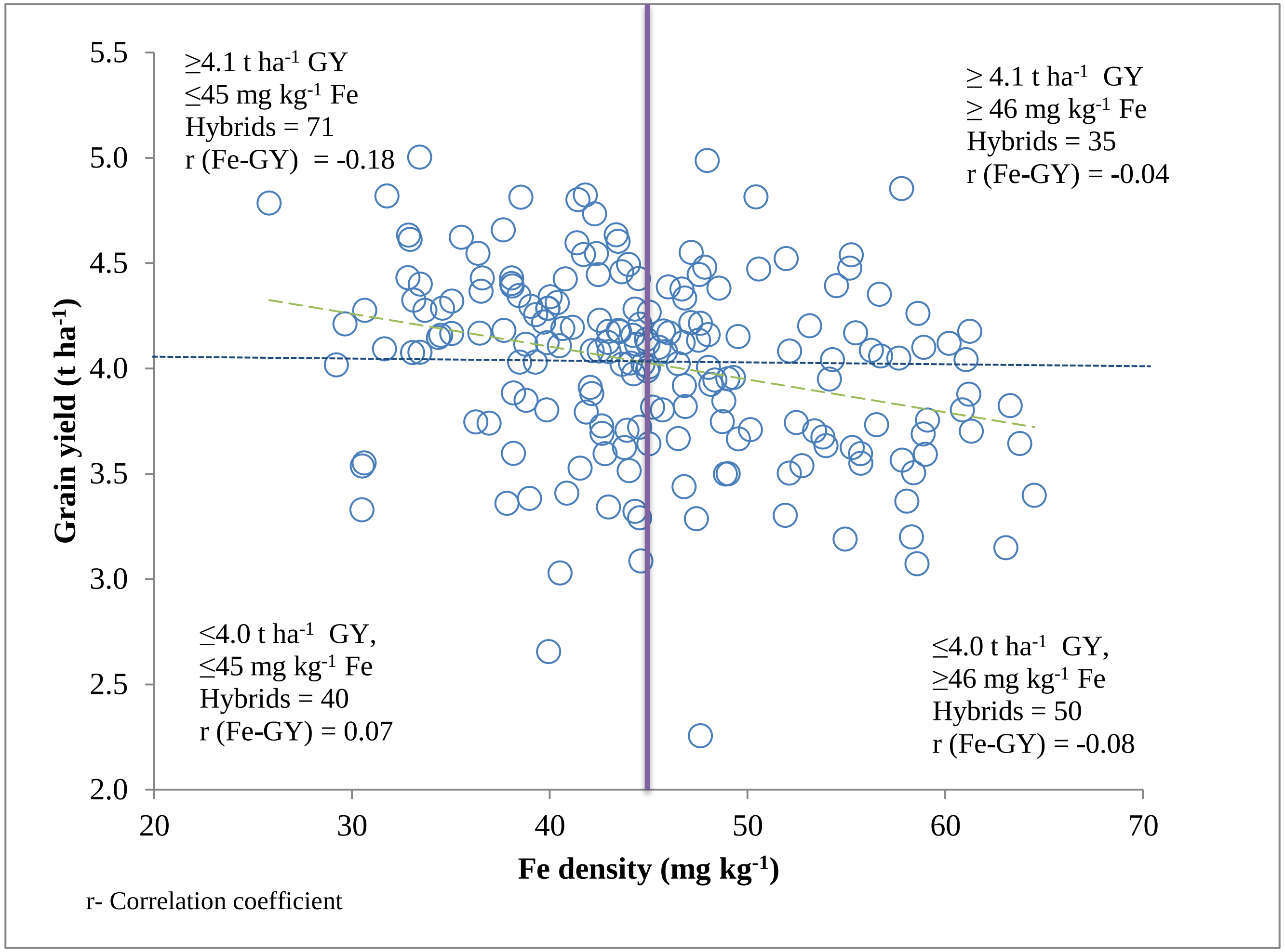

Figure 4.4. Scatter plot depicting association between grain iron (Fe) density and grain yield (GY) (horizontal and vertical lines are experimental mean for respective traits) among hybrids of line × tester study, averaged over environments (2011 rainy season and 2012 summer season), Patancheru

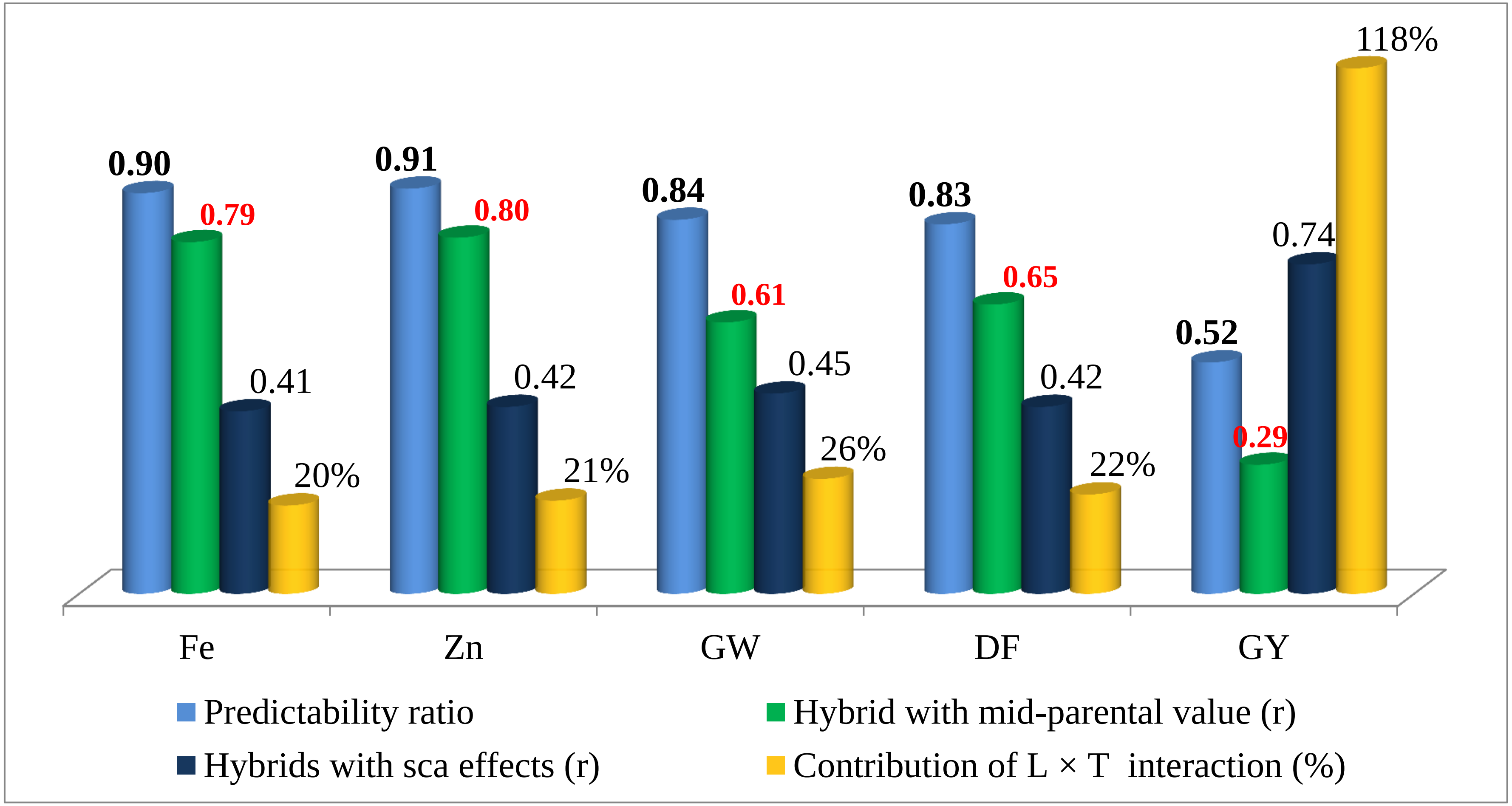

Figure 4.5. Summary of genetics: predictability ratios, relationship of hybrid performance *per se* with mid-parental value and *sca* effects, and contribution of L × T interaction effect to variability relative to those due to combined line and tester effects for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), days to 50% flowering (DF) and grain yield (GY) in line × tester study, averaged over environments (2011 rainy and 2012 summer seasons), Patancheru

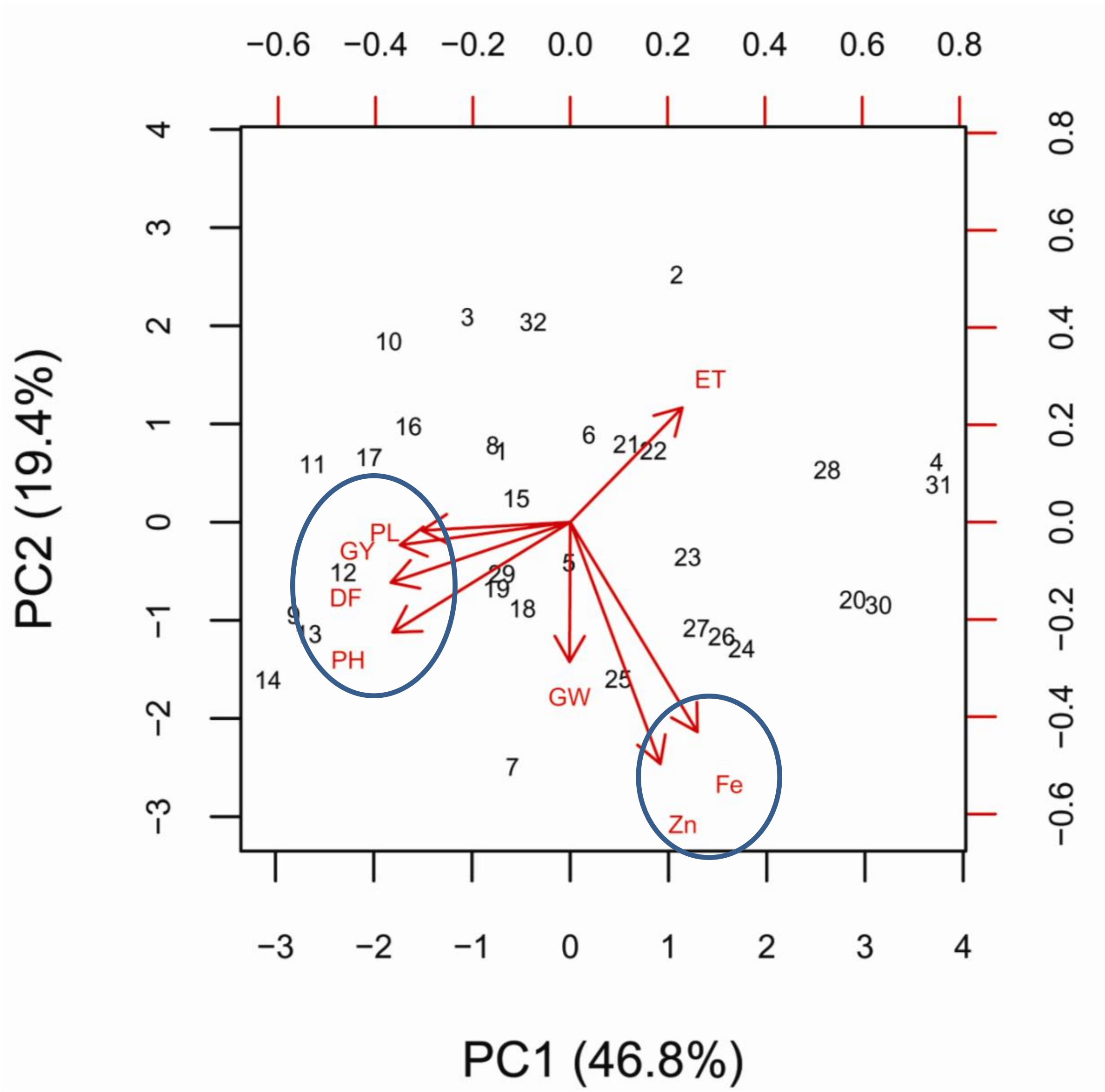

Fig 4.6. Principal component analysis for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), grain yield (GY), days to 50% flowering (DF), plant height (PH), panicle length (PL) and effective tillers (ET) among set-A hybrids of pearl millet, averaged over the environments, 2012 rainy season

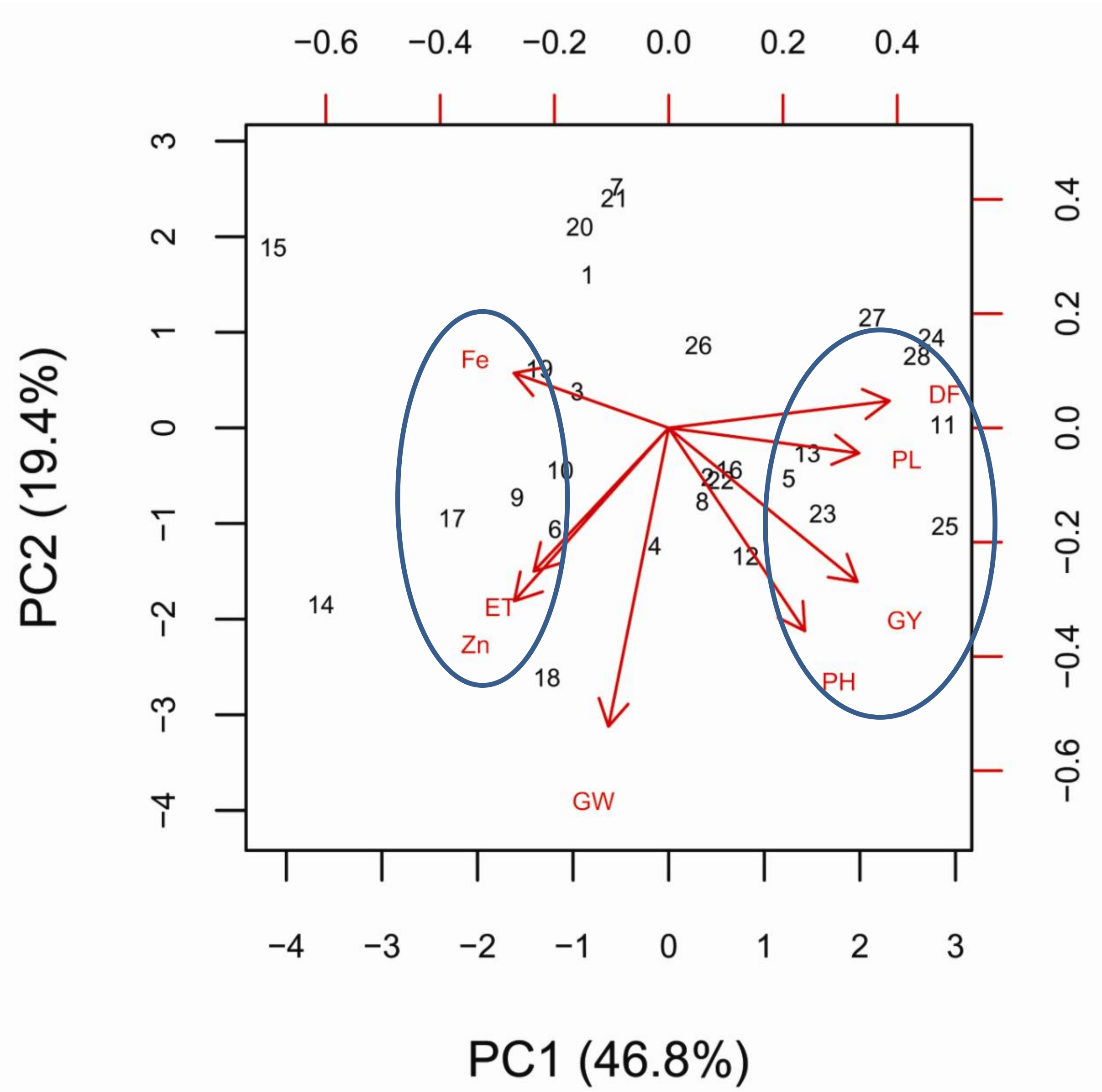

Fig 4.7. Principal component analysis for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW), grain yield (GY), days to 50% flowering (DF), plant height (PH), panicle length (PL) and effective tillers (ET) among set-B hybrids of pearl millet, averaged over the environments, 2012 rainy season

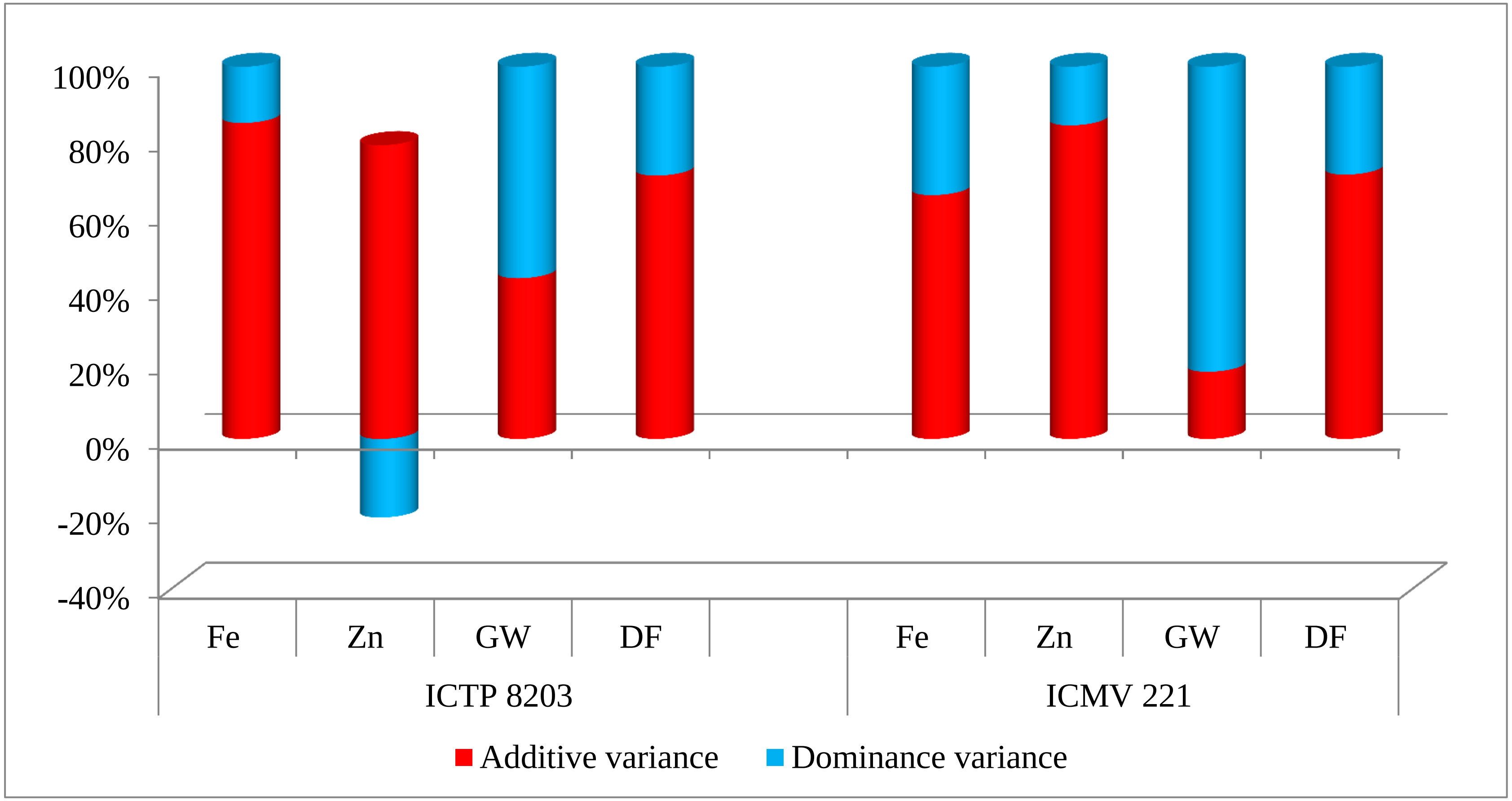

Figure 4.8. Proportion of additive and dominance variances relative to that due to total genetic variance for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW) and days to 50% flowering (DF) estimated from NCD-1 progenies of ICTP 8203 and ICMV 221, averaged over the environments (2012 rainy and 2013 summer seasons), Patancheru

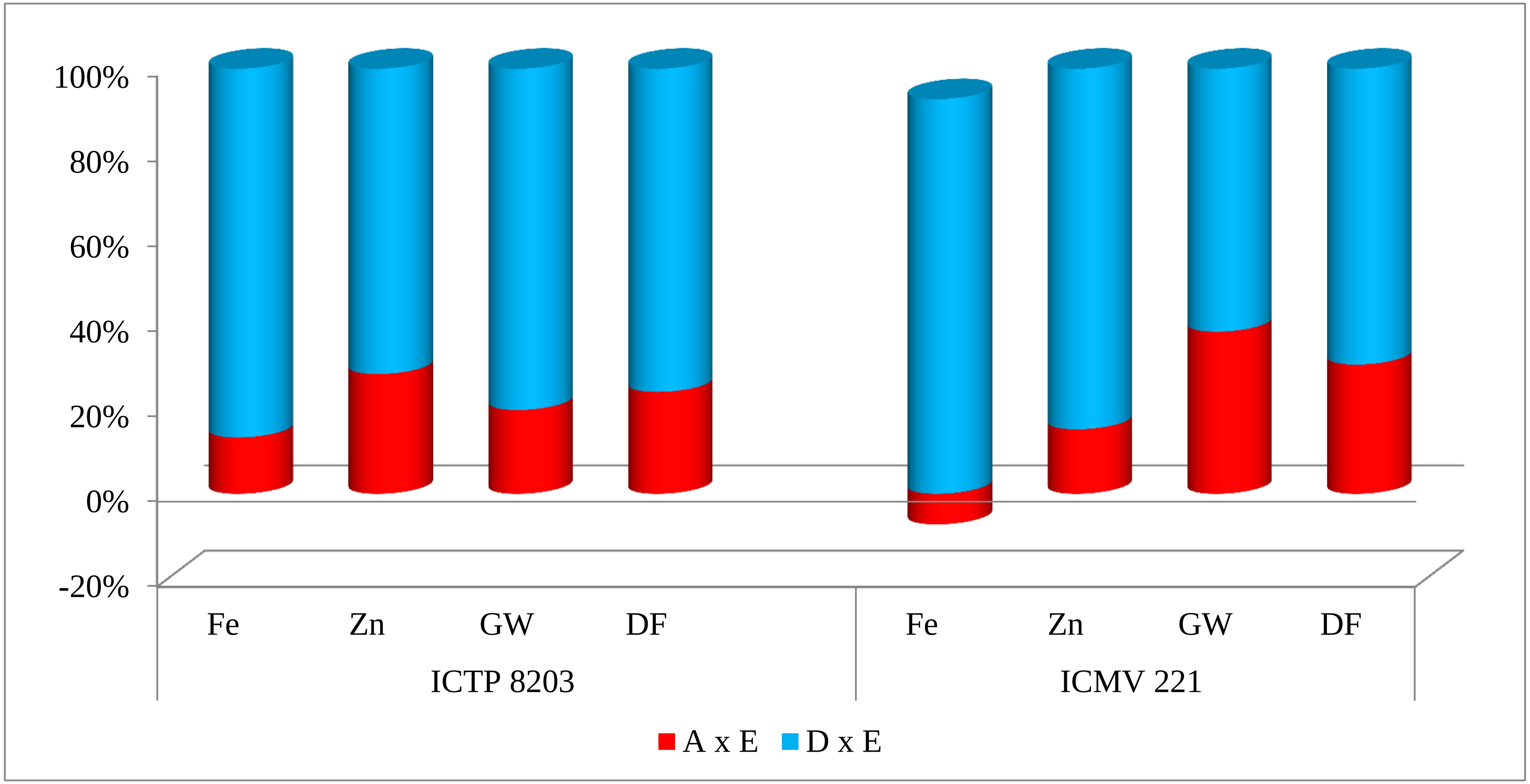

Figure 4.9. Proportion of additive × environment (A × E) and dominance × environment (D × E) variances relative to that due to total genotype × environment variance (G×E) for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW) and days to 50% flowering (DF) estimated from NCD-1 progenies of ICTP 8203 and ICMV 221, averaged over the environments (2012 rainy and 2013 summer seasons), Patancheru

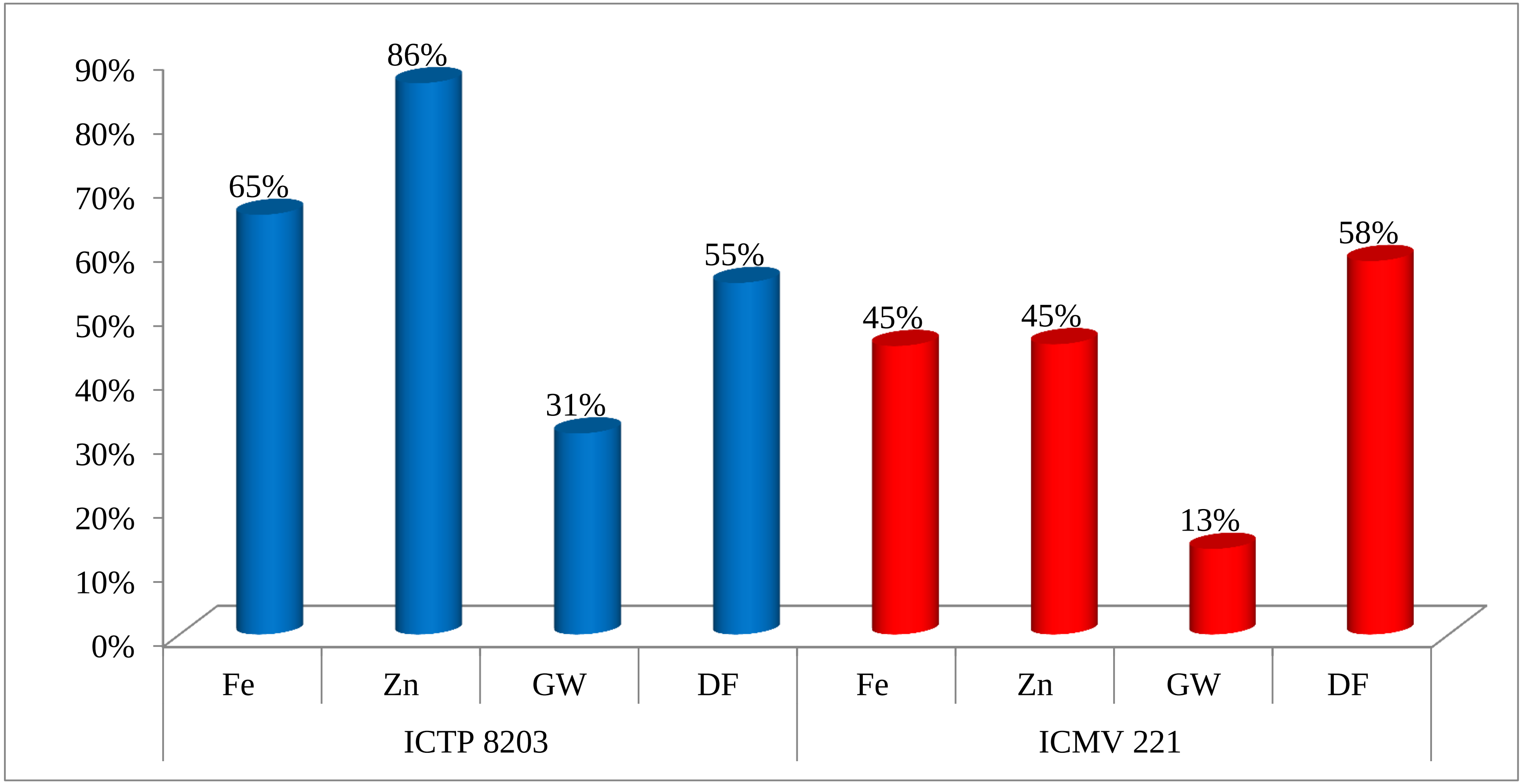

Figure 4.10. Narrow-sense heritability (%) for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW) and days to 50% flowering (DF) estimated from NCD-1 progenies of ICTP 8203 and ICMV 221, averaged over the environments (2012 rainy and 2013 summer seasons), Patancheru

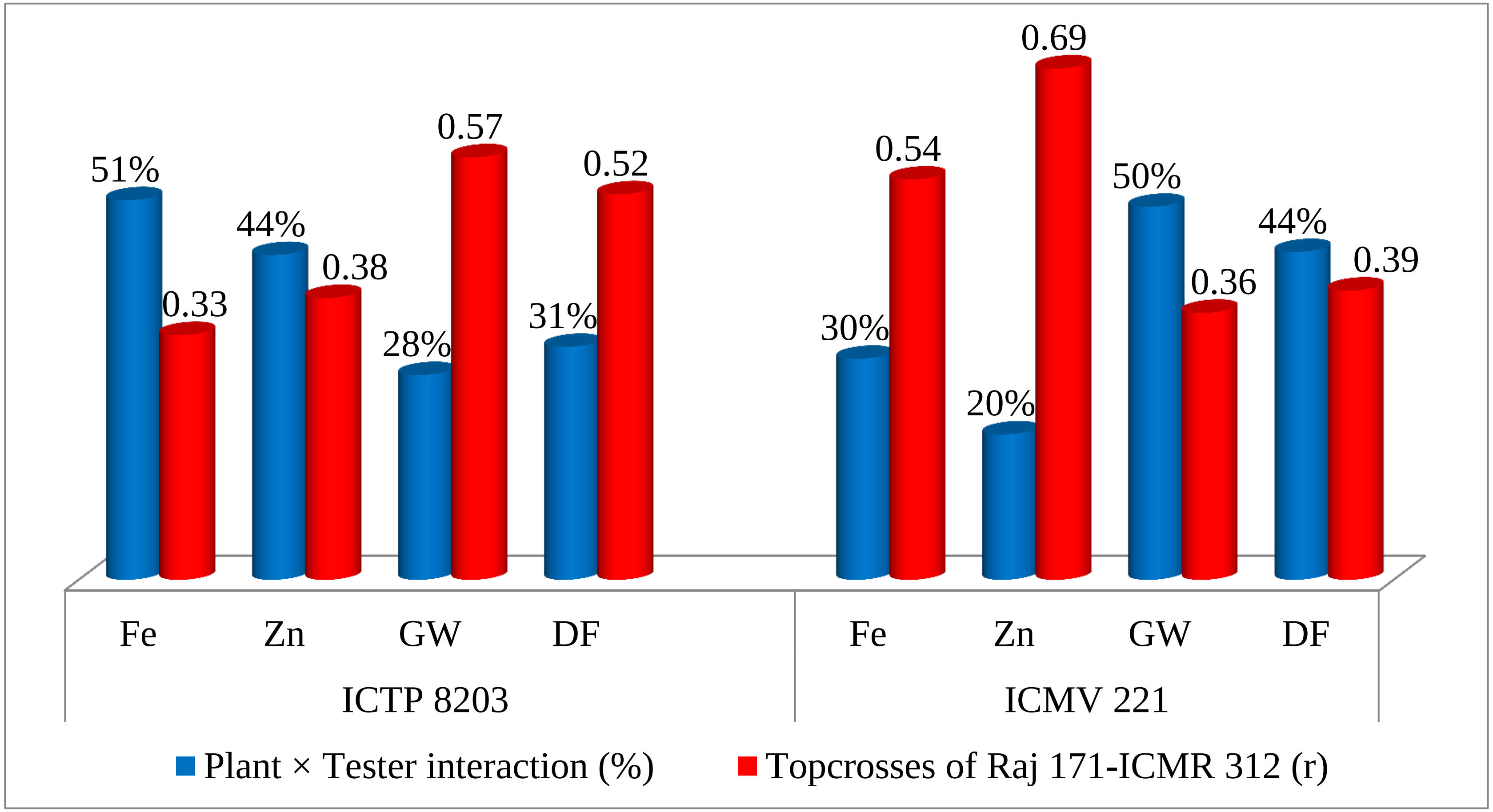

Figure 4.11. Contribution of plant × tester interaction to variability relative to those due to differences among the topcross hybrids of individual plants of ICTP 8203 and ICMV 221 (i.e. P effect), and the correlation between the topcross performance with tester-1 (Raj 171) and tester-2 (ICMR 312) in ICTP 8203 and ICMV 221, averaged over the environments (2012 rainy and 2013 summer seasons), Patancheru

Appendices

Appendix A. Weather data for cropping seasons during 2011, 2012 and 2013 at ICRISAT, Patancheru

Season	Month	Rain (mm)	Evaporation (mm)	Temperature (°C)		Relative humidity (%)		Wind Velocity (Kmph)	Solar Radiation (mj/ m^2)	Bright Sunshine (Hrs)
				Max.	Min.	at 07:17 h	at 14:17 h			
S11	February	0.4	148.2	30.8	15.4	88.2	33.3	5.8	18.1	9.0
	March	0.2	234.0	35.1	18.4	76.3	26.4	5.8	20.6	9.4
	April	7.5	254.9	36.6	22.7	72.7	31.4	7.1	20.8	8.7
	May	2.0	317.4	38.0	24.9	60.3	27.7	8.0	20.6	8.2
	Mean	**2.5**	**238.6**	**35.1**	**20.4**	**74.4**	**29.7**	**6.6**	**20.0**	**8.8**
R11	July	185.3	172.7	30.9	22.8	87.8	60.8	12.6	14.7	4.3
	August	155.5	113.8	29.2	22.4	92.8	72.8	9.6	13.8	3.6
	September	101.6	126.4	30.1	21.6	92.5	65.3	7.1	16.4	5.8
	October	35.6	138.7	31.4	20.0	91.9	49.7	3.7	17.1	7.7
	Mean	**119.5**	**137.9**	**30.4**	**21.7**	**91.3**	**62.1**	**8.2**	**15.5**	**5.4**
S12	February	0.0	198.7	32.9	15.7	79.4	32.1	6.4	18.4	9.5
	March	0.0	283.4	36.5	17.6	68.2	22.3	5.8	20.7	9.4
	April	17.4	263.9	37.5	22.8	68.7	29.1	7.5	18.9	7.7
	May	2.8	397.9	40.1	25.4	49.9	21.9	8.9	21.1	8.8
	Mean	**5.0**	**286.0**	**36.7**	**20.4**	**66.5**	**26.4**	**7.2**	**19.8**	**8.8**
R12	July	199.2	139.4	30.1	22.0	88.6	65.5	11.7	13.5	3.0
	August	94.7	125.4	29.7	21.8	89.6	68.2	9.7	15.4	4.9
	September	58.4	116.8	29.8	21.7	93.1	65.7	6.8	16.6	5.3
	October	73.8	133.7	30.4	18.0	92.5	50.7	3.9	16.6	6.9
	Mean	**106.5**	**128.8**	**30.0**	**20.9**	**90.9**	**62.5**	**8.0**	**15.5**	**5.0**
S13	February	10.1	168.7	31.1	16.3	85.5	33.6	7.0	17.7	8.8
	March	0.0	277.0	35.7	19.0	72.2	27.4	7.2	20.8	8.8
	April	60.4	276.6	37.5	22.5	73.3	33.5	7.5	22.0	9.2
	May	3.4	365.2	40.2	25.9	60.7	29.1	9.3	21.8	8.5
	Mean	**18.5**	**271.9**	**36.1**	**20.9**	**72.9**	**30.9**	**7.7**	**20.6**	**8.8**

S11, R11, S12, R12 and S13 - 2011 summer, 2011 rainy, 2012 summer, 2012 rainy and 2013 sumer seasons, respectively;
Max.-Maximum; Min. - Minimum

Appendix B. Soil available iron (Fe) and zinc (Zn) contents in the cropping seasons during 2011, 2012 and 2013 in the experimental fields at ICRISAT, Patancheru*

Experiments / Objectives					Season / Year	Field	Soil available Fe (mg kg^{-1})	Soil available Zn (mg kg^{-1})
1	2	3	4	5				
√					R11	RP 5A	13.0	7.2
√		√			S12	RP 4C	12.1	4.5
			√	√	R12	RP 10B	11.9	1.9
	√					RP10C	14.0	2.2
		√			S13	RP 3B	3.6	3.5
			√	√		RP 8A	2.7	6.1

R11- 2011 rainy season; S12- 2012 summer season; R12- 2012 rainy season; S13 - 2013 summer season

* Critical range for normal plant requirements is 2.6 to 4.5 mg kg^{-1} for Fe content, and 0.6 to 1.0 mg kg^{-1} for Zn (Tisdale *et al* ., 1993 and Sahrawat and Wani, 2013)

Appendix C. Performance *per se* (mean) of hybrids and their specific combining ability (*sca*) effects for grain iron (Fe) and zinc (Zn) densities and 1000-grain weight (GW) in line × tester study of pearl millet, 2011 rainy and 2012 summer seasons, Patancheru

Sl. No.	Hybrid[a]	Fe (mg kg^{-1})						Zn (mg kg^{-1})						GW (g)					
		P		R11		S12		P		R11		S12		P		R11		S12	
		Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*
1	1 × 15	45.2	-2.8	43.7	-1.2	46.7	-4.3	40.6	-1.0	35.7	0.6	45.6	-2.8	12.3	-0.7 **	12.7	-1.1 **	12.0	-0.3
2	2 × 15	33.0	-1.4	28.0	-5.0 *	36.3	0.6	33.0	-2.0	28.6	-1.2	37.3	-2.9	10.7	-0.2	10.7	-0.3	10.7	-0.2
3	3 × 15	42.5	3.4	37.1	-0.1	47.9	7.0 *	39.2	3.0 *	31.8	1.2	46.6	4.6 *	12.9	0.0	13.0	-0.3	12.7	0.4
4	4 × 15	48.0	-0.7	41.5	-3.2	54.4	1.8	42.7	-0.1	36.8	0.3	48.6	-0.6	12.6	-0.3	13.3	-0.4	11.9	-0.1
5	5 × 15	44.4	5.7 **	43.0	7.5 **	45.8	3.8	38.2	3.0 *	31.1	1.7	45.2	4.3	14.0	1.4 **	15.0	1.8 **	12.9	1.0 **
6	6 × 15	48.6	-2.6	45.7	-3.8	51.4	-1.3	41.1	-0.4	35.7	-1.1	46.6	0.1	11.9	-0.2	12.7	-0.1	11.1	-0.4
7	7 × 15	44.5	-0.2	38.3	-0.8	50.6	0.5	35.9	-3.4 *	30.7	-1.2	41.1	-5.8 *	11.9	0.2	12.8	0.4	11.0	0.0
8	8 × 15	44.3	-1.4	35.8	-5.6 *	57.2	7.0 *	41.6	0.8	31.7	-3.0 *	56.4	9.1 **	12.9	-0.3	13.9	0.3	11.8	-0.8 *
9	9 × 15	55.3	3.9 *	54.0	8.0 **	56.6	-0.2	42.2	-0.6	36.5	0.9	48.0	-2.2	13.5	0.1	14.7	0.3	12.3	-0.2
10	10 × 15	47.1	5.1 *	40.3	3.1	54.0	7.0 *	44.9	5.3 **	34.1	1.8	55.7	8.7 **	12.9	-0.4	13.6	-0.4	12.3	-0.4
11	11 × 15	38.8	-1.7	37.3	-0.1	40.4	-3.5	33.7	-1.8	28.5	-1.3	38.9	-2.6	11.8	0.0	11.8	-0.5	11.8	0.5
12	12 × 15	36.4	-0.8	38.4	3.0	34.4	-4.7	36.1	-0.5	33.0	1.5	39.1	-2.6	12.3	0.3	13.2	0.7 *	11.5	-0.1
13	13 × 15	46.8	-3.5	43.8	-1.9	49.9	-5.2	40.9	-0.7	36.1	0.4	45.6	-2.1	13.4	0.4 *	14.1	0.2	12.6	0.6 *
14	14 × 15	37.7	-4.6 *	35.9	-4.0	39.5	-5.3	38.7	-1.1	33.8	-0.7	43.6	-1.8	11.1	-0.4	11.1	-0.6 *	11.1	-0.2
15	1 × 16	52.8	-3.0	48.6	-4.8 *	56.9	-1.2	42.8	0.0	36.8	0.0	48.8	0.1	11.5	-0.6 **	11.6	-1.0 **	11.4	-0.3
16	2 × 16	47.5	5.4 **	45.9	4.4 *	49.2	6.5 *	35.8	-0.2	28.5	-3.0 *	43.1	2.6	10.2	0.1	9.9	0.1	10.5	0.2
17	3 × 16	54.5	7.6 **	53.2	7.4 **	55.8	7.9 *	42.8	5.5 **	36.9	4.6 **	48.8	6.5 **	12.5	0.5 *	13.6	1.5 **	11.4	-0.4
18	4 × 16	58.6	2.1	57.3	4.0	60.0	0.3	45.8	1.9	41.4	3.2 *	50.1	0.6	12.8	0.8 **	13.3	0.8 *	12.4	0.9 **
19	5 × 16	45.0	-1.5	47.3	3.3	42.7	-6.3 *	36.6	0.4	34.2	3.1 *	39.1	-2.1	11.6	0.0	12.3	0.4	10.9	-0.4
20	6 × 16	58.9	-0.1	56.2	-1.9	61.6	1.8	42.1	-0.5	39.1	0.7	45.0	-1.7	11.1	-0.1	11.6	0.1	10.6	-0.3
21	7 × 16	54.0	1.5	47.9	0.3	60.0	2.9	40.3	0.0	31.8	-1.8	48.8	1.7	10.8	0.0	11.7	0.5	9.9	-0.5
22	8 × 16	54.2	0.7	49.7	-0.2	58.6	1.4	40.0	-1.9	36.2	-0.2	43.8	-3.8	12.2	0.0	12.7	0.2	11.8	-0.2

Appendix C. (Cont.)

Sl. No.	Hybrid[a]	Fe (mg kg^{-1})						Zn(mg kg^{-1})						GW (g)					
		P		R11		S12		P		R11		S12		P		R11		S12	
		Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*
23	9 × 16	58.4	-0.8	53.7	-0.9	63.1	-0.7	42.9	-1.0	38.6	1.3	47.2	-3.3	12.9	0.3	13.3	0.2	12.4	0.5
24	10 × 16	49.0	-0.8	41.6	-4.1	56.4	2.3	42.0	1.3	30.8	-3.2 *	53.2	5.9 *	12.1	-0.3	12.4	-0.3	11.8	-0.2
25	11 × 16	47.4	-0.9	45.0	-0.9	49.9	-1.1	35.2	-1.4	30.1	-1.4	40.3	-1.5	10.7	-0.2	10.4	-0.7 *	11.0	0.2
26	12 × 16	40.5	-4.5 *	39.7	-4.2	41.3	-4.8	37.6	-0.1	32.8	-0.4	42.4	0.3	11.1	-0.1	10.7	-0.5	11.4	0.4
27	13 × 16	55.7	-2.4	56.3	2.1	55.2	-6.9 *	38.3	-4.4 **	35.0	-2.4	41.6	-6.5 **	11.9	-0.1	12.1	-0.5	11.7	0.3
28	14 × 16	46.8	-3.3	43.9	-4.5 *	49.7	-2.1	41.2	0.3	35.6	-0.5	46.7	1.0	10.1	-0.4 *	9.6	-0.9 **	10.6	0.0
29	1 × 17	59.0	0.1	59.7	4.6 *	58.3	-4.4	44.9	-0.8	40.8	0.7	49.1	-2.5	13.3	0.0	14.6	0.5	12.0	-0.4
30	2 × 17	43.0	-2.3	40.0	-3.2	45.9	-1.4	38.5	-0.6	34.8	-0.1	42.2	-1.2	12.1	0.9 **	12.1	0.7 *	12.1	1.1 **
31	3 × 17	49.0	-0.9	45.4	-2.0	52.7	0.1	40.2	-0.1	33.6	-2.0	46.8	1.7	14.1	1.0 **	14.6	0.8 *	13.7	1.3 **
32	4 × 17	61.1	1.5	55.8	0.8	66.3	2.0	46.4	-0.5	39.8	-1.7	52.9	0.5	14.1	0.9 **	15.4	1.2 **	12.7	0.6 *
33	5 × 17	48.9	-0.7	43.3	-2.4	54.5	0.9	39.2	0.0	32.3	-2.2	46.1	2.0	12.9	0.1	13.4	-0.1	12.3	0.3
34	6 × 17	63.3	1.3	59.3	-0.4	67.3	2.9	46.5	0.9	40.5	-1.3	52.5	2.9	12.1	-0.2	13.5	0.3	10.8	-0.8 *
35	7 × 17	51.9	-3.6	43.7	-5.7 *	60.1	-1.6	43.5	0.1	34.7	-2.3	56.5	6.5 **	11.1	-0.9 **	11.9	-0.9 **	10.3	-0.8 **
36	8 × 17	58.3	1.7	58.3	6.8 **	58.3	-3.5	47.9	3.0 *	45.4	5.6 **	50.3	-0.1	12.1	-1.3 **	12.7	-1.4 **	11.5	-1.1 **
37	9 × 17	61.3	-1.0	54.5	-1.8	68.2	-0.3	46.7	-0.3	41.2	0.5	52.2	-1.2	14.1	0.4	15.5	0.7 *	12.7	0.1
38	10 × 17	56.5	3.6	49.3	1.9	63.8	5.1	43.2	-0.5	35.7	-1.7	50.8	0.6	12.3	-1.2 **	13.0	-1.4 **	11.7	-1.1 **
39	11 × 17	54.9	3.5	48.8	1.3	61.1	5.5	41.8	2.2	35.5	0.6	48.1	3.4	11.9	-0.2	12.1	-0.6	11.7	0.2
40	12 × 17	43.9	-4.2 *	40.4	-5.2 *	47.5	-3.2	39.1	-1.6	35.8	-0.7	42.4	-2.6	12.2	-0.1	12.8	-0.1	11.6	0.0
41	13 × 17	63.1	1.9	58.7	2.8	69.6	2.9	46.5	0.8	43.4	2.5	51.3	0.4	13.6	0.4 *	15.0	0.7 *	12.2	0.2
42	14 × 17	53.8	0.6	52.7	2.6	54.9	-1.5	41.8	-2.1	41.8	2.3	41.7	-6.8 **	11.8	0.1	11.8	-0.3	11.8	0.5
43	1 × 18	48.2	-5.1 *	44.7	-6.0 *	51.6	-4.3	38.4	-1.8	30.9	-2.4	45.8	-1.1	13.4	0.4	14.6	0.9 **	12.3	-0.2
44	2 × 18	39.9	0.2	42.1	3.3	37.6	-2.8	36.7	3.3 *	32.7	4.6 **	40.7	2.1	10.1	-0.9 **	10.1	-0.8 *	10.1	-1.0 **
45	3 × 18	44.2	-0.2	43.3	0.2	45.2	-0.5	33.9	-0.7	27.1	-1.8	40.8	0.3	12.3	-0.6 **	12.3	-1.0 **	12.3	-0.3
46	4 × 18	50.6	-3.5	45.3	-5.3 *	55.8	-1.6	41.4	0.1	35.0	0.3	47.8	0.0	13.3	0.4	14.1	0.3	12.6	0.4
47	5 × 18	43.5	-0.6	42.0	0.7	44.9	-1.9	33.7	0.1	27.7	0.0	39.7	0.3	11.8	-0.8 **	11.8	-1.4 **	11.9	-0.2

Appendix C. (Cont.)

Sl. No.	Hybrid[a]	Fe (mg kg^{-1}) P		Fe (mg kg^{-1}) R11		Fe (mg kg^{-1}) S12		Zn(mg kg^{-1}) P		Zn(mg kg^{-1}) R11		Zn(mg kg^{-1}) S12		GW (g) P		GW (g) R11		GW (g) S12	
		Mean	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***
48	6 × 18	61.2	4.7 *	64.6	9.2 **	57.8	0.2	40.3	0.3	37.2	2.2	43.4	-1.5	12.1	0.0	12.4	-0.3	11.9	0.2
49	7 × 18	49.5	-0.4	47.2	2.2	51.9	-3.0	38.1	0.3	30.9	0.7	45.2	-0.1	11.5	-0.3	11.9	-0.4	11.1	-0.2
50	8 × 18	48.8	-2.2	44.3	-2.9	53.4	-1.6	38.0	-1.2	32.9	-0.2	43.2	-2.5	13.3	0.1	14.0	0.4	12.7	-0.1
51	9 × 18	57.7	0.9	52.1	0.2	63.3	1.7	41.3	0.0	32.4	-1.5	50.2	1.6	14.0	0.4 *	15.1	0.8 *	12.8	0.1
52	10 × 18	43.5	-3.8 *	40.4	-2.6	46.6	-5.2	36.0	-2.0	31.0	0.3	41.1	-4.3	13.4	0.0	14.5	0.6 *	12.4	-0.5
53	11 × 18	47.8	2.0	44.3	1.1	51.4	2.7	32.1	-1.9	25.1	-3.0 *	39.0	-0.9	12.2	0.3	12.3	0.1	12.1	0.4
54	12 × 18	43.0	0.4	38.7	-2.5	47.3	3.4	35.7	0.6	29.3	-0.5	42.1	1.8	12.1	-0.1	12.1	-0.4	12.1	0.3
55	13 × 18	60.9	5.2 **	52.9	1.4	68.9	9.0 **	41.8	1.7	34.1	0.0	49.6	3.4	13.8	0.8 **	14.8	0.9 **	12.9	0.7 *
56	14 × 18	50.2	2.5	47.0	1.3	53.3	3.7	39.3	1.1	34.0	1.3	44.6	0.8	11.9	0.3	11.9	0.2	11.9	0.4
57	1 × 19	48.0	-7.0 **	39.4	-11.2 **	56.7	-2.8	39.7	-3.7 *	28.5	-7.0 **	50.9	-0.5	13.3	0.9 **	14.3	1.2 **	12.4	0.6 *
58	2 × 19	42.5	1.1	40.7	2.0	44.2	0.1	37.4	0.7	31.0	0.8	43.7	0.6	9.9	-0.5 *	9.7	-0.6	10.1	-0.3
59	3 × 19	42.2	-3.9 *	39.8	-3.1	44.5	-4.8	37.0	-0.9	31.2	0.2	42.9	-2.1	13.3	1.0 **	13.2	0.5	13.4	1.4 **
60	4 × 19	57.8	2.1	56.8	6.3 **	58.8	-2.3	43.4	-1.1	36.3	-0.5	50.5	-1.8	11.8	-0.5 *	13.1	0.0	10.6	-1.0 **
61	5 × 19	45.8	0.0	39.8	-1.4	51.8	1.3	35.5	-1.3	28.5	-1.3	42.4	-1.5	12.2	0.2	13.1	0.6 *	11.3	-0.1
62	6 × 19	63.8	5.6 **	64.6	9.4 **	63.0	1.7	45.8	2.6	41.9	4.8 **	49.7	0.3	11.3	-0.2	11.9	-0.2	10.7	-0.3
63	7 × 19	53.4	1.7	46.2	1.4	60.6	2.0	43.3	2.4	34.9	2.6	51.7	1.8	10.8	-0.3	11.0	-0.7 *	10.7	0.1
64	8 × 19	56.7	4.0 *	48.2	1.1	65.3	6.7 *	46.2	3.7 **	36.8	1.7	55.6	5.3 *	12.9	0.3	13.1	0.2	12.6	0.5
65	9 × 19	54.3	-4.2 *	45.6	-6.1 *	63.0	-2.2	41.0	-3.5 *	31.5	-4.5 **	50.6	-2.6	11.9	-1.0 **	11.7	-1.9 **	12.1	0.0
66	10 × 19	49.3	0.2	46.5	3.6	52.1	-3.4	40.5	-0.8	35.5	2.7	45.5	-4.4 *	12.8	0.1	13.3	0.0	12.3	0.1
67	11 × 19	44.3	-3.2	42.9	-0.1	46.4	-5.9 *	37.5	0.3	31.5	1.3	46.6	2.2	10.9	-0.4	11.5	-0.1	10.2	-0.7 *
68	12 × 19	41.4	-2.8	36.4	-4.7 *	46.5	-1.0	36.8	-1.4	31.7	-0.2	42.0	-2.8	12.1	0.6 **	12.5	0.7 *	11.6	0.5
69	13 × 19	64.5	7.2 **	55.5	4.1	73.5	10.0 **	48.1	4.8 **	37.6	1.4	58.6	7.9 **	12.0	-0.4	13.1	-0.1	10.9	-0.6 *
70	14 × 19	47.6	-1.7	44.6	-1.0	50.6	-2.6	39.1	-2.4	32.9	-2.0	45.2	-3.1	10.9	0.0	11.3	0.3	10.4	-0.3
71	1 × 20	46.5	-0.4	41.0	-3.9	52.0	3.1	37.4	0.6	29.6	-0.4	45.1	1.8	14.3	1.4 **	14.9	1.1 **	13.7	1.7 **
72	2 × 20	31.8	-1.5	28.9	-4.0	34.6	1.1	31.1	1.1	25.3	0.5	36.9	1.8	10.9	0.0	11.0	0.0	10.7	0.0

Appendix C. (Cont.)

Sl. No.	Hybrid[a]	Fe (mg kg^{-1})						Zn(mg kg^{-1})						GW (g)					
		P		R11		S12		P		R11		S12		P		R11		S12	
		Mean	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***
73	3 × 20	38.5	0.4	39.6	2.4	37.4	-1.4	31.0	-0.3	27.6	2.0	34.3	-2.6	11.5	-1.3**	12.0	-1.4**	11.0	-1.2**
74	4 × 20	50.4	2.8	52.2	7.4**	48.7	-1.8	35.8	-2.0	30.5	-1.0	41.2	-3.0	13.0	0.2	14.4	0.6	11.6	-0.2
75	5 × 20	36.5	-1.2	32.8	-2.7	40.2	0.3	33.0	2.9*	26.6	2.2	39.5	3.6	11.5	-1.0**	12.6	-0.6*	10.4	-1.3**
76	6 × 20	48.4	-1.7	47.1	-2.4	49.7	-1.0	35.9	-0.7	31.1	-0.7	40.8	-0.6	12.3	0.3	12.9	0.1	11.8	0.6*
77	7 × 20	44.6	1.0	39.2	0.0	50.0	2.0	36.7	2.4	28.1	1.2	45.2	3.4	12.6	0.9**	12.7	0.3	12.4	1.6**
78	8 × 20	49.5	4.9*	46.4	5.1*	52.6	4.5	37.0	1.2	31.0	1.3	43.1	0.8	13.3	0.2	14.4	0.6*	12.2	-0.2
79	9 × 20	47.2	-3.2	44.6	-1.4	49.7	-5.0	36.2	-1.7	29.7	-0.9	42.7	-2.4	13.5	0.1	15.1	0.7*	11.9	-0.5
80	10 × 20	41.4	0.4	38.0	0.8	44.8	-0.2	34.8	0.1	28.7	1.4	40.8	-1.1	13.3	0.0	14.0	0.0	12.5	0.1
81	11 × 20	39.0	-0.4	35.4	-1.9	42.7	0.9	28.7	-1.9	24.0	-0.8	33.3	-3.1	11.3	-0.4*	11.9	-0.5	10.8	-0.4
82	12 × 20	36.6	0.4	34.6	-0.8	38.6	1.7	32.0	0.4	26.4	0.0	37.6	0.9	11.7	-0.3	12.5	-0.1	11.0	-0.4
83	13 × 20	45.5	-3.7*	45.3	-0.3	45.8	-7.2*	34.2	-2.5	28.2	-2.5	40.1	-2.6	13.4	0.6*	14.5	0.5	12.4	0.6*
84	14 × 20	43.8	2.5	41.8	1.9	45.8	3.1	35.3	0.5	27.2	-2.2	43.3	3.0	10.7	-0.7**	10.6	-1.1**	10.7	-0.3
85	1 × 21	46.0	-1.2	45.0	2.1	47.1	-4.5	38.4	0.0	34.5	2.7	42.2	-2.6	12.5	0.0	13.6	0.4	11.4	-0.3
86	2 × 21	33.1	-0.5	28.8	-2.2	37.5	1.4	31.6	0.0	28.1	1.5	35.2	-1.4	10.6	0.2	10.4	0.0	10.9	0.4
87	3 × 21	34.5	-3.8*	32.4	-2.9	36.6	-4.7	30.5	-2.4	25.1	-2.3	35.9	-2.5	12.0	-0.3	12.4	-0.4	11.7	-0.2
88	4 × 21	46.0	-2.0	41.4	-1.4	50.6	-2.5	38.7	-0.8	33.4	0.1	44.1	-1.6	12.0	-0.5*	12.8	-0.4	11.1	-0.5
89	5 × 21	38.1	0.1	31.8	-1.6	44.3	1.8	32.0	0.2	25.4	-0.8	38.6	1.2	11.9	-0.1	12.5	-0.1	11.3	-0.1
90	6 × 21	48.0	-2.4	45.3	-2.3	50.8	-2.5	36.7	-1.6	32.0	-1.6	41.4	-1.5	11.4	-0.2	12.0	-0.2	10.8	-0.2
91	7 × 21	42.5	-1.4	36.8	-0.4	48.3	-2.3	34.6	-1.4	27.3	-1.4	41.8	-1.5	10.9	-0.3	11.9	0.0	10.0	-0.6*
92	8 × 21	45.9	0.9	40.4	1.0	51.4	0.7	39.2	1.7	32.6	1.0	45.8	2.1	12.4	-0.2	12.6	-0.6	12.3	0.2
93	9 × 21	56.7	6.0**	47.0	2.9	66.4	9.1**	44.7	5.1**	34.4	2.0	54.9	8.3**	13.7	0.8**	15.2	1.4**	12.3	0.2
94	10 × 21	44.1	2.8	40.0	4.8*	48.2	0.6	34.9	-1.4	26.7	-2.4	43.0	-0.4	13.4	0.6*	13.6	0.2	13.1	0.9**
95	11 × 21	42.1	2.4	39.5	4.2	44.8	0.4	32.0	-0.2	26.5	-0.1	37.5	-0.4	11.3	-0.1	11.3	-0.4	11.2	0.3
96	12 × 21	35.5	-1.0	30.4	-3.1	40.7	1.2	31.1	-2.2	24.9	-3.3*	37.2	-1.0	11.9	0.3	12.5	0.5	11.2	0.1
97	13 × 21	44.6	-5.0*	38.4	-5.3*	50.8	-4.8	37.5	-0.8	32.6	0.0	42.4	-1.7	12.8	0.3	13.8	0.5	11.7	0.2

Appendix C. (Cont.)

Sl. No.	Hybrid[a]	Fe (mg kg^{-1})						Zn(mg kg^{-1})						GW (g)					
		P		R11		S12		P		R11		S12		P		R11		S12	
		Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*
98	14 × 21	46.9	5.3 **	42.4	4.4 *	51.3	6.1 *	40.2	3.8 **	35.9	4.6 **	44.6	2.8	10.4	-0.5 *	10.5	-0.7 *	10.4	-0.4
99	1 × 22	55.5	4.4 *	53.0	7.2 **	58.0	1.4	43.6	2.2	33.3	0.7	53.8	3.6	12.1	-0.6 **	12.4	-1.0 **	11.7	-0.3
100	2 × 22	29.2	-8.3 **	26.1	-7.8 **	32.4	-8.8 **	31.4	-3.2 **	25.2	-2.2	37.6	-4.5 *	10.0	-0.6 **	9.9	-0.7 *	10.1	-0.6
101	3 × 22	39.9	-2.3	36.7	-1.4	43.1	-3.3	34.6	-1.4	28.2	0.1	40.9	-3.0	13.3	0.8 **	14.1	1.2 **	12.6	0.4
102	4 × 22	58.1	6.2 **	49.0	3.4	67.2	9.0 **	48.2	5.7 **	36.1	2.1	60.2	9.1 **	11.9	-0.7 **	12.2	-1.2 **	11.6	-0.2
103	5 × 22	38.5	-3.4	32.5	-3.8	44.4	-3.1	31.0	-3.8 **	24.9	-2.0	37.0	-5.8 *	12.2	0.0	12.7	-0.1	11.6	0.0
104	6 × 22	55.7	1.5	49.8	-0.6	61.7	3.4	40.3	-0.9	32.8	-1.4	47.8	-0.5	12.3	0.5 *	12.9	0.5	11.8	0.6 *
105	7 × 22	46.7	-1.1	42.4	2.4	51.0	-4.6	36.8	-2.1	27.9	-1.6	45.7	-3.0	11.0	-0.4	11.6	-0.5	10.5	-0.2
106	8 × 22	45.0	-3.8 *	34.5	-7.7 **	55.4	-0.3	38.0	-2.4	29.1	-3.2 *	46.9	-2.2	13.4	0.6 *	13.7	0.4	13.1	0.8 *
107	9 × 22	61.2	6.7 **	54.5	7.6 **	68.0	5.7	45.4	2.9 *	38.6	5.4 **	52.2	0.1	12.8	-0.3	14.1	0.1	11.6	-0.7 *
108	10 × 22	45.0	-0.1	35.4	-2.7	54.7	2.2	40.0	0.7	30.4	0.5	49.6	0.8	12.3	-0.7 **	12.4	-1.2 **	12.2	-0.2
109	11 × 22	42.1	-1.6	35.4	-2.8	48.8	-0.7	34.7	-0.5	25.6	-1.7	43.7	0.4	12.5	1.0 **	12.8	0.9 **	12.2	1.1 **
110	12 × 22	40.7	0.3	39.1	2.8	42.3	-2.3	36.2	-0.1	31.0	2.0	41.3	-2.4	12.2	0.5 *	13.2	1.0 **	11.3	0.0
111	13 × 22	57.8	4.4 *	48.1	1.6	67.6	7.0 *	46.8	5.5 **	34.3	1.0	59.3	9.7 **	12.4	-0.2	13.7	0.2	11.1	-0.7 *
112	14 × 22	41.9	-3.6	42.7	1.9	40.6	-9.7 **	36.6	-2.9 *	32.0	0.1	43.5	-3.7	11.3	0.2	11.7	0.3	11.0	0.0
113	1 × 23	44.3	4.0 *	36.1	0.1	52.4	8.0 *	36.7	4.9 **	26.4	0.6	47.1	9.4 **	10.8	0.0	11.3	0.0	10.3	0.1
114	2 × 23	25.8	-0.8	23.6	-0.5	28.0	-0.9	25.9	0.8	20.2	-0.4	31.6	2.1	8.8	0.1	8.6	0.0	9.0	0.2
115	3 × 23	38.1	6.8 **	32.6	4.2	43.6	9.4 **	27.5	1.2	22.9	1.6	32.1	0.8	11.2	0.6 *	11.4	0.5	11.0	0.6 *
116	4 × 23	38.5	-2.4	31.7	-4.2	45.4	-0.6	32.0	-0.9	25.7	-1.5	38.3	-0.3	11.0	0.3	11.7	0.4	10.3	0.3
117	5 × 23	32.8	1.9	29.1	2.5	36.6	1.3	26.2	1.0	22.5	2.3	30.0	-0.2	10.2	-0.1	10.4	-0.3	10.0	0.2
118	6 × 23	38.2	-5.2 **	35.5	-5.2 *	40.9	-5.2	28.7	-2.9 *	23.0	-4.5 **	34.4	-1.3	9.5	-0.4 *	10.0	-0.3	8.9	-0.5
119	7 × 23	33.4	-3.4	29.7	-0.6	37.2	-6.2 *	25.8	-3.5 *	20.9	-1.8	30.8	-5.4 *	9.4	0.0	10.1	0.1	8.8	-0.2
120	8 × 23	37.7	-0.3	30.8	-1.7	44.5	1.0	29.1	-1.8	22.0	-3.5 *	36.2	-0.4	11.3	0.4	11.7	0.5	10.9	0.3
121	9 × 23	41.8	-1.8	32.1	-5.2 *	51.6	1.5	33.2	0.3	26.2	-0.2	40.3	0.8	10.9	-0.3	11.6	-0.3	10.3	-0.3
122	10 × 23	34.6	0.3	30.0	1.7	39.1	-1.2	30.2	0.5	25.1	2.0	35.3	-1.0	10.6	-0.4 *	11.1	-0.4	10.1	-0.5

Appendix C. (Cont.)

Sl. No.	Hybrid[a]	Fe ($mg\ kg^{-1}$)						Zn($mg\ kg^{-1}$)						GW (g)					
		P		R11		S12		P		R11		S12		P		R11		S12	
		Mean	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***	**Mean**	***sca***
123	11 × 23	33.5	0.7	31.6	3.1	35.3	-1.9	27.4	1.8	24.0	3.4 *	30.9	0.1	9.5	-0.1	9.7	-0.1	9.3	-0.1
124	12 × 23	32.9	3.4	33.4	6.8 **	32.4	0.0	26.8	0.1	23.9	1.7	29.6	-1.5	9.3	-0.5 *	9.5	-0.6 *	9.1	-0.4
125	13 × 23	42.3	-0.3	38.2	1.4	46.4	-2.0	30.6	-1.1	26.9	0.3	34.3	-2.7	10.6	-0.1	11.3	-0.1	10.0	0.0
126	14 × 23	31.7	-2.9	28.8	-2.3	34.5	-3.6	29.6	-0.2	25.2	0.0	34.1	-0.6	9.8	0.5 *	10.0	0.7 *	9.6	0.4
127	1 × 24	56.3	5.0 *	52.2	5.4 *	60.4	4.5	38.5	-1.4	32.4	-0.2	44.5	-2.7	11.3	-0.2	11.8	-0.4	10.8	0.0
128	2 × 24	36.5	-1.1	34.0	-0.9	39.1	-1.3	32.5	-0.6	27.2	-0.2	37.9	-1.1	10.0	0.6 *	10.7	1.2 **	9.3	-0.1
129	3 × 24	41.2	-1.2	33.6	-5.5 *	48.7	3.0	36.1	1.8	27.0	-1.0	45.2	4.4 *	12.1	0.7 **	13.2	1.4 **	11.0	0.1
130	4 × 24	52.0	0.0	45.2	-1.5	58.8	1.3	41.7	0.7	34.8	0.8	48.5	0.4	11.2	-0.2	11.6	-0.7 *	10.8	0.3
131	5 × 24	43.0	1.0	37.6	0.2	48.3	1.5	34.1	0.8	27.1	0.2	41.1	1.3	11.4	0.3	11.7	0.1	11.0	0.6 *
132	6 × 24	55.3	0.9	57.1	5.6 *	53.5	-4.1	41.2	1.5	38.1	3.8 *	44.2	-1.0	10.1	-0.5 *	10.3	-1.0 **	10.0	0.0
133	7 × 24	46.8	-1.1	38.2	-2.9	55.3	0.4	38.1	0.7	28.6	-0.8	47.6	2.0	10.5	0.2	11.1	0.2	9.9	0.3
134	8 × 24	47.6	-1.3	44.2	1.0	52.8	-2.2	36.8	-2.2	32.7	0.5	42.8	-3.3	10.6	-1.0 **	11.1	-1.1 **	9.9	-1.2 **
135	9 × 24	55.2	0.5	48.2	0.3	62.1	0.5	40.1	-1.0	30.9	-2.2	49.3	0.2	11.9	-0.1	12.4	-0.4	11.4	0.3
136	10 × 24	42.4	-2.9	36.1	-3.0	48.6	-3.2	34.1	-3.7 *	27.5	-2.3	40.7	-5.1 *	12.4	0.5 *	12.9	0.5	11.8	0.6 *
137	11 × 24	39.7	-4.1 *	34.2	-5.0 *	48.0	-0.8	33.9	0.2	27.5	0.2	40.3	0.0	9.6	-0.8 **	10.2	-0.5	9.0	-1.0 **
138	12 × 24	44.9	4.5 *	42.9	5.6 *	47.0	3.1	37.7	2.9 *	31.4	2.4	43.9	3.3	10.8	0.3	11.4	0.3	10.3	0.2
139	13 × 24	52.1	-1.4	47.9	0.4	56.3	-3.6	37.1	-2.7 *	30.8	-2.5	43.4	-3.1	10.8	-0.7 **	11.8	-0.5	9.7	-0.8 **
140	14 × 24	45.7	0.1	42.4	0.6	49.0	-0.6	40.8	2.8 *	33.2	1.3	48.3	4.1	10.7	0.7 **	11.2	1.0 **	10.1	0.3
141	1 × 25	58.9	8.4 **	54.5	8.9 **	63.3	7.9 *	46.9	4.5 **	39.9	5.1 **	53.8	3.9	12.1	0.0	13.1	0.3	11.1	-0.3
142	2 × 25	38.2	1.3	31.7	-2.0	44.6	4.6	37.4	1.7	29.1	-0.5	45.6	3.9	10.7	0.6 **	10.7	0.7 *	10.7	0.6 *
143	3 × 25	40.0	-1.6	37.5	-0.4	42.5	-2.8	34.8	-2.1	30.1	-0.2	39.4	-4.0	11.3	-0.7 **	11.2	-1.2 **	11.4	-0.2
144	4 × 25	48.7	-2.6	42.2	-3.3	55.3	-1.8	44.3	0.8	37.7	1.5	50.9	0.1	11.5	-0.5 *	11.8	-1.0 **	11.2	-0.1
145	5 × 25	40.0	-1.4	34.9	-1.3	45.0	-1.4	30.0	-5.8 **	21.5	-7.7 **	38.6	-3.8	11.7	0.0	11.9	-0.4	11.5	0.4
146	6 × 25	60.2	6.5 **	59.7	9.4 **	60.7	3.6	46.2	4.0 **	41.9	5.4 **	50.5	2.5	11.3	0.0	12.4	0.6	10.2	-0.5
147	7 × 25	46.5	-0.7	39.2	-0.7	53.8	-0.7	40.6	0.6	32.7	1.0	48.4	0.1	10.6	-0.2	11.2	-0.3	10.1	-0.1

Appendix C. (Cont.)

Sl. No.	Hybrid[a]	Fe (mg kg^{-1})						Zn(mg kg^{-1})						GW (g)					
		P		R11		S12		P		R11		S12		P		R11		S12	
		Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*
148	8 × 25	44.6	-3.7 *	40.3	-1.7	48.8	-5.8	40.6	-0.9	34.1	-0.4	47.2	-1.6	12.4	0.2	12.9	0.1	12.0	0.2
149	9 × 25	53.2	-0.9	45.7	-1.1	60.6	-0.6	44.2	0.6	34.1	-1.3	54.3	2.6	12.4	-0.2	13.4	0.0	11.3	-0.5
150	10 × 25	43.5	-1.2	35.6	-2.3	51.3	-0.1	39.6	-0.7	31.0	-1.1	48.2	-0.3	12.7	0.3	13.2	0.2	12.2	0.3
151	11 × 25	43.4	0.3	37.9	-0.1	48.8	0.5	36.3	0.1	28.8	-0.7	43.8	0.8	11.4	0.4 *	12.1	0.8 *	10.7	0.1
152	12 × 25	39.9	0.1	35.2	-1.0	44.7	1.2	35.9	-1.4	29.4	-1.8	42.3	-1.0	10.8	-0.3	10.9	-0.7 *	10.8	0.1
153	13 × 25	52.5	-0.4	47.3	0.9	57.7	-1.8	42.9	0.6	39.0	3.5 *	46.9	-2.4	12.3	0.2	13.0	0.0	11.6	0.4
154	14 × 25	40.9	-4.0 *	35.6	-5.1 *	46.2	-3.0	38.5	-2.0	31.1	-3.1 *	45.9	-0.9	10.9	0.3	11.7	0.9 **	10.1	-0.3
155	1 × 26	43.7	-5.3 **	37.4	-5.8 *	49.9	-4.7	36.9	-4.6 **	29.1	-3.5 *	44.6	-5.6 *	11.7	-0.6 *	12.1	-0.9 **	11.3	-0.2
156	2 × 26	38.8	3.5	42.4	11.1 **	35.2	-4.0	31.5	-3.2 *	25.7	-1.7	37.3	-4.6 *	9.8	-0.4 *	10.0	-0.2	9.5	-0.7 *
157	3 × 26	35.1	-5.0 *	32.0	-3.5	38.1	-6.4 *	33.9	-2.0	26.5	-1.6	41.4	-2.4	11.9	-0.3	12.6	0.1	11.1	-0.6 *
158	4 × 26	47.6	-2.1	41.0	-2.0	54.1	-2.1	38.9	-3.7 *	31.9	-2.1	45.9	-5.2 *	12.0	-0.2	12.6	-0.4	11.4	0.1
159	5 × 26	39.3	-0.4	32.6	-1.1	46.0	0.4	37.2	2.4	29.0	2.0	45.5	2.8	11.2	-0.6 *	11.8	-0.6 *	10.7	-0.5
160	6 × 26	59.1	7.0 **	46.5	-1.3	71.7	15.4 **	44.4	3.1 *	33.9	-0.4	55.0	6.8 **	12.2	0.9 **	12.4	0.4	12.1	1.3 **
161	7 × 26	44.0	-1.6	41.8	4.4	46.2	-7.5 *	38.4	-0.6	32.6	3.2 *	44.2	-4.5 *	11.6	0.7 **	12.5	0.9 **	10.8	0.5
162	8 × 26	43.7	-3.0	39.9	0.3	47.4	-6.3 *	39.9	-0.6	31.2	-1.1	48.6	-0.5	12.5	0.1	12.8	0.0	12.2	0.3
163	9 × 26	52.1	-0.2	45.9	1.6	58.4	-2.0	42.7	0.2	32.5	-0.6	53.0	1.0	12.9	0.2	13.7	0.1	12.2	0.3
164	10 × 26	45.0	2.1	34.0	-1.5	56.1	5.5	42.3	2.9 *	31.9	2.0	52.6	3.9	13.4	0.8 **	14.3	1.1 **	12.4	0.5
165	11 × 26	38.1	-3.4	33.7	-1.9	42.4	-5.1	33.2	-2.0	26.7	-0.7	39.8	-3.4	11.3	0.2	11.8	0.3	10.9	0.2
166	12 × 26	40.8	2.6	34.3	0.6	47.3	4.7	40.4	4.0 **	29.7	0.7	51.1	7.5 **	10.7	-0.6 *	11.3	-0.5	10.2	-0.6 *
167	13 × 26	58.6	7.3 **	45.0	1.0	72.2	13.6 **	46.2	4.8 **	36.7	3.4 *	55.7	6.2 *	11.7	-0.5 *	12.6	-0.5	10.8	-0.4
168	14 × 26	41.7	-1.5	36.6	-1.6	46.8	-1.5	38.7	-0.8	32.4	0.4	45.1	-2.1	10.8	0.1	11.2	0.3	10.4	-0.2
169	1 × 27	42.6	0.7	37.4	1.1	47.9	0.4	33.9	-0.7	26.9	-0.4	40.9	-0.9	13.0	0.3	13.8	0.3	12.2	0.2
170	2 × 27	30.5	2.3	26.8	2.4	34.2	2.2	30.3	2.5	24.1	2.0	36.5	2.9	10.7	0.0	10.8	0.0	10.7	0.0
171	3 × 27	30.5	-2.5	28.6	-0.1	32.5	-4.8	26.7	-2.4	21.1	-1.8	32.4	-3.0	12.9	0.3	13.4	0.3	12.5	0.4
172	4 × 27	44.7	2.1	42.0	5.8 *	47.4	-1.6	36.4	0.7	29.7	1.0	43.1	0.4	12.8	0.2	14.2	0.7 *	11.5	-0.3

Appendix C. (Cont.)

Sl. No.	Hybrid[a]	Fe (mg kg^{-1}) P Mean	P *sca*	R11 Mean	R11 *sca*	S12 Mean	S12 *sca*	Zn(mg kg^{-1}) P Mean	P *sca*	R11 Mean	R11 *sca*	S12 Mean	S12 *sca*	GW (g) P Mean	P *sca*	R11 Mean	R11 *sca*	S12 Mean	S12 *sca*
173	5 × 27	33.1	0.4	27.1	0.2	39.0	0.6	27.8	-0.3	23.0	1.2	32.6	-1.8	12.6	0.3	13.7	0.7 *	11.6	0.0
174	6 × 27	36.3	-8.8 **	31.8	-9.2 **	40.8	-8.4 **	30.3	-4.2 **	23.7	-5.4 **	36.9	-3.0	12.0	0.1	12.3	-0.2	11.7	0.5
175	7 × 27	46.8	8.3 **	33.0	2.4	60.7	14.2 **	37.3	5.1 **	26.7	2.5	47.9	7.6 **	11.1	-0.4	11.8	-0.4	10.4	-0.4
176	8 × 27	41.6	1.9	35.6	2.8	47.5	1.0	34.1	0.4	28.3	1.2	40.0	-0.7	13.2	0.3	13.2	-0.2	13.1	0.8 **
177	9 × 27	43.0	-2.4	33.6	-3.9	52.4	-0.8	37.0	1.2	29.8	1.9	44.3	0.6	12.3	-0.9 **	12.8	-1.3 **	11.9	-0.4
178	10 × 27	34.4	-1.6	30.8	2.2	37.9	-5.5	31.9	-0.7	24.5	-0.2	39.3	-1.1	13.5	0.4	14.6	0.8 *	12.4	-0.1
179	11 × 27	33.5	-1.0	27.0	-1.7	39.9	-0.4	28.8	0.4	24.0	1.9	33.6	-1.3	11.9	0.3	13.1	1.0 **	10.7	-0.4
180	12 × 27	29.7	-1.5	25.6	-1.3	33.7	-1.7	29.4	-0.1	23.9	0.2	34.9	-0.3	12.2	0.4 *	12.9	0.6	11.6	0.2
181	13 × 27	37.8	-6.4 **	32.3	-4.8 *	43.4	-8.1 *	31.1	-3.4 *	24.8	-3.2 *	37.4	-3.7	11.5	-1.2 **	12.2	-1.5 **	10.9	-0.9 **
182	14 × 27	44.6	8.4 **	35.3	3.9	54.0	12.8 **	34.3	1.6	25.6	-1.1	42.9	4.1	11.0	-0.2	10.7	-0.8 *	11.4	0.4
183	1 × 28	44.9	2.1	41.9	3.8	47.9	0.5	35.9	1.4	31.0	3.4 *	40.8	-0.5	11.1	-0.3	11.5	-0.3	10.7	-0.3
184	2 × 28	30.6	1.5	27.1	0.8	34.2	2.3	27.2	-0.5	22.2	-0.2	32.2	-0.8	9.5	0.2	9.1	0.1	9.9	0.2
185	3 × 28	36.9	3.1	35.6	5.1 *	38.2	1.1	29.8	0.7	24.1	0.9	35.4	0.6	9.6	-1.7 **	9.4	-1.9 **	9.7	-1.5 **
186	4 × 28	39.9	-3.6	31.2	-6.8 **	48.6	-0.3	34.7	-0.9	26.4	-2.6	43.0	0.9	11.4	0.1	11.9	0.1	10.9	0.0
187	5 × 28	33.7	0.2	28.7	0.0	38.7	0.4	28.1	0.2	23.6	1.6	32.7	-1.0	11.1	0.1	11.3	0.1	10.9	0.2
188	6 × 28	39.3	-6.7 **	36.6	-6.2 *	42.0	-7.0 *	33.1	-1.3	28.9	-0.5	37.3	-2.0	10.6	0.1	11.2	0.4	10.1	-0.2
189	7 × 28	40.4	1.0	30.7	-1.8	50.1	3.7	32.2	0.2	24.1	-0.4	40.4	0.6	10.7	0.6 *	11.0	0.6 *	10.3	0.5
190	8 × 28	40.5	0.0	33.8	-0.9	45.1	-1.4	33.9	0.3	27.7	0.4	40.0	-0.1	11.7	0.2	12.3	0.6	11.2	-0.2
191	9 × 28	42.8	-3.4	39.4	0.1	46.2	-6.9 *	33.2	-2.4	27.3	-0.9	39.2	-3.9	12.2	0.3	12.0	-0.4	12.4	1.0 **
192	10 × 28	30.7	-6.2 **	28.6	-1.9	33.7	-9.6 **	31.2	-1.3	25.0	0.1	37.3	-2.6	12.1	0.3	12.2	0.2	11.9	0.4
193	11 × 28	42.6	7.3 **	35.5	4.9 *	49.8	9.6 **	33.4	5.1 **	24.6	2.2	42.3	8.0 **	10.3	0.0	10.5	0.3	10.0	-0.2
194	12 × 28	35.1	3.0	32.7	4.0	37.4	2.0	28.4	-1.0	22.3	-1.7	34.4	-0.3	10.0	-0.5 *	9.8	-0.8 *	10.2	-0.2
195	13 × 28	44.0	-1.1	35.9	-3.0	52.1	0.8	32.8	-1.6	26.6	-1.7	39.0	-1.6	11.8	0.4 *	12.2	0.3	11.3	0.5
196	14 × 28	39.0	1.9	35.3	2.0	42.7	1.7	33.6	1.0	26.3	-0.6	40.8	2.5	10.0	0.1	10.3	0.6	9.8	-0.3
SE (mean, *sca*)		3.10	2.22	2.70	2.68	3.50	3.54	2.20	1.59	1.70	1.72	2.70	2.67	0.40	0.25	0.40	0.37	0.30	0.34
r (mean, *sca*)			0.41		0.46		0.49		0.42		0.42		0.53		0.45		0.48		0.53

[a]1-28 -ID of inbred lines detailed in the table 3.2.; r-Correlation coefficient between mean and *sca*; SE-Standard error; *, **-Significant at the 0.05, 0.01 probability levels, respectively; P- Pooled across environments; R11- 2011 rainy season; S12-2012 summer season.

Appendix D. Performance *per se* (mean) of hybrids and their specific combining ability (*sca*) effects for grain yield (GY) and days to 50% flowering (DF) in line × tester study of pearl millet, 2011 rainy and 2012 summer seasons, Patancheru

Sl. No.	Hybrid[a]	GY (kg ha^{-1})						DF (d)					
		P		R11		S12		P		R11		S12	
		Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*
1	1 × 15	3.82	-0.40*	3.62	-0.82**	4.01	0.02	46	1.28**	45	2.25**	48	0.32
2	2 × 15	4.61	0.25	4.54	0.03	4.69	0.46	51	0.27	45	-0.73	57	1.27*
3	3 × 15	4.08	-0.20	4.54	-0.05	3.62	-0.35	49	0.44	45	-0.09	54	0.98
4	4 × 15	4.99	0.41*	5.24	0.27	4.73	0.55*	52	0.14	46	0.03	57	0.25
5	5 × 15	4.11	-0.15	4.54	0.10	3.69	-0.39	49	0.91*	45	1.44**	53	0.39
6	6 × 15	4.38	0.21	4.69	0.44*	4.07	-0.01	49	-0.44	46	0.13	51	-0.99
7	7 × 15	4.43	0.13	4.31	-0.07	4.54	0.33	48	-1.76**	44	-1.21*	52	-2.30**
8	8 × 15	4.28	0.26	4.62	0.53*	3.94	0.00	49	-0.93*	44	-1.30*	53	-0.67
9	9 × 15	3.62	-0.64**	3.79	-0.77**	3.46	-0.50	48	-0.65	44	-0.94	52	-0.35
10	10 × 15	4.22	-0.18	4.50	-0.08	3.93	-0.27	47	-0.08	43	-0.47	51	0.32
11	11 × 15	3.85	-0.35*	3.80	-0.53*	3.89	-0.17	49	0.54	45	0.70	53	0.39
12	12 × 15	4.55	0.01	4.97	0.26	4.12	-0.24	48	-0.61	43	-0.42	53	-0.80
13	13 × 15	4.33	0.46*	4.41	0.54*	4.26	0.38	48	-0.82*	44	-0.59	51	-1.04
14	14 × 15	4.18	0.19	4.31	0.17	4.05	0.21	50	1.71**	45	1.20*	54	2.22**
15	1 × 16	3.54	-0.25	3.54	-0.13	3.54	-0.37	41	-2.50**	39	-0.37	44	-4.61**
16	2 × 16	4.13	0.19	3.62	-0.11	4.64	0.50	49	-0.34	43	-0.02	55	-0.66
17	3 × 16	4.39	0.53**	4.45	0.63**	4.33	0.43	50	2.50**	44	1.96**	56	3.06**
18	4 × 16	4.26	0.11	4.58	0.37	3.94	-0.16	50	-0.14	43	0.41	56	-0.68
19	5 × 16	4.01	0.17	3.93	0.26	4.08	0.08	45	-1.20**	39	-1.18*	52	-1.21
20	6 × 16	3.69	-0.05	3.03	-0.45*	4.34	0.34	48	0.62	43	1.18*	53	0.08
21	7 × 16	3.63	-0.24	3.50	-0.10	3.76	-0.38	49	0.97*	42	0.18	57	1.77**
22	8 × 16	3.95	0.36*	3.78	0.46*	4.12	0.25	49	0.63	43	0.41	55	0.73
23	9 × 16	3.50	-0.33	3.33	-0.45*	3.68	-0.20	48	0.58	42	-0.23	55	1.39*
24	10 × 16	3.95	-0.02	4.02	0.21	3.87	-0.25	46	0.15	40	0.25	52	0.06
25	11 × 16	3.29	-0.49**	3.40	-0.16	3.17	-0.81**	48	1.10*	41	-0.25	55	2.46**
26	12 × 16	4.11	0.00	3.81	-0.12	4.41	0.12	47	-0.72	40	-0.71	53	-0.73
27	13 × 16	3.59	0.14	3.35	0.26	3.84	0.03	46	-0.76	40	-1.21*	53	-0.30
28	14 × 16	3.44	-0.13	2.69	-0.68**	4.19	0.42	46	-0.90*	40	-0.42	51	-1.37*
29	1 × 17	3.59	0.04	3.74	0.04	3.44	0.04	42	-1.23**	39	-1.32*	44	-1.13
30	2 × 17	4.12	0.41*	4.25	0.48*	3.99	0.35	48	-0.91*	43	-0.63	52	-1.18
31	3 × 17	3.50	-0.13	3.73	-0.13	3.26	-0.13	46	-0.40	42	-0.66	50	-0.13
32	4 × 17	4.04	0.12	4.16	-0.08	3.92	0.32	49	-0.38	44	-0.21	54	-0.54
33	5 × 17	3.50	-0.10	3.68	-0.03	3.31	-0.18	49	3.06**	44	3.20**	53	2.94**
34	6 × 17	3.82	0.32	3.97	0.45*	3.67	0.18	45	-1.45**	42	-1.11*	48	-1.78**
35	7 × 17	3.30	-0.34*	3.55	-0.10	3.05	-0.58*	47	-0.60	42	-0.44	51	-0.75
36	8 × 17	3.20	-0.16	2.91	-0.44*	3.48	0.12	48	0.39	44	0.79	51	-0.12
37	9 × 17	3.70	0.10	3.95	0.13	3.46	0.07	46	-0.66	42	-0.52	50	-0.80
38	10 × 17	3.73	0.00	3.69	-0.16	3.78	0.15	45	0.24	41	-0.04	49	0.53
39	11 × 17	3.19	-0.35*	2.92	-0.68**	3.46	-0.02	47	0.36	43	0.46	50	0.27
40	12 × 17	3.71	-0.17	4.00	0.04	3.41	-0.37	47	0.54	41	-0.32	53	1.41*
41	13 × 17	3.15	-0.07	3.40	0.27	2.89	-0.41	47	0.84*	42	0.51	51	1.18

Appendix D. (Cont.)

Sl. No.	Hybrid[a]	GY (kg ha^{-1})						DF (d)					
		P		R11		S12		P		R11		S12	
		Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*
42	14 × 17	3.67	0.34 *	3.61	0.21	3.74	0.48	46	0.19	42	0.29	50	0.10
43	1 × 18	3.92	-0.06	4.39	0.28	3.45	-0.40	46	0.02	40	-1.13 *	51	1.18
44	2 × 18	3.80	-0.33	4.01	-0.17	3.59	-0.50	53	1.17 **	46	1.22 *	59	1.13
45	3 × 18	4.16	0.10	4.02	-0.26	4.30	0.46	50	0.35	45	0.87	55	-0.16
46	4 × 18	4.47	0.12	4.73	0.08	4.21	0.17	52	0.04	45	-0.35	59	0.44
47	5 × 18	4.18	0.15	4.06	-0.06	4.30	0.36	48	-0.69	41	-0.94	54	-0.42
48	6 × 18	3.88	-0.06	3.87	-0.06	3.88	-0.06	48	-1.70 **	43	-1.25 *	53	-2.13 **
49	7 × 18	3.66	-0.40 *	3.53	-0.53 *	3.80	-0.28	51	0.31	44	0.75	57	-0.11
50	8 × 18	3.84	0.06	4.07	0.30	3.62	-0.19	50	-0.03	44	-0.35	56	0.19
51	9 × 18	4.05	0.02	4.59	0.36	3.50	-0.32	51	0.92 *	45	1.34 *	56	0.51
52	10 × 18	4.17	0.01	4.05	-0.21	4.30	0.23	47	-0.84 *	42	-0.52	52	-1.16
53	11 × 18	4.48	0.51 **	4.27	0.26	4.69	0.77 **	48	-0.72	43	-0.02	53	-1.42 *
54	12 × 18	4.08	-0.22	4.05	-0.33	4.11	-0.11	50	1.12 **	44	1.20 *	57	1.06
55	13 × 18	3.80	0.16	3.73	0.18	3.87	0.13	49	0.42	43	-0.30	56	1.15
56	14 × 18	3.71	-0.05	3.97	0.15	3.45	-0.26	48	-0.39	42	-0.52	54	-0.25
57	1 × 19	4.16	0.13	4.70	0.41	3.62	-0.14	45	-0.27	42	0.37	48	-0.90
58	2 × 19	4.45	0.26	4.53	0.17	4.36	0.36	50	-0.95 *	45	-0.61	55	-1.28 *
59	3 × 19	4.08	-0.02	4.60	0.16	3.56	-0.19	48	-1.44 **	43	-0.97	52	-1.90 **
60	4 × 19	4.85	0.46 *	5.34	0.51 *	4.36	0.40	52	0.25	46	0.48	57	0.03
61	5 × 19	4.18	0.10	4.29	-0.01	4.06	0.21	48	-0.31	42	-0.44	53	-0.16
62	6 × 19	3.64	-0.34 *	3.72	-0.38	3.56	-0.29	50	1.35 **	46	0.91	55	1.79 **
63	7 × 19	3.70	-0.41 *	3.38	-0.85 **	4.03	0.03	49	-0.31	44	0.25	54	-0.85
64	8 × 19	4.06	0.22	4.27	0.33	3.85	0.12	50	0.52	45	-0.18	55	1.12
65	9 × 19	4.04	-0.03	4.06	-0.34	4.02	0.28	49	-0.03	45	0.84	53	-0.90
66	10 × 19	3.96	-0.25	3.92	-0.52 *	3.99	0.01	47	-0.29	42	-0.35	52	-0.23
67	11 × 19	3.32	-0.69 **	4.05	-0.14	2.59	-1.25 **	48	-0.17	43	-1.18 *	54	0.84
68	12 × 19	4.80	0.45 *	4.98	0.43	4.61	0.48	48	-0.83 *	42	-0.63	53	-1.02
69	13 × 19	3.40	-0.29	3.37	-0.35	3.42	-0.24	50	1.30 **	45	1.20 *	55	1.41 *
70	14 × 19	4.21	0.41 *	4.57	0.58 *	3.85	0.23	49	1.16 **	43	0.32	55	2.01 **
71	1 × 20	4.02	-0.21	4.19	-0.22	3.85	-0.21	45	-0.51	39	-2.02 **	51	1.01
72	2 × 20	4.82	0.43 *	5.00	0.52 *	4.63	0.34	51	-0.19	44	-0.32	58	-0.04
73	3 × 20	4.03	-0.28	4.39	-0.18	3.67	-0.37	50	0.83 *	45	0.98 *	56	0.68
74	4 × 20	4.81	0.21	5.42	0.47 *	4.21	-0.05	53	0.68	45	0.44	60	0.94
75	5 × 20	4.17	-0.11	4.45	0.03	3.89	-0.26	49	0.79 *	43	1.18 *	55	0.41
76	6 × 20	3.94	-0.24	3.11	-1.11 **	4.77	0.63 *	49	-0.22	44	0.20	54	-0.63
77	7 × 20	4.21	-0.11	4.36	0.01	4.05	-0.23	50	-0.21	43	-0.80	57	0.39
78	8 × 20	4.15	0.11	4.09	0.03	4.21	0.19	48	-2.22 **	43	-1.56 **	53	-2.98 **
79	9 × 20	4.55	0.27	4.78	0.25	4.32	0.28	50	0.06	44	-0.21	55	0.34
80	10 × 20	4.60	0.18	4.68	0.12	4.51	0.23	46	-1.36 **	42	-0.06	51	-2.66 **
81	11 × 20	4.29	0.08	4.26	-0.04	4.32	0.19	48	-0.58	43	-0.23	54	-0.92
82	12 × 20	4.43	-0.13	4.75	0.07	4.10	-0.32	50	1.27 **	43	0.98 *	57	1.56 *
83	13 × 20	4.10	0.20	4.23	0.38	3.97	0.02	50	1.40 **	43	0.48	57	2.32 **
84	14 × 20	3.62	-0.39 *	3.78	-0.33	3.46	-0.45	49	0.25	43	0.94	54	-0.42
85	1 × 21	4.17	0.08	3.95	-0.26	4.38	0.41	45	1.28 **	41	0.48	50	2.08 **

Appendix D. (Cont.)

Sl. No.	Hybrid[a]	GY (kg ha^{-1})						DF (d)					
		P		R11		S12		P		R11		S12	
		Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*
86	2 × 21	4.32	0.08	4.46	0.18	4.19	-0.02	51	1.43**	45	1.18*	57	1.70*
87	3 × 21	4.16	-0.01	4.51	0.14	3.80	-0.16	47	-0.39	42	-0.52	52	-0.25
88	4 × 21	4.39	-0.07	4.38	-0.37	4.39	0.23	50	0.14	45	0.60	56	-0.32
89	5 × 21	4.40	0.26	4.93	0.71**	3.87	-0.19	47	-0.09	41	-0.66	53	0.48
90	6 × 21	4.00	-0.04	4.22	0.20	3.79	-0.27	46	-1.60**	42	-1.30*	50	-1.90**
91	7 × 21	4.23	0.05	4.36	0.20	4.10	-0.10	51	2.24**	45	2.03**	57	2.46**
92	8 × 21	4.08	0.18	4.20	0.34	3.96	0.02	48	-0.10	43	-0.40	53	0.09
93	9 × 21	4.35	0.21	4.51	0.19	4.19	0.24	47	-0.82*	43	-0.37	51	-1.25*
94	10 × 21	4.02	-0.25	3.86	-0.50*	4.19	0.00	46	-0.25	42	0.44	50	-0.92
95	11 × 21	3.88	-0.20	3.67	-0.44*	4.09	0.04	46	-1.46**	41	-1.40**	51	-1.52*
96	12 × 21	4.62	0.21	4.62	0.14	4.62	0.28	47	-0.28	42	0.15	53	-0.71
97	13 × 21	3.29	-0.46*	3.06	-0.59*	3.52	-0.34	48	0.35	42	-0.35	53	1.06
98	14 × 21	3.82	-0.05	3.95	0.04	3.68	-0.14	46	-0.46	42	0.10	51	-1.02
99	1 × 22	4.17	0.25	4.32	0.08	4.01	0.41	43	-0.96*	41	0.10	44	-2.02**
100	2 × 22	4.01	-0.06	4.06	-0.25	3.97	0.14	51	1.36**	46	1.79**	55	0.94
101	3 × 22	4.12	0.13	4.38	-0.02	3.86	0.28	46	-0.96*	42	-1.56**	51	-0.35
102	4 × 22	3.37	-0.92**	3.96	-0.82**	2.78	-1.02**	51	1.06*	45	0.56	56	1.58*
103	5 × 22	4.35	0.38*	4.35	0.10	4.34	0.66*	46	-0.83*	42	-0.04	49	-1.61*
104	6 × 22	3.55	-0.32	3.55	-0.51*	3.55	-0.14	48	0.49	45	0.65	51	0.34
105	7 × 22	4.37	0.37*	4.63	0.45*	4.12	0.30	49	0.84*	43	-0.02	54	1.70*
106	8 × 22	4.12	0.39*	4.57	0.69**	3.66	0.10	47	-0.67	43	-1.11*	51	-0.34
107	9 × 22	4.18	0.21	4.52	0.16	3.83	0.26	48	0.78	44	0.25	52	1.32*
108	10 × 22	3.64	-0.46*	4.03	-0.35	3.25	-0.57*	47	0.85*	44	1.72**	49	-0.02
109	11 × 22	3.91	0.01	4.19	0.05	3.63	-0.04	46	-1.20**	41	-1.78**	50	-0.61
110	12 × 22	4.19	-0.05	4.60	0.10	3.77	-0.20	47	-0.02	42	-0.56	52	0.53
111	13 × 22	3.56	-0.02	3.68	0.01	3.44	-0.05	46	-0.39	42	-0.73	51	-0.04
112	14 × 22	3.79	0.10	4.25	0.31	3.33	-0.12	46	-0.36	43	0.72	49	-1.44*
113	1 × 23	3.97	-0.49**	4.47	-0.26	3.48	-0.71*	42	-0.69	39	-1.35*	46	-0.02
114	2 × 23	4.78	0.17	4.77	-0.02	4.79	0.37	51	2.14**	46	2.34**	55	1.94**
115	3 × 23	4.39	-0.14	4.89	0.01	3.89	-0.29	46	-1.02*	42	-0.68	49	-1.35*
116	4 × 23	4.81	-0.02	5.32	0.05	4.31	-0.08	49	0.17	43	-0.56	55	0.91
117	5 × 23	4.43	-0.08	4.28	-0.46*	4.58	0.30	46	0.28	41	0.18	51	0.39
118	6 × 23	3.88	-0.53**	4.42	-0.13	3.35	-0.93**	47	0.27	44	0.87	50	-0.32
119	7 × 23	5.00	0.46*	4.94	0.27	5.07	0.65*	46	-1.56**	41	-1.47**	51	-1.63*
120	8 × 23	4.66	0.39*	4.47	0.09	4.84	0.69*	48	0.27	44	1.10*	51	-0.67
121	9 × 23	4.82	0.32	5.09	0.25	4.55	0.39	48	0.89*	44	1.13*	51	0.65
122	10 × 23	4.28	-0.36*	5.08	0.21	3.49	-0.92**	46	0.46	41	-0.06	50	0.98
123	11 × 23	4.40	-0.05	4.61	-0.02	4.19	-0.08	46	-0.09	42	-0.23	50	0.06
124	12 × 23	4.63	-0.15	4.71	-0.28	4.55	-0.01	46	-0.58	41	-0.35	51	-0.80
125	13 × 23	4.73	0.61**	4.69	0.53*	4.78	0.69*	45	-1.11**	41	-0.85	49	-1.37*
126	14 × 23	4.09	-0.15	4.20	-0.23	3.99	-0.06	46	0.58	41	-0.06	51	1.22
127	1 × 24	4.08	0.04	3.87	-0.31	4.30	0.39	44	0.30	39	-0.73	49	1.19
128	2 × 24	4.37	0.17	4.45	0.21	4.28	0.13	50	0.78	45	1.96**	55	-0.52
129	3 × 24	4.19	0.08	4.58	0.25	3.80	-0.09	48	0.13	42	-0.06	53	0.19

Appendix D. (Cont.)

Sl. No.	Hybrid[a]	GY (kg ha^{-1})						DF (d)					
		P		R11		S12		P		R11		S12	
		Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*	Mean	*sca*
130	4 × 24	4.52	0.11	4.90	0.18	4.14	0.04	50	-0.01	43	-0.28	57	0.12
131	5 × 24	4.18	0.08	4.40	0.21	3.95	-0.05	45	-2.24 **	38	-2.54 **	51	-2.07 **
132	6 × 24	4.54	0.54 **	4.54	0.54 *	4.54	0.54 *	48	0.42	42	-0.52	54	1.22
133	7 × 24	4.12	-0.01	4.07	-0.05	4.17	0.03	50	1.09 *	43	1.15 *	56	0.91
134	8 × 24	2.25	-1.60 **	2.08	-1.74 **	2.51	-1.36 **	49	1.15 **	46	2.72 **	55	1.21
135	9 × 24	4.48	0.38 *	4.48	0.18	4.47	0.59 *	47	-0.47	42	-0.25	52	-0.81
136	10 × 24	4.54	0.32	4.78	0.46 *	4.31	0.18	46	-0.23	41	-0.11	51	-0.47
137	11 × 24	4.22	0.19	4.33	0.26	4.11	0.13	47	0.06	42	0.06	53	-0.07
138	12 × 24	3.99	-0.38 *	4.17	-0.27	3.80	-0.48	47	-0.10	41	-0.40	54	0.08
139	13 × 24	3.50	-0.21	3.36	-0.25	3.64	-0.16	47	-0.63	42	0.10	51	-1.50 *
140	14 × 24	3.80	-0.02	4.22	0.34	3.39	-0.38	47	0.06	40	-1.11 *	54	1.10
141	1 × 25	4.10	0.22	4.56	0.39	3.64	0.05	46	0.74	43	0.58	48	0.91
142	2 × 25	3.60	-0.44 *	3.78	-0.45 *	3.41	-0.43	49	-1.27 **	44	-2.06 **	55	-0.47
143	3 × 25	4.34	0.38 *	4.47	0.15	4.21	0.62 *	48	-0.26	45	-0.09	52	-0.42
144	4 × 25	3.75	-0.50 **	4.36	-0.35	3.13	-0.66 *	52	0.60	47	1.03 *	56	0.18
145	5 × 25	2.65	-1.28 **	2.35	-1.82 **	2.95	-0.73 **	48	0.37	43	-0.23	53	0.98
146	6 × 25	4.12	0.28	4.59	0.61 *	3.65	-0.04	50	1.03 *	45	-0.21	54	2.27 **
147	7 × 25	3.67	-0.30	3.37	-0.74 **	3.97	0.14	49	-0.46	45	0.46	53	-1.37 *
148	8 × 25	3.72	0.03	4.24	0.42	3.20	-0.36	49	0.03	45	-0.30	53	0.26
149	9 × 25	4.20	0.27	5.10	0.82 **	3.30	-0.27	49	-0.02	45	0.06	52	-0.09
150	10 × 25	4.60	0.54 **	4.51	0.19	4.70	0.88 **	47	0.39	43	0.20	51	0.58
151	11 × 25	4.63	0.77 **	4.99	0.93 **	4.28	0.60 *	49	0.34	46	1.37 *	51	-0.68
152	12 × 25	4.28	0.08	4.30	-0.13	4.27	0.30	48	-0.32	44	0.58	52	-1.21
153	13 × 25	3.74	0.20	3.92	0.32	3.56	0.07	47	-0.85 *	43	-0.59	51	-1.11
154	14 × 25	3.41	-0.25	3.52	-0.34	3.29	-0.17	47	-0.33	43	-0.80	52	0.15
155	1 × 26	4.46	0.33	4.89	0.49 *	4.02	0.16	49	1.62 **	45	1.48 **	53	1.77 **
156	2 × 26	4.11	-0.17	4.70	0.23	3.53	-0.57 *	52	-1.06 *	45	-1.49 **	59	-0.61
157	3 × 26	4.16	-0.04	4.86	0.30	3.47	-0.38	51	-0.54	46	0.15	55	-1.23
158	4 × 26	4.45	-0.05	4.68	-0.26	4.21	0.15	53	-0.85 *	46	-0.73	59	-0.97
159	5 × 26	4.03	-0.15	4.27	-0.13	3.79	-0.17	51	0.92 *	45	1.01 *	57	0.84
160	6 × 26	3.75	-0.33	3.95	-0.26	3.56	-0.40	53	1.24 **	47	0.37	58	2.13 **
161	7 × 26	4.49	0.28	4.65	0.31	4.33	0.24	51	-1.08 *	44	-1.30 *	57	-0.85
162	8 × 26	4.02	0.08	3.64	-0.40	4.40	0.57 *	51	-0.59	46	-0.40	56	-0.88
163	9 × 26	4.08	-0.10	4.37	-0.14	3.79	-0.05	50	-1.31 **	45	-0.71	55	-1.90 **
164	10 × 26	4.27	-0.05	4.72	0.18	3.81	-0.27	49	-0.40	43	-0.90	55	0.10
165	11 × 26	4.43	0.31	4.38	0.09	4.47	0.54 *	52	1.05 *	47	1.60 **	57	0.51
166	12 × 26	4.42	-0.03	4.35	-0.32	4.50	0.26	52	1.23 **	45	0.48	59	1.98 **
167	13 × 26	3.07	-0.72 **	3.03	-0.80 **	3.12	-0.64 *	51	-0.14	44	-0.68	57	0.41
168	14 × 26	4.54	0.63 **	4.80	0.70 **	4.28	0.56 *	50	-0.11	46	1.10 *	55	-1.32 *
169	1 × 27	3.73	0.04	4.12	0.23	3.33	-0.16	45	0.29	42	0.32	49	0.27
170	2 × 27	3.33	-0.51 **	3.50	-0.46 *	3.16	-0.57 *	50	-1.22 **	44	-0.99 *	55	-1.44 *
171	3 × 27	3.54	-0.22	3.40	-0.64 **	3.67	0.19	49	0.46	44	0.32	54	0.60
172	4 × 27	4.02	-0.04	4.37	-0.06	3.67	-0.01	50	-1.69 **	44	-0.90	55	-2.47 **
173	5 × 27	4.07	0.34 *	4.52	0.63 **	3.63	0.05	48	0.25	43	0.18	54	0.34

Appendix D. (Cont.)

Sl. No.	Hybrid[a]	GY (kg ha^{-1}) P Mean	P *sca*	R11 Mean	R11 *sca*	S12 Mean	S12 *sca*	DF (d) P Mean	P *sca*	R11 Mean	R11 *sca*	S12 Mean	S12 *sca*
174	6 × 27	3.74	0.11	3.81	0.11	3.68	0.10	48	-0.59	45	0.53	52	-1.71 *
175	7 × 27	3.92	0.15	4.41	0.59 *	3.42	-0.29	50	0.25	43	-0.47	56	0.98
176	8 × 27	3.52	0.03	3.74	0.20	3.31	-0.14	50	0.58	44	-0.56	56	1.62 *
177	9 × 27	3.34	-0.39 *	3.89	-0.12	2.79	-0.67 *	49	0.03	43	-0.87	55	0.94
178	10 × 27	4.15	0.28	4.36	0.33	3.93	0.22	48	0.93 *	43	0.27	54	1.60 *
179	11 × 27	4.08	0.40 *	3.78	0.00	4.37	0.81 **	49	0.89 *	45	1.10 *	54	0.68
180	12 × 27	4.21	0.20	4.32	0.17	4.10	0.24	48	-0.94 *	42	-0.68	53	-1.18
181	13 × 27	3.36	0.01	3.08	-0.23	3.63	0.25	49	0.53	45	1.48 **	53	-0.42
182	14 × 27	3.08	-0.38 *	2.83	-0.76 **	3.34	0.00	48	0.22	43	0.27	53	0.18
183	1 × 28	4.14	0.29	4.26	0.07	4.02	0.50	44	0.64	43	1.34 *	45	-0.06
184	2 × 28	3.55	-0.45 *	3.90	-0.35	3.20	-0.55 *	48	-1.21 **	43	-1.63 **	52	-0.78
185	3 × 28	3.74	-0.18	3.99	-0.35	3.49	-0.01	47	0.30	44	0.34	50	0.27
186	4 × 28	4.28	0.07	4.71	-0.01	3.86	0.14	49	-0.01	45	-0.54	54	0.53
187	5 × 28	4.28	0.38 *	4.64	0.45 *	3.91	0.31	45	-1.23 **	41	-1.13 *	48	-1.32 *
188	6 × 28	4.25	0.45 *	4.54	0.54 *	3.97	0.36	48	0.59	44	-0.44	51	1.63 *
189	7 × 28	4.31	0.38 *	4.74	0.62 **	3.88	0.14	48	0.27	45	0.89	51	-0.35
190	8 × 28	3.03	-0.63 **	3.01	-0.82 **	3.04	-0.43	49	1.09 *	46	1.13 *	51	0.95
191	9 × 28	3.59	-0.30	3.78	-0.51 *	3.40	-0.09	48	0.71	45	0.48	51	0.94
192	10 × 28	4.27	0.24	4.45	0.12	4.10	0.37	46	0.44	42	-0.37	49	1.27 *
193	11 × 28	3.69	-0.14	4.52	0.44 *	2.86	-0.72 *	46	-0.10	43	-0.21	49	0.01
194	12 × 28	4.32	0.15	4.70	0.25	3.94	0.05	47	0.24	43	0.68	50	-0.18
195	13 × 28	3.51	0.00	3.36	-0.26	3.67	0.26	46	-0.13	45	1.51 **	48	-1.75 **
196	14 × 28	3.38	-0.25	3.71	-0.17	3.05	-0.32	44	-1.60 **	41	-2.04 **	48	-1.16
SE (mean, *sca*)		0.30	0.20	0.30	0.26	0.30	0.31	0.70	0.48	0.60	0.59	0.70	0.75
r (mean, sca)			0.74		0.73		0.82		0.42		0.53		0.41

[a]1-28 -ID of inbred lines detailed in the table 3.2.; r-Correlation coefficient between mean and *sca* ; SE-Standard error; *, **-Significant at the 0.05, 0.01 probability levels, respectively; P- Pooled across environments; R11- 2011 rainy season; S12-2012 summer season.

Appendix E. Performance *per se* (mean) of hybrids and their heterosis over mid-parent (HMP) for grain iron (Fe) and zinc (Zn) densities and days to 50% flowering (DF) in line × tester study of pearl millet, 2011 rainy and 2012 summer seasons, Patancheru

Sl.No.	Hybrid[a]	Fe (mg kg^{-1})						Zn(mg kg^{-1})						DF (d)					
		P		R11		S12		P		R11		S12		P		R11		S12	
		Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP
1	1 × 15	45.2	-5.6	43.7	-3.6	46.7	-7.4	40.6	-0.6	35.7	-5.4	45.6	3.6	46	-11.6 **	45	-11.6 **	48	-11.7 **
2	2 × 15	33.0	-10.2	28.0	-14.4	36.3	-11.0	33.0	-4.6	28.6	-6.2	37.3	-3.4	51	-7.8 **	45	-10.8 **	57	-5.3 **
3	3 × 15	42.5	3.4	37.1	-5.2	47.9	11.2	39.2	4.7	31.8	-4.4	46.6	12.0	49	-5.4 **	45	-8.2 **	54	-3.0 *
4	4 × 15	48.0	-5.7	41.5	-8.0	54.4	-3.9	42.7	3.4	36.8	2.6	48.6	4.1	52	-7.1 **	46	-10.0 **	57	-4.5 **
5	5 × 15	44.4	7.9	43.0	15.8 *	45.8	1.4	38.2	5.6	31.1	-1.3	45.2	10.9	49	-6.4 **	45	-8.5 **	53	-4.5 **
6	6 × 15	48.6	-19.3 **	45.7	-18.8 **	51.4	-19.7 **	41.1	-5.5	35.7	-8.2	46.6	-3.3	49	-8.5 **	46	-9.9 **	51	-7.2 **
7	7 × 15	44.5	2.2	38.3	-10.2	50.6	14.2	35.9	-9.0	30.7	-12.0 *	41.1	-6.7	48	-11.4 **	44	-12.4 **	52	-10.6 **
8	8 × 15	44.3	-10.0	35.8	-21.7 **	57.2	8.2	41.6	-4.0	31.7	-18.5 **	56.4	18.2 **	49	-9.5 **	44	-10.7 **	53	-8.4 **
9	9 × 15	55.3	4.0	54.0	14.1 *	56.6	-4.1	42.2	-1.4	36.5	-1.9	48.0	-1.0	48	-10.1 **	44	-11.3 **	52	-9.0 **
10	10 × 15	47.1	0.0	40.3	-6.0	54.0	7.3	44.9	9.9	34.1	-5.6	55.7	22.1 **	47	-8.3 **	43	-10.4 **	51	-6.4 **
11	11 × 15	38.8	-10.6	37.3	-14.4 *	40.4	-6.7	33.7	-9.5	28.5	-18.7 **	38.9	-1.4	49	-7.4 **	45	-9.3 **	53	-5.7 **
12	12 × 15	36.4	-3.4	38.4	7.7	34.4	-13.3	36.1	4.1	33.0	4.7	39.1	3.5	48	-9.7 **	43	-11.9 **	53	-7.9 **
13	13 × 15	46.8	-9.0	43.8	0.7	49.9	-16.2 *	40.9	-0.8	36.1	2.7	45.6	-3.4	48	-12.0 **	44	-13.8 **	51	-10.5 **
14	14 × 15	37.7	-17.8 *	35.9	-24.1 **	39.5	-11.1	38.7	-3.3	33.8	-9.4 *	43.6	2.1	50	-6.4 **	45	-7.8 **	54	-5.2 **
15	1 × 16	52.8	-21.7 **	48.6	-21.8 **	56.9	-21.5 **	42.8	-10.4 *	36.8	-15.0 **	48.8	-6.5	41	-18.5 **	39	-17.4 **	44	-19.4 **
16	2 × 16	47.5	-15.4 *	45.9	-7.2	49.2	-21.8 **	35.8	-13.6 *	28.5	-20.9 **	43.1	-8.0	49	-8.3 **	43	-9.5 **	55	-7.3 **
17	3 × 16	54.5	-10.0	53.2	-4.9	55.8	-14.4 *	42.8	-3.4	36.9	-5.0	48.8	-2.1	50	-0.5	44	-3.7 *	56	2.1
18	4 × 16	58.6	-16.7 **	57.3	-7.6	60.0	-23.8 **	45.8	-5.0	41.4	0.0	50.1	-8.8	50	-6.9 **	43	-9.4 **	56	-4.8 **
19	5 × 16	45.0	-25.7 **	47.3	-12.3 *	42.7	-36.5 **	36.6	-14.8 **	34.2	-7.7	39.1	-20.2 **	45	-9.8 **	39	-14.3 **	52	-6.1 **
20	6 × 16	58.9	-26.0 **	56.2	-23.2 **	61.6	-28.4 **	42.1	-16.5 **	39.1	-11.8 **	45.0	-20.1 **	48	-5.7 **	43	-7.8 **	53	-3.9 **
21	7 × 16	54.0	-14.3 **	47.9	-19.4 **	60.0	-9.7	40.3	-13.0 *	31.8	-21.3 **	48.8	-6.5	49	-5.6 **	42	-9.7 **	57	-2.3
22	8 × 16	54.2	-21.2 **	49.7	-20.5 **	58.6	-21.7 **	40.0	-20.3 **	36.2	-18.6 **	43.8	-21.7 **	49	-5.8 **	43	-7.2 **	55	-4.7 **
23	9 × 16	58.4	-19.6 **	53.7	-16.4 **	63.1	-22.1 **	42.9	-13.7 **	38.6	-9.8 *	47.2	-16.7 **	48	-7.1 **	42	-10.1 **	55	-4.7 **
24	10 × 16	49.0	-26.4 **	41.6	-30.2 **	56.4	-22.1 **	42.0	-12.0 *	30.8	-25.9 **	53.2	-1.2	46	-7.1 **	40	-9.0 **	52	-5.5 **

Appendix E. (Cont.)

Sl.No.	Hybrid[a]	Fe (mg kg^{-1})						Zn(mg kg^{-1})						DF (d)					
		P		R11		S12		P		R11		S12		P		R11		S12	
		Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP
25	11 × 16	47.4	-24.6 **	45.0	-25.5 **	49.9	-23.7 **	35.2	-20.2 **	30.1	-25.8 **	40.3	-15.4 *	48	-5.6 **	41	-11.5 **	55	-0.6
26	12 × 16	40.5	-29.1 **	39.7	-24.3 **	41.3	-33.1 **	37.6	-9.6	32.8	-11.5 *	42.4	-8.0	47	-9.3 **	40	-12.8 **	53	-6.4 **
27	13 × 16	55.7	-21.5 **	56.3	-6.6	55.2	-32.4 **	38.3	-20.3 **	35.0	-13.9 **	41.6	-25.1 **	46	-11.4 **	40	-15.6 **	53	-7.9 **
28	14 × 16	46.8	-28.3 **	43.9	-31.5 **	49.7	-25.2 **	41.2	-12.2 *	35.6	-16.7 **	46.7	-8.3	46	-10.7 **	40	-11.4 **	51	-10.2 **
29	1 × 17	59.0	1.2	59.7	10.2 *	58.3	-6.6	44.9	0.4	40.8	-1.2	49.1	1.8	42	-14.7 **	39	-14.7 **	44	-14.7 **
30	2 × 17	43.0	-8.8	40.0	-3.6	45.9	-12.9	38.5	0.1	34.8	2.1	42.2	-1.4	48	-7.9 **	43	-5.8 **	52	-9.6 **
31	3 × 17	49.0	-4.8	45.4	-5.3	52.7	-4.3	40.2	-2.7	33.6	-8.7	46.8	2.2	46	-4.6 **	42	-4.2 **	50	-5.0 **
32	4 × 17	61.1	-0.4	55.8	3.3	66.3	-3.3	46.4	2.7	39.8	1.0	52.9	4.0	49	-5.8 **	44	-5.8 **	54	-5.8 **
33	5 × 17	48.9	-5.1	43.3	-5.8	54.5	-4.6	39.2	-2.0	32.3	-8.0	46.1	2.7	49	0.5	44	0.8	53	0.3
34	6 × 17	63.3	-10.3 *	59.3	-8.9 *	67.3	-11.4 *	46.5	-1.8	40.5	-4.4	52.5	0.3	45	-8.3 **	42	-7.7 **	48	-8.8 **
35	7 × 17	51.9	-3.7	43.7	-15.1 **	60.1	6.8	43.5	0.4	34.7	-9.6 *	56.5	17.4 **	47	-7.1 **	42	-6.0 **	51	-8.1 **
36	8 × 17	58.3	-2.2	58.3	7.1	58.3	-10.0	47.9	1.4	45.4	6.8	50.3	-3.1	48	-4.7 **	44	-1.1	51	-7.6 **
37	9 × 17	61.3	-3.5	54.5	-3.1	68.2	-3.8	46.7	-0.1	41.2	0.9	52.2	-0.8	46	-8.0 **	42	-5.6 **	50	-10.0 **
38	10 × 17	56.5	-1.7	49.3	-4.6	63.8	2.5	43.2	-3.4	35.7	-10.1 *	50.8	2.0	45	-5.2 **	41	-4.3 **	49	-6.0 **
39	11 × 17	54.9	2.1	48.8	-6.8	61.1	10.6	41.8	1.7	35.5	-8.1	48.1	10.3	47	-5.4 **	43	-4.8 **	50	-5.9 **
40	12 × 17	43.9	-8.6	40.4	-9.2	47.5	-8.0	39.1	1.5	35.8	2.1	42.4	0.9	47	-5.2 **	41	-6.8 **	53	-4.0 **
41	13 × 17	63.1	1.9	58.7	12.3 *	69.6	-2.6	46.5	3.2	43.4	11.9 *	51.3	-0.2	47	-6.8 **	42	-7.0 **	51	-6.7 **
42	14 × 17	53.8	-4.3	52.7	-6.1	54.9	-2.4	41.8	-4.8	41.8	2.3	41.7	-10.9	46	-7.1 **	42	-4.6 **	50	-9.1 **
43	1 × 18	48.2	-8.0	44.7	-7.1	51.6	-8.8	38.4	-6.0	30.9	-12.5 *	45.8	-1.0	46	-10.0 **	40	-14.6 **	51	-6.1 **
44	2 × 18	39.9	-3.2	42.1	18.6 *	37.6	-19.6 *	36.7	6.5	32.7	16.3 *	40.7	-0.3	53	-2.2	46	-2.5	59	-1.9
45	3 × 18	44.2	-3.0	43.3	3.1	45.2	-8.2	33.9	-9.2	27.1	-12.1 *	40.8	-7.1	50	-1.3	45	-1.5	55	-1.2
46	4 × 18	50.6	-8.6	45.3	-5.5	55.8	-11.0	41.4	0.5	35.0	4.7	47.8	-2.4	52	-3.3 *	45	-6.6 **	59	-0.6
47	5 × 18	43.5	-4.7	42.0	5.2	44.9	-12.4	33.7	-6.6	27.7	-4.8	39.7	-7.8	48	-5.3 **	41	-9.2 **	54	-2.1
48	6 × 18	61.2	-5.3	64.6	9.2 *	57.8	-17.6 **	40.3	-7.2	37.2	2.2	43.4	-13.9 *	48	-6.8 **	43	-8.5 **	53	-5.4 **
49	7 × 18	49.5	3.3	47.2	3.7	51.9	2.9	38.1	-3.3	30.9	-4.7	45.2	-2.3	51	-3.5 *	44	-4.0 **	57	-3.1 *

Appendix E. (Cont.)

Sl.No.	Hybrid[a]	Fe (mg kg^{-1})						Zn(mg kg^{-1})						DF (d)					
		P		R11		S12		P		R11		S12		P		R11		S12	
		Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP
50	8 × 18	48.8	-9.1	44.3	-8.7	53.4	-9.4	38.0	-12.1 *	32.9	-10.1 *	43.2	-13.6 *	50	-3.7 **	44	-4.3 **	56	-3.2 *
51	9 × 18	57.7	0.1	52.1	3.7	63.3	-2.7	41.3	-3.4	32.4	-6.9	50.2	-0.9	51	-3.0 *	45	-2.2	56	-3.7 **
52	10 × 18	43.5	-15.6 *	40.4	-11.5	46.6	-17.3 *	36.0	-11.6 *	31.0	-8.1	41.1	-14.1 *	47	-5.5 **	42	-6.0 **	52	-5.1 **
53	11 × 18	47.8	0.0	44.3	-4.5	51.4	4.1	32.1	-13.7 *	25.1	-23.0 **	39.0	-6.4	48	-5.7 **	43	-6.5 **	53	-5.0 **
54	12 × 18	43.0	2.1	38.7	0.7	47.3	3.4	35.7	3.2	29.3	0.6	42.1	5.0	50	-2.3	44	-4.0 **	57	-0.9
55	13 × 18	60.9	8.8	52.9	14.3 *	68.9	5.0	41.8	1.7	34.1	4.0	49.6	0.2	49	-5.7 **	43	-9.2 **	56	-2.9 *
56	14 × 18	50.2	-0.3	47.0	-6.2	53.3	5.6	39.3	-1.4	34.0	-2.4	44.6	-0.7	48	-6.3 **	42	-7.0 **	54	-5.8 **
57	1 × 19	48.0	-12.5 *	39.4	-23.6 **	56.7	-2.6	39.7	-7.7	28.5	-27.1 **	50.9	8.5	45	-12.9 **	42	-12.2 **	48	-13.6 **
58	2 × 19	42.5	-2.8	40.7	4.8	44.2	-8.8	37.4	1.8	31.0	-2.8	43.7	5.4	50	-8.4 **	45	-7.3 **	55	-9.3 **
59	3 × 19	42.2	-12.3	39.8	-12.2 *	44.5	-12.4	37.0	-6.4	31.2	-9.8	42.9	-3.7	48	-7.3 **	43	-6.5 **	52	-8.0 **
60	4 × 19	57.8	-0.1	56.8	10.5 *	58.8	-8.6	43.4	0.0	36.3	-2.4	50.5	1.7	52	-5.2 **	46	-5.8 **	57	-4.7 **
61	5 × 19	45.8	-4.9	39.8	-8.2	51.8	-2.2	35.5	-7.4	28.5	-13.3 *	42.4	-2.9	48	-7.0 **	42	-9.0 **	53	-5.4 **
62	6 × 19	63.8	-5.0	64.6	3.3	63.0	-12.3 *	45.8	0.4	41.9	4.3	49.7	-2.7	50	-3.4 *	46	-4.9 **	55	-2.1
63	7 × 19	53.4	5.8	46.2	-5.4	60.6	16.3 *	43.3	4.2	34.9	-3.6	51.7	10.2	49	-7.1 **	44	-6.0 **	54	-7.9 **
64	8 × 19	56.7	0.9	48.2	-7.1	65.3	7.8	46.2	1.6	36.8	-8.6 *	55.6	9.7	50	-5.1 **	45	-5.0 **	55	-5.1 **
65	9 × 19	54.3	-9.7	45.6	-14.9 **	63.0	-5.5	41.0	-8.7	31.5	-18.2 **	50.6	-1.6	49	-7.3 **	45	-4.2 **	53	-9.7 **
66	10 × 19	49.3	-8.9	46.5	-5.2	52.1	-10.2	40.5	-5.8	35.5	-5.3	45.5	-6.1	47	-6.9 **	42	-6.6 **	52	-7.2 **
67	11 × 19	44.3	-12.0	42.9	-13.7 *	46.4	-8.9	37.5	-4.7	31.5	-13.5 **	46.6	10.1	48	-7.1 **	43	-9.9 **	54	-4.7 **
68	12 × 19	41.4	-7.1	36.4	-13.0 *	46.5	-1.9	36.8	0.1	31.7	-3.7	42.0	3.2	48	-8.5 **	42	-9.0 **	53	-8.0 **
69	13 × 19	64.5	10.4	55.5	11.8 *	73.5	9.3	48.1	11.0 *	37.6	2.8	58.6	16.9 **	50	-6.4 **	45	-6.9 **	55	-6.0 **
70	14 × 19	47.6	-9.8	44.6	-16.6 **	50.6	-2.8	39.1	-7.3	32.9	-14.9 **	45.2	-0.7	49	-5.8 **	43	-6.1 **	55	-5.4 **
71	1 × 20	46.5	-1.3	41.0	-15.6 *	52.0	13.9	37.4	1.9	29.6	-15.6 **	45.1	17.8 *	45	-11.3 **	39	-16.1 **	51	-7.3 **
72	2 × 20	31.8	-11.6	28.9	-19.5 *	34.6	-3.7	31.1	2.4	25.3	-9.3	36.9	12.4	51	-5.0 **	44	-5.3 **	58	-4.7 **
73	3 × 20	38.5	-4.6	39.6	-6.6	37.4	-2.5	31.0	-6.9	27.6	-10.0	34.3	-4.3	50	-0.7	45	-0.7	56	-0.6
74	4 × 20	50.4	0.6	52.2	7.8	48.7	-6.0	35.8	-3.4	30.5	-8.2	41.2	0.5	53	-2.3	45	-4.6 **	60	-0.6

Appendix E. (Cont.)

Sl.No.	Hybrid[a]	Fe (mg kg^{-1})						Zn(mg kg^{-1})						DF (d)					
		P		R11		S12		P		R11		S12		P		R11		S12	
		Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP
75	5 × 20	36.5	-9.7	32.8	-18.8 *	40.2	-0.6	33.0	3.4	26.6	-7.9	39.5	12.6	49	-2.6 *	43	-4.1 **	55	-1.5
76	6 × 20	48.4	-18.6 **	47.1	-21.0 **	49.7	-16.2 *	35.9	-8.6	31.1	-14.1 **	40.8	-3.9	49	-4.2 **	44	-5.0 **	54	-3.6 **
77	7 × 20	44.6	4.3	39.2	-14.7 *	50.0	26.3 **	36.7	4.1	28.1	-12.7 *	45.2	18.2 *	50	-4.8 **	43	-6.9 **	57	-3.1 *
78	8 × 20	49.5	2.2	46.4	-5.0	52.6	9.5	37.0	-5.4	31.0	-14.5 **	43.1	2.5	48	-8.2 **	43	-6.6 **	53	-9.5 **
79	9 × 20	47.2	-10.0	44.6	-11.9 *	49.7	-8.2	36.2	-6.3	29.7	-14.2 *	42.7	0.0	50	-5.0 **	44	-5.1 **	55	-4.9 **
80	10 × 20	41.4	-10.7	38.0	-17.6 **	44.8	-1.6	34.8	-5.2	28.7	-14.1 *	40.8	2.3	46	-6.9 **	42	-4.5 **	51	-8.7 **
81	11 × 20	39.0	-8.4	35.4	-24.3 **	42.7	10.9	28.7	-13.2	24.0	-25.8 **	33.3	-1.1	48	-5.7 **	43	-6.5 **	54	-5.0 **
82	12 × 20	36.6	-0.8	34.6	-11.1	38.6	10.8	32.0	5.1	26.4	-8.4	37.6	17.3 *	50	-2.3	43	-4.1 **	57	-0.9
83	13 × 20	45.5	-10.2	45.3	-3.0	45.8	-16.4 *	34.2	-7.7	28.2	-13.2 *	40.1	-3.5	50	-4.1 **	43	-7.1 **	57	-1.7
84	14 × 20	43.8	-2.8	41.8	-17.3 **	45.8	15.6	35.3	-1.4	27.2	-21.3 **	43.3	17.3 *	49	-5.3 **	43	-3.3 *	54	-6.9 **
85	1 × 21	46.0	-0.6	45.0	7.9	47.1	-7.5	38.4	1.5	34.5	5.5	42.2	-1.5	45	-8.9 **	41	-11.9 **	50	-6.3 **
86	2 × 21	33.1	-5.6	28.8	-0.9	37.5	-8.9	31.6	0.4	28.1	10.1	35.2	-6.1	51	-2.9 *	45	-3.2 *	57	-2.6 *
87	3 × 21	34.5	-12.7	32.4	-8.9	36.6	-15.8	30.5	-11.2	25.1	-11.1	35.9	-11.3	47	-4.1 **	42	-5.2 **	52	-3.1 *
88	4 × 21	46.0	-6.7	41.4	-0.3	50.6	-11.3	38.7	1.3	33.4	8.1	44.1	-3.2	50	-4.3 **	45	-5.3 **	56	-3.4 **
89	5 × 21	38.1	-3.7	31.8	-4.9	44.3	-2.8	32.0	-3.3	25.4	-4.2	38.6	-2.7	47	-5.4 **	41	-9.3 **	53	-2.2
90	6 × 21	48.0	-18.0 **	45.3	-14.1 *	50.8	-21.2 **	36.7	-9.3	32.0	-5.6	41.4	-12.0 *	46	-8.0 **	42	-9.4 **	50	-6.8 **
91	7 × 21	42.5	1.4	36.8	-5.8	48.3	7.8	34.6	-5.0	27.3	-8.5	41.8	-2.5	51	-1.0	45	-1.8	57	-0.3
92	8 × 21	45.9	-3.7	40.4	-3.9	51.4	-3.6	39.2	-2.7	32.6	-4.1	45.8	-1.7	48	-5.1 **	43	-5.1 **	53	-5.0 **
93	9 × 21	56.7	9.9	47.0	7.4	66.4	11.8 *	44.7	12.3 *	34.4	6.6	54.9	16.1 **	47	-7.7 **	43	-6.6 **	51	-8.6 **
94	10 × 21	44.1	-3.2	40.0	1.9	48.2	-5.0	34.9	-7.7	26.7	-14.1 *	43.0	-3.3	46	-5.7 **	42	-4.6 **	50	-6.5 **
95	11 × 21	42.1	0.8	39.5	-1.0	44.8	2.5	32.0	-6.4	26.5	-11.7 *	37.5	-2.2	46	-8.5 **	41	-10.2 **	51	-7.0 **
96	12 × 21	35.5	-1.4	30.4	-5.2	40.7	1.6	31.1	-1.7	24.9	-6.1	37.2	1.5	47	-6.3 **	42	-7.1 **	53	-5.7 **
97	13 × 21	44.6	-10.7	38.4	-3.7	50.8	-15.3 *	37.5	-1.7	32.6	7.9	42.4	-8.0	48	-7.2 **	42	-10.1 **	53	-4.8 **
98	14 × 21	46.9	5.9	42.4	-3.0	51.3	14.6	40.2	9.0	35.9	11.1 *	44.6	7.4	46	-7.8 **	42	-6.4 **	51	-8.9 **
99	1 × 22	55.5	12.3	53.0	22.7 **	58.0	0.2	43.6	12.0 *	33.3	1.9	53.8	13.3 *	43	-16.0 **	41	-14.3 **	44	-17.5 **

Appendix E. (Cont.)

Sl.No.	Hybrid[a]	Fe (mg kg^{-1})						Zn(mg kg^{-1})						DF (d)					
		P		R11		S12		P		R11		S12		P		R11		S12	
		Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP
100	2 × 22	29.2	-23.5**	26.1	-14.7	32.4	-32.7**	31.4	-3.7	25.2	-1.2	37.6	-10.7	51	-5.6**	46	-3.8**	55	-7.1**
101	3 × 22	39.9	-6.4	36.7	-0.8	43.1	-14.7*	34.6	-2.6	28.2	0.0	40.9	-9.4	46	-7.9**	42	-9.4**	51	-6.7**
102	4 × 22	58.1	10.8	49.0	13.8*	67.2	5.0	48.2	22.6**	36.1	17.1**	60.2	20.0**	51	-5.1**	45	-7.2**	56	-3.4**
103	5 × 22	38.5	-9.8	32.5	-7.0	44.4	-15.6*	31.0	-9.4	24.9	-6.0	37.0	-16.4*	46	-9.6**	42	-9.7**	49	-9.5**
104	6 × 22	55.7	-9.6	49.8	-8.1	61.7	-13.6*	40.3	-2.8	32.8	-2.9	47.8	-7.3	48	-6.5**	45	-6.9**	51	-6.1**
105	7 × 22	46.7	3.8	42.4	4.6	51.0	-1.4	36.8	-1.8	27.9	-6.6	45.7	-3.7	49	-6.4**	43	-8.1**	54	-5.0**
106	8 × 22	45.0	-11.4	34.5	-20.7**	55.4	-7.9	38.0	-8.0	29.1	-14.1*	46.9	-8.4	47	-8.9**	43	-8.5**	51	-9.1**
107	9 × 22	61.2	12.1*	54.5	20.4**	68.0	2.6	45.4	11.1*	38.6	19.8**	52.2	0.5	48	-7.2**	44	-7.0**	52	-7.4**
108	10 × 22	45.0	-7.4	35.4	-13.2*	54.7	-5.1	40.0	2.9	30.4	-2.2	49.6	1.1	47	-6.2**	44	-3.7*	49	-8.4**
109	11 × 22	42.1	-6.3	35.4	-14.6*	48.8	-3.7	34.7	-1.6	25.6	-14.6*	43.7	1.9	46	-10.6**	41	-12.7**	50	-8.8**
110	12 × 22	40.7	3.9	39.1	16.6*	42.3	-10.1	36.2	10.7	31.0	17.1*	41.3	0.0	47	-8.4**	42	-10.4**	52	-6.8**
111	13 × 22	57.8	9.2	48.1	16.4*	67.6	1.1	46.8	19.3**	34.3	13.8*	59.3	16.9**	46	-11.2**	42	-12.5**	51	-10.1**
112	14 × 22	41.9	-11.5	42.7	-5.4	40.6	-21.6**	36.6	-3.7	32.0	-0.7	43.5	-5.8	46	-10.2**	43	-6.9**	49	-13.0**
113	1 × 23	44.3	-7.5	36.1	-17.6**	52.4	1.0	36.7	2.7	26.4	-17.6**	47.1	19.1**	42	-18.6**	39	-22.1**	46	-15.4**
114	2 × 23	25.8	-29.6**	23.6	-24.2*	28.0	-33.5**	25.9	-12.1	20.2	-18.6*	31.6	-7.3	51	-7.5**	46	-8.0**	55	-7.0**
115	3 × 23	38.1	-7.2	32.6	-13.4	43.6	-2.0	27.5	-14.9*	22.9	-16.7*	32.1	-13.5	46	-11.5**	42	-12.8**	49	-10.3**
116	4 × 23	38.5	-24.2**	31.7	-27.4**	45.4	-21.8**	32.0	-11.6	25.7	-14.8*	38.3	-9.4	49	-10.0**	43	-14.5**	55	-6.2**
117	5 × 23	32.8	-20.1*	29.1	-18.4*	36.6	-21.5**	26.2	-15.5*	22.5	-13.0	30.0	-17.3*	46	-10.8**	41	-14.5**	51	-7.6**
118	6 × 23	38.2	-36.5**	35.5	-35.3**	40.9	-37.5**	28.7	-25.2**	23.0	-30.5**	34.4	-21.1**	47	-10.3**	44	-11.7**	50	-9.1**
119	7 × 23	33.4	-23.1**	29.7	-27.9**	37.2	-18.8*	25.8	-24.7**	20.9	-28.3**	30.8	-22.1**	46	-14.2**	41	-16.3**	51	-12.4**
120	8 × 23	37.7	-23.5**	30.8	-30.2**	44.5	-18.0*	29.1	-24.0**	22.0	-33.9**	36.2	-16.4*	48	-10.4**	44	-9.2**	51	-11.4**
121	9 × 23	41.8	-21.3**	32.1	-30.2**	51.6	-14.5*	33.2	-12.0*	26.2	-17.0**	40.3	-8.4	48	-10.3**	44	-10.5**	51	-10.2**
122	10 × 23	34.6	-26.6**	30.0	-27.4**	39.1	-24.3**	30.2	-15.6*	25.1	-17.4**	35.3	-14.2*	46	-10.5**	41	-13.1**	50	-8.3**
123	11 × 23	33.5	-22.8**	31.6	-24.8**	35.3	-20.9*	27.4	-14.6*	24.0	-18.2**	30.9	-11.6	46	-11.8**	42	-14.6**	50	-9.3**
124	12 × 23	32.9	-12.6	33.4	-2.4	32.4	-21.1*	26.8	-9.4	23.9	-7.2	29.6	-11.1	46	-12.8**	41	-15.2**	51	-10.9**

Appendix E. (Cont.)

Sl.No.	Hybrid[a]	Fe (mg kg^{-1})						Zn(mg kg^{-1})						DF (d)					
		P		R11		S12		P		R11		S12		P		R11		S12	
		Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP
125	13 × 23	42.3	-17.8 **	38.2	-9.0	46.4	-23.9 **	30.6	-15.2 *	26.9	-8.8	34.3	-19.7 **	45	-15.8 **	41	-17.7 **	49	-14.0 **
126	14 × 23	31.7	-30.9 **	28.8	-37.1 **	34.5	-24.6 **	29.6	-15.0 *	25.2	-20.2 **	34.1	-10.7	46	-11.7 **	41	-13.9 **	51	-9.9 **
127	1 × 24	56.3	3.3	52.2	12.9 *	60.4	-8.5	38.5	-9.3	32.4	-8.4	44.5	-14.9 **	44	-13.3 **	39	-16.7 **	49	-10.3 **
128	2 × 24	36.5	-15.6 *	34.0	1.3	39.1	-30.5 **	32.5	-9.9	27.2	-3.5	37.9	-19.2 **	50	-6.5 **	45	-3.9 **	55	-8.5 **
129	3 × 24	41.2	-13.7 *	33.6	-16.0 *	48.7	-17.0 **	36.1	-7.2	27.0	-12.4 *	45.2	-9.3	48	-5.6 **	42	-6.6 **	53	-4.8 **
130	4 × 24	52.0	-9.6	45.2	-1.9	58.8	-18.6 **	41.7	-2.7	34.8	3.9	48.5	-11.8 *	50	-7.0 **	43	-9.4 **	57	-5.0 **
131	5 × 24	43.0	-9.9	37.6	-1.0	48.3	-20.4 **	34.1	-9.5	27.1	-7.0	41.1	-16.3 **	45	-12.2 **	38	-15.8 **	51	-9.3 **
132	6 × 24	55.3	-17.2 **	57.1	-0.3	53.5	-32.8 **	41.2	-8.6	38.1	4.5	44.2	-21.6 **	48	-6.5 **	42	-9.9 **	54	-3.6 **
133	7 × 24	46.8	-6.6	38.2	-12.3	55.3	-7.6	38.1	-6.9	28.6	-12.0 *	47.6	-8.9	50	-5.7 **	43	-6.1 **	56	-5.4 **
134	8 × 24	47.6	-14.6 *	44.2	-5.0	52.8	-22.8 **	36.8	-18.1 **	32.7	-10.5 *	42.8	-23.6 **	49	-5.2 **	46	-0.7	55	-5.4 **
135	9 × 24	55.2	-7.6	48.2	-0.1	62.1	-16.6 **	40.1	-9.7	30.9	-11.4 *	49.3	-13.2 **	47	-9.4 **	42	-8.6 **	52	-10.0 **
136	10 × 24	42.4	-21.1 **	36.1	-17.6 **	48.6	-26.1 **	34.1	-19.5 **	27.5	-18.3 **	40.7	-24.5 **	46	-8.2 **	41	-8.3 **	51	-8.1 **
137	11 × 24	39.7	-20.6 **	34.2	-23.0 **	48.0	-18.5 **	33.9	-12.6 *	27.5	-15.8 **	40.3	-15.6 **	47	-7.9 **	42	-9.4 **	53	-6.8 **
138	12 × 24	44.9	1.7	42.9	17.4 *	47.0	-14.8 *	37.7	4.1	31.4	7.8	43.9	-4.7	47	-8.4 **	41	-10.6 **	54	-6.6 **
139	13 × 24	52.1	-10.2	47.9	8.1	56.3	-25.0 **	37.1	-13.1 *	30.8	-6.0	43.4	-21.8 **	47	-11.4 **	42	-11.3 **	51	-11.5 **
140	14 × 24	45.7	-12.8 *	42.4	-12.0 *	49.0	-18.2 **	40.8	-1.8	33.2	-4.7	48.3	-5.2	47	-9.2 **	40	-11.4 **	54	-7.5 **
141	1 × 25	58.9	6.7	54.5	7.5	63.3	6.1	46.9	4.5	39.9	4.1	53.8	4.8	46	-9.6 **	43	-11.4 **	48	-7.9 **
142	2 × 25	38.2	-13.3	31.7	-16.6 *	44.6	-10.7	37.4	-3.0	29.1	-6.6	45.6	-0.6	49	-7.7 **	44	-10.0 **	55	-5.7 **
143	3 × 25	40.0	-17.3 *	37.5	-15.7 *	42.5	-18.8 **	34.8	-16.0 **	30.1	-11.1 *	39.4	-19.4 **	48	-3.5 *	45	-4.3 **	52	-2.8 *
144	4 × 25	48.7	-16.3 **	42.2	-16.6 **	55.3	-16.1 **	44.3	-2.1	37.7	3.2	50.9	-5.8	52	-3.1 *	47	-4.4 **	56	-2.0
145	5 × 25	40.0	-17.6 *	34.9	-17.8 *	45.0	-17.4 *	30.0	-25.1 **	21.5	-33.3 **	38.6	-19.6 **	48	-4.2 **	43	-8.2 **	53	-0.6
146	6 × 25	60.2	-10.8 *	59.7	-3.3	60.7	-17.1 **	46.2	-2.6	41.9	6.2	50.5	-9.0	50	-2.5	45	-6.9 **	54	1.6
147	7 × 25	46.5	-8.5	39.2	-18.4 **	53.8	0.4	40.6	-6.5	32.7	-8.0	48.4	-5.5	49	-5.9 **	45	-5.3 **	53	-6.5 **
148	8 × 25	44.6	-21.2 **	40.3	-21.0 **	48.8	-21.4 **	40.6	-14.1 **	34.1	-13.9 **	47.2	-14.3 **	49	-4.5 **	45	-4.9 **	53	-4.2 **
149	9 × 25	53.2	-12.1 *	45.7	-13.4 *	60.6	-11.1 *	44.2	-5.6	34.1	-10.1 *	54.3	-2.6	49	-5.8 **	45	-5.6 **	52	-6.0 **

Appendix E. (Cont.)

Sl.No.	Hybrid[a]	Fe ($mg\ kg^{-1}$)						Zn($mg\ kg^{-1}$)						DF (d)					
		P		R11		S12		P		R11		S12		P		R11		S12	
		Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP
150	10 × 25	43.5	-20.2 **	35.6	-26.2 **	51.3	-13.8 *	39.6	-11.7 *	31.0	-15.6 **	48.2	-9.0	47	-4.1 **	43	-5.1 **	51	-3.1 *
151	11 × 25	43.4	-14.5 *	37.9	-22.5 **	48.8	-7.0	36.3	-11.8 *	28.8	-19.2 **	43.8	-6.2	49	-4.6 **	46	-4.2 **	51	-4.9 **
152	12 × 25	39.9	-11.2	35.2	-14.3 *	44.7	-8.6	35.9	-7.1	29.4	-8.4	42.3	-6.1	48	-6.0 **	44	-6.0 **	52	-6.0 **
153	13 × 25	52.5	-10.7 *	47.3	-3.2	57.7	-16.1 **	42.9	-4.9	39.0	9.0	46.9	-14.0 **	47	-9.1 **	43	-10.3 **	51	-8.1 **
154	14 × 25	40.9	-23.1 **	35.6	-32.5 **	46.2	-13.9 *	38.5	-12.4 *	31.1	-18.0 **	45.9	-8.1	47	-7.2 **	43	-8.2 **	52	-6.3 **
155	1 × 26	43.7	-10.0	37.4	-16.3 *	49.9	-4.7	36.9	-12.7 *	29.1	-20.0 **	44.6	-7.2	49	-8.1 **	45	-8.2 **	53	-8.0 **
156	2 × 26	38.8	3.9	42.4	32.5 **	35.2	-17.5 *	31.5	-12.3	25.7	-12.1 *	37.3	-12.4 *	52	-7.6 **	45	-7.5 **	59	-7.6 **
157	3 × 26	35.1	-16.0 *	32.0	-16.7 *	38.1	-15.4 *	33.9	-12.5 *	26.5	-17.1 **	41.4	-9.4	51	-4.6 **	46	-2.5	55	-6.2 **
158	4 × 26	47.6	-7.7	41.0	-7.8	54.1	-7.6	38.9	-8.8	31.9	-7.6	45.9	-9.6	53	-6.2 **	46	-6.7 **	59	-5.8 **
159	5 × 26	39.3	-6.0	32.6	-10.5	46.0	-2.5	37.2	-0.7	29.0	-4.2	45.5	1.6	51	-3.6 **	45	-4.2 **	57	-3.1 *
160	6 × 26	59.1	-2.8	46.5	-16.4 **	71.7	8.7	44.4	-0.9	33.9	-9.8 *	55.0	5.4	53	-2.6 *	47	-4.4 **	58	-1.1
161	7 × 26	44.0	-0.3	41.8	-0.4	46.2	-0.3	38.4	-5.9	32.6	-2.8	44.2	-8.0	51	-7.4 **	44	-7.6 **	57	-7.3 **
162	8 × 26	43.7	-12.5 *	39.9	-11.3	47.4	-13.4 *	39.9	-10.7 *	31.2	-17.0 **	48.6	-6.1	51	-6.1 **	46	-3.8 **	56	-7.9 **
163	9 × 26	52.1	-3.1	45.9	-1.7	58.4	-4.2	42.7	-3.3	32.5	-9.4	53.0	0.9	50	-8.5 **	45	-5.9 **	55	-10.6 **
164	10 × 26	45.0	-5.7	34.0	-19.4 **	56.1	7.4	42.3	0.1	31.9	-8.4	52.6	6.0	49	-6.1 **	43	-6.1 **	55	-6.0 **
165	11 × 26	38.1	-13.5	33.7	-21.3 **	42.4	-6.2	33.2	-13.8 *	26.7	-21.0 **	39.8	-8.3	52	-3.7 **	47	-2.4	57	-4.8 **
166	12 × 26	40.8	6.5	34.3	-2.0	47.3	13.7	40.4	12.0	29.7	-1.8	51.1	22.0 **	52	-3.5 **	45	-4.9 **	59	-2.5 *
167	13 × 26	58.6	12.4 *	45.0	5.2	72.2	17.5 **	46.2	8.5	36.7	8.5	55.7	8.6	51	-8.0 **	44	-9.2 **	57	-7.1 **
168	14 × 26	41.7	-10.2	36.6	-21.5 **	46.8	1.1	38.7	-6.3	32.4	-9.9 *	45.1	-3.5	50	-7.1 **	46	-2.8 *	55	-10.4 **
169	1 × 27	42.6	0.8	37.4	-4.4	47.9	5.2	33.9	-1.7	26.9	-5.1	40.9	0.7	45	-12.5 **	42	-13.5 **	49	-11.7 **
170	2 × 27	30.5	-2.0	26.8	1.3	34.2	-4.4	30.3	7.6	24.1	13.9	36.5	3.9	50	-9.6 **	44	-9.3 **	55	-9.8 **
171	3 × 27	30.5	-14.1	28.6	-13.2	32.5	-14.9	26.7	-14.0	21.1	-12.0	32.4	-15.2 *	49	-4.4 **	44	-5.0 **	54	-3.8 **
172	4 × 27	44.7	-1.3	42.0	7.8	47.4	-8.2	36.4	4.2	29.7	12.1	43.1	-0.6	50	-9.4 **	44	-9.8 **	55	-9.1 **
173	5 × 27	33.1	-7.0	27.1	-12.3	39.0	-3.0	27.8	-6.8	23.0	3.4	32.6	-12.8	48	-6.6 **	43	-8.9 **	54	-4.7 **
174	6 × 27	36.3	-33.6 **	31.8	-36.6 **	40.8	-31.0 **	30.3	-18.4 **	23.7	-19.8 **	36.9	-17.6 **	48	-7.8 **	45	-6.9 **	52	-8.6 **

Appendix E. (Cont.)

Sl.No.	Hybrid[a]	Fe (mg kg^{-1})						Zn(mg kg^{-1})						DF (d)					
		P		R11		S12		P		R11		S12		P		R11		S12	
		Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP	Mean	HMP
175	7 × 27	46.8	23.4 **	33.0	-9.6	60.7	54.0 **	37.3	12.8	26.7	4.4	47.9	18.1 *	50	-6.7 **	43	-8.8 **	56	-5.1 **
176	8 × 27	41.6	-4.8	35.6	-9.8	47.5	-0.8	34.1	-7.7	28.3	-4.5	40.0	-9.9	50	-5.7 **	44	-7.0 **	56	-4.5 **
177	9 × 27	43.0	-9.7	33.6	-18.4 *	52.4	-3.0	37.0	1.5	29.8	6.7	44.3	-1.7	49	-7.8 **	43	-9.1 **	55	-6.8 **
178	10 × 27	34.4	-17.3 *	30.8	-15.9 *	37.9	-16.3 *	31.9	-7.6	24.5	-8.6	39.3	-6.9	48	-5.2 **	43	-6.6 **	54	-4.2 **
179	11 × 27	33.5	-11.6	27.0	-27.6 **	39.9	4.0	28.8	-6.7	24.0	-6.8	33.6	-6.6	49	-5.7 **	45	-6.3 **	54	-5.3 **
180	12 × 27	29.7	-7.6	25.6	-13.2	33.7	-2.7	29.4	4.1	23.9	7.9	34.9	1.6	48	-9.4 **	42	-10.3 **	53	-8.6 **
181	13 × 27	37.8	-17.6 *	32.3	-13.2	43.4	-20.5 **	31.1	-10.7	24.8	-3.9	37.4	-14.7 *	49	-8.6 **	45	-7.6 **	53	-9.4 **
182	14 × 27	44.6	10.8	35.3	-14.2 *	54.0	36.9 **	34.3	2.0	25.6	-8.3	42.9	9.2	48	-8.3 **	43	-7.5 **	53	-8.8 **
183	1 × 28	44.9	-2.0	41.9	4.2	47.9	-6.9	35.9	3.4	31.0	0.0	40.8	6.0	44	-13.2 **	43	-12.9 **	45	-13.5 **
184	2 × 28	30.6	-11.6	27.1	-1.9	34.2	-18.0 *	27.2	-4.2	22.2	-6.6	32.2	-2.5	48	-10.8 **	43	-12.2 **	52	-9.6 **
185	3 × 28	36.9	-5.4	35.6	4.6	38.2	-13.1	29.8	-4.9	24.1	-9.1	35.4	-1.8	47	-5.8 **	44	-6.7 **	50	-5.1 **
186	4 × 28	39.9	-18.2 **	31.2	-22.1 **	48.6	-15.5 *	34.7	-1.2	26.4	-9.3	43.0	4.5	49	-7.5 **	45	-10.7 **	54	-4.7 **
187	5 × 28	33.7	-13.8	28.7	-10.4	38.7	-16.1 *	28.1	-6.2	23.6	-5.0	32.7	-7.0	45	-10.8 **	41	-13.3 **	48	-8.6 **
188	6 × 28	39.3	-32.3 **	36.6	-28.6 **	42.0	-35.3 **	33.1	-11.4	28.9	-10.1	37.3	-12.4 *	48	-6.7 **	44	-10.5 **	51	-3.2 *
189	7 × 28	40.4	-2.5	30.7	-18.4 *	50.1	10.7	32.2	-3.1	24.1	-14.3 *	40.4	5.0	48	-7.9 **	45	-7.6 **	51	-8.1 **
190	8 × 28	40.5	-14.1 *	33.8	-16.8 *	45.1	-16.2 *	33.9	-8.9	27.7	-13.9 *	40.0	-5.1	49	-5.8 **	46	-5.2 **	51	-6.4 **
191	9 × 28	42.8	-16.2 *	39.4	-6.8	46.2	-22.8 **	33.2	-9.4	27.3	-10.5	39.2	-8.7	48	-7.7 **	45	-7.9 **	51	-7.6 **
192	10 × 28	30.7	-32.0 **	28.6	-24.3 **	33.7	-34.2 **	31.2	-10.2	25.0	-14.7 *	37.3	-6.9	46	-7.4 **	42	-9.7 **	49	-5.4 **
193	11 × 28	42.6	3.2	35.5	-7.6	49.8	12.6	33.4	7.6	24.6	-13.2 *	42.3	25.0 **	46	-8.9 **	43	-10.7 **	49	-7.2 **
194	12 × 28	35.1	-1.5	32.7	7.0	37.4	-7.9	28.4	-0.5	22.3	-9.8	34.4	6.6	47	-8.3 **	43	-9.1 **	50	-7.6 **
195	13 × 28	44.0	-10.9	35.9	-6.4	52.1	-13.7 *	32.8	-6.4	26.6	-6.3	39.0	-6.4	46	-11.1 **	45	-9.2 **	48	-12.8 **
196	14 × 28	39.0	-10.9	35.3	-16.5 *	42.7	-5.7	33.6	-0.8	26.3	-13.7 *	40.8	9.8	44	-13.1 **	41	-14.1 **	48	-12.2 **
SE (mean, HMP, HBP)		3.1	3.8	2.7	3.3	3.5	0.4	2.2	2.7	1.7	0.2	2.7	3.2	0.7	0.8	0.6	0.7	0.7	0.9
Min		25.8	-36.5	23.6	-37.1	28.0	-37.5	25.8	-25.2	20.2	-33.9	29.6	-25.1	41	-18.6	38	-22.1	44	-19.4
Max		64.5	23.4	64.6	32.5	73.5	54.0	48.2	22.6	45.4	19.8	60.2	25.0	53	0.5	47	0.8	60	2.1
Mean		45.3	-8.5	40.9	-8.5	49.7	-8.4	37.1	-4.7	30.7	-7.3	43.6	-3.1	48	-7.3	43	-8.2	53	-6.6

[a]1-28 -ID of inbred lines detailed in the table 3.2.; SE-Standard error; *, **-Significant at the 0.05, 0.01 probability levels, respectively; P- Pooled across environments; R11-2011 rainy season; S12-2012 summer season.

Appendix F. Performance *per se* (mean) of hybrids and their heterosis over mid-parent (HMP) and heterosis over better-parent (HBP) for 1000 grain weight (GW) and grain yield (GY) in line × tester study of pearl millet, 2011 rainy and 2012 summer seasons, Patancheru

Sl. No.	Hybrid[a]	GW (g)									GY(t ha^{-1})								
		P			R11			S12			P			R11			S12		
		Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP
1	1 × 15	12.3	21.1 **	12.2 **	12.7	25.9 **	14.4 **	12.0	16.4 **	10.0 *	3.8	37.6 **	29.5 **	3.6	52.5 **	43.1 **	4.0	29.2 **	24.3 *
2	2 × 15	10.7	27.4 **	14.0 **	10.7	38.9 **	17.6 **	10.7	17.6 **	10.5 *	4.6	92.2 **	77.4 **	4.5	117.5 **	104.5 **	4.7	72.8 **	57.2 **
3	3 × 15	12.9	15.8 **	0.2 -	13.0	13.9 **	- -	12.7	17.9 **	6.7 *	4.1	66.4 **	57.0 **	4.5	48.7 **	16.7 *	3.6	71.2 **	21.4 *
4	4 × 15	12.6	21.4 **	10.6 **	13.3	40.0 **	33.8 **	11.9	5.6 -	- -	5.0	74.3 **	59.8 **	5.2	100.8 **	74.5 **	4.7	52.1 **	46.1 **
5	5 × 15	14.0	25.1 **	7.9 *	15.0	34.2 **	12.9 **	12.9	15.9 **	2.5 -	4.1	32.0 **	13.2 -	4.5	76.2 **	54.6 **	3.7	0.8 -	- -
6	6 × 15	11.9	21.1 **	16.1 **	12.7	32.6 **	26.5 **	11.1	10.1 **	6.1 -	4.4	68.0 **	67.6 **	4.7	105.9 **	100.7 **	4.1	38.6 **	36.5 **
7	7 × 15	11.9	20.8 **	15.3 **	12.8	29.4 **	19.4 **	11.0	12.2 **	10.8 *	4.4	51.9 **	37.2 **	4.3	69.1 **	49.7 **	4.5	38.6 **	27.1 **
8	8 × 15	12.9	38.4 **	37.2 **	13.9	60.6 **	53.4 **	11.8	18.9 **	16.1 **	4.3	104.7 **	64.6 **	4.6	186.5 **	108.1 **	3.9	53.5 **	32.3 **
9	9 × 15	13.5	31.1 **	20.3 **	14.7	53.6 **	46.3 **	12.3	11.7 **	- -	3.6	57.2 **	39.4 **	3.8	97.1 **	70.7 **	3.5	28.7 *	16.1 -
10	10 × 15	12.9	27.6 **	18.8 **	13.6	43.3 **	37.4 **	12.3	13.8 **	3.2 -	4.2	72.0 **	62.2 **	4.5	143.8 **	103.0 **	3.9	28.6 **	25.5 *
11	11 × 15	11.8	32.4 **	26.1 **	11.8	53.3 **	30.1 **	11.8	16.6 **	11.3 **	3.8	54.1 **	48.0 **	3.8	110.0 **	71.4 **	3.9	22.2 *	14.9 -
12	12 × 15	12.3	21.2 **	12.4 **	13.2	35.0 **	26.1 **	11.5	8.5 *	- -	4.5	67.0 **	59.8 **	5.0	134.4 **	124.0 **	4.1	24.0 *	12.4 -
13	13 × 15	13.4	32.5 **	23.9 **	14.1	49.8 **	44.5 **	12.6	17.3 **	6.8 *	4.3	82.3 **	66.7 **	4.4	148.0 **	98.7 **	4.3	43.1 **	42.9 **
14	14 × 15	11.1	16.6 **	15.2 **	11.1	25.9 **	21.8 **	11.1	10.5 **	6.9 -	4.2	71.0 **	60.8 **	4.3	161.6 **	94.2 **	4.1	25.0 **	15.7 -
15	1 × 16	11.5	16.2 **	4.4 -	11.6	16.1 **	4.0 -	11.4	16.4 **	4.8 -	3.5	49.1 **	20.0 -	3.5	84.6 **	39.9 **	3.5	28.2 *	9.6 -
16	2 × 16	10.2	25.7 **	16.0 **	9.9	30.5 **	11.9 *	10.5	21.5 **	20.1 **	4.1	106.9 **	88.0 **	3.6	122.5 **	85.5 **	4.6	96.1 **	90.0 **
17	3 × 16	12.5	15.7 **	- -	13.6	20.7 **	- -	11.4	10.2 **	- -	4.4	114.0 **	90.4 **	4.5	71.4 **	14.4 -	4.3	144.6 **	89.0 **
18	4 × 16	12.8	27.2 **	12.5 **	13.3	41.6 **	33.4 **	12.4	14.7 **	- -	4.3	73.2 **	36.5 **	4.6	112.4 **	52.3 **	3.9	42.6 **	21.8 *
19	5 × 16	11.6	7.1 *	- -	12.3	11.2 **	- -	10.9	2.8 -	- -	4.0	47.5 **	10.3 -	3.9	85.5 **	33.9 **	4.1	23.2 *	- -
20	6 × 16	11.1	16.5 **	8.2 -	11.6	22.8 **	15.5 **	10.6	10.3 **	1.1 -	3.7	67.2 **	41.1 **	3.0	66.6 **	29.8 *	4.3	67.6 **	50.3 **
21	7 × 16	10.8	12.9 **	4.4 -	11.7	19.2 **	8.5 *	9.9	6.4 -	- -	3.6	44.6 **	12.6 -	3.5	67.7 **	21.9 *	3.8	28.2 **	5.2 -
22	8 × 16	12.2	35.9 **	32.6 **	12.7	48.3 **	43.7 **	11.8	24.7 **	15.8 **	3.9	133.7 **	119.6 **	3.8	227.2 **	189.5 **	4.1	85.2 **	79.9 **
23	9 × 16	12.9	28.7 **	14.6 **	13.3	41.1 **	32.6 **	12.4	17.6 **	- -	3.5	84.0 **	74.3 **	3.3	127.2 **	104.8 **	3.7	57.1 **	53.6 **

Appendix F. (Cont.)

Sl. No.	Hybrid[a]	GW (g)									GY(t ha^{-1})								
		P			R11			S12			P			R11			S12		
		Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP
24	10 × 16	12.1	23.4 **	11.3 **	12.4	32.5 **	25.3 **	11.8	15.1 **	- -	3.9	92.6 **	71.4 **	4.0	189.4 **	172.5 **	3.9	42.9 **	23.7 *
25	11 × 16	10.7	23.8 **	21.9 **	10.4	36.6 **	17.4 **	11.0	13.8 **	3.4 -	3.3	56.7 **	37.1 **	3.4	150.8 **	141.9 **	3.2	11.8 -	- -
26	12 × 16	11.1	11.9 **	0.6 -	10.7	11.3 **	2.5 -	11.4	12.5 **	- -	4.1	76.9 **	44.4 **	3.8	129.0 **	88.4 **	4.4	47.9 **	20.1 *
27	13 × 16	11.9	22.0 **	10.6 *	12.1	30.5 **	24.0 **	11.7	14.3 **	- -	3.6	81.9 **	66.9 **	3.4	153.9 **	150.8 **	3.8	45.8 **	29.1 *
28	14 × 16	10.1	10.1 *	5.3 -	9.6	10.7 *	8.7 -	10.6	11.7 **	2.9	3.4	68.2 **	50.2 **	2.7	125.9 **	106.1 **	4.2	44.5 **	19.5 *
29	1 × 17	13.3	18.1 **	15.4 **	14.6	26.2 **	21.3 **	12.0	9.5 **	9.0 *	3.6	40.4 **	21.8 *	3.7	73.7 **	47.8 **	3.4	19.0 -	6.8 -
30	2 × 17	12.1	27.7 **	4.9 -	12.1	31.3 **	29.5 -	12.1	24.3 **	10.3 **	4.1	88.8 **	87.5 **	4.3	128.2 **	117.7 **	4.0	59.5 **	55.8 **
31	3 × 17	14.1	16.2 **	10.1 **	14.6	12.8 **	5.8 -	13.7	19.9 **	15.1 **	3.5	56.4 **	51.7 **	3.7	31.7 **	- -	3.3	71.4 **	27.5 *
32	4 × 17	14.1	22.7 **	22.2 **	15.4	39.7 **	27.7 **	12.7	7.0 *	- -	4.0	52.8 **	29.5 **	4.2	74.2 **	38.5 **	3.9	35.2 **	21.0 *
33	5 × 17	12.9	5.1 -	- -	13.4	6.0 -	1.0 -	12.3	4.2 -	- -	3.5	20.6 *	- -	3.7	56.2 **	25.3 *	3.3	3.8 -	- -
34	6 × 17	12.1	11.5 **	5.2 -	13.5	22.1 **	11.8 **	10.8	0.5 -	- -	3.8	59.9 **	46.3 **	4.0	93.2 **	69.9 **	3.7	34.8 **	27.2 *
35	7 × 17	11.1	1.5 -	- -	11.9	4.2 -	- -	10.3	1.5 -	- -	3.3	22.4 *	2.3 -	3.5	52.6 **	23.4 *	3.1	0.5 -	- -
36	8 × 17	12.1	16.8 **	5.1 -	12.7	24.9 **	5.3 -	11.5	9.1 *	5.0 -	3.2	70.6 **	47.6 **	2.9	109.7 **	64.2 **	3.5	47.6 **	36.1 **
37	9 × 17	14.1	23.7 **	22.2 **	15.5	39.9 **	28.2 **	12.7	8.3 **	2.0 -	3.7	77.2 **	70.7 **	3.9	132.3 **	122.4 **	3.5	39.4 **	34.9 **
38	10 × 17	12.3	10.1 **	7.1 -	13.0	18.1 **	7.6 *	11.7	2.3 -	- -	3.7	66.9 **	62.0 **	3.7	126.9 **	107.8 **	3.8	32.7 -	20.6 *
39	11 × 17	11.9	18.7 **	3.1 -	12.1	31.3 **	0.1 -	11.7	8.0 *	6.4 -	3.2	39.8 **	33.1 *	2.9	83.9 **	64.7 **	3.5	16.2 -	2.0 -
40	12 × 17	12.2	8.6 *	6.1 -	12.8	13.5 **	6.1 -	11.6	3.6	1.2 -	3.7	47.8 **	30.3 **	4.0	111.0 **	98.1 **	3.4	9.3 -	- -
41	13 × 17	13.6	22.1 **	18.2 **	15.0	37.3 **	24.3 **	12.2	7.5 *	3.8 -	3.1	45.7 **	45.2 **	3.4	118.5 **	91.6 **	2.9	4.7 -	- -
42	14 × 17	11.8	11.6 **	2.4 -	11.8	14.7 **	- -	11.8	10.6 **	7.4 *	3.7	64.9 **	60.5 **	3.6	153.2 **	103.3 **	3.7	23.3 *	6.8 -
43	1 × 18	13.4	21.0 **	19.7 **	14.6	36.8 **	31.6 **	12.3	6.3 *	0.5 -	3.9	32.6 **	32.0 **	4.4	72.1 **	70.5 **	3.5	4.8 -	2.5 -
44	2 × 18	10.1	8.6 *	- -	10.1	22.2 **	- -	10.1	2.3 -	- -	3.8	47.1 **	27.9 *	4.0	77.2 **	55.8 **	3.6	23.5 *	6.6 -
45	3 × 18	12.3	2.3 -	- -	12.3	2.4 -	- -	12.3	2.3 -	1.2 -	4.2	57.5 **	39.8 **	4.0	24.1 **	3.1 -	4.3	86.1 **	27.6 **
46	4 × 18	13.3	17.9 **	17.0 **	14.1	38.8 **	36.6 **	12.6	1.0 -	- -	4.5	46.7 **	43.2 **	4.7	69.4 **	57.4 **	4.2	27.6 **	25.1 *
47	5 × 18	11.8	2.3 -	- -	11.8	0.2 -	- -	11.9	4.2 -	- -	4.2	26.6 **	15.1 -	4.1	47.3 **	38.3 **	4.3	11.7 -	- -
48	6 × 18	12.1	13.1 **	8.0 *	12.4	22.1 **	20.4 **	11.9	5.1 -	- -	3.9	38.8 **	30.5 **	3.9	57.6 **	50.3 **	3.9	24.0 *	15.2 -

Appendix F. (Cont.)

Sl. No.	Hybrid[a]	GW (g)									GY(t ha^{-1})								
		P			R11			S12			P			R11			S12		
		Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP
49	7 × 18	11.5	6.5 -	2.2 -	11.9	13.2 **	10.9 *	11.1	0.2 -	- -	3.7	18.3 *	13.6 -	3.5	29.4 **	22.7 *	3.8	9.5 -	6.3 -
50	8 × 18	13.3	30.5 **	18.7 **	14.0	50.8 **	36.0 **	12.7	13.6 **	4.1 -	3.8	68.9 **	29.4 **	4.1	127.2 **	57.9 **	3.6	31.1 **	7.6 -
51	9 × 18	14.0	24.3 **	24.3 **	15.1	48.6 **	46.8 **	12.8	4.2 -	3.2 -	4.0	62.5 **	36.2 **	4.6	118.7 **	78.2 **	3.5	21.6 *	4.1 -
52	10 × 18	13.4	21.5 **	19.6 **	14.5	43.8 **	41.2 **	12.4	2.7 -	1.4 -	4.2	58.2 **	40.5 **	4.1	100.0 **	57.3 **	4.3	32.2 **	27.6 **
53	11 × 18	12.2	23.6 **	8.5 *	12.3	48.2 **	19.8 **	12.1	5.6 -	- -	4.5	66.9 **	50.7 **	4.3	114.4 **	65.6 **	4.7	38.9 **	38.5 **
54	12 × 18	12.1	8.6 *	7.3 -	12.1	16.3 **	15.3 **	12.1	1.8 -	- -	4.1	40.2 **	37.2 **	4.1	76.2 **	57.2 **	4.1	16.7 *	11.9 -
55	13 × 18	13.8	25.6 **	23.0 **	14.8	47.3 **	43.8 **	12.9	7.3 *	5.5	3.8	48.3 **	27.9 *	3.7	90.7 **	44.8 **	3.9	22.2 *	15.0 -
56	14 × 18	11.9	14.2 **	5.9 -	11.9	26.7 **	15.7 **	11.9	5.6 -	- -	3.7	41.0 **	24.8 *	4.0	117.4 **	54.1 **	3.4	0.3 -	- -
57	1 × 19	13.3	36.4 **	21.2 **	14.3	46.8 **	28.3 **	12.4	26.1 **	14.0 **	4.2	55.0 **	41.2 **	4.7	99.9 **	85.7 **	3.6	22.9 *	12.3 -
58	2 × 19	9.9	24.0 **	15.7 **	9.7	32.6 **	16.5 **	10.1	16.6 **	14.8 **	4.4	92.5 **	83.8 **	4.5	119.9 **	109.0 **	4.4	70.5 **	63.3 **
59	3 × 19	13.3	24.1 **	3.3 -	13.2	19.3 **	- -	13.4	29.1 **	12.0 **	4.1	72.8 **	68.8 **	4.6	51.9 **	18.3 *	3.6	81.8 **	33.4 **
60	4 × 19	11.8	18.7 **	3.9 -	13.1	42.9 **	31.1 **	10.6	1.7 -	- -	4.9	75.2 **	55.5 **	5.3	106.5 **	77.8 **	4.4	47.7 **	34.7 **
61	5 × 19	12.2	13.4 **	- -	13.1	21.0 **	- -	11.3	5.6 -	- -	4.2	38.0 **	15.0 -	4.3	68.0 **	46.1 **	4.1	16.2 -	- -
62	6 × 19	11.3	20.5 **	10.6 *	11.9	29.7 **	18.8 **	10.7	11.6 **	2.7 -	3.6	44.8 **	39.4 **	3.7	65.2 **	59.3 **	3.6	28.1 *	23.2 *
63	7 × 19	10.8	14.9 **	5.0 -	11.0	15.6 **	2.6	10.7	14.2 **	7.6 -	3.7	31.2 **	14.8 -	3.4	33.9 **	17.4 -	4.0	29.0 **	12.7
64	8 × 19	12.9	45.1 **	39.9 **	13.1	58.3 **	57.8 **	12.6	33.6 **	24.5 **	4.1	102.9 **	67.7 **	4.3	169.0 **	96.7 **	3.8	59.4 **	44.2 **
65	9 × 19	11.9	20.1 **	5.8 -	11.7	27.3 **	16.4 **	12.1	13.9 **	- -	4.0	82.5 **	67.1 **	4.1	114.2 **	87.2 **	4.0	58.7 **	50.6 **
66	10 × 19	12.8	31.6 **	17.5 **	13.3	45.4 **	33.8 **	12.3	19.4 **	3.8 -	4.0	67.5 **	63.5 **	3.9	114.9 **	80.6 **	4.0	37.7 **	27.5 *
67	11 × 19	10.9	27.5 **	27.1 **	11.5	56.7 **	37.9 **	10.2	5.5 -	- -	3.3	37.9 **	37.3 **	4.0	126.7 **	86.7 **	2.6	14.4 -	- -
68	12 × 19	12.1	23.6 **	9.9 *	12.5	33.0 **	19.4 **	11.6	14.8 **	1.2 -	4.8	82.4 **	68.7 **	5.0	137.9 **	129.8 **	4.6	45.7 **	25.8 **
69	13 × 19	12.0	24.0 **	11.2 **	13.1	44.3 **	33.6 **	10.9	6.2 -	- -	3.4	48.5 **	40.4 **	3.4	92.1 **	55.3 **	3.4	21.4 *	15.2 -
70	14 × 19	10.9	19.9 **	13.3 **	11.3	34.7 **	33.3 **	10.4	9.1 *	0.8 -	4.2	79.0 **	74.2 **	4.6	181.9 **	110.8 **	3.9	24.9 *	10.1 -
71	1 × 20	14.3	30.1 **	29.9 **	14.9	33.5 **	32.7 **	13.7	26.6 **	26.2 **	4.0	49.1 **	36.5 **	4.2	87.9 **	65.8 **	3.9	24.4 *	19.4 *
72	2 × 20	10.9	17.8 **	- -	11.0	25.5 **	- -	10.7	10.7 **	- -	4.8	107.3 **	96.7 **	5.0	157.4 **	156.1 **	4.6	71.2 **	56.2 **
73	3 × 20	11.5	3.8 -	- -	12.0	4.0 -	- -	11.0	3.7 -	- -	4.0	69.4 **	64.5 **	4.4	50.6 **	12.7 -	3.7	74.1 **	23.7 *

Appendix F. (Cont.)

Sl. No.	Hybrid[a]	GW (g)									GY(t ha^{-1})								
		P			R11			S12			P			R11			S12		
		Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP
74	4 × 20	13.0	16.1 **	14.2 **	14.4	35.7 **	28.0 **	11.6	1.6 -	- -	4.8	72.8 **	54.2 **	5.4	119.5 **	80.4 **	4.2	35.6 **	29.9 **
75	5 × 20	11.5	4.0 -	- -	12.6	2.8 -	- -	10.4	11.1 **	- -	4.2	37.0 **	14.7 -	4.4	82.6 **	51.4 **	3.9	6.6 -	- -
76	6 × 20	12.3	16.2 **	11.9 **	12.9	21.1 **	14.4 **	11.8	11.3 **	9.4 *	3.9	55.8 **	50.9 **	3.1	45.9 **	33.3 *	4.8	63.0 **	60.9 **
77	7 × 20	12.6	17.8 **	14.1 **	12.7	15.7 **	13.0 **	12.4	20.0 **	15.1 **	4.2	48.3 **	30.5 **	4.4	81.4 **	51.7 **	4.1	24.0 *	13.4
78	8 × 20	13.3	31.5 **	20.7 **	14.4	47.4 **	27.9 **	12.2	16.8 **	13.3 **	4.2	105.9 **	69.4 **	4.1	178.6 **	111.6 **	4.2	64.3 **	41.9 **
79	9 × 20	13.5	21.1 **	20.0 **	15.1	41.6 **	33.9 **	11.9	2.4 -	- -	4.5	104.0 **	85.7 **	4.8	168.9 **	147.4 **	4.3	61.0 **	45.5 **
80	10 × 20	13.3	21.1 **	20.3 **	14.0	32.4 **	24.4 **	12.5	10.6 **	5.6 -	4.6	93.4 **	87.6 **	4.7	174.7 **	142.3 **	4.5	47.8 **	43.9 **
81	11 × 20	11.3	16.2 **	2.8 -	11.9	34.8 **	5.3 -	10.8	0.9 -	0.2 -	4.3	77.3 **	75.3 **	4.3	155.6 **	120.6 **	4.3	36.1 **	27.7 **
82	12 × 20	11.7	6.6 -	6.3 -	12.5	15.1 **	11.1 *	11.0	1.8 -	- -	4.4	67.3 **	55.7 **	4.8	140.4 **	135.2 **	4.1	23.7 *	11.8
83	13 × 20	13.4	23.2 **	21.8 **	14.5	37.6 **	28.6 **	12.4	9.7 **	5.2	4.1	78.1 **	67.4 **	4.2	158.5 **	118.7 **	4.0	33.8 **	33.7 **
84	14 × 20	10.7	3.4 -	- -	10.6	7.7 -	- -	10.7	1.1 -	- -	3.6	52.9 **	47.9 **	3.8	151.3 **	95.5 **	3.5	7.1 -	- -
85	1 × 21	12.5	19.3 **	13.7 **	13.6	31.5 **	22.2 **	11.4	7.5 *	5.1	4.2	49.9 **	41.4 **	4.0	63.9 **	56.3 **	4.4	42.3 **	35.8 **
86	2 × 21	10.6	22.6 **	6.9 -	10.4	31.4 **	9.1 -	10.9	15.2 **	4.8	4.3	79.7 **	65.4 **	4.5	109.9 **	94.3 **	4.2	55.8 **	42.9 **
87	3 × 21	12.0	5.6 -	- -	12.4	6.2 -	- -	11.7	4.9 -	- -	4.2	68.9 **	59.0 **	4.5	45.9 **	16.0 *	3.8	81.7 **	29.6 *
88	4 × 21	12.0	11.9 **	4.8 -	12.8	31.2 **	28.4 **	11.1	4.3 -	- -	4.4	53.0 **	40.5 **	4.4	65.2 **	45.7 **	4.4	42.5 **	35.7 **
89	5 × 21	11.9	4.1 -	- -	12.5	9.6 **	- -	11.3	1.3 -	- -	4.4	41.0 **	21.2 *	4.9	88.4 **	67.9 **	3.9	6.8 -	- -
90	6 × 21	11.4	12.6 **	11.2 *	12.0	22.4 **	19.7 **	10.8	3.4 -	3.0	4.0	53.2 **	53.2 **	4.2	82.3 **	80.6 **	3.8	30.1 **	29.2 *
91	7 × 21	10.9	7.9 *	6.0 -	11.9	17.3 **	10.9 *	10.0	1.6 -	- -	4.2	44.8 **	31.1 **	4.4	68.4 **	51.4 **	4.1	26.0 **	14.7 -
92	8 × 21	12.4	29.7 **	24.9 **	12.6	40.9 **	31.4 **	12.3	20.1 **	18.8 **	4.1	94.5 **	56.1 **	4.2	154.7 **	83.0 **	4.0	55.5 **	35.0 **
93	9 × 21	13.7	29.7 **	22.4 **	15.2	55.6 **	51.8 **	12.3	7.5 *	- -	4.4	88.2 **	66.5 **	4.5	130.4 **	96.7 **	4.2	57.2 **	42.9 **
94	10 × 21	13.4	28.3 **	22.8 **	13.6	40.0 **	37.5 **	13.1	18.0 **	10.5 **	4.0	63.7 **	54.0 **	3.9	104.8 **	68.2 **	4.2	38.2 **	33.7 **
95	11 × 21	11.3	22.2 **	13.1 **	11.3	42.5 **	18.5 **	11.2	6.8 *	5.5	3.9	54.9 **	48.5 **	3.7	98.5 **	60.0 **	4.1	29.4 **	20.6 *
96	12 × 21	11.9	13.3 **	8.0 *	12.5	24.7 **	19.3 **	11.2	2.7 -	- -	4.6	69.4 **	62.5 **	4.6	114.1 **	101.3 **	4.6	40.1 **	26.0 **
97	13 × 21	12.8	23.2 **	18.6 **	13.8	42.9 **	41.2 **	11.7	6.0 -	- -	3.3	38.0 **	25.9 *	3.1	68.3 **	33.2 *	3.5	19.4 *	18.6 -
98	14 × 21	10.4	6.5 -	4.6 -	10.5	15.8 **	9.4 *	10.4	0.3 -	0.2 -	3.8	55.8 **	46.1 **	4.0	134.7 **	72.3 **	3.7	14.5 -	5.1 -

Appendix F. (Cont.)

Sl. No.	Hybrid[a]	GW (g)									GY(t ha^{-1})								
		P			R11			S12			P			R11			S12		
		Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP
99	1 × 22	12.1	29.7**	9.6*	12.4	32.1**	11.5**	11.7	27.3**	7.7*	4.2	59.4**	41.4**	4.3	86.7**	70.9**	4.0	41.1**	24.4*
100	2 × 22	10.0	33.3**	31.6**	9.9	41.7**	29.2**	10.1	25.9**	18.6**	4.0	79.3**	76.1**	4.1	100.2**	93.1**	4.0	62.0**	61.5**
101	3 × 22	13.3	30.6**	3.8-	14.1	31.9**	2.7-	12.6	29.0**	5.2-	4.1	79.7**	78.7**	4.4	46.1**	12.5-	3.9	108.4**	57.1**
102	4 × 22	11.9	25.3**	4.3-	12.2	38.5**	22.4**	11.6	13.8**	- -	3.4	24.7*	7.9-	4.0	55.2**	31.8**	2.8	2.6-	- -
103	5 × 22	12.2	18.8**	- -	12.7	21.6**	- -	11.6	15.9**	- -	4.3	47.0**	19.6*	4.3	72.6**	48.1**	4.3	28.0**	0.3-
104	6 × 22	12.3	38.5**	20.6**	12.9	45.8**	28.7**	11.8	31.3**	12.9**	3.5	45.0**	35.8**	3.5	59.9**	51.9**	3.5	32.6**	22.8*
105	7 × 22	11.0	23.2**	6.9-	11.6	25.7**	7.6-	10.5	20.7**	6.1	4.4	58.9**	35.6**	4.6	85.9**	60.9**	4.1	36.6**	15.3-
106	8 × 22	13.4	59.5**	45.4**	13.7	71.7**	65.3**	13.1	48.5**	29.2**	4.1	113.2**	80.5**	4.6	194.5**	117.6**	3.7	58.5**	48.8**
107	9 × 22	12.8	36.4**	14.3**	14.1	58.9**	40.0**	11.6	16.4**	- -	4.2	94.6**	83.1**	4.5	142.4**	114.9**	3.8	57.9**	55.9**
108	10 × 22	12.3	33.3**	13.1**	12.4	41.1**	25.1**	12.2	26.2**	3.1	3.6	58.9**	58.1**	4.0	125.4**	91.8**	3.3	16.3-	3.8-
109	11 × 22	12.5	55.6**	47.3**	12.8	82.8**	67.1**	12.2	34.6**	14.9**	3.9	67.2**	63.2**	4.2	138.8**	99.1**	3.6	24.3*	7.3-
110	12 × 22	12.2	31.9**	11.5**	13.2	45.4**	25.8**	11.3	19.0**	- -	4.2	63.5**	47.3**	4.6	123.3**	119.0**	3.8	23.2*	2.9-
111	13 × 22	12.4	34.9**	14.9**	13.7	57.0**	39.9**	11.1	15.0**	- -	3.6	60.7**	56.3**	3.7	114.3**	75.3**	3.4	26.8*	15.9-
112	14 × 22	11.3	31.9**	18.1**	11.7	44.5**	37.3**	11.0	23.2**	6.5-	3.8	66.0**	65.7**	4.3	167.7**	102.4**	3.3	11.7-	- -
113	1 × 23	10.8	20.7**	- -	11.3	23.4**	1.9-	10.3	17.9**	- -	4.0	60.6**	34.8**	4.5	123.1**	76.5**	3.5	21.0*	8.0
114	2 × 23	8.8	23.1**	19.0**	8.6	26.7**	18.4**	9.0	19.8**	6.3-	4.8	127.8**	117.6**	4.8	178.6**	144.4**	4.8	92.8**	89.6**
115	3 × 23	11.2	13.2**	- -	11.4	8.7*	- -	11.0	18.3**	- -	4.4	103.8**	90.3**	4.9	82.3**	25.7**	3.9	105.9**	53.8**
116	4 × 23	11.0	19.9**	- -	11.7	35.9**	17.4**	10.3	5.8-	- -	4.8	87.9**	54.2**	5.3	137.5**	77.0**	4.3	49.4**	33.0**
117	5 × 23	10.2	2.9-	- -	10.4	1.2-	- -	10.0	4.8-	- -	4.4	57.3**	22.0*	4.3	94.0**	45.6**	4.6	33.7**	5.9-
118	6 × 23	9.5	10.3*	- -	10.0	15.6**	- -	8.9	5.0-	- -	3.9	68.3**	48.6**	4.4	131.8**	88.9**	3.3	23.7*	15.9-
119	7 × 23	9.4	9.2*	- -	10.1	12.0*	- -	8.8	6.3-	- -	5.0	91.5**	55.1**	4.9	127.1**	71.7**	5.1	66.0**	41.7**
120	8 × 23	11.3	40.1**	22.6**	11.7	51.0**	41.7**	10.9	29.9**	7.1-	4.7	160.0**	132.8**	4.5	260.9**	203.4**	4.8	106.7**	91.6**
121	9 × 23	10.9	20.3**	- -	11.6	34.0**	15.4**	10.3	7.9*	- -	4.8	140.5**	139.9**	5.1	228.8**	213.6**	4.6	84.9**	80.1**
122	10 × 23	10.6	19.4**	- -	11.1	29.6**	12.3*	10.1	9.8*	- -	4.3	99.1**	86.0**	5.1	244.6**	244.3**	3.5	23.2*	11.4-
123	11 × 23	9.5	23.1**	11.7*	9.7	42.6**	33.6**	9.3	7.6-	- -	4.4	100.1**	83.6**	4.6	220.4**	212.8**	4.2	41.6**	23.7*

Appendix F. (Cont.)

Sl. No.	Hybrid[a]	GW (g)									GY(t ha^{-1})								
		P			R11			S12			P			R11			S12		
		Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP
124	12 × 23	9.3	3.7 -	- -	9.5	6.9 -	- -	9.1	0.6 -	- -	4.6	91.2 **	62.8 **	4.7	169.7 **	133.2 **	4.6	46.9 **	24.1 **
125	13 × 23	10.6	20.2 **	- -	11.3	32.7 **	15.5 **	10.0	8.6 *	- -	4.7	127.9 **	119.8 **	4.7	233.7 **	218.3 **	4.8	73.8 **	60.8 **
126	14 × 23	9.8	18.1 **	1.6 -	10.0	26.3 **	17.1 **	9.6	12.9 **	- -	4.1	90.8 **	78.8 **	4.2	229.2 **	184.8 **	4.0	32.3 **	13.9 -
127	1 × 24	11.3	25.5 **	2.7 -	11.8	28.0 **	6.3 -	10.8	22.1 **	- -	4.1	70.4 **	38.6 **	3.9	83.3 **	52.9 **	4.3	64.4 **	33.4 **
128	2 × 24	10.0	39.0 **	35.2 **	10.7	56.5 **	45.4 **	9.3	22.3 **	9.8 *	4.4	115.8 **	98.6 **	4.5	144.4 **	127.9 **	4.3	92.3 **	75.1 **
129	3 × 24	12.1	21.8 **	- -	13.2	24.8 **	- -	11.0	17.6 **	- -	4.2	101.9 **	81.8 **	4.6	64.2 **	17.8 *	3.8	133.7 **	89.6 **
130	4 × 24	11.2	21.8 **	- -	11.6	33.8 **	16.2 **	10.8	10.5 **	- -	4.5	81.9 **	44.8 **	4.9	108.6 **	63.0 **	4.1	58.1 **	28.0 **
131	5 × 24	11.4	14.1 **	- -	11.7	13.6 **	- -	11.0	14.0 **	- -	4.2	52.4 **	14.9 -	4.4	90.1 **	49.8 **	4.0	24.8 *	- -
132	6 × 24	10.1	17.5 **	- -	10.3	18.2 **	2.5 -	10.0	16.1 **	- -	4.5	103.4 **	73.7 **	4.5	125.3 **	94.0 **	4.5	85.5 **	57.2 **
133	7 × 24	10.5	20.6 **	1.2 -	11.1	22.2 **	3.0 -	9.9	18.1 **	- -	4.1	62.5 **	27.8 **	4.1	78.5 **	41.6 **	4.2	49.4 **	16.6 -
134	8 × 24	10.6	30.9 **	15.2 **	11.1	41.9 **	34.1 **	9.9	17.0 **	- -	2.3	31.4 *	21.9 -	2.1	54.6 **	23.2 -	2.5	20.6	16.3 -
135	9 × 24	11.9	30.4 **	5.9 -	12.4	42.3 **	23.3 **	11.4	18.9 **	- -	4.5	132.0 **	122.6 **	4.5	170.2 **	164.9 **	4.5	103.2 **	86.7 **
136	10 × 24	12.4	38.1 **	13.5 **	12.9	49.4 **	30.1 **	11.8	26.8 **	- -	4.5	118.9 **	97.3 **	4.8	202.0 **	182.9 **	4.3	67.7 **	37.6 **
137	11 × 24	9.6	23.8 **	13.0 *	10.2	49.1 **	38.8 **	9.0	3.1	- -	4.2	98.9 **	76.2 **	4.3	179.9 **	156.3 **	4.1	52.4 **	21.3 *
138	12 × 24	10.8	20.6 **	- -	11.4	27.4 **	8.4 -	10.3	13.1 **	- -	4.0	70.0 **	40.2 **	4.2	124.9 **	106.4 **	3.8	34.1 **	3.7 -
139	13 × 24	10.8	21.2 **	16.5 **	11.8	38.1 **	21.0 **	9.7	4.9	- -	3.5	75.0 **	62.6 **	3.4	122.0 **	98.8 **	3.6	46.4 **	22.7 *
140	14 × 24	10.7	28.3 **	10.9 *	11.2	41.3 **	31.8 **	10.1	18.1 **	- -	3.8	83.8 **	66.1 **	4.2	204.9 **	149.5 **	3.4	23.0 *	- -
141	1 × 25	12.1	25.4 **	10.1 *	13.1	33.5 **	18.0 **	11.1	17.0 **	2.0 -	4.1	46.4 **	39.1 **	4.6	85.3 **	80.1 **	3.6	18.5 *	13.0 -
142	2 × 25	10.7	36.2 **	28.8 **	10.7	44.5 **	25.6 **	10.7	28.8 **	25.7 **	3.6	48.2 **	35.4 **	3.8	74.3 **	58.4 **	3.4	27.1 *	16.7 -
143	3 × 25	11.3	6.5 -	- -	11.2	0.1 -	- -	11.4	13.7 **	- -	4.3	74.9 **	63.5 **	4.5	42.4 **	14.8 *	4.2	101.8 **	44.0 **
144	4 × 25	11.5	16.7 **	0.9 -	11.8	27.7 **	18.6 **	11.2	6.9 *	- -	3.7	29.7 **	20.0 *	4.4	61.6 **	45.0 **	3.1	1.8 -	- -
145	5 × 25	11.7	9.8 **	- -	11.9	8.5 *	- -	11.5	11.2 **	- -	2.7	15.6 -	- -	2.4	11.6 -	- -	3.0	18.5 *	- -
146	6 × 25	11.3	21.7 **	10.4 *	12.4	33.8 **	24.0 **	10.2	9.6 *	- -	4.1	56.4 **	55.1 **	4.6	94.2 **	92.1 **	3.7	25.6 *	24.9 *
147	7 × 25	10.6	14.1 **	3.0 -	11.2	16.1 **	4.2 -	10.1	12.0 **	1.7 -	3.7	24.7 *	13.7 -	3.4	27.9 **	17.0	4.0	22.1 *	11.0 -
148	8 × 25	12.4	42.0 **	35.0 **	12.9	53.2 **	50.8 **	12.0	31.6 **	18.2 **	3.7	75.6 **	40.1 **	4.2	150.0 **	77.5 **	3.2	26.0 *	9.5 -

Appendix F. (Cont.)

Sl. No.	Hybrid[a]	GW (g)									GY(t ha^{-1})								
		P			R11			S12			P			R11			S12		
		Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP
149	9 × 25	12.4	26.5 **	10.0 *	13.4	44.5 **	33.7 **	11.3	10.1 **	- -	4.2	80.2 **	58.3 **	5.1	154.4 **	113.7 **	3.3	24.2 *	13.0 -
150	10 × 25	12.7	32.3 **	16.6 **	13.2	43.2 **	33.3 **	12.2	22.1 **	2.7 -	4.6	85.6 **	73.4 **	4.5	133.3 **	88.8 **	4.7	55.2 **	50.0 **
151	11 × 25	11.4	35.5 **	34.1 **	12.1	62.6 **	41.6 **	10.7	14.0 **	0.3 -	4.6	83.5 **	74.5 **	5.0	163.3 **	109.1 **	4.3	35.5 **	26.2 **
152	12 × 25	10.8	12.4 **	- -	10.9	14.2 **	3.7 -	10.8	10.6 **	- -	4.3	55.8 **	50.6 **	4.3	95.2 **	80.3 **	4.3	29.5 **	16.3 -
153	13 × 25	12.3	28.4 **	13.7 **	13.0	41.4 **	32.4 **	11.6	16.4 **	- -	3.7	55.7 **	41.0 **	3.9	110.6 **	64.3 **	3.6	21.0 *	20.0 -
154	14 × 25	10.9	21.9 **	13.7 **	11.7	37.4 **	37.1 **	10.1	10.0 *	- -	3.4	37.8 **	28.3 *	3.5	103.6 **	47.6 **	3.3	2.4 -	- -
155	1 × 26	11.7	26.2 **	6.1 -	12.1	27.9 **	8.5 *	11.3	24.5 **	3.7 -	4.5	93.5 **	51.3 **	4.9	162.0 **	93.4 **	4.0	55.0 **	24.8 *
156	2 × 26	9.8	30.9 **	30.1 **	10.0	42.3 **	29.0 **	9.5	20.8 **	11.8 *	4.1	113.1 **	87.1 **	4.7	197.6 **	140.5 **	3.5	60.0 **	44.4 **
157	3 × 26	11.9	16.6 **	- -	12.6	17.2 **	- -	11.1	16.0 **	- -	4.2	109.9 **	80.6 **	4.9	90.6 **	24.8 **	3.5	116.0 **	76.6 **
158	4 × 26	12.0	26.9 **	5.1 -	12.6	42.1 **	26.3 **	11.4	13.5 **	- -	4.4	85.9 **	42.4 **	4.7	122.2 **	55.6 **	4.2	62.0 **	30.2 **
159	5 × 26	11.2	9.8 *	- -	11.8	12.0 **	- -	10.7	7.6 *	- -	4.0	52.2 **	10.9 -	4.3	106.2 **	45.4 **	3.8	20.4 *	- -
160	6 × 26	12.2	37.9 **	19.5 **	12.4	39.2 **	23.5 **	12.1	36.6 **	15.7 **	3.8	75.6 **	43.6 **	4.0	123.1 **	69.0 **	3.6	46.5 **	23.1 *
161	7 × 26	11.6	30.7 **	12.8 **	12.5	35.4 **	16.6 **	10.8	25.6 **	8.6 *	4.5	83.9 **	39.3 **	4.7	128.0 **	61.7 **	4.3	56.5 **	21.3 *
162	8 × 26	12.5	49.7 **	35.7 **	12.8	60.2 **	55.2 **	12.2	40.0 **	19.9 **	4.0	147.9 **	141.9 **	3.6	229.7 **	202.3 **	4.4	113.3 **	103.7 **
163	9 × 26	12.9	38.0 **	15.1 **	13.7	53.9 **	36.4 **	12.2	23.7 **	- -	4.1	122.3 **	103.0 **	4.4	209.3 **	169.3 **	3.8	73.7 **	58.1 **
164	10 × 26	13.4	45.4 **	22.7 **	14.3	62.0 **	44.4 **	12.4	30.0 **	4.6 -	4.3	115.2 **	85.2 **	4.7	252.5 **	220.0 **	3.8	49.4 **	21.6 *
165	11 × 26	11.3	41.8 **	33.5 **	11.8	67.1 **	51.8 **	10.9	21.8 **	2.4 -	4.4	118.3 **	84.9 **	4.4	236.0 **	212.2 **	4.5	67.2 **	32.1 **
166	12 × 26	10.7	16.2 **	- -	11.3	23.5 **	7.5 -	10.2	9.1 *	- -	4.4	96.4 **	55.5 **	4.3	169.7 **	115.2 **	4.5	59.7 **	22.7 *
167	13 × 26	11.7	28.2 **	8.7 *	12.6	43.5 **	28.6 **	10.8	14.0 **	- -	3.1	61.0 **	42.6 **	3.0	138.2 **	126.4 **	3.1	26.2 *	4.9 -
168	14 × 26	10.8	26.1 **	12.2 *	11.2	37.8 **	31.8 **	10.4	17.8 **	0.2 -	4.5	129.9 **	98.4 **	4.8	321.1 **	298.6 **	4.3	56.5 **	22.2 *
169	1 × 27	13.0	36.9 **	18.3 **	13.8	40.7 **	24.4 **	12.2	32.8 **	12.1 **	3.7	70.7 **	26.4 *	4.1	116.9 **	62.8 **	3.3	38.9 **	3.3 -
170	2 × 27	10.7	38.9 **	33.6 **	10.8	44.8 **	25.7 **	10.7	33.5 **	25.5 **	3.3	84.0 **	51.4 **	3.5	117.1 **	79.0 **	3.2	57.5 **	29.3 *
171	3 × 27	12.9	23.9 **	0.6 -	13.4	19.7 **	- -	12.5	28.8 **	4.7 -	3.5	89.8 **	53.3 **	3.4	31.8 **	- -	3.7	160.4 **	133.9 **
172	4 × 27	12.8	32.1 **	12.5 **	14.2	53.4 **	42.5 **	11.5	12.7 **	- -	4.0	77.1 **	28.8 **	4.4	104.3 **	45.3 **	3.7	52.8 **	13.5 -
173	5 × 27	12.6	20.6 **	- -	13.7	25.1 **	2.8	11.6	15.7 **	- -	4.1	61.3 **	12.1 -	4.5	115.0 **	53.9 **	3.6	23.0 *	- -

Appendix F. (Cont.)

Sl. No.	Hybrid[a]	GW (g)									GY(t ha^{-1})								
		P			R11			S12			P			R11			S12		
		Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP	Mean	HMP	HBP
174	6 × 27	12.0	31.5 **	17.4 **	12.3	32.6 **	23.0 **	11.7	30.4 **	12.0 **	3.7	85.8 **	43.3 **	3.8	111.6 **	63.2 **	3.7	64.9 **	27.2 *
175	7 × 27	11.1	20.9 **	7.3 -	11.8	22.4 **	9.9 *	10.4	19.2 **	4.5 -	3.9	68.7 **	21.5 *	4.4	112.9 **	53.4 **	3.4	33.1 **	- -
176	8 × 27	13.2	52.9 **	43.0 **	13.2	57.2 **	54.6 **	13.1	48.8 **	29.2 **	3.5	135.0 **	122.9 **	3.7	228.9 **	194.6 **	3.3	77.7 **	53.4 **
177	9 × 27	12.3	28.2 **	9.9 *	12.8	37.6 **	27.4 **	11.9	19.4 **	- -	3.3	94.8 **	66.2 **	3.9	168.7 **	139.3 **	2.8	40.9 **	16.6 -
178	10 × 27	13.5	42.3 **	23.6 **	14.6	57.7 **	47.0 **	12.4	27.6 **	4.1 -	4.1	122.8 **	80.0 **	4.4	218.0 **	195.7 **	3.9	67.1 **	25.4 *
179	11 × 27	11.9	44.1 **	40.2 **	13.1	75.4 **	52.6 **	10.7	18.5 **	0.9 -	4.1	113.7 **	70.1 **	3.8	182.7 **	169.1 **	4.4	76.5 **	29.1 **
180	12 × 27	12.2	28.6 **	11.2 **	12.9	35.3 **	22.9 **	11.6	21.9 **	0.6 -	4.2	97.5 **	48.0 **	4.3	162.8 **	113.9 **	4.1	56.5 **	11.7 -
181	13 × 27	11.5	22.5 **	6.8 -	12.2	32.7 **	24.4 **	10.9	12.7 **	- -	3.4	88.0 **	55.9 **	3.1	136.7 **	130.7 **	3.6	60.0 **	22.3 *
182	14 × 27	11.0	25.1 **	14.8 **	10.7	25.3 **	25.0 **	11.4	27.4 **	9.8 *	3.1	66.4 **	34.8 *	2.8	141.2 **	122.8 **	3.3	31.8 **	- -
183	1 × 28	11.1	22.2 **	1.1 -	11.5	31.8 **	3.4	10.7	13.3 **	- -	4.1	62.7 **	40.4 **	4.3	123.2 **	68.2 **	4.0	29.2 **	24.6 *
184	2 × 28	9.5	30.4 **	28.6 **	9.1	44.1 **	43.7 **	9.9	20.0 **	16.9 **	3.5	63.7 **	61.5 **	3.9	141.0 **	99.6 **	3.2	17.7 -	6.9 -
185	3 × 28	9.6	4.5 -	- -	9.4	6.2 -	- -	9.7	2.8 -	- -	3.7	68.3 **	62.1 **	4.0	54.1 **	2.5 -	3.5	64.5 **	16.6 -
186	4 × 28	11.4	22.5 **	- -	11.9	45.8 **	19.2 **	10.9	4.2 -	- -	4.3	62.9 **	37.2 **	4.7	119.8 **	56.8 **	3.9	23.8 *	19.1 -
187	5 × 28	11.1	10.1 **	- -	11.3	14.8 **	- -	10.9	5.7 -	- -	4.3	48.2 **	17.7 *	4.6	119.9 **	58.0 **	3.9	6.8 -	- -
188	6 × 28	10.6	21.9 **	3.8 -	11.2	36.7 **	11.7 *	10.1	8.7 -	- -	4.3	79.1 **	62.8 **	4.5	150.9 **	94.3 **	4.0	34.9 **	32.6 **
189	7 × 28	10.7	21.8 **	3.3 -	11.0	28.9 **	2.5 -	10.3	15.0 **	4.2	4.3	60.8 **	33.7 **	4.7	128.1 **	64.9 **	3.9	18.1 *	8.5 -
190	8 × 28	11.7	43.2 **	27.5 **	12.3	67.8 **	48.2 **	11.2	23.4 **	10.7 *	3.0	62.8 **	41.6 **	3.0	163.4 **	134.8 **	3.0	18.1 -	1.7 -
191	9 × 28	12.2	32.0 **	8.3 *	12.0	46.2 **	19.3 **	12.4	20.7 **	- -	3.6	73.3 **	68.1 **	3.8	160.4 **	133.1 **	3.4	26.3 *	13.7 -
192	10 × 28	12.1	33.3 **	10.7 *	12.2	50.1 **	23.1 **	11.9	19.7 **	0.4	4.3	92.5 **	85.6 **	4.4	222.3 **	201.2 **	4.1	34.0 **	31.1 **
193	11 × 28	10.3	30.9 **	20.9 **	10.5	66.1 **	66.1 **	10.0	7.0 -	- -	3.7	62.8 **	54.1 **	4.5	236.1 **	221.7 **	2.9	10.2 -	- -
194	12 × 28	10.0	9.8 *	- -	9.8	16.3 **	- -	10.2	4.2 -	- -	4.3	73.4 **	51.8 **	4.7	184.4 **	132.5 **	3.9	18.3 *	7.4 -
195	13 × 28	11.8	31.0 **	9.2 *	12.2	51.8 **	25.0 **	11.3	14.0 **	- -	3.5	63.8 **	63.2 **	3.4	156.1 **	150.9 **	3.7	23.2 *	22.7 *
196	14 × 28	10.0	19.3 **	4.3 -	10.3	38.7 **	21.0 **	9.8	6.1 -	- -	3.4	52.8 **	47.8 **	3.7	214.5 **	189.1 **	3.1	5.9 -	- -
SE (mean, HMP, HBP)		0.4	0.4	0.5	0.4	0.5	0.5	0.3	0.4	0.5	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.4
Min		8.8	1.5	0.2	8.6	0.1	0.1	8.8	0.2	0.2	2.3	15.6	2.3	2.1	11.6	2.5	2.5	0.3	0.3
Max		14.3	59.5	47	15.5	82.8	67.1	13.7	48.8	29.2	5.0	160.0	141.9	5.4	321.1	298.6	5.1	160.4	133.9
Mean		11.8	22.9	15	12.3	33.3	25.2	11.3	14.0	8.4	4.0	71.9	54.3	4.2	122.2	90.4	3.9	42.6	30.1

[a]1-28 -ID of inbred lines detailed in the table 3.2.; SE-Standard error; *, **, Significant at the 0.05, 0.01 probability levels, respectively; P- Pooled across environments; R11-2011 rainy season; S12-2012 summer season.

Appendix G. Performance of pearl millet hybrids in set-A for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW) and grain yield (GY) at different environments, 2012 rainy season

Hybrid	Fe (mg kg^{-1})				Zn (mg kg^{-1})				GW (g)				GY (t ha^{-1})			
	E1	E2	E3	AA	E1	E2	E3	AA	E1	E2	E3	AA	E1	E2	E3	AA
1	53	50	54	52	31	30	20	27	18	12	13	14	4.2	2.78	3.19	3.37
2	43	45	54	47	26	32	22	27	15	9	11	12	3.6	2.17	2.56	2.78
3	49	36	51	45	28	28	21	25	17	12	13	14	3.4	2.58	3.96	3.32
4	56	53	72	60	30	35	21	29	18	10	14	14	2.7	1.20	2.20	2.02
5	52	52	58	54	30	34	23	29	18	15	15	16	4.1	2.15	3.55	3.25
6	56	43	48	49	31	38	20	29	18	11	11	14	3.4	3.27	3.33	3.35
7	61	57	73	64	34	37	25	32	19	14	14	16	3.0	3.61	4.15	3.59
8	55	48	58	54	26	32	18	26	16	13	11	14	3.3	2.66	3.13	3.04
9	46	47	54	49	31	35	23	29	16	16	14	15	4.3	2.48	3.56	3.44
10	42	43	52	46	24	33	20	26	14	10	11	12	3.7	2.92	3.83	3.48
11	38	42	58	46	33	33	22	29	14	11	11	12	4.0	3.82	4.00	3.94
12	48	45	53	49	32	41	25	32	15	11	11	12	3.8	3.59	3.72	3.70
13	55	38	55	49	32	32	24	29	19	15	15	17	3.8	3.11	3.92	3.60
14	56	42	73	57	29	31	28	29	16	16	11	14	3.9	3.16	2.80	3.30
15	58	57	66	60	30	33	22	28	13	9	10	11	3.0	2.49	3.28	2.92
16	54	38	52	48	28	31	18	26	17	12	11	13	3.4	2.11	3.04	2.86
17	53	38	57	49	29	28	19	25	17	12	12	14	3.5	2.36	2.26	2.72
18	56	47	58	54	37	37	22	32	17	13	12	14	3.6	3.03	3.23	3.27
19	59	53	65	59	29	36	23	29	17	11	11	13	3.7	2.67	3.27	3.21
20	63	50	64	59	36	37	24	33	20	11	13	15	2.7	1.11	2.71	2.18
21	52	53	61	55	28	36	18	27	15	13	12	13	3.4	2.40	2.56	2.77
22	60	47	59	55	30	38	22	30	16	11	11	12	3.4	1.75	2.81	2.65
23	56	60	65	60	32	37	21	30	17	12	12	14	2.9	2.47	3.50	2.97
24	58	58	64	60	33	46	24	34	19	15	13	15	2.9	2.06	2.98	2.64
25	63	50	84	66	31	39	25	31	18	13	13	15	3.1	2.46	3.43	2.98
26	75	60	64	66	34	42	22	33	15	11	10	12	3.4	1.80	2.71	2.65
27	64	49	71	61	34	35	23	31	20	14	15	16	2.7	1.60	3.17	2.50
28	55	49	67	57	33	40	23	32	14	11	10	12	3.3	1.76	2.71	2.59
29	60	59	66	62	33	34	21	29	15	12	11	13	3.8	2.99	3.75	3.50
30	65	66	71	67	34	45	21	33	14	10	10	11	3.2	1.31	2.92	2.48
31	61	57	74	64	29	34	23	29	20	13	15	16	3.3	1.12	2.68	2.37
32	50	42	56	49	28	27	20	25	17	11	13	13	3.0	2.28	3.88	3.04
SE±	2.3	3.4	2.9	2.0	1.8	3.0	0.9	1.5	0.7	0.7	0.6	0.5	0.2	0.2	0.3	0.2
Min	38	36	48	45	24	27	18	25	13	9	10	11	2.6	1.11	1.76	2.01
Max	75	66	84	67	37	46	28	34	20	16	15	17	5.0	4.75	5.08	4.95
Mean	55	49	62	55	31	35	22	29	17	12	12	14	3.5	2.49	3.28	3.08

E1- Patancheru; E2-Ahmedabad; E3-Aligarh; AA-Across the environments of hybrid set-A

Appendix H. Performance of pearl millet hybrids in set-A for days to 50% flowering (DF), plant height (PH), panicle length (PL) and effective number of tillers (ET) at different environments, 2012 rainy season

Hybrid	DF (d)				PH (cm)				PL (cm)				ET (no.)			
	E1	E2	E3	AA	E1	E2	E3	AA	E1	E2	E3	AA	E1	E2	E3	AA
1	44	47	43	45	187	193	186	189	21	19	22	21	1.34	1.25	1.28	1.29
2	44	50	47	47	163	183	190	179	18	15	20	18	2.07	1.46	1.52	1.69
3	40	45	44	43	182	203	208	198	20	23	23	22	1.71	1.39	1.44	1.51
4	37	43	42	40	155	170	180	168	16	17	19	17	1.57	1.22	1.35	1.38
5	43	47	45	40	177	222	212	203	17	19	21	19	1.45	1.33	1.35	1.38
6	42	46	44	44	162	200	178	180	18	19	22	20	1.57	1.27	1.39	1.41
7	42	51	49	47	182	233	223	213	17	21	22	20	1.49	1.16	1.36	1.34
8	44	48	47	46	165	203	199	189	19	22	26	22	1.49	1.18	1.16	1.28
9	46	53	48	49	187	225	226	213	21	23	23	22	1.14	0.91	1.06	1.04
10	44	47	48	46	182	228	219	210	19	24	23	22	1.60	1.36	1.41	1.46
11	45	57	51	51	182	252	234	223	18	22	21	20	2.00	1.21	1.44	1.55
12	44	52	50	49	177	233	234	215	20	23	25	22	1.29	1.16	1.39	1.28
13	44	52	48	48	197	240	222	220	19	23	23	22	1.41	1.05	1.18	1.21
14	46	58	54	53	188	252	238	226	19	21	26	22	1.19	0.97	1.02	1.06
15	42	47	45	45	180	222	220	207	20	22	25	22	1.36	1.09	1.49	1.31
16	41	51	48	47	182	215	195	197	18	24	24	22	1.13	0.96	1.13	1.07
17	44	52	48	48	187	222	218	209	19	23	24	22	1.34	0.92	1.05	1.10
18	42	50	46	46	178	223	196	199	19	22	23	21	1.45	1.26	1.30	1.34
19	43	50	48	47	188	220	212	207	17	21	21	20	1.42	1.01	1.15	1.19
20	40	45	42	42	163	177	186	175	16	20	21	19	1.57	1.24	1.28	1.36
21	42	48	42	44	173	222	183	193	19	18	19	19	1.32	1.34	1.32	1.33
22	40	44	43	42	177	197	206	193	17	24	24	22	1.70	1.29	1.47	1.49
23	42	48	44	44	175	210	182	189	17	20	20	19	1.41	1.34	1.54	1.43
24	40	46	43	43	165	200	197	187	17	22	23	21	1.80	1.24	1.36	1.47
25	40	48	46	45	177	232	223	210	17	22	25	21	1.69	1.32	1.39	1.47
26	40	45	43	43	183	203	197	195	20	20	23	21	1.47	1.42	1.33	1.40
27	39	46	43	43	175	217	209	200	18	21	25	21	2.07	1.22	1.26	1.52
28	40	44	42	42	167	167	178	170	18	18	20	19	1.53	1.58	1.44	1.52
29	42	49	46	46	175	212	196	194	20	22	24	22	1.42	1.23	1.33	1.32
30	40	40	40	40	190	163	178	177	17	16	21	18	1.22	1.50	1.03	1.25
31	39	42	39	40	165	160	163	163	17	20	20	19	1.97	1.63	1.49	1.70
32	38	44	42	42	173	197	199	190	21	22	24	22	1.59	1.24	1.36	1.40
SE±	0.5	0.5	0.8	0.4	5.7	8.1	4.0	4.4	0.8	0.9	0.8	0.6	0.1	0.1	0.1	0.1
Min	37	40	39	40	155	160	163	163	16	15	19	17	1.13	0.91	1.02	1.04
Max	46	58	54	53	197	252	238	226	21	24	26	22	2.07	1.63	1.54	1.70
Mean	42	48	45	45	177	209	203	196	18	21	23	21	1.53	1.24	1.31	1.36

E1- Patancheru; E2- Ahmedabad; E3- Aligarh; AA- Across the environments of hybrid set-A

Appendix I. Performance of pearl millet hybrids in set-B for grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW) and grain yield (GY) at different environments, 2012 rainy season

Hybrid	Fe (mg kg^{-1})				Zn (mg kg^{-1})				GW (g)				GY (t ha^{-1})			
	E1	E4	E5	AB	E1	E4	E5	AB	E1	E4	E5	AB	E1	E4	E5	AB
1	70	73	65	69	37	39	38	38	13	12	12	12	3.01	4.33	3.50	3.61
2	64	72	60	65	39	40	39	39	17	17	16	17	2.62	4.67	4.33	3.87
3	60	70	74	68	33	39	52	41	15	14	15	15	3.46	3.98	2.93	3.46
4	67	78	68	71	38	43	39	40	16	17	17	17	3.35	4.52	4.08	3.98
5	62	70	66	66	34	44	50	43	13	14	12	13	3.74	5.78	3.67	4.40
6	61	73	59	65	33	44	39	39	20	16	15	17	3.44	5.03	3.57	4.01
7	58	76	56	63	29	38	39	35	15	11	14	13	3.47	3.10	2.90	3.15
8	56	71	57	61	30	38	38	36	18	18	16	17	4.27	4.75	4.12	4.38
9	54	61	57	58	33	40	42	38	18	17	16	17	3.26	4.22	3.84	3.77
10	59	73	67	66	32	44	45	40	17	17	17	17	3.10	3.86	3.89	3.61
11	48	68	50	55	30	37	38	35	18	16	13	15	3.69	5.27	3.82	4.26
12	56	80	60	65	34	45	42	40	20	17	15	17	4.20	5.20	4.22	4.54
13	55	88	62	68	32	41	39	37	15	16	13	15	3.63	5.66	3.34	4.21
14	64	72	62	66	34	48	44	42	18	17	16	17	3.46	4.27	3.88	3.87
15	73	89	70	76	32	48	42	41	13	13	13	13	2.75	2.35	4.02	3.04
16	59	75	63	65	35	41	41	39	17	14	14	15	3.88	4.36	3.36	3.87
17	59	70	65	65	38	40	43	40	19	17	15	17	3.53	3.77	2.75	3.35
18	69	84	66	73	39	45	49	44	19	18	16	18	3.72	5.06	4.34	4.37
19	63	69	66	66	33	40	45	39	15	15	14	15	3.35	4.38	4.05	3.92
20	70	85	69	75	28	39	39	35	14	13	13	13	3.71	4.39	3.36	3.82
21	56	79	58	64	28	37	37	34	14	12	12	13	3.19	3.71	3.59	3.50
22	54	83	65	67	29	47	40	39	17	19	13	17	3.48	4.96	3.76	4.07
23	46	62	51	53	25	39	41	35	17	19	16	17	3.67	5.44	3.66	4.26
24	53	61	60	58	25	35	35	32	11	12	12	12	4.08	5.73	3.87	4.56
25	47	49	33	44	32	33	32	32	18	16	14	16	4.57	5.13	3.73	4.48
26	56	70	57	61	30	41	41	37	15	15	11	14	4.22	4.57	3.34	4.04
27	56	70	65	64	26	37	40	34	12	12	12	12	3.02	5.62	4.37	4.34
28	55	76	54	62	28	42	36	36	13	13	11	12	3.60	6.03	4.29	4.64
SE±	2.6	3.8	4.3	2.6	1.6	2.6	2.5	1.6	0.9	0.9	1.1	0.7	0.2	0.3	0.3	0.2
Min	46	49	33	44	25	33	32	32	11	11	11	12	2.62	2.35	2.75	3.04
Max	73	89	74	76	39	48	52	44	20	19	17	18	4.57	6.03	4.37	4.64
Mean	59	73	61	64	32	41	41	38	16	15	14	15	3.55	4.65	3.73	3.98

E1- Patancheru; E4- Aurangabad; E5- Dhule; AB- Across the environments of hybrid set-B

Appendix J. Performance of pearl millet hybrids in set-B for days to 50% flowering (DF), plant height (PH), panicle length (PL) and effective number of tillers (ET) at different environments, 2012 rainy season

Hybrid	DF (d)				PH (cm)				PL (cm)				ET (no.)			
	E1	E4	E5	AB	E1	E4	E5	AB	E1	E4	E5	AB	E1	E4	E5	AB
1	43	52	48	47	195	203	225	208	22	23	25	23	1.23	1.41	1.15	1.27
2	44	53	51	50	182	240	248	223	20	23	22	22	0.83	1.29	1.23	1.12
3	43	52	48	48	185	221	233	213	20	24	24	23	1.27	1.33	1.13	1.24
4	44	52	49	48	195	250	253	233	19	24	25	23	1.07	1.25	1.23	1.18
5	45	54	52	50	185	225	234	215	29	32	33	31	1.27	1.62	1.20	1.36
6	42	50	47	46	192	219	223	211	20	26	25	23	1.23	2.01	1.20	1.48
7	42	52	46	47	190	207	207	201	21	24	23	23	1.07	1.04	1.21	1.11
8	43	50	48	47	188	222	233	214	21	24	24	23	1.17	1.49	1.22	1.29
9	41	49	46	45	178	200	226	201	20	24	24	23	1.40	2.08	1.38	1.62
10	42	51	47	47	188	221	243	217	19	22	23	21	1.17	1.27	1.23	1.22
11	48	54	53	52	185	232	222	213	29	31	29	30	1.27	1.30	1.26	1.28
12	45	52	48	48	203	222	231	219	24	26	26	26	1.03	1.35	1.28	1.22
13	45	54	50	50	187	246	251	228	24	26	27	26	1.17	1.28	1.19	1.21
14	38	48	44	43	173	210	231	205	16	20	23	20	1.83	2.35	1.44	1.87
15	39	48	44	44	172	182	205	186	18	20	21	20	1.33	1.61	1.47	1.47
16	44	52	52	50	203	243	257	234	20	23	24	22	1.10	1.33	1.23	1.22
17	42	50	47	46	192	230	240	221	16	20	20	19	1.40	1.88	1.14	1.47
18	42	51	49	47	200	232	260	231	20	21	23	21	1.53	1.63	1.17	1.44
19	41	50	47	46	178	199	212	196	20	23	24	22	1.23	1.67	1.11	1.34
20	42	52	49	48	177	200	209	195	20	24	24	22	1.27	1.41	1.30	1.32
21	42	50	46	46	177	198	208	194	21	25	25	24	1.23	1.18	1.08	1.17
22	45	53	49	49	185	227	224	212	23	28	30	27	1.10	1.25	1.17	1.17
23	45	52	48	48	188	225	223	212	28	29	28	29	1.27	1.49	1.35	1.37
24	46	55	49	50	188	251	242	227	22	25	24	24	1.20	1.33	1.18	1.24
25	44	52	48	48	207	223	247	226	27	28	28	28	1.20	1.56	1.34	1.36
26	43	52	48	48	193	203	221	206	22	24	23	23	1.13	1.36	1.20	1.23
27	46	54	53	51	195	233	242	223	22	25	24	24	1.17	1.19	1.22	1.19
28	48	55	52	52	190	228	241	220	22	27	26	25	1.20	1.28	1.24	1.24
SE±	0.4	0.8	0.9	0.5	5.2	4.2	0.8	3.9	1.2	0.9	1.0	0.7	0.1	0.2	0.1	0.1
Min	38	48	44	43	172	182	205	186	16	20	20	19	0.83	1.04	1.08	1.11
Max	48	55	53	52	207	251	260	234	29	32	33	31	1.83	2.35	1.47	1.87
Mean	43	52	49	48	188	221	232	214	22	25	25	24	1.23	1.47	1.23	1.31

E1- Patancheru; E4- Aurangabad; E5- Dhule; AB- Across the environments of hybrid set-B

Appendix K. Grain iron (Fe) and zinc (Zn) densities, 1000-grain weight (GW) and days to 50% flowering (DF) among NCD-1 progenies of ICTP 8203 and ICMV 221, 2012 rainy and 2013 summer seasons, Patancheru

Top cross	Fe (mg kg^{-1})						Zn (mg kg^{-1})						GW (g)						DF (d)					
	ICTP 8203			ICMV 221			ICTP 8203			ICMV 221			ICTP 8203			ICMV 221			ICTP 8203			ICMV 221		
	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13
P 1	61.9	66.4	57.4	57.1	52.8	61.3	45.7	39.2	52.2	45.0	28.2	61.9	19.2	21.3	17.1	14.7	14.4	15.0	40	40	39	42	41	42
P 2	57.3	59.0	55.5	53.2	50.7	55.8	42.2	33.5	51.0	42.8	33.9	51.8	18.0	19.2	16.7	15.8	16.9	14.7	41	39	42	43	41	44
P 3	61.9	65.2	58.5	56.1	52.7	59.5	43.5	36.0	51.0	44.9	32.4	57.3	20.4	22.3	18.5	16.7	18.2	15.2	42	41	42	43	41	44
P 4	49.0	44.2	52.1	44.3	42.0	46.7	38.5	30.8	46.2	37.5	26.4	48.7	18.6	19.9	17.3	14.9	15.5	14.4	40	40	40	42	41	43
P 5	54.0	56.7	51.2	44.9	47.5	42.4	40.9	35.8	45.9	35.3	26.2	44.4	15.5	15.7	15.3	15.1	16.0	14.1	39	41	37	43	42	43
P 6	58.7	57.8	59.7	50.1	52.9	47.2	44.3	35.0	53.6	35.8	26.3	45.3	16.7	17.3	16.1	14.6	15.3	13.9	42	41	44	41	40	41
P 7	59.7	62.1	58.2	45.9	47.0	44.8	44.5	36.8	52.2	36.8	27.1	46.5	17.1	18.3	15.9	13.0	13.7	12.4	41	41	41	43	42	44
P 8	58.1	56.1	59.4	59.5	60.7	58.2	51.0	44.1	58.0	45.1	33.5	56.7	17.2	18.6	15.9	15.5	17.4	13.6	44	44	44	44	42	45
P 9	50.4	51.9	49.0	46.9	44.0	49.8	39.2	31.1	47.2	37.5	28.2	46.8	17.9	18.8	16.9	15.8	17.0	14.6	42	42	41	43	41	44
P 10	55.8	53.2	58.4	52.5	48.8	56.2	41.1	33.9	48.3	38.9	26.7	51.0	16.0	16.3	15.7	17.7	18.6	16.7	42	42	42	41	41	41
P 11	56.5	57.8	55.1	53.1	51.9	54.4	41.6	33.1	50.1	43.3	29.6	57.0	18.0	18.2	17.8	16.1	16.1	16.2	42	43	42	41	42	41
P 12	48.7	52.7	44.8	53.0	46.3	59.7	38.5	31.8	45.1	38.3	27.3	49.3	17.7	19.3	16.1	14.2	15.2	13.1	43	41	45	43	41	45
P 13	58.9	63.1	54.7	55.0	52.4	57.6	41.7	35.6	47.8	42.2	30.8	53.6	17.4	18.5	16.2	15.1	16.0	14.3	41	41	41	42	42	41
P 14	62.5	60.2	64.7	58.5	58.4	58.7	46.3	37.3	55.2	47.5	37.3	57.8	16.6	16.7	16.5	17.9	18.9	16.9	42	42	42	40	40	41
P 15	53.9	54.0	53.8	47.4	49.3	45.5	40.9	33.3	48.5	38.6	28.2	49.1	15.7	16.1	15.3	16.4	17.7	15.1	41	42	40	42	41	43
P 16	69.1	73.7	64.6	51.4	50.2	52.7	47.5	41.6	53.3	40.1	28.6	51.6	17.7	18.3	17.2	18.0	19.2	16.8	44	44	43	41	39	43
P 17	56.1	57.1	55.1	56.1	53.8	58.4	38.3	30.0	46.5	34.1	26.1	42.2	15.2	17.4	13.0	16.1	16.9	15.3	40	40	40	43	41	44
P 18	52.7	56.5	48.8	50.3	47.8	52.9	37.0	29.9	44.0	35.7	28.2	43.2	16.9	18.4	15.4	15.5	16.8	14.2	42	42	42	42	42	42
P 19	57.7	60.6	54.7	47.5	46.3	48.8	38.6	29.9	47.2	31.3	24.8	37.8	16.3	17.9	14.7	15.9	17.4	14.3	41	40	41	41	41	41
P 20	57.0	57.3	56.8	46.6	44.2	49.1	41.1	32.4	49.8	34.5	26.3	42.8	17.3	18.8	15.9	17.5	18.3	16.6	41	41	42	40	40	40
P 21	54.9	57.6	52.2	49.1	47.1	51.1	39.4	32.2	46.6	39.5	32.7	46.4	17.7	18.7	16.7	13.6	15.2	11.9	40	41	39	40	40	40
P 22	56.9	61.7	52.0	53.6	54.0	53.2	45.9	39.8	52.0	38.5	28.6	48.5	19.1	20.1	18.0	15.7	16.5	14.8	40	42	38	40	39	41

Appendix K. (Cont.)

Top cross	Fe (mg kg^{-1})						Zn (mg kg^{-1})						GW (g)						DF (d)					
	ICTP 8203			ICMV 221			ICTP 8203			ICMV 221			ICTP 8203			ICMV 221			ICTP 8203			ICMV 221		
	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13
P 23	55.7	56.2	55.2	54.9	48.1	61.7	45.1	37.5	52.6	42.6	29.4	55.7	18.4	19.4	17.3	13.5	13.7	13.4	42	42	41	41	40	42
P 24	50.6	52.9	48.4	50.4	51.8	48.9	42.1	35.6	48.6	40.5	31.6	49.4	19.0	20.0	18.0	15.1	16.3	13.8	41	42	39	41	40	43
P 25	53.9	59.2	48.5	64.3	59.7	69.0	43.8	37.9	49.8	41.0	29.9	52.1	15.6	16.4	14.9	16.7	17.7	15.7	41	42	41	44	41	46
P 26	57.5	57.4	57.5	49.2	50.2	48.5	41.9	35.5	51.6	32.5	25.9	39.1	17.4	18.2	16.1	14.7	13.8	15.5	41	41	41	42	41	43
P 27	48.7	50.5	46.8	59.6	62.8	54.7	40.6	34.5	46.6	37.2	29.9	48.2	15.6	16.1	15.1	16.3	18.9	13.8	42	42	41	42	40	43
P 28	57.9	61.4	54.4	66.7	64.4	69.1	46.4	36.1	56.7	42.3	32.1	52.4	16.4	17.2	15.6	14.3	15.7	12.9	41	42	41	42	41	42
P 29	63.0	61.7	64.3	55.6	55.8	55.5	46.1	36.0	56.2	40.8	31.6	50.0	15.0	14.6	15.5	16.8	17.2	16.3	41	41	41	42	41	44
P 30	58.0	59.4	56.5	55.4	52.9	58.0	45.9	36.8	55.1	43.2	33.5	52.8	14.1	13.9	14.4	17.1	18.0	16.2	44	43	44	44	43	45
P 31	62.5	66.0	59.1	51.4	46.1	56.6	44.9	37.5	52.3	45.4	33.9	56.9	18.1	19.8	16.4	15.5	17.3	13.7	42	42	41	43	41	45
P 32	49.8	48.9	50.6	48.4	49.4	47.5	42.2	33.2	51.3	39.2	30.5	47.9	16.1	17.8	14.4	15.7	16.4	15.1	43	43	42	41	40	43
P 33	54.4	57.1	52.6	58.3	54.0	62.5	40.0	32.4	47.7	46.3	34.1	58.4	16.3	17.7	14.8	16.8	18.5	15.1	39	39	39	42	41	42
P 34	59.6	67.2	52.1	52.3	52.4	52.3	41.0	32.8	49.3	40.4	29.4	51.3	17.0	18.2	15.8	16.3	16.3	16.4	41	39	42	42	41	42
P 35	55.0	57.3	52.7	60.4	56.9	63.9	40.2	30.8	49.5	45.2	34.5	56.0	16.0	17.7	14.3	18.4	18.5	18.3	40	40	40	39	40	39
P 36	56.4	55.5	57.4	58.8	61.3	56.4	38.5	26.4	50.6	46.6	37.1	56.1	16.0	17.1	14.9	16.1	17.0	15.1	43	43	42	41	41	40
P 37	58.7	60.3	57.2	54.8	48.8	60.8	45.8	33.8	57.9	40.2	29.2	51.1	17.0	18.8	15.3	14.4	15.3	13.5	42	42	41	43	42	44
P 38	60.3	61.9	58.6	50.5	48.9	52.1	46.6	35.1	58.2	38.5	28.7	48.3	17.6	18.5	16.8	16.5	17.8	15.2	43	43	42	40	41	39
P 39	59.3	58.3	60.4	51.6	52.0	51.2	46.2	35.6	56.9	37.8	30.8	44.8	17.4	18.4	16.5	15.2	16.2	14.2	40	40	41	41	40	41
P 40	54.0	52.0	56.0	45.3	45.8	44.8	42.6	27.5	57.6	32.5	25.6	39.4	15.1	16.7	13.5	13.6	14.5	12.7	41	41	41	42	42	42
P 41	64.0	65.7	62.3	48.7	47.0	50.4	45.8	35.6	56.1	42.1	33.2	51.0	15.5	16.1	15.0	17.3	18.5	16.0	40	38	41	40	40	40
P 42	59.8	60.1	59.4	44.2	46.2	42.1	37.9	30.0	45.8	40.4	31.2	49.6	15.4	16.2	14.5	16.0	17.1	15.0	40	39	41	40	40	40
P 43	63.4	58.7	68.1	50.2	50.8	49.5	46.8	32.8	60.8	39.7	31.0	48.5	16.1	16.9	15.2	15.6	16.7	14.5	42	40	44	39	39	39
P 44	66.4	64.5	68.2	43.1	42.3	43.9	43.4	32.4	54.5	37.1	29.1	45.2	15.2	16.9	13.5	15.9	16.6	15.2	42	42	41	40	39	40
P 45	69.0	70.6	67.4	47.5	43.3	51.7	45.2	32.5	57.9	36.6	23.7	49.4	16.5	18.0	15.0	15.5	17.0	14.0	43	43	42	39	38	39
P 46	70.4	69.4	71.5	56.5	54.2	58.1	45.7	33.2	58.1	38.2	28.7	47.7	15.7	17.4	14.1	13.5	13.3	13.7	42	41	42	41	40	41

Appendix K. (Cont.)

Top cross	Fe (mg kg^{-1})						Zn (mg kg^{-1})						GW (g)						DF (d)					
	ICTP 8203			ICMV 221			ICTP 8203			ICMV 221			ICTP 8203			ICMV 221			ICTP 8203			ICMV 221		
	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13
P 47	64.4	62.7	66.1	57.6	56.8	58.4	46.2	35.5	57.0	40.2	29.7	50.7	14.0	15.5	12.4	14.6	15.7	13.6	41	41	41	41	41	41
P 48	73.8	71.7	75.9	47.3	41.2	53.4	50.3	37.1	63.5	38.0	26.8	49.2	16.0	17.3	14.8	14.9	15.1	14.6	40	39	41	42	42	41
P 49	63.5	63.7	63.2	54.5	48.6	60.4	43.6	31.1	56.2	45.3	35.0	55.6	15.8	13.9	17.7	14.5	15.4	13.6	42	44	40	39	40	39
P 50	59.0	59.7	58.3	59.9	70.6	52.7	43.0	34.9	51.1	41.5	30.6	52.5	17.8	18.5	17.1	14.8	15.4	14.2	41	42	40	40	40	40
P 51	60.1	57.5	64.0	47.1	47.6	46.6	40.1	30.4	54.8	36.7	29.4	44.1	18.3	19.3	17.3	14.1	14.3	13.9	43	44	41	41	41	40
P 52	59.4	54.0	64.8	44.5	41.5	47.5	42.5	30.7	54.3	39.1	30.4	47.9	16.4	16.9	15.8	15.3	16.1	14.6	41	43	38	41	42	40
P 53	59.4	60.8	57.9	59.9	55.4	64.4	42.9	33.2	52.5	39.0	29.2	48.7	17.1	19.0	15.2	16.9	17.5	16.3	41	42	39	41	41	40
P 54	52.8	46.1	57.3	60.5	57.2	63.7	47.0	33.0	61.0	40.8	30.9	50.7	16.9	17.8	16.1	19.0	20.5	17.6	42	40	44	41	41	40
P 55	62.4	62.6	62.3	47.5	44.2	50.8	45.4	37.0	53.8	34.3	26.7	41.9	17.8	18.5	17.1	15.0	16.2	13.7	42	43	41	42	43	42
P 56	60.1	61.5	59.2	54.9	54.5	55.3	42.6	32.6	52.6	37.8	27.8	47.8	18.1	18.6	17.6	17.7	18.9	16.6	41	41	40	40	40	40
P 57	60.9	62.2	59.6	57.9	56.0	59.9	41.5	30.7	52.3	43.3	31.3	55.3	14.9	15.2	14.7	15.0	15.7	14.3	44	46	41	41	41	41
P 58	70.0	68.3	71.7	61.8	64.2	59.3	45.5	32.5	58.4	45.5	34.6	56.4	17.6	19.5	15.8	15.4	16.6	14.1	41	41	40	43	42	43
P 59	65.1	67.7	62.5	56.2	51.5	60.8	45.1	34.2	55.9	41.3	27.9	54.8	17.0	18.3	15.8	14.9	15.8	13.9	41	41	41	42	41	42
P 60	71.6	68.8	74.4	64.8	68.7	60.8	45.9	33.3	58.5	40.8	30.9	50.7	16.6	19.1	14.1	15.6	16.2	15.1	42	42	41	39	39	39
P 61	45.8	45.8	45.7	58.9	57.4	60.4	37.5	30.5	44.5	41.4	29.0	53.8	16.7	17.4	16.1	14.9	16.0	13.8	41	41	41	40	40	39
P 62	58.4	54.0	62.9	56.4	57.9	54.9	44.1	31.6	56.6	39.3	27.7	51.0	16.6	17.6	15.7	14.1	14.8	13.5	42	42	42	41	41	41
P 63	54.3	53.4	55.2	48.2	44.7	51.6	41.2	31.6	50.8	35.3	23.3	47.2	16.7	18.3	15.0	15.6	17.3	13.9	41	42	40	40	40	40
P 64	55.7	59.1	53.5	52.7	50.9	54.6	41.1	31.3	50.9	36.0	26.9	45.0	16.4	17.2	15.7	15.4	15.6	15.3	42	43	41	41	41	41
P 65	54.7	56.1	53.3	49.7	51.2	48.3	45.2	36.5	53.8	35.9	29.6	42.3	16.0	17.2	14.7	16.1	17.4	14.9	41	41	40	41	41	41
P 66	64.2	63.9	64.4	51.8	46.4	57.3	49.0	39.8	58.3	38.3	26.9	49.7	16.3	17.7	14.8	14.7	15.8	13.5	41	41	41	41	40	42
P 67	54.3	55.6	52.9	54.1	55.9	52.9	46.1	40.5	54.6	38.1	30.6	43.1	16.1	16.3	15.8	13.9	14.6	13.2	40	40	40	44	43	45
P 68	69.8	70.8	68.9	47.2	44.6	49.7	49.8	39.6	59.9	36.7	27.4	45.9	15.4	16.7	14.1	16.3	17.7	14.9	42	42	41	41	40	41
P 69	62.8	64.3	61.4	54.3	54.0	54.6	42.9	35.4	50.3	40.7	31.3	50.0	19.0	19.7	18.4	13.6	13.8	13.4	41	42	39	42	42	43
P 70	65.1	62.9	67.3	61.4	61.4	61.3	43.4	33.9	52.9	42.6	35.8	49.3	17.6	19.3	15.9	16.5	17.9	15.2	40	40	40	42	41	43

Appendix K. (Cont.)

Top cross	Fe (mg kg^{-1})						Zn (mg kg^{-1})						GW (g)						DF (d)					
	ICTP 8203			ICMV 221			ICTP 8203			ICMV 221			ICTP 8203			ICMV 221			ICTP 8203			ICMV 221		
	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13
P 71	66.5	70.7	62.4	54.0	49.9	58.0	45.2	37.8	52.6	40.4	30.7	50.1	19.4	21.2	17.7	13.8	15.1	12.4	42	43	40	44	42	46
P 72	65.5	62.7	68.3	54.3	50.2	58.5	42.1	34.3	50.0	43.7	28.9	58.4	17.1	18.8	15.3	13.6	13.5	13.7	43	44	43	44	44	44
P 73	50.9	49.5	52.2	62.3	57.2	67.4	40.5	31.3	49.6	41.7	26.1	57.3	17.1	19.0	15.1	13.6	14.2	12.9	42	42	42	41	41	41
P 74	44.0	44.8	43.3	51.5	55.4	47.7	34.6	28.1	41.1	34.0	27.3	40.7	15.9	16.1	15.7	13.1	12.6	13.6	40	40	41	40	39	41
P 75	61.7	59.5	64.0	53.9	58.3	49.4	49.1	36.5	61.8	38.1	31.4	44.8	16.8	18.9	14.7	13.5	12.7	14.4	42	42	41	40	40	40
P 76	52.4	54.3	50.6	61.5	58.2	64.8	45.1	34.8	55.3	46.4	32.3	60.4	18.1	19.9	16.3	14.4	15.4	13.4	42	43	42	41	41	42
P 77	55.7	55.1	56.3	55.4	59.2	51.6	45.4	36.5	54.3	40.9	36.0	45.8	16.0	17.3	14.8	13.5	14.6	12.4	40	40	41	42	42	41
P 78	70.3	70.5	70.2	52.3	51.8	52.8	50.2	39.1	61.3	34.9	29.5	43.1	16.3	17.5	15.1	13.5	14.3	12.8	41	41	41	41	40	42
P 79	56.6	60.9	52.3	51.6	51.0	52.1	41.2	34.2	48.2	38.4	29.5	47.4	15.1	16.0	14.3	14.7	15.1	14.3	42	42	42	42	41	43
P 80	59.0	56.5	61.6	52.7	49.9	55.5	46.6	36.0	57.3	37.7	26.0	49.4	15.6	16.4	14.9	15.9	17.4	14.4	43	42	43	42	40	43
P 81	49.9	46.5	53.2	52.6	48.1	57.1	42.0	32.0	52.1	41.4	30.5	52.4	16.2	16.8	15.6	14.4	15.4	13.4	41	41	40	41	41	41
P 82	51.4	50.1	52.8	50.7	48.0	53.4	42.5	34.0	51.1	38.7	26.1	51.2	17.1	18.1	16.0	15.9	17.1	14.6	42	41	43	42	42	41
P 83	50.8	48.6	53.0	50.2	48.1	52.3	42.0	31.2	52.8	41.5	29.1	54.0	17.7	18.3	17.1	15.6	16.8	14.5	41	42	40	41	41	40
P 84	56.2	52.4	60.0	46.1	45.5	46.7	42.0	31.7	52.3	40.0	32.4	47.5	16.9	18.3	15.6	15.1	16.6	13.6	43	43	42	42	41	42
P 85	52.2	50.2	54.1	51.2	49.1	53.2	42.3	34.0	50.5	36.3	28.1	44.5	17.4	17.7	17.1	14.4	15.2	13.7	41	41	41	41	41	40
P 86	48.9	47.3	50.5	48.5	45.8	51.3	39.7	31.5	48.0	36.3	28.0	44.6	15.7	17.0	14.5	15.9	17.7	14.2	42	42	42	42	42	42
P 87	52.3	52.1	52.5	50.3	42.6	57.9	42.6	34.3	50.8	38.3	27.7	48.9	15.5	16.0	14.9	15.0	16.0	14.1	42	42	42	41	42	41
P 88	63.4	61.4	65.3	56.5	59.5	53.5	47.7	34.3	61.0	38.0	30.4	45.6	16.8	18.2	15.3	14.1	15.1	13.2	43	43	44	44	44	44
P 89	55.4	53.5	57.3	46.5	43.4	49.7	46.9	35.1	58.7	38.7	26.6	50.9	18.3	18.7	18.0	15.2	15.9	14.4	43	42	44	43	44	42
P 90	55.0	51.5	58.5	41.8	41.1	42.5	47.3	36.5	58.0	35.1	29.5	40.8	18.0	19.3	16.8	14.8	15.4	14.2	42	42	42	43	44	42
P 91	57.3	54.5	60.1	43.2	39.4	47.0	47.9	37.9	57.8	38.6	26.5	50.7	18.5	18.8	18.2	14.7	15.3	14.1	44	44	43	43	42	43
P 92	54.1	47.6	60.6	46.2	45.1	47.4	48.5	34.9	62.1	38.2	28.5	47.9	17.2	18.1	16.4	16.9	17.8	16.0	45	46	44	42	42	41
P 93	55.4	54.6	56.3	42.8	37.8	47.9	45.5	32.6	58.3	38.4	25.6	51.3	16.2	17.0	15.3	16.1	17.3	15.0	43	42	44	41	41	41
P 94	57.0	60.1	53.9	45.9	45.1	46.8	48.0	39.0	57.1	40.5	30.3	50.8	15.4	15.9	14.9	13.9	14.8	12.9	41	40	43	45	44	47

Appendix K. (Cont.)

Top cross	Fe (mg kg^{-1})						Zn (mg kg^{-1})						GW (g)						DF (d)					
	ICTP 8203			ICMV 221			ICTP 8203			ICMV 221			ICTP 8203			ICMV 221			ICTP 8203			ICMV 221		
	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13
P 95	53.9	56.6	51.2	49.2	49.0	49.3	44.6	36.9	52.3	39.2	29.4	49.0	15.2	14.9	15.5	14.9	16.7	13.1	43	43	43	43	42	44
P 96	61.0	63.0	59.1	44.6	44.7	44.6	46.4	37.1	55.6	36.6	28.7	44.5	15.0	15.3	14.7	16.0	16.5	15.5	44	44	44	42	41	42
P 97	60.3	60.9	59.4	52.4	54.2	51.2	42.8	36.4	52.4	37.1	27.7	46.4	17.0	18.3	15.6	14.2	14.0	14.5	43	42	44	41	40	42
P 98	57.3	54.9	61.0	47.7	46.6	48.7	41.8	31.0	58.0	37.1	28.0	46.2	17.1	18.2	16.1	13.3	12.6	14.0	42	45	39	41	39	43
P 99	55.4	57.2	52.6	47.9	46.1	49.6	40.5	32.7	52.1	37.5	28.5	46.5	16.9	17.4	16.4	14.7	15.9	13.5	44	45	43	42	42	42
P 100	60.6	57.6	63.5	41.9	42.7	41.1	49.2	35.6	62.7	33.2	23.8	42.6	17.0	17.6	16.4	14.5	14.6	14.4	42	43	41	40	39	41
P 101	52.1	52.4	51.7	56.1	53.2	58.9	37.3	30.7	47.3	42.0	31.4	52.7	18.4	20.3	16.5	14.9	15.3	14.5	42	41	44	42	43	41
P 102	50.9	51.7	50.2	58.0	56.5	59.4	40.7	31.5	49.8	40.7	31.8	49.6	17.0	17.8	16.1	15.9	17.0	14.7	43	43	44	43	43	42
P 103	50.9	55.6	46.1	54.5	50.5	58.4	39.1	36.1	42.0	45.4	34.3	56.5	16.8	17.1	16.5	16.6	18.7	14.6	44	45	43	42	41	44
P 104	57.1	61.5	50.6	49.7	48.6	50.8	38.8	32.1	48.9	38.7	27.5	50.0	16.5	18.0	15.0	14.9	14.9	14.9	46	45	46	42	42	42
P 105	50.3	50.4	50.3	64.7	69.3	60.2	35.3	29.8	40.7	43.9	32.2	55.7	14.8	15.2	14.3	14.4	15.9	12.9	44	45	43	43	42	44
P 106	58.2	60.6	55.9	56.7	57.3	56.1	41.0	29.6	52.4	38.0	25.0	51.0	16.0	17.4	14.7	13.2	13.8	12.7	43	42	44	42	41	43
P 107	53.1	56.4	49.7	57.3	52.3	62.2	39.5	32.6	46.4	37.7	24.6	50.8	17.5	19.0	15.9	14.5	14.5	14.6	44	44	43	42	41	43
P 108	53.3	55.4	51.2	62.4	57.6	67.2	37.4	31.4	43.4	46.4	28.6	64.2	15.1	14.8	15.3	14.8	15.8	13.8	44	45	43	43	41	46
P 109	55.2	56.8	53.6	56.3	54.2	58.5	40.3	30.4	50.3	39.0	28.5	49.5	17.7	19.1	16.3	15.6	16.3	14.9	46	46	45	43	42	43
P 110	54.4	56.0	51.9	62.9	63.0	62.8	38.4	31.9	48.3	40.8	30.1	51.6	16.6	17.3	15.8	15.4	16.4	14.4	44	44	44	42	43	42
P 111	48.1	48.2	47.9	59.6	55.5	63.8	34.4	27.6	44.6	43.9	31.6	56.2	16.0	16.8	15.2	15.2	15.7	14.7	42	42	42	41	41	41
P 112	60.5	62.6	57.4	56.1	49.6	62.7	45.3	38.4	55.7	43.5	31.0	55.9	16.1	17.9	14.3	15.4	16.3	14.4	45	46	44	42	43	41
P 113	73.0	71.4	75.5	48.0	42.5	53.5	47.4	37.8	62.0	36.4	23.4	49.3	15.1	15.9	14.2	16.7	17.5	15.9	48	47	48	41	41	41
P 114	52.6	53.7	51.4	48.2	44.8	51.6	36.7	33.5	39.8	40.4	25.8	55.0	16.0	17.0	14.9	16.9	17.6	16.2	45	45	45	41	41	41
P 115	51.7	51.2	52.2	55.3	63.5	47.1	38.0	28.1	48.0	36.2	29.5	42.8	15.5	16.2	14.9	14.8	15.5	14.2	42	43	41	41	42	40
P 116	54.1	59.1	49.0	47.2	47.3	47.0	40.2	32.8	47.6	37.6	29.9	45.2	16.5	17.8	15.2	16.4	17.8	15.0	41	40	42	42	42	41
P 117	46.3	48.7	42.7	52.3	54.5	50.8	33.0	31.4	35.4	40.8	33.7	45.5	16.0	16.9	15.1	13.3	12.9	13.8	44	44	43	44	42	45
P 118	47.1	50.2	42.4	56.3	53.4	59.2	34.0	29.3	41.0	44.4	33.3	55.5	15.1	14.7	15.5	16.0	16.4	15.7	44	44	44	44	45	43

Appendix K. (Cont.)

Top cross	Fe (mg kg^{-1})						Zn (mg kg^{-1})						GW (g)						DF (d)					
	ICTP 8203			ICMV 221			ICTP 8203			ICMV 221			ICTP 8203			ICMV 221			ICTP 8203			ICMV 221		
	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13
P 119	48.7	51.7	45.7	51.9	50.7	53.0	38.5	31.1	45.9	39.3	30.4	48.1	17.7	18.7	16.7	16.3	16.8	15.8	42	43	41	42	42	42
P 120	54.3	57.5	51.1	54.3	47.8	58.7	40.4	33.2	47.7	46.5	30.5	62.6	15.7	16.7	14.7	14.9	13.5	16.3	44	44	44	41	42	41
P 121	51.1	53.6	48.6	56.6	57.0	56.2	42.2	34.2	50.2	44.3	31.9	56.6	18.6	20.0	17.2	14.0	13.6	14.4	41	41	42	44	42	46
P 122	51.1	49.2	53.9	51.4	45.0	57.9	38.2	31.8	47.8	34.6	23.7	45.6	17.5	19.1	15.9	15.9	15.6	16.2	41	41	42	43	41	44
P 123	52.5	51.8	53.2	51.5	47.6	55.4	40.4	32.4	48.3	40.3	27.6	53.0	17.0	17.1	17.0	14.6	14.5	14.8	43	42	43	42	42	41
P 124	53.8	59.0	48.7	55.0	52.4	57.7	40.4	34.2	46.6	40.6	28.5	52.8	17.0	18.5	15.5	14.1	13.7	14.6	42	41	43	41	40	41
P 125	55.0	59.4	50.5	59.6	53.6	65.7	42.3	33.4	51.3	38.1	23.5	52.6	13.8	14.5	13.1	15.0	15.0	15.1	41	42	41	45	43	46
P 126	59.0	55.5	62.5	53.2	53.2	53.2	45.7	32.9	58.5	34.0	23.8	44.2	15.5	15.6	15.3	14.8	15.3	14.3	41	41	40	45	44	45
P 127	63.3	69.3	54.4	44.8	41.3	48.3	41.8	34.2	53.2	35.8	25.0	46.7	17.6	19.9	15.3	13.4	14.1	12.7	41	41	41	43	42	44
P 128	60.7	58.0	63.3	49.0	49.5	48.6	46.3	35.4	57.3	37.1	28.1	46.0	17.1	18.1	16.1	14.4	15.0	13.8	43	43	43	41	41	41
P 129	61.3	64.2	58.3	38.3	35.9	40.7	42.2	33.4	50.9	32.6	23.5	41.7	16.8	18.0	15.6	14.0	14.1	13.9	41	41	41	43	41	45
P 130	53.9	52.6	55.2	38.5	34.1	42.8	40.1	28.8	51.4	31.5	22.5	40.5	17.3	18.9	15.8	15.4	16.4	14.5	42	43	42	43	42	43
P 131	52.0	53.0	50.9	41.6	38.3	44.9	37.6	29.7	45.4	35.4	26.0	44.8	16.2	17.1	15.3	12.9	14.3	11.6	40	41	39	42	41	43
P 132	61.5	62.6	60.3	47.9	41.6	54.2	42.1	30.8	53.4	40.5	27.7	53.2	17.5	19.5	15.4	13.7	13.8	13.6	42	43	42	43	41	44
P 133	59.3	52.7	69.1	54.1	43.7	64.4	40.3	30.4	55.1	40.7	25.5	56.0	16.2	17.0	15.3	14.8	15.4	14.1	45	43	47	43	43	42
P 134	60.1	51.8	65.6	56.5	56.3	56.8	43.4	36.1	50.8	40.4	29.8	51.1	15.7	16.0	15.5	14.4	15.7	13.1	45	45	44	41	42	40
P 135	65.8	64.7	66.9	47.1	53.5	40.6	49.3	35.2	63.4	40.5	33.1	47.8	15.7	16.8	14.5	13.1	13.3	13.0	44	45	43	47	46	48
P 136	62.3	63.2	61.4	46.4	45.5	47.2	45.5	35.3	55.7	37.5	26.3	48.7	15.0	15.7	14.3	15.2	15.7	14.7	45	45	45	43	42	44
P 137	59.9	67.2	52.6	53.6	51.0	56.2	42.6	37.2	48.1	39.9	32.6	47.1	13.7	14.5	12.8	15.0	15.7	14.2	46	46	46	42	42	43
P 138	59.8	59.1	61.0	43.3	40.2	46.3	41.6	30.9	57.6	34.4	27.2	41.5	14.0	15.4	12.6	14.4	15.1	13.7	47	47	47	40	40	40
P 139	61.6	64.2	57.8	52.4	49.4	55.4	42.1	34.3	53.9	38.2	28.8	47.5	19.0	20.7	17.3	14.0	14.2	13.7	43	43	43	42	41	42
P 140	69.5	69.5	69.5	52.5	44.1	60.9	47.8	37.1	63.8	40.6	31.4	49.7	18.6	20.2	17.1	14.3	15.2	13.5	43	43	42	45	43	46
P 141	59.6	56.2	63.1	50.8	42.6	59.0	43.3	31.7	54.8	39.4	24.4	54.4	15.5	16.6	14.4	13.4	14.3	12.6	40	39	40	41	41	40
P 142	52.1	51.9	52.4	56.9	51.7	62.1	36.3	29.7	42.9	42.6	30.0	55.2	15.2	16.5	13.8	15.4	15.7	15.0	43	42	44	41	40	42

Appendix K. (Cont.)

Top cross	Fe (mg kg^{-1})						Zn (mg kg^{-1})						GW (g)						DF (d)					
	ICTP 8203			ICMV 221			ICTP 8203			ICMV 221			ICTP 8203			ICMV 221			ICTP 8203			ICMV 221		
	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13	P	R12	S13
P 143	59.0	54.1	63.9	43.7	38.4	48.9	44.2	29.7	58.6	32.2	22.5	42.0	14.6	15.5	13.7	14.9	16.2	13.6	42	41	42	41	42	41
P 144	60.0	61.1	58.9	53.0	48.6	57.4	39.3	31.1	47.5	41.4	28.4	54.5	16.4	18.1	14.8	13.7	14.5	12.9	40	39	40	42	42	41
P 145	60.4	59.4	61.3	54.2	51.5	56.9	42.6	30.5	54.8	42.4	28.6	56.2	17.0	18.2	15.7	15.9	16.6	15.1	40	40	40	42	42	41
P 146	60.1	58.1	62.0	56.2	48.0	64.4	43.5	32.2	54.7	43.1	27.4	58.7	15.6	16.2	15.0	15.8	17.3	14.3	40	39	40	42	42	42
P 147	68.9	63.1	74.8	44.4	42.1	46.7	48.9	33.5	64.3	34.8	25.6	44.0	17.4	17.8	17.0	15.7	16.1	15.2	41	42	40	43	42	43
P 148	78.3	76.9	79.6	43.0	39.4	46.5	50.9	39.3	62.4	37.3	27.3	47.3	17.8	18.7	16.9	17.1	18.4	15.9	44	44	44	43	42	44
P 149	61.0	61.3	60.7	43.7	37.4	50.0	45.0	33.9	56.1	40.8	27.5	54.1	16.4	16.8	15.9	15.0	16.1	13.8	43	42	44	43	43	43
P 150	50.9	49.5	52.3	42.2	37.0	47.3	40.0	32.1	47.9	36.6	28.3	45.0	17.2	17.8	16.6	14.0	15.9	12.0	43	42	43	43	43	42
P 151	67.5	67.3	67.7	42.9	33.4	52.4	47.2	36.3	58.0	38.1	23.1	53.2	15.9	16.6	15.2	13.9	14.1	13.7	46	47	46	43	42	44
P 152	60.0	58.3	61.7	49.6	45.5	53.8	44.5	32.2	56.8	41.2	28.9	53.4	17.6	19.9	15.4	16.2	17.6	14.8	42	42	42	42	43	41
P 153	65.8	71.3	57.5	50.3	46.3	54.4	44.1	35.1	53.1	41.3	30.7	51.9	16.5	18.9	14.1	15.6	17.1	14.2	42	41	42	41	41	41
P 154	59.6	58.7	60.6	49.4	41.6	57.2	40.5	30.2	50.7	37.9	28.2	47.7	17.7	19.3	16.1	17.1	18.3	15.9	41	41	41	41	40	41
P 155	57.1	52.2	62.0	52.8	50.9	54.6	38.2	24.3	52.1	39.1	29.8	48.3	16.0	17.0	15.0	15.4	16.2	14.5	41	42	40	41	40	41
P 156	63.0	66.5	59.5	60.0	55.9	64.1	43.9	38.7	49.1	39.2	28.4	50.0	17.3	18.7	16.0	16.1	16.6	15.6	42	42	41	42	42	41
P 157	55.9	57.8	54.1	73.6	71.4	75.8	40.5	30.5	50.5	48.8	34.6	62.9	13.5	14.4	12.7	15.6	15.8	15.4	46	48	43	44	43	44
P 158	52.6	55.7	49.4	49.2	42.3	56.1	38.1	30.9	45.3	36.8	25.6	48.1	15.6	16.7	14.6	12.0	13.0	11.1	41	42	41	44	41	46
P 159	54.1	55.1	53.1	46.9	39.2	52.1	39.0	29.2	48.8	43.7	24.6	56.5	16.6	17.7	15.4	13.3	12.9	13.8	42	42	42	40	39	40
P 160	55.4	48.9	61.9	50.1	46.9	53.2	40.1	28.7	51.5	39.6	29.7	49.4	17.6	18.3	16.9	13.9	13.9	13.8	43	43	44	41	41	40
SE±	2.1	2.8	3.0	2.2	3.2	2.9	1.8	2.1	3.0	1.6	1.9	2.5	0.5	0.8	0.7	0.5	0.6	0.8	0.5	0.7	0.63	0.5	0.8	0.7
Min	44.0	44.2	42.4	38.3	33.4	40.6	33.0	24.3	35.4	31.3	22.5	37.8	13.5	13.9	12.4	12.0	12.6	11.1	39	38	37	39	38	39
Max	78.3	76.9	79.6	73.6	71.4	75.8	51.0	44.1	64.3	48.8	37.3	64.2	20.4	22.3	18.5	19.0	20.5	18.3	48	48	48	47	46	48
Mean	57.9	58.2	57.5	52.1	50.0	54.2	42.8	33.6	52.4	39.4	29.0	49.8	16.6	17.7	15.6	15.1	15.9	14.4	42	42	42	42	41	42

P- Pooled across environments; R12- 2012 rainy season; S13 - 2013 summer season ;