GENETICS OF GRAIN IRON AND ZINC CONCENTRATION IN PEARL MILLET (*Pennisetum glaucum* (L.) R. Br.)

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GENETICS OF GRAIN IRON AND ZINC CONCENTRATION IN PEARL MILLET (*Pennisetum glaucum* (L.) R. Br.)

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2011

This thesis dedicated

To

My mother, Amutha and my father, Mahalingam and

All those who spent their lives in research activities

for diminishing starvation from the world

"The road to regional health and life-long productivity cannot be passed without removing the obstacle of vitamin and mineral deficiency."

- Joseph Hunt,
Health and Nutrition Adviser,
Asian Development Bank.

CERTIFICATE

This is to certify that the thesis entitled "**GENETICS OF GRAIN IRON AND ZINC CONCENTRATION IN PEARL MILLET (*Pennisetum glaucum* (L.) R. Br.)** " submitted in part fulfilment of the requirements for the award of the degree of **Doctor of Philosophy (Agriculture) in Plant Breeding and Genetics** to the Tamil Nadu Agricultural University, Coimbatore is a record of *bonafide* research work carried out by **Mr. M.GOVINDARAJ** under my supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship or other similar titles or prizes and that the work has not been published in part or full in any scientific or popular journal or magazine.

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(M.GOVINDARAJ)

ABSTRACT

GENETICS OF GRAIN IRON AND ZINC CONCENTRATION IN PEARL MILLET (*Pennisetum glaucum* (L.) R. Br.)

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Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is an important staple crop for millions of poor rural households in the semi-arid tropics of Asia and Africa. Owing to its importance for addressing micronutrient malnutrition problem, especially iron (Fe) and zinc (Zn) concentration, considerable global efforts are under way to improve its Fe and Zn levels through genetic enhancement. Hence, this dissertation was aimed at investigating some of the factors that have direct bearing on breeding efficiency. These includes gene action, combining ability and heterosis for Fe and Zn, intra-population variance, efficiency of single plant selection, association of grain Fe and Zn concentration with grain yield and key agronomic traits (1000-grain mass and flowering), and response to recurrent selection.

In two sets of line x tester studies, parents were observed having a wide range of genetic variability for both grain Fe (34 -102 mg kg^{-1}) and Zn (34 - 84 mg kg^{-1}) concentration and this was also reflected in both sets of hybrids. over two season, ICMB 93222, ICMB 98222, 863 B, ICMB 95333, ICMB 96333 among seed parents (lines) and IPC 774, IPC 616, IPC 1650,

IPC 1178, IPC 536 and IPC 735 amongst pollen parents (testers) were found to have >60 mg kg^{-1} Fe and >55 mg kg^{-1} Zn concentration. All these inbreds are designated seed/pollinator parents in elite genetic backgrounds, indicating good scope for their effective use in hybrid and hybrid parents breeding.

The predictability ratio was around unity for all traits, revealing the predominance of *GCA* (additive) variance controlling these traits in both the sets. Highly significant positive correlation between mid-parent value and *per se* performance of hybrids further confirmed the predominant role of additive gene action for these traits. using both parameters (*per se* performance and positive significant *gca* effect), ICMB 93222, ICMB 98222, 863b, ICMB 91222, IPC 1650, IPC 843, IPC 774, IPC 1178, IPC 689 and IPC 735 were identified as good general combiners for grain Fe and Zn in hybrid breeding. similarly, 863 B x IPC 404 and ICMB 95333 x IPC 404 for both grain Fe and Zn, while ICMB 94111 x IPC 1178 and ICMB 89111 x IPC 843 for grain Zn had positive significant *sca* effects. Low level of heterosis over mid-parent for grain Fe and Zn, no hybrid with significant heterosis over better-parent, and largely additive genetic variances would imply that there would be little opportunity, to exploit heterosis for these traits. In fact, to breed hybrids with high Fe and Zn levels, these micronutrients will have to be incorporated in both parental lines.

Higher degree of positive and highly significant correlation between S_0 plants and their respective S_1 progenies both for grain Fe and Zn in all four populations indicated that individual plant performance for these micronutrients can be as effectively used for selection as the S_1 progeny performance. Highly significant positive correlation between Fe and Zn revealed good prospects of concurrent genetic improvement for both micronutrients. Recurrent selection for high grain Fe and Zn in two populations increased Fe concentration by 2.4% to 8.0% and Zn concentration by 5.4% to 7.9%. It also increased 1000-grain mass by 4.8% and 14.2%, changed flowering time from -2.3% to 0.8% and had no adverse effect on grain yield. This would indicate that selection for Fe and Zn concentration can be made without compromising on grain yield and other agronomic traits such as large seed size and earliness.

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CHAPTER 1

INTRODUCTION

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INTRODUCTION

The state shall regard the raising of the level of nutrition and the standard of living of its people and the improvement of public health as among its primary duties.

— *Article 47 of the Constitution of India (1960)*

Micronutrient malnutrition has been designated at the most serious challenge to humanity (Copenhagen Consensus, 2008) as two-third of the world's population is at risk of deficiency in one or more essential mineral elements (Cakmak, 2002; White and Broadley, 2009; Stein, 2010). The mineral elements most commonly lacking in human diets are iron (Fe) and zinc (Zn) (White and Broadley, 2009; Stein, 2010), which ranked fifth and sixth, respectively, among the top ten risk factors contributing to burden of disease (WHO, 2002). Malnutrition is particularly widespread in Asia, with about 70% of the undernourished people globally living in this region, predominantly in India and China. For example, 80% of the pregnant women, 52% of the non-pregnant women and 74% of the children (6-35 months) in India suffer from Fe deficiency-induced anaemia (IDA) (Chakravarty and Ghosh, 2000). Likewise, about 49% of the world population is at risk due to low Zn intake (International Zinc Association, 2000; FAO, 2003). The systematically collected information on the quantitative estimates of zinc deficiency is lacking in India (Bhan *et al.,* 2001). Another critical region of the world suffering from malnutrition is Sub-Saharan Africa with about 200 million people undernourished (Cakmak, 2002). The widespread deficiencies of Fe and Zn in developing countries are mostly due to monotonous consumption of cereal-based foods with low concentration and reduced bioavailability of Fe and Zn (Welch and Graham, 1999; Graham *et al*., 2001). In addition, these populations have also limited access to meat, fruits and vegetables, which are rich sources of micronutrients (Sandstead, 1991; Gibson, 1994). The recommended daily allowance (RDA) of both Fe and Zn is 12-15 mg for adults and 10 mg for children (FAO, 2003; ICMR, 2009). Both the minerals have health and clinical significance as these affect growth and development, and many physiological and neurophysiological functions (Sandstead, 1994).

Mineral-dense seeds produce more viable and vigorous seedlings and such plants are more efficient in mineral uptake as well as those improve disease resistance and agronomic characteristics (Rengel and Graham, 1995; Graham and Welch, 1996). Welch and Graham (2005) report that the improved seedling vigor is associated with the production of more and longer roots under micronutrient-deficient conditions, allowing seedlings to scavenge more soil volume for micronutrients and water early in growth, an advantage that can lead to improved yields compared to seeds with low micronutrient stores grown on the same soils. Additionally, greater stress-tolerance has been noticed in seedlings grown from micronutrient-dense seeds resulting in higher agricultural production (Welch, 1986; Cakmak, 2008).

In the past, food fortification, supplementation and dietary diversification have been used to address malnutrition; however, these approaches have had limited effect on reducing micronutrient deficiency in the developing countries, because of weak infrastructure and high recurring costs (Timmer, 2003). Biofortification (both agronomic and genetic) is another approach to increase the concentration and bioavailability of mineral elements in agricultural produce (Cakmak, 2004, 2008; Graham *et al*., 2007; Pfeiffer and McClafferty, 2007; Morris *et al*., 2008; White and Broadley, 2009). Agronomic biofortification refers to applying mineral element-rich fertilizer to overcome micronutrient deficiency as evidenced by cultivating wheat under large-tract of zinc-deficient soils in Turkey (Cakmak, 2008, 2009). The genetic biofortification refers to the development of mineral dense edible plant part by breeding (conventional or biotechnology) (Bouis *et al*., 2000; Bouis, 2002). Genetic biofortification is sustainable and cost-effective approach as no more recurring cost is involved once biofortified crop cultivars are developed and adapted for large-scale cultivation. The underlying assumption is that the produce from such biofortified crops will be readily and cheaply available even to population living in remote areas for consumption. Towards this end, CGIAR Challenge Program on "Biofortified Crops for Improved Human Nutrition" was initiated in 2004 with support from the Bill and Melinda Gates Foundation, the World Bank and USAID to improve the health of poor people by breeding staple food crops that are rich in iron, zinc and β-carotene (a precursor of vitamin A). Biofortification breeding under this program has already been initiated on rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), cassava (*Manihot esculenta* Crantz), sweet potato (*Ipomoea* *batatas* (L.) Lam.), common beans (*Phaseolus vulgaris* L.) and pearl millet (*Pennisetum glauccum* (L.) R. Br). This program is a multi-national, multi-sectoral, multi-disciplinary, multi-crop, multi-nutrient, and multi-partnered undertaking (Pfeiffer and McClafferty, 2007; Bouis and Islam, 2011).

Pearl millet has significant potential as a food, feed and fodder crop in subsistence farming in the semi-arid tropics. It has the ability to produce grains with high nutritive value even under hot, dry conditions on infertile soils of low water holding capacity, where other cereal crops fail (Hulse *et al.*, 1980; Khairwal and Yadav, 2005). Globally, pearl millet is cultivated on about 26 m ha, with India in South Asia and Nigeria, Niger, Burkina Faso and Mali in Sub-Saharan Africa as the major producers. For example, pearl millet acreage in India is about 9.3 m ha, with a production of 9.5 m t, and productivity of 1044 kg ha^{-1} (Rai *et al.,* 2009; AICPMIP, 2011). The major pearl millet states in India constitute Rajasthan, Maharashtra, Gujarat, Haryana, Uttar Pradesh, Karnataka, Madhya Pradesh, Tamil Nadu and Andhra Pradesh (Deshmukh *et al.,* 2010), with first five states accounting for more than 90% of pearl millet acreage in the country (AICPMIP, 2011).

Nutritionally, pearl millet is a richer source of dietary protein, fat, calcium, phosphorus, iron and zinc and essential amino acids in comparison to other cereals such as maize, rice, sorghum (*Sorghum bicolor* (L.) Moench) and wheat (Khairwal *et al*., 1999; Davis *et al*., 2003; Filardi *et al*., 2005; Deshmukh *et al*., 2010). The energy value of pearl millet grain is relatively higher compared to maize, wheat or sorghum (Hill and Hanna 1990). Pearl millet in India is largely consumed as staple food in Gujarat and Rajasthan, with the highest per capita consumption in the rural population of western Rajasthan (92 kg year^{-1}) followed dry areas of Gujarat (70 kg year^{-1}). The other pearl millet consuming regions include central, western and northern Maharashtra, Saurashtra region of Gujarat and northeastern Rajasthan. In these regions, pearl millet contributes to about 20 - 40% of the total energy and protein intake and 30 to 50% of the intake of Fe and Zn (Parthasarathy Rao *et al*., 2006). In spite of high consumption of pearl millet in Gujarat and Rajasthan, it is these two provinces that reportedly have high prevalence of anaemia among children (66%) and severe anaemia (up to 34%) among adolescent girls (www.harvestplus.org; Seshadri, 1998). This is probably due to lower bioavailability of Fe in pearl millet flour or inadequate quantity of Fe/Zn in the locally grown pearl millet cultivars to meet daily body requirement of Fe and Zn.

A few pearl millet studies provide preliminary insight into some of the factors influencing breeding efficiency for grain Fe and Zn density. For instance, evaluation of pearl millet germplasm and populations has shown substantial variation for seed Fe and Zn concentration (Jambunathan and Subramanian, 1988; Velu *et al*., 2007, 2008a, b). Positive and significant correlations between grain Fe and Zn (r = 0.66 to 0.85; Velu *et al.,* 2008a) shows that it is possible to make simultaneous improvement in grain Fe and Zn in pearl millet. Further, a positive but low to moderate correlation (r = 0.28 to 0.56) between grain Fe/Zn and 1000-grain mass, and no correlation between grain Fe/Zn and flowering and grain yield shows that it is possible to breed for grain Fe/Zn dense pearl millet into improved genetic back ground (Deosthale *et al*., 1971; Arulselvi, 2004; Velu *et al*., 2008a, Gupta *et al.,* 2009). A recent study in pearl millet revealed that grain Fe and Zn concentration are controlled by additive gene action (Velu *et al.,* 2011a).

HarvestPlus pearl millet biofortification program at ICRISAT aims at developing seed minerals (iron and zinc) dense pearl millet into agronomically improved genetic background. As a part of this program, the present study was undertaken with the following specific objectives:

- To estimate combining ability, gene effects and heterosis for grain Fe and Zn in pearl millet inbreds by using two sets of line × tester crosses.
- To estimate genetic components of variance of grain Fe and Zn in two different populations (AIMP 92901 and ICMR 312) using selfed (S_1) and half-sib progenies.
- To test the efficiency of single plant selection for grain Fe and Zn in four populations (ICTP 8203, JBV 3, AIMP 92901 and ICMR 312) and study the association between Fe, Zn, with agronomic traits.
- To assess the response of recurrent selection in two populations (AIMP 92901 and ICMR 312) for grain Fe and Zn concentration.

CHAPTER 2

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

2.1. Pearl millet area and production

Pearl millet (*Pennisetum glaucum* (L.) R. Br.), the 6th most important cereals worldwide, is cultivated on 26 million ha, mainly grown by millions of resource-poor and subsistence farmers in Asia and Africa (Rai *et al.,* 2009; Upadhyaya *et al.,* 2011) and accounting for ~95% of the production and acreage (Basavaraj *et al*., 2010). Pearl millet area in Africa is ~14 million ha with annul production of 10.5 million tones (Velu, 2006). The major production areas are in Nigeria, Niger, Burkina Faso, Chad, Mali, Mauritania and Senegal in the western Africa and Sudan and Uganda in the eastern Africa (www.cgiar.org). In Asia, pearl millet is mainly restricted to India although Myanmar, Pakistan and Yemen also produce small quantities (ICRISAT/FAO, 1996). India continues to be the single largest producer of pearl millet in the world (Basavaraj *et al*., 2010). It is the fourth most important food grain after rice, wheat and sorghum (Girase *et al.,* 2010), producing 9.5 m t from an area of 9.3 m ha, with per ha grain yield ~1.0 t. (AICPMIP, 2011). The major pearl millet growing states in India are Rajasthan, Maharashtra, Gujarat, Haryana, Uttar Pradesh, Karnataka, Madhya Pradesh, Tamil Nadu and Andhra Pradesh, with first five states accounting for more than 90% of pearl millet acreage in the country (AICPMIP, 2011). The recent trends indicate that pearl millet area in India has increased, although marginally (2%); however, total production and productivity has gone up by 7% and 19%, respectively (AICPMIP, 2011).

2.2. Pearl millet as a food, feed and nutraceutical crop

Pearl millet is the staple diet for farm households in the world’s poorest countries and among the poorest people. It supplies 80-90% of the calories for several millions of the poor people in the semi-arid tropics of world (Burton *et al.,* 1972). Over 50% pearl millet grain production in India is utilized for food purpose, while 20% is used for feed purpose (Velu *et al*., 2007). In rural areas of northwestern India (Rajasthan and Gujarat), pearl millet is an important cereal for human consumption (Parthasarathy Rao *et al*., 2006; Basavaraj *et al.*, 2010). The domestic consumption of pearl millet is rising steadily in Africa (Ajetomobi, 2008). For example, pearl millet represents ~75% of total cereal consumption in Niger and over 30% in most other countries in the Sahelian region. It is also important in Namibia (25%) and Uganda (20%) (ICRISAT/FAO, 1996).

Pearl millet stover constitutes a major component of ruminant ration in marginal production environments (Sharma and Shrikant, 2006). It is an excellent forage crop with low hydrocyanic acid and best annual summer grazing crop for livestock production (Hanna, 1996). The pearl millet pasture grazed rotationally by dairy cows provides total digestible nutrients in the range of 1400-2300 kg ha^{-1}, a quantity generally superior to that of Sudan grass and sorghum (Faires *et al*., 1941; Roark *et al*., 1952). In comparison to sorghum and maize, pearl miller grain offers an excellent alternative as feed for cattle and broilers, as it has higher feed conversion rates (Sullivan *et al*., 1990). Several reports indicate that pearl millet grain compares favorably with maize in poultry diets (French, 1948; Singh and Barsaul, 1976; Sharma *et al*., 1979; Stringhini and Franca, 1999). Lloyd (1964) observed that broilers fed on pearl millet rations were heavier and had better feed conversion than those fed on maize ration. Enhancing the productivity of pearl millet to keep pace with rapidity growing food and feed demand in the semi-arid tropics is a massive task requiring concerted efforts from national and international research (Rai and Anand Kumar, 1994).

The pearl millet grains have high biological food value (Rai *et al*., 1999). Nutritionally, the grains are rich source of protein (12%), fat (5%), carbohydrates (67%), high energy value (>360 Kcal 100^{-1} g), and high Ca, Fe and Zn compared to other cereals (Aykroyd, 1956; Maiti and Bidinger, 1981; Khairwal *et al.,* 1997; Abadalla *et al*., 1998; Rai *et al*., 1999; Devos *et al.,* 2006; Velu, 2006), and better amino acid profile (Chauhan *et al.,* 1986). Thus, pearl millet is the cheapest source not only for energy and protein but also for micronutrients such as Fe and Zn (Parthasarathy Rao *et al*., 2006). For instance, the cost of 100 g protein from pearl millet is Rs 5.4, which is less than half the cost for same amount from rice (Rs. 14.60) and pulses (Rs. 12.10) (Parthasarathy Rao *et al*., 2006). Pearl millet is thus more nutritious than other cereals, and it should not be branded as poor’s man crop (AICPMIP, 2011). Hence, pearl millet serves as staple food, feed and nutraceuticals crop for the poorest of the poor people.

2.3. Micronutrient deficiency and human health

2.3.1. Essentiality of iron and zinc in human physiology

Each essential element has a specific role in the metabolism and one cannot be replaced by any other element. The human body requires iron (Fe) for the synthesis of the oxygen transport proteins (such as haemoglobin and myoglobin), for the formation of haem and other enzymes particularly important for energy production, for immune defense and thyroid function (Roeser, 1986; Zhang *et al.,* 2004), and for cytochrome system which is important in the derivation of energy from cellular respiration (Tuman and Doisy, 1978). The food-based Fe includes non-haem Fe (present in both plant and animal foods) and haem-Fe (mainly from haemoglobin and myoglobin in animal products). Haem Fe represents 30-70% of the total Fe in meat and is well absorbed. However, people in many poorer regions of the world consume little animal foods, and mostly rely on non-haem Fe. Inadequate Fe absorption will lead to the mobilization of storage Fe and insufficient Fe transport to the bone marrow and finally it lowers the haemoglobin level which ultimately causes anaemia (Tuman and Doisy, 1978).

Zinc (Zn) acts as a stabilizer of the structures of membranes, cellular components and for detoxification of highly aggressive free radicals (Cakmak, 2000). Its biochemical function is essential for synthesis and degradation of carbohydrates, lipids, proteins and nucleic acids (Rosell and Ulrich, 1964) as well as receptor proteins for steroid and thyroid hormones and vitamins A and D (Bender and Bender, 1999). It is required for virtually all aspects of cellular metabolism (Ruz, 2003) and plays a major role in gene expression (Sandstrom, 1997), almost 40 per cent of the Zn-binding proteins are needed for gene regulation and 60% enzymes and proteins are involved in ion transport (Andreini *et al*., 2006). These biochemical functions of Zn give it a unique role for growth and development; therefore it is obvious that insufficient Zn in the diet will have adverse health consequences (Solomons, 2003).

2.3.2. Iron, zinc deficiency and consequences to human health

Today, people consume diets that are less diverse than 30 years ago, leading to deficiencies in micronutrients, especially Fe and Zn. About three billion people suffer from micronutrient malnutrition (Welch and Graham, 2004), predominantly in South and Southeast Asia and sub-Saharan Africa (Reddy *et al*., 2005). For example, WHO estimates indicate that 10.8 million child deaths occur globally every year due to Fe, Zn, and vitamin A deficiencies (WHO, 2002). The Fe and Zn deficiencies are most prevalent in the developing countries, where 50% of population is at risk factor for low Fe and Zn intake and anaemic condition (DeMaeyer and Adiels-Tegman 1985; Lucca *et al*., 2001; Welch, 2002; Cichy *et al.,* 2005).

Iron deficiency-induced anaemia (IDA) is widespread in India and is common in children and more so in women because of blood losses that occur during menstruation and child birth (Singh, 2009). For instance, substantial populations from Rajasthan and Gujarat have severe IDA (www.harvestplus.org; Seshadri, 1998). IDA can decrease mental and physiological development in children (Lozoff and Brittenham, 1986; Lozoff *et al.,* 1991; Pollitt, 1993), increase both morbidity and mortality of mother and child at childbirth, decrease work performance, decrease resistance to infection, impair cognitive skills and physical activity (Scrimshaw, 1984; Hercberg *et al.,* 1987; Welch, 2002).

Zinc deficiency alone is a major cause of child death in the world, and responsible for nearly 450,000 children deaths (4.4% of the children deaths per year globally) under 5 years of age (Black *et al*., 2008). The Zn deficiency in human will result in a number of cellular disturbances and impairments such as immune dysfunctions and high susceptibility to infectious diseases, retardation of mental development, altered reproductive biology, gastrointestinal problems and stunted growth of children (Prasad, 1996; Solomons, 2003; Black *et al*., 2008). Zn deficiency can also contribute to Vitamin A deficiency, since lack of Zn impairs the synthesis of retinol binding protein (Bender and Bender, 1999).

The disability-adjusted life year (DALY) is a measure of overall disease burden, expressed as the number of years lost due to ill-health, disability or early death. Fe deficiency results in ~2.4% of global DALYs, whereas Zn deficiency results in ~1.9% of global DALYs (WHO, 2002, Ezzati *et al*., 2002). Worldwide, Zn deficiency is responsible for ~16% of infections of respiratory tract, 18% of malaria and 10% of diarrheal diseases (Were *et al*, 2010). The annual burden of Fe and Zn in India is estimated to be 4.0 million and 2.8 million DALYs, respectively. Fe biofortification of wheat and rice may reduce this burden by 19-58%, saving 0.8-2.3 million DALYs each year. Likewise, Zn biofortification of these crops may reduce the burden by 16-55%, saving 0.5-1.6 million DALYs each year in India (Stein *et al.,* 2007).

The intake of Fe and Zn appears to be below the recommended dietary allowance for an average Indian adult (ICMR, 2002), particularly in low income rural households in pearl millet consuming regions such as Rajasthan, Gujarat, Haryana and Maharashtra (Parthasarathy Rao *et al.*, 2006). This is probably due to predominant use of pearl millet as staple food high in grain phytate rendering Fe/Zn less bioavailable or because of inadequate quantity of Fe/Zn consumed through locally grown pearl millets, not sufficient to meet daily body requirement of Fe and Zn. In these regions, pearl millet is the predominant source of micronutrients (Fe and Zn), and it contributes 30 to 50% of Fe and Zn (Parthasarathy Rao *et al.*, 2006). This indicates that doubling the Fe and Zn density of food staples could increase total intake of these minerals by ≥ 50% (Ruel and Bouis, 1998).

2.4. Linkage between poverty and micronutrient malnutrition

Poverty and malnutrition are closely related in that the direct effects of poverty results in low income, limited education, poor sanitation, malnutrition and illness (WHO/SEARO, 2000; Pena and Bacallao, 2002; Haseen, 2004). The number of undernourished people in the world has dramatically increased, largely due to higher food prices (FAO, 2008; McClafferty, 2009).

Poor people are caught in a vicious cycle of poverty that breeds ill-health and keeps poor people as poor, which lead to malnutrition (Wagstaff, 2002; Weinberger, 2002, Haddad *et al.*, 2003). Malnutrition dis-empowers individuals by causing or aggravating infection, diminishing livelihood skills (ACC/SCN, 2004) and depleting family savings (Pena and Bacallao, 2002). Thus, family welfare is significantly dependent on health, nutritional status, and physical and intellectual capacity of the adults. Though malnutrition is a complex social and public health problem, knowledge of these factors may help facilitate implementation of health interventions along with other poverty reduction indicators designed to reduce malnutrition in resource poor inhabitants. Substantially large numbers of poor people live in South Asia. Incidence of poverty is relatively higher, in terms of percentage of people living below poverty, in Sub-Saharan Africa (46 %) than South Asia (40 %) (Navaneetham and Sunny Jose, 2005). However, the total number of poor and malnourished people is higher in South Asia. In order to relieve malnutrition and poverty, government must continue taking active role in the affairs of its citizens. Thus, reducing malnutrition is essential to reducing poverty. The developed nations and private sectors need to lend their support to eliminate malnutrition in the developing countries. India is a country historically plagued by malnutrition, where 26 % of people lie below poverty line, and low dietary intake due to poverty and low purchasing power largely contribute to severe malnutrition in India (Tenth Five Year Plan, Govt. of India). Micronutrient deficiencies alone may cost India US $2.5 billion annually (Gragnolati *et al.*, 2005) and that the productivity loss of almost 3% of GDP (Horton, 1999). Malnutrition therefore remains a serious problem in India and other developing countries, which is not only a consequence of poverty but also a cause of poverty (IFPRI, 2011).

2.5. Importance of iron and zinc in plant nutrition

Singh (2009) reported that 49% soils in India are deficient in available Zn and 12 % in available Fe. The application of Zn is reported to increase cereals yields by 6.3% – 9.3% and pulses yields by 12.5% – 48.2% (Singh, 2010). Fe deficiency is only second in importance after zinc in India (Nayyar *et al.*, 2001), with largest deficiency in provinces of Haryana (26%), Tamil Nadu (18%), Punjab (12%), Gujarat and Uttar Pradesh (8 to 9%) (Singh, 2009).

Fe is one of the 16 essential elements needed for plant growth, and the most common nutrient limiting plant growth (Guerinot, 2001). It is used for the synthesis of chlorophyll and is essential for the function of chloroplasts (Abadia, 1992). Iron deficiency in plants is manifested as interveinal chlorosis on new leaves (Acquaah, 2002). Zinc is an essential micronutrient required for growth and development of the higher plants (Kochian, 1993; Marschner, 1995), and is involved in membrane integrity, enzyme activation, and gene expression (Kim *et al.*, 2002). It promotes biosynthesis of growth hormone, the formation of starch, and grain production and maturation (Brady and Weil, 2002). Plants deficient in Zn have reduced leaf size and shortened internodes. The impact of micronutrient deficiency in crop production is well documented (Shukla *et al.*, 2009) and yield losses could reach as high as 100% due to omission of micronutrients in cropping system (Katyal and Vlek, 1985). Therefore, balanced micronutrient fertilization to soil and thereby its higher levels in grain and feeds is very much desired to reduce malnutrition in animals and humans (Singh *et al.*, 2009a).

2.6. Micronutrient bioavailability

2.6.1. Bioavailability in plant foods

Bioavailability is defined as the amount of a nutrient available for absorption from a meal and utilizable for metabolic processes in the body (Welch and Graham, 2004).

Increasing the concentration of micronutrients in plant foods is the first step in making these foods richer sources of micronutrients for humans. The next question to ask is how much of the available micronutrient in the food is bioavailable through absorption to the humans. A number of factors unrelated to the characteristics of the foodstuff may influence bioavailability. These include the previous intake of the nutrient, the body status of the nutrient, gut transit time, and gastrointestinal function (King, 2002). Plant genotypes differ not only in grain micronutrient concentration but also in anti-nutrients and promoters in their grains (Cakmak and Marschner, 1986; Marschner, 1995; Torun *et al*., 2001; Khoshgoftarmanesh *et al*., 2007). Anti-nutrients interfere with the absorption or utilization of nutrients in human intestine (Gibson *et al*., 2000). Some common antinutrients in staple foods are phytin (phytic acid), tannins (polyphenols), oxalic acid, fiber, hemagglutinins (lectins) and heavy metals (Cd, Hg, Pb, Ag). Phytate and polyphenols found in vegetarian diets inhibit non-heme Fe absorption. Thus, absorption of both Fe and Zn is lower in vegetarian than non-vegetarian diets. Certain organic acids (such as ascorbate, fumarate, malate and citrate), amino acids (methionine, cystine, histidine and lysine), palmitic fatty acid, phytoferritin (Fe-storage protein), and carotene (provitamin A carotenoids) are reported to enhance the bioavailability and absorption of non-heme Fe (Craig, 1994; Ruel and Bouis, 1997; Welch, 2002; Muminjanov *et al*., 2007). These compounds are normal plant metabolites and only small changes in their concentration may have significant effects on the bioavailability of micronutrients. Therefore, it is highly recommended that plant breeders and molecular biologists closely scrutinize the strategy of increasing promoter substances in food crops when attempting to improve food crops as sources of micronutrients for people (Welch, 1993).

The *in vitro* study revealed that phytate degradation enhanced Fe and Zn of whole pearl millet flour (Lestienne *et al.*, 2005a, 2005b). The bioavailability of non-heme Fe improves when molar ratios of ascorbic acid to iron are 0.8:1 and maximum at 1.6:1 (Glahn *et al*., 1999). However, ascorbic acid has not been shown to influence the bioavailability of Zn (Gibson *et al*., 2000). Phytate/Zn molar ratio in foods is a good predictor of Zn bioavailability (IZiNCG, 2004; Gargari *et al*., 2007; Hassan *et al.,* 2011). However, when diets those are high in phytate and calcium, phytate × calcium/zinc molar ratio is a better indicator of Zn bioavailability (Bindra *et al.,* 1986; Fordyce *et al.,* 1987; Gibson *et al.,* 1991).

Bioavailability studies are expensive in human. Several animals' models (rats, pigs and poultry) have been used to assess bioavailability of nutrients in foods (King, 2002). However, results may not be applicable in human due to differences in gastrointestinal function. The pig model is more acceptable because the gastrointestinal function of pig closely parallels that of humans (King, 2002). Studies on rats have shown that diets supplemented with amino acids increased the absorption of Zn from an initial 64% to 69% with lysine, 82% with methionine, and 86% with both amino acids (House *et al*., 1996). Studies on human showed that cysteine had a positive effect on Zn absorption (Snedeker and Greger, 1981, 1983; Martinez-Torres and Layrisse, 1970). Lutein, zeaxanthin and β- carotene increase Fe absorption in human from maize or wheat based diet. Food preparation techniques have potential to significantly impact on bioavailability of micronutrients (Gibson and Hotz, 2001; Hotz *et al*., 2001). Furthermore, the fermentation, germination or soaking cereal grains before cooking improve the bioavailability of Fe and Zn (King, 2002).

Phytic acid and fiber are major mineral inhibitors in cereals. Phytic acid forms insoluble complexes by chelating minerals and proteins; as a result the bioavailability of micronutrients is decreased (Sandberg *et al*., 1999). Mechanical processing, such as milling and polishing and enzymatic degradation of inhibitors could help remove phytic acid and fiber (Resurreccion *et al.,* 1979; Gibson *et al*., 2000). Loss of phytic acid during milling was about 70% in rice (Tabekhia and Luh, 1979). However, this option is not helpful in improving mineral status, because most nutrients are lost during milling. Archana *et al.* (1998) reported that blanching of pearl millet significantly reduces phytic acids (38%) in grains. Malting of pearl millet reduces more phytic acid (46 to 50%) than blanching. Therefore, the inhibitory effect of phytate should be taken into account when assessing Fe and Zn deficiencies.

2.6.2. Bioavailability in soils

Plants require small amount of micronutrients that significantly impact crop production (Yang *et al*., 2007). The soils have a number of chemical and physical factors which reduce solubility and availability of Fe and Zn in soils. Among the soil factors, high pH, low soil moisture, and low organic matter are the most critical factors reducing solubility and absorption of micronutrients (Tisdale *et al*., 1993; Marschner, 1995). Zinc is the most common micronutrient deficiency, particularly in high-pH soils (Graham *et al*., 1992; White and Zasoski, 1999; Cakmak, 2002, 2004;

Alloway, 2004). For example, an increase in soil pH from 6 to 7 is responsible for about 30-fold decrease in solubility of Zn in soil, which, in turn, significantly decreases concentration of Zn in plant. Similar impairment in root absorption of soil Zn has been reported with limited moisture and low organic matters (Cakmak, 2009).

The bioavailability of Fe in calcareous soils results in moderate to severe Fe deficiency, which is more pronounced under moisture stressed conditions (Singh, 2008) or even at low temperature (Guruprasad *et al.,* 2009). Further, soil microbial activity plays an important role in favoring plant Fe uptake. However, the actual mechanism by which soil microbes contribute to plant Fe acquisition remains unknown (Jin *et al*., 2010). Siderophores are small, high-affinity Fe chelating compounds secreted by microorganisms such as bacteria, fungi and grasses. More recently, it was revealed that phenolic compounds exuded from red clover (*Trifolium pratense*) roots under Fe-deficient conditions may selectively modify the microbial community structure favoring more siderophore-secreting microbes, which helps to improve the solubility of insoluble Fe and plant Fe nutrition *via* microbial siderophores. Such an interrelated system plays a very important ecological role in plant Fe acquisition in calcareous soils (Jin *et al.,* 2010).

2.7. Biofortification - a key weapon to fight micronutrient malnutrition

A combination of strategies involving food fortification, pharmaceutical supplementation and dietary diversification has been suggested to fight micronutrient malnutrition (Stein *et al*., 2005). However, neither of these strategies have been universally successful in developing countries, largely due to lack of safe delivery systems, stable government policies, appropriate infrastructures and continued adequate investment (Graham *et al*., 2001; Bouis, 2003; Timmer, 2003; Lyons *et al.,* 2003; Misra *et al*., 2004). Thus, a complimentary solution to micronutrient malnutrition has been proposed and termed as ‘biofortification’ (Bouis, 2003). Biofortification is defined as the process of increasing the concentration of essential elements in edible portions of crops through agronomic and /or genetic intervention. There is considerable interest in breeding grain minerals-dense crops, which is a sustainable and cost effective approach, and the produce from such biofortified crops will be available for consumption even in remote rural populations (Bouis, 2003; Mannar and Sankar, 2004; Nestel *et al*., 2006; McClafferty, 2009). Moreover, the biofortified crops, once developed, adapted and released for cultivation, will continue to be grown and consumed year after year, thus contributing significantly to overcoming malnutrition (Stein *et al*., 2005; Graham *et al*., 2007; White and Broadley, 2009; Stein, 2010; White and Brown, 2010). Thus, the genetic biofortification has been recognized as sustainable solution to combat micronutrient malnutrition in developing countries (www.harvestplus.org).

2.8. Micronutrient dense crops for increased production and human nutrition

In addition to human nutrition there are some agronomic benefits from biofortification approach. The grain mineral dense cultivars are reported to grow well and produce more grains when grown under micronutrient deficient soils (Graham, 1984; Welch, 1986, 1999; Ruel and Bouis, 1998; Graham *et al.,* 2001). The grain mineral dense cultivars have ability to resist pest and diseases and other environmental stresses. For instance, a study in common bean (*Phaseolus vulgaris* L.) demonstrated that the germplasm with high grain Fe showed less susceptibility to bacterial blight (Islam *et al*., 2002). Moreover, grainlings from grain mineral dense grains had a higher proportion of survival, more rapid initial growth and higher yields particularly on mineral deficient or infertile soils (Nestel *et al*., 2006), mainly because of deep and extensive root systems to capture more subsoil moisture and nutrients (Rengel and Graham, 1995; Khoshgoftarmanesh *et al*., 2010). Malnutrition is thus a multifaceted vicious cycle involving soils - plants - humans. Soil is a basal medium for all living organisms on earth, thus sick soil results in sick plants and sick people. It is simple to cure sick soils than sick people and for that to happen we must make soil building the basis of food building in order to accomplish human nutrition.

2.9. Environment effects on grain micronutrients

Differential response of genotypes to varying environments is evident because of significant genotype × environment interaction (GEI) for grain Fe and Zn in pearl millet (Velu, 2006; Velu *et al*., 2008a; Gupta *et al*., 2009). In maize, Oikeh *et al.* (2004) reported that the effects of GEI were significant ($P<0.05$) for grain Fe and Zn. The GEI effect was about double the contribution of the genotype (G) for grain Fe and Zn; however, partitioning of GEI revealed predominance of location effect to GEI for both micronutrients (Oikeh *et al.,* 2004).

In rice, the levels of grain Fe remained stable across four environments, with environments but not the GEI significantly impacting grain Fe. Most of the cultivars had lower grain Fe during the wet season than the dry season. The environment explained 74.42% of total variation, whereas G and GEI, respectively, contributed 5.60% and 19.67% phenotypic variation (Suwarto and Nasrullah, 2011).

In wheat, the GEI largely influenced grain Fe, whereas location (environment) had predominant effect on Zn (Morgounov *et al.,* 2007). In some recent studies, environments largely contributed to phenotypic variation for grain Fe and Zn in wheat (Zhang *et al.,* 2010; Gomez-Becerra *et al.,* 2010). Growth phenology and variation in temperature, relative humidity and rainfall have significant effect on grain Fe and Zn in wheat. Fe example, the maximum temperature before flowering and relative humidity and rain fall after flowering influenced grain Fe, whereas rainfall after flowering and minimum temperature before and after flowering significantly impacted grain Zn (Joshi *et al*., 2010). Some other studies in wheat also reported significant GEI interaction for grain Fe and Zn (Maziya-Dixon *et al.,* 2000; Monasterio and Graham, 2000; Long *et al.*, 2004). Such interactions (GEI) for grain Fe and Zn have also been observed in Bean (Beebe *et al.*, 2000; Msolla and Tryphone, 2010).

2.10. Genetic variation for grain iron and zinc in pearl millet germplasm

Several reports indicate the existence of large amount of variability for grain Fe and Zn in various types of genetic materials (cultivars, populations and S_1 progenies) of pearl millet. For example, the variation for grain Fe and Zn ranged from 20 to 580 mg kg^{-1} and from 10 to 70 mg kg^{-1}, respectively (Table 1a).

Preliminary studies at Patancheru, India have shown large variability for grain Fe and Zn in germplasm, populations, hybrid parents and hybrids in pearl millet (Velu *et al*., 2007; 2008a, b; Gupta *et al.,* 2009). Seasons effects had also been reported. The average grain Fe and Zn in the rainy season were 19 to 20% higher than those in the summer season, largely because of high Fe and Zn levels in the soil, as the field used during the rainy season had 155% more extractable Fe and 38% more extractable Zn than the field used during the summer season (Velu *et al.,* 2007). In another study, however, the differences in soil Fe and Zn between seasons were not reflected in grain Fe and Zn (Gupta *et al.,* 2009). The variable response of seasons to grain Fe/Zn in pearl millet could be due to significant GEI effects (Velu *et al.,* 2007, 2008a; Gupta *et al.,* 2009).

Table 1a. Mean and range for grain iron and zinc concentration in pearl millet

Entry	Mean	Range	Reference
Fe concentration (mg kg^{-1})			
163	60	20–120	Goswami *et al.*,1969a,b;1970a,b
12	130	110–150	Shukla and Bhatia, 1971
14	30	20–50	Uprety and Austin, 1972
21	66	68-83	Varriano-Marston and Hoseney,1979
27	–	40–580	Jambunathan and Subramanian, 1988
10	–	70–180	Abdalla *et al.*,1998
120	45.5	30.1–75.7	Velu *et al.*, 2007
68	55	42- 79.9	Velu *et al.*, 2008a
30 S_1's	46.7	29.9-77.2	Gupta *et al.*, 2009
24 S_1's	37	26.8-48.3	Gupta *et al.*, 2009
Zn concentration (mg kg^{-1})			
4	31.75	28-38	Varriano-Marston and Hoseney, 1979
27	–	10–66	Jambunathan and Subramanian, 1988
10	–	53–70	Abdalla *et al.*, 1998
120	43.9	24.5-64.8	Velu *et al.*, 2007
68	38	27.2 -50.2	Velu *et al.*, 2008a
30 S_1's	44.6	30.7- 63	Gupta *et al.*, 2009
24 S_1's	37.2	28.2-50.9	Gupta *et al.*, 2009

2.11. Nature of gene action, combining ability, heterosis and heritability

2.11.1. a. Gene action and combing ability for grain iron and zinc in pearl millet and other cereals

Arulselvi *et al.* (2009) reported predominance of non additive genetic variance for grain Fe and Zn, while Velu (2006) and Velu *et al*. (2011a) detected predominance of additive genetic variance for these traits in pearl millet. Arulselvi *et al.* (2009) found some degree of relationship between specific combining ability effects (*sca*) of crosses and general combining ability effects (*gca*) of their parents. Crosses involving both parents having superior *gca* or one parent having superior *gca* had large *sca* effects suggesting that both *gca* and *sca* were important for grain Fe and Zn in pearl millet. The importance of additive gene effect for grain Zn concentration was reported in pearl millet (Rai *et al.,* 2007). Velu *et al.* (2011a) also reported significant *GCA* x E interaction for grain Fe in pearl millet.

Rice among the cereals has been most extensively studied for the genetics of grain Fe and Zn. Few reports indicate the predominance of additive genetic variance for both grain Fe and Zn (Zhang *et al*., 2000; Gregorio, 2002; Gregorio and Htut, 2003), while other report predominance of non-additive genetic variance for grain Fe and additive genetic variance for Zn (Zhang *et al.,* 1996). Zn efficiency in rice is governed by additive as well (though to a smaller degree) by dominant gene action (Majumdar *et al*., 1990), while Hartwig *et al*. (1991) suggested that only a few genes control the Zn efficiency in soybean. In maize, Gorsline *et al.* (1964), Arnold and Bauman (1976) and Chen *et al*. (2007) reported predominance of additive gene action for both leaf and grain Fe and Zn. Long *et al*. (2004) reported the importance of *gca* effects for flour Fe and Zn in high yielding environments, indicating the role of additive genetic effect on grain Fe and Zn in maize. More recently, Chakraborti *et al.* (2010) detected higher magnitude of additive gene action as compared to dominance for grain Fe, while dominance was relatively more important for grain Zn in maize.

2.11.1. b. Gene action and combining ability for flowering and 1000-grain mass in pearl millet

A summary of combining ability and gene action through line x tester and diallel mating designs in pearl millet revealed that *GCA* had greater role in the control of flowering and 1000-grain mass, which confirm the additive gene action for expression of these traits (Table 1b); however, non additive gene actions for these two traits were also reported. Few studies reported the importance of both additive and non-additive gene action controlling these traits in pearl millet (Table 1b).

Table 1.b. Nature of gene action for flowering and 1000-grain mass in pearl millet

Gene action	Reference
Flowering	
Predominant additive genetic variance	Vyas and Pokhriyal,1985; Maciel *et al*., 1987; Singh and Singh,1988; Navale *et al*.,1991; Quendeba *et al*., 1993; Talukdar *et al*.,1993; Lynch *et al*.,1995; Joshi *et al.,* 2001; Ali *et al*., 2001; Meena Kumari *et al*., 2003; Shanmuganathan *et al*., 2005; Velu, 2006; Dangariya *et al.,* 2009
Predominant non-additive genetic variance	Khangura, 1975; Rao and Reddy, 1989; Kulkarni *et al*., 1993; Chavan and Nerkar,1994; Meena Kumari *et al*., 2003; Sushir *et al.,* 2005; Ashok kumar *et al*., 2007.
Both additive and non-additive genetic variance	Singh *et al.,* 1982; Choi *et al*.,1989; Rathore *et al*., 2004; Izge *et al*., 2007
1000-grain mass	
Predominant additive genetic variance	Vyas and Pokhriyal, 1985; Quendeba *et al.,* 1993; Shanmuganathan *et al*., 2005; Velu, 2006; Dangariya *et al.,* 2009
Predominant non-additive genetic varaince	Vaidya *et al.,* 1983; Kulkarni *et al.,* 1993; Joshi *et al.,* 2001; Meena Kumari *et al*., 2003; Izge *et al.,* 2007; Ashok Kumar *et al*., 2007
Both additive and non-additive genetic variance	Gotmare and Govila, 1999; Rathore *et al*., 2004

2.11.2. a. Heterosis for grain iron and zinc concentration in pearl millet and other cereal crops

Arulselvi *et al.* (2006) reported significant heterosis for grain Fe and Zn in pearl millet. In their study, 22 and 13 hybrids had positive and significant heterosis over mid-parent (MP) and better parent (BP) for grain Fe, respectively, while 22 and 18 hybrids had positive and significant MP and BP heterosis for grain Zn, respectively. Velu (2006) reported significant differences between parents and hybrids for grain Fe. However, only two hybrids in their study involving parents with high Zn showed positive significant heterosis over MP and one hybrid had positive significant heterosis over BP. None of the hybrids with high grain Fe showed significant positive

BP heterosis. The average MP heterosis was negative for grain Fe and negligible for grain Zn. Among the crosses showing negative MP and BP heterosis, 67% of hybrids had at least one parent that had high in Fe and Zn (Velu, 2006). In an another study, MP heterosis for grain Zn 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; however, none of the hybrids could even match the level of Zn levels as detected in their parents (Rai *et al*., 2007). More recently, Velu *et al*. (2011a) in 4 of the 90 hybrids detected significant and positive MP heterosis for grain Fe (11.5 – 19.3%) and Zn (11.8 – 19.6%).

In maize, Chen *et al*. (2007) reported high heterosis for ear leaf (flag leaf) Fe but not for grain Fe. Similarly, other studies found no significant positive MP or BP heterosis for grain Fe and Zn, with most of the hybrids showing negative heterosis for these traits (Chakraborti *et al*., 2009, 2010). However, a number of hybrids displayed significant positive standard heterosis (heterosis over the commercial variety or hybrid) for grain Fe (Chakraborti *et al*., 2009).

A study in cabbage revealed that a cross (Pride of Asia x C-2) exhibited positive MP (81.5%) and BP heterosis (69.6%) for Fe; however, none of the hybrids excelled MP or BP heterosis for Zn, with most of the crosses showing negative heterosis for these two minerals (Singh *et al.,* 2009b).

2.11.2. b. Heterosis for flowering and 1000-grain mass in pearl millet

Parents that flower early are termed as better parent and crosses with significant negative heterosis are most desirable from view of adaptation in certain agro-ecological regions. Shinde *et al.* (1984) and Karad and Harer (2004) reported significant negative heterosis BP (the earliest flowering) parent for flowering, while several others reported negative MP and BP heterosis was reported for flowering (Balakrishnan and Das, 1996; Azhaguvel *et al.,* 1998; Gandhi *et al*., 1999; Sheoran *et al.,* 2000; Singh and Sagar, 2001; Arulselvi, 2004; Manga and Dubey, 2004; Velu, 2006; Vaghasiya *et al.,* 2009). The negative significant MP and BP heterosis was also reported for flowering (Vagadiya *et al*., 2010). The heterotic crosses for grain yield did always not show high heterosis for all the yield component traits, and that there was a mutual complementation in various yields attributing characters (Vaghasiya *et al*., 2009). The magnitude of MP or BP heterosis for 1000-grain mass in pearl millet varied across studies reported in the literature. Most of the hybrids recorded significant positive MP heterosis (up to 60.41%) and BP heterosis (up to 16.31%) for 1000-grain mass (Arulselvi *et al.*, 2006), while Velu (2006) found MP heterosis up to 33% and BP heterosis up to 24% for 1000-grain mass. In another study, Vaghasiya *et al.* (2009) observed positive BP heterosis (41%) for 1000- grain weight. Furthermore, environments (locations) had significant effects on expression of heterosis (Presterl and Weltzien, 2003).

2.11.3. a. Heritability of grain iron and zinc concentration in pearl millet and other crops

The inheritance of nutritional traits appears to be mostly quantitative, influenced by the environment, but more specific to source genotypes (Guzman-Maldonado *et al.*, 2003; Cichy *et al.*, 2005, 2009; Blair *et al.*, 2009). Heritability is a measure of observed phenotypic differences for a trait due to genetic differences (Klug and Cummings, 2005). There are two types of heritability, broad-sense heritability (h^2bs) and narrow-sense heritability (h^2ns), with former less sensitive to environments than the latter (Klug and Cummings, 2005).

Both high h^2bs for grain Fe (65 to 71.2%) and Zn (65 to 80%) (Gupta *et al.,* 2009) and h^2ns for grain Fe (80%) and Zn (77%) (Velu, 2006) have been reported in pearl millet, which indicates that substantial portion of total variation for Fe/Zn is due to genetic effects. In contrast, Vogel *et al.* (1989) reported low h^2bs for Fe (0.38) in wheat, while Gregorio *et al.* (2000) reported moderate h^2ns (43%) and high h^2bs (88%) for Fe in rice. Rawat *et al*. (2009) detected high h^2bs for grain Fe (0.98) and Zn (0.96) in wheat. Chakraborti *et al*. (2010) reported high h^2bs for grain Fe (78% and 73%) and grain Zn (71% and 76%) in maize. Both moderate h^2bs (54%) and high h^2ns (78-82%) were reported for grain Zn in common bean (Cichy *et al*., 2005; da Rosa *et al*., 2010).

Seasons had significant impact on heritability estimates for grain Fe and Zn in pearl millet: high h^2bs for Fe (81%) and Zn (70%) in rainy but moderate in summer (Fe 52% and Zn 44%) (Velu, 2006).

2.11.3. b. Heritability for flowering and 1000-grain mass in pearl millet

Both high (Virk, 1988; Kulkarni *et al.,* 2000; Berwal *et al*., 2001; Vidyadhar *et al*., 2006) and low h^2ns (Velu, 2006) have been reported for flowering in pearl millet. Several reports indicated moderate to high h^2bs for 1000-grain mass

(Chaudhary *et al.,* 1980; Kunjir and Patil, 1986; Pathak and Ahmad, 1988; Gupta *et al.*, 1988; Sachan and Singh, 2001; Solanki *et al.*, 2002; Borkhataria *et al.*, 2005; Velu, 2006; Vengadessan, 2008; Gupta *el al.,* 2009), while others reported low to moderate h^2bs in pearl millet (Hash, 1986; Arulselvi, 2004; Vidyadhar *et al.,* 2006). The environments (seasons) had least or no significant effect on h^2bs both for days to flower and 1000-grain mass (Velu, 2006).

2.12. Genetic components of variance for agronomic traits in maize and pearl millet

Phenotypic variance (σ^2_P) of a population is the sum of genetic (σ^2_G) and environmental (σ^2_E) variances. The σ^2_G is made of additive (σ^2_A), dominant ($\sigma^2_{D)}$ or epistatic components (Bains, 1971; Falconer and Mackay, 1996). In population breeding, half sibs (HS) are produced by crossing a common female line with a set of male lines, whereas in full sibs (FS) both male and female lines are different. Progeny obtained by self-pollinating an individual (S_0) in a population is known as S_1 (selfed) progeny. Progeny testing in the form of HS, FS or S_1 families is widely used for improving populations (Lonnquist, 1949; Duclos and Crane, 1968; Horner *et al.*, 1969; Carangal *et al.*, 1971). S_1 progeny has been studied as a means of population improvement in maize. HS progenies were reported to be less effective in increasing population yield than S_1 progeny testing that involved either two or four selection cycles in maize (Burton *et al.*, 1971; Genter, 1973), while Duclos and Crane (1968) found HS superior over S_1 in maize. It is reasonable to believe that S_1 progeny performance reflect mainly additive genetic effects while HS performance reflect non-additive effects as well due to some dominant or epistatic relationships between the parents (Goulas and Lonnquist, 1976). Phenotypic variances among S_1 families were approximately twice than HS families in maize (Goulas and Lonnquist, 1976).

The estimates of components of σ^2_A and σ^2_D in genetically broad-based maize populations suggest that greater portion of σ^2_G was due to σ^2_A, with negligible epistatic effects (Hallauer and Carena, 2009). Phenotypic variance among S_1 is approximately twice to those among the HS families, while among the family variance component for S_1 families is three times that of HS families (Goulas and Lonnquist, 1976). G x E variance for grain yield was greater in S_1 than HS progenies (Burton *et al.*, 1971; Carangal *et al.*, 1971).

Stuber *et al.* (1966) reported larger additive variance than dominance variance for flowering in maize population, whereas magnitude of additive and dominance variance was similar for grain yield. For grain weight, greater additive genetic variance in sample I and greater dominance variance in sample II were reported in two samples of the same maize population (Williams *et al*., 1966). The difference between the estimates of two samples might have been due to high estimation errors linked with variance components or progeny x year interaction biases. The ratio σ^2_D / σ^2_A was less than one for grain weight in sample I and slightly grater than one for grain weight in sample II. Thus, both additive and dominance variance exist for grain weight in maize (Williams *et al*., 1966). Additive variance was important than dominance variance for ear diameter, ear length and ear per plant in maize (Wolf *et al*., 2000). More recently, Hallauer *et al.* (2010) detected high σ^2_A for flowering, kernel weight and oil content, while greater σ^2_D for grain yield in the F_2 population of maize.

The only report in pearl millet revealed negative estimates of σ^2_D for plant height, ear head length, ear head diameter and grain yield (Ghorpade and Metta, 1993). Negative estimates of dominance variance could arise from an inadequate model, inadequate sampling or inadequate experiments (Lindsey *et al*., 1962; Wolf *et al*., 2000), which could be due to lack of random matting for the development of HS. For example, variation in flowering within population could lead to assortative matting in the production of HS. Mating involving early anthesis male may largely restrict to early flowering females and vive versa, which would create upward bias in the estimates of additive variance and downward bias in estimate of dominance (Lindsey *et al.,* 1962). However, the best solution would be to interpret them as zero and re-estimate other components (Wolf *et al*., 2000).

2.13. Efficiency of single plant selection

Previously several authors have suggested that single plant selection for yield is inefficient (Bell, 1963; McGinnis and Shebeski, 1968; Walker, 1969). However, superior performance of single plant selection reported by Hamblin *et al*. (1978) has generated interest among researchers to further investigate the efficiency of single plant selection for enhancing the trait value. Phul and Athwal (1969) and Hash (1986) recommended that, selection based on progeny testing would be most effective for improving grain weight in pearl millet. Generally, selection efficiency was greater for individual progeny selection than for family (out crossed population) selection (Wright and Cockerham, 1986). However efficiency of both methods (progeny and family selection) was greater than that of mass selection (Wright and Cockerham, 1985). Single plant selection for phosphorus (P) was effective with 7 to 12 % increase over the check in first cycle and an additional 6% increase with a second cycle of selection in alfalfa (Miller *et al.,* 1987). In the same study, no detrimental effects of selection for high P concentration were reported for yield (grain or fodder) and non target minerals (Fe, Mn, Mg, B, Cu and Al). In general, the performance of single plant in experimental plot is influenced by genotype, microenvironment, and competition from the neighbouring plant of same genotype (Hamblin *et al.,* 1978).

Single plant selection under low population density have been effectively used to assess within cultivar variation for grain yield in bread wheat (Fasoula, 1990), for pod number and grain yield in bean (Traka- Mavrona *et al*., 2000), and for grain protein, oil, and fatty acid composition in soybean (Fasoula and Boerma, 2005). Single plant selection is more effective for traits with high heritability than for yield (Haddad *et al*., 1982).

2.14. Recurrent selection for enhancing mineral concentration and grain yield

Various forms of recurrent selection have been used to enhance intra- and inter-population improvements, mostly in cross pollinated crops (Wiersma *et al*., 2001; Doerksen *et al*., 2003). Pearl millet is amenable to conducting all forms of recurrent-selection methods (Rai and Anand Kumar, 1994; Rai *et al.,* 1999). These methods have been first developed and refined in maize (Hull, 1945; Comstock *et al*., 1949; Lonnquist, 1951; Robinson *et al.,* 1955; Sprague *et al.,* 1952, 1959). S_1 progeny selection has been more frequently used than S_2 progeny selection because of extra generation per cycle is required with the latter approach. Earlier studies compared S_1 and S_2 selection methods with full-sib (FS) and half-sib (HS) selection methods for grain yield in pearl millet, based on only one cycle of selection, showed that S_1 method is more effective than FS or HS methods (Rai and Virk, 1999).

In a preliminary study in pearl millet, based on mean performance of the populations across the two environments, C_1 bulks had 21-22% higher grain Fe than the C_0 bulks of both AIMP 92901 (66 ppm) and GB 8735 (62 ppm). Recurrent selection for high grain yield in pearl millet showed non significant difference between initial vs. advanced generation bulks of different composite populations for grain Fe. The advanced bulk (C_4) of Serere composite 1 (52.1 mg kg^{-1}) had significantly lower grain Fe than the initial bulk (64.3 mg kg^{-1}), whereas the advanced bulk (C_3) of smut resistant composite (C_0) showed significant improvement of grain Fe (47.7 mg kg^{-1}) over its original bulk (43.3 mg kg^{-1}). This study arrives at the conclusion that recurrent selection for high grain yield does not bring in the significant changes in grain Fe and Zn concentration in pearl millet (Velu, 2006).

Byrne and Rasmusson (1974) studied three cycles of recurrent selection for grain Sr (Strontium a mineral element) in wheat and barley. In wheat, each cycle of selection resulted in genetic gain of 7.4 ± 2.6 % per cycle in high Sr population and of -12.4 ± 1.5% in the low Sr population. In barley, average response per cycle was 12.2 ± 3.8 % in the high Sr population and -11.2 ± 4.9% in the low Sr population. They also reported correlated changes between grain Sr and Ca concentration, i.e., changes in grain Ca had positive parallel changes in Sr in all plant parts in both wheat and barely. The selection for grain Sr also negatively affected the P, K, Mg and Mn in wheat, and K and Na in barley, whereas Ca and Mg were positively correlated with Sr in barely (Byrne and Rasmusson, 1974).

Grain methionine has been successfully manipulated with a selection response of 0.004g / 100 g tissue per cycle using recurrent selection in maize (Paul Scott *et al.*, 2008). Increases in grain protein have also been achieved in wheat using recurrent selection among F_3 families (McNeal *et al.*, 1978; Loeffler *et al.*, 1983). In spring wheat, Delzer *et al.* (1995) reported a gain of 2.7% per cycle for grain protein after four cycles of selection. Frascaroli and Landi (1998) report that recurrent selection for grain yield in maize led to a correlated response for cob color that was consistent with the responses for grain yield. The frequency of the red cob allele increased with selection for grain yield, which followed a highly significant linear trend. Sprague *et al.* (1950, 1952) succeeded in increasing the oil percentage of the maize kernel from 7% to 10.5% after two cycles of recurrent selection. Coutiño *et al.* (2008) reported that the original population means for ear length, ear diameter, grains per ear, grain weight and oil were significantly increased ($P<0.05$) whereas protein showed diminishing trend through the selection cycles in corn.

In pearl millet, Singh *et al.* (1988) found significant grain yield increases in six composites, improved through several cycles of selection. In another study, grain yield increases ranged from 1% to 5% per cycle over 4–5 cycles of recurrent selection in four composites evaluated in multi-location trials (Rattunde and Witcombe, 1993). Rattunde *et al*. (1997) showed an improvement of 13% in grain yield after two cycles of S_1 selection in a population, with most of this improvement occurring in the first cycle. Yoshida *et al*. (1999) reported the improvement of yield component traits (*viz*., grain weight and panicle numbers) in two cycles of selection in pearl millet, with other non-target traits (plant height, panicle weight and length, and harvest index) also showing positive grains. Bidinger and Raju (2000) found that two cycles of S_1 recurrent selection achieved an 18% increase in grain mass (8.05 to 9.52 mg grain^{-1}) with no changes in grain yield. Unnikrishnan *et al*. (2004) observed significant improvement for grain yield in two populations in pearl millet. An increase of 19% and 24% in grain yield was recorded after the first cycle of simple recurrent selection over the base populations. Maximum yield advantages of 33% and 37% were obtained through reciprocal recurrent selection over the base populations (Unnikrishnan *et al*., 2004).

Hadi (2003) reported that recurrent selection in three maize populations led to an average gain of 7.5% for grain yield per cycle, with four cycles of recurrent selection providing 30% gain for grain yield. Busch and Kofoid (1982) initiated recurrent selection to increase kernel weight in spring wheat. They showed substantial increase in kernel weight after the first four cycles of selection. Using similar procedure, Wiersma *et al*. (2001) showed genetic gain of about 4.5% per cycle after eight cycle of selection for kernel weight in spring wheat.

2.15. Correlation between grain iron and zinc concentration and agronomic traits

The nature and magnitude of correlation coefficients between grain Fe and Zn and agronomic traits in cereals including pearl millet reported by the earlier workers are presented in Table 1c. In pearl millet, the correlation between grain Fe and Zn is positive and highly significant ($P<0.01$), which varies from 0.66 to 0.85, similar to those reported for maize ($r = 0.56$ to 0.88) and sorghum ($r = 0.55$ to 0.75). However, low to very high correlations (but significant) between Fe and Zn have been reported in rice ($r = 0.10$ to 0.92) and wheat ($r = 0.17$ to 0.81).

Further, the researchers reported variable but significant correlations (both in coefficients and direction) involving grain Fe and Zn with other agronomic traits.

For example, Velu (2006) reported negative association (r = -0.31 to -60) between grain Fe and flowering in pearl millet, while Gupta *et al.* (2009) found positive correlation (r = 0.40) between these two traits in pearl millet. Grain Fe and flowering in wheat were positively correlated (r = 0.34) (Vogel, 1989). Velu *et al.* (2008a) reported positive association between 1000-grain mass and grain Fe in pearl millet (r = 0.34 to 0.56), whereas Gupta *et al.* (2009) found no such association between these two traits in pearl millet. Grain yield and grain Fe in common beans were positively correlated (r =0.34), while no such association was reported in pearl millet (Velu *et al.,* 2008a). However, grain yield and grain Fe were found negatively associated in maize (r = -0.26), sorghum (r = -0.32 to – 0.36) and wheat (r = -0.39 to -0.41).

In pearl millet, Velu (2006) reported negative association (r = -0.32 to -0.53) between grain Zn and flowering, while Gupta *et al.* (2009) reported positive non significant association (r = 0.26) in pearl millet. Grain Zn and 1000-grain weight in pearl millet were positively associated (r = 0.34 to 0.46) (Velu *et al.,* 2008a), while in another study, no such association between grain weight and Zn were detected (Gupta *et al.,* 2009). Low but positive correlation (r =0.21) between grain yield and Zn have been reported in common bean. Grain yield and grain Zn were negatively associated in sorghum (r = -0.46 to -0.54) and wheat (r = -0.24 to -0.64), while no such association was detected in pearl millet.

Table 1.c. Nature and magnitude of correlation coefficients between grain Fe and Zn and agronomic traits in cereals

Crop	Correlation coefficient (r)	Reference
Grain Fe and Zn concentration		
Wheat	0.17 *	Vogel, 1989
	0.70 **	Monasterio and Graham, 2000
	0.79 **	Morgounov *et al.*, 2007
	0.57 **	Peleg *et al.,* 2008
	0.81 **	Velu *et al.,* 2011b
Rice	0.92 **	Deosthale *et al.*, 1979
	0.42 **	Kabir *et al.*, 2003
	0.10 *	Zeng *et al.*, 2005
Beans	0.66 **	Beebe *et al.*, 2000
	0.60 **	Hacisalihoglu *et al.*, 2005
	0.40 *	Gelin *et al.*, 2007

Crop	Correlation coefficient (r)	Reference
Pearl millet	0.84 **	Velu, 2006
	0.66 to 0.85**	Velu *et al.*, 2008a
	0.65 **	Velu *et al.*, 2008b
	0.81 **	Gupta *et al.*, 2009
Maize	0.88 **	Maziya-Dixon *et al.*, 2000
	0.56 to 0.72**	Long *et al.*, 2004
Sorghum	0.55 **	Reddy *et al.*, 2005
	0.75 **	Ashok kumar *et al.*, 2009
Grain Fe and flowering		
Wheat	0.34 **	Vogel, 1989
	0.05 ^{ns}	Morgounov *et al.*, 2007
Pearl millet	0.40 *	Gupta *et al.*, 2009
	-0.31 to -0.60**	Velu, 2006
	-0.20 ^{ns}	Gupta *et al.*, 2009
	-0.29 ^{ns}	Velu *et al.*, 2008a
Grain Fe and 1000-grain mass		
Pearl millet	0.34 to 0.56*	Velu, 2006; Velu *et al.*, 2008a
	0.27 ^{ns}	Gupta *et al.*, 2009
Wheat	0.05 ^{ns}	Morgounov *et al.*, 2007
Triticale	-0.47 ^{ns}	Feil and Fossati, 1995
Grain Fe and grain yield		
Beans	0.34 *	Gelin *et al.*, 2007
Wheat	-0.39 **	Vogel, 1989
	-0.41 *	Morgounov *et al.*, 2007
Triticale	-0.75 *	Feil and Fossati, 1995
Maize	-0.26 *	Chakraborti *et al.*, 2009
Pearl millet	-0.02 ^{ns}	Gupta *et al.*, 2009
Sorghum	-0.32 *	Reddy *et al.*, 2005
	-0.36 *	Ashok kumar *et al.*, 2009
Grain Zn and flowering		
Wheat	0.10 ^{ns}	Vogel, 1989
	-0.13 ^{ns}	Morgounov *et al.*, 2007
Pearl millet	0.26 ^{ns}	Gupta *et al.*, 2009
	-0.32 to -0.53**	Velu, 2006
	-0.31 ^{ns}	Velu *et al.*, 2008a
Maize	-0.25 to -0.27 *	Chakraborti *et al.*, 2009
Grain Zn and 1000-grain mass		
Pearl millet	0.34 to 0.46 *	Velu, 2006; Velu *et al.*, 2008a

	0.33 ^{ns}	Gupta *et al.*, 2009

Crop	**Correlation coefficient (r)**	**Reference**
Wheat	0.03 ^{ns}	Morgounov *et al.*, 2007
Triticale	-0.49 ^{ns}	Feil and Fossati, 1995
Grain Zn and grain yield		
Beans	0.21 *	Gelin *et al.*, 2007
Maize	0.18 ^{ns}	Chakraborti *et al.*, 2009
Wheat *sp*	-0.24 **	Vogel, 1989
Wheat	-0.64 **	Morgounov *et al.*, 2007
	-57 to -0.61**	McDonald *et al.*, 2008
Triticale	-0.57 ^{ns}	Feil and Fossati, 1995
Pearl millet	-0.10 ^{ns}	Gupta *et al.*, 2009
Sorghum	-0.54 **	Reddy *et al.*, 2005
	-0.46 **	Ashok kumar *et al.,*2009

*, **= significant at $P \leq 0.05$ and $P \leq 0.01$,respectively; ns = not significant

CHAPTER 3

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

The present investigation was carried out to study the combining ability, gene action, heterosis, population genetic variance, efficiency of single plant selection, character association and response to recurrent selection for grain iron (Fe) and zinc (Zn) concentration pearl millet during the period from January 2008 to June 2011 at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru (17.53° N; 78.27° E), Andhra Pradesh, India. All the experiments were conducted in the Alfisol (red soil) fields at ICRISAT, Patancheru. The weather data (total rainfall during the crop season, min and max temperature, relative humidity, total evaporation, solar radiation and bright sunshine hours) for each cropping season for the year 2008, 2009 and 2010 at Patancheru are given in Appendix I.

3.1. EXPERIMENTAL MATERIALS

3.1.1. LINE X TESTER ANALYSIS

3.1.1.1. Selection of parental lines and developing hybrids

Two sets of line x tester crosses form the experimental materials for this study. Parental lines of these crosses in set I consisted of eight B- lines as female and nine R-lines as male (or tester), while set II consisted of 16 B-lines and 12 R-lines. The B- and -R lines were developed at ICRISAT, Patancheru, India. These lines differ in their pedigree, and for agronomic traits such as tillering, plant height, panicle size, maturity, 1000-grain mass, and grain color (Table 2). The set-II inbreds were selected based on differences on variability in grain iron (Fe) and zinc (Zn) concentration, while such information in set I were not available at the time of selection of parents, but represented agronomically diverse group. However, parents from both the sets were classified into high, medium and low categories for grain Fe and Zn concentration after two season's evaluation (Table 3 and 4).

Pearl millet is an outbreeding species, and producing hybrid grains is easy because of protogynous nature of the crop. The panicle of B- (grain parent) and -R (pollen parent) lines were covered with 30 x 10 cm butter paper bag when slightly to halfway emerged from the boot leaf sheath to avoid contamination of foreign pollen. Bagging was done every day. At full bloom (as detected by protruding white feathery stigma on the panicle), the pollen from R-line was collected in butter paper cover and dusted on B-line panicle by gentle tapping thoroughly in morning hours between 8.00 AM to 11.30 AM. Soon after pollination, the panicles of B-line were covered with butter paper bag to avoid pollen contamination and labeled properly. The butter paper bags remained over the crossed panicle until harvest, which were harvested and threshed to collect hybrid grains. Eight B-lines in set I were crossed with nine R-lines to produce 72 crosses during the 2008 summer season for set I, while 16 B-lines in set II were crossed with 12 R-lines to produce 192 crosses during the 2009 summer season for set II.

3.2. FIELD EVALUATION OF EXPERIMENTAL MATERIALS

3.2.1. Evaluating parental lines and F_1 hybrids

Set I trial consisted of 89 entries (17 parents and 72 hybrids) which were grown in a two replicate-randomized complete blocks design (RCBD) during the 2009 summer and rainy seasons. Set II trial consisted of 192 hybrids and 28 parents which were also grown in a two replicate-RCBD during the 2009 rainy and 2010 summer seasons at Patancheru. The parents and F_1 hybrids in both trials were randomized separately and evaluated in separate adjacent blocks. The parents and F_1's were each planted in a single row of 2 m length, spaced at 15 cm between plants and 75 cm between rows in rainy season and 60 cm between rows in summer season. Basal dose of 100 kg of DAP (Diammonium phosphate, contains 18%N: 46%P) was applied at the time of field preparation and 100 kg of urea (46%N) was applied as top dressing to meet the recommended dose of 64 kg of N ha^{-1} and 46 of P ha^{-1} in each of the trials. All the experiments were sown by tractor mounted 4-cone experimental planter (7100 US model) having base units from John Deer, USA and metering units from Winter Steiger, Austria and Almako (USA). The grainlings were thinned at 15 days after sowing to maintain one healthy grainling per hill at a spacing of approximately 15 cm. The off types (parental type) were removed before and after flowering. Grain Fe and Zn, days to 50% flower and 1000-grain mass were recorded in both the sets of lines x testers trial and in both the trials, 5 - 8 main panicles per plot were selfed to produce grain samples for Fe and Zn estimation and for 1000-grain mass, while days to 50% flower was recorded on plot basis (detailed measurement of these traits were given in the subheads 3.2.6).

3.2.3. Evaluating S_1 and half-sib progeny variances

The two open pollinated varieties (OPVs), AIMP 92901 and ICMR 312, were selected for genetic variance study. Both the populations mature early and possess bold grains with abundant variation for grain Fe and Zn. The populations were planted during the 2009 summer season in 40 beds (i.e., 20 row of two meter bed^{-1}) to produce selfed (S_1) and half-sib (HS) progenies. The first and last beds were not used for production of S_1 and half-sib progenies because of poor expressions. Among the 38 beds, four beds (80 rows) were used to produce 60 HS and 60 S_1's from each population. The rest of the 34 beds (680 rows) from each population were used to produce 300 S_1's which were used for recurrent selection trial (detailed under the sub-heading 3.2.5). The HS were produced by collecting bulk pollen from each population and sib mated within the population, whereas S_1's were produced by selfing.

Sixty S_1 and sixty HS grains from each population were planted in a single row of 2 m length with spacing of 15 cm between plant and 75 between rows, during the 2009 rainy season. The S_1 and HS progenies of each population were randomized together in RCBD and planted in a two replication trial, so that each S_1 and HS goes to low as well as high fertility variation in the experimental field. All the agronomic practices were adopted at par as discussed earlier. The same trial (remnant grains of original S_1 and HS generations) was repeated for second season evaluation during the 2010 summer season. The grain samples were produced from both season by selfing the 5 - 8 main panicle per plot for 1000-grain mass and estimating grain Fe and Zn. Days to 50% flowering was recorded on plot basis.

3.2.4. Efficiency of single plant selection and character association

3.2.4.1. Selecting S_0 plant and producing S_1 grains

ICTP 8203 and JBV3 were selected for this study. ICTP 8203 is a large-grained, early-maturing Iniari based well adopted OPV (Rai et al., 1990), whereas JBV3 is a non- iniari based OPV originated from smut resistant composite II (Millet breeding, ICRISAT). To develop S_0 population, approximately 20 rows of each of these two populations were grown in 4 m length with 15 x 75 cm spacing between plant and between rows respectively, during the 2008 rainy season (August - November) at Patancheru, hereafter referred as set-I. Similarly, two additional early maturing and bold-grained populations, AIMP 92901 and ICMR 312 (Millet breeding, ICRISAT), were grown in 20 rows of 2 m length at 15 x 60 cm spacing between plant and between rows respectively, during the 2009 summer season, hereafter referred as set-II. In both the sets, the main panicle of each random plant in a plot was covered with selfing bag to produce S_1 grain. All the selfed main panicles were harvested and visually scored for self grain set percentage (SSS %). The selfed panicles with > 80 % grain set were carefully threshed and serially numbered. Forty S_1 progenies were obtained from each population for experimentation.

3.2.4.2. Evaluating S_1 progenies

Forty S_1 progenies from Set-I populations were evaluated in single row plot with 2 m length in two-replicate trial in RCBD during the 2009 summer and rainy seasons. Likewise, S_1's from the set-II populations were also evaluated in RCBD with two replications during the 2009 rainy and 2010 summer seasons, grown in three row plots with 2 m length (in both the seasons). The first row was used to collect grain samples for grain Fe and Zn analysis and for 1000-grain mass, while the remaining two rows were used to record observations on grain yield. However, all three rows were considered for days to 50% flowering. Selfed grains from 5-8 plants in both the sets (I and II) were collected for analysis of Fe and Zn concentration and for 1000-grain mass.

3.2.5. RECURRENT SELECTION

AIMP 92901 and ICMR 312, the two open pollinated populations, were selected to study the effect of one cycle of recurrent selection on grain Fe and Zn. Initially, 300 S_1's were produced from each population during summer 2009 (as indicated under heading 3.2.3), by bagging and selfing the main panicle. All the 300 S_1's from each population were planted in two replications, spaced 75 cm between rows and 15 cm between the plants in rainy season 2009 at Patancheru. Approximately 5-8 main panicles were selfed to produce grain samples. Selfed panicles were harvested and threshed, and grain samples were analyzed for Fe and Zn in Waite analytical laboratory, Adelaide University, Australia.

3.2.5.1. Constituting C_0 bulks

To develop a control (original or unimproved) population, equal quantity of grains from each of the 300 S_1's were pooled and planted in 2010 summer season separately for each population. Each bulk had 15 rows (4 m length) for recombination by hand pollination (sib-mating) with bulk pollen collected from 50 - 60 plants (within population) and crossed on 15-20 plants of same population on each day. A total of 100-120 plants main panicles were crossed with bulk pollen in each population. The sib-mated panicles were harvested from each population and threshed separately as bulks to constitute the C_0 bulk of the two populations.

3.2.5.2. Developing C_1 bulk

In order to evaluate for the second season and to select best progenies for recombination, the same trial (rainy 2009 trial) was repeated during summer 2010 and the data were recorded on self grain set percentage (SSS %) at maturity. The agronomic score (1-5) was given to each entry at the time of harvest. Based on the grain Fe concentration in rainy 2009 trial and good SSS % data from summer 2010 trial, top 20 S_2 progeny bulks were selected from each population and planted (4m-row) in late summer 2010 for recombination using full diallel mating design. The crossed panicles were harvested and threshed for each cross combination separately. Based on agronomic score, crosses involving entries that had ≥ 3 score (score 5: agronomically best and score 1: agronomically poor) were selected. Thus, crosses involving 13 S_2 progeny bulks from AIMP 92901 and 17 S_2 progeny bulks from ICMR 312 were selected. Equal quantity of grains from these selected crosses was bulked to constitute C_1 bulks for each population (improved population).

3.2.5.3. Evaluating C_0 and C_1 bulks

The C_0 grain bulk (original) and C_1 grain bulk (improved) were grown in a three-replicate trial in RCBD design during the 2010 rainy season at Patancheru. A four row plot of four meter length was adopted, with a spacing of 75 between rows and 15 cm between plants within a row. The recommended agronomic practices were followed to raise a good crop as discussed earlier. The agronomic score and other plant traits (days to 50% flower, plant height, panicle length, 1000-grain mass and grain yield) were recorded as discussed in subhead 3.2.6.

3.2.6. OBSERVATIONS RECORDED

3.2.6.1. Days to 50 percent flowering

Fifty percent flowering was recorded in all the trials as number of days taken from sowing to the stigma emergence in 50% of the main shoots in a plot. This observation was taken in all the trials.

3.2.6.2. Plant height (cm)

The height as measured from the ground level to the tip of the main panicle was recorded at the time of harvest with help of measurement rod and expressed in centimeters. This trait was recorded in recurrent selection trial.

3.2.6.4. Panicle length (cm)

The length of the panicle in the main tiller was measured from the base to the tip of the panicle at maturity and expressed in centimeters. This trait was recorded in recurrent selection trial.

3.2.6.2. 1000 grain weight (g)

Two hundred grains for each replication were counted, weighed and multiplied by a factor of five to derive 1000-grain weight. This observation was taken in all the trials.

3.2.6.3. Grain yield (Kg plot^{-1})

After threshing, grains obtained from all productive tillers of an individual plot at optimum moisture level was weighed and recorded. Plot yield converted into yield kg ha^{-1} by using following formula.

$$\text{Yield ha}^{-1}\ (\text{kg ha}^{-1}) = \frac{X \times 10000}{\text{Plot size}}$$

Where,

X = grain yield per plot

This observation recorded in single plant selection set-II trial for character association study and in recurrent selection trial.

3.2.6.4. Self grain set percentage (SSS %)

Selfed panicles from recurrent selection experiment were scored visually for self grain set percentage and categorized into following classes

Classes	Self grain set %
1	0 - 20
2	21 - 40
3	41 - 60
4	61 - 80
5	81 - 100

Note: mostly those panicles that had 81-100% grain set, were used for Fe and Zn and 1000-grain mass

3.3. LABORATORY ANALYSIS OF MICRONUTRIENTS

3.3.1. Soil micronutrient analysis

3.1.1.1. Collecting soil samples

Two to four soil samples were collected from each experimental field by using hand auger at the soil depths of 0 - 30 cm by adopting random sampling procedure. 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 sample was further pulverized with a wooden rolling pin and screened through a 1mm stainless sieve, and used for the laboratory analyses.

3.1.1.2. Analysis of soil samples for Fe and Zn

The soil Fe and Zn were analyzed following DTPA extractable method at Central Analytical Services Laboratory, ICRISAT, Patancheru, and expressed as mg kg^{-1}. 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 cycle's min^{-1}.

After 2 hours shaking, the suspensions were filtered by gravity through Whatman no. 42 filter paper. The filtrates were analyzed for Fe and Zn using atomic absorption spectrophotometry (AAS) (Sahrawat et al., 2002) with appropriate standards of included in the analysis

3.3.2. Grain micronutrient analysis

3.3.2.1. Collecting grain samples

In all the experiments, the selfed grain samples were produced and used to estimate grain Fe and Zn, expressed in mg kg^{-1}. Inserting a parchment paper bag over a panicle prior to stigma emergence produced selfed grains. The selfed panicles were hand harvested at physiological maturity (85–90 days after planting) and dried in the sun to <12% post-harvest grain moisture. The dried panicles were threshed with well-cleaned single head thresher (Wintersteiger - ID780ST4), and the grains were manually cleaned, free from glumes, panicle chaff and debris. Ten-gram grain samples were taken from the grain lot of each plot and transferred to new non metal fold (imported) envelops for grain Fe and Zn analysis. Care was taken at each step to avoid any contamination of the grains with dust particles and any other extraneous matter.

3.3.2.2. Chemical analysis at Waite Analytical Laboratory, Adelaide University, Australia

The selfed grain samples from four populations of single plant selection experiments (set-I and II) were analyzed for Fe and Zn following the method described by Zarcinas et al. (1987). Grain samples were oven-dried overnight at 85ºC prior to digestion, grounded enough to pass through 1 mm stainless steel sieve using Christie and Norris hammer mill and stored in screw-top polycarbonate vials. The samples were digested with di-acid (Nitric / Perchloric acid) mixture and the digests were used for Fe and Zn determination using Spectro CIROS Axial Inductively Coupled Plasma Optical Emission Spectrometer (ICPOES or ICP).

Ten ml of nitric acid and 1 ml of perchloric acid were added into a 1.0 g flour sample and stored overnight at room temperature. The samples were heated for one hour at 120º C, increased to 175º C (until digests turn black in color, if the digests turn black, add nitric acid drop wise until the digest clears) and then further increased to 225º C that was maintained for approximately 10 min to allow complete digestion of the sample. To cool it, the digests were left at room temperature for 20 minutes. After cooling, the digests were diluted with 20 ml of 1% nitric acid.

Amorphous silica was separated from the digests solution by settling overnight and then transferred the supernatant into an auto-sampler test tube before aspirating directly into the plasma for the determination of Fe and Zn. An increase in the background emission occurs if silica is aspirated into the plasma, resulting in false high analyses. The digested solution was introduced into the plasma using a modified Babington Pneumatic nebulizer. A Gilson Minipuls 2 peristaltic pump with a Tygon red-red (1.14 mm) pump tube was used for solution delivery to the nebulizer. A stabilization time of 30 seconds was followed by three 20 seconds integrations. The Fe concentration was read at 259.94 nm and Zn concentration at 213.86 nm in the ICPOES. Reagent bottles, volumetric ware (plastic and glass) and digestion tubes were cleaned after usage by soaking overnight in 2 N HCl, rinsed with water and oven dried at 60º C. Double distilled water was used for all analytical purposes

3.3.2.3. Chemical analysis at Central Analytical Services Laboratory, ICRISAT, India

Selfed grain samples were used for estimation of Fe and Zn in lines x testers, genetic variance and single plant selection experiments, while in recurrent selection trial, open-pollinated (OP) grain samples were analyzed for Fe and Zn. The Fe and Zn estimation were done based on triacid mixture method (Sahrawat et al., 2002). The grain samples were finely ground (<60 mesh for grain samples) using cyclone mill and oven dried at 60°C for 48 h before analysis.

Ground and dried grain samples of 0.5 g were transferred to 125 ml conical flasks. Twelve ml of tri-acid mixture of nitric acid, sulfuric acid and perchloric acid (9:2:1(v/v)) were added to the flasks. The flour samples were digested in a room temperature for 3 h followed by digestion for 2–3 h on a hot plate, until the digest was clear or colorless. The flasks were allowed to cool and concentration was diluted to an appropriate volume. The digests were used for Fe and Zn determination using Atomic Absorption Spectrophotometry (AAS). Both ICP and AAS methods were found highly reliable and the readings were significantly correlated (r = 0.85 for iron and r = 0.86 for zinc), which showed the reliability of both the methods in determining iron and zinc concentration (Blair et al., 2010).

3.4. STATISTICAL ANALYSIS

3.4.1. Analysis of variance (ANOVA)

The analysis of variance for all characters under the study was carried out for individual trial using fixed model as follows by using GenStat (ver. 12, Rothamsted, UK).

Source of variation	**Degree of freedom**	**Mean square**	**Expected mean square (EMS)**	**F ratio**
Replication	(r-1)	MSr	$\sigma^2_e + t\,\sigma^2_r$	
Genotypes	(g-1)	MSg	$\sigma_e^2 + r\frac{1}{g-1}\sum_i si^2$	MSg / MSe
Error	(r-1) (t-1)	MSe	σ^2_e	
Total	(rt-1)			

where,

r = number of replications

t = number of treatments (genotypes)

$\frac{1}{t-1}\sum_i si^2$ = genotypic variance of character X

σ^2_e = error variance of character X, and

MSr, MSg and MSe defined as mean squares due to replications, treatments and error, respectively.

3.4.1.1. Pooled analysis of variance

Pooled analysis of variance for each character across two seasons was done as per the fixed model by using GenStat (ver. 12, Rothamsted, UK) (McIntosh, 1983).

Sources of variation	**Degree of freedom**	**M.S.**	**Expected M.S.**	**F ratio**
Environments (Env)	(e–1)	MSe	$\sigma^2 + g\sigma^2_{r\,(e)} + rg\sigma^2_e$	
Replication / Env	e(r–1)	MSr	$\sigma^2 + g\sigma^2_{r\,(e)}$	MSr/MSE
Genotypes	(g–1)	MSg	$\sigma^2 + re\sigma^2_g$	MSg/MSE
Genotype × Env	(g–1) (e–1)	MSge	$\sigma^2 + r\frac{1}{(g-1)(e-1)}\sum_j \sum_i S^2 giej$	MSge/MSE
Pooled error	r(e–1) (g–1)	MSe	σ^2	

Where,

e = number of environments

r = number of replications within an environment

g = number of treatments or genotypes

$\frac{1}{(g-1)(e-1)}\sum_{j}\sum_{j}s^{2}giej$ = genotypic variance of character ‘x’

$\sigma^2_{r\,(e)}$ = variance of character ‘x’ due to replications within environment

σ^2_{ge} = variance of character ‘x’ due to genotype × environment interactions

σ^2 = error variance of character ‘x’, and

MSr, MSg, MSge and MSE defined as mean sum of squares due to replications, genotypes, genotype × environment interactions and error, respectively.

For fixed model, the mean square expectations will not be written as variance symbols e.g., genotypic variance and genotype x environment can not be written as (variance) σ^2_g and σ^2_{ge}, respectively. It can be written as follows (variance estimates)

$\frac{1}{t-1}\sum_{i}si^{2}$ = genotypic variance

$\frac{1}{(g-1)(e-1)}\sum_{j}\sum_{j}s^{2}giej$ = genotypic x environment variance

However, for the simplicity of presentation and understanding purpose hereafter those were written as σ^2_g and $\sigma^2_{ge,}$ respectively.

3.4.2. GENERAL STATISTICS

3.4.2.1. Mean

Mean value ($\overline{X}$) of each character in each trial environment was determined by dividing the sum of the observed values to the corresponding number of observations:

$$\overline{X} = \sum X_{ij} / N$$

Where,

X_{ij} = observation in the ith treatment and jth replication, and

N = total number of observations

3.4.2.2. Standard error

Standard errors of means were calculated for each character for each trial in each environment from the corresponding mean square error values from the analysis of variance tables as:

$$\text{S.E. (m)} = \frac{\sqrt{\text{MSe}}}{r}$$

Where,

MSe = estimated error variance

S.E. $_{(m)}$ = the standard error of the mean, and

r = number of replications

3.4.2.3. Least significant difference (LSD)

LSD values were calculated as suggested by Tukey (1953).

$$\text{LSD} = \sigma^2_d \times t_{(5\%)}$$

t = Table t value at error df in both 5% and 1% level of significance

Where,

$\sigma^2_d = 2 \times \text{MSe} / r$

r = number of replications

Standard error [SE (m)] and critical difference (CD) were calculated to find the significance of treatment differences.

3.4.2.4. Genotypic and phenotypic variances

The genotypic and phenotypic variances for each trait in single plant selection trial (both in set-I and II) were calculated according to the formula given by Hallauer *et al.* (2010)

Genotypic variance of character X = $\sigma^2_{g\,=}$ (MSg – MSe) / r

Phenotypic variance of character X = $\sigma^2_p = \sigma^2_g + \sigma^2_e / r$

3.4.2.5. Estimates of broad-sense heritability (*h*^{2})

Broad-sense heritability h^2 was estimated in each of the two seasons for all the characters studied in S_1 and HS comparison trial. It is the ratio of total genotypic variance to phenotypic variance and was calculated following (Hallauer *et al.*, 2010) for the data recorded in individual seasons.

$$h^2 = \text{Vg} / \text{Vp}$$

$$h^2 = \frac{\sigma^2 g}{(\sigma^2 g + \sigma_e^2 / r)}$$

Broad-sense heritability estimates across the environments were computed by the formula

$$h^2 = Vg / [Vg + Ve]$$

$$h^2 = \frac{\sigma^2 g}{(\sigma^2 g + \sigma_e^2/re)}$$

Where,

h^2 = broad-sense heritability

Vg = genotypic variance = σ^2_g

Vp = phenotypic variance = $\sigma^2_p = \sigma^2_g + \sigma^2_e/r$

Ve = Error variance = σ^2_e

The range of heritability was categorized as suggested by Robinson *et al*. (1949)

Low	-	<30
Moderate	-	30 to 60
High	-	>60

3.4.3. ANALYSIS OF COMBINING ABILITY

3.4.3.1. ANOVA for combining ability (individual season)

Line x tester analysis was carried out to test parents and hybrids with respect to their general and specific combining ability, respectively, following Kempthorne (1957) and Arunachalam (1974). The mean values of parents and hybrids were utilized for statistical analysis. The mean squares due to different sources of variation as well as their genetic expectations were estimated as follows.

Sources of variation	**Degrees of freedom**	**Mean squares**	**Expectations of mean squares**
ANOVA for parents			
Replications	r-1		
Parents	p-1	Mp	$\sigma_e^2 + r\frac{1}{p-1}\sum_i pi^2$
Error	(r-1)(p-1)	Me	σ^2_e
Total	(rp-1)		
ANOVA for combining ability analysis			
Replications	r-1		
Crosses	lt-1	Mc	

Lines	l-1	Ml	$\sigma_e^2 + rt\frac{1}{l-1}\sum_i gi^2$
Testers	t-1	Mt	$\sigma_e^2 + rl\frac{1}{t-1}\sum_j gj^2$
Lines × testers	(l-1) (t-1)	M l x t	$\sigma_e^2 + r\frac{1}{(l-1)(t-1)}\sum_i \sum_j s^2_{ij}$
Error	(r-1)(lt-1)	Me	σ^2_e
Total	(rlt-1)		

where,

r = number of replications,

l = number of lines and

t = number of testers.

3.4.3.2. Estimating general combining ability (*GCA*) and specific combining ability (SCA) variance

σ^2_{GCA} and σ^2_{SCA} were estimated following fixed effect model (Kaushik *et al.*, 1984) as detailed below,

$$\sigma^2_l = (M\,l - Me) / rt$$

$$\sigma^2_t = (Mt - Me) / rl,$$

and used to estimate variance due to general combining ability (σ^2_{GCA})

$$\sigma^2_{GCA} = \frac{\{(l-1)\,\sigma^2_l + (t-1)\,\sigma^2 t\}}{(l + t - 2)}$$

and variance due to specific combining ability as

$$\sigma^2_{SCA} = (M_{l\,x\,t} - Me) / r$$

$$= \frac{M_3 - M_4}{r}$$

From the variances of *GCA* and SCA, the predictability ratio for gene action was calculated as follows

3.4.3.3. Predictability ratio

Predictability ratio (PR) was computed following Baker (1978),

$$\text{Predictability Ratio (PR)} = \frac{2\,\sigma^2_{gca}}{(2\,\sigma^2_{gca} + \sigma^2_{sca})}$$

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.

3.4.3.4. Proportional contribution of line, tester and line x tester to total genotypic variance (K N Rai Pers. Comm.)

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

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

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

3.4.3.5. Estimating general combining ability (*gca*) and specific combining ability (*sca*) effects

General combining ability effect (*gca*) of parents and specific combining ability effect (*sca*) of hybrids of ijkth observation was arrived at using the mathematical model given below.

$$Xijk = \mu + \hat{g}i + \hat{g}j + \hat{s}ij + \hat{e}ijk$$

Where,

$Xijk$ = Value of ijkth observation,

i = number of lines,

j = number of testers,

k = number of replications,

μ = population mean,

$\hat{g}i$ = *gca* effect of ith line,

$\hat{g}j$ = *gca* effect of jth tester,

$\hat{s}ij$ = *sca* effect of ijth hybrid and

$\hat{e}ijk$ = error associated with ijkth observation.

$$\text{Mean } (\mu) = \frac{X...}{rlt}$$

Where,

X… = Total of all hybrids,

r = number of replications,

l = number of lines and

t = number of testers.

3.4.3.6. *gca* and *sca* effects

The individual *gca* and *sca* effects were estimated as follows.

$$\textit{gca} \text{ effects of lines} = gi = \frac{xi..}{rt} - \frac{x...}{rlt}$$

$$\textit{gca} \text{ effects of testers} = gj = \frac{x.j.}{rl} - \frac{x...}{rlt}$$

$$\textit{sca} \text{ effects of hybrids} = Sij = \frac{xij.}{r} - \frac{xi..}{rt} - \frac{x.j.}{rl} + \frac{x...}{rlt}$$

where,

x… = grand total of all hybrid combinations,

xi.. = total of i^{th} line over ‘t’ s ($j = 1- n_2$) tester and ‘r’ replications ($k = 1 - n_3$) ,

x.j. = total of j^{th} tester over ‘l’ ($i = 1 – n_1$) lines and ‘r’ ($k = 1 – n_3$) replications and

xij. = total of the hybrid between i^{th} line and j^{th} tester over r replications.

3.4.3.7. Testing significance of combining ability effects

The standard errors pertaining to *gca* effect of lines and testers and *sca* effects of hybrids were calculated as detailed below (Singh and Chaudhary, 1985).

1. S.E. of *gca* of lines (ĝi) $= \sqrt{\frac{\sigma^2 e}{rt}}$

2. S.E. of *gca* of testers $= \sqrt{\frac{\sigma^2 e}{rl}}$

3. S.E of *sca* of hybrids $= \sqrt{\frac{\sigma^2 e}{r}}$

Where,

S.E. = Standard error and

σ^2_e = Error mean square.

The significance of *gca* effect of lines and testers and *sca* effects of hybrids was tested against twice the standard error at 5% and 1% level.

3.4.4. ESTIMATING 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 Fonseca and Patterson (1968).

3.4.4.1. 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.

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

3.4.4.2. Better parent (BP) heterosis

It was estimated as the percent deviation of the mean performance of F_1 over the 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,

$\overline{MP}$ = Mean value of the two parents involved in the cross,

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

The significance of mid-parent and better parent heterosis was tested at error degrees of freedom (Turner, 1953 and KN Rai Pers. Comm.).

i. ‘t’ for MP heterosis =

$$\frac{\overline{F_1} - \overline{MP}}{\sqrt{[\sigma^2_{e\,(c)} + ½\,\sigma^2_{e\,(p)}] / r}}$$

ii. ‘t’ for BP heterosis =

$$\frac{\overline{F_1} - \overline{BP}}{\sqrt{[\sigma^2_{e\,(c)} + \sigma^2_{e\,(p)}] / r}}$$

Where,

$\sigma^2_{e\,(p)}$ = Error variance from ANOVA for parents

$\sigma^2_{e\,(c)}$ = Error variance from ANOVA for crosses

r = Number of replications.

The calculated 't' values for mid-parent heterosis and better parent heterosis were compared with table 't' value for error degrees of freedom at 5% and 1% levels.

3.4.5. ANOVA for combining ability across seasons

The analysis of variance for combining ability over the seasons (environments) were estimated as suggested by El-Itriby *et al.* (1981)

Source of variation	Degrees of freedom	Expectation of mean squares
ANOVA for parents and crosses		
Environments	(e-1)	
Replication / environment	e (r-1)	
Parents	(p-1)	$\sigma^2 + r\sigma^2_{pe} + re\sigma^2_p$
Parents × environments	(p-1) (e-1)	$\sigma^2 + r\sigma^2_{pe}$
Error	e(r–1) (p–1)	σ^2
ANOVA for combining ability analysis		
Environments	(e-1)	
Replication / environment	e (r-1)	
Crosses	(lt-1)	$\sigma^2 + r\sigma^2_{ce} + re\sigma^2_c$
Lines	(l-1)	$\sigma^2 + r\,\sigma^2\,lte + rt\sigma^2 le + re\sigma^2\,lt + rte\sigma^2 l$
Testers	(t-1)	$\sigma^2 + r\,\sigma^2\,lte + rl\sigma^2\,te + re\sigma^2\,lt + rle\sigma^2 t$
Lines × testers	(l-1) (t-1)	$\sigma^2 + r\,\sigma^2\,lte + re\sigma^2\,lt$
Crosses × environments	(lt-1) (e-1)	$\sigma^2 + r\sigma^2_{ce}$
Lines × environments	(l-1) (e-1)	$\sigma^2 + r\,\sigma^2\,lte + rt\sigma^2 le$
Testers × environments	(t-1) (e-1)	$\sigma^2 + r\,\sigma^2\,lte + rl\sigma^2 te$
(Lines × testers) × environments	(m-1) (f-1) (e-1)	$\sigma^2 + r\,\sigma^2\,lte$
Error	e(r-1) (lt-1)	σ^2

Where,

e = number of environments

l = number of line parents

t = number of tester parents

r = number of replications

σ^2 = pooled error variance

$\sigma^2 e$ = environment variance

$\sigma^2 c$ = cross variance

$\sigma^2 lt$ = variance due to interaction between lines and testers

$\sigma^2 fe$ = the variance due to interaction between lines effects and environments.

$\sigma^2 te$ = variance due to interaction between tester effects and environments.

$\sigma^2 lte$ = variance due to interaction among line, tester and environments.

First calculated σ^2_l and σ^2_t as discussed below (Kaushik *et al.,* 1984),

$$\sigma^2_l = (M\,l - Me) / rte$$

$$\sigma^2_t = (M\,t - Me) / rle,$$

and used line and tester variance to determine σ^2_{GCA} and σ^2_{SCA} following Kaushik *et al.* (1984) as follows

$$\sigma^2_{GCA} = \frac{\{(l-1)\,\sigma^2 l + (t-1)\,\sigma^2 t\}}{(l + t - 2)}$$

$$\sigma^2_{SCA} = \frac{(M_{l \times t} - Me)}{re}$$

3.4.6. Estimating genetic variance components

Fisher (1918) partitioned the hereditary (genetic) variance of a population into additive variance (σ^2_A), dominant variance (σ^2_D) and epistatic variance (σ^2_I) as detailed below,

$$\sigma^2_G = \sigma^2_A + \sigma^2_D + \sigma^2_I$$

Assuming there is no epistasis, the additive and dominant variances were estimated from the observed data by applying the expected genetic variance (Hallauer and Miranda, 1981) as detailed below,

$$\sigma^2_{HS} = \tfrac{1}{4}\,\sigma^2_A$$

$\sigma^2{}_{S1} = \sigma^2{}_A + ¼\, \sigma^2{}_D$

Theoretically, the total genetic variance (among and within half-sib families) equals the total genetic variance in the reference population, i.e., $\sigma^2{}_G = \sigma^2{}_A + \sigma^2{}_D$. From this total variance (¼) $\sigma^2{}_A$ is expressed among half-sib families. The remainder, (¾) $\sigma^2{}_A + \sigma^2{}_D$, is expected to be present within half-sib families over the entire population of families. Distribution of genetic variances among and within lines estimated under continuous selfing when p = *q* = 0.5 (Hallauer *et al.,* 2010). Similarly according to Hallauer (1981), in the absence of interaction effects (epistasis), the total genotypic variance will be partitioned as follows

Selection method	$\sigma^2{}_G$	
	$\sigma^2{}_A$	$\sigma^2{}_D$
HS progenies	¼	0
S_1 Progenies	1 [a]	¼ [c]

Where,

a - not equal to $\sigma^2{}_A$ unless p = q = 0.5 and dominance decreases to zero with inbreeding

c – co-efficient difficult to define unless p = q = 0.5.

3.4.6.1. Estimating additive (A) and dominance (D) genetic variance

The data of S_1 and HS progenies was subjected to analysis of variance by using GenStat (12 version) for individual season as follows

Source of variation	**df**	**MS**	**Expected MS**
Replications	r-1		
Genotypes (S_1&HS)	g-1	MSg	$\sigma^2e + r\,\sigma^2g$
S_1 progenies (S_1)	s-1	MS_{S1}	$\sigma^2e + r\,\sigma^2s_1$
HS progenies (HS)	hs-1	MS_{HS}	$\sigma^2e + r\,\sigma^2{}_{HS}$
S_1 Vs HS	1	$MS_{S1\cdot HS}$	$\sigma^2e + r\,\sigma^2s_{1.\ HS}$
Error	(r-1) (g-1)	MSe	σ^2e

Likewise, both S_1 and HS progenies data were subjected to analysis of variance over the season as follows

Source of variation	**df**	**MS**	**Expected MS**
Environments (Env)	e-1	MSe	$\sigma^2 + r\sigma^2ge + g\sigma^2re + rg\sigma^2e$
Replication / Env	e(r-1)	MSr	$\sigma^2 + g\,\sigma^2re$
Genotypes (S_1 & HS)	g-1	MSg	$\sigma^2 + r\sigma^2ge + re\sigma^2_g$
S_1 progenies	s-1	MSs	$\sigma^2 + r\sigma^2_{S1.e} + re\sigma^2_{S1}$
HS progenies	hs-1	MS_{HS}	$\sigma^2 + r\sigma^2_{HS.e} + re\sigma^2_{HS}$
S_1 Vs HS	1	MS_{S1vHS}	$\sigma^2 + r\sigma^2_{S1v\,HS.\,e} + re\sigma^2_{S1vHS}$
Genotypes ×Env	(g-1) (e-1)	MSge	$\sigma^2 + r\sigma^2ge$
S_1 × Env	(s-1)(e-1)	$MS_{S1.e}$	$\sigma^2 + r\sigma^2_{S1.\,e}$
HS × Env	(hs-1) (e-1)	$MS_{HS\cdot e}$	$\sigma^2 + r\sigma^2_{HS\cdot e}$
S_1 Vs HS × Env	1	$MS_{S1vHS\cdot e}$	$\sigma^2 + r\sigma^2_{S1v\,HS.\,e}$
Pooled error	e (r-1) (g-1)	MSE	σ^2

Where,

e = number of environments

r = number of replications within an environment

g = number of treatments or genotypes

$\sigma^2 s_1$ = S_1 genotypic variance of character ‘x’

σ^2_{HS} = HS genotypic variance of character ‘x’

$\sigma^2 re$ = variance of character ‘x’ due to replications within environment

$\sigma^2_{S1.e}$ = variance of character ‘x’ due to S_1 × environment interactions

$\sigma^2_{HS.e}$ = variance of character ‘x’ due to HS × environment interactions

σ^2 = error variance of character ‘x’,

The genetic components of variances were obtained as outlined by Jan-Orn *et al.* (1976) and the observed mean squares were substituted into the equations as follows:

Estimation of genotypic variance: $\sigma^2_g = (MSg – MS_e) / r$

3.4.6.1.1. Estimating additive variance (A)

$\sigma^2{}_{HS} = [MS_{HS} - MS_e] / r$

Since, $\sigma^2{}_{HS} = ¼\, \sigma^2{}_A$

$\sigma^2{}_A = 4\ (\sigma^2{}_{HS})$, It can be rewritten as follows

$¼\, \sigma^2{}_A = [(MS_{HS} - MS_e) / r]$

$\sigma^2{}_A = 4\ [(MS_{HS} - MS_e) / r]$

3.4.6.1.2. Estimating dominance variance (D)

$\sigma^2{}_{S1} = (MS_{S1} - MS_e) / r$

Since, $\sigma^2{}_{S1} = \sigma^2{}_A + ¼\, {}_D$

$\sigma^2{}_{S1} = [4\ (\sigma^2{}_{HS}) + ¼\, \sigma^2{}_D]$

$¼\, \sigma^2{}_D = [\sigma^2{}_{S1} - 4\ (\sigma^2{}_{HS})]$

$\sigma^2{}_D = 4\ [\sigma^2{}_{S1} - 4\ (\sigma^2{}_{HS})]$

since, $\sigma^2{}_A = 4\ (\sigma^2{}_{HS})$ this can simplified as follows

$\sigma^2{}_D = 4\ [\sigma^2{}_{S1} - \sigma^2{}_A]$

3.4.6.1.3. Estimating additive variance from pooled ANOVA

$\sigma^2{}_{HS} = [MS_{HS} - MS_e] / re$

Since, $\sigma^2{}_{HS} = ¼\, \sigma^2{}_A$

$\sigma^2{}_A = 4\ (\sigma^2{}_{HS})$, It can be rewritten as follows

$¼\, \sigma^2{}_A = [(MS_{HS} - MS_e) / re]$

$\sigma^2{}_A = 4\ [(MS_{HS} - MS_e) / re]$

3.4.6.1.4. Estimating dominanace variance from pooled ANOVA

$\sigma^2{}_{S1} = (MS_{S1} - MS_e) / re$

Since, $\sigma^2{}_{S1} = \sigma^2{}_A + ¼\, {}_D$

$\sigma^2{}_{S1} = [4\ (\sigma^2{}_{HS}) + ¼\, \sigma^2{}_D]$

$¼\, \sigma^2{}_D = [\sigma^2{}_{S1} - 4\ (\sigma^2{}_{HS})]$

$\sigma^2{}_D = 4\ [\sigma^2{}_{S1} - 4\ (\sigma^2{}_{HS})]$

since, $\sigma^2{}_A = 4\ (\sigma^2{}_{HS})$ this can simplified as follows

$$\sigma^2{}_D = 4\ [\sigma^2{}_{S1} - \sigma^2{}_A]$$

3.4.7. Genetic gain

Genetic gain per cycle was determined by direct comparison of cycles (C_0 and C_1) of both original and selected populations, and the gain realized in the selection was measured by the difference between the C_0 and C_1 populations (Keeling, 1982)

$$\text{Gain cycle}^{-1} = (\mu C_1 - \mu C_0) / \mu C_0$$

Where,

μC_1 = mean of selected populations for traits 'x' evaluated

μC_0 = mean of original populations for traits 'x' evaluated.

Realized response to selection was calculated as follows (Totok *et al.,* 1998):

$$\text{Realized response} = \mu C_1 - \mu C_0$$

3.4.8. CORRELATION ANALYSIS

The phenotypic correlation amongst grain Fe and Zn concentration, 1000-grain mass, flowering and grain yield was worked out for individual and pooled seasons. Phenotypic correlation coefficient were estimated using the formula as suggested by Al-Jibouri *et al.* (1958),

$$r_{p\ (xy)} = \frac{\text{Cov}_p(X, Y)}{\sqrt{\text{Var}_p\ (X)\ \text{Var}_p\ (Y)}}$$

Where,

$r_{p\ (xy)}$ = phenotypic correlation coefficient

Cov_p (X, Y) = phenotypic covariance between characters X, Y

Var_p (X) = phenotypic variance in character X

Var_p (Y) = phenotypic variance in character Y

The significance of correlation coefficient was tested by referring to the standard table given by Snedecor and Cochran (1967). The observed correlation co-efficient was compared with the tabulated value for (n-2) degrees of freedom for test of significance.

CHAPTER 4

EXPERIMENTAL RESULTS

CHAPTER 4

EXPERIMENTAL RESULTS

The present study was carried out to i) determine combining ability, nature of gene action and heterosis for grain Fe and Zn, 1000-grain mass and days to 50% flowering (*hereafter referred as* flowering) in two sets of line x tester mating design; ii) estimate genetic variance for grain Fe and Zn in two populations using selfed (S_1) and half-sib (HS) family structure; iii) asses the efficiency of single plant selection for grain Fe and Zn in four populations; iv) assess intra-population variability for enhancing grain Fe and Zn using one cycle of recurrent selection; and v) to examine the relationships between grain minerals (Fe and Zn) and agronomic traits (flowering, 1000-grain mass and grain yield). All the trials were conducted in Alfisols at ICRISAT centre, Patancheru.

4.1. Soil Fe and Zn variability in experimental fields

Soil samples (appendix ii) collected at the depth of 0 - 30 cm from all the experimental fields during the 2009 and 2010 seasons were analyzed for fe and Zn. The suggested critical limit of the elements in the soil is 2.0 mg kg^{-1} for Fe and 0.75 mg kg^{-1} for Zn (K. L. Sahrawat Pers. Comm.). The experimental fields used in this study had more than sufficient levels of available soil Fe and Zn (DTPA extractable). However, the available soil Fe and Zn in the fields that were used varied across the seasons. The soil Fe in summer season (2009) fields varied from 5.4 to 15.8 mg kg^{-1}, while in rainy season (2009) fields it varied from 5.1 to 7.6 mg kg^{-1}. The soil Zn ranged from 4.1 to 5.7 mg kg^{-1} in summer season fields, while it varied from 2.3 to 3.9 mg kg^{-1} in rainy season fields. the average soil Fe in summer (15.35 ± 0.44 mg kg^{-1}) was 165% more compared to rainy season (5.8 ± 0.82 mg kg^{-1}), whereas average Zn in summer (5.25 ± 0.54 mg kg^{-1}) was 128% more than in rainy season (2.3 ± 0.00 mg kg^{-1}). in 2010 rainy season, the average Fe (7.53 ± 0.10 mg kg^{-1}) was 22.4% higher than in summer (6.15 ± 1.04 mg kg^{-1}), whereas Zn in summer (4.34 ± 0.22 mg kg^{-1}) was 14.7% higher than in rainy season (3.76 ± 0.17 mg kg^{-1}). The summer 2009 season had soil Fe and Zn, respectively, greater than 150% and 21% than in 2010 summer. Likewise, the 2010 rainy season field had soil Fe and Zn greater than 30% and 63% than in 2009 rainy season.

4.2. Line x tester analysis

4.2.1. 8 lines × 9 testers trial (set - I)

4.2.1.1. Analysis of variance

The differences among parents and crosses were highly significant ($p<0.01$) for grain Fe and Zn, 1000-grain mass and flowering during the two seasons (summer and rainy) (table 5a and 5b). The pooled analysis of variance showed highly significant differences among parents (P), environment (E) and P x E interaction (PEI) for all the characters except grain Fe (table 6a). Similarly, interaction of crosses with environment was significant for all the characters (table 6b).

4.2.1.2. Analysis of variance for combining ability

Analysis of variance for combining ability (table 5b) revealed that differences due to lines as well as testers were highly significant for all characters in both the seasons. The line x tester interaction effect was highly significant for 1000-grain mass in both the seasons, while for other characters it was highly inconsistent from one season to the other. the magnitude of variance due to general combining ability (σ^2*gca*) variance was more than the variance due to specific combining ability (σ^2sca) for all the characters in both the seasons, indicating the predominance of additive genetic effects on the expression of these traits (table 5 b). The predictability ratio (pr) ranged from 0.79 (1000-grain mass) to 0.91 (grain Fe and Zn) in summer season, whereas it was from 0.77 (grain Fe) to 1.0 (grain Zn) in rainy season. The pr ratio 1.0 observed for grain Zn during rainy season was due to negative value of σ^2sca that was assumed as zero while estimating the pr ratio.

The pooled analysis of variance for combining ability revealed that the variances due to lines, testers and lines x tester's interactions were all highly significant for all traits (Table 6b). Further lines x environments and testers x environments interaction effects were also significant for all traits. The line x tester x environment means square was significant only for 1000-grain mass. The magnitude of variance due to σ^2*gca* was higher than that due to σ^2sca for all four traits. However, the estimates of σ^2*gca* variance for grain Fe and Zn were much more than those detected for1000-grain mass and flowering. The predictability ratio was closer to unity for all traits, with values greater for grain Zn and flowering (0.93 to 0.95) in comparison to grain Fe and 1000-grain mass (0.84) (Table 6 b).

4.2.1.3. Contribution of lines, testers and line x tester interactions to total genotypic variation

The testers in both the seasons (summer and rainy) contributed more genetic variation for flowering (53.8% in summer and 57.1% in rainy), grain Fe (51.2% in summer and 47.7% in rainy) and Zn (52.6% in summer and 78.0% in rainy) (Table 7). Similar trends (testers contributed more) for these traits were also observed in across seasons. For 1000-grain mass, both lines and testers equally contributed during the summer (39.5% and 39.8%). In rainy and across the seasons, lines contributed more genetic variation for 1000-grain mass (43.8% in rainy and 43.6% across season). In contrast, variance due to line x tester contributed much less than either lines or testers alone for all four traits, and no contribution for grain Zn during rainy season.

4.2.1.4. *Per se* performance of parents and hybrids

4.2.1.4.1. Grain Fe concentration

The grain Fe ranged from 61.8 (ICMB 97111) to 129.7 mg kg^{-1} (ICMB 98222) in summer season and from 36.3 (ICMB 00888) to 79.4 mg kg^{-1} (ICMB 94111) in rainy season, with an average of 55.8 mg kg^{-1} in rainy season and 88.7 mg kg^{-1} in summer season. Based on pooled mean, Fe amongst the lines ranged from 53.7 (ICMB 93333; low parent) to 101.5 mg kg^{-1} (ICMB 98222; high parent), with an average of 72.2 mg kg^{-1} (Appendix III and Fig. 1). Amongst the testers, grain Fe ranged from 51.1 (IPC 390) to 114.2 mg kg^{-1} (IPC 1650) in summer seasons and from 33.6 (IPC 1354) to 87.3 mg kg^{-1} (IPC 1650) in rainy season, with an average of 57.5 mg kg^{-1} in rainy season and 79.6 mg kg^{-1} in summer season. The mean Fe concentration across seasons among the testers varied from 40.5 (IPC 1354) to 100.7 mg kg^{-1} (IPC 1650). Like lines, the average tester's performance for grain Fe was much more during the summer season (79.6 mg kg^{-1}) than during the rainy (57.5 mg kg^{-1}) season. Across the seasons, ICMB 98222 amongst the lines and IPC 1650 amongst the testers were found superior for grain Fe, both having about 101 mg kg^{-1}. The average grain Fe was 59% and 38% greater, respectively, for lines and testers in the summer season than in the rainy season (Appendix III).

The variation for grain Fe among hybrids ranged from 42.9 (ICMB 97111 x IPC 1354; L x L) to 94.4 mg kg^{-1} (ICMB 00888 x IPC 1178; M x M) with a mean of 61.1 mg kg^{-1} in summer season, whereas in rainy season it varied from 26.3 (ICMB 93333 x IPC 390; L x L) to 61.3 mg kg^{-1} (ICMB 94111 x IPC 1178; H x M), with a mean of 40.9 mg kg^{-1}. The pooled mean showed variability from 35.6 (ICMB 93333 x IPC 390) to 75.4 mg kg^{-1} (ICMB 93222 x IPC 1178 H x M), with a mean of 51 mg kg^{-1}. The average grain Fe in summer was 49% more than in rainy season (40.9 mg kg^{-1}). On the basis of pooled mean, all the H x H and H x M crosses showed ≥50 mg kg^{-1}, with most of the hybrids involving H x H and H x M crosses had >60 mg kg^{-1} of grain Fe. However, L x L hybrids showed low grain Fe (<50 mg kg^{-1}). Overall, the hybrid (ICMB 93333 x IPC 390) consistently showed lower grain Fe in individual environment as well as across the seasons. Hybrids with high grain Fe were not consistent in performance as was the case with the low grain Fe hybrids. For example, ICMB 00888 x IPC 1178 in summer season and ICMB 94111 x IPC 1178 in rainy season had high grain Fe. However, across the seasons, another hybrid (ICMB 93222 x IPC 1178) had shown high grain Fe.

4.2.1.4.2. Grain Zn concentration

The grain Zn among lines varied from 49.3 (ICMB 97111) to 93.4 (ICMB 98222) in summer season, from 30.8 (ICMB 97111) to 52.8 mg kg^{-1} (ICMB 98222) in rainy season, and from 40.1 (ICMB 97111) to 73.1 mg kg^{-1} (ICMB 98222) across the seasons, with an average of 44.8 mg kg^{-1} in rainy season and 73.5 mg kg^{-1} in summer season. Both higher (ICMB 98222) and lower (ICMB 97111) grain Zn parents, respectively, exhibited consistently higher and lower levels of Zn across the seasons (Appendix III and Fig. 2). The variation for grain Zn amongst the testers ranged from 40.9 (IPC 390) to 90.7 mg kg^{-1} (IPC 774) in summer season, from 26.4 (IPC 1354) to 84.5 mg kg^{-1} (IPC 1650) in rainy season, and from 34.4 (IPC 1354) to 84.1 mg kg^{-1} (IPC 774) across the seasons, with an average of 54.2 mg kg^{-1} in rainy season and 66.8 mg kg^{-1} in summer season. The average grain Zn was 64% and 23% greater, respectively, for lines and testers in the summer than in the rainy season (Appendix III).

The grain Zn among hybrids varied from 40.7 (ICMB 97111 x IPC 390) to 83.1 mg kg^{-1} (ICMB 04777 x IPC 774) in summer season, from 27.9 (ICMB 97111 x IPC 390) to 60.7 mg kg^{-1} (ICMB 04777 x IPC 1178) in rainy season, and from 34.3 (ICMB 97111 x IPC 390) to 69.5 (ICMB 94111 x IPC 1178) across the seasons, with an average of 40.4 mg kg^{-1} in rainy season and 62.5 mg kg^{-1} in summer season. The average grain Zn in the summer season was 55% more than in the rainy season (40.9 mg kg^{-1}). The H x M and M x M crosses, in general, had wider range for grain Zn (50 to 69.5 mg kg^{-1}) than those hybrids (51.9 - 60.5 mg kg^{-1}) which had in their pedigree's both parents with high grain Zn. In contrast, hybrids involving both the parents with lower Zn levels had shown lower variability, except for hybrid ICMB 93333 x IPC 1307 (53.3 mg kg^{-1}), for grain Zn (33.3 – 46.7 mg kg^{-1}). Hybrids involving M x H (ICMB 04777 x IPC 774) in summer season and M x M (ICMB 04777x IPC 1178) in the rainy season had shown higher grain Zn concentration, with latter hybrid also showing high grain Zn in across the seasons.

4.2.1.4.3. 1000-grain mass

The 1000-grain mass among the lines varied from 6.4 (ICMB 93333) to 11.7 g (ICMB 00888) in summer season and from 5.9 (ICMB 89111) to 13.4 g (ICMB 00888) in rainy seasons. However, the mean grain mass between the two seasons remained about 9 g per 1000 grains. In the pooled analysis, it ranged from 6.4 (ICMB 89111) to 12.5 g (ICMB 00888), again with a mean of 9 g (Appendix III). Among the testers, 1000-grain mass ranged from 5.7 g (IPC 1178) to 9.6 g (IPC 1354) in summer season, from 5.9 (IPC 390) to 13.2 g (IPC 828) in rainy season, and from 5.9 (IPC 390) to 11.2 g (IPC 828) across the seasons.

Among the hybrids, 1000-grain mass varied from 7.9 (ICMB 93333 x IPC 616) to 14.1 g (ICMB 93222 x IPC 774) in summer season, from 7.4 g (ICMB 89111 x IPC 1307) to 15.8 g (ICMB 00888 x IPC 1178) in rainy season, and from 7.9 (ICMB 89111 x IPC 1307) to 14.7 (ICMB 93222 x IPC 774 and ICMB 00888 x IPC 828) across the seasons, with an average of 11 g in summer season and 12 g in rainy seasons. Twelve of the 72 hybrids exhibited $\geq$13 g of 1000-grain mass. Of these, 10 hybrids had at least one parent either with high or medium grain Fe/Zn, which indicate that high Fe and Zn hybrids do not necessarily have smaller grain. Based on two season analysis, it appears that hybrids involving H x H, M x H, M x M and M x L parents had shown greater 1000-grain mass in the range of 10 – 14 g.

4.2.1.4.4. Flowering

Flowering among the lines ranged from 48 (ICMB 97111) to 59 days (ICMB 04777) in summer season, from 47 (ICMB 00888) to 58 days (ICMB 04777) in rainy season, and from 48 (ICMB 00888) to 59 days (ICMB 04777) across the seasons. However, mean flowering time was similar among lines between seasons and across seasons (52-53 days) (Appendix-III). The line ICMB 00888 flowered earliest (48 days) whereas ICMB 04777 was latest to flower (59 days) in individual environment as well as across the seasons. The flowering amongst testers (pollen parents) ranged from 48 (IPC 774) to 61 days (IPC 1307) in summer season, from 52 (IPC 774) to 58 days (IPC 1307) in rainy season, and from 50 (IPC 774) to 59 days (IPC 1307) across the seasons. IPC 774 flowered in 48-52 days (earliest) in both the seasons, while IPC 1307 flowered in 58-61 days (late) in the two seasons. The mean flowering time was similar among testers in individual environment as well as across the seasons (54 -55 days).

Among the hybrids, flowering ranged from 46 to 58 days, with an average of 50 days during summer season. Four hybrids (ICMB 97111 x IPC 774, ICMB 98222 x IPC 390, ICMB 94111 x IPC 774 and ICMB 89111 x IPC 774) flowered in 46 days, while hybrid ICMB 93333 x IPC 828 flowered in 58 days. In rainy season, flowering varied from 44 (ICMB 00888 x IPC 774) to 55 (ICMB 04777 x IPC 828) days, and the average flowering time was similar in both the seasons 49-50 days. Some of early flowering (44-46 days) hybrids were ICMB 89111 x IPC 774, ICMB 97111 x IPC 774, ICMB 94111 x IPC 774, ICMB 97111 x IPC 390, ICMB 97111 x IPC 616, ICMB 98222 x IPC 1354, ICMB 00888 x IPC 616, ICMB 00888 x IPC 390, ICMB 89111 x IPC 390, ICMB 98222 x IPC 616 and ICMB 00888 x IPC 1354. Over the two seasons, the flowering varied from 46 (ICMB 00888 x IPC 616, ICMB 89111 x IPC 774, ICMB 97111 x IPC 616, ICMB 97111 x IPC 774, ICMB 97111 x IPC 390) to 55 days (ICMB 93333 x IPC 1178, ICMB 04777 x IPC 1307 and ICMB 04777 x IPC 828), with an average of 50 days. Five of the six hybrids (early flowering), based on two seasons' performance, had at least one high Fe/Zn parent in their pedigrees. Hybrids in general flowered 2-4 days earlier than parental lines in individual environment as well as across the seasons.

4.2.1.5. General combing ability effects

4.2.1.5.1. Grain Fe concentration

The general combing ability (*gca*) effects for grain Fe ranged from -12.4 (ICMB 97111) to 8.1 (ICMB 93222) in summer season, from -5.0 (ICMB 97111) to 5.1 (ICMB 93222) in rainy season, and from -8.7 (ICMB 97111) to 6.6

(ICMB 93222) across the seasons among the lines, whereas among testers, it ranged from -9.5 (IPC 390) to 16.6 (IPC 1178) in summer season, from -8.0 (IPC 390) to 7.8 (IPC 1178) in rainy season and from -8.7 (IPC 390) to 12.2 (IPC 1178) across seasons (Table 8a). Among the lines, ICMB 93222 and ICMB 98222 exhibited highly significant positive *gca* effects for grain Fe in individual environment as well across seasons, while ICMB 04777 showed highly significant positive *gca* effects during summer and across the seasons. ICMB9333 and ICMB 97111 had significant negative effects in individual environment as well as across the seasons. Among testers, IPC 1178 exhibited highly significant *gca* effects in individual environment as well as across the seasons, while IPC 843 and IPC 774 had positive and significant *gca* effects in summer and across seasons. IPC 1650 had positive significant *gca* effect (P<0.05) in rainy season. IPC 1354 and IPC 390 had significant negative *gca* effects in individual environment as well as across the seasons.

Based on two seasons, parents were classified into three distinct classes (high, medium and low) for grain Fe (Table 3). It is clear that parents with high (ICMB 93222, ICMB 98222, and IPC 774) or medium Fe levels (ICMB 04777, IPC 843, and IPC 1178) exhibited positive and significant *gca* effects for Fe, whereas parents with low Fe levels (ICMB 93333, ICMB 89111, ICMB 97111, IPC 1354, IPC 390 and IPC 828) had negative and significant *gca* effects for Fe. The correlation between *per se* performance of the lines and its *gca* effects was positive and highly significant (P<0.01) in individual environment (r = 0.89 in summer and 0.73 in rainy) as well as across the seasons (r = 0.90), whereas such positive and significant correlations among testers was observed only in summer (r = 0.84; P<0.01) and across seasons (r = 0.75; P<0.05). Overall, correlation between parents *per se* (lines and testers) and its *gca* effects was positive and highly significant (r = 0.75; P<0.01; Fig. 3).

4.2.1.5.2. Grain Zn concentration

The *gca* effects for grain Zn among lines ranged from -14.0 (ICMB 97111) to 6.6 (ICMB 98222) in summer season, from -5.8 (ICMB 97111) to 3.9 (ICMB 04777) in rainy season, and from -9.9 (ICMB 97111) to 5.0 (ICMB 04777) across the seasons. Among the testers, *gca* effects varied from -9.8 (IPC 390) to 12.3 (IPC 1178) in summer season, from -6.5 (IPC 390) to 9.2 (IPC 1178) in rainy season, and from -8.1 (IPC 390) to 10.75 (IPC 1178) across the seasons (Table 8a).

Based on two seasons, parents were classified into three distinct classes (high, medium and low) for Zn (Table 3). The parents with either high (ICMB 93222, ICMB 98222, ICMB 04777, IPC 1650, and IPC 774) or medium Zn levels (ICMB 04777, IPC 843, and IPC 1178) exhibited significant positive *gca* effects, while parents with low Zn levels (ICMB 97111, IPC 1354, IPC 390 and IPC 828) had negative and significant *gca* effects. In contrast, another parent with high Zn ICMB 94111 exhibited significantly negative *gca* for Zn. Overall, the parents with low Zn levels (ICMB 97111, IPC 1354, IPC 390 and IPC 828) consistently had negative significant *gca* for Zn. The *per se* performance of the lines and testers were highly significant ($P<0.01$) and positively associated with their *gca* effects in summer (lines $r = 0.91$, testers $r = 0.88$) as well across the seasons (lines $r = 0.87$ and testers $r = 0.77$). Across the seasons, similar positive and highly significant correlation was found between *per se* of parents (lines and testers) and its *gca* effects($r = 0.78$; $P<0.01$; Fig. 3).

4.2.1.5.3. 1000-grain mass

The *gca* effects for 1000-grain mass varied from -1.3 (ICMB 93333) to 1.3 (ICMB 00888) among lines and from -1.0 (IPC 616) to 1.4 (IPC 828) among testers in summer (Table 8b), whereas in rainy season, the *gca* effects ranged from -1.2 (ICMB 89111) to 2.0 (ICMB 00888) among lines and from -1.6 (IPC 1307) to 1.5 (IPC 828) among testers. Across seasons, it ranged from -1.2 (ICMB 93333) to 1.6 (ICMB 00888) among lines and from -1.2 (IPC 1307) to 1.4 (IPC 828) among testers.

The ICMB 98222, ICMB 00888 and ICMB 97111 among lines and IPC 774, IPC 1354 and IPC 828 among testers showed significant positive *gca* effects in individual environment as well as across the seasons (Table 8b). In addition, ICMB 93222 amongst lines and IPC 1178 amongst testers showed significant positive *gca* effects during rainy as well across seasons. ICMB 94111, ICMB 93333, ICMB 89111 among lines and IPC 843, IPC 616 and IPC 1307 among testers exhibited highly significant negative *gca* effects in individual environment as well as across the seasons. Parents either with high (ICMB 98222 and IPC 774) or medium (ICMB 00888) grain Fe/Zn levels had positive and significant *gca* effects for 1000-grain mass, while parents (ICMB 93333, ICMB 89111, IPC 1307) with low grain Fe/Zn levels exhibited significant negative *gca* effects in individual environment as well as across the seasons. The correlation coefficients between *per se* performance of lines and its *gca* effects were positive and significant ($r = 0.86$ to 0.94; $P<0.01$);

however, correlations involving *per se* performance and *gca* effect though moderate (r = 0.54 to 0.66) but statistically non significant for testers.

4.2.1.5.4. Flowering

The *gca* effects for flowering ranged from -1.3 (ICMB 97111) to 2.3 (ICMB 93333) among lines and from -2.3 (IPC 774) to 2.4 (IPC 1307, IPC 1178) among testers in summer season (Table 8b), whereas in rainy season, the *gca* effects ranged from -2.2 (ICMB 00888) to 2.9 (ICMB 04777) among lines and from -3.0 (IPC 774) to 2.42 (IPC 828) among testers. Across the seasons, it ranged from -1.4 (ICMB 98222 and ICMB 00888) to 2.2 (ICMB 04777) among lines and from -2.7 (IPC 774) to 2.2 (IPC 1307 and IPC 828) among testers.

Among lines, ICMB 93333 and ICMB 04777 had highly significant positive *gca* effects for flowering, whereas IPC 1307, IPC 828 and IPC 1178 among testers had highly significant positive *gca* effect in individual environment as well as across the seasons. Since early flowering is desirable to escape drought, it is desirable to identify parents with negative *gca* effects. ICMB 98222, ICMB 94111 and ICMB 97111 among lines and IPC 616, IPC 774, IPC 1354 and IPC 390 among testers exhibited significant negative *gca* effects for flowering. Of these, ICMB 98222, ICMB 94111, IPC 616 and IPC 774 had high grain Fe and Zn levels. On the other hand, ICMB 93333, IPC 828 and IPC 1307 had positive *gca* effects but low in grain Fe and Zn in individual environment as well as across the seasons. A very high positive and significant correlation between *per se* performance and *gca* effects (r = 0.87 to 0.96; $P<0.01$ for lines and r = 0.81 to 0.96; $P< 0.01$ for testers) were observed in individual environment as well as across the seasons.

4.2.1.6. Specific combining ability effects

4.2.1.6.1. Grain Fe concentration

Out of 72 hybrids tested for specific combing ability (*sca*) effects, four hybrids in summer season and five in rainy seasons had significant *sca* effects for Fe (Table 9a). Of these, ICMB 00888 x IPC 1178 and ICMB 89111 x IPC 843 in summer season and ICMB 98222 x IPC 1650, ICMB 94111 x IPC 1178 and ICMB 04777 x IPC 1178 in rainy seasons recorded positive *sca* effects, while ICMB 04777 x IPC 843 and ICMB 97111 x IPC 1178 in summer season and ICMB 98222 x IPC 1307 and ICMB 97111 x IPC 1178 in rainy season had negative *sca* effects. Across the seasons, ICMB 94111 x IPC 1178, ICMB 89111 x IPC 843 and ICMB 89111 x IPC 390 showed significant positive *sca* effects, whereas ICMB 98222 x IPC 1307, ICMB 04777 x IPC 843, ICMB 04777 x IPC 828, ICMB 89111 x IPC 1650 and ICMB 97111 x IPC 1178 showed significant negative *sca* effects. Moreover, none of the hybrids had shown consistently positive and significant *sca* effects in individual environment as well as across the seasons. However, hybrid ICMB 94111 x IPC 1178 had positive significant *sca* effects in rainy and across the seasons and ICMB 89111 x IPC 843 had positive significant *sca* effects in summer and across the seasons. In contrast, hybrid ICMB 97111 x IPC 1178 had significant negative *sca* effects in individual environment as well across the seasons.

Hybrids with positive significant *sca* effects had involved at least one parent either with high or medium grain Fe. The correlation between *sca* effects and *per se* performance of hybrids was positive and highly significant ($r = 0.47$ in summer, 0.59 in rainy, 0.47 across seasons; $P<0.01$).

4.2.1.6.2. Grain Zn concentration

Out of 72 hybrids tested for *sca* effects, only eight hybrids in summer season and three hybrids in rainy season had significant *sca* effects for Zn (Table 9a). Of these, ICMB 94111 x IPC 1178 and ICMB 04777 x IPC 774 in summer season and ICMB 94111 x IPC 1178 in rainy season had positive *sca* effects, while six hybrids (ICMB 93222 x IPC 843, ICMB 00888 x IPC 774, ICMB 04777 x IPC 390, ICMB 04777 x IPC 828, ICMB 89111 x IPC 1650 and ICMB 97111 x IPC 1178) in summer season and two hybrids (ICMB 04777 x IPC 828 and ICMB 97111 x IPC 1178) in rainy season had significant negative *sca* effects. Across the seasons, two hybrids (ICMB 94111 x IPC 1178 and ICMB 04777 x IPC 774) showed significant positive *sca* effects, whereas four hybrids (ICMB 04777 x IPC 843, ICMB 04777 x IPC 828, ICMB 89111 x IPC 1650 and ICMB 97111 x IPC 1178) had shown significant negative *sca* effects. The hybrid ICMB 94111 x IPC 1178 had significant positive *sca* effects in individual environmental as well as across the seasons. Likewise, hybrids ICMB 04777 x IPC 828 and ICMB 97111 x IPC 1178 had significant negative *sca* effects in individual environment as well as across the seasons.

Hybrids with positive significant *sca* effects had involved at least one parent either with high or medium grain Zn. The *per se* performance of hybrids and their *sca* effects were positively and significantly correlated (r = 0.41 in summer, 0.44 in rainy, and 0.36 across seasons; P<0.01).

4.2.1.6.3. 1000-grain mass

Out of 72 hybrids, 19 in summer season and 11 in rainy season had significant *sca* effects for 1000-grain mass (Table 9b). Of these, eight hybrids (ICMB 93222 x IPC 774, ICMB 98222 x IPC 774, ICMB 98222 x IPC 1354, ICMB 94111 x IPC 828, ICMB 93333 x IPC 390, ICMB 04777 x IPC 616, ICMB 89111 x IPC 843 and ICMB 97111 x IPC 774) in summer season and four hybrids (ICMB 93222 x IPC 774, ICMB 94111 x IPC 1650, ICMB 04777 x IPC 616 and ICMB 04777 x IPC 1178) in rainy season had significant positive *sca* effects, while 11 hybrids in summer and seven hybrids in rainy seasons had significant negative *sca* effects. Across seasons, nine hybrids (ICMB 93222 x IPC 774, ICMB 98222 x IPC 1307, ICMB 93333 x IPC 390, ICMB 04777 x IPC 616, ICMB 04777 x IPC 390, ICMB 04777 x IPC 1178, ICMB 89111 x IPC 843, ICMB 89111 x IPC 828 and ICMB 97111 x IPC 774) showed significant positive *sca* effects, whereas 12 hybrids had negative significant *sca* effects.

Six of the eight hybrids in summer season and three of the four hybrids in rainy season with positive *sca* effects had at least one parent with high grain Fe/Zn, whereas seven of the nine hybrids with positive *sca* effects in across the seasons had at least one parent either with high or medium grain Fe/Zn. In general, hybrids ICMB 93222 x IPC 774 and ICMB 04777 x IPC 616 had positive significant *sca* effects for 1000-grain mass in individual environment as well as across the seasons. The correlation between *sca* effects and *per se* performance of hybrids was positive and highly significant (r = 0.49 in summer and rainy, and 0.43 across seasons; P<0.01).

4.2.1.6.4. Flowering

Out of 72 hybrids tested for *sca* effects, only seven in summer season and only one in rainy season had significant *sca* effects (Table 9b). Of these, four hybrid (ICMB 98222 x IPC 616, ICMB 98222 x IPC 774, ICMB 93333 x IPC 828 and ICMB 04777 x IPC 1307) in summer season had significant positive *sca* effects, while three hybrids (ICMB 98222 x IPC 1307, ICMB 00888 x IPC 1307 and ICMB 04777 x IPC 616) in summer season and one hybrid (ICMB 93333 x IPC 390) in rainy had significant negative *sca* effects. Across seasons, ICMB 98222 x IPC 774, ICMB 94111 x IPC 390, ICMB 93333 x IPC 828 and ICMB 89111 x IPC 616 showed significant positive *sca* effects, whereas four hybrids (ICMB 93222 x IPC 828, ICMB 93333 x IPC 390, ICMB 04777 x IPC 1650 and ICMB 89111 x IPC 774) had negative and significant *sca* effects for flowering. Hybrid ICMB 93333 x IPC 390 had shown significant negative *sca* effect in the rainy as well as across the seasons.

Hybrids with significant negative *sca* effects for flowering had involved at least one parent either with high or medium grain Zn. The correlation between *sca* effects and *per se* performance of hybrids was positive and significant (r = 0.42 in summer, 0.33 in summer, 0.31 across seasons; P<0.01).

4.2.1.7. Heterosis

4.2.1.7.1. Grain Fe concentration

The average mid-parent (MP) heterosis for grain Fe was negative (summer: -26.23%; rainy: -25.79% and across seasons: -26.32%). It ranged from -46.20 (ICMB 89111 x IPC 1650) to 0.87% (ICMB 89111 x IPC 843) in summer season, from -51.36% (ICMB 94111 x IPC 616) to 18.05% (ICMB 00888 x IPC 1307) in rainy season, and from -47.62% (ICMB 89111 x IPC 1650) to -3.99% (ICMB 00888 x IPC 1178) across the seasons (Table 10a). In total, 49 hybrids in summer season and 39 hybrids in rainy season had significant negative heterosis over MP, while across seasons 56 hybrids had significant negative MP heterosis.

None of the hybrids significantly exceeded the better parent (BP) for grain Fe (higher grain Fe parent) in individual environment as well as across the seasons. However, in rainy season, hybrids ICMB 00888 x IPC 1307, ICMB 00888 x IPC 1354 and ICMB 97111 x IPC 1307 had positive BP heterosis with a range of 4.13% to 13.17%. Of these, two hybrids involve M x L parent for grain Fe. The *per se* performance of the hybrids and MP heterosis were significantly positively correlated (r = 0.70 in summer; 0.51 in rainy; 0.67 across seasons; P<0.01) (Fig. 4).

4.2.1.7.2. Grain Zn concentration

The average MP heterosis for grain Zn was negative (summer: -10.14%; rainy: -16.19% and across season: -12.86%). It ranged from -26.52% (ICMB 00888 x IPC 774) to 19.15% (ICMB 04777 x IPC 1307) in summer season, from -47.75% (ICMB 94111 x IPC 616) to 21.63% (ICMB 00888 x IPC 1354) in rainy season, and from -35.84% (ICMB 94111 x IPC 616) to 11.52% (ICMB 93333 x IPC 1307) across the seasons (Table 10 b). In summer, 29 of 72 hybrids showed significant negative heterosis over MP. Although 12 hybrids had positive heterosis over MP, only one hybrid (ICMB 04777 x IPC 1307) showed significant (P<0.01) positive heterosis over MP. In rainy season, 29 hybrids showed significant negative heterosis over MP, while none of the hybrids had significant positive heterosis over MP. Across seasons, 37 hybrids had significant negative heterosis over MP. All of the H x H and L x H crosses produced hybrids with significant negative heterosis over MP in individual environment as well as across the seasons.

None of the hybrids significantly exceeded the better parent (BP) for grain Zn (higher grain Zn parent) in individual environment as well as across the seasons. However, in rainy season, hybrids ICMB 00888 x IPC 1307, ICMB 00888 x IPC 1354, ICMB 04777 x IPC 1178, ICMB 97111 x IPC 1307 and ICMB 97111 x IPC 1354 had positive BP heterosis with a range of 1.0% to 9.8%. Of these, first three hybrids had at least one parent with medium grain Zn. The correlation between mid-parent value and *per se* performance of hybrids was highly significant (r = 0.80 in summer; rainy 0.54; 0.73 across seasons; P<0.01) (Fig. 4).

4.2.1.7.3. 1000-grain mass

The average MP heterosis for 1000-grain mass was positive (35.33% in summer; 40.55% in rainy and 37.46% across season). It ranged from 7.63% (ICMB 94111 x IPC 1650) to 72.82% (ICMB 93222 x IPC 774) in summer season, from 4.34% (ICMB 97111 x IPC 843) to 78.37% (ICMB 98222 x IPC 390) in rainy season, and from 8.28% (ICMB 97111 x IPC 843) to 67.79% (ICMB 89111 x IPC 1178) across the seasons (Table 10c). In summer season, all the hybrids, except ICMB 94111 x IPC 1650, showed positive significant MP heterosis (up to 73%), while 67 hybrids in rainy showed positive significant MP heterosis (up to 78%). Across seasons, all the hybrids showed significant positive heterosis over MP (up to 68%). Hybrids showing ≥30% superiority for1000-grain mass had at least one parent with high grain Fe/ Zn level.

The average BP heterosis for 1000-grain mass was positive (24.26% in summer, 28.60% in rainy, 26.81% across seasons). It ranged from 1.81% (ICMB 97111 x IPC 1650) to 60.36% (ICMB 9333 x IPC 390) in summer season, from 0.23% (ICMB 89111 x IPC 828) to 75.40% (ICMB 89111 x IPC 390) in rainy season, and from 0.70% (ICMB 97111 x IPC 1178) to 66.60% (ICMB 89111 x IPC 1178) across the seasons. Forty-eight hybrids in summer season (up to 60%), 43 hybrids in rainy season (up to 75%), and 57 hybrids across the seasons (up to 67%) had shown positive and significant BP heterosis. Hybrids showing greater BP heterosis (≥30% superiority) for 1000-grain mass had at least one parent with high grain Fe/Zn level. The correlation between mid-parent values and *per se* performance of the hybrids for 1000-grain mass was positive and highly significant (r = 0.62 to 0.72; P<0.01).

4.2.1.7.4. Flowering

The average MP heterosis for flowering was negative (-6.45% in summer; -7.79% in rainy and -7.13% across season). It ranged from -12.89% (ICMB 04777 x IPC 616) to 1.77% (ICMB 93333 x IPC 828) in summer season, from -15.45% (ICMB 93333 x IPC 390) to -1.41% (ICMB 94111 x IPC 828) in rainy season, and from -12.08% (ICMB 89111 x IPC 774) to -0.90% (ICMB 93333 x IPC 828) across the seasons (Table 10d). Out of 72 hybrids, 64 hybrids in summer, 65 hybrids in rainy and 71 hybrids across seasons had negative significant heterosis over MP.

The average BP heterosis was negative (approximately -10% to -11% in individual environment as well as across seasons). It ranged from -20.66% (ICMB 98222 x IPC 1307) to -2.06% (ICMB 98222 x IPC 774) in summer season, from -16.51% (ICMB 97111 x IPC 390) to –3.67% (ICMB 94111 x IPC 828) in rainy season, and from -16.46% (ICMB 98222 x IPC 1307) to -1.34% (ICMB 93333 x IPC 828) across the seasons (Table 10d). Sixty-seven hybrids in summer and 71 hybrids in rainy as well across seasons had significant negative heterosis over BP. Most of the hybrids flowered significantly earlier than their parents, as evidenced by significant negative heterosis over MP/BP. Hybrids that flowered earlier had at least one parent with high grain Fe/Zn. For example, 9 hybrids exhibited > -15% heterosis over BP, and all these had at least one high or medium Fe/Zn parent in summer season, so as the case for some hybrids in rainy as well across seasons. The correlation between mid-parent value and *per se* performance of the hybrids was highly significant (r = 0.79 to 0.87; P<0.01).

4.2.2. 16 lines x 12 testers trial (set –ii)

4.2.2.1. Analysis of variance

Highly significant differences ($p<0.01$) were detected among parents and crosses for grain Fe and Zn, 1000-grain mass and flowering in rainy (2009) and summer (2010) seasons (Table 11a and 11b). The pooled analysis of variance showed highly significant differences among parents (p), environments (E) for all traits. Differences due to parents x environment interaction (PEI) were significant only for 1000-grain mass and flowering (Table 12a). However, the interaction of crosses with environment was significant for all the characters (Table 12b).

4.2.2.2. Analysis of variance for combining ability

Mean squares due to lines (L), testers (T) and L x T effects were significant for grain Fe and Zn, 1000-grain mass and flowering in summer and rainy seasons (Table 11b). The combining ability analysis over two environments revealed that mean squares due L, T and L × T effects were highly significant for all the four traits. The interaction components with environments, L x E, T x E, L x T x E, were significant for all four traits (Table 12b). In individual environment analysis, the variances due to $\sigma^2 gca$ were predominant for all four traits (Table 11b), so and so was the case in the pooled analysis (Table 12b). The predictability ratio (PR) was closer to unity for all the traits in individual (0.97 to 0.99; Table 11b) as well across the seasons (0.84 to 0.88; Table 12b), indicating predominance of additive genetic variance for expression of grain Fe and Zn, 1000-grain mass and flowering.

4.2.2.3. Proportional contribution of line, tester and line x tester to total genotypic variation

Of the three components, lines (σ^2L) contributed greater genetic variation for grain Fe (58.7%), testers (σ^2T) to flowering (47.6%) and 1000-grain mass (51.5%), while L x T interaction (σ^2LT) contributed more variation for grain Zn (41.6%) in rainy season (Table 13). In summer, σ^2L contributed more variation to grain Fe (50.4%), σ^2T to grain Zn (52.5%), 1000-grain mass (49.8%) and for flowering (46.6%). In the pooled analysis, σ^2T contributed greater proportion of variation to grain Zn (53.2%), 1000-grain mass (54.5%) and flowering (49.1%), while σ^2L to grain Fe (54.7%).

4.2.2.4. *Per se* performance of parents and hybrids

4.2.2.4.1. Grain Fe concentration

Grain Fe among lines ranged from 28.7 (ICMB 92111) to 95.6 mg kg^{-1} (ICMB 91222) in rainy season, from 38.4 (ICMB 92111) to 117.7 mg kg^{-1} (ICMB 95333) in summer season, and from 33.5 (ICMB 92111) to 95.9 mg kg^{-1} (ICMB 95333) across the seasons. Among testers, grain Fe varied from 33.3 (IPC 1268) to 98.6 mg kg^{-1} (IPC 735) in rainy season, from 39.2 (IPC 1268) to 101 mg kg^{-1} (IPC 735) in summer season, and from 36.3 (IPC 1268) to 99.8 mg kg^{-1} (IPC 735) across the seasons (Appendix IV and Fig. 5). Based on two season's data the parents were classified into high, medium and low category for grain Fe (Table 4). The average grain Fe was 18% and 23% greater, respectively, for lines and testers in the summer season than in the rainy season (56.5 mg kg^{-1} for lines and 48.2 mg kg^{-1} for tester) (Appendix IV).

Among the hybrids, grain Fe varied from 25.2 (ICMB 92111 x IPC1254) to 66.6 mg kg^{-1} (ICMB 91222 x IPC 735) in rainy season, from 29.3 (ICMB 92111 x IPC 811) to 100.1 mg kg^{-1} (ICMB 91222 x IPC 689) in summer season, and from 30.1 (ICMB 92111 x IPC 536) to 80.0 mg kg^{-1} (ICMB 91222 x IPC 689) across the seasons. Eighty-four hybrids in rainy season and 81 hybrids in summer season had greater grain Fe than with their respective trial means (rainy 40.3 mg kg-^{1}; summer 55.2 mg kg-^{1}), while 83 hybrids across seasons had greater grain Fe than the trial mean (47.7 mg kg-^{1}). Overall, the grain Fe in the summer season was 37% more than in the rainy season (40.3 mg kg^{-1}). Most of the H x H crosses produced hybrids with grain Fe >54 mg kg$^{-1,}$ while hybrids involving L x L parents had always lower grain Fe (30.4 - 49.7 mg kg^{-1})

4.2.2.4.2. Grain Zn concentration

Grain Zn among lines ranged from 36.6 (ICMB 92111) to 75.6 mg kg^{-1} (ICMB 96333) in rainy season, from 34.0 (ICMB 88006) to 69.7 mg kg^{-1} (ICMB 95333) in summer season, and from 38.2 (ICMB 88006) to 72.1 mg kg^{-1} (ICMB 96333) across the seasons. Among testers, Zn varied from 34.4 (IPC 1254) to 75 mg kg^{-1} (IPC 735) in rainy season, from 39.6 (IPC 811) to 78.4 (IPC 735) in summer season, and from 39.5 (IPC 811) to 76.7 mg kg^{-1} (IPC 735) across the seasons (Appendix IV and Fig. 6). Based on two season's data the parents were classified as high, medium and low category for grain Zn (Table 4). The average Zn was 14% and 17% greater, respectively, for lines and testers in the summer season than in the rainy season (50.9 mg kg^{-1} for lines and 45.5 mg kg^{-1} for testers) (Appendix IV).

Among hybrids, grain Zn varied from 28.7 (ICMB 9211 x IPC 338) to 56.2 mg kg^{-1} (863B x IPC 404) in rainy season, from 31.9 (ICMB 92111 x IPC 811) to 72.2 mg kg^{-1} (863 B x IPC 735) in summer season, and from 30.9 (ICMB 92111 x IPC 811) to 63.6 mg kg^{-1} (863 B x IPC 735) across the seasons. In rainy season, 87 hybrids exceeded the trial mean (39.5 mg kg-^{1}), whereas 93 hybrids in summer season exceeded the trial mean (51.3 mg kg-^{1}). Across the seasons, 88 hybrids exceeded the trial mean (45.4 mg kg-^{1}). Overall, the grain Zn in the summer season was 30% more than in the rainy season (39.5 mg kg^{-1}). All the hybrids with grain Zn >50 mg kg^{-1} had at least one parent either high or medium grain Zn, while hybrids involving L x L parents had grain Zn in range of 30.9 to 49.3 mg kg^{-1}.

4.2.2.4.3. 1000-grain mass

1000-grain mass among lines ranged from 6.2 (ICMB 91222) to 17.9 g (863B) in rainy season, from 7.9 (ICMB 95333) to 12.2 g (ICMB 96333) in summer season, and from 7.4 (ICMB 91222) to 14.9 g (863B) across the seasons (Appendix IV). Among testers, 1000-grain mass varied from 5.5 (IPC 536) to 14.9 g (IPC 689) in rainy season, from 6.0 (IPC 1254) to 13.5 g (IPC 404) in summer season, and from 5.8 (IPC 1254) to 13.7 g (IPC 689) across the seasons. A high grain Fe (82 mg kg^{-1}) and Zn (72 mg kg^{-1}) parent, ICMB 96333, had >10g grain mass across the seasons, whereas another parent with high Fe (58 mg kg^{-1}) and medium Zn levels (54 mg kg^{-1}), IPC 689, also had 1000-grain mass >10g across the seasons. Moderate grain Fe (55.4 mg kg^{-1}) parent ICMB 04222 and high Fe (73 mg kg^{-1}) and Zn (61.4 mg kg^{-1}) parent 863B showed >10 g grain mass in individual environment as well across seasons.

Among hybrids, 1000-grain mass varied from 6.3 (ICMB 92111 x ICMR 06888) to 18 g (ICMB 04888 x IPC 1642) in rainy season, from 7.9 (ICMB 00999 x IPC 1268) to 16.48 g (ICMB 04888 x IPC 1642) in summer season, and from 7.2 (ICMB 92111 x ICMR 06888) to 17.2 g (ICMB 04888 x IPC 1642) across the seasons. In both the seasons, 92 of 192 hybrids exceeded the trial mean (>11.4 g in rainy and 11.1 g in summer). Overall, crosses involving H x H, M x H, and M x M Fe and Zn parents produced hybrids with larger grains (10 - 17.2 g).

4.2.2.4.4. Flowering

Among the lines, flowering ranged from 44 (843B) to 56 days (ICMB 04555) in rainy season, from 45 (ICMB 04222) to 60 days (ICMB 95333) in summer season, and from 45 (843B) to 57 days (ICMB 95333) across the seasons. Among the testers, flowering ranged from 48 (IPC 689) to 56 days (IPC 735 and IPC 1268) in rainy season, from 45 (IPC 404) to 60 days (IPC 735) in summer season, and from 47 (IPC 404) to 58 days (IPC 735) across seasons. Seasons had no major influence on mean flowering of lines and testers (51-52 days) (Appendix IV). However, 843B and ICMB 04222 (44 - 48 days) amongst lines and IPC 404 and IPC 689 (45 – 49 days) amongst testers were earlier to flower in individual environment as well as across seasons, The variation in grain Fe and Zn among parents (L and T) had no major effect on flowering, which ranges from 48 to 58 days.

Among hybrids, flowering ranged from 39 (843B x ICMR 06888) to 55 days (ICMB 95333 x IPC 1254) in rainy season, from 43 (843B x ICMR 06888) to 57 days (ICMB 95333 x IPC 1254) in summer season, and from 41 (843B x ICMR 06888) to 56 days (ICMB 95333 x IPC 1254) across seasons. The hybrids 843B x ICMR 06888, 843B x IPC 536, ICMB 03111 x ICMR 06888 were earliest to flower (39-43 days), whereas ICMB 95333 x IPC 1254 flowered very late (55-57 days) in individual environment as well as across the seasons. Out of 192 hybrids, 36 hybrids in rainy season and 12 hybrids in summer season had flowered ≤ 45 days. Variations in grain Fe and Zn among the parental lines had no influence on flowering pattern in hybrids. Hybrids in general flowered 3-4 days earlier (48 days) than parents (lines 51 days and testers 52 days).

4.2.2.5. General combining ability

4.2.2.5.1. Grain Fe concentration

Among lines, *gca* effects for grain Fe ranged from -8.9 (ICMB 92111) to 13.2 (ICMB 91222) in rainy season, from -12.9 (ICMB 92111) to 15.5 (ICMB 91222) in summer season, and from -10.9 (ICMB 92111) to 14.4 (ICMB 91222) across the seasons (Table 14a). Among the testers, *gca* effects ranged from -5.3 (IPC 1268) to 6.3 (IPC 1642) in rainy season, from -11.6 (IPC 1268) to 12.2 (IPC 689) in summer season, and from -8.5 (IPC 1268) to 8.2 (IPC 689) across the seasons. 863 B, ICMB 91222, ICMB 95333 and ICMB 04222 amongst lines and IPC 689, IPC 735 and IPC 1642 amongst testers showed positive and significant *gca* effects in individual environment as well as across the seasons. In contrast, 841B, ICMB 88006, ICMB 92111, ICMB 04555, and ICMB04999 amongst lines and IPC 811, IPC 1254, IPC 1268 and ICMR 356 amongst testers showed negative and significant *gca* effects in individual environment as well as across seasons.

Parents either with high or medium grain Fe levels (863B, ICMB 04222, ICMB 91222, ICMB 95333, IPC 689, IPC 735 and IPC 1642) showed positive and significant *gca* effects in individual environment as well as across the seasons. In contrast, the low Fe parents (841B, ICMB 88006, ICMB 92111, ICMB 04555, ICMB 04999, IPC 811, and IPC 1268) exhibited significant negative *gca* effect in individual environment as well as across the seasons. The correlation between *per se* performance of lines and their *gca* effects was positive and significant for grain Fe (r = 0.81 in rainy; 0.70 in summer, 0.78 across seasons; $P<0.01$), whereas it was non significant among testers (r = 0.49 in rainy; 0.57 in summer; 0.52 across seasons). However, parents *per se* (lines and testers) and their *gca* effects were positive and highly significant across season (r = 0.68; $P<0.01$; Fig. 7)

4.2.2.5.2. Grain Zn concentration

The *gca* for grain Zn among lines ranged from -4.4 (ICMB 88006) to 5.0 (863B) in rainy season, from -6.8 (ICMB 92111) to 5.0 (841B) in summer season, and from -5.4 (ICMB 92111) to 4.6 (863B) across seasons (Table 14a). The *gca* among testers ranged from -5.8 (IPC 811) to 5.2 (IPC 735) in rainy, from -7.9 (IPC 811) to 6.1 (IPC 1642) in summer season, and from -6.8 (IPC 811) to 5.3 (IPC 735) across seasons. 841B, 863 B, ICMB 91222, ICMB 04888 amongst lines and IPC 689, IPC 735 and IPC 1642 amongst testers showed positive and significant *gca* effects in individual environment as well as across the seasons. In contrast, ICMB 88006, ICMB 92111, ICMB 04555, ICMB04999 amongst lines and IPC 811 and ICMR 06333 amongst testers showed negative and significant *gca* effects in individual environment as well as across the seasons.

Parents either with high or medium grain Zn levels (841B, 863B, ICMB 91222, ICMB 04888, IPC 689 and IPC 735) showed positive and significant *gca* effects in individual environment as well as across the seasons. On the other hand, low grain Zn parents (ICMB 88006, ICMB 92111, ICMB 04555, ICMB 04999, IPC 811, ICMR 06333 and ICMR 06888) exhibited significant negative *gca* effects in individual environment as well as across the seasons. The correlation between *per se* performance of the parents and *gca* effects was positive and significant for lines (r = 0.79 in rainy, 0.63 in summer; 0.75 across seasons; P<0.01) and testers (r = 0.64 in rainy; 0.70 in summer, 0.68 across seasons; P<0.05). Across the season, *per se* of parents (lines and testers) and their *gca* effects had positive significant correlation (r = 0.69; P<0.01; Fig. 7)

4.2.2.5.3. 1000-grain mass

For 1000-grain mass, *gca* effects among lines varied from -1.4 (841 B) to 1.7 (ICMB 88006) in rainy season, from -1.5 (ICMB 00999) to 1.6 (863 B) in summer season, and from -1.4 (841B) to 1.5 (ICMB 04888) across seasons. The *gca* effects of testers ranged from -2.1 (ICMR 06888) to 3.0 (IPC 1642) in rainy season, from -1.7 (IPC 1268) to 2.1 (IPC 1642) in summer season, and from -1.6 (ICMR 06888) to 2.6 (IPC 1642) across seasons (Table 14b). 863B, ICMB 88006 and ICMB 04888 amongst lines and IPC 404, IPC 689, IPC 1642 and ICMR 06333 amongst testers showed positive and significant *gca* effects in individual environment as well as across the seasons. In contrast, 841B, ICMB 92111, ICMB 00999, ICMB 03111 and ICMB 04999 amongst lines and IPC 536, IPC 1268, ICMR 356 and ICMR 06888 amongst testers showed negative and significant *gca* effects in individual environment as well as across seasons.

Notably, some of the parents (863B, IPC 404, IPC 689, IPC 1642 and ICMR 06333) with significant positive *gca* effects had shown greater 1000-grain mass (>10-18g), while those with negative but significant *gca* effects (841B, ICMB 92111, ICMB 00999, ICMB 04999, IPC 536, IPC 1268, ICMR 06888) had smaller 1000-grain mass (5 to 10 g per 1000 grains). The correlation between *per se* performance and *gca* effects for 1000-grain mass was significant among lines (r = 0.51 in rainy; P<0.05; 0.67 in summer and 0.68 across seasons; P<0.01) and among testers (r = 0.67 in rainy, 0.66 in summer, 0.68 across seasons; P<0.05).

4.2.2.5.4. Flowering

The *gca* for flowering among lines varied from -3.3 (843B) to 2.6 (ICMB 00999) in rainy season, from -2.5 (843B) to 3.0 (ICMB 95333) in summer season, and from -2.9 (843B) to 2.3 (ICMB 95333) across seasons. The *gca* of testers ranged from -2.8 (IPC 536) to 2.1 (IPC 735) in rainy season, from -2.4 (ICMR 06888) to 3.2 (IPC 735) in summer season, and from -2.6 (ICMR 06888) to 2.7 (IPC 735) across seasons

(Table 14b). 843B, ICMB 03111 and ICMB 04222 amongst lines and IPC 536, IPC 1642, ICMR 356, and ICMR 06888 amongst testers had negative (in desirable direction) and significant *gca* effect in individual environment as well as across the seasons. In contrast, ICMB 88006, ICMB 92111, ICMB 95333, ICMB 00999, and ICMB 04555 amongst lines and IPC 338, IPC 689, IPC 735, IPC 1254, and IPC 1268 amongst testers showed positive and significant *gca* effects in individual environment as well as across seasons. Of the parents with significant negative *gca* effects, only 843B, ICMB 04222, IPC 536 and ICMB 03111 flowered earlier (44-49 days) in individual environment as well as across the seasons, with former three having high and/or medium grain Fe/Zn. The correlation between *per se* performance of parents and its *gca* effects was positive and significant among lines (r = 0.85 in rainy, 0.88 in summer, 0.91 across seasons; $P<0.01$) but non-significant among testers (r = 0.52 in rainy, 0.34 in summer, 0.42 across seasons).

4.2.2.6. Specific Combining Ability

4.2.2.6.1. Grain Fe concentration

The specific combining ability (*sca*) effects for gain Fe varied from -10.12 (863B x IPC 338) to 17.60 (863B x IPC 404) in rainy season, from -17.88 (863B x IPC 1254) to 21.16 (ICMB 02444 x IPC 1254) in summer season, and from -13.18 (863B x IPC 1254) to 18.72 (863B x IPC 404) across the seasons (Table 15a). Out of 192 hybrids tested for *sca* effects, 13 hybrids in rainy season and 14 hybrids in summer season had positive and significant *sca* effects, while 14 hybrids in rainy season and eight hybrids in summer season had negative but significant *sca* effects for grain Fe. Across the seasons 14 and 13 hybrids showed, respectively, significant positive and negative *sca* effects for grain Fe. Of these, hybrids 863B x IPC 404, ICMB 95333 x IPC 404 and ICMB 96333 x IPC 338, in individual environment as well as across the seasons, had positive significant *sca* effects for grain Fe. Interestingly, these positive significant *sca* hybrids involve at least one best general combiner (positive significant *gca*) in their crosses. These hybrids had moderate to high levels of Fe in individual environment as well as across seasons (59.6 to 72.2 mg kg^{-1}). The correlation between *sca* effects and *per se* performance of hybrids was positive and highly significant (r = 0.42 to 0.54; $P<0.01$).

4.2.2.6.2. Grain Zn concentration

The *sca* effects for grain Zn varied from -8.94 (863B x IPC 689) to 10.53 (ICMB 95333 x IPC 404) in rainy season, from -11.08 (863B x IPC 1254) to 11.56 (ICMB 88006 x IPC 404) in summer season, and from -9.99 (863B x IPC 1254) to 8.29 (863B x IPC 735) across seasons (Table 15a). Seven hybrids had shown positive and significant *sca* effects in rainy and summer seasons, while 10 hybrids in both the seasons had significant negative *sca* effects for grain Zn. Across the seasons, nine hybrids each in rainy and summer seasons had significant positive and negative *sca* effects for Zn. Only, two hybrids (863B x IPC 404 and ICMB 95333 x IPC 404), with moderate levels of grain Zn (average 53.9 to 58.2 mg kg^{-1}), had positive and significant *sca* effects in rainy as well as across seasons. Interestingly, these positive significant *sca* hybrids involve parents with best general combining ability (positive significant *gca*) in their crosses. Hybrids (863B x IPC 1254 and ICMB 00999 x IPC 735) with low grain Zn (35.0 to 48.0 mg kg^{-1}) are the one that showed negative and significant *sca* in individual environment as well as across the seasons. The correlation between *sca* effects and *per se* performance of hybrids was positive and significant (r = 0.64 in rainy, 0.61 in summer, 0.52 across seasons; $P<0.01$).

4.2.2.6.3. 1000-grain mass

The *sca* effects for 1000-grain mass varied from -3.09 (ICMB 04999 x ICMR 06333) to -3.42 (ICMB 99444 x IPC 735) in rainy season, from -1.72 (863B x IPC 338) to 1.86 (ICMB 04888 x IPC 1642) in summer season, and from -1.90 (ICMB 04999 x ICMR 06888) to 2.06 (ICMB 92111 x IPC 1268) across seasons (Table 15b). Twenty and 17 hybrids in rainy season and 8 and 9 hybrids in summer season had, respectively, showed significant positive and negative *sca* effects for 1000-grain mass. Likewise, 21 and 20 hybrids had significant positive and negative *sca* effects across the seasons, respectively. Hybrid 863B x ICMR 06333 and ICMB 04888 x IPC 1642 showed positive significant *sca* effects for 1000-grain mass in individual environment as well as across seasons. These hybrids combine large grain size (≥15g / 1000 grains) and moderate to high levels of grain Fe/Zn (Fe: 54.4-60.8 and Zn: 46-54 mg kg^{-1}). The correlation between *per se* performance of the hybrids and their s*ca* effects was positive and highly significant (r = 0.55 in rainy, 0.44 in summer, 0.43 across seasons; $P<0.01$).

4.2.2.6.4. Flowering

The *sca* effects for flowering varied from -3.52 (ICMB 99444 x IPC 735) to 4.19 (ICMB 95333 x IPC 1254) in rainy season, from -2.55 (863B x IPC 735) to 3.84 (ICMB 04555 x IPC 338) in summer season, and from -2.91 (ICMB 99444 x IPC 735) to 3.86 (ICMB 95333 x IPC 1254) across the seasons (Table 15b). In rainy season, 23 hybrids each had, respectively, significant positive and negative significant *sca* effects, while 11 and 8 hybrids, respectively, had significant positive and negative *sca* effects in summer season. Across the seasons, 20 and 16 hybrids showed significant positive and negative *sca* effects, respectively. Moreover, hybrids 863B x IPC 735, ICMB 99444 x IPC 735, ICMB 99444 x IPC 1254 and ICMB 04555 x IPC 404 flowered early (46-49 days) and these hybrids had significant negative *sca* effects in individual environment as well as across the seasons. The correlation between *per se* performance of hybrids and *sca* effects was positive and significant ($r = 0.43$ in rainy, 0.44 in summer, 0.39 across seasons; $P<0.01$).

4.2.2.7. Heterosis

4.2.2.7.1. Grain Fe concentration

The average mid-parent (MP) heterosis for grain Fe was negative (-20.94% rainy, -11.19% summer, -15.90% across seasons). It varied from -57.71% (ICMB 88006 x IPC 735) to 24.52% (ICMB 04222 x IPC 1642) in rainy season, from -46.19% (ICMB 95333 x IPC 735) to 38.51% (863B x IPC 404) in summer season, and from -49.03% (ICMB 88006 x IPC 735) to 26.36% (863B x IPC 404) across the seasons (Table 16a). In rainy season, only one hybrid (ICMB 04222 x IPC 1642) had positive and significant MP heterosis. Both the parental lines of this hybrid had moderate grain Fe. In contrast, 77 hybrids in rainy season had significant negative MP heterosis. In summer season, 6 and 56 hybrids, respectively, had significant positive and negative MP heterosis. Hybrids with significant positive MP heterosis (863B x IPC 404, 863B x IPC 689, ICMB 91222 x IPC 689, ICMB 91222 x IPC 1642, ICMB 02444 x IPC 1642 and ICMB 04222 x IPC 689) had grain Fe in the range of 74.8 to 100.1 mg kg^{-1}. All these hybrids had at least one parent with either high or medium grain Fe. Across the seasons, two and 91 hybrids, respectively, had significant positive and negative MP heterosis. Hybrids with positive MP heterosis (863B x IPC 404 and ICMB 04222 x IPC 1642), across the seasons, had shown greater grain Fe (64.2 -77.2 mg kg^{-1}).

The significant heterosis over better parent (BP) was not observed for grain Fe in individual environment as well as across the seasons. However, six hybrids in rainy season had positive heterosis over BP but only one hybrid (ICMB 04999 x IPC 1642) had 14.32% heterosis over BP. Similarly 22 hybrids in summer season had positive BP heterosis with a range of 1% (ICMB 04222 x IPC 338) to 22% (ICMB 91222 x IPC 689). Two hybrids (863B x IPC 404 and ICMB 91222 x IPC 689) had positive and significant heterosis over BP (20-22%). In total, 9 hybrids had >11% heterosis over BP. They are as follows ICMB 03111 x ICMR 06888, ICMB 04222 x IPC 689 ICMB 04222 x IPC 1642, ICMB 03111 x IPC 338, 863B x IPC 689, ICMB 04999 x IPC 338, ICMB 91222 x IPC 1642, 863B x IPC 404 and ICMB 91222 x IPC 689. Across the seasons, six hybrids recorded positive BP heterosis with a range of 1% (ICMB 04999 x IPC 1642) to 16% (ICMB 04222 x IPC 1642). The correlation between mid-parent value and hybrid *per se* performance was positive and significant ($r = 0.59$ in rainy, 0.58 in summer, 0.63 across seasons; $P<0.01$) (Fig. 8).

4.2.2.7.2. Grain Zn concentration

The average MP heterosis for grain Zn was negative (-17.07%, -6.90% and -11.80% in rainy, summer and across seasons, respectively). It varied from -40.84% (ICMB 88006 x IPC 735) to 12.23% (ICMB 95333 x IPC 404) in rainy season, from -37.39% (ICMB 95333 x IPC 735) to 37.80% (ICMB 88006 x IPC 404) in summer season, and from -36.82% (ICMB 96333 x ICMR 356) to 14.10% (841B x IPC 1642) across the seasons (Table 16b). In rainy season, 90 hybrids had significant negative MP heterosis, while in summer, 4 hybrids (841B x IPC 1642, ICMB 88006 x IPC 689, ICMB 88006 x IPC 1642 and ICMB 88006 x IPC 404) and 38 hybrids, respectively, had significant positive and negative heterosis over MP. These four hybrids with positive heterosis (19-38%) had grain Zn in the range of 56.0 to 65.5 mg kg^{-1}. Across the seasons, 81 hybrids had negative significant MP heterosis and one hybrid 841B x IPC 1642 had shown significant positive heterosis over MP (14%).

None of the hybrids recorded significant positive heterosis over BP either in rainy, summer or across seasons. However, three hybrids ICMB 95333 x IPC 404, ICMB 03111 x IPC 689 and 841B x IPC 1642 in rainy season had positive BP heterosis (2% to 4.3%). Sixteen hybrids in summer season had positive BP heterosis with a range of 2% to 13.3%. Of these, only two hybrids (ICMB 88006 x IPC 404 and ICMB 88006 x IPC 1642) had ≥ 10% Bp heterosis. Across the season, only two hybrids namely, ICMB 88006 x IPC 1642 (2%) and 841B x IPC 1642 (7%) had positive BP heterosis. The correlation between mid-parent value and hybrid *per se* performance was positive and significant (r = 0.55 in rainy, 0.53 in summer, 0.61 across seasons; P<0.01) (Fig. 8).

4.2.2.7.3. 1000-grain mass

The average MP heterosis for 1000-grain mass was positive (11%) in individual environment as well as across seasons. It ranged from -27.14% (ICMB 04999 x ICMR 06333) to 102.39% (ICMB 91222 x IPC1254) in rainy, from -14.80% (ICMB 92111 x IPC 811) to 78.53% (ICMB 88006 x IPC 1254) in summer, and from -18.73% (863B x IPC 338) to 68.46% (ICMB 91222 x IPC 1254) across seasons. BP heterosis for 1000-grain mass varied from 0.22% (ICMB 02444 x ICMR 06333) to 90.91% (ICMB 91222 x IPC 1254) in rainy season, from 0.13% (863B x ICMR 06888) to 55.03% (ICMB 88006 x IPC 1254) in summer season, and from 0.26% (ICMB 03111 x IPC 735) to 49.75% (ICMB 91222 x IPC 1254) in across the seasons (Table 16c).

Eighty-one hybrids in rainy season and 87 hybrids in summer season showed significant positive heterosis over MP; however, 95 hybrids across the seasons exhibited significant positive MP heterosis. Of these, 49 hybrids in rainy season, 32 in summer season and 37 across the seasons had MP heterosis >30%. Further, most of these hybrids had at least one parental line either with medium or high grain Fe and Zn level. Thirty hybrids in rainy season and 33 in summer season and 38 across the seasons exhibited positive and significant heterosis over BP. Of these, only 27 hybrids in rainy season, 24 in summer season and 22 in across the seasons exhibited BP heterosis >20%. Most of these hybrids had at least one parent either with medium or high grain Fe and Zn concentration. The correlation between mid-parent value and hybrid *per se* performance was positive and highly significant (r = 0.51 in rainy, 0.58 in summer, 0.61 across seasons; P<0.01).

4.2.2.7.4. Flowering

The average MP heterosis for flowering was negative (-7.86%, -6.52% and -7.20% in rainy, summer and across season, respectively). It ranged from -17.20% (843B x ICMR 06888) to 4.62% (ICMB 04999 x IPC 811) in rainy season, from -18.02% (ICMB 00999 x IPC 1642) to 5.83% (ICMB 00999 x IPC 689) in summer season, and from -15.51% (ICMB 95333 x IPC 1642) to 3.94% (ICMB 04999 x IPC 689) in across the seasons. The BP heterosis varied from -22.22% (843B x ICMR 06888) to -0.99% (ICMB 04888 x IPC 811) in rainy season, from -21.62% (ICMB 04222 x IPC 1642) to -0.94 % (841B x IPC 689) in summer season, and from -20.37% (ICMB 04222 x IPC 1642) to -0.53% (ICMB 03111 x IPC 404) in across the seasons (Table 16d).

Most of the hybrids showed significant negative MP heterosis in individual environment as well as across seasons (172 in rainy, 128 in summer and 163 in across seasons). Likewise, 182 hybrids in rainy, 164 in summer and 182 in across the seasons all had significant negative BP heterosis. Further, hybrids showing negative heterosis with ≥ -15% over BP had at least one parent either with medium or high grain Fe and Zn. For example, 19 of the 40 hybrids in rainy, 25 of the 34 hybrids in summer and 15 of the 27 hybrids across seasons had at least one parent either with medium or high grain Fe and Zn level. The correlation between mid-parent value and hybrid *per se* performance for flowering was positive and significant (r =0.62 in rainy, 0.54 in summer, 0.60 across seasons; P<0.01).

4.3. INTRA -POPULATION GENETIC VARIANCE

4.3.1. Analysis of variance

In both the populations used in this study, mean square due to genotype was highly significant for grain Fe and Zn, 1000-grain mass and flowering in both the seasons. Further partitioning showed that the mean squares due to s_1 were significant for all traits. Those due to half-sib (HS) progenies were also significant for most of the traits, except for grain Fe and Zn in AIMP 92901 and for grain Zn in ICMR 312 in summer season (table 17). High genetic variance (σ^2_g) was observed for Fe and Zn in both populations. In the pooled analysis, the mean squares due to genotypes were highly significant for all the four traits in both the populations. Likewise, differences among the S_1, HS, and the differences between the S_1 and HS were also highly significant for all four traits (table 18). However, the magnitude of σ^2_g was greater than due to σ^2_{ge} for all traits in both the populations. The magnitude of σ^2_{ge} for grain Fe and Zn was 0.5, while 0.6 and 0.4 respectively, for 1000-grain mass and flowering in AIMP 92901. Similarly, σ^2_{ge} for grain Fe, Zn and 1000-grain mass was 0.7, while 0.4 for flowering in ICMR 312. The low σ^2_{ge}/σ^2_g ratio further indicates lower contribution of environmental interaction to total phenotypic variation.

The heritability (broad sense) ranged from 64 to 93% in AIMP 92901 and from 61 to 90 % in ICMR 312 (table17). In both the seasons, flowering and 1000-grain mass had high magnitude of heritability in both populations (77 to 93% in AIMP 92901 and 79 to 90% in ICMR 312). In pooled analysis, high heritability was observed for all traits in both the populations. however, grain Fe had higher estimates (80%) than the grain Zn (75%) in AIMP 92901 (table 18). the comparable estimates of heritability for all the traits in individual environment as well as across the seasons in both the populations imply that g x e interaction (environment) had low influence and genetic factors predominate on the expression of these traits.

4.3.2. Genetic components of variance for grain Fe/Zn, 1000-grain mass and flowering

s_1 progeny variance far exceeded that due to HS progeny variance for all the four traits in both the populations, except for grain Zn ($\sigma^2_{hs} > \sigma^2_{s1}$) in ICMR 312 in rainy season (table 19). The dominance genetic variance (σ^2_d) was more important for grain Fe and Zn in summer in both the populations, whereas σ^2_a was predominant for grain Fe and Zn during the rainy season in both the populations. For 1000-grain mass in population ICMR 312, both σ^2_a and σ^2_d variances were equally important in the summer trial but only σ^2_a in population AIMP 92901 in summer season. In rainy season, the predominance of σ^2_a was observed for 1000-grain mass in both the populations. In both the seasons, it is only σ^2_a that controlled flowering in both the populations. in the pooled analysis, both grain Fe and Zn had predominant σ^2_d in population AIMP 92901, while it was σ^2_a that predominated in population ICMR 312 for grain Fe and Zn.

4.3.3. population progenies *per se* performance

4.3.3.1. grain fe concentration

the mean grain Fe among s_1 progenies ranged from 26.7 to 74.7 mg kg^{-1} in rainy season, from 32.1 to 118.4 mg kg^{-1} in summer season, and from 29.4 to 87.9 mg kg^{-1} in across the seasons in AIMP 92901, whereas in ICMR 312 progenies, it ranged from 27.1 to 73.3 mg kg^{-1} in rainy season, 49.9 to 112.5 mg kg^{-1} in summer season, and 42.1 to 89.2 mg kg^{-1} in across the seasons (appendix V.a and b). In HS progenies, grain Fe varied from 31.9 to 58.6 mg kg^{-1} in rainy season, from 42 .7 to 75.5 mg kg^{-1} in summer season, and from 42.0

to 64.7 mg kg^{-1} in across the seasons in AIMP 92901, while in ICMR 312, it varied from 29.5 to 74.5 mg kg^{-1} in rainy season, from 42.4 to 81.2 mg kg^{-1} in summer season, and from 39.8 to 71.2 mg kg^{-1} in across the seasons. The s_1 progeny mean (average across all progenies) for grain Fe in both the populations was greater than HS progeny mean (average across all progenies) in individual environment as well as across seasons (appendix V.a and b). The average grain Fe in summer season was 41% and 35% higher than in the rainy season, respectively for S_1 and HS progenies.

4.3.3.2. Grain Zn concentration

the mean grain Zn among s_1 progenies in AIMP population ranged from 28.1 to 60.1 mg kg^{-1} in rainy season, from 33.9 to 92.5 mg kg^{-1} in summer season, and from 32.0 to 70.6 mg kg^{-1} in across the seasons, whereas in ICMR 312 progenies, it ranged from 29.1 to 61.9 mg kg^{-1} in rainy season, from 44.4 to 77.5 mg kg^{-1} in summer season, and from 36.8 to 69.7 mg kg^{-1} in across the seasons (appendix v. a and b.). similarly, grain Zn among HS progenies in AIMP 92901 population varied from 31.7 to 54.9 mg kg^{-1} in rainy season, from 42.8 to 64.3 mg kg^{-1} in summer season, and from 41.7 to 59.4 mg kg^{-1} in across the seasons, while in ICMR 312 population progenies, it varied from 27.9 to 84.6 mg kg^{-1} in rainy season, from 43.8 to 67.1 mg kg^{-1} in summer season, and from 37.3 to 68.7 mg kg^{-1} in across the seasons. The average grain Zn in the summer season was 29% and 25% higher than in the rainy season, respectively for S_1 and HS progenies.

4.3.3.3. 1000-grain mass and flowering

the S_1 and HS progenies of AIMP 92901 and ICMR 312 populations had almost similar range (AIMP 92901: 7.6 – 15.8 g in S_1 and 8.9 – 16.4 in HS; ICMR 312: 8.5 – 17.4 in S_1 and 10.7 – 16.6 in HS) and mean (11 – 12.4 g in AIMP 92901 and 11.6 – 13 g in ICMR 312) in individual environment as well as across the seasons (appendix V.a and b). For flowering, the s_1 had similar mean (46-47 in AIMP 92901 and 48 - 49 days in ICMR 312) and range (42 – 51 days in AIMP 92901 and 41 -54 days in ICMR 312) in individual environment as well as across the seasons in each population. Similarly, HS progenies also had similar mean (44-45 days in AIMP 92901 and 47 days in ICMR 312) and range (41 – 49 days in

AIMP 92901 and 44-54 days in ICMR 312) in individual environment as well as across the seasons in each population.

4.4. SINGLE PLANT SELECTION

4.4.1. Set - I populations

4.4.1.1. Analysis of variance

S_1 progenies from two broad-based populations, ICTP 8203 and JBV3, were evaluated for grain Fe/Zn, flowering and 1000-grain mass for two seasons (summer and rainy, 2009). S_1 progenies mean squares were highly significant for grain Fe and Zn, flowering, and 1000-grain mass (Table 20). In both the seasons, σ^2_g was higher for grain Fe in ICTP 8203 (318.5 in summer; 131.6 in rainy). In case of JBV3, σ^2_g was higher in summer (380.5) but lower in rainy (69.8) seasons. For grain Zn, both the populations showed higher σ^2_g in summer than the rainy season. However, JBV3 population was more variable for Zn than ICTP 8203 during the summer season.

The heritability (broad sense) ranged from 56% to 97% in ICTP 8203 progenies, whereas in JBV3, it ranged from 56% to 94%. Flowering and 1000-grain mass in ICTP 8203 and JBV3 had high heritability in both the seasons and comparable between seasons. However, variable estimates of heritability in both the populations were observed for Fe (in ICTP 8203) and Zn (in JBV3) between two seasons. For example, high heritability for Fe during summer (81%) but moderate in rainy (56%) in population ICTP 8203, while high heritability for grain Zn in summer (83%) but moderate in rainy (56%) in population JBV3. In the pooled analysis, high heritability observed for all the traits ranged from 81% to 95% in ICTP 8203 and from 85% to 95% (Table 21)

In the pooled analysis, the mean squares due to progenies were highly significant for all the four traits in both the populations (Table 21). The progenies x environments (seasons) interactions were significant for flowering and 1000-grain mass in both the populations, while for grain Fe it was significant only in JBV3 population progenies. For all the four traits, the genotypic variance contributed more than the interaction (i.e., progenies x environment), as also evidenced by low σ^2_{ge}/σ^2_g ratio (<1). However, the magnitude of σ^2_{ge} was very low for grain Fe and Zn (0.1 to 0.3) than the 1000-grain mass and flowering (0.5 to 0.9) (Table 21). This observation was further supported by positive and significant correlation coefficients between seasons in both populations: Fe ($r = 0.64$; $P<0.01$ in ICTP 8203; $r = 0.87$; $P<0.01$ in

JBV3) and Zn ($r = 0.61$; $P<0.01$ in ICTP 8203; $r = 0.74$; $P<0.01$ in JBV3) (Table 22; Fig. 9 and 10). Similar trends were also observed for 50% flowering ($r = 0.52$; $P<0.01$ in ICTP 8203; $r = 0.39$; $P<0.05$ in JBV3) and 1000-grain mass ($r = 0.55$; $P<0.01$ in ICTP 8203; $r = 0.47$; $P<0.01$ in rainy). The correlation between grain Fe and Zn among S_0 plants were positive and significant in both the populations ($r = 0.70$; $P<0.01$ in ICTP 8203; $r = 0.77$; $P<0.01$ in JBV3) as is the case observed amongst S_1 progenies in both the populations (ICPT 8203: $r = 0.72$, 0.86, 0.80 in summer, rainy and across seasons; JBV3: $r = 0.83$, 0.78, 0.82 for summer, rainy and across seasons) (Table 23).

4.4.1.2. S_1 progenies *per se* performance

4.4.1.2.1. ICTP 8203 S_1 progenies

Variability for grain Fe and Zn among randomly selected S_0 plants in rainy season ranged from 52.8 to 102.8 mg kg^{-1} for Fe and from 45.7 to 84.9 mg kg^{-1} for Zn, averaging 77.3 mg kg^{-1} Fe and 64.5 mg kg^{-1} Zn. The S_1 progenies in the pooled analysis had shown larger variability for Fe (61.3 to 133.3 mg kg^{-1}) than Zn (50.4 to 91.1 mg kg^{-1}), averaging 90.7 mg kg^{-1} Fe and 74 mg kg^{-1} and Zn (Appendix VI; Fig. 11 and 12). Seasons had influenced the range and progeny means for grain Fe and Zn, for example, more variation for Fe and Zn in summer season (91 and 49 mg kg^{-1} differences for Fe and Zn, respectively) than in the rainy season (only 60 and 36 mg kg^{-1} differences for Fe and Zn, respectively). Furthermore, the average grain Fe and Zn in summer (108.6 mg kg^{-1}for Fe and 85.6 mg kg^{-1}for Zn) were 49% and 37% higher than those in the rainy season (72.7 mg kg^{-1} Fe and 62.4 mg kg^{-1} Zn), respectively.

The average percent change of S_1 progenies over S_0 plants was 18% for grain Fe and 15% for grain Zn (Fig. 13 and 14). However, larger variability in performance of S_1 progenies over corresponding S_0 plants were observed for both elements (-11 to 50% for Fe; -7 to 45% for Zn) (Appendix VI). Fifteen S_1 progenies for Fe and 12 S_1 progenies for Zn had >20% higher micronutrient levels than their corresponding S_0 plants. The correlation between S_0 and S_1 was highly significant ($P<0.01$) both for grain Fe ($r = 0.69$; 0.50 and 0.66 in summer, rainy and across seasons, respectively) and Zn ($r = 0.61$, 0.63 and 0.69 in summer, rainy and across seasons, respectively) (Table 23 and Fig 15).

S_1 progenies had similar range and mean for flowering (range 40 to 52, mean 46) in individual environment as well as across the seasons. The S_1 progenies with high grain Fe (≥100 mg kg^{-1}) and Zn (≥70 mg kg^{-1}) flowered early to intermediate (42 - 49 days) in across environments. The earliest flowering S_1 progeny (40 days in summer and 42 days in rainy) had high Fe (87 and 118.7 mg kg^{-1}) and Zn (75.5 and 94.4 mg kg^{-1}) in both the seasons (Appendix VI). Overall results showed no significant correlation of flowering with grain Fe and Zn. The variability for 1000-grain mass ranged from 8.8 to 17.6 g in summer season and from 8.3 to 16.2 g in rainy season, whereas across environments it varied from 8.6 to 15.8 g, with an average of 12.6 g in individual environment as well as across the seasons (Appendix VI). The large-grained S_1 progenies (>14 g) had high Fe (78 - 127 mg kg^{-1} in summer, 64 - 103 mg kg^{-1} in rainy, and 64 -117 mg kg^{-1} across seasons) and Zn (72 - 99 mg kg^{-1} in summer, 54 - 80 mg kg^{-1} in rainy, and 65 - 87 mg kg^{-1} across seasons), which indicate that large-grain size could be combined with high grain Fe and Zn in the progenies without scarifying the grain size.

4.4.1.2.2. JBV3 S_1 progenies

Variability for grain Fe and Zn among the random S_0 plants ranged from 29.5 to 74.9 mg kg^{-1} for Fe and from 33.7 to 73.2 mg kg^{-1} for Zn, averaging 50.3 mg kg^{-1} Fe and 46.8 mg kg^{-1} Zn. The S_1 progenies in the pooled analysis had shown larger variability for grain Fe (36.6-113.1 mg kg^{-1}) than Zn (37.6 to 88.9 mg kg^{-1}), averaging 57.3 mg kg^{-1} Fe and 53.1 mg kg^{-1} Zn (Appendix VII; Fig. 11 and 12). Seasons had significant influence on the range and progeny mean for grain Fe and Zn, for example, more average grain Fe (70.9 mg kg^{-1}) and Zn (63.3 mg kg^{-1}) in the summer season observed than in the rainy season (Fe 43.8 mg kg^{-1}; Zn 42.8 mg kg^{-1}) season.

The average percent change of S_1 progenies over S_0 plants was 15% for both grain Fe and Zn (Appendix VII; Fig. 16 and 17). However, larger variability in performance of S_1 progenies over corresponding S_0 plant was observed for both elements (-45 to 74% for Fe; -21 to 69% for Zn) (Appendix VII). Sixteen S_1 progenies had >20% higher micronutrient levels than their corresponding S_0 plants for both Fe and Zn concentration. The correlation between S_0 and S_1 was highly significant ($P<0.01$) for both grain Fe (r = 0.54, 0.62 and 0.58 in summer, rainy and across environments, respectively) and Zn (r = 0.64, 0.57 and 0.65 in summer, rainy and across environments, respectively) (Table 23; Fig 18).

S_1 progenies had similar range and mean for flowering (range 44 – 56, mean 51 days) in individual environment as well as across the seasons. The high Fe ($\geq$73 mg kg^{-1}) and moderate Zn ($\geq$53 mg kg^{-1}) S_1 progenies had intermediate to late flowering (47 – 54 days) across the seasons. The earliest flowering S_1 (44 days in summer and 46 days in rainy) had low to moderate mean Fe (54.9 mg kg^{-1} in summer and 35.2-41.3 mg kg^{-1} in rainy) and Zn (48.2 mg kg^{-1} in summer and 37.5-43.1 mg kg^{-1} in rainy) in both the seasons (Appendix VII). However, overall results showed no significant correlation of flowering with grain Fe and Zn. The variability for 1000-grain mass varied from approximately from 7 to 12 g in individual environment as well as across the seasons. In comparison to ICTP 8203 population, JBV 3 is less responsive to S_1 progeny selection for grain Fe/Zn and grain mass.

4.4.2. Set - II populations

4.4.2.1. Analysis of variance

Highly significant differences among progenies were observed for grain Fe and Zn, 1000-grain mass, flowering and grain yield in population AIMP 92901 and ICMR 312 in both the seasons (Table 24). The AIMP 92901 had greater σ^2_g for grain Fe and Zn than ICMR 312. For grain yield, greater σ^2_g was recorded in population ICMR 312 than AIMP 92901 in both the seasons.

The heritability (broad sense) ranged from 59% to 95% in AIMP 92901 progenies, whereas in ICMR 312 it ranged from 44% to 98%. For grain Fe, both the populations had similar high heritability in two seasons (59-71%). In population AIMP 92901, high heritability for grain Zn was large but comparable (73% and 76%) between seasons, while moderate but variable (44% and 58%) heritability between the seasons for Zn in ICMR 312 (Table 24). In general, in both the populations' high heritability observed for 1000-grain mass, flowering and grain yield and comparable between seasons. In the pooled analysis, high heritability observed for all the traits in both the populations and it ranged from 78% to 97% in AIMP 92901 and from 63% to 96% in ICMR 312. The high heritability observed for each trait was comparable between the populations except for grain Zn (85% in AIMP 92901 and 63% in ICMR 312).

The two population (AIMP 92901 and ICMR 312) progenies in the pooled analysis showed significant differences for grain Fe and Zn, 1000-grain mass, grain yield and flowering (Table 25). For grain yield and flowering, progenies x environment (P x E) interactions were highly significant in both the populations. This interaction had no influence on grain Fe and Zn and 1000-grain mass in population AIMP 92901, while P x E interaction effect was significant for grain Fe and 1000 grain mass in population ICMR 312. Moreover, the environment had larger contribution to grain yield as evidenced by σ^2_{ge}/σ^2_g ratio >1 in both the population. For other traits it was less than unity in both populations (Table 25).

The higher magnitude of correlation coefficients between seasons for grain Fe and Zn in AIMP12901 than ICMR 312 revealed that the AIMP population S_1 progenies had performed fairly stable across environments (Fig. 19, 20 and Table 22). The correlation between grain Fe and Zn among S_0 plants were positive and significant in both the populations ($r = 0.87$; $P<0.01$ in AIMP 9290; $r = 0.63$; $P<0.01$ in ICMR 312) as was the case observed amongst S_1 progenies in both the populations (AIMP 92901, $r = 0.70$; 0.83, 0.78 in summer, rainy and across seasons; ICMR 312, $r = 0.56$, 0.49, 0.43 for summer, rainy and across seasons) (Table 23).

4.4.2.2. S_1 progenies *per se* performance

4.4.2.2.1. AIMP 92901 progenies

Variability for grain Fe and Zn concentration among the random S_0 plants ranged from 35.5 to 112.3 mg kg^{-1} for Fe and from 31.6 to 91.9 mg kg^{-1} for Zn, with an average of 68.5 mg kg^{-1} Fe and 61.1mg kg^{-1} Zn. The S_1 progenies based on the two seasons data had shown larger variability for grain Fe (40.3-96.1 mg kg^{-1}) than for the grain Zn (40.4 - 78.7 mg kg^{-1}), which was also reflected in their average performance, i.e., high mean grain Fe (64.3 mg kg^{-1}) than Zn (55.6 mg kg^{-1}) (Appendix VIII; Fig. 11 and 12). The average grain Fe (77 mg kg^{-1}) and Zn (64.4 mg kg^{-1}) in summer were, respectively, 49% and 37% higher than those in the rainy seasons (51.5 mg kg^{-1} Fe and 46.9 mg kg^{-1} Zn).

Although, the average percent change in S_1 progenies over S_0 plants were negligible (-3% for Fe and -6% for Zn), however 6 S_1's for Fe (≥13 to 56%) and 5 S_1's for Zn (≥14-30%) had higher micronutrient levels than their corresponding S_0 plants (Appendix VIII; Fig 21 and 22). The correlation between S_0 and S_1 was highly significant ($P<0.01$) for Fe ($r = 0.58$; 0.59 and 0.66 in rainy, summer and across seasons, respectively) and Zn ($r = 0.65$; 0.69 and 0.73 in rainy, summer and across seasons, respectively) (Table 23 and Fig.23).

The S_1 progenies had similar range and mean for flowering (range 41-55, mean 46-47 days) in individual environment as well as across the seasons. The high Fe (>70 mg kg^{-1}) and Zn (>55 mg kg^{-1}) S_1 progenies flowered between 43 - 50 days across seasons. The earliest flowering S_1 progenies (41- 42 days) had moderate Fe (51.7 – 67.1. mg kg^{-1}) and low Zn (35.3 - 45.4 mg kg^{-1}) in both the seasons (Appendix VIII). Overall results showed no significant correlation of flowering with grain Fe and Zn. The variability for 1000-grain mass had similar range and mean (range 8 – 14 g; mean 11 g) in individual environment as well as across the seasons. The larger-grained S_1 progenies (≥12g) had moderate to high Fe (55.5 - 96.1 mg kg^{-1}) and Zn concentration (50.3-78.7 mg kg^{-1}) based on the mean of the two seasons but this was not consistent in individual season. The grain yield among S_1 progenies ranged from 1213 to 2221 kg ha^{-1} in rainy season, from 1565 to 3627 kg ha^{-1} in summer season and from 1484 to 2924 kg ha^{-1} in across the seasons. The average grain yield in summer season was 51% higher than those in the rainy season trials (1746 kg ha^{-1} in rainy and 2631 kg ha^{-1} in summer). The progeny which had highest yield (2221 kg ha^{-1} rainy, 3627 kg ha^{-1} in summer) also had low grain Fe (33.6 mg kg^{-1} rainy and 55 mg kg^{-1} summer) and Zn (34.2 mg kg^{-1} rainy and 47.6 mg kg^{-1} summer) (Appendix VIII). Overall results indicates that negative but weak significant correlation between grain Fe and grain yield but no such correlation was observed between grain yield and Zn (see section 4.6)

4.4.2.2.2. ICMR 312 progenies

Variability for grain Fe and Zn concentration among the random S_0 plants ranged from 46.6 to 98.6 mg kg^{-1} for Fe and from 50.7 to 78.8 mg kg^{-1} for Zn, averaging 71 mg kg^{-1} Fe and 62.7 mg kg^{-1} Zn. Based on two seasons evaluation, S_1 progenies had large variability for grain Fe (48.7 - 81.9 mg kg^{-1}) than for Zn (44 - 62.5 mg kg^{-1}), which was also reflected in their average performance, i.e., high mean grain Fe (63.2 mg kg^{-1}) than Zn (52.2 mg kg^{-1}) (Appendix IX; Fig. 11 and 12). As similar to other trials, the average grain Fe and Zn concentration in summer season (76.4 mg kg^{-1} Fe and 62.4 mg kg^{-1} Zn) were 53% and 49% higher than those in the rainy season (49.9 mg kg^{-1} Fe and 41.9 mg kg^{-1} Zn).

The average percent change in S_1 progenies over S_0 plants was negative for Fe (-10%) and Zn (-16%) concentration (Fig. 24 and 25); however, only two S_1 progenies for grain Fe had shown 11% higher micronutrient than their corresponding S_0 plants. The correlation between S_0 and S_1's was highly significant ($P<0.01$) for grain Fe (r = 0.53; 0.69 and 0.75 in rainy, summer and across seasons, respectively) and Zn (r = 0.69 in summer and 0.61 across season) (Table 23; Fig. 26).

S_1 progenies had similar range variation (44 - 56 days) and mean (49 days) for flowering. The high Fe (>70 mg kg^{-1}) and Zn (>55 mg kg^{-1}) S_1 progenies flowered between 47-55 days across the seasons. The earliest flowering S_1 progenies (44 - 46 days) had low to moderate grain Fe (38 - 70.5 mg kg^{-1}) and Zn (47.3 - 51.5 mg kg^{-1}) in both the seasons (Appendix IX). Overall results showed positive and weak but significant correlation of flowering with grain Fe and Zn (see section 4.6). The variability for 1000-grain mass among S_1 progenies was similar (9 – 15 g) in individual environment as well as across seasons. The large-grained S_1 progenies (>12.5g) had moderate to high grain Fe (57.7 - 75.6 mg kg^{-1}) and low to moderate Zn (47.7 – 58 mg kg^{-1}) across seasons. Overall results showed no significant correlation of grain mass with grain Fe and Zn. The grain yield among S_1 progenies ranged from 481 to 2467 kg ha^{-1} in rainy season, from 1618 to 4263 kg ha^{-1} in summer season and from 1375 to 2942 kg ha^{-1} across the seasons. The average grain yield in summer season was 35% higher than those in the rainy season (1833 kg ha^{-1} in rainy). The highest yielding S_1 progenies in individual environment as well as across the seasons (2487 kg ha^{-1} in rainy, summer 4263 kg ha^{-1} and 2942 kg ha^{-1} across seasons) had shown moderate to high grain Fe (59.8 mg kg^{-1} in rainy, 78.3 mg kg^{-1} in summer and 70.7 mg kg^{-1} across seasons) and low Zn (37.9 mg kg^{-1} in rainy, 53.5 mg kg^{-1} in summer and 48.6 mg kg^{-1} across seasons) (Appendix IX). Overall results indicates no correlation between grain Fe/Zn and grain yield except summer season (see section 4.6)

4.4.3. Efficiency of single plant selection

Progeny evaluation in breeding for Fe and Zn density, as for any other trait, is generally conducted in unreplicated nurseries. Thus, present study examined the effectiveness of unreplicated S_1 progeny selection with that of the s_0 plant selection by comparing the correlation of the S_1 progeny performance between two replicates with correlations of the s_0 performance with either of the two replicates (table 23). In both the seasons, grain Fe between S_0 plants and un-replicated (each replication considered as separate trial) S_1 progenies was significant and positively correlated in all the four populations [S_0 and S_1 (R_1) r = 0.37 to 0.66 and S_0 and S_1 (R_2) r = 0.39 to 0.60]. Similarly, the relationships between s_0 and un-replicated S_1 progenies for grain Zn was also positive and significant in all populations (except for ICMR 312 in rainy) [S_0 and S_1 (R_1) r = 0.48 to 0.61 and S_0 and S_1 (R_2) r = 0.35 to 0.69]. Overall it was observed that in all cases the correlation coefficients were positive and highly significant for both micronutrients in all four populations, and there was no systematic pattern to indicate that the s_0 plant selection was any less effective than the s_1 progeny selection. for instance, in 8 cases represented by 2-seaon S_1 trials of four populations, top ranking 20 S_0 plants (i.e., 50% of the plants used in this study) for high Fe density corresponded to 70-90% of the top ranking 10 S_1 progenies (i.e., 25% of the top ranking S_1 progenies) (data not presented).

4.5. Recurrent selection

4.5.1. Population response

The effect of one cycle of recurrent selection on grain Fe/Zn and agronomic traits was studied in two populations (Table 26). Of the agronomic traits, one cycle of recurrent selection had significantly improved the mean performance for 1000-grain mass in both populations (AIMP 92901 and ICMR 312); however, the improvement in panicle length was observed only in case of AIMP 92901. Grain Fe and Zn on the other hand had shown only marginal superiority in C_1 over C_0 cycle (Table 26; Fig.27 and 28). The genetic gain after one cycle of recurrent selection was 2.4% for Fe and 7.9% for Zn in AIMP 92901, while in case of ICMR 312 population; it was 8.0% for Fe and 5.4% for Zn. For 1000-grain weight, ICMR 312 population had shown greater genetic gain (14.2%) in comparison to AIMP 92901 (genetic gain 4.8%). However, both populations had shown almost similar gain for panicle length (9.1% in AIMP 92901 and 7.3% in ICMR 312).

4.6. Correlations between grain Fe/Zn and agronomic traits

Grain Fe and Zn were found significantly and positively associated in all the four populations; however, the correlation coefficients were >0.70 in three populations (ICTP 8203, JBV3 and AIMP 92901), both in individual environment as well as across the seasons (Table 27). For population ICMR 312, the correlation between grain Fe and Zn were moderate (0.43, 0.49, 0.56) but significant and positively associated in individual environment as well as across seasons. Likewise, Fe and Zn were also found significant and positive (0.69 to 0.86) in individual environment as well as across the seasons in both sets of line x tester trials. The correlation between grain Fe and Zn were found significantly and positively associated in S_1 and HS progenies in both the populations, in individual environment as well as across the seasons. However, the correlation coefficients in general were greater (r >0.80) in S_1 than HS progenies in AIMP 92901 in individual environment as well as across the seasons, while it was r > 0.70 in S_1 but variable among HS (r = 0.69 to 0.78) in ICMR 312 in individual environment as well as across the seasons (Table 28).

For 1000-grain mass, low to moderate but significant and positive correlation coefficients (0.22 to 0.45) were observed in set II of line x tester trial (Table 27). Likewise, low but significant and positive correlation coefficients were observed with grain Fe in S_1 from AIMP 92901 during rainy (r = 0.32) and across seasons (r = 0.27). Similarly correlation between grain Zn and 1000-grain mass was low (r = 0.29 to 0.33) but positively significant among S_1 and HS in both populations only in rainy season (Table 28). Flowering in most of the cases was not correlated with grain Fe/Zn, however, significant positive but weak correlation was detected during rainy season in ICMR 312 S_1 progeny trial and set I line x tester trial (Table 27). The significant negative but weak correlation between grain Fe and flowering was detected in S_1 (r = -0.27) from AIMP 92901 during summer season, whereas positive significant but weak correlation in S_1 (r = 0.28) from ICMR 312 across seasons (Table 28). Grain yield was significantly but negatively associated with grain Fe and Zn (r = -0.32 and -0.42) during the rainy season in population ICMR 312, while in AIMP 92901, only grain Fe was negatively correlated with grain yield (r = -0.43) in summer season.

CHAPTER 5

DISCUSSION

CHAPTER 5

DISCUSSION

Micronutrient malnutrition arising from deficiency of one or more essential micronutrients affects two-third of world's population (White and Broadley, 2009; Stein, 2010). Crop biofortification is a sustainable and cost-effective approach to address micronutrient malnutrition, especially in the developing world. It refers to the development of micronutrient-dense staple crops using conventional breeding practices or biotechnology (Bouis, 2003). It has the potential to help alleviate the suffering, death, disability, and failures to achieve full human potential that result from micronutrient deficiency-related diseases. In comparison to other strategies (fortification, supplementation or dietary diversification), it provides a truly feasible means of reaching out to remote and rural areas to deliver naturally-fortified foods to population groups with limited access to diverse diets, supplements and commercially fortified foods (Bouis, 2003). Moreover, as the trace mineral requirements in human and plant nutrition are similar, biofortification could improve human nutrition as well as farm productivity (Ma, 2007). India annually produces about 9.5 m t pearl millet, and in parts of some provinces (Rajasthan, Maharashtra, Gujarat, Haryana and Uttar Pradesh) it constitutes the major staple diet, with highest average pearl millet consumption reported from Gujarat and Rajasthan. These two provinces reportedly also have high prevalence of anaemia among children (66%) and severe anaemia (up to 34%) among adolescent girls (www.harvestplus.org; Seshadri, 1998). The HarvestPlus Challenge Program of the Consultative Group on International Agricultural Research supports the development of grain minerals (Fe and Zn) dense cultivars of staple crops, including pearl millet through conventional breeding. Knowledge on natural genetic variation for grain Fe and Zn in germplasm collection, identification of grain mineral dense germplasm, genotype x environment interaction, relationships between grain minerals and agronomic traits and its genetic control, all have potential to significantly impact breeding efficiency for developing grain mineral dense cultivars. This dissertation was aimed at investigating combining ability, gene action, heritability, and heterosis; intra-populations variances; efficiency of single plant selection, associations among micronutrients and agronomic traits and, response to recurrent selection.

5.1. Genetic variability for grain iron and zinc concentration, 1000-grain mass and flowering among grain (lines) and pollen (tester) parents and hybrids

Availability of traits of concern in improved genetic background greatly enhances the breeding efficiency for the target trait combining with other desirable agronomic traits. We evaluated two sets (8 x 9 and 16 x 12) of line x tester parents and their hybrids for two seasons at Patancheru. Most of these inbreds were the designated grain (line)/pollinator (tester) parents (Talukdar *et al*., 1995; Rai *et al.,* 2009). Pollen parents showed greater variability for grain Fe and Zn than the grain parents, which is expected as pollen parents are based on much wider genetic background. Based on two season mean, ICMB 93222, ICMB 98222, 863B ICMB 95333, ICMB 96333 among grain parents and IPC 774, IPC 616, IPC 1650, IPC 1178, IPC 536 and IPC 735 amongst pollen parents were found superior to grain Fe (>60 mg kg^{-1}) and Zn (>55 mg kg^{-1}) concentration. These parents can be utilized for development of hybrids with elevated grain minerals (Fe/Zn) levels, and also further used in hybridization programme to develop parental lines with still higher levels of grain Fe and Zn concentration.

Thirteen hybrids in set-I and 21 hybrids in set II had >60 mg kg^{-1} of grain Fe, while for Zn, there were 13 hybrids in set I and eight hybrids in set II that recorded >55 mg kg^{-1} of Zn across seasons. Overall in set I, hybrids ICMB 98222 x IPC 1178, ICMB 00888 x IPC 1178, ICMB 04777 x IPC 1178, ICMB 94111 x IPC 1178 and ICMB 93222 x IPC 1178 were superior for grain Fe (67.1 – 75.4 mg kg^{-1}). Hybrids ICMB 98222 x IPC 1178, ICMB 89111 x IPC 1178, ICMB 04777 x IPC 774, ICMB 04777 x IPC 1178 and ICMB 94111 x IPC 1178 were superior for grain Zn (65-69 mg kg^{-1}). In set II, hybrids ICMB 91222 x IPC 689, ICMB 91222 x IPC 1642, ICMB 91222 x IPC 735, 863B x IPC 404 and 863 x IPC 735 had grain Fe in the range of 70.2-80.0 mg kg^{-1}, while hybrids 863 B x IPC 404, 863 B x IPC 735, ICMB 91222 x IPC 1642 and ICMB 91222 x IPC 689 had grain Zn in the range of 56.5 – 63.6 mg kg^{-1}. The hybrids in both the sets showed greater variability for Fe (30 - 80 mg kg^{-1}) than for Zn (31 – 70 mg kg^{-1}). The previous reports in pearl millet (Velu *et al.,* 2007; Velu *et al.,* 2008a; Gupta *et al.,* 2009) have also found similar variation for grain Fe and Zn as detected in the present study.

Pearl millet is traditionally a small grain crop, adapted to marginal environments. However, farmers in some regions in India especially in Maharashtra and Karnataka prefer large-grained pearl millet (Bidinger and Raju, 2000), which fetch them higher market price (Phul and Athwal, 1969). Large grain size (1000-grain mass) also increases flour extraction (Wiersma *et al.,* 2001). Almost all of the commercial hybrids have 9 – 12 g 1000^{-1} grain mass. In set I, 12 large-grained hybrids with $\geq$13 g 1000^{-1} grain mass were identified, of which six hybrids had moderate to high levels of grain Fe (51 - 69 mg kg^{-1}) and Zn (50 - 62 mg kg^{-1}). In set II, 29 large-grained hybrids ($\geq$13 g 1000^{-1} grain mass) were identified, of which 11 hybrids had moderate to high levels of grain Fe (60 – 77 mg kg $^{-1}$) and Zn (51 – 64 mg kg $^{-1}$). These results indicated that it would be feasible to combine large-grain size and greater grain Fe and/or Zn in pearl millet. Seasons had no influence on 1000-grain mass.

For example, the average 1000-grain mass among parents and hybrids in both the sets was 9-10 g and 11-12 g between seasons, respectively. Moreover, the lower genotype x environment interaction (GEI) for 1000-grain mass indicated that this trait are fairly stable, although these need to be confirmed through experimentations on a wider range of environments.

Selection for early flowering helps the plant to escape from terminal drought in pearl millet (Rattunde *et al*., 1989). Across the two seasons, grain parents ICMB 00888 and 843B and the pollen parents IPC 774 and IPC 404 were earliest to flower (45-50 days), while others flowered in 51-59 days. For the ease of hybrid grain production, it is good if the grain parents flowered 2-3 days earlier than the pollen parents, which will ensure the availability of pollen when the stigma of the grain parents is receptive. However, this is not a decisive factor in pearl millet since it produces side tillers and provides continuous pollen flow to the females. No systematic patterns in grain Fe and Zn were noticed, which could be related to flowering (or maturity).

Early flowering and early maturity is a key factor that determines the adaptation of the newly developed varieties or hybrids to various agro-ecological conditions and cropping systems. This study identified some hybrids that flowered in 43-46 days, 1 – 4 days later than the earliest-maturing commercial hybrid HHB 67 (42 days). Hybrids ICMB 00888 x IPC 616, ICMB 89111 x IPC 774, ICMB 97111 x

IPC 616, ICMB 97111 x IPC 774 and ICMB 97111 x IPC 390 in set I and hybrids 843B x ICMR 06888, 843B x IPC 536 and ICMB 03111 x ICMR 06888 in set II were earliest to flower. Moreover, all the hybrids (in both sets) flowered 2-4 days earlier than the parents.

5. 2. Seasonal effect on grain iron and zinc concentration

Season had significant influence on grain Fe and Zn. The average grain Fe and Zn were greater in the summer season than in the rainy season. For example, hybrids showed 37% to 49% greater grain Fe and 30% to 55% grain Zn in summer season than in the rainy season (43 and 40 mg kg^{-1} of grain Fe and Zn, respectively, in set I and 40 and 39 mg kg^{-1} of grain Fe and Zn, respectively, in set II). The variability and availability of Fe and Zn in the soil together with variation in environmental parameters such as rainfall, relative humidity and temperature might have contributed to differences in grain Fe and Zn between the two seasons. For example, high temperature and low relative humidity during summer season (especially after flowering to maturity) leads to higher transpiration that will accelerate more water and minerals uptake and translocation (transpiration pull) or re-translocate minerals in stress situation from source to sink. The crops like rice, maize and wheat are highly sensitive to water stress and high temperature, which will impede normal growth and development, thus adversely affecting uptake and translocation of nutrients. In contrast, pearl millet performs well under drought and high temperature conditions, thereby continuous uptake and translocation of substrates. Our observation support the previous findings that variations in weather parameters have significantly impacted grain Fe and Zn in summer season in wheat (Joshi *et al*., 2010) and rice (Ramos *et al.,* 2004). The Fe and Zn in the experimental fields of the present study were more than the critical limits (2.0 mg kg^{-1} for Fe and 0.75 mg kg^{-1} for Zn, KL Sahrawat, pers. Comm.) in both seasons. Selfing in pearl millet leads to variable reduction in grain set, depending on the genotypes. Reduction in grain set leads to increase in Fe and Zn concentration in grains (KN Rai, pers. Comm.). Thus, it is probable that selfed grain used in this study was the result of relatively greater reduction in grain set in summer, and consequently the higher Fe and Zn concentration.

5.3. Broad sense heritability (h^2bs) for grain iron and zinc concentration, 1000-grain mass and flowering

Heritability is a measure of observed phenotypic differences for a trait due to genetic differences (Klug and Cummings, 2005). In the present study, high h^2bs for grain Fe (78% to 94%) and Zn (63% to 85%) in all the four populations (ICTP 8203, JBV3, AIMP 92901 and ICMR 312) in individual environment as well as across the seasons revealed that both grain Fe and Zn are highly heritable. The previous studies also reported high h^2bs for grain Fe and Zn (Velu, 2006; Arulselvi *et al.,* 2007; Gupta *et al.,* 2009) in pearl millet, while moderate h^2bs for grain Fe and Zn in common bean and rice (Gregorio *et al*., 2000; da Rosa *et al*., 2010). Unlike in the present study, Velu (2006) reported variable estimates of between seasons h^2_{bs}: 52% (summer) to 81% (rainy) for grain Fe and 44% (summer) to 70% (rainy) for Zn. High h^2_{bs} heritability for flowering and 1000-grain mass, noted in the present study, confirm previous reports that both flowering and grain mass are highly heritable traits in pearl millet (Velu, 2006; Arulselvi *et al.,* 2007; Gupta *et al.,* 2009).

Taken together, the above findings suggest that genetic improvement for Fe and Zn concentration should be fairly effective in pearl millet. A caution to our work is that heritability estimates may differ between populations or its progenies. Secondly, the soil environment most likely will affect micronutrient uptake and thus alter heritability estimates as observed in sweet potato (Courtney, 2007). Finally, h^2_{bs} is based on total genetic variance which includes fixable (additive) and non-fixable (dominant and epistatic) variances, which does not give an indication of the magnitude of fixable genetic variance (Ramanujam and Tirumalachar, 1967; Lal and Singh, 1970).

5.4. Combining ability and gene action for grain iron and zinc concentration, 1000-grain mass and flowering

Combing ability analysis provides us information about the potential of a line to produce hybrids with high value of that trait with the likelihood of this occurring in the breeding programme. General combining ability (*GCA*) determines the average performance of a line in a series of crosses, whereas specific combining ability (SCA) is used to estimate the situations in which certain hybrid combinations do relatively better or worse than the prediction based on the *GCA* of parental lines. Analysis of combining ability also provide information about nature of gene action involved, which may help design appropriate breeding strategy to develop cultivars/hybrids. A suitable mating design is required to investigate such information. In the present study, two sets of line × tester trials (8 x 9 and 16 x 12) were conducted to evaluate the combining ability of parents and determine nature of genetic variance controlling grain Fe and Zn, 1000-grain mass and flowering in pearl millet. In both the sets, the variances due to crosses, lines, testers and line x tester interactions were significant in individual environment as well as across the seasons.

The testers contributed more genetic variance for grain Fe and Zn, and flowering in set-I; for grain Zn, 1000-grain mass and flowering in set II, while lines contributed more genetic variance for 1000-grain mass in set I and for grain Fe in set II in individual environment as well as across the seasons. The line x tester variance contributed much less than either lines or testers alone for these traits in both sets. This means that the performance of hybrids for grain Fe and Zn, 1000-grain mass and flowering mostly depend on male than the female parents included in this study.

The *GCA* (parents) and SCA (line x tester) mean square in both the sets were highly significant for grain Fe and Zn, 1000-grain mass and flowering across seasons. However, the predictability ratio closer to unity, as observed in the present study, revealed the predominance of *GCA* (additive) variance controlling these traits in both the sets. Highly significant positive correlation between mid-parent value and *per se* performance of hybrids further confirmed the predominant role of additive gene action for these traits in both the sets. Previous reports also indicate the greater importance of additive gene action for grain Fe and Zn in pearl millet (Velu, 2006; Rai *et al.,* 2007; Velu *et al.,* 2011a) and maize (Gorsline *et al.*, 1964; Arnold and Bauman, 1976; Long *et al.*, 2004; Chen *et al.*, 2007). The greater importance of additive gene action for 1000-grain mass and flowering in pearl millet has also been reported in earlier studies (Tyagi *et al.*, 1975, 1982; Shanmuganathan *et al.*, 2005; Velu, 2006; Dangariya *et al.,* 2009).

The correlation between per se performance of the parents and their *gca* effects indicate that per se performance of the parents in general is a good indicator of hybrid performance. In the present study, the per se performance of the parents and their *gca* effects were positive and highly significant for grain Fe and Zn, 1000-grain mass and flowering, as also reported by Velu et al. (2011a). The high grain Fe and Zn parents in this study had positive and significant *gca* effects, while parents with low grain Fe and Zn had significant negative *gca* effects. Using both parameters (per se performance and *gca* effect), ICMB 93222, ICMB 98222, IPC 1650, IPC 843, IPC 774 and IPC 1178 in set I and 863B, ICMB 91222, IPC 689 and IPC 735 in set II were identified as the best general combiners for use in hybrid breeding. The grain parent 863B is an iniari landrace-derivative (thick panicle, large and dark grey grains), medium to short height, and resistant to five diverse pathotypes downy mildew (Sclerospora graminicola (Sacc.) Schrot.) (Rai et al., 2009). It is involved as female parent in three commercially released hybrids (by private company) in India. Another grain parent 843B is an earliest-maturing line, involved the pedigree of the most popular and earliest maturing hybrid, HHB 67 (65 days), released for cultivation in India (especially in Haryana and Rajasthan). ICMB 89111 and ICMB 91222 have medium plant height, medium and grey grains (Rai et al., 2009). The former is involved in the pedigree of two commercially released hybrids, HHB 94 (from Chaudhary Charan Singh Haryana Agricultural University, Hisar) and RHB 121 (from Rajasthan Agricultural University, Agricultural Research Station, Durgapura), while the latter in another commercially released hybrid JBH-2 (jointly developed by JNKVV College of Agriculture, Gwalior and ICRISAT). ICMB 98222 has bold and deep grey grains and matures in 80 days. ICMB 00888 and ICMB 97111 in set I and 863B, ICMB 04888, IPC 404, IPC 689, IPC 1642 and ICMR 06333 in Set II for 1000-grain mass, and ICMB 00888 and ICMB 97111 in set I and 843B, ICMB 03111, ICMB 04222 and ICMR 06888 in set II for early flowering were identified as good general combiner grain and pollen parents.

It is generally believed that hybrids that perform well (*per se* performance) exhibit significant specific combining ability effects (*sca*) (Izge *et al.,* 2007). The correlation between *per se* performance of the hybrids and their *sca* effects in the present study were highly significant for all the four traits. In set I, none of the hybrids had shown consistent *sca* effects (positive and significant) in individual as well across seasons for grain Fe. However, hybrid ICMB 94111 x IPC 1178 and ICMB 89111 x IPC 843 had positive significant *sca* effects for grain Fe in one season as well as across the seasons. Hybrid ICMB 94111 x IPC 1178 had positive significant *sca* effects for grain Zn in individual environment as well across the seasons. Both the hybrids (ICMB 94111 x IPC 1178 and ICMB 89111 x IPC 843), which originated from low and high *gca* effects parents, had high mean grain Fe and Zn (Fe: 62-73 mg kg^{-1} and

Zn: 61-70 mg kg^{-1}) across seasons. The high grain Fe and Zn in these two hybrids may be due to interaction between positive alleles from high *gca* effect parent and negative alleles from low *gca* effect parents. In set II, hybrids 863B x IPC 404 and ICMB 95333 x IPC 404 had positive significant *sca* effects for grain Fe in individual environment as well as across the seasons. These hybrids had moderate to high levels of Fe in individual environment as well as across the seasons (59.6 to 72.2 mg kg^{-1}). For grain Zn, none of the hybrids exhibited positive significant *sca* effect in individual environment as well across the seasons; however, the two hybrids mentioned-above had shown positive and significant *sca* effects and moderate levels of grain Zn (average 53.9 to 58.2 mg kg^{-1}) in rainy season as well as across the seasons. In general, analysis of combining ability of crosses in relation to *gca* effects of parents showed that most of the hybrids that had significant positive *sca* effects involved at least one parent with high *gca* effects. This indicates that at least one parent with high *gca* and/or high mean (significant correlation between *gca* and mean) should be involved in a cross to realize high performance of the hybrid.

For 1000-grain mass, hybrids ICMB 93222 x IPC 774 and ICMB 04777 x IPC 616 in set I and hybrids 863B x ICMR 06333 and ICMB 04888 x IPC 1642 in set II had positive and significant *sca* effects in individual environment as well as across the seasons. Most of the hybrids with positive *sca* effects had at least one parent with high grain Fe/Zn. These hybrids combine large grain size (≥15g 1000^{-1} grain mass) and moderate grain Fe/Zn (Fe: 54.4-60.8 and Zn: 46-54 mg kg^{-1}), which indicate that moderate grain Fe and Zn can be combined with large grains. Hybrid ICMB 93333 x IPC 390 in set I and hybrids 863B x IPC 735, ICMB 99444 x IPC 735, ICMB 99444 x IPC 1254 and ICMB 04555 x IPC 404 in set II had shown significant negative *sca* effect for flowering in the rainy season as well as across the seasons. However, some of the hybrids (ICMB 98222 x IPC 843, ICMB 98222 x IPC 774, ICMB 02444 x IPC 1642 and ICMB 91222 x IPC 7642) flowered early (46-47 days), had large grains (>11g 1000 grains), and high grain Fe (60-70 mg kg^{-1}) and Zn (53-60 mg kg^{-1}). All these hybrids had involved at least one high general combiner in their pedigrees for all these four traits.

5. 5. Heterosis for grain iron and zinc concentration, 1000-grain mass and flowering

Heterosis is defined as the superiority in performance of hybrids over it parents, largely explained either due to dominance or overdominance effects. From practical standpoint, this definition of heterosis must translate into better parent heterosis. Thus, for traits like Fe and Zn concentration and 1000-grain mass better parents would be those that have higher values, while for time to 50% flower better parents are those with early flowering. The dominance model assumes that each of the inbred lines contains a combination of dominant and recessive alleles at different loci, which together in the F_1 hybrid, lead to heterosis (Davenport, 1908; Jones, 1918). The over dominance model suggests that the heterozygous combination of alleles at a given locus is phenotypically superior to either of the homozygous combinations at that locus. The hybrid with either significant positive or negative heterosis over the mid-parent indicates partial dominance of alleles either with positive or negative effect. Where the F_1 values do not deviate significantly from their mid-parent values, it would be indicative of additive gene effects, assuming unidirectional dominances, if any.

In set I, none of the hybrids showed positive and significant mid parent (MP) or better parent (BP) heterosis for grain Fe or Zn. In set II, two hybrids (863B x IPC 404, ICMB 04222 x IPC 1642) for grain Fe and one hybrid (841B x IPC 1642) for grain Zn showed positive and significant MP heterosis across seasons. These hybrids had of 21-26% higher Fe and 14% higher Zn concentration compared to their mid-parent values. None of the hybrids showed BP heterosis, except the two hybrids (863B x IPC 404 and ICMB 91222 x IPC 689) that showed positive and significant BP heterosis (20-22%) for grain Fe only in summer season; however, this positive BP heterosis dissipated when estimated across seasons. These results indicate that there would be little opportunity to exploit heterosis for these micronutrients. Similar negative heterosis for grain Fe and Zn was also reported in pearl millet (Velu, 2006; Rai et al., 2007) and maize (Chakraborti et al., 2009). More recently, da Rossa et al. (2010) reported positive MP heterosis for grain Zn in two crosses in common bean; however, the magnitude (4% and 9%) was much less than those reported in the present study (14%).

For 1000-grain mass, all the hybrids in set I and ~50% of hybrids in set II showed positive MP heterosis across seasons, while 79% hybrid in set I and 20% hybrids in set II showed positive BP heterosis. Most of the hybrids with ≥30% MP heterosis or >20% BP heterosis for 1000-grain mass had at least one parent either with medium or high grain Fe and Zn, which indicates that parents with high Fe and Zn could be used to produce large-grained hybrids.

For flowering, ~95% hybrids in both the sets had negative significant BP heterosis, i.e., the hybrids were earlier than the better parent (earlier-flowering parent) in that cross combination. This could be either due to over-dominance or due to repulsion phase distribution of qualitative dominant genes for earliness. Hybrids with negative BP heterosis ($\geq$ 15%) for earliness had at least one parent either with medium or high grain Fe and Zn. An earlier study in pearl millet also reported similar results (Velu, 2006). However, overall results of the present study indicate no relationship between early flowering and grain micronutrients (Fe/Zn).

5. 6. Intra-population genetic variance for grain iron and zinc concentration, 1000-grain mass and flowering in two populations

the S_1 and half sib (HS) progenies from two populations (AIMP 92901 and ICMR 312) were evaluated for grain Fe/Zn, 1000 grain mass and flowering for two seasons. the genetic variance in both the populations was greater than variance due to G ×E for all traits, as also evidenced by lower σ^2_{ge}/σ^2_g ratio (<1), which indicates that selection for these traits will be effective in both the populations.

The S_1 progeny variance (σ^2_{S1}) exceeded that of half-sibs (σ^2_{HS}) for all the four traits, as also evidenced in a previous study for plant height and panicle length in pearl millet (Zaveri, 1982; Metta, 1987). Assuming no epistatic variance, the magnitude of additive (σ^2_A) and dominant (σ^2_D) genetic variance differed in both the populations for grain Fe and Zn across seasons. For example, the population AIMP 92901 had a larger proportion of σ^2_D than σ^2_A for grain Fe and Zn, which does not conform to the genetical findings of line x tester studies. However, ICMR 312 had greater σ^2_A for these two traits across seasons, which conforms to the results of line x tester studies. Both 1000-grain mass and flowering were predominantly controlled by σ^2_A in both the populations, similar to those earlier reported in pearl millet populations (Jindla, 1981; Zaveri, 1982; Metta, 1987; Ghorpade and Metta, 1993).

The predominance of additive genetic variance suggests that intra-population improvement such as mass selection and recurrent selection can be effectively used for genetic improvement of these traits in pearl millet. In two populations of common bean, the grain Zn has been reported having larger additive genetic variance (da Rosa *et al.,* 2010).

The variance estimated in the present study is based on σ^2_{HS} = ¼ σ^2_A and σ^2_{S1} = σ^2_A+ ¼ σ^2_D (Jan-orn *et al.,* 1976). The estimates of σ^2_A in S_1 progeny will be valid only in the absence of epistasis or when $p = q = 0.5$. These negative estimates of dominance variance, as observed in case of grain Fe and Zn in population ICMR 312 and for 1000 grain mass and flowering in both populations (AIMP 92901 and ICMR 312) could arise either from the inadequacy of the model or inadequate sampling (Lindsey *et al*., 1962; Wolf *et al*., 2000). The sampling errors may be either due to small number (~20 plants) of pollinator's (males) used in the development of half sib progenies (Jan-orn *et al.,* 1976), or lack of random matting while making crosses to produce HS. The assortative mating (i.e., early flowering male crossed with early flowering female) would bring upward bias in the estimate of additive variance and underestimate dominance variance (Lindsey *et al.,* 1962).

5.7. Efficiency of single plant selection for enhancing grain iron and zinc concentration

The difference among the S_1 progenies was highly significant both for grain Fe and Zn concentration in all four populations. The progeny x environment interaction for Zn concentration was non-significant in all four populations. For the Fe concentration, the interaction term was significant in only two populations (JBV 3 and ICMR 312), but its contribution to the total variability was about half to one-fifth of that contributed by the difference among the progenies. These results showed that though both micronutrients were stable, Zn concentration was slightly more stable than the Fe concentration over these two contrasting environments. Stability of these micronutrients, however, need to be tested over the large number and more diverse environments, including different soil Fe and Zn content levels. Several studies in wheat have evaluated the stability of Fe and Zn concentration through more extensive multilocation trials, but the results are not always consistent. For instance, while Morgounov *et al.* (2007) and Joshi *et al.* (2010) found no significant genotype x environment interaction both for Fe and Zn concentration. Highly significant genotype x environment interactions for both micronutrients were found in other studies, but Fe was relatively less stable than Zn (Zhang *et al*., 2010) or just the reverse (Gomez-Becerra *et al.,* 2010).

Since in our study, genotype x environment interaction was not significant, data from both environments were pooled. Results showed large variability among the individual (S_0) plants and among the corresponding progenies for both micronutrients in all four populations. The highest levels and widest range of variability both for Fe and Zn concentration in the S_0 plants and the S_1 progenies were found in ICTP 8203, and the lowest levels and the smallest range in JBV 3. The higher levels of Fe and Zn in ICTP 8203 compared to those in JBV 3 is not unexpected since ICTP 8203 is derived from an *iniari* genetic background which is generally found to have higher levels of both micronutrients than the *non-iniari* genetic background which JBV 3 represents (Velu *et al.,* 2007). In both populations, the Fe and Zn densities in the S_1 progenies were generally 6-14 mg kg^{-1} higher than in the S_0 plants. In the other two populations, the Fe and Zn densities in the S_1 progenies was generally 5-11 mg kg^{-1} less than in the S_0 plants. These S_0 plant and S_1 progeny differences could be due to environmental effects since the grain samples from the S_0 plants came from environments that were different from those in which S_1 progenies were evaluated and grains were produced for micronutrient analysis. These differences might be related to the available Fe and Zn concentration in the soil. For instance, the during the 2009 rainy season and 2010 summer season (S_1 progeny testing environments) the extractable soil Fe content in the top 30 cm layers were 5.8 to 6.1 mg kg^{-1} and Zn contents were 2.3 to 4.3 mg kg^{-1}, while during the 2009 rainy season (S_0 test environment) the soil Fe content was 15.4 mg kg^{-1} and soil Zn content was 5.2 mg kg^{-1}.

The correlation coefficients between the performance of S_0 plants and the mean performance of their S_1 progenies were positive and highly significant both for Fe and Zn concentration in all four populations. The correlation coefficients between the performance of the S_1 progenies from the two environments were also positive and highly significant for both micronutrients, which is not unexpected considering the absence of progeny x environment interactions, or relatively lesser contribution of this interaction to the total variability in comparison to that due to differences among the progenies. These results showed that the S_1 progeny performance for these micronutrients can be as well predicted from the S_0 plants from which these progenies were derived as it can be done from the performance of the same very progenies grown in another environment. The correlation between the S_0 plants and the S_1 progenies were of similar order (for both Fe and Zn) when all four populations were considered together. However, with the larger spread of the values, as depicted for Fe concentration (Fig. 29), the low Fe lines could easily be discarded using S_0 plant performance.

Progeny evaluation in breeding for Fe and Zn concentration, as for any other trait, is generally conducted in unreplicated nurseries. Thus, present study examined the effectiveness of unreplicated S_1 progeny selection with that of the S_0 plant selection by comparing the correlation of the S_1 progeny performance between two replicates with correlations of the S_0 performance with either of the two replicates. It was observed that in all cases the correlation coefficients were positive and highly significant for both micronutrients in all four populations, and there was no systematic pattern to indicate that the S_0 plant selection was any less effective than the S_1 progeny selection. For instance, in 8 cases represented by 2-seaon S_1 trials of four populations, top ranking 20 S_0 plants (i.e., 50% of the plants used in this study) for high Fe concentration included to 70-90% of the top ranking 10 S_1 progenies (i.e., 25% of the top ranking S_1 progenies) (data not presented). Single plant selection, if carried at low population concentration, has been found effective even within the cultivars for phosphorus content in alfalfa (Miller *et al.,* 1987) and protein content in wheat (Tokatlidis *et al.,* 2004). Single plant selection at low plant concentration was shown to be effective in soybean for both oil and protein content (Fasoula and Boerma, 2005). However, the effectiveness of low plant concentration on selection for Fe and Zn concentration in pearl millet remains to be evaluated.

In an applied breeding program, genetic improvement for Fe and Zn concentration would seek to combine these micronutrients with high grain yield potential and other agronomic traits such as early maturity and large grain size. An earlier study has shown that Fe and Zn concentration are not correlated with grain yield, grain size and time to flowering (Gupta *et al.,* 2009). Progeny-based selection is more effective than single plant selection for grain yield, and it is routinely practiced in all crop breeding programs, including pearl millet. This implies that individual plant selection backed by S_1 selection will allow for two-stage selection for Fe and Zn concentration, which is likely to be more effective than the single-stage S_1 selection. However, exercising this approach would have a cost implication with respect to grain samples for analysis for Fe and Zn concentration. An X-ray Fluorescence Spectrometer (XRF) analytical tool has now available that runs 300 samples a day, does non-destructive analysis, and costs USD <1/samples compared to USD >17/sample for the ICP analysis at Adelaide which runs about 150 samples a day. Very high and significantly positive correlation (r > 0.98) between the XRF and ICP values have been found both for Fe and Zn concentration in pearl millet (James Stangoulis, pers. Comm.).

5.8. Response to recurrent selection for high grain iron on agronomic traits

The initial (C_0) and advanced (C_1) cycle bulks were evaluated for grain Fe and Zn and days to flowering, plant height, panicle length, 1000-grain mass and grain yield in two populations (AIMP92901 and ICMR 312), evaluated in 2010 rainy season. The differences between the C_0 and C_1 generation bulk means in both the populations were non significant for flowering, plant height and grain yield, which means that selection for high grain Fe and Zn have had no adverse effect on grain yield. Velu (2006) found that selection for high grain yield had no adverse effect on grain Fe and Zn in pearl millet. Although no significant difference between C_0 and C_1 bulks for grain Fe and Zn concentration, both the populations the C_1 bulks had 2.4% more Fe and 7.9% more Zn in AIMP 92901; and 8% more Fe and 5.4% more Zn in ICMR 312 and this could be because of the progenies used for recombinations and constituting the C_1 bulks were selected on the basis of one season evaluation for their micronutrients. Recurrent selection for micronutrients has bees shown to be effective. For instance, significant improvement for grain strontium (Sr) concentration in wheat (gain per cycle 7.4%) and barley (gain per cycle 12.2%) was reported (Byrne and Rasmusson, 1974). For 1000-grain mass, the two bulks (C_0 and C_1) differed significantly in both the populations, whereas the panicle length differed only in AIMP 92901.

Interestingly, selection for high grain Fe and Zn significantly increased 1000-grain mass by 4.8% and 14.2% in the AIMP 92901 and ICMR 312, respectively, as also evidenced in a previous study (Bidinger and Raju, 2000), who reported genetic gain of 7-11% for 1000-grain mass. These results should be seen in the context of population size used to recombine C_1 bulks.

5.9. Correlation between grain iron and zinc and agronomic traits

Knowledge of genetic variation and interrelationships among component traits is prerequisite to combining multiple traits into improved genetic background. In the present study, four genetically diverse populations as well two sets of line x tester progeny trials were evaluated for two seasons to estimate correlation coefficients among grain Fe and Zn, 1000-grain mass, flowering and/or grain yield. Grain Fe and Zn were positively associated, with correlation coefficients >0.70 (P= <0.01) in individual environment as well as across the seasons, except for population ICMR312 (r = 0.4 to 0.5, P>0.01). A strong positive correlation between grain Fe and Zn reveals that selection for high grain Fe will automatically lead to increased grain Zn concentration and vice-versa. The previous reports also revealed significant and positive correlation between Fe and Zn in pearl millet (Velu 2006; Velu *et al.,* 2007, 2008 and Gupta *et al.,* 2009).

Further, understanding the relationships between flowering and 1000-grain mass with that of grain Fe and Zn may accelerate selection of progenies that mature early, possess large grains and contain high Fe and Zn in the grains. Both flowering and 1000-grain mass, in general, were not found correlated with grain Fe and Zn. The previous studies also reported either no or week but significant positive correlation involving flowering, 1000-grain mass, and grain Fe and/or Zn in pearl millet (Velu *et al.,* 2008b; Gupta *et al.,* 2009) and wheat (Calderin and Ortiz-monasterio, 2003). This indicates that it is possible to combine large-grain size with high grain Fe and Zn in early maturing background. In set II line x tester cross, low to moderate (r= 0.22 to 0.45; P >0.01) correlation was detected between 1000-grain mass and grain Fe and Zn, as also reported in a previous study in pearl millet (Velu *et al.,* 2008a). Such correlations indicate good opportunities to select/breed mineral dense cultivars with larger grains, which confer greater advantage in crop establishment. In addition, the large grain size improves processing quality, easy to decorticate, and thus improves flour yield (Rooney and Mc Donough, 1987).

While selecting for high grain mineral concentration, breeders should always take into consideration the impact of selection on productivity. However in most of the studies the discussion has focused only on grain mineral concentration, with little consideration that grain yield may be an important factor influencing mineral. In the present study, correlation between grain yield and grain Fe and Zn was determined in two populations. The magnitude varied from virtually no correlations to significant negative correlations (r =-0.32 to -0.50). The previous studies also reported either grain yield not correlated with grain Fe and Zn in pearl millet (Gupta *et al*., 2009) or significantly negatively associated with grain yield in sorghum (Reddy *et al.,* 2005;

Ashok Kumar *et al.,* 2009) and wheat (Mc Donald and Graham, 2008; Morgounov *et al.,* 2007). Such negative association between grain yield and grain Fe and Zn may pose problem to selecting for increased grain Fe and Zn with high yield potential. The negative correlation in the present study, however, may be an artifact in the sense that S_1 progenies having undergone inbreeding depression for yield and increase in Fe and Zn concentration may lead to an unnatural negative association. Thus, there is a need to confirm these results using the analysis of open-pollinated grain samples of half-sib progenies and hybrids.

CHAPTER 6

SUMMARY

CHAPTER 6

SUMMARY

The main objective of this thesis was to determine the gene action, combining ability, heterosis for Fe and Zn by using two sets of line x tester analysis; intra-population variances using S_1 and half-sibs in two populations; efficiency of single plant selection for grain Fe and Zn concentration and its association with key agronomic traits (1000-grain mass, flowering and grain yield) in four populations and response to recurrent selection for grain Fe and Zn in two populations. All these trials were evaluated for two seasons in Alfisols at ICRISAT, Patancheru and the results are summarized hereunder.

- In both sets of line x tester studies, parents had a wide range of genetic variability for both grain Fe (34 -102 mg kg^{-1}) and Zn (34 - 84 mg kg^{-1}) concentration. Large variability was also observed in both sets of hybrids for grain Fe (30 - 80 mg kg^{-1}) and Zn (31 - 70 mg kg^{-1}). over two season, ICMB 93222, ICMB 98222, 863B ICMB 95333, ICMB 96333 among grain parents (lines) and IPC 774, IPC 616, IPC 1650, IPC 1178, IPC 536 and IPC 735 amongst pollen parents (testers) were found superior for grain Fe (>60 mg kg^{-1}) and Zn (>55 mg kg^{-1}). All these inbreds are in elite genetic backgrounds, thus providing useful materials for direct use in hybrid development for high grain Fe and Zn concentration.
- Evaluation of hybrids or population progenies had shown significant influence of seasons on average grain Fe and Zn. For example, hybrids showed 37% - 49% greater grain Fe and 30% - 55% grain Zn in summer season than in the rainy season. These differences may be due to variability of available Fe and Zn in the experimental fields together with variation in environmental parameters such as relative humidity and temperature. Further studies are required to determine environmental effect on grain Fe and Zn concentration
- The testers contributed more genetic variance for grain Fe and Zn followed by lines in individual season as well the across seasons. Line x tester variance contributed much less than either lines or testers for all traits in both sets.

- The *GCA* (parents) and SCA (line x tester) mean square in both the sets were highly significant for grain Fe and Zn, 1000-grain mass and flowering across seasons, indicating that both additive and non-additive variance were involved in the expression of these traits. However, the predictability ratio was around unity, revealing the predominance of *GCA* (additive) variance controlling these traits in both the sets. Highly significant positive correlation between mid-parent value and *per se* performance of hybrids further confirmed the predominant role of additive gene action for these traits.
- The correlation between *per se* performance of the parents and their general combining ability (*gca*) effects indicated that *per se* performance of the parents in, general, would be a good indicator of general combining ability. On the other hand, the high grain Fe and Zn parents in this study had positive and significant *gca* effects, while parents with low grain Fe and Zn had significant negative *gca* effects. Using both parameters (*per se* performance and positive significant *gca* effect), ICMB 93222, ICMB 98222, IPC 1650, IPC 843, IPC 774 and IPC 1178 in set I and 863B, ICMB 91222, IPC 689 and IPC 735 in set II were identified as promising lines for grain Fe and Zn in hybrid and hybrid parents breeding.
- Out of 192 hybrids tested in the set II for specific combining ability (*sca*), 863B x IPC 404, ICMB 95333 x IPC 404 and ICMM 96333 x IPC 338 had positive significant *sca* effects for grain Fe in individual as well across seasons. For grain Zn, the same two hybrids had shown positive and significant *sca* effects in rainy as well as across the seasons. Out of 72 hybrids tested in the set I for *sca,* hybrids ICMB 94111 x IPC 1178 and ICMB 89111 x IPC 843 had positive significant *sca* effects for grain Fe in one season as well across seasons, while hybrid ICMB 94111 x IPC 1178 had positive significant *sca* effects for grain Zn in individual as well across seasons. The *sca* of crosses in relation to *gca* effects of parents showed that the hybrids with significant positive *sca* effects involved at least one parent with high *gca* effects. This indicates that at least one parent with high *gca* and/or high mean (significant correlation between *gca* and mean) should be involved in a cross to realize high performance of the hybrid.
- Low level of heterosis over mid-parent (MP) for grain Fe and Zn and no hybrid with significant heterosis over better-parent (BP) for Fe and Zn, suggested that there would be little opportunity, if any, to exploit heterosis for these traits.

This would also mean that to breed high Fe and high Zn hybrids, these traits will have to bred into both parental lines of hybrids.

- As expected, the half-sibs displayed narrow range and lower genetic variance than the S_1 progenies for all the traits. Estimates of genetic components of variance (additive and dominance) in this study are specific for each population because they depend on the additive and dominance effects of the segregating loci, which differ among populations. However, the overall results of this study showed that both additive and dominance variance were equally important for the expression of grain Fe and Zn concentration, whereas additive effects were more important than dominance for 1000-grain mass and flowering.
- The grain Fe and Zn in the S_1 progenies were generally 6-14 ppm higher than in the S_0 plants in both ICTP 8203 and JBV3, whereas in the other two populations (AIMP 92901 and ICMR 312), the Fe and Zn in the S_1 progenies were generally 5-11 ppm less than in the S_0 plants. These S_0 vs S_1 differences could be partly due to environmental effects since the grain samples from the S_0 plants came from environments that were different from those in which S_1 progenies were evaluated and grains were produced for micronutrient analysis. Correlation between S_0 plants and their respective S_1 progenies (whether individual environment or the mean of both environments) both for grain Fe and Zn were positive, highly significant, and of the similar order as the correlation coefficients between the S_1 progeny performance from two environments. These results showed that individual plant selection for these micronutrients can be as well effective as the S_1 progeny selection. Form this finding, it can be inferred that Fe and Zn concentration are fairly heritable traits.
- higher magnitude of broad-sense heritability (>61%) for grain Fe and Zn, 1000-grain mass and flowering, indicated that genetic variance is a major component of the total phenotypic variance arising from the loci controlling these traits in four different populations (ICTP 8203, JBV3, AIMP 92901 and ICMR 312). further, the present findings suggest that genetic improvement is possible using simple selection techniques.
- One cycle of recurrent selection showed improvement for grain Fe and Zn in C_1 over C_0 bulks with an increase of 2.4% (Fe) and 7.9% (Zn) in AIMP 92901 and of

8% (Fe) and 5.4% (Zn) in ICMR 312. Interestingly, selection for high grain Fe and Zn significantly increased 1000-grain mass by 4.8% and 14.2% in the AIMP 92901 and ICMR 312, respectively and had no adverse effect on grain yield but this should be validated with >2 cycle of selection.

- A strong positive correlation between grain Fe and Zn reveals that selection for high grain Fe will automatically lead to increased grain Zn concentration. Both flowering and 1000-grain mass, in general, were not found correlated with grain Fe and Zn. This indicates that it is possible to combine large-grain size with high grain Fe and Zn into early maturing background. Correlation between grain yield and grain Fe and Zn was weak in both populations.

BREEDING IMPLICATIONS

Large variability was observed in a wide range of materials (grain parents, pollinators, broad-based populations and its progenies) used in this study. Since these inbreds and populations are designated parents and released cultivars, these can be more effectively used for applied crop breeding as they would not bring in adverse allelic effects (normally observed in crosses involving wild species and landraces) while transferring these micronutrients into agronomically elite cultivars. On the other hand, combining ability of these inbred was tested, thus, those inbreds with high, positive, significant *gca* and with high *per se* will have immediate impact on hybrid breeding. Among the populations studied ICTP 8203 had higher grain Fe and Zn concentration. This variety is based on *iniari* germplasm (well known for early maturity and large grey grain). This germplasm has made the greatest impact on varietal and grain-parent development in India. The large genetic variability found in intra-population (within population) study coupled with largely additive genetic variance, indicates good prospects for enhancing grain Fe and Zn levels by population improvement.

Highly significant positive correlation between Fe and Zn revealed good prospects of concurrent genetic improvement for both micronutrients. Also, weak and inconsistence significant association with 1000-grain mass and flowering suggested that it is possible to select/breed for the high grain Fe and Zn genotypes without altering maturity and grain size nature of cultivars as these two traits are increasingly becoming farmer-preferred traits in most of the pearl millet growing areas. A major portion of variance was attributable by genetic factors rather than environmental interaction effects for both grain Fe and Zn content, indicating that the G × E interaction might not be serious as evidenced by low $\sigma^2_{ge}/\sigma^2_{g}$ ratio (<1) for these traits in the present study. Greater role of additive genetic variance implies that it would be necessary to have high Fe and Zn concentration in both parental lines to breed high Fe and Zn hybrids. With the demonstration of effectiveness of individual plant selection and availability of XRF (X-ray Fluorescence Spectrometer) method for rapid, large-scale and cost effective screening, a large number of breeding lines/ plants can be effectively handled in a breeding programme.

Based on the above results, it can be concluded that there are good prospects of genetic enhancement for grain Fe and Zn concentration in term of both population development as well as hybrid parents and hybrid development in pearl millet.

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TABLES (2 to 28)[1]

Table 2. Pedigree description of materials used in the present study, during the summer and rainy seasons 2009-2010, ICRISAT- Patancheru (source: Rai *et al*, 2009).

Sl. No.	Entry	Pedigree / Origin / description
Line x Tester (Set-I)		
Line (grain parent)		
1	ICMB 93222	(26B x 834B)-11-2-B-B
2	ICMB 98222	ARD-288-1-10-1-2 (RM)-5
3	ICMB 00888	(843B×ICTP8202-161-5)-20-3-B-B-3
4	ICMB 94111	{(ICMB 89111×ICMB 88002) × [(81B×SRL53-1) ×843B]-3+× IP9402-2+}-31
5	ICMB 93333	(843B × ICMPS 900-9-3-8-2)-21-8-4
6	ICMB 04777	(SRC II C3 S1-19-3-2 x HHVBC)-17-3-1-3
7	ICMB 89111	[843B x (GNS x SS-48-40-4)-1-9-8]-30-B-B-1
8	ICMB 97111	HTBC-48-B-1-1-1-1
Tester (pollen parent)		
9	IPC 1650	[(J1623x700544+)x700651+}x{G75-FS-171 x (J1623x700544+)]
10	IPC 843	[(J834 × 700516)]-1-4-4-2-4
11	IPC 616	(J 260-1 x 700557-1-4-10-5-1)-1-2-1-3
12	IPC 774	[{(J934x700544+)x(J1644x700490+)}x{G75-FS+x(J1623x700544+)}]-4+
13	IPC 1307	(LCSN 72-1-2-2 x S10B-106)-2-2-4
14	IPC 1354	EICP 8103-5
15	IPC 390	(F4FC 1498-1-1-3 x J 104)-11-2-1-1
16	IPC 828	(B 282 x S10B-38)-2-1-5-1-1
17	IPC 1178	(A 836 x J 1798-32-2-2)-5-1-1
Line x Tester (Set-II)		
Line (grain parent)		
18	841 B	Downy mildew resistant selection from grain lot #8015 of 5141B
19	843 B	Selection from KSU line BKM 2068
20	863 B	Togo-13-4-1
21	ICMB 88006	[(81B x SRL 53-1) x 843B]-30-2-B
22	ICMB 91222	(26B x 81B)-4-1-2
23	ICMB 92111	(81B x 843B)-11-1-1-B
24	ICMB 95333	[{(B282 x S10B-38)-35 x Togo-29-2-2}-53 x {843B x {843B x (B 282 x 3/4 EB-100)-11-9-2}}]-60-29-1
25	ICMB 96333	[{{843B x (843B x 700651)-11-1-2-B} x 1163B} x (ICMB 89111 x ICMB 88005)]-5-2-2
26	ICMB 99444	(SPF3/S91-327 x SPF3/S91-5)-6-2-2

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[1] **Table 1 is presented in chapter 2**

Table 2. continued

Sl. No.	Entry	Pedigree / Origin / description
27	ICMB 00999	(ICMB 89111 x 863B)-65-8-B-B
28	ICMB 02444	(BSECBPT/91-38 x SPF3/S91-529)-2-1-B-2
29	ICMB 03111	[{{843B x (843B x 700651)-11-1-2-B} x 1163B}x (ICMB 89111 x ICMB 88005)]-5-3-B
30	ICMB 04222	(843B x EEBC S1-407)-12-3-B
31	ICMB 04555	{D2BLN/95-214 x (ICMB 96333 x HHVBC)}-11-B-2
32	ICMB 04888	[(843B x ICTP 8202-161-5)-20-3-B-B-3 x B-lines bulk]-2-B-1-3
33	ICMB 04999	(EBC-Gen-S1-40-2-2-1 x B-line bulk)-25-B-B
Tester (pollen parent)		
34	IPC 338	(LCSN 439-5-3-2 x Gulisitha)-6-1-1-1
35	IPC 404	Togo 17-4-1-18
36	IPC 536	(J 260-1 x 700557-1-4-10-5-1)-1-2-2-2
37	IPC 689	R-294-1-2-8-2
38	IPC 735	(J 1399-1 x B 282)-6-1-2-1-2
39	IPC 811	(B 282 x S10B-38)-6-1-1-1
40	IPC 1254	(700619 x 700599)-3-2-13-7-3-4
41	IPC 1268	8082-1-3-4-1
42	IPC 1642	(23DBE-19-2 x S10B-106)-2-1-2-4
43	ICMR 356	(B 282 x J 104)-12-B-B-B-B
44	ICMR 06333	SDMV 90031-S1-93-3-1-1-3-2-2-1-1-B
45	ICMR 06888	MRC HS-219-2-1-2-B-B-B-B
Population / OP variety (OPV)		
46	ICTP 8203	Large-grained OPV, bred from 5 S_2 progenies of *iniari* (early maturing) landrace originating from northern Togo in the West Africa. The progenies were visually selected for yield, plant height, flowering time, panicle type and resistance to downy mildew at patancheru.These were intercrossed and subsequently random matted twice to breed ICTP 8203. it was released in 1988 for cultivation in peninsular inida.
47	JBV 3	Bred jointly by Jawaharlal Nehru Krishi Vidyapeeth and ICRISAT by random-mating 15 Smut Resistant Composite II C_3 full-sib progenies selected visually at Patancheru in 1995. It was released in 2001 for cultivation in northern India.
48	AIMP 92901	Bred by random mating 272 Bold-Grained Early Composites (BSEC) S_1 progenies selected at Aurangabad and BSEC S1s bulk at Patancheru in 1991. it was released in 2001 for cultivation in peninsular India.
49	ICMR 312	BSEC TCP2 C_3. 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 it was released in 1993 for cultivation in peninsular India.

Table 3. Inbred parental lines with their mean levels of grain Fe and Zn concentartions in line x tester (set-I) trial (based on two season data).

Class	Range (mg kg-1)	Entries
Lines		
High	Fe ≥ 85 Zn ≥ 65	ICMB 93222; ICMB 98222; ICMB 94111
Medium	Fe : 60 - 84 Zn : 55 - 64	ICMB 00888; ICMB 04777
Low	Fe ≤ 59 Zn ≤ 54	ICMB 93333; ICMB 89111; ICMB 97111
Testers		
High	Fe ≥ 81 Zn ≥ 75	IPC 1650;IPC 616; IPC 774
Medium	Fe : 70 - 80 Zn : 60 - 74	IPC 843; IPC 1178
Low	Fe ≤ 55 Zn ≤ 50	**IPC** 1307; IPC 1354; IPC 390; IPC 828

Table 4. Inbred parental lines with their mean levels of grain Fe and Zn concentrations in line x tester (set-II) trial (based on two season data

Class	Range (mg kg-1)	Entries
Lines		
High	Fe ≥ 81	ICMB 96333; ICMB 91222; ICMB 95333; ICMB 99444
	Zn ≥ 61	863 B; ICMB 96333; ICMB 99444; ICMB 95333
Medium	Fe : 55 - 80	863 B; ICMB 02444; ICMB 04222; ICMB 04888;
	Zn : 51 - 60	841 B; 843 B; ICMB 91222; ICMB 00999; ICMB 02444; ICMB 04888

Low	Fe ≤ 55	841 B; 843 B; ICMB 88006; ICMB 92111; ICMB 03111; ICMB 00999; ICMB 04555; ICMB 04999;
	Zn ≤ 50	ICMB 88006; ICMB 92111; ICMB 04555; ICMB 04999; ICMB 03111; ICMB 04222
Testers		
High	Fe ≥ 59	IPC 536; IPC 735; IPC 689
	Zn ≥ 55	IPC 536; IPC 735
Medium	Fe : 50 - 55	IPC 1642; IPC 338; ICMR 356
	Zn : 51 - 54	ICMR 356; IPC 689
Low	Fe ≤ 49	IPC 1268; IPC 811; IPC 1254; IPC 404; ICMR 06888; ICMR 06333
	Zn ≤ 50	IPC 404; IPC 1268; IPC 811; IPC 1254; IPC 338; IPC 1642; ICMR 06333; ICMR 06888

Table 5a. Analysis of variance for parents for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in line x tester trial (set-I), summer and rainy seasons 2009, Patancheru

Source of variation	df	Mean square							
		Fe (mg kg^{-1})		Zn (mg kg^{-1})		1000-grain mass (g)		Days to 50% flower	
		Summer 2009	Rainy 2009	Summer 2009	Rainy 2009	Summer 2009	Rainy 2009	Summer 2009	Rainy 2009
Replications	1	368.9	116.7	0.3	8.5	0.1	0.5	2.4	2.4
Parents	16	1340.6 **	572.4 **	632.5 **	522.7 **	6.6 **	10.4 **	30.7 **	17.7 **
Error	16	113.6	172.3	26.7	76.1	0.2	0.7	0.8	1.2

Table 5b. Analysis of variance for combining ability for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in line x tester trial (set-I), summer and rainy seasons 2009, Patancheru

Source of variation	df	Mean square							
		Fe (mg kg^{-1})		Zn (mg kg^{-1})		1000-grain mass (g)		Days to 50% flower	
		Summer 2009	Rainy 2009	Summer 2009	Rainy 2009	Summer 2009	Rainy 2009	Summer 2009	Rainy 2009
Replication	1	0.1	330.0 **	2.8	193.7 **	0.9	1.4	0.4	0.1
Crosses	71	288.4 **	95.4 **	218.8 **	89.7 **	3.4 **	5.3 **	11.6 **	13.2 **
Lines	7	990.9 **	241.9 **	771.3 **	183.8 **	12.8 **	21.7 **	38.5 **	50.2 **
Testers	8	1132.8 **	336.6 **	938.0 **	481.9 **	11.6 **	16.4 **	51.2 **	60.9 **
Lines x Testers	56	80.0	42.7 *	47.0 *	21.9	1.0 **	1.6 **	2.6 **	1.8
Error	71	55.6	24.0	26.9	23.6	0.3	0.6	1.4	1.6
σ^2 gca		60.15	16.07	49.67	19.43	0.70	1.07	2.62	3.24
σ^2 sca		12.21	9.35	10.03	-0.83	0.37	0.52	0.62	0.09
$(2\sigma^2 \text{gca})/(2\sigma^2 \text{gca} + \sigma^2 \text{sca})$		0.91	0.77	0.91	1.00	0.79	0.81	0.89	0.99

* = Significant at $P \le 0.05$; ** = Significant at $P \le 0.01$.

Table 6a. Pooled analysis of variance for parents for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in line x tester trial (set-I), summer and rainy seasons 2009, Patancheru

Source of variation	df	Mean squares			
		Fe (mg kg^{-1})	Zn (mg kg^{-1})	1000-grain mass (g)	Days to 50% flower
Environments (E)	1	12691.8	6880.2	4.0	0.9
Replication / E	2	242.8	4.4	0.3	2.4
Parents (P)	16	1633.3 **	984.6 **	14.3 **	42.7 **
P x E	16	279.7	170.6 **	2.7 **	5.7 **
Error	32	142.9	51.4	0.5	1.0

Table 6b. Pooled analysis of variance for combining ability for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in line x tester trial (set-I), summer and rainy seasons 2009, Patancheru

Source of variation	df	Mean square			
		Fe (mg kg^{-1})	Zn (mg kg^{-1})	1000-grain mass (g)	Days to 50% flower
Environments (E)	1	29241.7	34826.0	74.4	17.0
Replication / E	2	165.1	98.2	1.1	0.1
Crosses (C)	71	322.8 **	267.9 **	7.6 **	21.4 **
Lines (L)	7	1067.7 **	811.0 **	32.3 **	74.4 **
Testers (T)	8	1294.6 **	1353.7 **	26.5 **	106.7 **
Lines x Testers (L x T)	56	90.9 *	44.9 *	1.8 **	2.6 **
C x E	71	61.0 *	40.6 *	1.1 **	3.4 **
L x E	7	165.0 **	144.1 **	2.2 **	14.3 **
T x E	8	174.8 **	66.2 **	1.4 **	5.4 **
L x T x E	56	31.8	24.0	0.9 **	1.8
Error	142	39.8	25.2	0.4	1.5
σ^2 gca		34.2	32.3	0.8	2.7
σ^2 sca		12.8	4.9	0.3	0.3
$(2\sigma^2 \text{gca})/(2\sigma^2 \text{gca} + \sigma^2 \text{sca})$		0.84	0.93	0.84	0.95

* = Significant at $P \le 0.05$; ** = Significant at $P \le 0.01$.

Table 7. Proportional contribution of lines, testers and line x tester to total variance among crosses for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in line x tester (set-I) trial summer and rainy season 2009 and pooled analysis, Patancheru

Character	Proportional contribution (%)											
	Summer 2009				Rainy 2009				Pooled			
	σ^2 L	σ^2 T	σ^2 LT	Total	σ^2 L	σ^2 T	σ^2 LT	Total	σ^2 L	σ^2 T	σ^2 LT	Total
Grain Fe (mg kg^{-1})	39.5	51.2	9.3	100	29.5	47.7	22.8	100	35.5	48.7	15.9	100
Grain Zn (mg kg^{-1})	38.2	52.6	9.3	100	24.2	78.0	-2.3	100	32.0	60.8	7.2	100
1000-grain mass (g)	39.5	39.8	20.7	100	43.8	36.8	19.4	100	43.6	40.1	16.4	100
Days to 50% flower	35.5	53.8	10.7	100	41.6	57.1	1.3	100	36.1	58.7	5.1	100

σ^2L = Line variance ; σ^2T = Tester variance and σ^2LT = Line x Tester variance

Table 8a . General combining ability (*gca*) effects of parents and their *per se* performance for grain Fe and Zn concentration in line x tester trial (set -I), summer and rainy seasons 2009 and pooled analysis, Patancheru.

Parent	Fe (mg kg^{-1})									Zn (mg kg^{-1})								
	Summer 2009			Rainy 2009			Pooled			Summer 2009			Rainy 2009			Pooled		
Lines	**Mean**	***gca***		**Mean**	***gca***		**Mean**	***gca***		**Mean**	***gca***		**Mean**	***gca***		**Mean**	***gca***	
ICMB 93222	121.0	8.1	**	59.3	5.1	**	90.1	6.6	**	86.0	3.6	**	44.2	1.9		65.1	2.7	**
ICMB 98222	129.7	7.4	**	73.4	4.4	**	101.5	5.9	**	93.4	6.6	**	52.8	2.2		73.1	4.4	**
ICMB 00888	91.1	2.8		36.3	-1.3		63.7	0.7		76.4	1.9		35.9	-1.0		56.1	0.5	
ICMB 94111	92.2	0.3		79.4	1.5		85.8	0.9		70.0	-2.8	*	53.1	-2.1		61.6	-2.4	**
ICMB 93333	60.7	-8.2	**	46.7	-3.6	**	53.7	-5.9	**	67.1	-0.6		43.7	2.5	*	55.4	0.9	
ICMB 04777	90.3	5.2	**	61.9	1.1		76.1	3.1	**	75.4	6.0	**	51.3	3.9	**	63.4	5.0	**
ICMB 89111	62.6	-3.1		51.0	-2.1		56.8	-2.6	*	70.3	-0.8		46.6	-1.6		58.5	-1.2	
ICMB 97111	61.8	-12.4	**	38.4	-5.0	**	50.1	-8.7	**	49.3	-14.0	**	30.8	-5.8	**	40.1	-9.9	**
SE (lines)		1.76			1.15			1.05			1.22			1.14			0.84	
r (between mean and *gca*)		0.89	**		0.73	*		0.90	**		0.91	**		0.61			0.87	**
Testers																		
IPC 1650	114.2	-1.4		87.3	2.7	*	100.7	0.7		81.1	2.7	*	84.5	4.7	**	82.8	3.7	**
IPC 843	90.1	5.4	**	56.1	2.2		73.1	3.8	**	78.2	7.2	**	53.8	4.2	**	66.0	5.7	**
IPC 616	103.2	3.1		80.4	-0.4		91.8	1.3		84.4	1.4		70.7	-2.2		77.5	-0.4	
IPC 774	97.3	3.8	*	69.8	2.2		83.5	3.0	**	90.7	4.6	**	77.4	3.1	*	84.1	3.8	**
IPC 1307	54.5	-1.1		38.8	0.2		46.7	-0.5		47.0	-1.9		32.9	-2.1		39.9	-2.0	*
IPC 1354	47.4	-9.4	**	33.6	-4.7	**	40.5	-7.1	**	42.4	-7.5	**	26.4	-4.9	**	34.4	-6.2	**
IPC 390	51.1	-9.5	**	40.2	-8.0	**	45.7	-8.7	**	40.9	-9.8	**	36.6	-6.5	**	38.8	-8.1	**
IPC 828	59.5	-7.5	**	49.6	-2.0		54.6	-4.7	**	48.5	-9.0	**	46.2	-5.7	**	47.3	-7.3	**
IPC 1178	99.3	16.6	**	62.0	7.8	**	80.6	12.2	**	88.1	12.3	**	59.2	9.2	**	73.6	10.8	**
SE (testers)		1.86			1.22			1.11			1.30			1.21			0.89	
r (between mean and *gca*)		0.84	**		0.55			0.75	*		0.88	**		0.57			0.77	*

r = Correlation coefficient; * = Significant at P ≤0.05; ** = Significant at P ≤0.01.

Table 8b . General combining ability (*gca*) effects of parents and their *per se* performance for 1000-grain mass and days to 50% flower in line x tester trial (set-I), summer and rainy seasons 2009 and pooled analysis, Patancheru.

Parent	**1000-grain mass (g)**									**Days to 50% flower**								
	Summer 2009			**Rainy 2009**			**Pooled**			**Summer 2009**			**Rainy 2009**			**Pooled**		
Lines	**Mean**	***gca***		**Mean**	***gca***		**Mean**	***gca***		**Mean**	***gca***		**Mean**	***gca***		**Mean**	***gca***	
ICMB 93222	9.0	0.2		10.5	0.7	**	9.7	0.5	**	54	0.4		54	1.6	**	54	1.0	**
ICMB 98222	9.9	0.6	**	8.2	0.5	*	9.1	0.5	**	49	-1.9	**	52	-0.8	**	50	-1.4	**
ICMB 00888	11.7	1.3	**	13.4	2.0	**	12.5	1.6	**	50	-0.5		47	-2.2	**	48	-1.4	**
ICMB 94111	8.2	-0.7	**	8.3	-0.5	*	8.2	-0.6	**	50	-0.7	**	52	-0.7	*	51	-0.7	**
ICMB 93333	6.4	-1.3	**	8.8	-1.1	**	7.6	-1.2	**	57	2.6	**	56	0.8	**	56	1.7	**
ICMB 04777	7.8	-0.1		8.0	-0.8	**	7.9	-0.5	**	59	1.5	**	58	2.9	**	59	2.2	**
ICMB 89111	6.9	-0.7	**	5.9	-1.2	**	6.4	-0.9	**	56	0.0		52	-0.3		54	-0.2	
ICMB 97111	11.3	0.7	**	11.5	0.4	*	11.4	0.5	**	48	-1.3	**	50	-1.3	**	49	-1.3	**
SE (lines)		0.13			0.19			0.11			0.26			0.29			0.20	
r (between mean and *gca*)		0.94	**		0.86	**		0.92	**		0.87	**		0.94	**		0.96	**
Testers																		
IPC 1650	8.5	-0.3	*	7.3	-0.2		7.9	-0.3	*	54	-0.1		56	1.2	**	55	0.6	**
IPC 843	8.1	-0.7	**	8.6	-0.7	**	8.3	-0.7	**	52	-1.3	**	55	-0.1		53	-0.7	**
IPC 616	6.3	-1.0	**	6.5	-1.0	**	6.4	-1.0	**	54	-0.6	*	53	-1.1	**	53	-0.9	**
IPC 774	7.3	1.2	**	9.0	0.9	**	8.2	1.0	**	48	-2.3	**	52	-3.0	**	50	-2.7	**
IPC 1307	6.4	-0.7	**	7.5	-1.6	**	6.9	-1.2	**	61	2.4	**	58	2.0	**	59	2.2	**
IPC 1354	9.6	0.6	**	6.6	0.8	**	8.1	0.7	**	53	-0.7	*	54	-1.6	**	53	-1.1	**
IPC 390	5.9	-0.3	*	5.9	-0.2		5.9	-0.2		51	-1.6	**	55	-1.7	**	53	-1.7	**
IPC 828	9.3	1.4	**	13.2	1.5	**	11.2	1.4	**	57	1.9	**	55	2.4	**	56	2.2	**
IPC 1178	5.7	-0.1		7.3	0.6	**	6.5	0.3	*	58	2.4	**	57	1.9	**	58	2.1	**
SE (testers)		0.14			0.20			0.12			0.28			0.31			0.22	
r (between mean and *gca*)		0.54			0.55			0.66			0.96	**		0.81	**		0.93	**

r = Correlation coefficient; * = Significant at P ≤0.05; ** = Significant at P ≤0.01.

Table 9 a. Specific combining ability (*sca*) effect of hybrids for grain Fe and Zn concentration in line x tester trial (set -I), summer and rainy seasons 2009 and pooled analysis, Patancheru.

Sl. No	F_1 Hybrid			Fe Class	*sca* effects						
					Fe (mg kg^{-1})			Zn Class	Zn (mg kg^{-1})		
	Line		Tester		Summer	Rainy	Pooled		Summer	Rainy	Pooled
1	ICMB 93222	x	IPC 1650	H x H	1.65	1.17	1.41	H x H	2.17	-1.60	0.28
2	ICMB 93222	x	IPC 843	H x M	-9.16	2.24	-3.46	H x M	-7.77 *	2.90	-2.44
3	ICMB 93222	x	IPC 616	H x H	5.22	-0.20	2.51	H x H	0.98	1.77	1.38
4	ICMB 93222	x	IPC 774	H x H	2.97	0.17	1.57	H x H	-1.21	-1.98	-1.59
5	ICMB 93222	x	IPC 1307	H x L	-1.16	-1.76	-1.46	H x L	-0.71	1.71	0.50
6	ICMB 93222	x	IPC 1354	H x L	-4.28	-4.89	-4.59	H x L	4.42	-0.54	1.94
7	ICMB 93222	x	IPC 390	H x L	0.78	-2.64	-0.93	H x L	2.17	-3.42	-0.63
8	ICMB 93222	x	IPC 828	H x L	-4.22	2.86	-0.68	H x L	1.35	0.77	1.06
9	ICMB 93222	x	IPC 1178	H x M	8.22	3.05	5.63	H x M	-1.40	0.40	-0.50
10	ICMB 98222	x	IPC 1650	H x H	-0.13	8.90 *	4.39	H x H	-1.83	4.01	1.09
11	ICMB 98222	x	IPC 843	H x M	4.56	1.46	3.01	H x M	-0.77	-0.99	-0.88
12	ICMB 98222	x	IPC 616	H x H	1.94	3.02	2.48	H x H	5.48	1.88	3.68
13	ICMB 98222	x	IPC 774	H x H	1.19	1.90	1.54	H x H	-0.71	0.63	-0.04
14	ICMB 98222	x	IPC 1307	H x L	-6.94	-10.04 **	-8.49 **	H x L	-4.71	-3.68	-4.19
15	ICMB 98222	x	IPC 1354	H x L	1.44	1.33	1.39	H x L	3.42	-1.43	0.99
16	ICMB 98222	x	IPC 390	H x L	-5.00	-6.42	-5.71	H x L	-1.33	1.19	-0.07
17	ICMB 98222	x	IPC 828	H x L	4.50	2.58	3.54	H x L	0.35	1.88	1.12
18	ICMB 98222	x	IPC 1178	H x M	-1.56	-2.73	-2.15	H x M	0.10	-3.49	-1.69
19	ICMB 00888	x	IPC 1650	M x H	-1.01	-4.38	-2.7	M x H	-1.67	-3.27	-2.47
20	ICMB 00888	x	IPC 843	M x M	-1.83	-5.32	-3.57	M x M	4.90	0.23	2.56
21	ICMB 00888	x	IPC 616	M x H	-6.45	-2.26	-4.35	M x H	-0.85	-1.90	-1.38
22	ICMB 00888	x	IPC 774	M x H	-8.20	1.12	-3.54	M x H	-8.04 *	-0.15	-4.09
23	ICMB 00888	x	IPC 1307	M x L	-2.33	4.18	0.93	M x L	-0.04	-0.46	-0.25

Sl. No	F_1 Hybrid			Fe Class	*sca* effects						
					Fe (mg kg^{-1})			Zn Class	Zn (mg kg^{-1})		
	Line		Tester		Summer	Rainy	Pooled		Summer	Rainy	Pooled
24	ICMB 00888	x	IPC 1354	M x L	6.05	4.06	5.05	M x L	0.58	3.29	1.94
25	ICMB 00888	x	IPC 390	M x L	1.11	1.31	1.21	M x L	3.83	2.92	3.38
26	ICMB 00888	x	IPC 828	M x L	-1.39	4.81	1.71	M x L	0.02	2.60	1.31
27	ICMB 00888	x	IPC 1178	M x M	14.05 **	-3.51	5.27	M x M	1.27	-3.27	-1.00
28	ICMB 94111	x	IPC 1650	H x H	3.93	1.84	2.89	H x H	-1.50	-0.66	-1.08
29	ICMB 94111	x	IPC 843	H x M	2.62	-0.60	1.01	H x M	1.56	-1.66	-0.05
30	ICMB 94111	x	IPC 616	H x H	2.49	-3.03	-0.27	H x H	-4.19	-3.78	-3.99
31	ICMB 94111	x	IPC 774	H x H	0.74	-0.66	0.04	H x H	-1.88	-0.53	-1.20
32	ICMB 94111	x	IPC 1307	H x L	-0.88	-4.60	-2.74	H x L	1.63	0.15	0.89
33	ICMB 94111	x	IPC 1354	H x L	-7.01	-0.72	-3.86	H x L	-6.25	-2.60	-4.42
34	ICMB 94111	x	IPC 390	H x L	-4.44	-0.47	-2.46	H x L	-1.50	-0.47	-0.99
35	ICMB 94111	x	IPC 828	H x L	-4.44	-2.47	-3.46	H x L	1.69	0.72	1.20
36	ICMB 94111	x	IPC 1178	H x M	6.99	10.72 **	8.85 **	H x M	10.44 **	8.84 **	9.64 **
37	ICMB 93333	x	IPC 1650	L x H	0.49	-5.05	-2.28	L x H	4.39	2.78	3.59
38	ICMB 93333	x	IPC 843	L x M	1.67	1.01	1.34	L x M	0.95	0.28	0.62
39	ICMB 93333	x	IPC 616	L x H	-5.45	1.58	-1.94	L x H	-6.80	-1.34	-4.07
40	ICMB 93333	x	IPC 774	L x H	-1.20	0.45	-0.38	L x H	-2.99	4.41	0.71
41	ICMB 93333	x	IPC 1307	L x L	2.17	2.51	2.34	L x L	3.01	2.60	2.81
42	ICMB 93333	x	IPC 1354	L x L	4.05	3.89	3.97	L x L	0.64	-2.15	-0.76
43	ICMB 93333	x	IPC 390	L x L	1.11	-3.36	-1.13	L x L	2.39	-2.03	0.18
44	ICMB 93333	x	IPC 828	L x L	5.61	2.14	3.88	L x L	4.58	-1.84	1.37
45	ICMB 93333	x	IPC 1178	L x M	-8.45	-3.17	-5.81	L x M	-6.17	-2.72	-4.44
46	ICMB 04777	x	IPC 1650	M x H	3.60	4.73	4.16	M x H	3.22	0.34	1.78
47	ICMB 04777	x	IPC 843	M x M	-10.72 *	-5.71	-8.21 **	M x M	-5.72	-4.16	-4.94 *
48	ICMB 04777	x	IPC 616	M x H	3.66	-3.15	0.26	M x H	7.03	0.72	3.88
49	ICMB 04777	x	IPC 774	M x H	9.41	-0.27	4.57	M x H	9.85 **	3.47	6.66 **
50	ICMB 04777	x	IPC 1307	M x L	7.28	2.29	4.79	M x L	5.85	-0.85	2.50

Sl. No	F_1 Hybrid			Fe Class	*sca* effects						
					Fe (mg kg^{-1})			Zn Class	Zn (mg kg^{-1})		
	Line		Tester		Summer	Rainy	Pooled		Summer	Rainy	Pooled
51	ICMB 04777	x	IPC 1354	M x L	1.16	-1.83	-0.34	M x L	1.47	-1.60	-0.06
52	ICMB 04777	x	IPC 390	M x L	-7.28	-0.08	-3.68	M x L	-9.28 *	2.53	-3.38
53	ICMB 04777	x	IPC 828	M x L	-8.78	-5.08	-6.93 *	M x L	-9.59 **	-7.28 *	-8.44 **
54	ICMB 04777	x	IPC 1178	M x M	1.66	9.10 **	5.38	M x M	-2.84	6.84 *	2.00
55	ICMB 89111	x	IPC 1650	L x H	-9.18	-6.55	-7.86 *	L x H	-8.50 *	-1.66	-5.08 *
56	ICMB 89111	x	IPC 843	L x M	13.51 *	6.01	9.76 **	L x M	6.06	3.84	4.95 *
57	ICMB 89111	x	IPC 616	L x H	3.38	2.58	2.98	L x H	-1.69	-0.78	-1.24
58	ICMB 89111	x	IPC 774	L x H	-5.37	-0.55	-2.96	L x H	2.13	-3.03	-0.45
59	ICMB 89111	x	IPC 1307	L x L	0.01	3.01	1.51	L x L	0.13	-3.35	-1.61
60	ICMB 89111	x	IPC 1354	L x L	-5.12	-2.61	-3.86	L x L	-5.25	3.90	-0.67
61	ICMB 89111	x	IPC 390	L x L	7.94	5.64	6.79 *	L x L	2.00	-0.47	0.76
62	ICMB 89111	x	IPC 828	L x L	0.94	-4.86	-1.96	L x L	-0.81	-0.28	-0.55
63	ICMB 89111	x	IPC 1178	L x M	-6.12	-2.67	-4.4	L x M	5.94	1.84	3.89
64	ICMB 97111	x	IPC 1650	L x H	0.65	-0.66	0	L x H	3.72	0.06	1.89
65	ICMB 97111	x	IPC 843	L x M	-0.66	0.90	0.12	L x M	0.78	-0.44	0.17
66	ICMB 97111	x	IPC 616	L x H	-4.78	1.47	-1.66	L x H	0.03	3.44	1.74
67	ICMB 97111	x	IPC 774	L x H	0.47	-2.16	-0.85	L x H	2.85	-2.81	0.02
68	ICMB 97111	x	IPC 1307	L x L	1.84	4.40	3.12	L x L	-5.15	3.88	-0.64
69	ICMB 97111	x	IPC 1354	L x L	3.72	0.78	2.25	L x L	0.97	1.13	1.05
70	ICMB 97111	x	IPC 390	L x L	5.78	6.03	5.9	L x L	1.72	-0.25	0.74
71	ICMB 97111	x	IPC 828	L x L	7.78	0.03	3.9	L x L	2.41	3.44	2.92
72	ICMB 97111	x	IPC 1178	L x M	-14.78 **	-10.78 **	-12.78 **	L x M	-7.34 *	-8.44 *	-7.89 **
	S.E. (*sca*)				5.27	3.46	3.15		3.67	3.43	2.51
	r (between F_1 mean and *sca*)				0.47 **	0.59 **	0.47 **		0.41 **	0.44 **	0.36 **

r = Correlation coefficient; * = Significant at P ≤0.05; ** = Significant at P ≤0.01.

Table 9 b. Specific combining ability (*sca*) effect of hybrids for 1000-grain mass and days to 50% flower in line x tester trial (set -I), summer and rainy seasons 2009 and pooled analysis, Patancheru.

Sl. No	F$_1$ Hybrid			*sca* effects					
				1000-grain mass (g)			Days to 50% flower		
	Line		Tester	Summer	Rainy	Pooled	Summer	Rainy	Pooled
1	ICMB 93222	x	IPC 1650	0.28	-1.84 **	-0.78 *	-1.15	-0.62	-0.89
2	ICMB 93222	x	IPC 843	-0.53	-0.61	-0.57	1.10	0.19	0.65
3	ICMB 93222	x	IPC 616	0.33	-0.34	-0.01	-0.09	1.19	0.55
4	ICMB 93222	x	IPC 774	1.73 **	1.80 **	1.77 **	-0.40	0.13	-0.14
5	ICMB 93222	x	IPC 1307	-0.49	1.09	0.30	0.91	0.63	0.77
6	ICMB 93222	x	IPC 1354	-0.09	0.55	0.23	0.47	-0.81	-0.17
7	ICMB 93222	x	IPC 390	-1.46 **	-0.41	-0.93 *	0.41	1.32	0.87
8	ICMB 93222	x	IPC 828	-0.01	-0.17	-0.09	-1.15	-1.31	-1.23 *
9	ICMB 93222	x	IPC 1178	0.23	-0.07	0.08	-0.09	-0.74	-0.42
10	ICMB 98222	x	IPC 1650	0.46	-0.74	-0.14	0.68	0.72	0.70
11	ICMB 98222	x	IPC 843	-0.68	0.50	-0.09	-0.07	-0.47	-0.27
12	ICMB 98222	x	IPC 616	-0.86 *	-0.26	-0.56	1.74 *	-1.47	0.14
13	ICMB 98222	x	IPC 774	-1.40 **	0.24	-0.58 *	1.93 *	0.97	1.45 *
14	ICMB 98222	x	IPC 1307	0.34	0.67	0.51 *	-2.26 **	0.47	-0.90
15	ICMB 98222	x	IPC 1354	0.91 *	-0.14	0.38	0.31	-1.47	-0.58
16	ICMB 98222	x	IPC 390	0.53	0.28	0.40	-0.76	0.65	-0.05
17	ICMB 98222	x	IPC 828	0.65	-0.22	0.21	-0.82	0.53	-0.15
18	ICMB 98222	x	IPC 1178	0.05	-0.32	-0.14	-0.76	0.09	-0.33
19	ICMB 00888	x	IPC 1650	-0.37	-0.38	-0.38	-0.26	-0.34	-0.30
20	ICMB 00888	x	IPC 843	-0.10	0.12	0.01	-0.51	0.47	-0.02
21	ICMB 00888	x	IPC 616	-0.17	-1.20 *	-0.69 *	0.80	-0.53	0.14
22	ICMB 00888	x	IPC 774	0.56	0.68	0.62	1.49	-0.09	0.70
23	ICMB 00888	x	IPC 1307	-0.36	-0.14	-0.25	-1.70 *	-0.09	-0.90
24	ICMB 00888	x	IPC 1354	-0.13	0.93	0.40	0.36	0.47	0.42
25	ICMB 00888	x	IPC 390	0.32	0.15	0.23	0.30	0.60	0.45
26	ICMB 00888	x	IPC 828	0.01	0.37	0.19	-1.26	-0.03	-0.65
27	ICMB 00888	x	IPC 1178	0.25	-0.52	-0.13	0.80	-0.47	0.17
28	ICMB 94111	x	IPC 1650	-1.07 **	1.90 **	0.41	-0.04	1.10	0.53
29	ICMB 94111	x	IPC 843	-0.09	0.41	0.16	0.21	-0.58	-0.19
30	ICMB 94111	x	IPC 616	-0.15	0.73	0.29	-0.98	-1.08	-1.03
31	ICMB 94111	x	IPC 774	-0.84 *	-1.20 *	-1.02 *	-0.79	-0.15	-0.47
32	ICMB 94111	x	IPC 1307	0.96 *	-1.01	-0.02	0.02	-1.15	-0.56
33	ICMB 94111	x	IPC 1354	-0.30	-0.39	-0.35	0.08	-0.58	-0.25
34	ICMB 94111	x	IPC 390	0.31	-0.31	0.00	1.52	1.04	1.28 *
35	ICMB 94111	x	IPC 828	0.86 *	-0.66	0.10	-0.54	1.42	0.44
36	ICMB 94111	x	IPC 1178	0.32	0.53	0.43	0.52	-0.02	0.25
37	ICMB 93333	x	IPC 1650	0.19	0.15	0.17	0.68	-0.84	-0.08
38	ICMB 93333	x	IPC 843	0.48	-0.39	0.05	0.43	0.97	0.70
39	ICMB 93333	x	IPC 616	-0.79 *	-0.71	-0.75	-0.26	0.97	0.36
40	ICMB 93333	x	IPC 774	0.33	-0.40	-0.04	-1.07	-0.09	-0.58
41	ICMB 93333	x	IPC 1307	0.21	0.50	0.35	0.24	-1.09	-0.42

Sl. No	F$_1$ Hybrid			*sca* effects					
				1000-grain mass (g)			**Days to 50% flower**		
	Line		**Tester**	**Summer**	**Rainy**	**Pooled**	**Summer**	**Rainy**	**Pooled**
42	ICMB 93333	x	IPC 1354	0.16	0.29	0.22	-1.19	0.47	-0.36
43	ICMB 93333	x	IPC 390	0.90 *	0.64	0.77 *	-1.26	-1.90 *	-1.58 *
44	ICMB 93333	x	IPC 828	-1.20 **	0.15	-0.52	3.18 **	0.47	1.83 **
45	ICMB 93333	x	IPC 1178	-0.27	-0.23	-0.25	-0.76	1.04	0.14
46	ICMB 04777	x	IPC 1650	-0.10	0.53	0.21	-1.21	-1.51	-1.36 *
47	ICMB 04777	x	IPC 843	-0.12	0.12	0.00	-0.96	-0.19	-0.58
48	ICMB 04777	x	IPC 616	0.89 *	1.53 **	1.21 **	-1.65 *	0.81	-0.42
49	ICMB 04777	x	IPC 774	-1.29 **	-1.68 **	-1.49 **	0.54	0.24	0.39
50	ICMB 04777	x	IPC 1307	0.40	-0.26	0.07	1.85 *	-0.26	0.80
51	ICMB 04777	x	IPC 1354	-0.16	-1.25 *	-0.70 *	-0.08	-0.19	-0.14
52	ICMB 04777	x	IPC 390	0.42	0.96	0.69 *	-0.15	0.43	0.14
53	ICMB 04777	x	IPC 828	-0.41	-1.09	-0.75 *	1.29	0.31	0.80
54	ICMB 04777	x	IPC 1178	0.37	1.14 *	0.76 *	0.35	0.37	0.36
55	ICMB 89111	x	IPC 1650	0.45	0.08	0.26	0.29	0.22	0.25
56	ICMB 89111	x	IPC 843	1.10 *	1.10	1.10 **	-1.46	0.03	-0.72
57	ICMB 89111	x	IPC 616	0.45	0.49	0.47	1.35	1.53	1.44 *
58	ICMB 89111	x	IPC 774	-0.13	-0.35	-0.24	-1.46	-1.04	-1.25 *
59	ICMB 89111	x	IPC 1307	-1.09 **	-1.80 **	-1.44 **	-0.15	0.47	0.16
60	ICMB 89111	x	IPC 1354	-0.85 *	-0.42	-0.64	-0.08	0.53	0.22
61	ICMB 89111	x	IPC 390	-0.33	-0.21	-0.27	0.35	-1.35	-0.50
62	ICMB 89111	x	IPC 828	0.47	0.92	0.69 **	0.79	-0.47	0.16
63	ICMB 89111	x	IPC 1178	-0.08	0.19	0.06	0.35	0.09	0.22
64	ICMB 97111	x	IPC 1650	0.17	0.31	0.24	1.01	1.27	1.14
65	ICMB 97111	x	IPC 843	-0.05	-1.26 *	-0.65 *	1.26	-0.42	0.42
66	ICMB 97111	x	IPC 616	0.29	-0.23	0.03	-0.92	-1.42	-1.17
67	ICMB 97111	x	IPC 774	1.04 **	0.90	0.97 **	-0.24	0.02	-0.11
68	ICMB 97111	x	IPC 1307	0.02	0.96	0.49	1.08	1.02	1.05
69	ICMB 97111	x	IPC 1354	0.47	0.43	0.45	0.14	1.58	0.86
70	ICMB 97111	x	IPC 390	-0.69	-1.10	-0.89 **	-0.42	-0.79	-0.61
71	ICMB 97111	x	IPC 828	-0.38	0.70	0.16	-1.49	-0.92	-1.20
72	ICMB 97111	x	IPC 1178	-0.86 *	-0.73	-0.79 *	-0.42	-0.35	-0.39
	S.E. (*sca*)			0.39	0.54	0.33	0.83	0.90	0.61
	r (between F$_1$ mean and *sca*)			0.49 **	0.49 **	0.43 **	0.42 **	0.33 **	0.31 **

r = Correlation coefficient; * = Significant at P ≤0.05; ** = Significant at P ≤0.01.

Table 10 a. ***Per se*** **performance and mid-parent (MP) heterosis for grain Fe concentration (mg kg^{-1}) in line x tester (set-I) trial, summer and rainy seasons 2009 and pooled analysis, Patancheru**

Sl. No.	F_1 Hybrid			Fe Class			Summer 2009			Rainy 2009			Pooled		
	Line		Tester				F_1 Mean	MP Heterosis		F_1 Mean	MP Heterosis		F_1 Mean	MP Heterosis	
1	ICMB 93222	x	IPC 1650	H	x	H	69.2	-41.18	**	49.9	-31.81	**	59.8	-37.43	**
2	ICMB 93222	x	IPC 843	H	x	M	65.7	-37.76	**	50.5	-12.32		58.0	-28.94	**
3	ICMB 93222	x	IPC 616	H	x	H	77.4	-30.97	**	45.1	-35.29	**	61.5	-32.42	**
4	ICMB 93222	x	IPC 774	H	x	H	76.2	-30.19	**	48.6	-24.59	*	62.3	-28.35	**
5	ICMB 93222	x	IPC 1307	H	x	L	66.9	-23.83	**	44.3	-9.45		55.8	-18.76	*
6	ICMB 93222	x	IPC 1354	H	x	L	55.6	-34.02	**	36.2	-21.73		46.0	-29.64	**
7	ICMB 93222	x	IPC 390	H	x	L	60.8	-29.42	**	35.4	-28.69		48.0	-29.41	**
8	ICMB 93222	x	IPC 828	H	x	L	57.5	-36.37	**	46.7	-14.00		52.3	-27.81	**
9	ICMB 93222	x	IPC 1178	H	x	M	94.0	-14.69	*	56.8	-6.00		75.5	-11.70	
10	ICMB 98222	x	IPC 1650	H	x	H	67.1	-45.01	**	57.0	-28.92	**	62.0	-38.77	**
11	ICMB 98222	x	IPC 843	H	x	M	78.2	-28.83	**	48.7	-24.63	*	63.8	-27.04	**
12	ICMB 98222	x	IPC 616	H	x	H	73.5	-36.85	**	48.0	-37.38	**	60.8	-37.21	**
13	ICMB 98222	x	IPC 774	H	x	H	73.4	-35.34	**	49.6	-30.56	**	61.5	-33.60	**
14	ICMB 98222	x	IPC 1307	H	x	L	60.6	-34.25	**	35.2	-37.11	**	48.0	-35.46	**
15	ICMB 98222	x	IPC 1354	H	x	L	60.4	-31.78	**	41.5	-22.09		51.3	-27.94	**
16	ICMB 98222	x	IPC 390	H	x	L	53.9	-40.39	**	31.1	-45.12	**	42.5	-42.37	**
17	ICMB 98222	x	IPC 828	H	x	L	65.6	-30.63	**	45.9	-25.17	*	55.8	-28.64	**
18	ICMB 98222	x	IPC 1178	H	x	M	83.8	-26.83	**	50.5	-25.19	*	67.0	-26.58	**
19	ICMB 00888	x	IPC 1650	M	x	H	61.7	-39.83	**	37.8	-38.68	**	49.8	-39.42	**
20	ICMB 00888	x	IPC 843	M	x	M	67.7	-25.29	**	36.6	-20.63		52.0	-23.81	**
21	ICMB 00888	x	IPC 616	M	x	H	60.3	-37.87	**	36.9	-36.61	**	48.8	-37.20	**
22	ICMB 00888	x	IPC 774	M	x	H	59.6	-36.73	**	42.7	-19.32		51.3	-30.27	**
23	ICMB 00888	x	IPC 1307	M	x	L	60.1	-17.39		44.1	18.05		52.3	-5.43	
24	ICMB 00888	x	IPC 1354	M	x	L	60.4	-12.74		38.8	11.48		49.8	-4.33	
25	ICMB 00888	x	IPC 390	M	x	L	55.6	-21.80	*	33.2	-12.85		44.3	-18.99	*
26	ICMB 00888	x	IPC 828	M	x	L	55.4	-26.46	**	42.4	-0.96		48.8	-17.37	
27	ICMB 00888	x	IPC 1178	M	x	M	94.4	-0.79		43.6	-10.92		69.3	-3.99	
28	ICMB 94111	x	IPC 1650	H	x	H	64.0	-37.91	**	47.0	-43.48	**	55.5	-40.56	**
29	ICMB 94111	x	IPC 843	H	x	M	69.5	-23.72	**	43.9	-35.01	**	56.8	-28.62	**
30	ICMB 94111	x	IPC 616	H	x	H	67.1	-31.27	**	38.8	-51.36	**	53.0	-40.37	**
31	ICMB 94111	x	IPC 774	H	x	H	66.0	-30.31	**	44.3	-40.47	**	55.0	-35.10	**
32	ICMB 94111	x	IPC 1307	H	x	L	59.3	-19.01		38.1	-35.24	**	48.8	-26.69	**
33	ICMB 94111	x	IPC 1354	H	x	L	45.4	-34.94	**	36.9	-34.44	**	41.0	-35.18	**
34	ICMB 94111	x	IPC 390	H	x	L	47.3	-33.98	**	33.9	-43.10	**	40.8	-38.14	**
35	ICMB 94111	x	IPC 828	H	x	L	49.5	-34.62	**	38.3	-40.38	**	43.8	-37.72	**
36	ICMB 94111	x	IPC 1178	H	x	M	84.7	-11.48		61.3	-13.08		73.0	-12.44	*
37	ICMB 93333	x	IPC 1650	L	x	H	52.1	-40.49	**	34.8	-48.12	**	43.5	-43.69	**
38	ICMB 93333	x	IPC 843	L	x	M	60.0	-20.63	*	40.4	-21.59		50.3	-20.71	*

Sl. No.	F_1 Hybrid			Fe Class			Summer 2009			Rainy 2009			Pooled		
	Line		Tester				F_1 Mean	MP Heterosis		F_1 Mean	MP Heterosis		F_1 Mean	MP Heterosis	
39	ICMB 93333	x	IPC 616	L	x	H	50.7	-38.26	**	38.3	-39.84	**	44.5	-38.83	**
40	ICMB 93333	x	IPC 774	L	x	H	55.5	-29.88	**	40.0	-31.55	*	47.8	-30.42	**
41	ICMB 93333	x	IPC 1307	L	x	L	54.0	-6.46		39.8	-7.11		47.0	-6.70	
42	ICMB 93333	x	IPC 1354	L	x	L	47.6	-12.30		36.5	-9.42		42.0	-10.88	
43	ICMB 93333	x	IPC 390	L	x	L	44.8	-20.12		26.3	-39.62	*	35.3	-29.15	**
44	ICMB 93333	x	IPC 828	L	x	L	50.7	-15.81		37.2	-22.88		44.3	-18.24	
45	ICMB 93333	x	IPC 1178	L	x	M	60.6	-24.40	**	41.9	-23.11		51.5	-23.42	**
46	ICMB 04777	x	IPC 1650	M	x	H	68.4	-33.04	**	49.5	-33.68	**	59.0	-33.24	**
47	ICMB 04777	x	IPC 843	M	x	M	61.0	-32.29	**	38.6	-34.72	**	49.8	-33.22	**
48	ICMB 04777	x	IPC 616	M	x	H	73.1	-24.39	**	38.2	-46.34	**	55.8	-33.53	**
49	ICMB 04777	x	IPC 774	M	x	H	79.7	-14.90		44.2	-32.86	**	61.8	-22.57	**
50	ICMB 04777	x	IPC 1307	M	x	L	72.7	0.61		44.4	-11.96		58.5	-4.88	
51	ICMB 04777	x	IPC 1354	M	x	L	58.0	-15.64		35.5	-25.64		46.8	-19.74	*
52	ICMB 04777	x	IPC 390	M	x	L	49.1	-30.44	**	34.1	-33.19	*	41.8	-31.42	**
53	ICMB 04777	x	IPC 828	M	x	L	49.8	-33.36	**	35.0	-37.30	**	42.5	-34.87	**
54	ICMB 04777	x	IPC 1178	M	x	M	84.4	-10.79		58.6	-5.42		71.8	-8.45	
55	ICMB 89111	x	IPC 1650	L	x	H	47.7	-46.20	**	35.2	-49.07	**	41.3	-47.62	**
56	ICMB 89111	x	IPC 843	L	x	M	77.2	0.87		46.7	-12.92		62.0	-4.43	
57	ICMB 89111	x	IPC 616	L	x	H	64.4	-22.53	**	40.6	-38.26	**	52.8	-28.96	**
58	ICMB 89111	x	IPC 774	L	x	H	56.4	-29.67	**	40.2	-33.43	**	48.5	-30.84	**
59	ICMB 89111	x	IPC 1307	L	x	L	57.0	-3.07		41.7	-7.18		49.5	-4.58	
60	ICMB 89111	x	IPC 1354	L	x	L	43.1	-21.97		31.3	-26.03		37.5	-22.88	*
61	ICMB 89111	x	IPC 390	L	x	L	56.2	-1.57		36.3	-20.44		46.5	-9.27	
62	ICMB 89111	x	IPC 828	L	x	L	51.3	-16.21		32.2	-35.99	*	41.8	-24.94	**
63	ICMB 89111	x	IPC 1178	L	x	M	68.7	-15.37		43.9	-22.31		56.3	-18.18	*
64	ICMB 97111	x	IPC 1650	L	x	H	48.1	-45.41	**	38.0	-39.28	**	43.0	-43.05	**
65	ICMB 97111	x	IPC 843	L	x	M	53.4	-29.78	**	39.2	-16.82		46.3	-24.95	**
66	ICMB 97111	x	IPC 616	L	x	H	47.3	-42.71	**	36.8	-37.82	**	42.0	-40.85	**
67	ICMB 97111	x	IPC 774	L	x	H	52.5	-34.04	**	36.1	-32.99	*	44.5	-33.46	**
68	ICMB 97111	x	IPC 1307	L	x	L	49.0	-15.86		40.6	5.80		45.0	-7.46	
69	ICMB 97111	x	IPC 1354	L	x	L	42.9	-21.63		32.1	-10.43		37.5	-17.36	
70	ICMB 97111	x	IPC 390	L	x	L	45.2	-20.05		34.1	-12.78		39.5	-17.71	
71	ICMB 97111	x	IPC 828	L	x	L	49.3	-18.91		33.9	-22.58		41.5	-20.76	*
72	ICMB 97111	x	IPC 1178	L	x	M	50.4	-37.56	**	33.3	-33.29	*	41.8	-36.26	**
	Mean						61.1	-26.23		40.9	-25.79		51.0	-26.32	
	Minimum						42.9	-46.20		26.3	-51.36		35.3	-47.62	
	Maximum						94.4	0.87		61.3	18.05		75.5	-3.99	
	S.E.							7.50			7.42			5.27	

Correlation between MP value and hybrid performance:summer 2009 = 0.70 **; rainy 2009 = 0.51**; pooled = 0.67**
* = Significant at P ≤0.05; ** = Significant at P ≤0.0; Note: Significant BP heterosis not observed

Table 10 b. ***Per se*** **performance and mid-parent (MP) heterosis for grain Zn concentration (mg kg^{-1}) in line x tester (set-I) trial, summer and rainy seasons 2009 and pooled analysis, Patancheru**

Sl. No.	F_1 Hybrid			Zn Class	Summer 2009			Rainy 2009			Pooled		
	Line		Tester		F_1 Mean	MP Heterosis		F_1 Mean	MP Heterosis		F_1 Mean	MP Heterosis	
1	ICMB 93222	x	IPC 1650	H x H	70.9	-15.15	**	45.3	-29.44	**	58.3	-21.15	**
2	ICMB 93222	x	IPC 843	H x M	65.7	-19.98	**	49.6	1.37		57.5	-12.21	*
3	ICMB 93222	x	IPC 616	H x H	68.1	-20.05	**	41.6	-27.46	**	55.3	-22.59	**
4	ICMB 93222	x	IPC 774	H x H	69.6	-21.28	**	43.3	-28.73	**	56.5	-24.03	**
5	ICMB 93222	x	IPC 1307	H x L	63.7	-4.26		41.7	8.55		52.8	0.48	
6	ICMB 93222	x	IPC 1354	H x L	62.8	-2.18		37.1	5.47		50.0	0.76	
7	ICMB 93222	x	IPC 390	H x L	58.4	-7.96		32.6	-19.08		45.5	-12.29	
8	ICMB 93222	x	IPC 828	H x L	58.5	-12.91		37.5	-16.73		48.0	-14.67	*
9	ICMB 93222	x	IPC 1178	H x M	77.2	-11.29	*	52.2	1.22		64.5	-7.03	
10	ICMB 98222	x	IPC 1650	H x H	69.8	-19.88	**	51.3	-25.33	**	60.8	-21.99	**
11	ICMB 98222	x	IPC 843	H x M	75.4	-11.90	*	46.0	-13.81		60.8	-12.59	*
12	ICMB 98222	x	IPC 616	H x H	76.1	-14.15	**	42.8	-30.86	**	59.3	-21.39	**
13	ICMB 98222	x	IPC 774	H x H	73.0	-20.53	**	46.7	-28.35	**	59.8	-23.76	**
14	ICMB 98222	x	IPC 1307	H x L	62.3	-10.96		37.1	-13.52		49.8	-11.95	
15	ICMB 98222	x	IPC 1354	H x L	64.8	-4.27		36.7	-7.53		50.8	-5.36	
16	ICMB 98222	x	IPC 390	H x L	58.3	-12.89		37.4	-16.62		47.8	-14.54	*
17	ICMB 98222	x	IPC 828	H x L	60.3	-14.72	*	38.8	-21.80		49.8	-17.43	**
18	ICMB 98222	x	IPC 1178	H x M	81.6	-9.92	*	48.5	-13.62		65.0	-11.41	*
19	ICMB 00888	x	IPC 1650	M x H	65.6	-16.46	**	40.9	-32.10	**	53.3	-23.24	**
20	ICMB 00888	x	IPC 843	M x M	76.5	-0.79		44.2	-1.63		60.3	-1.23	
21	ICMB 00888	x	IPC 616	M x H	64.7	-19.32	**	35.3	-33.76	**	50.3	-24.86	**
22	ICMB 00888	x	IPC 774	M x H	61.3	-26.52	**	42.3	-25.42	**	51.8	-25.94	**
23	ICMB 00888	x	IPC 1307	M x L	62.7	1.98		36.9	7.24		49.8	3.65	
24	ICMB 00888	x	IPC 1354	M x L	57.7	-2.56		38.0	21.63		47.8	5.82	
25	ICMB 00888	x	IPC 390	M x L	58.4	-0.07		36.0	-0.98		47.3	-0.26	
26	ICMB 00888	x	IPC 828	M x L	55.2	-11.23		36.6	-11.00		46.0	-11.11	
27	ICMB 00888	x	IPC 1178	M x M	78.0	-4.91		45.2	-5.06		61.8	-4.82	
28	ICMB 94111	x	IPC 1650	H x H	61.2	-18.94	**	42.6	-37.98	**	51.8	-28.37	**
29	ICMB 94111	x	IPC 843	H x M	68.3	-7.86		41.0	-23.25	*	54.8	-14.29	*
30	ICMB 94111	x	IPC 616	H x H	57.3	-25.80	**	32.3	-47.78	**	44.8	-35.84	**
31	ICMB 94111	x	IPC 774	H x H	62.9	-21.75	**	41.1	-36.98	**	51.8	-28.87	**
32	ICMB 94111	x	IPC 1307	H x L	59.7	2.01		36.2	-15.73		48.0	-5.65	
33	ICMB 94111	x	IPC 1354	H x L	45.9	-18.33	*	31.2	-21.51		38.5	-19.79	**
34	ICMB 94111	x	IPC 390	H x L	48.4	-12.65		31.7	-29.21	*	40.0	-20.40	**
35	ICMB 94111	x	IPC 828	H x L	52.8	-10.89		33.5	-32.53	**	43.0	-21.28	**
36	ICMB 94111	x	IPC 1178	H x M	82.6	4.44		56.5	0.75		69.5	2.58	
37	ICMB 93333	x	IPC 1650	L x H	69.3	-6.41		50.6	-21.27	*	59.8	-13.56	**
38	ICMB 93333	x	IPC 843	L x M	69.6	-4.20		47.7	-2.42		58.8	-3.29	
39	ICMB 93333	x	IPC 616	L x H	56.5	-25.31	**	39.3	-31.52	**	48.0	-27.95	**
40	ICMB 93333	x	IPC 774	L x H	63.9	-18.98	**	50.2	-17.36	*	57.0	-18.13	**
41	ICMB 93333	x	IPC 1307	L x L	63.1	10.76		43.6	13.35		53.3	11.52	

Sl. No.	F_1 Hybrid			Zn Class			Summer 2009			Rainy 2009			Pooled		
	Line		Tester				F_1 Mean	MP Heterosis		F_1 Mean	MP Heterosis		F_1 Mean	MP Heterosis	
42	ICMB 93333	x	IPC 1354	L	x	L	54.9	0.33		36.3	3.12		45.5	1.39	
43	ICMB 93333	x	IPC 390	L	x	L	54.4	0.83		34.5	-14.35		44.5	-5.57	
44	ICMB 93333	x	IPC 828	L	x	L	57.5	-0.41		35.9	-20.48		46.5	-9.71	
45	ICMB 93333	x	IPC 1178	L	x	M	67.7	-12.66	*	49.2	-4.56		58.8	-9.09	
46	ICMB 04777	x	IPC 1650	M	x	H	74.3	-4.83		49.8	-26.49	**	62.0	-15.07	**
47	ICMB 04777	x	IPC 843	M	x	M	70.1	-8.50		44.5	-15.07		57.3	-11.41	*
48	ICMB 04777	x	IPC 616	M	x	H	77.0	-3.42		43.3	-28.80	**	60.0	-14.89	**
49	ICMB 04777	x	IPC 774	M	x	H	83.1	0.23		51.2	-20.24	*	67.0	-8.84	
50	ICMB 04777	x	IPC 1307	M	x	L	72.7	19.15	**	41.1	-2.01		57.0	10.41	
51	ICMB 04777	x	IPC 1354	M	x	L	62.6	6.65		37.8	-2.29		50.3	3.08	
52	ICMB 04777	x	IPC 390	M	x	L	49.4	-14.80		40.6	-7.40		45.0	-11.76	
53	ICMB 04777	x	IPC 828	M	x	L	49.8	-19.25	**	31.3	-35.57	**	40.8	-26.41	**
54	ICMB 04777	x	IPC 1178	M	x	M	78.1	-4.18		60.7	10.23		69.3	1.09	
55	ICMB 89111	x	IPC 1650	L	x	H	55.8	-26.10	**	42.0	-36.06	**	49.0	-30.62	**
56	ICMB 89111	x	IPC 843	L	x	M	75.1	1.37		47.1	-6.56		61.0	-2.01	
57	ICMB 89111	x	IPC 616	L	x	H	61.9	-19.78	**	36.2	-38.54	**	48.8	-28.44	**
58	ICMB 89111	x	IPC 774	L	x	H	68.4	-14.92	**	39.0	-37.28	**	53.8	-24.43	**
59	ICMB 89111	x	IPC 1307	L	x	L	59.7	2.13		33.7	-15.69		46.8	-5.08	
60	ICMB 89111	x	IPC 1354	L	x	L	49.1	-12.60		37.8	2.90		43.5	-6.20	
61	ICMB 89111	x	IPC 390	L	x	L	54.2	-2.19		32.1	-23.33		43.0	-11.57	
62	ICMB 89111	x	IPC 828	L	x	L	52.0	-12.24		32.8	-29.61	*	42.5	-19.81	**
63	ICMB 89111	x	IPC 1178	L	x	M	80.3	1.62		49.8	-6.12		65.0	-1.70	
64	ICMB 97111	x	IPC 1650	L	x	H	55.0	-15.51	*	39.7	-31.18	**	47.3	-23.01	**
65	ICMB 97111	x	IPC 843	L	x	M	56.4	-11.39		38.1	-10.07		47.5	-10.38	
66	ICMB 97111	x	IPC 616	L	x	H	50.2	-24.73	**	35.8	-29.66	**	43.0	-26.96	**
67	ICMB 97111	x	IPC 774	L	x	H	56.4	-19.28	**	28.5	-47.40	**	45.5	-26.46	**
68	ICMB 97111	x	IPC 1307	L	x	L	41.3	-13.97		36.2	13.40		39.0	-2.50	
69	ICMB 97111	x	IPC 1354	L	x	L	41.9	-8.29		30.9	7.82		36.5	-1.68	
70	ICMB 97111	x	IPC 390	L	x	L	40.7	-9.37		27.9	-17.50		34.3	-13.02	
71	ICMB 97111	x	IPC 828	L	x	L	41.9	-13.91		32.6	-15.44		37.3	-14.86	
72	ICMB 97111	x	IPC 1178	L	x	M	53.4	-22.04	**	35.7	-20.90		44.5	-21.76	**
	Mean						62.5	-10.14		40.4	-16.19		51.5	-12.86	
	Minimum						40.7	-26.52		27.9	-47.78		34.3	-35.84	
	Maximum						83.1	19.15		60.7	21.63		69.5	11.52	
	S.E.							4.49			5.55			3.57	

Correlation between MP value and hybrid performance : summer 2009 = 0.80 **; rainy 2009 =0.54**; pooled = 0.73** * = Significant at P ≤0.05; ** = Significant at P ≤0.01; Note: Significant BP heterosis not observed

Table 10 c. ***Per se*** **performance, mid-parent (MP) and better parent (BP) heterosis for 1000-grain mass (g) in line x tester (set-I) trial, summer and rainy seasons 2009 and pooled analysis, Patancheru**

Sl. No.	F_1 Hybrid			Summer 2009			Rainy 2009			Pooled		
	Line		Tester	F_1 Mean	MP Heterosis	BP Heterosis	F_1 Mean	MP Heterosis	BP Heterosis	F_1 Mean	MP Heterosis	BP Heterosis
1	ICMB 93222	x	IPC 1650	11.2	28.51 **	24.82 **	10.7	19.50 *	1.57	10.9	23.95 **	12.29 *
2	ICMB 93222	x	IPC 843	10.0	16.92 **	10.99	11.4	19.83 **	9.06	10.7	18.46 **	9.95 *
3	ICMB 93222	x	IPC 616	10.5	36.82 **	16.79 **	11.3	33.47 **	8.20	10.9	35.06 **	12.16 *
4	ICMB 93222	x	IPC 774	14.1	72.82 **	57.11 **	15.4	57.75 **	46.54 **	14.7	64.62 **	51.41 **
5	ICMB 93222	x	IPC 1307	10.0	30.07 **	11.10	12.2	35.62 **	16.12 *	11.1	33.06 **	13.80 **
6	ICMB 93222	x	IPC 1354	11.7	25.36 **	21.03 **	14.1	64.57 **	34.00 **	12.9	44.13 **	32.16 **
7	ICMB 93222	x	IPC 390	9.4	27.11 **	5.24	12.1	48.23 **	15.78 *	10.8	38.19 **	10.93 *
8	ICMB 93222	x	IPC 828	12.5	37.34 **	35.04 **	14.1	18.78 **	6.64	13.3	26.86 **	18.37 **
9	ICMB 93222	x	IPC 1178	11.3	54.31 **	26.38 **	13.2	48.68 **	26.13 **	12.3	51.22 **	26.25 **
10	ICMB 98222	x	IPC 1650	11.7	27.90 **	18.54 **	11.5	47.96 **	40.16 **	11.6	37.10 **	28.33 **
11	ICMB 98222	x	IPC 843	10.2	13.34 **	2.78	12.3	46.33 **	42.97 **	11.2	29.29 **	24.11 **
12	ICMB 98222	x	IPC 616	9.7	18.90 **	-	11.2	51.83 **	36.20 **	10.4	34.56 **	15.05 **
13	ICMB 98222	x	IPC 774	11.3	31.42 **	14.39 **	13.6	57.67 **	50.75 **	12.4	44.53 **	37.45 **
14	ICMB 98222	x	IPC 1307	11.2	37.35 **	12.73 *	11.5	46.86 **	40.28 **	11.3	42.02 **	25.21 **
15	ICMB 98222	x	IPC 1354	13.0	33.38 **	31.57 **	13.1	77.15 **	59.72 **	13.1	52.25 **	44.32 **
16	ICMB 98222	x	IPC 390	11.8	49.49 **	19.14 **	12.6	78.37 **	53.26 **	12.2	63.12 **	34.60 **
17	ICMB 98222	x	IPC 828	13.6	41.33 **	36.87 **	13.8	28.59 **	4.32	13.7	34.62 **	21.58 **
18	ICMB 98222	x	IPC 1178	11.5	47.50 **	16.36 **	12.7	64.09 **	55.09 **	12.1	55.77 **	33.91 **
19	ICMB 00888	x	IPC 1650	11.6	15.16 **	-	13.4	29.05 **	-	12.5	22.20 **	-
20	ICMB 00888	x	IPC 843	11.4	15.84 **	-	13.4	22.15 **	0.37	12.4	19.17 **	-

Sl. No.	F$_1$ Hybrid			Summer 2009			Rainy 2009			Pooled		
	Line		Tester	F$_1$ Mean	MP Heterosis	BP Heterosis	F$_1$ Mean	MP Heterosis	BP Heterosis	F$_1$ Mean	MP Heterosis	BP Heterosis
21	ICMB 00888	x	IPC 616	11.0	22.38 **	-	11.7	18.01 **	-	11.4	20.08 **	-
22	ICMB 00888	x	IPC 774	14.0	46.86 **	19.58 **	15.5	38.60 **	15.94 **	14.7	42.39 **	17.64 **
23	ICMB 00888	x	IPC 1307	11.1	23.64 **	-	12.2	17.01 *	-	11.7	20.09 **	-
24	ICMB 00888	x	IPC 1354	12.7	18.83 **	8.44	15.7	57.05 **	17.25 **	14.2	37.32 **	13.14 **
25	ICMB 00888	x	IPC 390	12.3	39.72 **	5.06	13.9	44.81 **	4.34	13.1	42.38 **	4.67
26	ICMB 00888	x	IPC 828	13.6	29.77 **	16.45 **	15.8	19.34 **	18.52 **	14.7	23.94 **	17.56 **
27	ICMB 00888	x	IPC 1178	12.4	42.61 **	6.26	14.0	35.70 **	4.94	13.2	38.86 **	5.55
28	ICMB 94111	x	IPC 1650	9.0	7.63	5.98	13.2	68.77 **	59.14 **	11.1	37.24 **	34.39 **
29	ICMB 94111	x	IPC 843	9.5	17.02 **	16.06 *	11.3	33.31 **	30.87 **	10.4	25.32 **	24.65 **
30	ICMB 94111	x	IPC 616	9.1	25.33 **	11.17	11.2	51.49 **	35.30 **	10.2	38.53 **	23.31 **
31	ICMB 94111	x	IPC 774	10.6	36.94 **	29.79 **	11.2	29.17 **	24.07 **	10.9	32.85 **	32.26 **
32	ICMB 94111	x	IPC 1307	10.5	44.84 **	28.57 **	8.9	12.60	7.06	9.7	28.07 **	17.75 **
33	ICMB 94111	x	IPC 1354	10.6	18.46 **	9.61	11.9	60.07 **	43.69 **	11.2	37.39 **	36.33 **
34	ICMB 94111	x	IPC 390	10.3	46.70 **	26.01 **	11.0	55.64 **	33.19 **	10.7	51.19 **	29.62 **
35	ICMB 94111	x	IPC 828	12.5	43.26 **	34.88 **	12.4	15.16 *	-	12.4	27.77 **	10.75 *
36	ICMB 94111	x	IPC 1178	10.5	51.55 **	28.69 **	12.6	61.96 **	52.38 **	11.6	57.05 **	40.61 **
37	ICMB 93333	x	IPC 1650	9.6	29.05 **	13.55 *	10.8	33.40 **	22.05 *	10.2	31.32 **	29.13 **
38	ICMB 93333	x	IPC 843	9.5	30.71 **	17.44 **	9.8	12.53	10.97	9.6	20.77 **	15.73 **
39	ICMB 93333	x	IPC 616	7.9	23.12 **	22.35 **	9.1	18.88 *	3.22	8.5	20.80 **	11.27
40	ICMB 93333	x	IPC 774	11.2	62.56 **	52.42 **	11.3	26.91 **	25.85 **	11.3	42.43 **	37.78 **
41	ICMB 93333	x	IPC 1307	9.2	43.46 **	42.68 **	9.7	19.34 *	10.06	9.4	29.93 **	23.78 **
42	ICMB 93333	x	IPC 1354	10.4	29.60 **	8.00	11.9	54.71 **	34.99 **	11.2	41.91 **	37.73 **
43	ICMB 93333	x	IPC 390	10.3	67.40 **	60.36 **	11.3	53.93 **	28.26 **	10.8	60.06 **	41.76 **

Sl. No.	F_1 Hybrid			Summer 2009			Rainy 2009			Pooled		
	Line		Tester	F_1 Mean	MP Heterosis	BP Heterosis	F_1 Mean	MP Heterosis	BP Heterosis	F_1 Mean	MP Heterosis	BP Heterosis
44	ICMB 93333	x	IPC 828	9.8	25.33 **	6.04	12.5	13.73 *	-	11.2	18.56 **	-
45	ICMB 93333	x	IPC 1178	9.3	53.71 **	45.33 **	11.2	38.95 **	26.85 **	10.3	45.28 **	34.62 **
46	ICMB 04777	x	IPC 1650	10.5	28.93 **	24.20 **	11.5	49.20 **	42.92 **	11.0	38.77 **	38.53 **
47	ICMB 04777	x	IPC 843	10.0	26.47 **	24.71 **	10.6	27.66 **	23.31 *	10.3	27.08 **	23.99 **
48	ICMB 04777	x	IPC 616	10.7	51.24 **	36.85 **	11.7	60.36 **	45.35 **	11.2	55.85 **	41.15 **
49	ICMB 04777	x	IPC 774	10.7	41.64 **	37.16 **	10.3	21.40 **	14.79	10.5	30.94 **	29.00 **
50	ICMB 04777	x	IPC 1307	10.5	48.59 **	34.55 **	9.3	19.66 *	15.60	9.9	33.49 **	24.96 **
51	ICMB 04777	x	IPC 1354	11.3	28.98 **	16.93 **	10.7	46.39 **	33.37 **	11.0	36.91 **	35.33 **
52	ICMB 04777	x	IPC 390	11.0	60.47 **	40.49 **	11.9	71.75 **	49.03 **	11.5	66.15 **	44.81 **
53	ICMB 04777	x	IPC 828	11.8	37.97 **	27.22 **	11.6	9.22	-	11.7	22.06 **	4.10
54	ICMB 04777	x	IPC 1178	11.2	64.65 **	42.46 **	12.9	68.08 **	60.64 **	12.0	66.47 **	51.66 **
55	ICMB 89111	x	IPC 1650	10.5	36.44 **	23.96 **	10.6	60.30 **	44.96 **	10.6	47.50 **	33.72 **
56	ICMB 89111	x	IPC 843	10.7	43.05 **	32.84 **	11.2	54.39 **	30.47 **	11.0	48.64 **	31.61 **
57	ICMB 89111	x	IPC 616	9.7	46.62 **	40.62 **	10.2	64.58 **	57.25 **	10.0	55.32 **	55.23 **
58	ICMB 89111	x	IPC 774	11.3	59.27 **	54.60 **	11.3	51.17 **	25.46 **	11.3	55.13 **	38.55 **
59	ICMB 89111	x	IPC 1307	8.5	27.95 **	22.81 **	7.4	9.74	-	7.9	18.79 **	14.58 *
60	ICMB 89111	x	IPC 1354	10.0	21.02 **	3.89	11.1	77.96 **	69.12 **	10.6	45.56 **	30.39 **
61	ICMB 89111	x	IPC 390	9.7	51.43 **	40.19 **	10.4	75.99 **	75.40 **	10.0	63.23 **	56.46 **
62	ICMB 89111	x	IPC 828	12.1	49.81 **	30.67 **	13.2	38.22 **	0.23	12.7	43.53 **	12.80 **
63	ICMB 89111	x	IPC 1178	10.1	60.63 **	46.85 **	11.6	74.62 **	58.25 **	10.9	67.79 **	66.60 **
64	ICMB 97111	x	IPC 1650	11.5	16.63 **	1.81	12.5	32.78 **	8.95	12.0	24.50 **	5.40
65	ICMB 97111	x	IPC 843	10.9	12.35 **	-	10.5	4.34	-	10.7	8.28 *	-
66	ICMB 97111	x	IPC 616	10.9	23.26 **	-	11.1	23.91 **	-	11.0	23.59 **	-

Sl. No.	F_1 Hybrid			Summer 2009			Rainy 2009			Pooled		
	Line		Tester	F_1 Mean	MP Heterosis	BP Heterosis	F_1 Mean	MP Heterosis	BP Heterosis	F_1 Mean	MP Heterosis	BP Heterosis
67	ICMB 97111	x	IPC 774	13.9	48.41 **	22.24 **	14.1	38.32 **	23.49 **	14.0	43.13 **	22.87 **
68	ICMB 97111	x	IPC 1307	10.9	23.64 **	-	11.7	23.84 **	2.31	11.3	23.74 **	-
69	ICMB 97111	x	IPC 1354	12.7	20.94 **	11.87 **	13.6	50.78 **	18.78 **	13.1	34.74 **	15.34 **
70	ICMB 97111	x	IPC 390	10.7	23.88 **	-	11.1	28.28 **	-	10.9	26.09 **	-
71	ICMB 97111	x	IPC 828	12.6	22.45 **	11.34 *	14.6	18.51 **	10.74	13.6	20.31 **	19.45 **
72	ICMB 97111	x	IPC 1178	10.7	25.51 **	-	12.2	30.53 **	6.90	11.5	28.14 **	0.70
	Mean			11.0	35.33	24.26	12.0	40.55	28.60	11.5	37.46	26.81
	Minimum			7.9	7.63	1.81	7.4	4.34	0.23	7.9	8.28	0.70
	Maximum			14.1	72.82	60.36	15.8	78.37	75.40	14.7	67.79	66.60
	S.E.				0.45	0.52		0.69	0.81		0.41	0.48

Correlation between MP value and hybrid performance :summer 2009 = 0.66 **; rainy 2009 = 0.62**; pooled = 0.72**

* = Significant at P ≤0.05; ** = Significant at P ≤0.01; Note: - no BP heterosis observed

Table 10 d. *Per se* performance, mid-parent (MP) and better parent (BP) heterosis for days to 50% flower in line x tester (set-I) trial, summer and rainy seasons 2009 and pooled analysis, Patancheru

Trt No.	F_1 Hybrid			Summer 2009					Rainy 2009					Pooled				
	Line		Tester	F_1 Mean	MP Heterosis		BP Heterosis		F_1 Mean	MP Heterosis		BP Heterosis		F_1 Mean	MP Heterosis		BP Heterosis	
1	ICMB 93222	x	IPC 1650	49	-8.84	**	-9.26	**	52	-5.50	**	-7.21	**	50	-7.16	**	-8.22	**
2	ICMB 93222	x	IPC 843	50	-4.76	**	-6.54	**	51	-5.56	**	-6.42	**	51	-5.16	**	-5.61	**
3	ICMB 93222	x	IPC 616	50	-7.48	**	-7.48	**	51	-4.23	*	-4.67	*	50	-5.85	**	-6.07	**
4	ICMB 93222	x	IPC 774	48	-6.40	**	-11.21	**	48	-8.57	**	-10.28	**	48	-7.51	**	-10.75	**
5	ICMB 93222	x	IPC 1307	54	-6.14	**	-11.57	**	54	-4.04	*	-7.76	**	54	-5.10	**	-9.70	**
6	ICMB 93222	x	IPC 1354	50	-6.10	**	-6.54	**	49	-9.35	**	-9.35	**	49	-7.73	**	-7.94	**
7	ICMB 93222	x	IPC 390	49	-6.22	**	-8.41	**	51	-6.48	**	-7.34	**	50	-6.35	**	-7.01	**
8	ICMB 93222	x	IPC 828	51	-7.27	**	-9.73	**	52	-3.70		-4.59	*	52	-5.50	**	-7.21	**
9	ICMB 93222	x	IPC 1178	53	-5.83	**	-9.48	**	52	-5.88	**	-8.77	**	52	-5.86	**	-9.13	**
10	ICMB 98222	x	IPC 1650	49	-5.37	**	-10.19	**	51	-5.61	**	-9.01	**	50	-5.49	**	-9.59	**
11	ICMB 98222	x	IPC 843	47	-7.00	**	-9.71	**	48	-9.43	**	-11.93	**	47	-8.25	**	-10.85	**
12	ICMB 98222	x	IPC 616	49	-3.92	*	-8.41	**	46	-11.96	**	-13.21	**	48	-7.99	**	-10.80	**
13	ICMB 98222	x	IPC 774	48	-1.55		-2.06		47	-9.71	**	-9.71	**	47	-5.76	**	-6.00	**
14	ICMB 98222	x	IPC 1307	48	-11.93	**	-20.66	**	51	-6.85	**	-12.07	**	50	-9.38	**	-16.46	**
15	ICMB 98222	x	IPC 1354	48	-6.40	**	-10.38	**	46	-13.33	**	-14.95	**	47	-9.93	**	-12.68	**
16	ICMB 98222	x	IPC 390	46	-8.54	**	-10.78	**	48	-10.38	**	-12.84	**	47	-9.49	**	-11.85	**
17	ICMB 98222	x	IPC 828	49	-6.67	**	-13.27	**	52	-2.83		-5.50	*	50	-4.74	**	-9.46	**
18	ICMB 98222	x	IPC 1178	50	-7.04	**	-14.66	**	51	-6.91	**	-11.40	**	50	-6.98	**	-13.04	**
19	ICMB 00888	x	IPC 1650	49	-5.77	**	-9.26	**	48	-5.88	**	-13.51	**	49	-5.83	**	-11.42	**
20	ICMB 00888	x	IPC 843	48	-6.40	**	-7.77	**	48	-5.94	**	-12.84	**	48	-6.17	**	-10.38	**
21	ICMB 00888	x	IPC 616	50	-4.35	*	-7.48	**	46	-8.54	**	-14.15	**	48	-6.40	**	-10.80	**

Trt No.	F$_1$ Hybrid			Summer 2009			Rainy 2009			Pooled		
	Line		Tester	F$_1$ Mean	MP Heterosis	BP Heterosis	F$_1$ Mean	MP Heterosis	BP Heterosis	F$_1$ Mean	MP Heterosis	BP Heterosis
22	ICMB 00888	x	IPC 774	49	-1.02	-3.00	44	-10.20 **	-14.56 **	46	-5.61 **	-7.04 **
23	ICMB 00888	x	IPC 1307	50	-9.50 **	-17.36 **	49	-6.22 **	-15.52 **	50	-7.91 **	-16.46 **
24	ICMB 00888	x	IPC 1354	49	-4.85 **	-7.55 **	46	-8.00 **	-14.02 **	48	-6.40 **	-10.80 **
25	ICMB 00888	x	IPC 390	48	-4.95 **	-5.88 **	46	-8.91 **	-15.60 **	47	-6.93 **	-10.90 **
26	ICMB 00888	x	IPC 828	50	-6.10 **	-11.50 **	50	-1.98	-9.17 **	50	-4.10 **	-10.36 **
27	ICMB 00888	x	IPC 1178	53	-2.78	-9.48 **	49	-6.28 **	-14.91 **	51	-4.49 **	-12.17 **
28	ICMB 94111	x	IPC 1650	49	-5.31 **	-9.26 **	51	-5.12 **	-8.11 **	50	-5.21 **	-8.68 **
29	ICMB 94111	x	IPC 843	48	-4.95 **	-6.80 **	48	-9.86 **	-11.93 **	48	-7.47 **	-9.43 **
30	ICMB 94111	x	IPC 616	48	-7.77 **	-11.21 **	47	-11.43 **	-12.26 **	47	-9.62 **	-11.74 **
31	ICMB 94111	x	IPC 774	46	-5.64 **	-7.07 **	46	-12.08 **	-12.50 **	46	-8.96 **	-9.85 **
32	ICMB 94111	x	IPC 1307	52	-6.36 **	-14.88 **	50	-10.00 **	-14.66 **	51	-8.18 **	-14.77 **
33	ICMB 94111	x	IPC 1354	49	-5.37 **	-8.49 **	47	-11.85 **	-13.08 **	48	-8.65 **	-10.80 **
34	ICMB 94111	x	IPC 390	49	-2.49	-3.92	48	-9.86 **	-11.93 **	49	-6.28 **	-8.06 **
35	ICMB 94111	x	IPC 828	51	-4.72 **	-10.62 **	53	-1.41	-3.67	52	-3.06 *	-7.21 **
36	ICMB 94111	x	IPC 1178	52	-3.26	-10.34 **	51	-7.34 **	-11.40 **	51	-5.31 **	-10.87 **
37	ICMB 93333	x	IPC 1650	53	-4.07 *	-6.19 **	51	-9.01 **	-9.01 **	52	-6.55 **	-7.59 **
38	ICMB 93333	x	IPC 843	52	-4.63 **	-8.85 **	51	-7.27 **	-8.11 **	51	-5.96 **	-8.48 **
39	ICMB 93333	x	IPC 616	52	-6.36 **	-8.85 **	50	-7.83 **	-9.91 **	51	-7.09 **	-9.38 **
40	ICMB 93333	x	IPC 774	49	-6.22 **	-13.27 **	47	-12.15 **	-15.32 **	48	-9.22 **	-14.29 **
41	ICMB 93333	x	IPC 1307	55	-5.98 **	-9.09 **	51	-10.13 **	-12.07 **	53	-8.03 **	-10.55 **
42	ICMB 93333	x	IPC 1354	51	-7.76 **	-10.62 **	49	-10.09 **	-11.71 **	50	-8.92 **	-11.16 **
43	ICMB 93333	x	IPC 390	50	-7.91 **	-12.39 **	47	-15.45 **	-16.22 **	48	-11.72 **	-14.29 **
44	ICMB 93333	x	IPC 828	58	1.77	-	53	-3.64	-4.50 *	55	-0.90	-1.34

Trt No.	F_1 Hybrid			Summer 2009					Rainy 2009					Pooled				
	Line		Tester	F_1 Mean	MP Heterosis		BP Heterosis		F_1 Mean	MP Heterosis		BP Heterosis		F_1 Mean	MP Heterosis		BP Heterosis	
45	ICMB 93333	x	IPC 1178	54	-5.68	**	-6.90	**	53	-5.78	**	-7.02	**	54	-5.73	**	-6.96	**
46	ICMB 04777	x	IPC 1650	50	-11.50	**	-15.25	**	52	-8.37	**	-10.34	**	51	-9.93	**	-12.82	**
47	ICMB 04777	x	IPC 843	49	-11.31	**	-16.95	**	52	-7.56	**	-10.34	**	51	-9.42	**	-13.68	**
48	ICMB 04777	x	IPC 616	49	-12.89	**	-16.95	**	52	-6.31	**	-10.34	**	51	-9.62	**	-13.68	**
49	ICMB 04777	x	IPC 774	50	-7.48	**	-16.10	**	50	-9.59	**	-14.66	**	50	-8.55	**	-15.38	**
50	ICMB 04777	x	IPC 1307	56	-7.11	**	-8.26	**	54	-6.90	**	-6.90	**	55	-7.01	**	-7.59	**
51	ICMB 04777	x	IPC 1354	51	-9.82	**	-14.41	**	51	-9.42	**	-12.93	**	51	-9.62	**	-13.68	**
52	ICMB 04777	x	IPC 390	50	-10.00	**	-16.10	**	51	-9.33	**	-12.07	**	50	-9.66	**	-14.10	**
53	ICMB 04777	x	IPC 828	55	-5.63	**	-7.63	**	55	-2.22		-5.17	*	55	-3.95	**	-6.41	**
54	ICMB 04777	x	IPC 1178	54	-7.69	**	-8.47	**	55	-5.22	**	-6.03	**	54	-6.47	**	-7.26	**
55	ICMB 89111	x	IPC 1650	50	-8.68	**	-9.91	**	51	-6.05	**	-9.01	**	50	-7.37	**	-8.22	**
56	ICMB 89111	x	IPC 843	47	-12.15	**	-15.32	**	49	-7.98	**	-10.09	**	48	-10.07	**	-10.70	**
57	ICMB 89111	x	IPC 616	51	-7.34	**	-9.01	**	50	-5.71	**	-6.60	**	50	-6.54	**	-6.98	**
58	ICMB 89111	x	IPC 774	46	-11.11	**	-17.12	**	45	-13.04	**	-13.46	**	46	-12.08	**	-15.35	**
59	ICMB 89111	x	IPC 1307	52	-10.34	**	-14.05	**	52	-6.36	**	-11.21	**	52	-8.41	**	-12.66	**
60	ICMB 89111	x	IPC 1354	49	-9.68	**	-11.71	**	48	-9.00	**	-10.28	**	49	-9.35	**	-9.77	**
61	ICMB 89111	x	IPC 390	49	-8.92	**	-12.61	**	46	-13.62	**	-15.60	**	47	-11.27	**	-12.09	**
62	ICMB 89111	x	IPC 828	53	-6.25	**	-7.08	**	51	-4.23	*	-6.42	**	52	-5.26	**	-6.76	**
63	ICMB 89111	x	IPC 1178	53	-7.49	**	-9.48	**	51	-6.42	**	-10.53	**	52	-6.97	**	-10.00	**
64	ICMB 97111	x	IPC 1650	50	-2.94		-8.33	**	51	-3.81		-9.01	**	50	-3.38	*	-8.68	**
65	ICMB 97111	x	IPC 843	49	-2.51		-5.83	**	48	-8.65	**	-12.84	**	48	-5.65	**	-9.43	**
66	ICMB 97111	x	IPC 616	47	-7.39	**	-12.15	**	46	-11.22	**	-14.15	**	46	-9.31	**	-13.15	**
67	ICMB 97111	x	IPC 774	46	-4.17	*	-4.17		45	-10.89	**	-12.62	**	46	-7.61	**	-8.54	**

Trt No.	F_1 Hybrid			Summer 2009			Rainy 2009			Pooled		
	Line		Tester	F_1 Mean	MP Heterosis	BP Heterosis	F_1 Mean	MP Heterosis	BP Heterosis	F_1 Mean	MP Heterosis	BP Heterosis
68	ICMB 97111	x	IPC 1307	52	-4.15 *	-14.05 **	51	-5.12 **	-12.07 **	52	-4.63 **	-13.08 **
69	ICMB 97111	x	IPC 1354	48	-4.95 **	-9.43 **	48	-6.80 **	-10.28 **	48	-5.88 **	-9.86 **
70	ICMB 97111	x	IPC 390	47	-6.06 **	-8.82 **	46	-12.50 **	-16.51 **	46	-9.36 **	-12.80 **
71	ICMB 97111	x	IPC 828	49	-6.22 **	-13.27 **	50	-4.81 *	-9.17 **	49	-5.52 **	-11.26 **
72	ICMB 97111	x	IPC 1178	51	-4.72 **	-12.93 **	50	-7.04 **	-13.16 **	50	-5.88 **	-13.04 **
	Mean			50	-6.45	-10.33	49	-7.79	-10.78	50	-7.13	-10.35
	Minimum			46	-12.89	-20.66	44	-15.45	-16.51	46	-12.08	-16.46
	Maximum			58	1.77	-2.06	55	-1.41	-3.67	55	-0.90	-1.34
	S.E.				0.94	1.03		1.05	1.18		0.70	0.79

Correlation between MP value and hybrid performance : summer 2009 = 0.83**; rainy 2009 = 0.79**; pooled = 0.87** * = Significant at P ≤0.05; ** = Significant at P ≤0.01; Note : - no negative BP heterosis observed

Table 11a. Analysis of variance for parents for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in line x tester trial (set II), rainy 2009 and summer 2010, Patancheru

Source of variation	df	Mean square							
		Fe (mg kg^{-1})		Zn (mg kg^{-1})		1000-grain mass (g)		Days to 50% flower	
		Rainy 2009	Summer 2010	Rainy 2009	Summer 2010	Rainy 2009	Summer 2010	Rainy 2009	Summer 2010
Replications	1	0.7	100.2	4.5	66.7	0.5	0.4	1.8	0.9
Parents	27	682.2 **	706.1 **	213.8 **	207.5 **	20.2 **	8.3 **	24.6 **	33.5 **
Error	27	124.5	89.4	39.2	70.6	0.9	0.5	0.9	2.4

Table 11 b. Analysis of variance for combining ability for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in line x tester trial (set II), rainy 2009 and summer 2010, Patancheru

Source of variation	df	Mean square							
		Fe (mg kg^{-1})		Zn (mg kg^{-1})		1000-grain mass (g)		Days to 50% flower	
		Rainy 2009	Summer 2010	Rainy 2009	Summer 2010	Rainy 2009	Summer 2010	Rainy 2009	Summer 2010
Replications	1	73.3	7.3	38.4	99.2	0.4	0.9	1.6	1.5
Crosses	191	124.9 **	292.6 **	56.1 **	91.0 **	8.0 **	4.9 **	12.7 **	13.7 **
Lines	15	802.0 **	1700.9 **	197.4 **	248.1 **	24.5 **	23.4 **	59.0 **	69.2 **
Testers	11	432.1 **	1695.1 **	304.3 **	659.6 **	64.4 **	36.7 **	100.1 **	98.4 **
Lines x Testers	165	42.9 **	71.1 **	26.7 **	38.8 **	2.8 **	1.1 **	2.7 **	3.0 **
Error	191	22.7	38.0	16.6	21.6	1.0	0.7	0.7	1.7
σ^2 gca		492.5	1061.2	116.8	150.0	15.5	14.7	37.8	43.4
σ^2 sca		10.1	16.5	5.1	8.6	0.9	0.2	1.0	0.7
$(2\sigma^2$ gca$)/(2\sigma^2$ gca $+ \sigma^2$ sca$)$		0.99	0.99	0.98	0.97	0.97	0.99	0.99	0.99

* = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$.

Table 12a. Pooled analysis of variance for parents for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in line x tester set-II trial, rainy 2009 and summer 2010, Patancheru

		Mean square							
Source of variations	**df**	**Fe (mg kg^{-1})**		**Zn (mg kg^{-1})**		**1000-grain mass (g)**		**Days to 50% flower**	
Environments (E)	1	3099.6		1563.8		19.0		422.8	
Replication / E	2	50.4		35.6		0.3		1.9	
Parents (P)	27	1254.5	**	356.8	**	23.0	**	50.8	**
P x E	27	133.9		64.6		5.5	**	7.3	**
Error	54	106.9		54.9		0.8		1.3	

Table 12 b. Pooled analysis of variance for combining ability for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in line x tester trial (set-II), rainy 2009 and summer 2010, Patancheru

		Mean square							
Source of variation	**df**	**Fe (mg kg^{-1})**		**Zn (mg kg^{-1})**		**1000-grain mass (g)**		**Days to 50% flower**	
Environments (E)	1	42502.3		27050.1		15.3		404.0	
Replication / E	2	240.3		153.8		0.7		2.5	
Crosses (C)	191	350.5	**	112.9	**	10.9	**	21.4	**
Lines (L)	15	2301.3	**	404.2	**	42.3	**	104.5	**
Testers (T)	11	1867.1	**	887.1	**	96.2	**	172.8	**
Lines x Testers (L x T)	165	72.1	**	34.8	**	2.4	**	3.7	**
C x E	191	67.1	**	34.2	**	2.0	**	5.1	**
L x E	15	201.6	**	41.3	**	5.6	**	23.7	**
T x E	11	260.1	**	76.8	**	4.9	**	25.7	**
L x T x E	165	42.0	*	30.7	**	1.5	**	2.0	**
Error	382	30.4		19.1		0.8		1.2	
σ^2 gca		39.4		10.4		1.1		2.4	
σ^2 sca		10.4		3.9		0.4		0.6	
$(2\sigma^2$ gca$)/(2\sigma^2$ gca $+ \sigma^2$ sca$)$		0.88		0.84		0.86		0.88	

* = Significant at P ≤0.05; ** = Significant at P ≤0.01.

Table 13. Proportional contribution of lines, testers and line x tester to total variance among crosses for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in line x tester (set-II) trial rainy 2009 and summer 2010 and pooled analysis, Patancheru

Character	Proportional contribution (%)											
	Rainy 2009				Summer 2010				Pooled			
	σ^2 L	σ^2 T	σ^2 LT	Total	σ^2 L	σ^2 T	σ^2 LT	Total	σ^2 L	σ^2 T	σ^2 LT	Total
Grain Fe (mg kg^{-1})	58.7	23.1	18.2	100	50.4	37.6	12.0	100	54.7	33.2	12.1	100
Grain Zn (mg kg^{-1})	34.9	41.6	23.5	100	24.9	52.5	22.6	100	31.4	53.2	15.4	100
1000-grain mass (g)	25.5	51.5	23.1	100	42.0	49.8	8.2	100	31.7	54.5	13.8	100
Days to 50% flower	37.3	47.6	15.1	100	43.4	46.6	10.1	100	39.4	49.1	11.4	100

σ^2L = Line variance ; σ^2T = Tester variance and σ^2LT = Line x Tester variance

Table 14a. General combining ability (*gca*) effects of parents and their *per se* performance for grain Fe and Zn concentration in line x tester (set -II) trial, rainy 2009, summer 2010 and pooled analysis, Patancheru.

Parent	Fe (mg kg^{-1})						Zn (mg kg^{-1})					
	Rainy 2009		Summer 2010		Pooled		Rainy 2009		Summer 2010		Pooled	
Lines	**Mean**	***gca***	**Mean**	***gca***	**Mean**	***gca***	**Mean**	***gca***	**Mean**	***gca***	**Mean**	***gca***
841 B	45.1	-4.8 **	50.7	-4.9 **	47.9	-4.9 **	45.4	1.9 *	60.3	5.0 **	52.9	3.5
843 B	41.0	-1.6	64.5	-7.0 **	52.7	-4.3 **	45.4	-1.5	65.9	0.8	55.6	-0.3
863 B	68.6	6.5 **	78.2	14.5 **	73.4	10.5 **	64.4	5.0 **	58.4	4.1 **	61.4	4.6
ICMB 88006	38.2	-8.5 **	46.3	-9.7 **	42.2	-9.1 **	42.3	-4.4 **	34.0	-3.8 **	38.2	-4.1
ICMB 91222	95.6	13.2 **	81.8	15.5 **	88.7	14.4 **	56.2	2.3 **	64.4	3.9 **	60.3	3.1
ICMB 92111	28.7	-8.9 **	38.4	-12.9 **	33.5	-10.9 **	36.6	-4.0 **	47.4	-6.8 **	42.0	-5.4
ICMB 95333	74.2	2.8 **	117.7	8.8 **	95.9	5.8 **	53.0	2.1 *	69.7	0.3	61.4	1.2
ICMB 96333	82.2	2.7 **	81.4	-1.2	81.8	0.7	75.6	2.4 **	68.5	-0.4	72.1	1.0
ICMB 99444	82.6	2.1 *	82.0	0.5	82.3	1.3	67.3	2.5 **	58.9	0.0	63.1	1.2
ICMB 00999	46.7	-0.6	60.2	-3.1 *	53.5	-1.8 *	54.9	1.1	64.1	1.0	59.5	1.1
ICMB 02444	70.5	-0.4	88.5	4.6 **	79.5	2.1 **	50.2	-0.4	64.9	0.2	57.5	-0.1
ICMB 03111	50.1	-0.1	55.7	1.8	52.9	0.9	47.6	0.1	53.9	1.5	50.7	0.8
ICMB 04222	55.6	6.3 **	55.2	3.4 **	55.4	4.9 **	44.5	-1.1	56.6	-0.7	50.5	-0.9
ICMB 04555	42.3	-6.2 **	48.8	-11.4 **	45.5	-8.8 **	45.4	-3.3 **	46.9	-4.7 **	46.2	-4.0
ICMB 04888	47.6	0.3	68.1	3.8 **	57.9	2.1 **	48.3	1.7 *	62.5	2.0 *	55.4	1.8
ICMB 04999	35.3	-2.8 **	46.9	-2.6 *	41.1	-2.7 **	36.7	-4.4 **	49.4	-2.5 **	43.0	-3.4
SE (lines)		0.97		1.26		0.80		0.83		0.95		0.63
r (between mean and *gca*)		0.81 **		0.70 **		0.78 **		0.79 **		0.63 **		0.75
Testers												
IPC 338	55.1	1.6	49.7	3.1 **	52.4	2.4 **	45.9	-1.2	44.6	-1.1	45.2	-1.1
IPC 404	40.5	1.2	57.1	4.2 **	48.8	2.7 **	43.1	1.9 *	56.5	3.2 **	49.8	2.5
IPC 536	57.0	-1.1	63.4	-3.3 **	60.2	-2.2 **	46.4	-1.1	63.2	2.2 **	54.8	0.6
IPC 689	50.0	4.2 **	67.0	12.2 **	58.5	8.2 **	49.3	4.4 **	58.3	5.5 **	53.8	4.9
IPC 735	98.6	4.8 **	101.0	6.6 **	99.8	5.7 **	75.0	5.2 **	78.4	5.4 **	76.7	5.3
IPC 811	42.8	-4.0 **	47.0	-8.8 **	44.9	-6.4 **	39.4	-5.8 **	39.6	-7.9 **	39.5	-6.8
IPC 1254	38.0	-3.2 **	53.7	-1.6	45.8	-2.4 **	34.4	-0.6	47.3	-2.0 *	40.8	-1.3
IPC 1268	33.3	-5.3 **	39.2	-11.6 **	36.3	-8.5 **	43.5	-1.3	51.6	-4.4 **	47.5	-2.9
IPC 1642	37.7	6.3 **	62.7	10.0 **	50.2	8.2 **	42.8	3.1 **	49.3	6.1 **	46.1	4.6
ICMR 356	39.9	-2.6 **	68.9	-3.3 **	54.4	-3.0 **	42.5	-1.1	59.3	-0.3	50.9	-0.7
ICMR 06333	42.3	-0.5	47.4	-3.7 **	44.8	-2.1 **	42.3	-1.5 *	41.2	-5.2 **	41.7	-3.4
ICMR 06888	43.1	-1.4	56.6	-3.7 **	49.9	-2.6 **	41.1	-1.9 **	48.6	-1.5	44.9	-1.7
SE (testers)		0.84		1.09		0.69		0.72		0.82		0.55
r (between mean and *gca*)		0.49		0.57		0.52		0.64 *		0.70 *		0.68

r = Correlation coefficient; * = Significant at P ≤0.05; ** = Significant at P ≤0.01.

Table 14 b. General combining ability (*gca*) effects of parents and their *per se* performance for 1000-grain mass and days to 50% flower in line x tester (set -II) trial, rainy 2009, summer 2010 and pooled analysis, Patancheru.

Parents	1000-grain mass (g)						Days to 50% flower					
	Rainy 2009		Summer 2010		Pooled		Rainy 2009		Summer 2010		Pooled	
Lines	**Mean**	***gca***	**Mean**	***gca***	**Mean**	***gca***	**Mean**	***gca***	**Mean**	***gca***	**Mean**	***gca***
841 B	8.2	-1.4 **	8.7	-1.4 **	8.5	-1.4 **	52	0.5 **	53	-0.6 *	53	-0.1
843 B	10.4	-0.6 **	11.5	0.6 **	11.0	0.0	44	-3.3 **	46	-2.5 **	45	-2.9 **
863 B	17.9	1.1 **	11.9	1.6 **	14.9	1.3 **	50	1.0 **	47	-1.9 **	49	-0.4 **
ICMB 88066	15.6	1.7 **	8.2	1.3 **	11.9	1.5 **	54	0.6 **	54	2.1 **	54	1.3 **
ICMB 91222	6.2	0.7 **	8.6	-0.1	7.4	0.3 *	50	-0.4 *	54	0.4	52	0.0
ICMB 92111	7.5	-1.5 **	8.4	-1.0 **	7.9	-1.3 **	54	1.1 **	54	1.6 **	54	1.3 **
ICMB 95333	9.5	0.4 *	7.9	-0.6 **	8.7	-0.1	55	1.6 **	60	3.0 **	57	2.3 **
ICMB 96333	9.0	0.0	12.2	0.2	10.6	0.1	49	-0.8 **	54	0.2	51	-0.3 *
ICMB 99444	11.7	0.1	9.1	-0.8 **	10.4	-0.4 **	52	0.1	57	2.4 **	54	1.3 **
ICMB 00999	8.5	-0.6 **	7.9	-1.5 **	8.2	-1.0 **	56	2.6 **	56	0.8 **	56	1.7 **
ICMB 02444	9.4	0.4	9.6	0.2	9.5	0.3 *	51	-0.3	53	-1.4 **	52	-0.8 **
ICMB 03111	9.8	-1.0 **	9.5	-0.6 **	9.7	-0.8 **	45	-2.4 **	49	-1.4 **	47	-1.9 **
ICMB 04222	10.1	0.3	12.0	1.1 **	11.0	0.7 **	48	-2.5 **	45	-2.4 **	46	-2.5 **
ICMB 04555	11.2	-0.1	10.5	0.2	10.8	0.1	56	0.7 **	55	0.7 *	55	0.7 **
ICMB 04888	9.5	1.7 **	11.3	1.4 **	10.4	1.5 **	51	0.7 **	53	-0.4	52	0.1
ICMB 04999	9.1	-1.1 **	9.3	-0.6 **	9.2	-0.9 **	48	0.9 **	48	-0.4	48	0.2
SE (lines)		0.20		0.17		0.13		0.17		0.27		0.16
r (between mean and *gca*)		0.51 *		0.67 **		0.68 **		0.85 **		0.88 **		0.91 **
Testers												
IPC 338	13.8	0.0	11.8	-0.2	12.8	-0.1	53	0.7 **	50	1.7 **	51	1.2 **
IPC 404	13.4	0.9 **	13.5	1.3 **	13.4	1.1 **	49	0.1	45	-1.5 **	47	-0.7 **
IPC 536	5.5	-1.6 **	6.5	-1.1 **	6.0	-1.3 **	51	-2.8 **	55	-0.8 **	53	-1.8 **
IPC 689	14.9	1.0 **	12.6	0.5 **	13.7	0.7 **	48	0.4 **	48	1.8 **	48	1.1 **
IPC 735	7.1	0.3	8.4	0.2	7.8	0.2	56	2.1 **	60	3.2 **	58	2.7 **
IPC 811	11.7	-0.3	10.3	-0.4 **	11.0	-0.4 **	50	1.5 **	50	-0.7 **	50	0.4 **
IPC 1254	5.5	0.0	6.0	-0.2	5.8	-0.1	57	2.0 **	57	1.2 **	57	1.6 **
IPC 1268	6.0	-1.4 **	7.0	-1.7 **	6.5	-1.5 **	56	1.5 **	55	0.5 *	55	1.0 **
IPC 1642	12.8	3.0 **	10.4	2.1 **	11.6	2.6 **	53	-1.9 **	56	-2.3 **	54	-2.1 **
ICMR 356	8.9	-0.9 **	11.0	-0.3 *	10.0	-0.6 **	49	-1.3 **	53	-1.2 **	51	-1.3 **
ICMR 06333	13.6	1.1 **	12.2	0.9 **	12.9	1.0 **	55	0.5 **	52	0.3	53	0.4 **
ICMR 06888	7.3	-2.1 **	7.0	-1.0 **	7.1	-1.6 **	50	-2.7 **	49	-2.4 **	49	-2.6 **
SE (testers)		0.17		0.15		0.11		0.15		0.23		0.14
r (between mean and *gca*)		0.67 *		0.66 *		0.68		0.52		0.34		0.42

r = Correlation coefficient; * = Significant at P ≤0.05; ** = Significant at P ≤0.01.

Table 15a. Specific combining ability (*sca*) effects of hybrids for grain Fe and Zn concentration in line x tester trial (set -II), rainy 2009 and summer 2010 and pooled analysis, Patancheru.

Sl. No.	F_1 Hybrid			*sca* effects							
	Line		Tester	Fe class	Fe (mg kg^{-1}) Rainy 2009	Fe (mg kg^{-1}) Summer 2010	Fe (mg kg^{-1}) Pooled	Zn class	Zn (mg kg^{-1}) Rainy 2009	Zn (mg kg^{-1}) Summer 2010	Zn (mg kg^{-1}) Pooled
1	841 B	x	IPC 338	L x M	1.18	0.19	0.68	M x L	4.20	1.72	2.96
2	841 B	x	IPC 404	L x L	-1.80	-2.73	-2.26	M x L	-6.56 *	0.58	-2.99
3	841 B	x	IPC 536	L x H	-1.21	7.77	3.28	M x H	0.34	6.28	3.31
4	841 B	x	IPC 689	L x H	-2.13	-3.14	-2.64	M x M	0.79	-2.19	-0.70
5	841 B	x	IPC 735	L x H	0.42	-4.81	-2.19	M x H	1.60	-3.65	-1.03
6	841 B	x	IPC 811	L x L	1.13	1.29	1.21	M x L	-3.45	-3.08	-3.26
7	841 B	x	IPC 1254	L x L	-4.68	3.34	-0.67	M x L	-2.27	3.20	0.46
8	841 B	x	IPC 1268	L x L	-2.87	-0.09	-1.48	M x L	1.67	-8.39 *	-3.36
9	841 B	x	IPC 1642	L x M	1.38	-4.99	-1.80	M x L	2.89	3.16	3.03
10	841 B	x	ICMR 356	L x M	7.98 *	1.77	4.87	M x M	-2.33	0.01	-1.16
11	841 B	x	ICMR 06333	L x L	-0.71	3.11	1.20	M x L	2.12	4.47	3.30
12	841 B	x	ICMR 06888	L x L	1.31	-1.70	-0.20	M x L	1.01	-2.12	-0.55
13	843 B	x	IPC 338	L x M	-1.55	0.27	-0.64	M x L	-1.25	4.44	1.60
14	843 B	x	IPC 404	L x L	-6.68 *	2.60	-2.04	M x L	-3.81	4.41	0.30
15	843 B	x	IPC 536	L x H	-3.34	-0.70	-2.02	M x H	-2.52	1.21	-0.65
16	843 B	x	IPC 689	L x H	-3.77	-8.50	-6.14 *	M x M	-5.02	-6.12	-5.57 *
17	843 B	x	IPC 735	L x H	-0.31	-3.43	-1.87	M x H	0.59	0.42	0.51
18	843 B	x	IPC 811	L x L	3.80	1.27	2.53	M x L	1.65	0.35	1.00
19	843 B	x	IPC 1254	L x L	3.84	2.77	3.31	M x L	2.87	-1.92	0.48
20	843 B	x	IPC 1268	L x L	1.55	0.20	0.87	M x L	2.16	-2.17	0.00
21	843 B	x	IPC 1642	L x M	-0.85	-3.01	-1.93	M x L	0.94	-3.92	-1.49
22	843 B	x	ICMR 356	L x M	4.79	5.25	5.02	M x M	-0.19	4.73	2.27
23	843 B	x	ICMR 06333	L x L	2.45	0.99	1.72	M x L	3.07	-1.05	1.01
24	843 B	x	ICMR 06888	L x L	0.07	2.29	1.18	M x L	1.50	-0.39	0.56
25	863 B	x	IPC 338	M x M	-10.12 **	-2.78	-6.45 *	H x L	-7.97 **	-0.66	-4.32 *
26	863 B	x	IPC 404	M x L	17.60 **	19.85 **	18.72 **	H x L	9.87 **	1.55	5.71 **
27	863 B	x	IPC 536	M x H	1.94	-6.71	-2.38	H x H	1.91	3.70	2.81
28	863 B	x	IPC 689	M x H	-7.19 *	7.24	0.03	H x M	-8.94 **	2.27	-3.33
29	863 B	x	IPC 735	M x H	6.57	12.52 **	9.54 **	H x H	5.22	11.37 **	8.29 **
30	863 B	x	IPC 811	M x L	4.52	-12.28 **	-3.88	H x L	3.53	-9.56 **	-3.02
31	863 B	x	IPC 1254	M x L	-8.48 *	-17.88 **	-13.18 **	H x L	-8.90 **	-11.08 **	-9.99 **
32	863 B	x	IPC 1268	M x L	-8.57 *	-3.01	-5.79 *	H x L	-6.16 *	4.27	-0.94
33	863 B	x	IPC 1642	M x M	2.33	-9.46 *	-3.57	H x L	1.32	-9.82 **	-4.25
34	863 B	x	ICMR 356	M x M	9.17 **	6.65	7.91 **	H x M	10.49 **	1.52	6.01 **
35	863 B	x	ICMR 06333	M x L	-5.82	2.33	-1.74	H x L	-5.05	3.74	-0.66
36	863 B	x	ICMR 06888	M x L	-1.95	3.53	0.79	H x L	4.68	2.70	3.69
37	ICMB 88006	x	IPC 338	L x M	4.70	-2.50	1.10	L x L	1.26	-4.66	-1.70
38	ICMB 88006	x	IPC 404	L x L	-0.38	8.78 *	4.20	L x L	-0.65	11.56 **	5.46 *
39	ICMB 88006	x	IPC 536	L x H	-1.09	3.02	0.97	L x H	0.30	0.21	0.26
40	ICMB 88006	x	IPC 689	L x H	-3.32	-5.48	-4.40	L x M	-1.05	4.13	1.54
41	ICMB 88006	x	IPC 735	L x H	-7.66 *	-8.50	-8.08 **	L x H	-5.59	-3.63	-4.61 *
42	ICMB 88006	x	IPC 811	L x L	3.00	2.00	2.50	L x L	2.76	-1.45	0.66
43	ICMB 88006	x	IPC 1254	L x L	-3.11	-0.70	-1.91	L x L	-3.61	-1.37	-2.49
44	ICMB 88006	x	IPC 1268	L x L	3.05	2.72	2.89	L x L	2.53	2.28	2.41
45	ICMB 88006	x	IPC 1642	L x M	-6.25	-0.93	-3.59	L x L	0.10	2.28	1.19
46	ICMB 88006	x	ICMR 356	L x M	0.49	1.63	1.06	L x M	-0.97	-1.72	-1.34
47	ICMB 88006	x	ICMR 06333	L x L	3.25	-0.69	1.28	L x L	1.79	-1.30	0.24

Sl. No.	F_1 Hybrid			*sca* effects							
	Line		Tester	Fe class	Fe (mg kg^{-1})			Zn class	Zn (mg kg^{-1})		
					Rainy 2009	Summer 2010	Pooled		Rainy 2009	Summer 2010	Pooled
48	ICMB 88006	x	ICMR 06888	L x L	7.32 *	0.66	3.99	L x L	3.12	-6.34	-1.61
49	ICMB 91222	x	IPC 338	H x M	-0.07	-4.57	-2.32	M x L	2.40	4.68	3.54
50	ICMB 91222	x	IPC 404	H x L	-0.40	-10.73 *	-5.56 *	M x L	1.84	-6.96 *	-2.56
51	ICMB 91222	x	IPC 536	H x H	-1.26	3.76	1.25	M x H	-2.56	0.49	-1.03
52	ICMB 91222	x	IPC 689	H x H	2.17	17.21 **	9.69 **	M x M	-1.16	7.21 *	3.03
53	ICMB 91222	x	IPC 735	H x H	8.22 *	1.64	4.93	M x H	5.55	-7.64 *	-1.05
54	ICMB 91222	x	IPC 811	H x L	-5.02	0.58	-2.22	M x L	-0.25	-1.77	-1.01
55	ICMB 91222	x	IPC 1254	H x L	7.77 *	4.94	6.35 *	M x L	0.53	4.21	2.37
56	ICMB 91222	x	IPC 1268	H x L	5.63	-2.69	1.47	M x L	-0.03	1.26	0.62
57	ICMB 91222	x	IPC 1642	H x M	-4.52	13.50 **	4.49	M x L	-2.71	1.72	-0.50
58	ICMB 91222	x	ICMR 356	H x M	-3.32	-6.24	-4.78	M x M	0.07	1.91	0.99
59	ICMB 91222	x	ICMR 06333	H x L	-7.11 *	-7.90	-7.51 **	M x L	-2.78	-0.67	-1.72
60	ICMB 91222	x	ICMR 06888	H x L	-2.09	-9.50 *	-5.80 *	M x L	-0.89	-4.46	-2.67
61	ICMB 92111	x	IPC 338	L x M	-2.58	-0.88	-1.73	L x L	-5.50	-1.90	-3.70
62	ICMB 92111	x	IPC 404	L x L	3.20	-2.49	0.35	L x L	0.64	-3.94	-1.65
63	ICMB 92111	x	IPC 536	L x H	-1.12	-7.90	-4.51	L x H	-2.07	-4.04	-3.05
64	ICMB 92111	x	IPC 689	L x H	1.31	1.05	1.18	L x M	3.03	4.69	3.86
65	ICMB 92111	x	IPC 735	L x H	-4.84	15.38 **	5.27	L x H	-0.51	9.33 **	4.41 *
66	ICMB 92111	x	IPC 811	L x L	3.97	-4.18	-0.10	L x L	0.25	-4.70	-2.22
67	ICMB 92111	x	IPC 1254	L x L	-2.99	-4.82	-3.90	L x L	-4.28	-2.67	-3.47
68	ICMB 92111	x	IPC 1268	L x L	4.38	8.80 *	6.59 *	L x L	2.06	2.74	2.40
69	ICMB 92111	x	IPC 1642	L x M	-0.13	-4.15	-2.14	L x L	-1.46	-0.11	-0.79
70	ICMB 92111	x	ICMR 356	L x M	-0.33	0.16	-0.09	L x M	1.96	3.49	2.72
71	ICMB 92111	x	ICMR 06333	L x L	1.63	0.14	0.89	L x L	2.22	-2.65	-0.21
72	ICMB 92111	x	ICMR 06888	L x L	-2.50	-1.11	-1.81	L x L	3.65	-0.24	1.71
73	ICMB 95333	x	IPC 338	H x M	-1.08	9.19 *	4.06	H x L	1.84	4.66	3.25
74	ICMB 95333	x	IPC 404	H x L	13.24 **	8.88 *	11.06 **	H x L	10.53 **	3.82	7.17 **
75	ICMB 95333	x	IPC 536	H x H	-7.02 *	-8.53	-7.78 **	H x H	-3.27	-2.88	-3.08
76	ICMB 95333	x	IPC 689	H x H	-1.00	3.32	1.16	H x M	0.67	2.34	1.51
77	ICMB 95333	x	IPC 735	H x H	2.16	-11.71 **	-4.77	H x H	-0.66	-10.71 **	-5.69 **
78	ICMB 95333	x	IPC 811	H x L	-3.93	-5.06	-4.50	H x L	-5.06	-1.14	-3.10
79	ICMB 95333	x	IPC 1254	H x L	-1.04	3.04	1.00	H x L	-0.94	1.29	0.18
80	ICMB 95333	x	IPC 1268	H x L	3.57	-3.03	0.27	H x L	1.35	0.44	0.90
81	ICMB 95333	x	IPC 1642	H x M	3.42	4.76	4.09	H x L	2.68	5.05	3.86
82	ICMB 95333	x	ICMR 356	H x M	-4.39	2.07	-1.16	H x M	-1.45	-2.31	-1.88
83	ICMB 95333	x	ICMR 06333	H x L	-5.22	-2.69	-3.96	H x L	-0.49	0.96	0.24
84	ICMB 95333	x	ICMR 06888	H x L	1.29	-0.24	0.53	H x L	-5.20	-1.53	-3.37
85	ICMB 96333	x	IPC 338	H x M	8.11 *	9.47 *	8.79 **	H x L	3.11	1.52	2.32
86	ICMB 96333	x	IPC 404	H x L	-3.47	-1.99	-2.73	H x L	-4.45	4.58	0.07
87	ICMB 96333	x	IPC 536	H x H	-0.88	4.20	1.66	H x H	0.10	1.93	1.02
88	ICMB 96333	x	IPC 689	H x H	3.10	-3.60	-0.25	H x M	3.70	-0.24	1.73
89	ICMB 96333	x	IPC 735	H x H	2.75	4.68	3.71	H x H	0.11	7.25 *	3.68
90	ICMB 96333	x	IPC 811	H x L	0.11	-3.48	-1.68	H x L	-0.79	-2.28	-1.53
91	ICMB 96333	x	IPC 1254	H x L	-1.05	-0.92	-0.99	H x L	1.34	-1.15	0.10
92	ICMB 96333	x	IPC 1268	H x L	-1.19	-1.60	-1.39	H x L	0.78	-1.74	-0.48
93	ICMB 96333	x	IPC 1642	H x M	-7.14 *	1.95	-2.60	H x L	-3.40	7.91 *	2.26
94	ICMB 96333	x	ICMR 356	H x M	-6.50	-4.59	-5.54 *	H x M	-3.92	-9.79 **	-6.86 **
95	ICMB 96333	x	ICMR 06333	H x L	1.47	-1.01	0.23	H x L	1.69	-1.88	-0.09
96	ICMB 96333	x	ICMR 06888	H x L	4.69	-3.11	0.79	H x L	1.72	-6.12	-2.20

Sl. No.	F$_1$ Hybrid			*sca* effects							
	Line		Tester	Fe class	Fe (mg kg^{-1})			Zn class	Zn (mg kg^{-1})		
					Rainy 2009	Summer 2010	Pooled		Rainy 2009	Summer 2010	Pooled
97	ICMB 99444	x	IPC 338	H x M	8.32 *	2.24	5.28	H x L	0.97	-4.69	-1.86
98	ICMB 99444	x	IPC 404	H x L	-10.00 **	1.93	-4.04	H x L	-2.84	4.53	0.84
99	ICMB 99444	x	IPC 536	H x H	7.38 *	-2.33	2.53	H x H	2.36	0.98	1.67
100	ICMB 99444	x	IPC 689	H x H	0.41	-4.68	-2.14	H x M	1.86	-3.60	-0.87
101	ICMB 99444	x	IPC 735	H x H	2.11	6.19	4.15	H x H	0.62	1.25	0.93
102	ICMB 99444	x	IPC 811	H x L	-4.48	4.84	0.18	H x L	-2.63	1.12	-0.75
103	ICMB 99444	x	IPC 1254	H x L	-1.14	1.99	0.43	H x L	1.05	5.20	3.12
104	ICMB 99444	x	IPC 1268	H x L	-2.52	2.27	-0.13	H x L	-1.26	-3.25	-2.26
105	ICMB 99444	x	IPC 1642	H x M	-1.28	-7.54	-4.41	H x L	1.21	-1.64	-0.22
106	ICMB 99444	x	ICMR 356	H x M	-2.73	-0.23	-1.48	H x M	-1.66	1.15	-0.26
107	ICMB 99444	x	ICMR 06333	H x L	5.13	0.51	2.82	H x L	1.99	2.67	2.33
108	ICMB 99444	x	ICMR 06888	H x L	-1.20	-5.19	-3.20	H x L	-1.67	-3.72	-2.70
109	ICMB 00999	x	IPC 338	L x M	-1.74	-1.96	-1.85	M x L	4.27	-1.56	1.35
110	ICMB 00999	x	IPC 404	L x L	3.73	-3.67	0.03	M x L	1.96	1.80	1.88
111	ICMB 00999	x	IPC 536	L x H	4.32	1.07	2.69	M x H	1.46	-0.10	0.68
112	ICMB 00999	x	IPC 689	L x H	0.55	1.27	0.91	M x M	0.51	-0.98	-0.24
113	ICMB 00999	x	IPC 735	L x H	0.25	-9.56 *	-4.65	M x H	-5.78 *	-9.83 **	-7.81 **
114	ICMB 00999	x	IPC 811	L x L	-1.34	13.34 **	6.00 *	M x L	0.52	8.84 **	4.68 *
115	ICMB 00999	x	IPC 1254	L x L	-1.15	4.34	1.60	M x L	1.70	1.02	1.36
116	ICMB 00999	x	IPC 1268	L x L	-3.04	2.37	-0.34	M x L	-2.21	2.92	0.36
117	ICMB 00999	x	IPC 1642	L x M	-0.04	-4.09	-2.06	M x L	-2.19	-4.67	-3.43
118	ICMB 00999	x	ICMR 356	L x M	-1.85	-2.03	-1.94	M x M	-4.31	-2.53	-3.42
119	ICMB 00999	x	ICMR 06333	L x L	4.07	1.01	2.54	M x L	-0.31	-0.01	-0.16
120	ICMB 00999	x	ICMR 06888	L x L	-3.76	-2.09	-2.93	M x L	4.38	5.10	4.74 *
121	ICMB 02444	x	IPC 338	M x M	1.05	-5.46	-2.21	M x L	-2.79	0.95	-0.92
122	ICMB 02444	x	IPC 404	M x L	3.57	-5.83	-1.13	M x L	2.40	-4.04	-0.82
123	ICMB 02444	x	IPC 536	M x H	2.91	-1.33	0.79	M x H	1.14	-2.44	-0.65
124	ICMB 02444	x	IPC 689	M x H	4.34	6.76	5.55 *	M x M	1.24	-2.56	-0.66
125	ICMB 02444	x	IPC 735	M x H	-7.81 *	-4.51	-6.16 *	M x H	-4.55	3.58	-0.48
126	ICMB 02444	x	IPC 811	M x L	-0.85	-2.06	-1.46	M x L	0.56	4.35	2.45
127	ICMB 02444	x	IPC 1254	M x L	-0.81	-4.16	-2.48	M x L	5.43	-0.37	2.53
128	ICMB 02444	x	IPC 1268	M x L	-2.39	-0.34	-1.37	M x L	0.77	-0.56	0.10
129	ICMB 02444	x	IPC 1642	M x M	4.20	21.16 **	12.68 **	M x L	3.75	3.49	3.62
130	ICMB 02444	x	ICMR 356	M x M	-2.30	-3.28	-2.79	M x M	-4.08	-0.26	-2.17
131	ICMB 02444	x	ICMR 06333	M x L	-2.99	-6.24	-4.62	M x L	-1.67	-6.10	-3.88
132	ICMB 02444	x	ICMR 06888	M x L	1.08	5.30	3.19	M x L	-2.19	3.96	0.89
133	ICMB 03111	x	IPC 338	L x M	-0.49	2.48	0.99	L x L	3.19	1.54	2.37
134	ICMB 03111	x	IPC 404	L x L	-5.12	-1.54	-3.33	L x L	-4.62	-2.14	-3.38
135	ICMB 03111	x	IPC 536	L x H	-3.53	0.11	-1.71	L x H	-0.22	-5.04	-2.63
136	ICMB 03111	x	IPC 689	L x H	9.09 **	-7.10	1.00	L x M	6.72 *	-1.77	2.48
137	ICMB 03111	x	IPC 735	L x H	-8.20 *	0.33	-3.94	L x H	-7.91 **	1.92	-2.99
138	ICMB 03111	x	IPC 811	L x L	1.55	-1.12	0.22	L x L	2.34	2.30	2.32
139	ICMB 03111	x	IPC 1254	L x L	0.25	4.23	2.24	L x L	2.01	-2.77	-0.38
140	ICMB 03111	x	IPC 1268	L x L	-1.74	-1.55	-1.64	L x L	-2.75	2.93	0.09
141	ICMB 03111	x	IPC 1642	L x M	3.46	-4.80	-0.67	L x L	2.18	-4.12	-0.97
142	ICMB 03111	x	ICMR 356	L x M	-1.85	-1.74	-1.79	L x M	1.50	2.13	1.82
143	ICMB 03111	x	ICMR 06333	L x L	5.26	1.05	3.16	L x L	-1.64	-1.00	-1.32
144	ICMB 03111	x	ICMR 06888	L x L	1.33	9.64 *	5.49 *	L x L	-0.80	6.01	2.60
145	ICMB 04222	x	IPC 338	M x M	2.76	-6.01	-1.62	L x L	4.21	-3.99	0.11

Sl. No.	F$_1$ Hybrid			*sca* effects							
	Line		Tester	Fe class	Fe (mg kg^{-1})			Zn class	Zn (mg kg^{-1})		
					Rainy 2009	Summer 2010	Pooled		Rainy 2009	Summer 2010	Pooled
146	ICMB 04222	x	IPC 404	M x L	-7.52 *	-4.87	-6.20 *	L x L	-5.15	-5.58	-5.37 *
147	ICMB 04222	x	IPC 536	M x H	1.37	-2.13	-0.38	L x H	2.84	-3.73	-0.44
148	ICMB 04222	x	IPC 689	M x H	2.85	4.02	3.43	L x M	2.19	2.09	2.14
149	ICMB 04222	x	IPC 735	M x H	-2.55	1.79	-0.38	L x H	-6.25 *	1.89	-2.18
150	ICMB 04222	x	IPC 811	M x L	-1.79	2.64	0.42	L x L	1.11	2.31	1.71
151	ICMB 04222	x	IPC 1254	M x L	5.45	-3.56	0.95	L x L	6.23 *	-4.56	0.84
152	ICMB 04222	x	IPC 1268	M x L	-0.69	-0.28	-0.49	L x L	1.32	-0.66	0.33
153	ICMB 04222	x	IPC 1642	M x M	5.76	1.56	3.66	L x L	-4.30	3.20	-0.55
154	ICMB 04222	x	ICMR 356	M x M	-0.55	0.52	-0.01	L x M	2.57	5.14	3.86
155	ICMB 04222	x	ICMR 06333	M x L	-2.48	4.56	1.04	L x L	-0.77	-1.89	-1.33
156	ICMB 04222	x	ICMR 06888	M x L	-2.61	1.76	-0.43	L x L	-3.99	5.77	0.89
157	ICMB 04555	x	IPC 338	L x M	-0.47	-1.26	-0.87	L x L	-0.36	-6.14	-3.25
158	ICMB 04555	x	IPC 404	L x L	-6.10	-3.53	-4.81	L x L	-1.47	-7.27 *	-4.37 *
159	ICMB 04555	x	IPC 536	L x H	7.54 *	5.07	6.30 *	L x H	2.73	2.53	2.63
160	ICMB 04555	x	IPC 689	L x H	-4.59	-8.49	-6.54 *	L x M	-4.17	-3.65	-3.91
161	ICMB 04555	x	IPC 735	L x H	-0.23	-9.11 *	-4.67	L x H	1.94	-0.15	0.89
162	ICMB 04555	x	IPC 811	L x L	3.97	0.69	2.33	L x L	1.99	2.02	2.01
163	ICMB 04555	x	IPC 1254	L x L	2.77	0.74	1.75	L x L	-0.88	5.55	2.33
164	ICMB 04555	x	IPC 1268	L x L	-1.87	4.11	1.12	L x L	-0.14	5.35	2.61
165	ICMB 04555	x	IPC 1642	L x M	-3.17	-1.79	-2.48	L x L	-2.07	-1.69	-1.88
166	ICMB 04555	x	ICMR 356	L x M	-1.03	1.17	0.07	L x M	1.61	-1.20	0.21
167	ICMB 04555	x	ICMR 06333	L x L	0.33	9.46 *	4.89	L x L	-1.19	4.02	1.42
168	ICMB 04555	x	ICMR 06888	L x L	2.85	2.95	2.90	L x L	2.00	0.63	1.31
169	ICMB 04888	x	IPC 338	M x M	-6.86 *	0.55	-3.16	M x L	-8.22 **	0.94	-3.64
170	ICMB 04888	x	IPC 404	M x L	-1.99	1.18	-0.40	M x L	1.83	2.21	2.02
171	ICMB 04888	x	IPC 536	M x H	-4.30	-1.68	-2.99	M x H	-2.43	-4.54	-3.48
172	ICMB 04888	x	IPC 689	M x H	2.62	1.87	2.25	M x M	1.92	-5.27	-1.67
173	ICMB 04888	x	IPC 735	M x H	6.63 *	6.65	6.64 *	M x H	8.43 **	1.87	5.15 *
174	ICMB 04888	x	IPC 811	M x L	-5.21	-0.75	-2.98	M x L	-3.77	1.20	-1.28
175	ICMB 04888	x	IPC 1254	M x L	5.28	4.10	4.69	M x L	2.26	2.88	2.57
176	ICMB 04888	x	IPC 1268	M x L	0.84	-5.43	-2.29	M x L	-0.75	-0.37	-0.56
177	ICMB 04888	x	IPC 1642	M x M	3.49	2.27	2.88	M x L	1.83	2.63	2.23
178	ICMB 04888	x	ICMR 356	M x M	1.58	-1.42	0.08	M x M	1.55	-3.87	-1.16
179	ICMB 04888	x	ICMR 06333	M x L	0.90	-3.89	-1.49	M x L	4.16	2.85	3.50
180	ICMB 04888	x	ICMR 06888	M x L	-2.99	-3.44	-3.21	M x L	-6.81 *	-0.54	-3.67
181	ICMB 04999	x	IPC 338	L x M	-1.16	1.04	-0.06	L x L	0.64	3.15	1.90
182	ICMB 04999	x	IPC 404	L x L	2.11	-5.83	-1.86	L x L	0.48	-5.09	-2.30
183	ICMB 04999	x	IPC 536	L x H	-1.70	6.32	2.31	L x H	-0.12	5.42	2.65
184	ICMB 04999	x	IPC 689	L x H	-4.43	-1.74	-3.08	L x M	-2.28	3.64	0.68
185	ICMB 04999	x	IPC 735	L x H	2.48	2.44	2.46	L x H	7.19 *	-3.27	1.96
186	ICMB 04999	x	IPC 811	L x L	0.59	2.29	1.44	L x L	1.24	1.46	1.35
187	ICMB 04999	x	IPC 1254	L x L	-0.92	2.54	0.81	L x L	-2.54	2.54	0.00
188	ICMB 04999	x	IPC 1268	L x L	5.84	-2.44	1.70	L x L	0.65	-5.06	-2.20
189	ICMB 04999	x	IPC 1642	L x M	-0.66	-4.44	-2.55	L x L	-0.77	-3.46	-2.11
190	ICMB 04999	x	ICMR 356	L x M	0.83	0.32	0.58	L x M	-0.85	1.59	0.37
191	ICMB 04999	x	ICMR 06333	L x L	-0.15	-0.74	-0.45	L x L	-3.14	-2.19	-2.67
192	ICMB 04999	x	ICMR 06888	L x L	-2.84	0.25	-1.29	L x L	-0.50	1.27	0.38
S.E. (*sca*)					3.37	4.36	2.76		2.88	3.29	2.18
r (between F$_1$ mean and *sca*)					0.54 **	0.46 **	0.42 **		0.64 **	0.61 **	0.52 **

r = Correlation coefficient; * = Significant at P ≤0.05; ** = Significant at P ≤0.01.

Table 15b. Specific combining ability (*sca*) effect of hybrids for 1000-grain mass and days to 50% flower in line x tester trial (set -II), rainy 2009 and summer 2010 and pooled analysis, Patancheru.

Sl. No.	F_1 Hybrid			*sca* effects					
				1000-grain mass (g)			Days to 50% flower		
	Line		Tester	Rainy 2009	Summer 2010	Pooled	Rainy 2009	Summer 2010	Pooled
1	841 B	x	IPC 338	0.36	0.59	0.48	0.55	-0.83	-0.14
2	841 B	x	IPC 404	-0.07	-0.22	-0.15	-1.35 *	0.42	-0.46
3	841 B	x	IPC 536	-0.12	-0.23	-0.17	2.55 **	0.20	1.38 *
4	841 B	x	IPC 689	0.32	0.68	0.50	-1.13	2.64 **	0.75
5	841 B	x	IPC 735	0.12	0.42	0.27	0.65	-1.80	-0.57
6	841 B	x	IPC 811	-1.66 *	-0.13	-0.90	0.27	0.61	0.44
7	841 B	x	IPC 1254	-1.06	-0.62	-0.84	-0.73	-0.30	-0.51
8	841 B	x	IPC 1268	-0.55	0.92	0.19	1.21 *	0.92	1.07
9	841 B	x	IPC 1642	-1.40 *	-0.87	-1.13 *	0.12	0.67	0.39
10	841 B	x	ICMR 356	2.18 **	-0.28	0.95 *	0.09	-0.42	-0.17
11	841 B	x	ICMR 06333	1.08	0.05	0.56	-1.23 *	0.08	-0.57
12	841 B	x	ICMR 06888	0.80	-0.33	0.24	-1.01	-2.20 *	-1.61 **
13	843 B	x	IPC 338	1.15	-0.03	0.56	-0.70	-1.45	-1.07
14	843 B	x	IPC 404	0.12	-1.27 *	-0.58	0.90	0.30	0.60
15	843 B	x	IPC 536	0.87	0.33	0.60	-0.70	0.58	-0.06
16	843 B	x	IPC 689	-0.42	0.52	0.05	-0.38	-0.48	-0.43
17	843 B	x	IPC 735	0.69	0.00	0.35	2.40 **	0.58	1.49 **
18	843 B	x	IPC 811	-1.42 *	0.93	-0.25	-0.48	-0.02	-0.25
19	843 B	x	IPC 1254	1.13	-0.56	0.29	-0.48	-0.42	-0.45
20	843 B	x	IPC 1268	1.52 *	-0.09	0.71	-0.04	0.80	0.38
21	843 B	x	IPC 1642	-1.59 *	0.79	-0.40	0.87	0.05	0.46
22	843 B	x	ICMR 356	-0.86	0.64	-0.11	1.34 *	0.45	0.89
23	843 B	x	ICMR 06333	-1.04	-1.62 **	-1.33 **	0.02	0.95	0.49
24	843 B	x	ICMR 06888	-0.16	0.37	0.11	-2.76 **	-1.33	-2.04 **
25	863 B	x	IPC 338	-0.69	-1.72 **	-1.21 **	0.01	0.42	0.22
26	863 B	x	IPC 404	1.42 *	0.03	0.72	-0.89	0.67	-0.11
27	863 B	x	IPC 536	-0.21	-0.85	-0.53	-0.99	0.45	-0.27
28	863 B	x	IPC 689	-0.41	0.81	0.20	0.33	-0.61	-0.14
29	863 B	x	IPC 735	1.09	0.32	0.70	-1.39 *	-2.55 **	-1.97 **
30	863 B	x	IPC 811	-0.62	0.81	0.09	-0.77	0.86	0.05
31	863 B	x	IPC 1254	-2.38 **	-1.43 *	-1.90 **	1.73 **	0.45	1.09 *
32	863 B	x	IPC 1268	-0.46	1.18 *	0.36	2.67 **	0.67	1.67 **
33	863 B	x	IPC 1642	0.04	-0.89	-0.43	-0.42	0.42	0.00
34	863 B	x	ICMR 356	0.32	-0.07	0.13	-0.96	-0.67	-0.81
35	863 B	x	ICMR 06333	1.46 *	1.51 *	1.49 **	-0.77	-0.17	-0.47
36	863 B	x	ICMR 06888	0.45	0.30	0.37	1.45 *	0.05	0.75
37	ICMB 88006	x	IPC 338	-0.91	-1.46 *	-1.18 *	0.97	1.46	1.22 *
38	ICMB 88006	x	IPC 404	-1.30	-0.88	-1.09 *	-0.43	-0.79	-0.61
39	ICMB 88006	x	IPC 536	1.15	0.64	0.90	0.47	-0.01	0.23
40	ICMB 88006	x	IPC 689	-0.12	0.11	0.00	-0.72	-1.07	-0.89
41	ICMB 88006	x	IPC 735	-0.48	-0.41	-0.45	1.07	0.49	0.78
42	ICMB 88006	x	IPC 811	-2.86 **	0.50	-1.18 *	-0.31	-0.60	-0.45
43	ICMB 88006	x	IPC 1254	0.77	0.55	0.66	-0.81	-1.01	-0.91
44	ICMB 88006	x	IPC 1268	0.09	-0.41	-0.16	0.63	1.71	1.17 *
45	ICMB 88006	x	IPC 1642	0.46	-0.46	0.00	-0.47	-0.04	-0.25
46	ICMB 88006	x	ICMR 356	0.72	-0.26	0.23	0.00	-0.13	-0.06
47	ICMB 88006	x	ICMR 06333	1.57 *	1.02	1.30 **	-0.81	0.37	-0.22

Sl. No.	**F_1 Hybrid**			***sca* effects**					
				1000-grain mass (g)			**Days to 50% flower**		
	Line		**Tester**	**Rainy 2009**	**Summer 2010**	**Pooled**	**Rainy 2009**	**Summer 2010**	**Pooled**
48	ICMB 88006	x	ICMR 06888	0.91	1.05	0.98 *	0.41	-0.41	0.00
49	ICMB 91222	x	IPC 338	0.76	0.64	0.70	0.39	1.17	0.78
50	ICMB 91222	x	IPC 404	-0.49	-0.76	-0.63	0.48	-1.08	-0.30
51	ICMB 91222	x	IPC 536	0.27	0.05	0.16	-0.11	-2.30 *	-1.20 *
52	ICMB 91222	x	IPC 689	-0.64	-0.80	-0.72	0.70	-1.86 *	-0.58
53	ICMB 91222	x	IPC 735	-0.79	0.06	-0.37	-1.02	-0.80	-0.91
54	ICMB 91222	x	IPC 811	-0.36	0.42	0.03	-0.89	0.11	-0.39
55	ICMB 91222	x	IPC 1254	-0.19	-0.38	-0.28	1.11	1.70	1.40 *
56	ICMB 91222	x	IPC 1268	0.17	0.24	0.21	-0.46	-0.58	-0.52
57	ICMB 91222	x	IPC 1642	-0.94	-0.44	-0.69	-2.05 **	2.67 **	0.31
58	ICMB 91222	x	ICMR 356	0.25	0.57	0.41	0.42	0.08	0.25
59	ICMB 91222	x	ICMR 06333	1.18	0.88	1.03 *	0.61	0.58	0.59
60	ICMB 91222	x	ICMR 06888	0.78	-0.47	0.15	0.83	0.30	0.56
61	ICMB 92111	x	IPC 338	0.03	0.43	0.23	1.47 *	0.42	0.95
62	ICMB 92111	x	IPC 404	-1.57 *	0.32	-0.62	0.07	0.17	0.12
63	ICMB 92111	x	IPC 536	0.33	0.09	0.21	0.97	-1.05	-0.04
64	ICMB 92111	x	IPC 689	-1.10	0.17	-0.46	-0.72	-0.11	-0.41
65	ICMB 92111	x	IPC 735	-0.57	0.55	-0.01	0.57	0.95	0.76
66	ICMB 92111	x	IPC 811	0.42	-1.70 **	-0.64	-0.31	-0.64	-0.48
67	ICMB 92111	x	IPC 1254	1.49 *	0.46	0.98 *	-1.31 *	-0.05	-0.68
68	ICMB 92111	x	IPC 1268	3.07 **	1.05	2.06 **	-2.87 **	-1.33	-2.10 **
69	ICMB 92111	x	IPC 1642	-0.63	-0.36	-0.49	0.53	-0.58	-0.02
70	ICMB 92111	x	ICMR 356	0.05	-0.48	-0.21	1.50 *	1.83 *	1.67 **
71	ICMB 92111	x	ICMR 06333	-0.07	0.41	0.17	0.19	-0.67	-0.24
72	ICMB 92111	x	ICMR 06888	-1.45 *	-0.94	-1.20 **	-0.09	1.05	0.48
73	ICMB 95333	x	IPC 338	-0.08	0.03	-0.03	-0.03	-0.49	-0.26
74	ICMB 95333	x	IPC 404	1.37	1.11	1.24 **	1.07	-1.74	-0.34
75	ICMB 95333	x	IPC 536	0.30	0.12	0.21	-0.53	-1.46	-1.00
76	ICMB 95333	x	IPC 689	1.37	-0.65	0.36	-0.22	-0.03	-0.12
77	ICMB 95333	x	IPC 735	-0.90	0.65	-0.12	-0.93	0.04	-0.45
78	ICMB 95333	x	IPC 811	-0.01	0.68	0.33	-0.81	-1.56	-1.18 *
79	ICMB 95333	x	IPC 1254	-0.03	-1.16	-0.60	4.19 **	3.54 **	3.86 **
80	ICMB 95333	x	IPC 1268	-0.19	-0.21	-0.20	-1.37 **	-1.24	-1.31 *
81	ICMB 95333	x	IPC 1642	0.75	-0.20	0.28	-0.97	-1.49	-1.23 *
82	ICMB 95333	x	ICMR 356	-1.30	-0.24	-0.77	-1.50 *	0.91	-0.29
83	ICMB 95333	x	ICMR 06333	0.27	-0.10	0.08	-0.31	1.91 *	0.80
84	ICMB 95333	x	ICMR 06888	-1.55 *	-0.05	-0.80	1.41 *	1.63	1.52 **
85	ICMB 96333	x	IPC 338	1.23	0.83	1.03 *	-1.15 *	-0.62	-0.89
86	ICMB 96333	x	IPC 404	-0.77	0.43	-0.17	-0.56	0.63	0.04
87	ICMB 96333	x	IPC 536	0.23	-0.09	0.07	-1.15 *	0.41	-0.37
88	ICMB 96333	x	IPC 689	0.41	-0.51	-0.05	-0.34	-0.65	-0.50
89	ICMB 96333	x	IPC 735	1.03	0.99	1.01 *	1.44 *	1.91 *	1.68 **
90	ICMB 96333	x	IPC 811	-0.04	-0.20	-0.12	-0.43	-1.68	-1.06
91	ICMB 96333	x	IPC 1254	0.51	0.66	0.59	0.07	0.41	0.24
92	ICMB 96333	x	IPC 1268	-0.69	-0.98	-0.83	1.00	-1.37	-0.18
93	ICMB 96333	x	IPC 1642	-1.38 *	0.28	-0.55	-0.09	-0.12	-0.11
94	ICMB 96333	x	ICMR 356	0.29	-0.36	-0.03	-0.62	0.79	0.08
95	ICMB 96333	x	ICMR 06333	-1.04	-1.26 *	-1.15 *	1.07	-0.21	0.43
96	ICMB 96333	x	ICMR 06888	0.21	0.20	0.20	0.78	0.51	0.64

Sl. No.	F_1 Hybrid			*sca* effects					
				1000-grain mass (g)			Days to 50% flower		
	Line		Tester	Rainy 2009	Summer 2010	Pooled	Rainy 2009	Summer 2010	Pooled
97	ICMB 99444	x	IPC 338	-0.71	0.58	-0.06	0.39	1.17	0.78
98	ICMB 99444	x	IPC 404	0.12	-0.63	-0.26	-1.52 **	-1.08	-1.30 *
99	ICMB 99444	x	IPC 536	0.23	1.27 *	0.75	0.89	-1.80	-0.45
100	ICMB 99444	x	IPC 689	-0.11	0.18	0.04	1.20 *	1.64	1.42 *
101	ICMB 99444	x	IPC 735	3.42 **	-0.26	1.58 **	-3.52 **	-2.30 *	-2.91 **
102	ICMB 99444	x	IPC 811	1.58 *	-0.65	0.46	0.61	1.11	0.86
103	ICMB 99444	x	IPC 1254	-0.28	1.26 *	0.49	-1.89 **	-2.30 *	-2.10 **
104	ICMB 99444	x	IPC 1268	-1.88 **	0.21	-0.84	-0.46	1.42	0.48
105	ICMB 99444	x	IPC 1642	-0.64	0.07	-0.29	-0.05	-1.33	-0.69
106	ICMB 99444	x	ICMR 356	-1.35	-1.05	-1.20 **	1.92 **	-0.42	0.75
107	ICMB 99444	x	ICMR 06333	-0.18	-0.60	-0.39	1.11	2.08 *	1.59 **
108	ICMB 99444	x	ICMR 06888	-0.19	-0.38	-0.28	1.33 *	1.80	1.56 **
109	ICMB 00999	x	IPC 338	-0.77	0.48	-0.14	-0.03	-1.79	-0.91
110	ICMB 00999	x	IPC 404	-1.70 *	1.34 *	-0.18	0.07	-0.04	0.01
111	ICMB 00999	x	IPC 536	-0.55	0.14	-0.21	-0.03	1.24	0.61
112	ICMB 00999	x	IPC 689	-1.09	-0.41	-0.75	-0.22	3.18 **	1.48 **
113	ICMB 00999	x	IPC 735	-0.87	0.57	-0.15	2.07 **	-0.26	0.90
114	ICMB 00999	x	IPC 811	2.59 **	-0.35	1.12 *	-0.31	2.15 *	0.92
115	ICMB 00999	x	IPC 1254	-0.95	-0.62	-0.78	-0.31	-0.76	-0.53
116	ICMB 00999	x	IPC 1268	3.38 **	-0.06	1.66 **	0.63	0.46	0.55
117	ICMB 00999	x	IPC 1642	-0.17	-0.72	-0.44	0.03	-1.79	-0.88
118	ICMB 00999	x	ICMR 356	0.21	-0.21	0.00	-0.50	0.12	-0.19
119	ICMB 00999	x	ICMR 06333	0.35	-0.23	0.06	0.69	-0.88	-0.10
120	ICMB 00999	x	ICMR 06888	-0.45	0.06	-0.19	-2.09 **	-1.66	-1.88 **
121	ICMB 02444	x	IPC 338	-0.55	0.22	-0.16	-1.70 **	-1.08	-1.39 *
122	ICMB 02444	x	IPC 404	1.42 *	-0.65	0.38	-0.10	0.67	0.29
123	ICMB 02444	x	IPC 536	-0.46	-0.90	-0.68	-1.20 *	0.95	-0.12
124	ICMB 02444	x	IPC 689	-0.03	0.69	0.33	-0.38	0.39	0.00
125	ICMB 02444	x	IPC 735	0.27	0.17	0.22	0.90	-0.55	0.18
126	ICMB 02444	x	IPC 811	1.67 *	0.64	1.16 *	1.02	-0.64	0.19
127	ICMB 02444	x	IPC 1254	-0.88	0.56	-0.16	1.02	0.95	0.99
128	ICMB 02444	x	IPC 1268	-0.90	-0.27	-0.58	0.96	-1.33	-0.18
129	ICMB 02444	x	IPC 1642	0.30	-1.40 *	-0.55	0.37	0.92	0.64
130	ICMB 02444	x	ICMR 356	-0.66	0.97	0.15	-0.66	-0.67	-0.67
131	ICMB 02444	x	ICMR 06333	0.75	0.93	0.84	0.02	-0.67	-0.32
132	ICMB 02444	x	ICMR 06888	-0.94	-0.96	-0.95 *	-0.26	1.05	0.39
133	ICMB 03111	x	IPC 338	1.26	0.64	0.95 *	0.39	0.88	0.63
134	ICMB 03111	x	IPC 404	-0.80	-0.58	-0.69	0.98	1.13	1.06
135	ICMB 03111	x	IPC 536	0.82	0.45	0.63	1.39 *	-0.09	0.65
136	ICMB 03111	x	IPC 689	1.16	-0.44	0.36	-0.30	-0.65	-0.48
137	ICMB 03111	x	IPC 735	-1.16	-0.80	-0.98 *	-1.02	0.91	-0.05
138	ICMB 03111	x	IPC 811	-0.44	0.01	-0.21	-0.39	-0.18	-0.29
139	ICMB 03111	x	IPC 1254	1.16	0.86	1.01 *	-1.39 *	-0.09	-0.74
140	ICMB 03111	x	IPC 1268	-0.40	0.65	0.12	-0.46	-0.37	-0.41
141	ICMB 03111	x	IPC 1642	-0.89	-0.44	-0.67	-0.05	0.88	0.42
142	ICMB 03111	x	ICMR 356	-0.54	-0.43	-0.48	0.92	-0.71	0.10
143	ICMB 03111	x	ICMR 06333	-0.34	-0.41	-0.37	0.11	-1.21	-0.55
144	ICMB 03111	x	ICMR 06888	0.17	0.50	0.33	-0.17	-0.49	-0.33
145	ICMB 04222	x	IPC 338	0.74	0.01	0.37	0.05	-2.04 *	-0.99

Sl. No.	F_1 Hybrid			*sca* effects					
				1000-grain mass (g)			Days to 50% flower		
	Line		Tester	Rainy 2009	Summer 2010	Pooled	Rainy 2009	Summer 2010	Pooled
146	ICMB 04222	x	IPC 404	-0.24	0.06	-0.09	-0.35	1.71	0.68
147	ICMB 04222	x	IPC 536	-0.74	0.24	-0.25	0.05	0.99	0.52
148	ICMB 04222	x	IPC 689	0.36	-0.01	0.18	0.87	-1.07	-0.10
149	ICMB 04222	x	IPC 735	1.05	-0.79	0.13	-0.35	-0.01	-0.18
150	ICMB 04222	x	IPC 811	1.44 *	-0.30	0.57	0.27	-0.10	0.09
151	ICMB 04222	x	IPC 1254	0.47	0.42	0.45	-0.23	-0.51	-0.37
152	ICMB 04222	x	IPC 1268	-0.34	-0.86	-0.60	-0.29	1.71	0.71
153	ICMB 04222	x	IPC 1642	-0.65	1.17 *	0.26	-0.38	-0.54	-0.46
154	ICMB 04222	x	ICMR 356	-2.36 **	0.20	-1.08 *	-0.91	-0.63	-0.77
155	ICMB 04222	x	ICMR 06333	0.82	0.52	0.67	0.27	-0.63	-0.18
156	ICMB 04222	x	ICMR 06888	-0.55	-0.67	-0.61	0.99	1.09	1.04
157	ICMB 04555	x	IPC 338	-0.29	-1.13	-0.71	-0.15	3.84 **	1.84 **
158	ICMB 04555	x	IPC 404	-0.11	1.37 *	0.63	-1.56 **	-1.91 *	-1.74 **
159	ICMB 04555	x	IPC 536	-1.85 **	-0.93	-1.39 **	-0.15	0.37	0.11
160	ICMB 04555	x	IPC 689	0.50	-0.16	0.17	-0.34	0.81	0.23
161	ICMB 04555	x	IPC 735	-0.77	-0.12	-0.45	-0.06	0.37	0.15
162	ICMB 04555	x	IPC 811	-0.52	0.29	-0.11	0.57	-1.72	-0.58
163	ICMB 04555	x	IPC 1254	1.14	0.61	0.87	-0.93	-0.63	-0.78
164	ICMB 04555	x	IPC 1268	-0.78	-0.78	-0.78	-1.00	-0.41	-0.70
165	ICMB 04555	x	IPC 1642	2.57 **	0.71	1.64 **	0.91	-0.16	0.37
166	ICMB 04555	x	ICMR 356	0.08	0.48	0.28	0.38	0.24	0.31
167	ICMB 04555	x	ICMR 06333	-0.35	-0.44	-0.39	0.57	-0.76	-0.10
168	ICMB 04555	x	ICMR 06888	0.38	0.11	0.25	1.78 **	-0.04	0.87
169	ICMB 04888	x	IPC 338	-0.63	0.31	-0.16	-0.65	-0.54	-0.60
170	ICMB 04888	x	IPC 404	1.82 **	0.24	1.03 *	1.44 *	0.21	0.83
171	ICMB 04888	x	IPC 536	-0.28	0.23	-0.03	-1.65 **	-0.01	-0.83
172	ICMB 04888	x	IPC 689	0.80	-0.13	0.34	0.66	-1.57	-0.45
173	ICMB 04888	x	IPC 735	-1.60 *	-1.38 *	-1.49 **	-0.06	1.99 *	0.97
174	ICMB 04888	x	IPC 811	1.06	0.08	0.57	0.57	0.90	0.73
175	ICMB 04888	x	IPC 1254	-0.89	-0.70	-0.79	0.07	-0.01	0.03
176	ICMB 04888	x	IPC 1268	-1.54 *	-0.78	-1.16 *	2.00 **	0.21	1.11 *
177	ICMB 04888	x	IPC 1642	1.91 **	1.86 **	1.88 **	1.91 **	0.96	1.44 **
178	ICMB 04888	x	ICMR 356	0.94	0.02	0.48	-0.62	-1.13	-0.88
179	ICMB 04888	x	ICMR 06333	-1.37	-0.73	-1.05 *	-1.93 **	-0.63	-1.28 *
180	ICMB 04888	x	ICMR 06888	-0.22	0.99	0.39	-1.72 **	-0.41	-1.06
181	ICMB 04999	x	IPC 338	-0.90	-0.41	-0.65	0.18	-0.54	-0.18
182	ICMB 04999	x	IPC 404	0.80	0.09	0.45	1.77 **	0.71	1.24 *
183	ICMB 04999	x	IPC 536	0.00	-0.53	-0.26	0.18	1.49	0.84
184	ICMB 04999	x	IPC 689	-1.01	-0.07	-0.54	0.99	-0.57	0.21
185	ICMB 04999	x	IPC 735	-0.52	0.04	-0.24	-0.73	0.99	0.13
186	ICMB 04999	x	IPC 811	-0.81	-1.04	-0.93 *	1.40 *	1.40	1.40 *
187	ICMB 04999	x	IPC 1254	-0.01	0.08	0.04	-0.10	-1.01	-0.55
188	ICMB 04999	x	IPC 1268	-0.51	0.18	-0.16	-2.16 **	-1.29	-1.73 **
189	ICMB 04999	x	IPC 1642	2.26 **	0.89	1.57 **	-0.26	-0.54	-0.40
190	ICMB 04999	x	ICMR 356	2.00 **	0.49	1.24 **	-0.79	0.37	-0.21
191	ICMB 04999	x	ICMR 06333	-3.09 **	0.04	-1.52 **	0.40	-0.13	0.13
192	ICMB 04999	x	ICMR 06888	1.79 *	0.24	1.01 *	-0.88	-0.91	-0.90
S.E. (*sca*)				0.70	0.60	0.46	0.59	0.93	0.55
r (between F_1 mean and *sca*)				0.55 **	0.44 **	0.43 **	0.43 **	0.44 **	0.39 **

r = Correlation coefficient; * = Significant at P ≤0.05; ** = Significant at P ≤0.01.

Table 16 a. *Per se* performance and mid-parent (MP) heterosis for grain Fe concentration (mg kg^{-1}) in line x tester (set-II) trial, rainy 2009 and summer 2010 and pooled analysis, Patancheru

Sl. No.	Hybrids			Fe class	Rainy 2009		Summer 2010		Pooled	
	Line		Tester		F_1 mean	MP Heterosis	F_1 mean	MP Heterosis	F_1 mean	MP heterosis
1	841 B	x	IPC 338	L x M	38.3	-23.65	53.6	6.80	45.9	-8.42
2	841 B	x	IPC 404	L x L	34.9	-18.57	51.7	-4.06	43.3	-10.48
3	841 B	x	IPC 536	L x H	33.2	-35.02 **	54.7	-0.70	44.0	-17.21 *
4	841 B	x	IPC 689	L x H	37.5	-21.09	59.4	0.91	48.4	-8.92
5	841 B	x	IPC 735	L x H	40.7	-43.31 **	52.1	-31.32 **	46.4	-37.16 **
6	841 B	x	IPC 811	L x L	32.6	-25.80	42.8	-12.29	37.7	-18.69
7	841 B	x	IPC 1254	L x L	27.6	-33.57 *	52.0	-0.29	39.8	-15.04
8	841 B	x	IPC 1268	L x L	27.3	-30.40	38.6	-14.15	32.9	-21.73 *
9	841 B	x	IPC 1642	L x M	43.1	4.10	55.3	-2.40	49.2	0.34
10	841 B	x	ICMR 356	L x M	40.8	-3.91	48.8	-18.42	44.8	-12.39
11	841 B	x	ICMR 06333	L x L	34.2	-21.68	49.7	1.48	42.0	-9.44
12	841 B	x	ICMR 06888	L x L	35.4	-19.81	44.9	-16.32	40.1	-17.90
13	843 B	x	IPC 338	L x M	38.7	-19.45	51.5	-9.76	45.1	-14.19
14	843 B	x	IPC 404	L x L	33.1	-18.74	54.9	-9.68	44.0	-13.32
15	843 B	x	IPC 536	L x H	34.2	-30.16 *	44.1	-28.90 **	39.2	-29.46 **
16	843 B	x	IPC 689	L x H	39.1	-14.07	51.9	-21.12 *	45.5	-18.24 *
17	843 B	x	IPC 735	L x H	43.2	-38.11 **	51.3	-38.02 **	47.3	-38.06 **
18	843 B	x	IPC 811	L x L	38.5	-8.08	40.7	-27.02 **	39.6	-18.89 *
19	843 B	x	IPC 1254	L x L	39.3	-0.60	49.4	-16.50	44.3	-10.13
20	843 B	x	IPC 1268	L x L	34.9	-6.09	36.8	-29.10 *	35.8	-19.49
21	843 B	x	IPC 1642	L x M	44.1	12.00	55.2	-13.21	49.7	-3.57
22	843 B	x	ICMR 356	L x M	40.9	1.05	50.1	-24.94 **	45.5	-15.13
23	843 B	x	ICMR 06333	L x L	40.6	-2.58	45.4	-18.80	43.0	-11.88
24	843 B	x	ICMR 06888	L x L	37.4	-11.18	46.8	-22.80 *	42.1	-18.04 *
25	863 B	x	IPC 338	M x M	38.3	-38.04 **	70.0	9.47	54.2	-13.89
26	863 B	x	IPC 404	M x L	60.7	11.28	93.7	38.51 **	77.2	26.36 **
27	863 B	x	IPC 536	M x H	47.7	-24.10 *	59.6	-13.43	53.6	-18.52 **
28	863 B	x	IPC 689	M x H	43.8	-26.01 *	89.1	22.74 *	66.5	0.83
29	863 B	x	IPC 735	M x H	58.3	-30.32 **	88.7	-0.97	73.5	-15.14 **
30	863 B	x	IPC 811	M x L	47.4	-14.86	48.6	-22.30 *	48.0	-18.80 *
31	863 B	x	IPC 1254	M x L	35.1	-34.09 **	50.2	-23.92 *	42.6	-28.47 **
32	863 B	x	IPC 1268	M x L	33.0	-35.23 **	55.0	-6.32	44.0	-19.75 *
33	863 B	x	IPC 1642	M x M	55.5	4.35	70.3	-0.27	62.9	1.72
34	863 B	x	ICMR 356	M x M	53.4	-1.54	73.0	-0.72	63.2	-1.07
35	863 B	x	ICMR 06333	M x L	40.5	-27.00 *	68.3	8.74	54.4	-8.02
36	863 B	x	ICMR 06888	M x L	43.5	-22.15	69.5	3.13	56.5	-8.32
37	ICMB 88006	x	IPC 338	L x M	38.1	-18.33	46.0	-4.09	42.1	-11.11
38	ICMB 88006	x	IPC 404	L x L	32.6	-17.23	58.4	12.94	45.5	-0.10
39	ICMB 88006	x	IPC 536	L x H	29.6	-37.89 **	45.2	-14.65	37.4	-25.66 **
40	ICMB 88006	x	IPC 689	L x H	32.7	-25.85	52.1	-7.95	42.4	-15.78
41	ICMB 88006	x	IPC 735	L x H	28.9	-57.71 **	43.5	-40.97 **	36.2	-49.03 **
42	ICMB 88006	x	IPC 811	L x L	30.8	-23.93	38.7	-17.04	34.7	-20.24
43	ICMB 88006	x	IPC 1254	L x L	25.4	-33.22	43.1	-13.71	34.3	-22.15 *
44	ICMB 88006	x	IPC 1268	L x L	29.6	-17.34	36.6	-14.49	33.1	-15.79
45	ICMB 88006	x	IPC 1642	L x M	31.8	-16.30	54.6	0.16	43.2	-6.60
46	ICMB 88006	x	ICMR 356	L x M	29.6	-24.08	43.7	-24.02 *	36.7	-24.04 *
47	ICMB 88006	x	ICMR 06333	L x L	34.5	-14.23	41.0	-12.34	37.8	-13.21
48	ICMB 88006	x	ICMR 06888	L x L	37.7	-7.23	42.4	-17.59	40.0	-13.02

Sl. No.	Hybrids			Fe class	Rainy 2009		Summer 2010		Pooled	
	Line		Tester		F_1 mean	MP Heterosis	F_1 mean	MP Heterosis	F_1 mean	MP heterosis
49	ICMB 91222	x	IPC 338	H x M	55.1	-26.95 **	69.2	5.30	62.2	-11.92
50	ICMB 91222	x	IPC 404	H x L	54.3	-20.27 *	64.2	-7.65	59.2	-13.89 *
51	ICMB 91222	x	IPC 536	H x H	51.2	-32.98 **	71.1	0.66	61.1	-16.81 **
52	ICMB 91222	x	IPC 689	H x H	59.8	-17.79 *	100.1	34.55 **	80.0	8.67
53	ICMB 91222	x	IPC 735	H x H	66.6	-31.48 **	78.9	-13.68	72.7	-22.85 **
54	ICMB 91222	x	IPC 811	H x L	44.5	-35.73 **	62.6	-2.87	53.5	-19.89 **
55	ICMB 91222	x	IPC 1254	H x L	58.1	-13.10	74.0	9.28	66.0	-1.83
56	ICMB 91222	x	IPC 1268	H x L	53.8	-16.54	56.4	-6.82	55.1	-11.83
57	ICMB 91222	x	IPC 1642	H x M	55.2	-17.15	94.3	30.46 **	74.7	7.61
58	ICMB 91222	x	ICMR 356	H x M	47.5	-29.87 **	61.1	-18.88 *	54.3	-24.08 **
59	ICMB 91222	x	ICMR 06333	H x L	45.9	-33.48 **	59.1	-8.54	52.5	-21.42 **
60	ICMB 91222	x	ICMR 06888	H x L	50.0	-27.90 **	57.5	-16.96 *	53.7	-22.43 **
61	ICMB 92111	x	IPC 338	L x M	30.5	-27.41	44.5	1.11	37.5	-12.81
62	ICMB 92111	x	IPC 404	L x L	35.7	3.21	43.9	-8.04	39.8	-3.31
63	ICMB 92111	x	IPC 536	L x H	29.2	-31.86 *	31.0	-36.58 **	30.1	-34.38 **
64	ICMB 92111	x	IPC 689	L x H	36.9	-6.23	55.5	5.36	46.2	0.41
65	ICMB 92111	x	IPC 735	L x H	31.4	-50.73 **	64.2	-7.86	47.8	-28.33 **
66	ICMB 92111	x	IPC 811	L x L	31.4	-12.26	29.3	-31.24 *	30.4	-22.59
67	ICMB 92111	x	IPC 1254	L x L	25.2	-24.53	35.8	-22.13	30.5	-23.14 *
68	ICMB 92111	x	IPC 1268	L x L	30.5	-1.81	39.4	1.64	35.0	0.11
69	ICMB 92111	x	IPC 1642	L x M	37.5	12.89	48.2	-4.65	42.9	2.31
70	ICMB 92111	x	ICMR 356	L x M	28.4	-17.19	39.1	-27.13 *	33.8	-23.25 *
71	ICMB 92111	x	ICMR 06333	L x L	32.5	-8.64	38.7	-9.77	35.6	-9.26
72	ICMB 92111	x	ICMR 06888	L x L	27.5	-23.49	37.5	-21.16	32.5	-22.16 *
73	ICMB 95333	x	IPC 338	H x M	43.7	-32.41 **	76.3	-8.83	60.0	-19.11 **
74	ICMB 95333	x	IPC 404	H x L	57.5	0.31	77.0	-11.87	67.3	-7.05
75	ICMB 95333	x	IPC 536	H x H	35.0	-46.64 **	52.1	-41.18 **	43.6	-43.50 **
76	ICMB 95333	x	IPC 689	H x H	46.4	-25.33 *	79.5	-13.94 *	62.9	-18.52 **
77	ICMB 95333	x	IPC 735	H x H	50.1	-41.99 **	58.8	-46.19 **	54.5	-44.34 **
78	ICMB 95333	x	IPC 811	H x L	35.3	-39.69 **	50.2	-39.07 **	42.7	-39.33 **
79	ICMB 95333	x	IPC 1254	H x L	38.9	-30.74 **	65.5	-23.61 **	52.2	-26.43 **
80	ICMB 95333	x	IPC 1268	H x L	41.4	-22.94	49.3	-37.15 **	45.4	-31.37 **
81	ICMB 95333	x	IPC 1642	H x M	52.8	-5.64	78.8	-12.67	65.8	-9.98
82	ICMB 95333	x	ICMR 356	H x M	36.2	-36.61 **	62.7	-32.78 **	49.4	-34.23 **
83	ICMB 95333	x	ICMR 06333	H x L	37.4	-35.75 **	57.6	-30.25 **	47.5	-32.53 **
84	ICMB 95333	x	ICMR 06888	H x L	43.1	-26.60 *	60.1	-31.09 **	51.6	-29.28 **
85	ICMB 96333	x	IPC 338	H x M	52.7	-23.25 *	66.5	1.45	59.6	-11.19
86	ICMB 96333	x	IPC 404	H x L	40.7	-33.71 **	56.1	-19.03 *	48.4	-25.92 **
87	ICMB 96333	x	IPC 536	H x H	41.1	-41.04 **	54.9	-22.18 **	48.0	-31.56 **
88	ICMB 96333	x	IPC 689	H x H	50.3	-23.92 *	62.6	-15.73	56.4	-19.59 **
89	ICMB 96333	x	IPC 735	H x H	50.6	-44.07 **	65.2	-28.54 **	57.9	-36.27 **
90	ICMB 96333	x	IPC 811	H x L	39.1	-37.46 **	41.7	-35.01 **	40.4	-36.22 **
91	ICMB 96333	x	IPC 1254	H x L	38.7	-35.57 **	51.5	-23.82 *	45.1	-29.35 **
92	ICMB 96333	x	IPC 1268	H x L	36.6	-36.76 **	40.7	-32.52 **	38.6	-34.60 **
93	ICMB 96333	x	IPC 1642	H x M	42.1	-29.76 **	65.9	-8.51	54.0	-18.16 **
94	ICMB 96333	x	ICMR 356	H x M	33.9	-44.56 **	46.0	-38.79 **	39.9	-41.38 **
95	ICMB 96333	x	ICMR 06333	H x L	44.0	-29.43 **	49.2	-23.54 *	46.6	-26.44 **
96	ICMB 96333	x	ICMR 06888	H x L	46.3	-26.18 *	47.1	-31.73 **	46.7	-29.09 **
97	ICMB 99444	x	IPC 338	H x M	52.4	-18.25	61.0	-7.37	56.7	-12.74
98	ICMB 99444	x	IPC 404	H x L	33.6	-40.91 **	61.8	-11.21	47.7	-24.56 **

Sl. No.	Hybrids			Fe class	Rainy 2009		Summer 2010		Pooled	
	Line		Tester		F_1 mean	MP Heterosis	F_1 mean	MP Heterosis	F_1 mean	MP heterosis
99	ICMB 99444	X	IPC 536	H x H	48.8	-25.09 *	50.0	-29.35 **	49.4	-27.31 **
100	ICMB 99444	X	IPC 689	H x H	47.0	-23.57 *	63.1	-15.24	55.1	-19.01 **
101	ICMB 99444	X	IPC 735	H x H	49.4	-42.49 **	68.4	-25.27 **	58.9	-33.61 **
102	ICMB 99444	X	IPC 811	H x L	34.0	-41.37 **	51.8	-19.74 *	42.9	-29.98 **
103	ICMB 99444	X	IPC 1254	H x L	38.1	-31.44 **	56.0	-17.40	47.1	-23.72 **
104	ICMB 99444	X	IPC 1268	H x L	34.6	-34.97 **	46.3	-23.59 *	40.5	-28.91 **
105	ICMB 99444	X	IPC 1642	H x M	47.5	-14.38	58.2	-19.58 *	52.8	-17.32 *
106	ICMB 99444	X	ICMR 356	H x M	37.1	-34.36 **	52.1	-30.89 **	44.6	-32.38 **
107	ICMB 99444	X	ICMR 06333	H x L	47.1	-18.44	52.4	-18.91	49.7	-18.69 *
108	ICMB 99444	X	ICMR 06888	H x L	39.9	-31.36 **	46.7	-32.58 **	43.3	-32.02 **
109	ICMB 00999	X	IPC 338	L x M	39.6	-22.30	53.2	-3.17	46.4	-12.37
110	ICMB 00999	X	IPC 404	L x L	44.6	2.23	52.6	-10.39	48.6	-5.01
111	ICMB 00999	X	IPC 536	L x H	42.9	-17.27	49.8	-16.80	46.4	-17.02 *
112	ICMB 00999	X	IPC 689	L x H	44.5	-8.01	65.5	3.01	55.0	-1.75
113	ICMB 00999	X	IPC 735	L x H	44.8	-38.36 **	49.1	-39.16 **	46.9	-38.78 **
114	ICMB 00999	X	IPC 811	L x L	34.4	-23.16	56.7	5.73	45.6	-7.41
115	ICMB 00999	X	IPC 1254	L x L	35.3	-16.64	54.8	-3.75	45.1	-9.25
116	ICMB 00999	X	IPC 1268	L x L	31.4	-21.63	42.8	-13.92	37.1	-17.36
117	ICMB 00999	X	IPC 1642	L x M	45.9	8.64	58.0	-5.63	52.0	0.18
118	ICMB 00999	X	ICMR 356	L x M	35.2	-18.72	46.7	-27.64 **	41.0	-24.06 **
119	ICMB 00999	X	ICMR 06333	L x L	43.2	-2.91	49.4	-8.16	46.3	-5.78
120	ICMB 00999	X	ICMR 06888	L x L	34.6	-23.09	46.3	-20.83	40.4	-21.81 *
121	ICMB 02444	X	IPC 338	M x M	42.5	-32.36 **	57.4	-17.48	50.0	-24.54 **
122	ICMB 02444	X	IPC 404	M x L	44.6	-19.70	58.1	-20.70 *	51.4	-20.27 **
123	ICMB 02444	X	IPC 536	M x H	41.7	-34.70 **	55.1	-26.01 **	48.4	-30.02 **
124	ICMB 02444	X	IPC 689	M x H	48.4	-19.71	78.8	0.69	63.6	-8.19
125	ICMB 02444	X	IPC 735	M x H	36.9	-56.43 **	61.8	-35.06 **	49.4	-45.11 **
126	ICMB 02444	X	IPC 811	M x L	35.0	-38.17 **	49.0	-28.19 **	42.0	-32.72 **
127	ICMB 02444	X	IPC 1254	M x L	35.9	-33.95 **	54.0	-24.50 **	44.9	-28.58 **
128	ICMB 02444	X	IPC 1268	M x L	32.2	-38.11 **	47.9	-25.64 *	40.0	-31.21 **
129	ICMB 02444	X	IPC 1642	M x M	50.3	-7.06	91.0	19.64 *	70.7	8.53
130	ICMB 02444	X	ICMR 356	M x M	35.0	-36.71 **	53.2	-32.79 **	44.1	-34.40 **
131	ICMB 02444	X	ICMR 06333	M x L	36.3	-35.62 **	49.9	-27.08 **	43.1	-30.94 **
132	ICMB 02444	X	ICMR 06888	M x L	39.6	-30.38 **	61.4	-15.98	50.5	-22.28 **
133	ICMB 03111	X	IPC 338	L x M	41.4	-26.37 *	62.6	18.71	52.0	-4.55
134	ICMB 03111	X	IPC 404	L x L	36.3	-25.82	59.6	5.62	48.0	-8.97
135	ICMB 03111	X	IPC 536	L x H	35.7	-37.63 **	53.8	-6.72	44.7	-22.11 **
136	ICMB 03111	X	IPC 689	L x H	53.6	-0.14	62.1	1.13	57.8	0.54
137	ICMB 03111	X	IPC 735	L x H	36.9	-52.68 **	63.9	-18.47 *	50.4	-35.53 **
138	ICMB 03111	X	IPC 811	L x L	37.8	-24.40	47.1	-8.25	42.5	-16.22
139	ICMB 03111	X	IPC 1254	L x L	37.3	-21.75	59.7	9.05	48.5	-5.29
140	ICMB 03111	X	IPC 1268	L x L	33.2	-26.65	43.8	-7.71	38.5	-16.96
141	ICMB 03111	X	IPC 1642	L x M	50.0	5.21	62.3	5.11	56.1	5.15
142	ICMB 03111	X	ICMR 356	L x M	35.8	-26.39 *	51.9	-16.67	43.9	-20.93 *
143	ICMB 03111	X	ICMR 06333	L x L	45.0	-9.64	54.3	5.33	49.7	-2.02
144	ICMB 03111	X	ICMR 06888	L x L	40.2	-19.92	62.9	12.00	51.6	-3.06
145	ICMB 04222	X	IPC 338	M x M	51.0	-7.95	55.7	6.12	53.3	-1.10
146	ICMB 04222	X	IPC 404	M x L	40.3	-16.18	57.9	3.02	49.1	-5.83
147	ICMB 04222	X	IPC 536	M x H	46.9	-16.71	53.1	-7.44	50.0	-12.03
148	ICMB 04222	X	IPC 689	M x H	53.6	1.61	74.8	22.31 *	64.2	12.72

Sl. No.	Hybrids			Fe class	Rainy 2009		Summer 2010		Pooled	
	Line		Tester		F_1 mean	MP Heterosis	F_1 mean	MP Heterosis	F_1 mean	MP heterosis
149	ICMB 04222	x	IPC 735	M x H	48.9	-36.62 **	66.9	-14.34	57.9	-25.41 **
150	ICMB 04222	x	IPC 811	M x L	40.8	-17.00	52.5	2.69	46.7	-6.96
151	ICMB 04222	x	IPC 1254	M x L	48.8	4.33	53.5	-1.88	51.1	0.99
152	ICMB 04222	x	IPC 1268	M x L	40.7	-8.60	46.7	-1.27	43.7	-4.82
153	ICMB 04222	x	IPC 1642	M x M	58.1	24.52 *	70.2	19.02	64.2	21.45 *
154	ICMB 04222	x	ICMR 356	M x M	43.5	-8.95	55.8	-10.11	49.6	-9.61
155	ICMB 04222	x	ICMR 06333	M x L	43.6	-10.90	59.4	15.86	51.5	2.79
156	ICMB 04222	x	ICMR 06888	M x L	42.6	-13.75	56.6	1.21	49.6	-5.80
157	ICMB 04555	x	IPC 338	L x M	35.2	-27.73 *	45.6	-7.36	40.4	-17.50
158	ICMB 04555	x	IPC 404	L x L	29.2	-29.53	44.4	-16.15	36.8	-22.02 **
159	ICMB 04555	x	IPC 536	L x H	40.5	-18.40	45.5	-16.07	43.0	-17.18
160	ICMB 04555	x	IPC 689	L x H	33.7	-26.91	47.4	-18.03	40.6	-21.97 *
161	ICMB 04555	x	IPC 735	L x H	38.7	-45.12 **	41.2	-45.01 **	39.9	-45.06 **
162	ICMB 04555	x	IPC 811	L x L	34.1	-19.89	35.7	-25.44	34.9	-22.83 *
163	ICMB 04555	x	IPC 1254	L x L	33.6	-16.22	42.9	-16.33	38.3	-16.28
164	ICMB 04555	x	IPC 1268	L x L	27.0	-28.72	36.2	-17.67	31.6	-22.78 *
165	ICMB 04555	x	IPC 1642	L x M	37.2	-7.06	52.0	-6.66	44.6	-6.83
166	ICMB 04555	x	ICMR 356	L x M	30.4	-26.00	41.6	-29.37 **	36.0	-27.98 **
167	ICMB 04555	x	ICMR 06333	L x L	33.9	-19.86	49.5	3.04	41.7	-7.68
168	ICMB 04555	x	ICMR 06888	L x L	35.5	-16.79	43.0	-18.45	39.3	-17.71
169	ICMB 04888	x	IPC 338	M x M	35.4	-31.11 *	62.7	6.39	49.0	-11.08
170	ICMB 04888	x	IPC 404	M x L	39.8	-9.68	64.3	2.71	52.1	-2.40
171	ICMB 04888	x	IPC 536	M x H	35.3	-32.63 **	54.0	-15.39	44.6	-23.16 **
172	ICMB 04888	x	IPC 689	M x H	47.4	-2.73	73.0	8.13	60.2	3.58
173	ICMB 04888	x	IPC 735	M x H	52.1	-28.73 **	72.2	-14.65	62.1	-21.18 **
174	ICMB 04888	x	IPC 811	M x L	31.5	-30.39 *	49.5	-14.05	40.5	-21.24 *
175	ICMB 04888	x	IPC 1254	M x L	42.7	-0.23	61.5	0.99	52.1	0.48
176	ICMB 04888	x	IPC 1268	M x L	36.2	-10.59	41.9	-21.89	39.1	-17.03
177	ICMB 04888	x	IPC 1642	M x M	50.4	18.01	71.3	9.02	60.8	12.57
178	ICMB 04888	x	ICMR 356	M x M	39.6	-9.54	54.2	-20.84 *	46.9	-16.44 *
179	ICMB 04888	x	ICMR 06333	M x L	41.0	-8.77	51.4	-11.00	46.2	-10.03
180	ICMB 04888	x	ICMR 06888	M x L	36.2	-20.12	51.8	-16.91	44.0	-18.26 *
181	ICMB 04999	x	IPC 338	L x M	38.0	-16.06	56.7	17.39	47.3	1.21
182	ICMB 04999	x	IPC 404	L x L	40.8	7.47	50.9	-2.26	45.8	1.84
183	ICMB 04999	x	IPC 536	L x H	34.7	-24.84	55.6	4.42	45.2	-9.18
184	ICMB 04999	x	IPC 689	L x H	37.3	-12.65	63.0	10.56	50.1	0.62
185	ICMB 04999	x	IPC 735	L x H	44.9	-33.06 **	61.5	-16.78	53.2	-24.52 **
186	ICMB 04999	x	IPC 811	L x L	34.1	-12.72	46.1	-1.84	40.1	-6.78
187	ICMB 04999	x	IPC 1254	L x L	33.4	-8.90	53.5	6.31	43.4	-0.10
188	ICMB 04999	x	IPC 1268	L x L	38.1	10.92	38.5	-10.61	38.3	-1.06
189	ICMB 04999	x	IPC 1642	L x M	43.2	18.07	58.1	6.10	50.7	10.89
190	ICMB 04999	x	ICMR 356	L x M	35.7	-5.08	49.5	-14.44	42.6	-10.76
191	ICMB 04999	x	ICMR 06333	L x L	36.9	-5.05	48.1	2.02	42.5	-1.18
192	ICMB 04999	x	ICMR 06888	L x L	33.3	-15.17	49.1	-5.19	41.2	-9.49
	Mean				40.3	-20.94	55.2	-11.19	47.7	-15.90
	Minimum				25.2	-57.71	29.3	-46.19	30.1	-49.03
	Maximum				66.6	24.52	100.1	38.51	80.0	26.36
	S.E.					6.52		6.43		4.58

Correlation between MP value and hybrid performance : rainy 2009 = 0.59** ; summer 2010 = 0.58** ; pooled = 0.63**

* = Significant at P ≤0.05; ** = Significant at P ≤0.01; Note: - no BP heterosis observed

Table 16 b. ***Per se*** **performance and mid-parent (MP) heterosis for grain Zn concentration (mg kg^{-1}) in Line x tester (set-II) trial, rainy 2009 and summer 2010 and pooled analysis, Patancheru**

Sl. No.	F_1 Hybrid			Zn class	Rainy 2009		Summer 2010		Pooled	
	Line		Tester		F_1 mean	MP Heterosis	F_1 mean	MP Heterosis	F_1 mean	MP heterosis
1	841 B	x	IPC 338	M x L	44.4	-2.75	57.0	8.60	50.7	3.32
2	841 B	x	IPC 404	M x L	36.7	-17.05	60.1	2.93	48.4	-5.68
3	841 B	x	IPC 536	M x H	40.7	-11.25	64.8	4.88	52.8	-1.99
4	841 B	x	IPC 689	M x M	46.5	-1.72	59.6	0.46	53.1	-0.50
5	841 B	x	IPC 735	M x H	48.3	-19.84 **	58.1	-16.22 *	53.2	-17.90 **
6	841 B	x	IPC 811	M x L	32.2	-24.15 *	45.4	-9.15	38.8	-16.04 *
7	841 B	x	IPC 1254	M x L	38.5	-3.48	57.6	6.92	48.0	2.49
8	841 B	x	IPC 1268	M x L	41.8	-5.97	43.5	-22.24 *	42.7	-15.04 *
9	841 B	x	IPC 1642	M x L	47.4	7.40	65.5	19.49 *	56.4	14.10 *
10	841 B	x	ICMR 356	M x M	38.0	-13.55	56.1	-6.34	47.0	-9.39
11	841 B	x	ICMR 06333	M x L	42.0	-4.11	55.6	9.40	48.8	3.14
12	841 B	x	ICMR 06888	M x L	40.6	-6.18	52.8	-3.16	46.7	-4.50
13	843 B	x	IPC 338	M x L	35.5	-22.10 *	55.5	0.45	45.5	-9.75
14	843 B	x	IPC 404	M x L	36.0	-18.47	59.7	-2.41	47.9	-9.15
15	843 B	x	IPC 536	M x H	34.5	-24.88 **	55.5	-14.05	45.0	-18.55 **
16	843 B	x	IPC 689	M x M	37.3	-21.16 *	51.5	-17.12 *	44.4	-18.87 **
17	843 B	x	IPC 735	M x H	43.8	-27.15 **	57.9	-19.69 **	50.9	-23.08 **
18	843 B	x	IPC 811	M x L	33.9	-20.09 *	44.6	-15.55	39.2	-17.57 *
19	843 B	x	IPC 1254	M x L	40.2	0.91	48.2	-14.83	44.2	-8.32
20	843 B	x	IPC 1268	M x L	38.9	-12.50	45.5	-22.52 *	42.2	-18.21 **
21	843 B	x	IPC 1642	M x L	42.0	-4.76	54.2	-5.88	48.1	-5.40
22	843 B	x	ICMR 356	M x M	36.7	-16.37	56.5	-9.78	46.6	-12.50
23	843 B	x	ICMR 06333	M x L	39.6	-9.67	45.8	-14.47	42.7	-12.31
24	843 B	x	ICMR 06888	M x L	37.7	-12.90	50.3	-12.23	44.0	-12.52
25	863 B	x	IPC 338	H x L	35.3	-35.99 **	53.7	4.33	44.5	-16.52 **
26	863 B	x	IPC 404	H x L	56.2	4.66	60.1	4.77	58.2	4.71
27	863 B	x	IPC 536	H x H	45.4	-18.09 *	61.3	0.84	53.3	-8.18
28	863 B	x	IPC 689	H x M	39.9	-29.78 **	63.2	8.30	51.5	-10.49
29	863 B	x	IPC 735	H x H	54.9	-21.15 **	72.2	5.65	63.6	-7.88
30	863 B	x	IPC 811	H x L	42.2	-18.67 *	38.0	-22.43 *	40.1	-20.50 **
31	863 B	x	IPC 1254	H x L	35.0	-29.22 **	42.3	-19.85 *	38.6	-24.38 **
32	863 B	x	IPC 1268	H x L	37.0	-31.40 **	55.3	0.55	46.1	-15.27 *
33	863 B	x	IPC 1642	H x L	48.8	-8.84	51.6	-4.06	50.2	-6.45
34	863 B	x	ICMR 356	H x M	53.8	0.76	56.6	-3.78	55.2	-1.62
35	863 B	x	ICMR 06333	H x L	38.0	-28.79 **	54.0	8.41	46.0	-10.82
36	863 B	x	ICMR 06888	H x L	47.3	-10.38	56.6	5.91	51.9	-2.18
37	ICMB 88006	x	IPC 338	L x L	35.1	-20.54 *	41.8	6.48	38.4	-7.82
38	ICMB 88006	x	IPC 404	L x L	36.2	-15.16	62.3	37.80 **	49.3	12.07
39	ICMB 88006	x	IPC 536	L x H	34.3	-22.68 *	49.9	2.75	42.1	-9.38
40	ICMB 88006	x	IPC 689	L x M	38.3	-16.37	57.2	24.00 *	47.8	3.89
41	ICMB 88006	x	IPC 735	L x H	34.7	-40.84 **	49.4	-12.11	42.0	-26.79 **
42	ICMB 88006	x	IPC 811	L x L	32.0	-21.72 *	38.2	3.96	35.1	-9.56
43	ICMB 88006	x	IPC 1254	L x L	30.8	-19.87	44.2	8.71	37.5	-5.17
44	ICMB 88006	x	IPC 1268	L x L	36.3	-15.47	45.5	6.33	40.9	-4.59
45	ICMB 88006	x	IPC 1642	L x L	38.2	-10.25	55.9	34.23 **	47.0	11.74
46	ICMB 88006	x	ICMR 356	L x M	32.9	-22.35 *	45.6	-2.32	39.2	-11.85
47	ICMB 88006	x	ICMR 06333	L x L	35.4	-16.40	41.1	9.21	38.2	-4.35
48	ICMB 88006	x	ICMR 06888	L x L	36.3	-13.00	39.7	-3.79	38.0	-8.42

Sl. No.	F_1 Hybrid			Zn class	Rainy 2009		Summer 2010		Pooled	
	Line		Tester		F_1 mean	MP Heterosis	F_1 mean	MP Heterosis	F_1 mean	MP heterosis
49	ICMB 91222	X	IPC 338	M x L	43.0	-15.74	58.9	8.05	50.9	-3.46
50	ICMB 91222	X	IPC 404	M x L	45.5	-8.30	51.5	-14.81	48.5	-11.87
51	ICMB 91222	X	IPC 536	M x H	38.2	-25.58 **	57.9	-9.19	48.1	-16.50 **
52	ICMB 91222	X	IPC 689	M x M	45.0	-14.74	68.0	10.81	56.5	-1.00
53	ICMB 91222	X	IPC 735	M x H	52.6	-19.89 **	53.0	-25.70 **	52.8	-22.92 **
54	ICMB 91222	X	IPC 811	M x L	35.7	-25.24 **	45.6	-12.19	40.7	-18.44 **
55	ICMB 91222	X	IPC 1254	M x L	41.7	-7.90	57.5	2.99	49.6	-1.89
56	ICMB 91222	X	IPC 1268	M x L	40.5	-18.79 *	52.2	-10.03	46.3	-14.08 *
57	ICMB 91222	X	IPC 1642	M x L	42.1	-14.91	63.0	10.93	52.6	-1.10
58	ICMB 91222	X	ICMR 356	M x M	40.8	-17.36 *	56.9	-8.08	48.8	-12.20 *
59	ICMB 91222	X	ICMR 06333	M x L	37.5	-23.74 **	49.4	-6.46	43.5	-14.80 *
60	ICMB 91222	X	ICMR 06888	M x L	39.0	-19.76 *	49.3	-12.64	44.2	-15.93 *
61	ICMB 92111	X	IPC 338	L x L	28.7	-30.32 **	41.6	-9.67	35.1	-19.43 *
62	ICMB 92111	X	IPC 404	L x L	37.9	-4.74	43.7	-15.79	40.8	-11.00
63	ICMB 92111	X	IPC 536	L x H	32.3	-22.06 *	42.6	-22.92 *	37.5	-22.55 **
64	ICMB 92111	X	IPC 689	L x M	42.8	-0.23	54.7	3.40	48.8	1.77
65	ICMB 92111	X	IPC 735	L x H	40.2	-27.92 **	59.3	-5.77	49.7	-16.18 **
66	ICMB 92111	X	IPC 811	L x L	29.9	-21.30	31.9	-26.57 *	30.9	-24.11 **
67	ICMB 92111	X	IPC 1254	L x L	30.6	-13.87	39.9	-15.84	35.2	-14.99
68	ICMB 92111	X	IPC 1268	L x L	36.2	-9.63	42.8	-13.46	39.5	-11.75
69	ICMB 92111	X	IPC 1642	L x L	37.0	-6.71	50.4	4.24	43.7	-0.70
70	ICMB 92111	X	ICMR 356	L x M	36.3	-8.20	47.7	-10.63	42.0	-9.60
71	ICMB 92111	X	ICMR 06333	L x L	36.2	-8.20	36.7	-17.27	36.4	-13.00
72	ICMB 92111	X	ICMR 06888	L x L	37.3	-4.01	42.8	-10.91	40.0	-7.83
73	ICMB 95333	X	IPC 338	H x L	42.2	-14.78	55.2	-3.34	48.7	-8.65
74	ICMB 95333	X	IPC 404	H x L	53.9	12.23	58.6	-7.04	56.3	1.29
75	ICMB 95333	X	IPC 536	H x H	37.2	-25.19 **	51.0	-23.34 **	44.1	-24.13 **
76	ICMB 95333	X	IPC 689	H x M	46.5	-9.14	59.5	-7.14	53.0	-8.02
77	ICMB 95333	X	IPC 735	H x H	46.1	-28.05 **	46.4	-37.39 **	46.2	-33.05 **
78	ICMB 95333	X	IPC 811	H x L	30.7	-33.64 **	42.6	-21.98 *	36.7	-27.32 **
79	ICMB 95333	X	IPC 1254	H x L	39.9	-8.73	50.9	-12.93	45.4	-11.13
80	ICMB 95333	X	IPC 1268	H x L	41.5	-13.96	47.7	-21.30 *	44.6	-18.05 **
81	ICMB 95333	X	IPC 1642	H x L	47.2	-1.43	62.7	5.44	55.0	2.37
82	ICMB 95333	X	ICMR 356	H x M	38.9	-18.48 *	49.1	-23.95 **	44.0	-21.63 **
83	ICMB 95333	X	ICMR 06333	H x L	39.6	-16.97	47.4	-14.62	43.5	-15.71 *
84	ICMB 95333	X	ICMR 06888	H x L	34.5	-26.79 **	48.6	-17.77 *	41.6	-21.77 **
85	ICMB 96333	X	IPC 338	H x L	43.8	-27.93 **	51.4	-9.08	47.6	-18.85 **
86	ICMB 96333	X	IPC 404	H x L	39.3	-33.78 **	58.7	-6.04	49.0	-19.56 **
87	ICMB 96333	X	IPC 536	H x H	41.0	-32.90 **	55.0	-16.49 *	48.0	-24.38 **
88	ICMB 96333	X	IPC 689	H x M	50.0	-20.05 **	56.2	-11.38	53.1	-15.68 **
89	ICMB 96333	X	IPC 735	H x H	47.2	-37.32 **	63.6	-13.40	55.4	-25.51 **
90	ICMB 96333	X	IPC 811	H x L	35.3	-38.67 **	40.8	-24.58 **	38.0	-31.85 **
91	ICMB 96333	X	IPC 1254	H x L	42.6	-22.58 **	47.8	-17.50	45.2	-19.98 **
92	ICMB 96333	X	IPC 1268	H x L	41.4	-30.54 **	44.8	-25.44 **	43.1	-27.98 **
93	ICMB 96333	X	IPC 1642	H x L	41.5	-29.89 **	64.9	10.14	53.2	-9.93
94	ICMB 96333	X	ICMR 356	H x M	36.9	-37.57 **	40.8	-36.12 **	38.9	-36.82 **
95	ICMB 96333	X	ICMR 06333	H x L	42.1	-28.63 **	43.8	-20.11 *	43.0	-24.52 **
96	ICMB 96333	X	ICMR 06888	H x L	41.7	-28.52 **	43.3	-26.02 **	42.5	-27.27 **
97	ICMB 99444	X	IPC 338	H x L	41.7	-23.06 **	45.6	-11.91	43.6	-17.62 **
98	ICMB 99444	X	IPC 404	H x L	41.0	-22.33 **	59.0	2.35	50.0	-9.44

Sl. No.	F_1 Hybrid			Zn class	Rainy 2009		Summer 2010		Pooled	
	Line		Tester		F_1 mean	MP Heterosis	F_1 mean	MP Heterosis	F_1 mean	MP heterosis
99	ICMB 99444	x	IPC 536	H x H	43.3	-20.50 **	54.5	-10.81	48.9	-15.37 **
100	ICMB 99444	x	IPC 689	H x M	48.2	-13.77	53.2	-9.26	50.7	-11.46
101	ICMB 99444	x	IPC 735	H x H	47.8	-30.45 **	57.9	-15.58 *	52.8	-23.02 **
102	ICMB 99444	x	IPC 811	H x L	33.5	-34.14 **	44.6	-9.50	39.0	-22.02 **
103	ICMB 99444	x	IPC 1254	H x L	42.3	-12.51	54.5	2.59	48.4	-4.61
104	ICMB 99444	x	IPC 1268	H x L	39.3	-25.67 **	43.6	-20.97 *	41.5	-23.27 **
105	ICMB 99444	x	IPC 1642	H x L	46.2	-12.14	55.7	2.98	51.0	-4.48
106	ICMB 99444	x	ICMR 356	H x M	39.1	-25.39 **	52.1	-11.80	45.6	-18.19 **
107	ICMB 99444	x	ICMR 06333	H x L	42.4	-18.88 *	48.7	-2.67	45.6	-10.96
108	ICMB 99444	x	ICMR 06888	H x L	38.4	-25.81 **	46.1	-14.22	42.2	-19.90 **
109	ICMB 00999	x	IPC 338	M x L	43.6	-13.56	49.7	-8.52	46.7	-10.94
110	ICMB 00999	x	IPC 404	M x L	44.3	-9.57	57.3	-4.93	50.8	-7.01
111	ICMB 00999	x	IPC 536	M x H	40.9	-19.26 *	54.5	-14.52	47.7	-16.62 **
112	ICMB 00999	x	IPC 689	M x M	45.4	-12.95	56.9	-7.12	51.1	-9.80
113	ICMB 00999	x	IPC 735	M x H	40.0	-38.48 **	48.0	-32.68 **	44.0	-35.45 **
114	ICMB 00999	x	IPC 811	M x L	35.3	-25.24 **	53.3	2.80	44.3	-10.56
115	ICMB 00999	x	IPC 1254	M x L	41.6	-6.91	51.4	-7.78	46.5	-7.40
116	ICMB 00999	x	IPC 1268	M x L	37.0	-24.81 **	50.9	-12.07	43.9	-17.93 **
117	ICMB 00999	x	IPC 1642	M x L	41.4	-15.29	53.7	-5.28	47.6	-9.91
118	ICMB 00999	x	ICMR 356	M x M	35.1	-27.94 **	49.6	-19.73 *	42.3	-23.35 **
119	ICMB 00999	x	ICMR 06333	M x L	38.7	-20.31 *	47.1	-10.54	42.9	-15.23 *
120	ICMB 00999	x	ICMR 06888	M x L	43.1	-10.34	56.0	-0.65	49.5	-5.11
121	ICMB 02444	x	IPC 338	M x L	35.1	-26.97 **	51.4	-6.05	43.3	-15.83 **
122	ICMB 02444	x	IPC 404	M x L	43.4	-7.02	50.7	-16.41	47.0	-12.33
123	ICMB 02444	x	IPC 536	M x H	39.2	-18.87 *	51.3	-19.91 *	45.2	-19.46 **
124	ICMB 02444	x	IPC 689	M x M	44.7	-10.23	54.5	-11.53	49.6	-10.95
125	ICMB 02444	x	IPC 735	M x H	39.8	-36.44 **	60.5	-15.47 *	50.2	-25.25 **
126	ICMB 02444	x	IPC 811	M x L	33.8	-24.47 **	48.0	-8.02	40.9	-15.61 *
127	ICMB 02444	x	IPC 1254	M x L	43.9	3.81	49.2	-12.26	46.6	-5.35
128	ICMB 02444	x	IPC 1268	M x L	38.5	-17.72	46.6	-19.94 *	42.6	-18.95 **
129	ICMB 02444	x	IPC 1642	M x L	45.9	-1.32	61.1	7.03	53.5	3.28
130	ICMB 02444	x	ICMR 356	M x M	33.9	-26.90 **	51.0	-17.87 *	42.4	-21.73 **
131	ICMB 02444	x	ICMR 06333	M x L	35.9	-22.28 *	40.2	-24.15 *	38.1	-23.28 **
132	ICMB 02444	x	ICMR 06888	M x L	35.0	-23.27 *	54.1	-4.72	44.5	-12.99
133	ICMB 03111	x	IPC 338	L x L	41.5	-11.28	53.3	8.27	47.4	-1.25
134	ICMB 03111	x	IPC 404	L x L	36.7	-18.97 *	53.9	-2.40	45.3	-9.88
135	ICMB 03111	x	IPC 536	L x H	38.2	-18.70 *	50.0	-14.72	44.1	-16.49 *
136	ICMB 03111	x	IPC 689	L x M	50.6	4.41	56.5	0.70	53.6	2.42
137	ICMB 03111	x	IPC 735	L x H	36.9	-39.89 **	60.1	-9.05	48.5	-23.89 **
138	ICMB 03111	x	IPC 811	L x L	36.0	-17.16	47.2	0.99	41.6	-7.76
139	ICMB 03111	x	IPC 1254	L x L	40.9	-0.30	48.0	-5.08	44.5	-2.94
140	ICMB 03111	x	IPC 1268	L x L	35.5	-22.13 *	51.4	-2.63	43.4	-11.66
141	ICMB 03111	x	IPC 1642	L x L	44.7	-1.02	54.7	6.04	49.7	2.74
142	ICMB 03111	x	ICMR 356	L x M	39.9	-11.47	54.6	-3.58	47.2	-7.07
143	ICMB 03111	x	ICMR 06333	L x L	36.4	-18.95 *	46.6	-2.10	41.5	-10.28
144	ICMB 03111	x	ICMR 06888	L x L	36.8	-16.94	57.3	11.84	47.1	-1.51
145	ICMB 04222	x	IPC 338	L x L	41.4	-8.51	45.6	-9.93	43.5	-9.26
146	ICMB 04222	x	IPC 404	L x L	35.1	-19.90 *	48.2	-14.72	41.6	-16.98 *
147	ICMB 04222	x	IPC 536	L x H	40.1	-11.72	49.1	-18.08 *	44.6	-15.34 *
148	ICMB 04222	x	IPC 689	L x M	44.9	-4.29	58.3	1.34	51.6	-1.19

Sl. No.	F$_1$ Hybrid			Zn class	Rainy 2009		Summer 2010		Pooled	
	Line		Tester		F_1 mean	MP Heterosis	F_1 mean	MP Heterosis	F_1 mean	MP heterosis
149	ICMB 04222	x	IPC 735	L x H	37.3	-37.53 **	58.0	-14.14	47.6	-25.12 **
150	ICMB 04222	x	IPC 811	L x L	33.6	-19.85 *	45.1	-6.34	39.4	-12.63
151	ICMB 04222	x	IPC 1254	L x L	43.9	11.34	44.1	-15.22	44.0	-3.76
152	ICMB 04222	x	IPC 1268	L x L	38.4	-12.76	45.6	-15.75	42.0	-14.41 *
153	ICMB 04222	x	IPC 1642	L x L	37.1	-15.05	59.9	13.03	48.5	0.34
154	ICMB 04222	x	ICMR 356	L x M	39.8	-8.50	55.5	-4.33	47.6	-6.11
155	ICMB 04222	x	ICMR 06333	L x L	36.1	-16.80	43.6	-11.02	39.8	-13.74
156	ICMB 04222	x	ICMR 06888	L x L	32.5	-24.04 *	54.9	4.32	43.7	-8.40
157	ICMB 04555	x	IPC 338	L x L	34.6	-24.30 **	39.4	-13.85	37.0	-19.07 *
158	ICMB 04555	x	IPC 404	L x L	36.6	-17.37 *	42.6	-17.63	39.6	-17.51 *
159	ICMB 04555	x	IPC 536	L x H	37.8	-17.59	51.3	-6.82	44.6	-11.72
160	ICMB 04555	x	IPC 689	L x M	36.3	-23.30 **	48.5	-7.79	42.4	-15.14 *
161	ICMB 04555	x	IPC 735	L x H	43.4	-28.02 **	51.9	-17.13 *	47.6	-22.47 **
162	ICMB 04555	x	IPC 811	L x L	32.4	-23.72 *	40.8	-5.72	36.6	-14.63
163	ICMB 04555	x	IPC 1254	L x L	34.7	-13.21	50.2	6.53	42.4	-2.53
164	ICMB 04555	x	IPC 1268	L x L	34.7	-21.96 *	47.6	-3.38	41.1	-12.19
165	ICMB 04555	x	IPC 1642	L x L	37.1	-15.82	51.0	5.95	44.1	-4.47
166	ICMB 04555	x	ICMR 356	L x M	36.7	-16.57	45.2	-15.01	40.9	-15.72 *
167	ICMB 04555	x	ICMR 06333	L x L	33.5	-23.60 **	45.5	3.16	39.5	-10.19
168	ICMB 04555	x	ICMR 06888	L x L	36.3	-16.18	45.8	-4.11	41.0	-9.85
169	ICMB 04888	x	IPC 338	M x L	31.7	-32.65 **	53.3	-0.51	42.5	-15.55 *
170	ICMB 04888	x	IPC 404	M x L	44.8	-1.83	58.7	-1.20	51.8	-1.47
171	ICMB 04888	x	IPC 536	M x H	37.7	-20.40 *	51.0	-18.85 *	44.3	-19.52 **
172	ICMB 04888	x	IPC 689	M x M	47.4	-2.87	53.6	-11.24	50.5	-7.50
173	ICMB 04888	x	IPC 735	M x H	54.8	-11.07	60.7	-13.81 *	57.7	-12.53 *
174	ICMB 04888	x	IPC 811	M x L	31.6	-27.98 **	46.7	-8.57	39.1	-17.54 *
175	ICMB 04888	x	IPC 1254	M x L	42.8	3.45	54.2	-1.18	48.5	0.81
176	ICMB 04888	x	IPC 1268	M x L	39.0	-14.91	48.6	-14.77	43.8	-14.84 *
177	ICMB 04888	x	IPC 1642	M x L	46.0	0.99	62.1	11.06	54.0	6.54
178	ICMB 04888	x	ICMR 356	M x M	41.5	-8.49	49.2	-19.21 *	45.4	-14.64 *
179	ICMB 04888	x	ICMR 06333	M x L	43.8	-3.16	51.0	-1.64	47.4	-2.35
180	ICMB 04888	x	ICMR 06888	M x L	32.4	-27.39 **	51.3	-7.54	41.9	-16.39 *
181	ICMB 04999	x	IPC 338	L x L	34.5	-16.32	51.0	8.43	42.8	-3.14
182	ICMB 04999	x	IPC 404	L x L	37.5	-5.99	47.0	-11.29	42.2	-9.01
183	ICMB 04999	x	IPC 536	L x H	33.9	-18.36	56.4	0.20	45.2	-7.68
184	ICMB 04999	x	IPC 689	L x M	37.2	-13.42	58.0	7.68	47.6	-1.68
185	ICMB 04999	x	IPC 735	L x H	47.6	-14.82	51.0	-20.22 *	49.3	-17.70 **
186	ICMB 04999	x	IPC 811	L x L	30.5	-19.69	42.4	-4.63	36.5	-11.57
187	ICMB 04999	x	IPC 1254	L x L	32.0	-10.06	49.4	2.15	40.7	-3.03
188	ICMB 04999	x	IPC 1268	L x L	34.4	-14.04	39.4	-22.03 *	36.9	-18.50 **
189	ICMB 04999	x	IPC 1642	L x L	37.4	-5.90	51.4	4.15	44.4	-0.33
190	ICMB 04999	x	ICMR 356	L x M	33.2	-16.18	50.1	-7.81	41.6	-11.34
191	ICMB 04999	x	ICMR 06333	L x L	30.5	-22.62 *	41.4	-8.58	36.0	-15.11
192	ICMB 04999	x	ICMR 06888	L x L	32.8	-15.67	48.6	-0.74	40.7	-7.34
	Mean				39.5	-17.07	51.3	-6.90	45.4	-11.80
	Minimum				28.7	-40.84	31.9	-37.39	30.9	-36.82
	Maximum				56.2	12.23	72.2	37.80	63.6	14.10
	S.E.					4.25		5.33		3.41

Correlation between MP value and hybrid performance : rainy 2009 = 0.55** ; summer 2010 = 0.53** ; pooled = 0.61**

* = Significant at P ≤0.05; ** = Significant at P ≤0.01; Note: - no BP heterosis observed

Table16 c. *Per se* performance, mid-parent (MP) and better parent (BP) heterosis for 1000-grain mass (g) in line x tester (set-II) trial, rainy 2009 and summer 2010 and pooled analysis, Patancheru

Sl. No.	F_1 Hybrid			Rainy 2009			Summer 2010			Pooled		
	Line		Tester	F_1 mean	MP Heterosis	BP Heterosis	F_1 mean	MP Heterosis	BP Heterosis	F_1 mean	MP heterosis	BP heterosis
1	841 B	x	IPC 338	10.3	-5.97	-	10.1	-1.05	-	10.2	-3.59	-
2	841 B	x	IPC 404	10.8	0.14	-	10.8	-2.41	-	10.8	-1.15	-
3	841 B	x	IPC 536	8.2	20.32	0.61	8.4	11.02	-	8.3	15.43 *	-
4	841 B	x	IPC 689	11.2	-2.58	-	10.9	2.49	-	11.1	-0.15	-
5	841 B	x	IPC 735	10.4	35.38 **	26.42 *	10.3	20.43 *	18.36 *	10.3	27.48 **	22.26 **
6	841 B	x	IPC 811	8.0	-19.49 *	-	9.2	-3.36	-	8.6	-11.61 *	-
7	841 B	x	IPC 1254	8.9	29.88 *	8.60	8.9	20.26 *	1.84	8.9	24.89 **	5.12
8	841 B	x	IPC 1268	8.0	13.35	-	9.0	14.17	3.10	8.5	13.78	0.59
9	841 B	x	IPC 1642	11.6	10.55	-	11.0	14.79 *	5.26	11.3	12.58 *	-
10	841 B	x	ICMR 356	11.2	30.69 **	25.21 *	9.1	-7.47	-	10.2	10.26	1.83
11	841 B	x	ICMR 06333	12.1	11.34	-	10.7	1.72	-	11.4	6.62	-
12	841 B	x	ICMR 06888	8.6	11.22	5.25	8.4	7.30	-	8.5	9.25	0.74
13	843 B	x	IPC 338	11.9	-1.47	-	11.5	-1.59	-	11.7	-1.53	-
14	843 B	x	IPC 404	11.8	-0.82	-	11.7	-6.28	-	11.7	-3.62	-
15	843 B	x	IPC 536	10.0	26.13 *	-	10.9	21.42 **	-	10.5	23.63 **	-
16	843 B	x	IPC 689	11.3	-10.62	-	12.7	5.28	0.87	12.0	-2.85	-
17	843 B	x	IPC 735	11.7	34.10 **	13.02	11.9	18.82 **	2.73	11.8	25.95 **	7.60
18	843 B	x	IPC 811	9.0	-18.13 *	-	12.2	11.74	5.76	10.6	-3.28	-
19	843 B	x	IPC 1254	11.9	49.56 **	14.51	10.9	23.86 **	-	11.4	36.05 **	3.90
20	843 B	x	IPC 1268	10.9	33.21 **	4.92	9.9	6.87	-	10.4	19.20 **	-
21	843 B	x	IPC 1642	12.2	5.30	-	14.6	32.88 **	26.60 **	13.4	18.74 **	15.43 **
22	843 B	x	ICMR 356	8.9	-7.38	-	12.0	6.43	4.03	10.5	0.06	-
23	843 B	x	ICMR 06333	10.8	-9.87	-	10.9	-7.97	-	10.9	-8.92	-
24	843 B	x	ICMR 06888	8.5	-4.44	-	11.1	19.62 **	-	9.8	7.86	-
25	863 B	x	IPC 338	11.8	-25.75 **	-	10.8	-9.34	-	11.3	-18.73 **	-
26	863 B	x	IPC 404	14.8	-5.50	-	14.0	10.13	3.90	14.4	1.51	-
27	863 B	x	IPC 536	10.7	-9.11	-	10.7	16.53 *	-	10.7	2.17	-
28	863 B	x	IPC 689	13.0	-20.73 **	-	14.0	13.85 *	10.92	13.5	-5.92	-
29	863 B	x	IPC 735	13.8	10.45	-	13.1	29.08 **	10.00	13.5	18.80 **	-
30	863 B	x	IPC 811	11.6	-22.06 **	-	13.1	17.39 **	9.33	12.3	-5.15	-
31	863 B	x	IPC 1254	10.1	-14.06	-	11.0	22.29 **	-	10.5	1.73	-
32	863 B	x	IPC 1268	10.6	-11.13	-	12.2	28.31 **	1.88	11.4	6.32	-
33	863 B	x	IPC 1642	15.5	1.14	-	13.9	24.13 **	16.37 *	14.7	10.84 **	-
34	863 B	x	ICMR 356	11.8	-11.91	-	12.3	6.86	2.72	12.1	-3.26	-
35	863 B	x	ICMR 06333	15.0	-4.76	-	15.0	24.39 **	22.87 **	15.0	7.90 *	0.60
36	863 B	x	ICMR 06888	10.8	-14.70 *	-	12.0	26.53 **	0.13	11.4	2.96	-
37	ICMB 88006	x	IPC 338	12.2	-16.76 **	-	10.8	7.68	-	11.5	-6.86	-
38	ICMB 88006	x	IPC 404	12.7	-12.02 *	-	12.8	18.39 **	-	12.8	1.00	-
39	ICMB 88006	x	IPC 536	12.7	20.17 *	-	12.0	63.02 **	45.89 **	12.3	37.76 **	3.59
40	ICMB 88006	x	IPC 689	14.0	-8.36	-	13.0	25.19 **	3.37	13.5	5.26	-
41	ICMB 88006	x	IPC 735	12.9	13.90	-	12.2	46.27 **	44.44 **	12.5	27.58 **	5.42
42	ICMB 88006	x	IPC 811	10.0	-26.89 **	-	12.5	34.95 **	21.20 **	11.2	-1.90	-
43	ICMB 88006	x	IPC 1254	13.9	31.69 **	-	12.7	78.53 **	55.03 **	13.3	50.57 **	11.85 *
44	ICMB 88006	x	IPC 1268	11.8	9.79	-	10.3	35.59 **	25.84 *	11.1	20.47 **	-
45	ICMB 88006	x	IPC 1642	16.6	17.15 **	6.51	14.1	50.90 **	34.69 **	15.3	30.55 **	28.94 **
46	ICMB 88006	x	ICMR 356	12.9	5.22	-	11.8	22.96 **	7.26	12.4	13.02 **	3.93
47	ICMB 88006	x	ICMR 06333	15.8	8.19	1.25	14.3	39.85 **	16.78 **	15.0	21.24 **	16.45 **
48	ICMB 88006	x	ICMR 06888	11.9	3.84	-	12.5	64.33 **	51.86 **	12.2	27.94 **	2.35
49	ICMB 91222	x	IPC 338	12.8	28.28 **	-	11.4	12.15	-	12.1	20.13 **	-

Sl. No.	F_1 Hybrid			Rainy 2009			Summer 2010			Pooled		
	Line		Tester	F_1 mean	MP Heterosis	BP Heterosis	F_1 mean	MP Heterosis	BP Heterosis	F_1 mean	MP heterosis	BP heterosis
50	ICMB 91222	x	IPC 404	12.5	27.41 **	-	11.5	4.39	-	12.0	15.20 **	-
51	ICMB 91222	x	IPC 536	10.7	83.03 **	72.65 **	10.0	31.81 **	15.34	10.3	54.18 **	39.31 **
52	ICMB 91222	x	IPC 689	12.4	17.39 *	-	10.7	0.68	-	11.5	9.00	-
53	ICMB 91222	x	IPC 735	11.6	73.36 **	62.45 **	11.2	31.46 **	29.75 **	11.4	49.84 **	46.60 **
54	ICMB 91222	x	IPC 811	11.4	27.33 **	-	11.0	16.07 *	6.70	11.2	21.55 **	1.77
55	ICMB 91222	x	IPC 1254	11.9	102.39 **	90.91 **	10.4	41.37 **	20.14 *	11.1	68.46 **	49.75 **
56	ICMB 91222	x	IPC 1268	10.9	78.16 **	74.58 **	9.6	21.99 *	10.59	10.2	46.56 **	37.36 **
57	ICMB 91222	x	IPC 1642	14.1	49.02 **	10.82	12.7	32.84 **	21.34 **	13.4	40.91 **	15.56 **
58	ICMB 91222	x	ICMR 356	11.4	50.00 **	27.11 *	11.2	14.34 *	2.00	11.3	29.87 **	13.25 *
59	ICMB 91222	x	ICMR 06333	14.3	44.75 **	5.48	12.7	22.05 **	4.08	13.5	33.10 **	4.82
60	ICMB 91222	x	ICMR 06888	10.7	58.17 **	46.27 **	9.5	22.05 *	10.19	10.1	38.83 **	36.12 **
61	ICMB 92111	x	IPC 338	9.9	-6.74	-	10.3	2.28	-	10.1	-2.35	-
62	ICMB 92111	x	IPC 404	9.2	-11.51	-	11.7	7.05	-	10.5	-2.02	-
63	ICMB 92111	x	IPC 536	8.6	32.39 *	14.69	9.1	22.21 *	8.35	8.9	26.96 **	11.35
64	ICMB 92111	x	IPC 689	9.8	-12.82	-	10.7	2.41	-	10.2	-5.46	-
65	ICMB 92111	x	IPC 735	9.6	31.37 **	27.79 *	10.8	28.37 **	28.10 **	10.2	29.77 **	28.24 **
66	ICMB 92111	x	IPC 811	10.0	4.34	-	8.0	-14.80	-	9.0	-5.09	-
67	ICMB 92111	x	IPC 1254	11.4	74.83 **	51.46 **	10.3	42.67 **	22.79 *	10.8	57.93 **	36.35 **
68	ICMB 92111	x	IPC 1268	11.6	71.82 **	54.06 **	9.4	22.62 *	12.71	10.5	45.59 **	32.26 **
69	ICMB 92111	x	IPC 1642	12.3	21.23 *	-	11.8	25.76 **	13.30	12.1	23.41 **	3.99
70	ICMB 92111	x	ICMR 356	9.0	9.38	0.67	9.3	-4.43	-	9.1	1.91	-
71	ICMB 92111	x	ICMR 06333	10.9	3.48	-	11.4	10.11	-	11.1	6.76	-
72	ICMB 92111	x	ICMR 06888	6.3	-15.00	-	8.1	6.00	-	7.2	-4.33	-
73	ICMB 95333	x	IPC 338	11.7	1.01	-	10.4	5.20	-	11.1	2.93	-
74	ICMB 95333	x	IPC 404	14.1	23.41 **	5.35	13.0	20.94 **	-	13.5	22.21 **	0.73
75	ICMB 95333	x	IPC 536	10.5	40.48 **	11.15	9.6	32.82 **	20.58 *	10.0	36.72 **	15.46 *
76	ICMB 95333	x	IPC 689	14.1	16.20 *	-	10.4	1.12	-	12.3	9.30	-
77	ICMB 95333	x	IPC 735	11.2	35.12 **	18.34	11.3	38.69 **	34.82 **	11.3	36.90 **	29.50 **
78	ICMB 95333	x	IPC 811	11.5	8.76	-	10.8	18.30 *	4.75	11.2	13.18 *	1.32
79	ICMB 95333	x	IPC 1254	11.8	57.31 **	24.47 *	9.1	30.59 **	14.98	10.5	44.41 **	20.14 **
80	ICMB 95333	x	IPC 1268	10.2	32.71 **	8.19	8.6	15.50	8.81	9.4	24.23 **	8.47
81	ICMB 95333	x	IPC 1642	15.6	40.27 **	22.15 **	12.5	35.53 **	19.28 *	14.0	38.12 **	20.86 **
82	ICMB 95333	x	ICMR 356	9.6	3.99	1.16	10.0	5.14	-	9.8	4.58	-
83	ICMB 95333	x	ICMR 06333	13.2	14.30	-	11.3	11.94	-	12.2	13.19 **	-
84	ICMB 95333	x	ICMR 06888	8.1	-3.13	-	9.5	27.21 **	19.32 *	8.8	11.14	1.15
85	ICMB 96333	x	IPC 338	12.6	10.79	-	11.9	-0.35	-	12.3	5.08	-
86	ICMB 96333	x	IPC 404	11.5	2.99	-	13.0	1.62	-	12.3	2.26	-
87	ICMB 96333	x	IPC 536	10.0	37.85 **	10.96	10.1	8.55	-	10.1	21.38 **	-
88	ICMB 96333	x	IPC 689	12.8	6.84	-	11.3	-8.88	-	12.0	-1.16	-
89	ICMB 96333	x	IPC 735	12.7	57.45 **	40.68 **	12.5	20.87 **	2.17	12.6	36.94 **	18.57 **
90	ICMB 96333	x	IPC 811	11.1	6.80	-	10.7	-5.02	-	10.9	0.65	-
91	ICMB 96333	x	IPC 1254	11.9	63.77 **	31.82 **	11.7	28.58 **	-	11.8	44.19 **	11.36
92	ICMB 96333	x	IPC 1268	9.3	24.40 *	3.27	8.6	-10.05	-	9.0	5.06	-
93	ICMB 96333	x	IPC 1642	13.0	19.69 *	2.23	13.7	21.10 **	12.47	13.4	20.40 **	15.26 **
94	ICMB 96333	x	ICMR 356	10.8	19.58 *	18.98	10.6	-8.51	-	10.7	3.75	0.68
95	ICMB 96333	x	ICMR 06333	11.4	1.19	-	10.9	-10.72	-	11.2	-4.99	-
96	ICMB 96333	x	ICMR 06888	9.5	15.84	4.81	10.5	9.64	-	10.0	12.49 *	-
97	ICMB 99444	x	IPC 338	10.8	-15.58 *	-	10.7	2.08	-	10.7	-7.63	-
98	ICMB 99444	x	IPC 404	12.5	-0.42	-	10.9	-3.08	-	11.7	-1.68	-
99	ICMB 99444	x	IPC 536	10.1	17.09	-	10.5	34.25 **	14.95	10.3	25.23 **	-
100	ICMB 99444	x	IPC 689	12.3	-7.40	-	10.9	0.88	-	11.6	-3.69	-

Sl. No.	F_1 Hybrid			Rainy 2009			Summer 2010			Pooled		
	Line		Tester	F_1 mean	MP Heterosis	BP Heterosis	F_1 mean	MP Heterosis	BP Heterosis	F_1 mean	MP heterosis	BP heterosis
101	ICMB 99444	x	IPC 735	15.2	60.92 **	29.15 **	10.2	16.05	11.71	12.7	39.32 **	21.54 **
102	ICMB 99444	x	IPC 811	12.8	8.84	8.68	9.2	-5.15	-	11.0	2.51	-
103	ICMB 99444	x	IPC 1254	11.2	29.66 **	-	11.3	49.08 **	24.08 **	11.2	38.73 **	7.82
104	ICMB 99444	x	IPC 1268	8.2	-7.31	-	8.8	9.12	-	8.5	0.52	-
105	ICMB 99444	x	IPC 1642	13.9	13.08	8.62	12.5	27.50 **	19.23 **	13.2	19.48 **	13.40 *
106	ICMB 99444	x	ICMR 356	9.2	-11.23	-	8.9	-11.66	-	9.0	-11.44 *	-
107	ICMB 99444	x	ICMR 06333	12.4	-2.23	-	10.5	-1.27	-	11.5	-1.79	-
108	ICMB 99444	x	ICMR 06888	9.2	-4.01	-	8.9	10.68	-	9.0	2.71	-
109	ICMB 00999	x	IPC 338	10.1	-9.78	-	9.9	0.36	-	10.0	-5.02	-
110	ICMB 00999	x	IPC 404	10.0	-8.35	-	12.2	14.39 *	-	11.1	2.89	-
111	ICMB 00999	x	IPC 536	8.7	23.60 *	1.70	8.7	20.12	9.14	8.7	21.84 **	5.28
112	ICMB 00999	x	IPC 689	10.7	-8.57	-	9.7	-5.63	-	10.2	-7.19	-
113	ICMB 00999	x	IPC 735	10.2	30.90 **	19.98	10.3	26.28 **	22.64 *	10.3	28.54 **	24.87 **
114	ICMB 00999	x	IPC 811	13.1	29.78 **	12.16	8.8	-3.15	-	11.0	14.17 *	-
115	ICMB 00999	x	IPC 1254	9.9	40.62 **	15.70	8.7	25.08 *	10.21	9.3	32.87 **	13.06
116	ICMB 00999	x	IPC 1268	12.8	76.97 **	50.32 **	7.9	5.12	-	10.3	40.48 **	25.66 **
117	ICMB 00999	x	IPC 1642	13.7	28.51 **	7.25	11.0	19.75 **	5.31	12.3	24.45 **	6.38
118	ICMB 00999	x	ICMR 356	10.1	15.56	12.91	9.1	-4.38	-	9.6	5.19	-
119	ICMB 00999	x	ICMR 06333	12.3	10.94	-	10.2	1.41	-	11.3	6.40	-
120	ICMB 00999	x	ICMR 06888	8.2	4.04	-	8.7	16.19	9.08	8.4	9.92	2.61
121	ICMB 02444	x	IPC 338	11.2	-3.23	-	11.3	5.70	-	11.3	1.05	-
122	ICMB 02444	x	IPC 404	14.1	23.67 **	5.46	11.9	3.29	-	13.0	13.42 **	-
123	ICMB 02444	x	IPC 536	9.7	30.01 **	2.97	9.3	15.47	-	9.5	22.47 **	-
124	ICMB 02444	x	IPC 689	12.7	4.55	-	12.5	12.22	-	12.6	8.21	-
125	ICMB 02444	x	IPC 735	12.3	49.05 **	30.68 **	11.6	28.69 **	20.63 *	12.0	38.43 **	25.61 **
126	ICMB 02444	x	IPC 811	13.2	24.49 **	12.38	11.5	15.43 *	11.60	12.3	20.10 **	12.01 *
127	ICMB 02444	x	IPC 1254	10.9	45.73 **	15.42	11.6	48.04 **	20.53 *	11.2	46.91 **	18.00 **
128	ICMB 02444	x	IPC 1268	9.5	23.31 *	0.64	9.3	12.05	-	9.4	17.46 *	-
129	ICMB 02444	x	IPC 1642	15.1	36.05 **	18.35 *	12.0	19.63 **	14.88 *	13.6	28.25 **	16.79 **
130	ICMB 02444	x	ICMR 356	10.2	10.66	7.79	11.9	15.50 *	8.17	11.0	13.22 *	10.64
131	ICMB 02444	x	ICMR 06333	13.6	18.29 *	0.22	13.1	19.55 **	6.74	13.3	18.90 **	3.31
132	ICMB 02444	x	ICMR 06888	8.7	3.82	-	9.3	12.30	-	9.0	8.04	-
133	ICMB 03111	x	IPC 338	11.6	-1.42	-	11.0	3.12	-	11.3	0.74	-
134	ICMB 03111	x	IPC 404	10.5	-9.69	-	11.3	-2.07	-	10.9	-5.89	-
135	ICMB 03111	x	IPC 536	9.6	25.02 *	-	9.9	23.79 **	4.05	9.7	24.39 **	0.80
136	ICMB 03111	x	IPC 689	12.5	1.05	-	10.6	-4.21	-	11.5	-1.43	-
137	ICMB 03111	x	IPC 735	9.5	12.06	-	9.9	10.32	3.94	9.7	11.17	0.26
138	ICMB 03111	x	IPC 811	9.6	-10.48	-	10.1	2.17	-	9.9	-4.42	-
139	ICMB 03111	x	IPC 1254	11.5	50.36 **	17.45	11.2	43.38 **	17.24 *	11.3	46.84 **	17.34 **
140	ICMB 03111	x	IPC 1268	8.6	8.72	-	9.5	14.87	-	9.0	11.87	-
141	ICMB 03111	x	IPC 1642	12.5	10.62	-	12.2	22.41 **	16.94 *	12.3	16.16 **	6.42
142	ICMB 03111	x	ICMR 356	8.9	-5.36	-	9.8	-4.80	-	9.3	-5.07	-
143	ICMB 03111	x	ICMR 06333	11.1	-5.02	-	11.0	1.01	-	11.0	-2.12	-
144	ICMB 03111	x	ICMR 06888	8.4	-2.07	-	10.0	21.76 *	5.41	9.2	9.62	-
145	ICMB 04222	x	IPC 338	12.4	4.28	-	12.0	1.05	-	12.2	2.67	-
146	ICMB 04222	x	IPC 404	12.4	5.42	-	13.6	6.43	0.82	13.0	5.94	-
147	ICMB 04222	x	IPC 536	9.3	20.01	-	11.4	22.83 **	-	10.4	21.54 **	-
148	ICMB 04222	x	IPC 689	13.0	4.27	-	12.7	3.14	0.91	12.9	3.71	-
149	ICMB 04222	x	IPC 735	13.0	51.59 **	29.39 **	11.6	13.22	-	12.3	30.72 **	11.26
150	ICMB 04222	x	IPC 811	12.8	17.91 *	9.56	11.5	2.89	-	12.2	10.30 *	10.09
151	ICMB 04222	x	IPC 1254	12.1	56.06 **	20.79 *	12.4	37.11 **	2.95	12.3	45.87 **	11.06

Sl. No.	FF_1 Hybrid			Rainy 2009			Summer 2010			Pooled		
	Line		Tester	F_1 mean	MP Heterosis	BP Heterosis	F_1 mean	MP Heterosis	BP Heterosis	F_1 mean	MP heterosis	BP heterosis
152	ICMB 04222	x	IPC 1268	10.0	24.34 *	-	9.7	1.55	-	9.8	11.95	-
153	ICMB 04222	x	IPC 1642	14.0	23.15 **	10.11	15.5	37.96 **	28.80 **	14.8	30.50 **	27.41 **
154	ICMB 04222	x	ICMR 356	8.4	-11.79	-	12.1	4.85	0.37	10.2	-2.66	-
155	ICMB 04222	x	ICMR 06333	13.6	14.93 *	-	13.6	12.04 *	11.15	13.6	13.47 **	5.28
156	ICMB 04222	x	ICMR 06888	9.0	3.57	-	10.5	10.94	-	9.8	7.42	-
157	ICMB 04555	x	IPC 338	11.0	-11.96	-	10.0	-10.29	-	10.5	-11.17 *	-
158	ICMB 04555	x	IPC 404	12.1	-1.69	-	14.0	16.70 **	3.75	13.0	7.39	-
159	ICMB 04555	x	IPC 536	7.8	-6.28	-	9.3	9.61	-	8.6	1.72	-
160	ICMB 04555	x	IPC 689	12.7	-2.30	-	11.6	0.93	-	12.2	-0.78	-
161	ICMB 04555	x	IPC 735	10.8	17.80	-	11.3	20.08 **	8.25	11.1	18.96 **	2.08
162	ICMB 04555	x	IPC 811	10.5	-8.58	-	11.2	7.63	6.73	10.8	-0.87	-
163	ICMB 04555	x	IPC 1254	12.4	48.59 **	10.85	11.7	41.30 **	11.40	12.0	44.97 **	11.12
164	ICMB 04555	x	IPC 1268	9.1	6.15	-	8.9	1.11	-	9.0	3.61	-
165	ICMB 04555	x	IPC 1642	16.9	40.76 **	32.18 **	14.1	35.16 **	34.97 **	15.5	38.15 **	33.61 **
166	ICMB 04555	x	ICMR 356	10.4	3.40	-	11.5	6.60	3.99	10.9	5.05	0.90
167	ICMB 04555	x	ICMR 06333	12.0	-3.05	-	11.7	3.32	-	11.9	0.00	-
168	ICMB 04555	x	ICMR 06888	9.5	2.84	-	10.4	19.44 *	-	10.0	10.89	-
169	ICMB 04888	x	IPC 338	12.5	7.31	-	12.6	8.78	6.84	12.5	8.05	-
170	ICMB 04888	x	IPC 404	15.8	38.64 **	18.43 *	14.0	12.77 *	3.90	14.9	25.17 **	11.14 *
171	ICMB 04888	x	IPC 536	11.2	49.75 **	18.42	11.6	30.17 **	2.25	11.4	39.11 **	9.60
172	ICMB 04888	x	IPC 689	14.9	22.13 **	-	12.8	7.08	1.79	13.8	14.66 **	0.82
173	ICMB 04888	x	IPC 735	11.8	42.12 **	24.38 *	11.2	13.64	-	11.5	26.63 **	10.52
174	ICMB 04888	x	IPC 811	13.9	31.05 **	18.52 *	12.1	11.94	6.78	13.0	21.39 **	18.10 **
175	ICMB 04888	x	IPC 1254	12.2	62.96 **	28.87 **	11.5	32.45 **	1.50	11.9	46.57 **	13.95 *
176	ICMB 04888	x	IPC 1268	10.2	31.87 **	7.44	10.0	8.79	-	10.1	19.33 **	-
177	ICMB 04888	x	IPC 1642	18.0	62.21 **	41.36 **	16.4	50.87 **	44.89 **	17.2	56.60 **	48.57 **
178	ICMB 04888	x	ICMR 356	13.1	42.29 **	38.31 **	12.2	8.63	7.05	12.6	23.83 **	21.27 **
179	ICMB 04888	x	ICMR 06333	12.8	11.23	-	12.6	6.76	2.86	12.7	8.97	-
180	ICMB 04888	x	ICMR 06888	10.8	28.05 **	13.46	12.5	35.99 **	9.69	11.6	32.19 **	11.40
181	ICMB 04999	x	IPC 338	9.4	-18.14 *	-	9.9	-6.26	-	9.6	-12.44 *	-
182	ICMB 04999	x	IPC 404	12.0	6.61	-	11.9	4.26	-	11.9	5.43	-
183	ICMB 04999	x	IPC 536	8.7	18.63	-	8.9	12.36	-	8.8	15.37 *	-
184	ICMB 04999	x	IPC 689	10.2	-14.86 *	-	10.9	-0.43	-	10.5	-7.97	-
185	ICMB 04999	x	IPC 735	10.0	23.70 *	10.23	10.7	20.52 *	14.78	10.3	22.04 **	12.53
186	ICMB 04999	x	IPC 811	9.2	-11.94	-	9.0	-7.98	-	9.1	-10.02	-
187	ICMB 04999	x	IPC 1254	10.2	40.34 **	12.71	10.3	34.51 **	10.97	10.3	37.35 **	11.83
188	ICMB 04999	x	IPC 1268	8.4	11.06	-	9.0	10.02	-	8.7	10.52	-
189	ICMB 04999	x	IPC 1642	15.5	42.18 **	21.76 **	13.5	36.61 **	29.09 **	14.5	39.54 **	25.06 **
190	ICMB 04999	x	ICMR 356	11.3	25.42 **	24.42 *	10.6	4.68	-	11.0	14.43 *	9.92
191	ICMB 04999	x	ICMR 06333	8.3	-27.14 **	-	11.4	5.69	-	9.8	-11.15 *	-
192	ICMB 04999	x	ICMR 06888	9.9	20.82 *	9.02	9.71	19.43 *	4.41	9.8	20.13 **	6.69
	Mean			11.4	15.78	19.83	11.1	14.84	13.54	11.2	14.71	14.13
	Minimum			6.3	-27.14	0.22	7.9	-14.80	0.13	7.2	-18.73	0.26
	Maximum			18.0	102.39	90.91	16.4	78.53	55.03	17.2	68.46	49.75
	S.E.				0.84	0.96		0.70	0.78		0.56	0.65

Correlation between MP value and hybrid performance : rainy 2009 = 0.51** ; summer 2010 = 0.58** ; pooled = 0.61**

* = Significant at P ≤0.05; ** = Significant at P ≤0.01; Note: - no BP heterosis observed

Table 16d. ***Per se*** **performance, mid-parent (MP) and better parent (BP) heterosis for days to 50% flower in line x tester (set-II) trial, rainy 2009 and summer 2010 and pooled analysis, Patancheru**

Sl. No.	F_1 Hybrid			Rainy 2009			Summer 2010			Pooled		
	Line		Tester	F1 mean	MP Heterosis	BP Heterosis	F1 mean	MP Heterosis	BP Heterosis	F1 mean	MP heterosis	BP heterosis
1	841 B	x	IPC 338	49	-6.67 **	-7.55 **	49	-4.39	-7.55 **	49	-5.54 **	-6.67 **
2	841 B	x	IPC 404	47	-7.46 **	-10.58 **	47	-4.08	-11.32 **	47	-5.79 **	-10.95 **
3	841 B	x	IPC 536	48	-7.77 **	-8.65 **	48	-12.04 **	-13.64 **	48	-9.95 **	-10.38 **
4	841 B	x	IPC 689	47	-5.53 **	-9.62 **	53	4.48	-0.94	50	-0.50	-5.24 **
5	841 B	x	IPC 735	51	-6.48 **	-9.82 **	50	-12.00 **	-16.81 **	50	-9.30 **	-13.42 **
6	841 B	x	IPC 811	50	-2.46	-4.81 **	48	-6.34 **	-9.43 **	49	-4.41 **	-7.14 **
7	841 B	x	IPC 1254	49	-10.09 **	-14.04 **	49	-10.50 **	-13.27 **	49	-10.30 **	-13.66 **
8	841 B	x	IPC 1268	51	-6.05 **	-9.01 **	50	-8.33 **	-10.00 **	50	-7.19 **	-9.50 **
9	841 B	x	IPC 1642	46	-11.96 **	-12.38 **	47	-14.29 **	-16.22 **	46	-13.15 **	-14.35 **
10	841 B	x	ICMR 356	47	-7.92 **	-10.58 **	47	-12.26 **	-12.26 **	47	-10.14 **	-11.43 **
11	841 B	x	ICMR 06333	47	-11.74 **	-13.76 **	49	-7.62 **	-8.49 **	48	-9.69 **	-10.33 **
12	841 B	x	ICMR 06888	44	-13.30 **	-15.38 **	44	-14.29 **	-17.92 **	44	-13.79 **	-16.67 **
13	843 B	x	IPC 338	44	-8.81 **	-16.98 **	47	-2.62	-6.06 *	45	-5.73 **	-11.71 **
14	843 B	x	IPC 404	45	-2.17	-7.22 **	45	-1.10	-2.17	45	-1.64	-3.74 *
15	843 B	x	IPC 536	41	-14.29 **	-20.59 **	46	-8.91 **	-16.36 **	43	-11.51 **	-18.40 **
16	843 B	x	IPC 689	44	-3.30 *	-7.37 **	48	1.60	-	46	-0.81	-3.68 *
17	843 B	x	IPC 735	49	-2.51	-13.39 **	50	-5.21 *	-15.97 **	49	-3.90 **	-14.72 **
18	843 B	x	IPC 811	45	-3.23 *	-9.09 **	46	-4.71	-8.08 **	45	-3.98 **	-8.59 **
19	843 B	x	IPC 1254	46	-9.45 **	-20.18 **	47	-8.29 **	-16.81 **	46	-8.87 **	-18.50 **
20	843 B	x	IPC 1268	46	-8.08 **	-18.02 **	48	-5.94 *	-13.64 **	47	-7.00 **	-15.84 **
21	843 B	x	IPC 1642	43	-10.42 **	-18.10 **	44	-13.30 **	-20.72 **	44	-11.90 **	-19.44 **
22	843 B	x	ICMR 356	44	-4.86 **	-10.20 **	46	-8.08 **	-14.15 **	45	-6.53 **	-12.25 **
23	843 B	x	ICMR 06333	45	-9.18 **	-18.35 **	48	-3.06	-8.65 **	46	-6.12 **	-13.62 **
24	843 B	x	ICMR 06888	39	-17.20 **	-22.22 **	43	-10.05 **	-12.37 **	41	-13.60 **	-17.35 **
25	863 B	x	IPC 338	49	-4.85 **	-7.55 **	49	1.55	-1.01	49	-1.75	-4.39 **
26	863 B	x	IPC 404	48	-3.55 *	-5.00 **	46	0.00	-2.13	47	-1.84	-3.61 *
27	863 B	x	IPC 536	45	-11.88 **	-12.75 **	47	-8.82 **	-15.45 **	46	-10.34 **	-14.15 **
28	863 B	x	IPC 689	49	0.51	-2.00	48	1.59	-	49	1.04	-
29	863 B	x	IPC 735	49	-7.55 **	-12.50 **	48	-10.80 **	-20.17 **	48	-9.18 **	-16.45 **
30	863 B	x	IPC 811	49	-1.51	-2.00	47	-2.59	-5.05	48	-2.04	-3.03
31	863 B	x	IPC 1254	52	-2.80 *	-8.77 **	49	-6.28 **	-14.16 **	50	-4.51 **	-11.45 **
32	863 B	x	IPC 1268	53	-0.47	-5.41 **	48	-5.88 *	-12.73 **	50	-3.13 *	-9.05 **
33	863 B	x	IPC 1642	46	-10.24 **	-12.38 **	45	-12.20 **	-18.92 **	46	-11.22 **	-15.74 **
34	863 B	x	ICMR 356	46	-7.07 **	-8.00 **	45	-10.00 **	-15.09 **	46	-8.54 **	-10.78 **
35	863 B	x	ICMR 06333	48	-8.13 **	-11.93 **	47	-5.05 *	-9.62 **	48	-6.63 **	-10.80 **
36	863 B	x	ICMR 06888	47	-5.53 **	-6.00 **	45	-6.81 **	-8.25 **	46	-6.15 **	-6.63 **
37	ICMB 88006	x	IPC 338	50	-7.48 **	-8.33 **	54	4.35	-	52	-1.66	-4.17 **
38	ICMB 88006	x	IPC 404	48	-7.32 **	-12.04 **	49	-2.02	-10.19 **	48	-4.71 **	-11.11 **
39	ICMB 88006	x	IPC 536	46	-13.33 **	-15.74 **	50	-8.26 **	-9.09 **	48	-10.75 **	-11.57 **
40	ICMB 88006	x	IPC 689	48	-6.40 **	-12.04 **	52	1.48	-4.63	50	-2.46	-8.33 **
41	ICMB 88006	x	IPC 735	51	-7.27 **	-8.93 **	55	-3.96	-8.40 **	53	-5.59 **	-8.66 **
42	ICMB 88006	x	IPC 811	49	-5.31 **	-9.26 **	50	-4.35	-8.33 **	49	-4.83 **	-8.80 **
43	ICMB 88006	x	IPC 1254	49	-11.71 **	-14.04 **	51	-7.69 **	-9.73 **	50	-9.71 **	-11.89 **
44	ICMB 88006	x	IPC 1268	50	-8.68 **	-9.91 **	53	-2.75	-3.64	52	-5.72 **	-6.79 **
45	ICMB 88006	x	IPC 1642	46	-14.55 **	-15.74 **	49	-11.42 **	-12.61 **	47	-12.96 **	-12.96 **
46	ICMB 88006	x	ICMR 356	47	-9.71 **	-13.89 **	50	-7.48 **	-8.33 **	48	-8.57 **	-11.11 **
47	ICMB 88006	x	ICMR 06333	48	-12.44 **	-12.84 **	52	-2.83	-4.63	50	-7.69 **	-8.33 **
48	ICMB 88006	x	ICMR 06888	46	-12.08 **	-15.74 **	48	-6.34 **	-11.11 **	47	-9.22 **	-13.43 **
49	ICMB 91222	x	IPC 338	48	-6.80 **	-9.43 **	52	0.48	-3.70	50	-3.15 *	-3.85 *
50	ICMB 91222	x	IPC 404	48	-3.55 *	-5.00 **	47	-6.06 *	-13.89 **	47	-4.81 **	-9.62 *

Sl. No.	F₁ Hybrid			Rainy 2009			Summer 2010			Pooled		
	Line		Tester	F1 mean	MP Heterosis	BP Heterosis	F1 mean	MP Heterosis	BP Heterosis	F1 mean	MP heterosis	BP heterosis
51	ICMB 91222	x	IPC 536	44	-12.87 **	-13.73 **	46	-15.60 **	-16.36 **	45	-14.29 **	-15.09 **
52	ICMB 91222	x	IPC 689	48	-1.54	-4.00 **	49	-3.45	-9.26 **	49	-2.51	-6.73 **
53	ICMB 91222	x	IPC 735	48	-9.43 **	-14.29 **	52	-9.25 **	-13.45 **	50	-9.34 **	-13.85 **
54	ICMB 91222	x	IPC 811	48	-4.52 **	-5.00 **	49	-6.28 **	-10.19 **	48	-5.42 **	-7.69 **
55	ICMB 91222	x	IPC 1254	50	-6.54 **	-12.28 **	52	-5.88 **	-7.96 **	51	-6.21 **	-10.13 **
56	ICMB 91222	x	IPC 1268	48	-9.00 **	-13.51 **	49	-10.09 **	-10.91 **	49	-9.56 **	-12.22 **
57	ICMB 91222	x	IPC 1642	43	-16.10 **	-18.10 **	50	-9.59 **	-10.81 **	46	-12.74 **	-14.35 **
58	ICMB 91222	x	ICMR 356	46	-7.07 **	-8.00 **	48	-10.28 **	-11.11 **	47	-8.74 **	-9.62 **
59	ICMB 91222	x	ICMR 06333	48	-8.13 **	-11.93 **	50	-5.66 *	-7.41 **	49	-6.89 **	-7.98 **
60	ICMB 91222	x	ICMR 06888	45	-9.55 **	-10.00 **	47	-8.29 **	-12.96 **	46	-8.91 **	-11.54 **
61	ICMB 92111	x	IPC 338	51	-5.16 **	-5.61 **	53	1.45	-2.78	52	-1.90	-4.19 **
62	ICMB 92111	x	IPC 404	49	-4.90 **	-9.35 **	49	-1.01	-9.26 **	49	-2.99 *	-9.30 **
63	ICMB 92111	x	IPC 536	47	-11.00 **	-13.08 **	49	-11.01 **	-11.82 **	48	-11.01 **	-11.63 **
64	ICMB 92111	x	IPC 689	48	-4.95 **	-10.28 **	52	2.46	-3.70	50	-1.23	-6.98 **
65	ICMB 92111	x	IPC 735	51	-6.85 **	-8.93 **	55	-3.96	-8.40 **	53	-5.38 **	-8.66 **
66	ICMB 92111	x	IPC 811	50	-3.88 **	-7.48 **	49	-5.31 *	-9.26 **	49	-4.60 **	-8.37 **
67	ICMB 92111	x	IPC 1254	49	-11.31 **	-14.04 **	52	-6.79 **	-8.85 **	50	-9.05 **	-11.45 **
68	ICMB 92111	x	IPC 1268	47	-13.76 **	-15.32 **	50	-9.17 **	-10.00 **	48	-11.47 **	-12.67 **
69	ICMB 92111	x	IPC 1642	47	-11.32 **	-12.15 **	48	-13.24 **	-14.41 **	47	-12.30 **	-12.50 **
70	ICMB 92111	x	ICMR 356	49	-5.37 **	-9.35 **	51	-4.67 *	-5.56 *	50	-5.01 **	-7.44 **
71	ICMB 92111	x	ICMR 06333	49	-9.26 **	-10.09 **	50	-5.66 *	-7.41 **	50	-7.48 **	-7.91 **
72	ICMB 92111	x	ICMR 06888	46	-11.65 **	-14.95 **	49	-4.39	-9.26 **	47	-8.03 **	-12.09 **
73	ICMB 95333	x	IPC 338	50	-8.33 **	-10.00 **	53	-2.75	-10.92 **	51	-5.53 **	-10.48 **
74	ICMB 95333	x	IPC 404	50	-3.38 *	-9.09 **	49	-7.18 **	-18.49 **	49	-5.29 **	-13.97 **
75	ICMB 95333	x	IPC 536	46	-14.15 **	-17.27 **	50	-13.54 **	-16.81 **	48	-13.83 **	-17.03 **
76	ICMB 95333	x	IPC 689	49	-4.39 **	-10.91 **	54	0.00	-10.08 **	51	-2.15	-10.48 **
77	ICMB 95333	x	IPC 735	50	-9.91 **	-10.71 **	55	-7.56 **	-7.56 **	53	-8.70 **	-9.09 **
78	ICMB 95333	x	IPC 811	50	-5.26 **	-10.00 **	50	-9.17 **	-16.81 **	50	-7.26 **	-13.54 **
79	ICMB 95333	x	IPC 1254	55	-1.79	-3.51 *	57	-2.59	-5.04 *	56	-2.19	-2.62
80	ICMB 95333	x	IPC 1268	49	-11.31 **	-11.71 **	51	-10.92 **	-14.29 **	50	-11.11 **	-12.66 **
81	ICMB 95333	x	IPC 1642	46	-14.42 **	-16.36 **	48	-16.52 **	-19.33 **	47	-15.51 **	-17.90 **
82	ICMB 95333	x	ICMR 356	46	-11.54 **	-16.36 **	52	-8.44 **	-13.45 **	49	-9.93 **	-14.85 **
83	ICMB 95333	x	ICMR 06333	49	-10.50 **	-10.91 **	54	-3.14	-9.24 **	52	-6.79 **	-10.04 **
84	ICMB 95333	x	ICMR 06888	48	-9.09 **	-13.64 **	51	-5.56 *	-14.29 **	49	-7.29 **	-13.97 **
85	ICMB 96333	x	IPC 338	46	-9.36 **	-13.21 **	50	-2.91	-6.54 *	48	-6.11 **	-6.34 **
86	ICMB 96333	x	IPC 404	46	-5.15 **	-5.15 **	48	-2.54	-10.28 **	47	-3.84 **	-7.84 **
87	ICMB 96333	x	IPC 536	43	-14.57 **	-16.67 **	49	-10.60 **	-11.82 **	46	-12.50 **	-14.15 **
88	ICMB 96333	x	IPC 689	47	-3.13 *	-4.12 **	50	-0.99	-6.54 *	48	-2.03	-5.39 **
89	ICMB 96333	x	IPC 735	50	-4.31 **	-10.71 **	54	-4.42 *	-9.24 **	52	-4.37 **	-9.96 **
90	ICMB 96333	x	IPC 811	48	-3.06 *	-4.04 *	47	-9.71 **	-13.08 **	47	-6.47 **	-7.84 **
91	ICMB 96333	x	IPC 1254	49	-8.06 **	-14.91 **	51	-8.18 **	-10.62 **	50	-8.12 **	-12.78 **
92	ICMB 96333	x	IPC 1268	49	-5.77 **	-11.71 **	48	-11.52 **	-12.73 **	49	-8.71 **	-12.22 **
93	ICMB 96333	x	IPC 1642	45	-11.88 **	-15.24 **	47	-14.68 **	-16.22 **	46	-13.33 **	-15.74 **
94	ICMB 96333	x	ICMR 356	45	-8.72 **	-9.18 **	49	-8.92 **	-9.35 **	47	-8.82 **	-8.82 **
95	ICMB 96333	x	ICMR 06333	48	-6.80 **	-11.93 **	49	-7.11 **	-8.41 **	49	-6.95 **	-8.92 **
96	ICMB 96333	x	ICMR 06888	45	-9.18 **	-10.10 **	47	-7.84 **	-12.15 **	46	-8.50 **	-10.29 **
97	ICMB 99444	x	IPC 338	49	-7.62 **	-8.49 **	54	1.89	-4.42	51	-2.84 *	-5.53 **
98	ICMB 99444	x	IPC 404	46	-8.46 **	-11.54 **	49	-4.43	-14.16 **	47	-6.44 **	-12.90 **
99	ICMB 99444	x	IPC 536	46	-11.65 **	-12.50 **	49	-13.00 **	-14.16 **	47	-12.35 **	-13.36 **
100	ICMB 99444	x	IPC 689	49	-1.51	-5.77 **	55	4.81 *	-3.54	52	1.72	-4.61 **
101	ICMB 99444	x	IPC 735	46	-14.81 **	-17.86 **	52	-10.34 **	-12.61 **	49	-12.50 **	-15.15 **
102	ICMB 99444	x	IPC 811	50	-2.46	-4.81 **	52	-2.83	-8.85 **	51	-2.65 *	-6.91 **

Sl. No.	F_1 Hybrid			Rainy 2009			Summer 2010			Pooled		
	Line		Tester	F1 mean	MP Heterosis	BP Heterosis	F1 mean	MP Heterosis	BP Heterosis	F1 mean	MP heterosis	BP heterosis
103	ICMB 99444	x	IPC 1254	48	-12.84 **	-16.67 **	50	-11.50 **	-11.50 **	49	-12.16 **	-14.10 **
104	ICMB 99444	x	IPC 1268	49	-9.77 **	-12.61 **	53	-4.93 *	-6.19 *	51	-7.31 **	-8.14 **
105	ICMB 99444	x	IPC 1642	46	-12.92 **	-13.33 **	48	-15.18 **	-15.93 **	47	-14.09 **	-14.29 **
106	ICMB 99444	x	ICMR 356	48	-4.95 **	-7.69 **	50	-9.59 **	-12.39 **	49	-7.36 **	-10.14 **
107	ICMB 99444	x	ICMR 06333	49	-7.98 **	-10.09 **	54	-1.38	-5.31 *	51	-4.65 **	-5.53 **
108	ICMB 99444	x	ICMR 06888	46	-9.36 **	-11.54 **	51	-3.81	-10.62 **	48	-6.54 **	-11.06 **
109	ICMB 00999	x	IPC 338	51	-7.34 **	-9.82 **	50	-5.71 *	-10.81 **	50	-6.54 **	-10.31 **
110	ICMB 00999	x	IPC 404	50	-4.31 **	-10.71 **	48	-4.48	-13.51 **	49	-4.39 **	-12.11 **
111	ICMB 00999	x	IPC 536	47	-12.15 **	-16.07 **	50	-9.50 **	-9.91 **	49	-10.80 **	-13.00 **
112	ICMB 00999	x	IPC 689	50	-3.38 *	-10.71 **	55	5.83 *	-1.80	52	1.21	-6.28 **
113	ICMB 00999	x	IPC 735	54	-3.57 **	-3.57 *	53	-8.70 **	-11.76 **	53	-6.17 **	-7.79 **
114	ICMB 00999	x	IPC 811	51	-3.32 *	-8.93 **	51	-2.86	-8.11 **	51	-3.09 *	-8.52 **
115	ICMB 00999	x	IPC 1254	52	-8.85 **	-9.65 **	50	-10.71 **	-11.50 **	51	-9.78 **	-10.57 **
116	ICMB 00999	x	IPC 1268	52	-6.73 **	-7.14 **	51	-8.60 **	-9.01 **	51	-7.66 **	-8.07 **
117	ICMB 00999	x	IPC 1642	48	-11.52 **	-14.29 **	46	-18.02 **	-18.02 **	47	-14.81 **	-16.14 **
118	ICMB 00999	x	ICMR 356	48	-8.57 **	-14.29 **	49	-10.60 **	-12.61 **	48	-9.60 **	-13.45 **
119	ICMB 00999	x	ICMR 06333	51	-7.69 **	-8.93 **	49	-8.84 **	-11.71 **	50	-8.26 **	-10.31 **
120	ICMB 00999	x	ICMR 06888	45	-14.69 **	-19.64 **	46	-12.50 **	-18.02 **	45	-13.60 **	-18.83 **
121	ICMB 02444	x	IPC 338	46	-11.54 **	-13.21 **	48	-6.34 **	-9.43 **	47	-8.96 **	-9.62 **
122	ICMB 02444	x	IPC 404	47	-5.53 **	-7.84 **	47	-5.10 *	-12.26 **	47	-5.32 **	-10.10 **
123	ICMB 02444	x	IPC 536	43	-15.69 **	-15.69 **	48	-12.04 **	-13.64 **	45	-13.81 **	-14.62 **
124	ICMB 02444	x	IPC 689	47	-4.57 **	-7.84 **	50	-1.49	-6.60 *	48	-3.02 *	-7.21 **
125	ICMB 02444	x	IPC 735	50	-6.54 **	-10.71 **	50	-11.11 **	-15.97 **	50	-8.88 **	-13.42 **
126	ICMB 02444	x	IPC 811	50	-1.49	-2.94	46	-10.24 **	-13.21 **	48	-5.91 **	-8.17 **
127	ICMB 02444	x	IPC 1254	50	-7.41 **	-12.28 **	50	-9.59 **	-12.39 **	50	-8.51 **	-12.33 **
128	ICMB 02444	x	IPC 1268	50	-7.04 **	-10.81 **	47	-13.89 **	-15.45 **	48	-10.49 **	-13.12 **
129	ICMB 02444	x	IPC 1642	46	-12.08 **	-13.33 **	46	-15.21 **	-17.12 **	46	-13.68 **	-15.28 **
130	ICMB 02444	x	ICMR 356	45	-10.00 **	-11.76 **	46	-14.15 **	-14.15 **	45	-12.14 **	-12.98 **
131	ICMB 02444	x	ICMR 06333	48	-9.95 **	-12.84 **	47	-10.48 **	-11.32 **	47	-10.21 **	-11.27 **
132	ICMB 02444	x	ICMR 06888	44	-12.44 **	-13.73 **	46	-9.36 **	-13.21 **	45	-10.89 **	-13.46 **
133	ICMB 03111	x	IPC 338	46	-5.64 **	-13.21 **	50	1.52	-	48	-2.04	-6.34 **
134	ICMB 03111	x	IPC 404	46	-1.08	-5.15 **	47	0.00	-4.08	47	-0.53	-0.53
135	ICMB 03111	x	IPC 536	44	-8.90 **	-14.71 **	47	-10.58 **	-15.45 **	45	-9.77 **	-15.09 **
136	ICMB 03111	x	IPC 689	45	-2.17	-5.26 **	49	0.52	-1.02	47	-0.80	-1.58
137	ICMB 03111	x	IPC 735	46	-8.46 **	-17.86 **	52	-5.07 *	-13.45 **	49	-6.70 **	-15.58 **
138	ICMB 03111	x	IPC 811	46	-2.13	-7.07 **	47	-5.58 *	-6.06 *	46	-3.90 **	-6.57 **
139	ICMB 03111	x	IPC 1254	46	-10.34 **	-20.18 **	49	-8.06 **	-14.16 **	47	-9.18 **	-17.18 **
140	ICMB 03111	x	IPC 1268	46	-8.00 **	-17.12 **	48	-8.65 **	-13.64 **	47	-8.33 **	-15.38 **
141	ICMB 03111	x	IPC 1642	43	-11.34 **	-18.10 **	46	-11.96 **	-17.12 **	45	-11.66 **	-17.59 **
142	ICMB 03111	x	ICMR 356	45	-4.81 **	-9.18 **	46	-10.78 **	-14.15 **	45	-7.93 **	-11.76 **
143	ICMB 03111	x	ICMR 06333	46	-8.08 **	-16.51 **	47	-7.92 **	-10.58 **	46	-8.00 **	-13.62 **
144	ICMB 03111	x	ICMR 06888	42	-10.64 **	-15.15 **	45	-8.72 **	-9.18 **	43	-9.66 **	-11.73 **
145	ICMB 04222	x	IPC 338	46	-9.45 **	-14.15 **	46	-2.65	-7.07 *	46	-6.15 **	-10.73 **
146	ICMB 04222	x	IPC 404	45	-7.29 **	-8.25 **	47	3.33	-	46	-2.15	-2.67
147	ICMB 04222	x	IPC 536	42	-14.72 **	-17.65 **	47	-7.00 **	-15.45 **	44	-10.83 **	-16.51 **
148	ICMB 04222	x	IPC 689	46	-3.16 *	-3.16	47	1.62	-1.05	47	-0.80	-2.11
149	ICMB 04222	x	IPC 735	47	-10.14 **	-16.96 **	50	-5.26 *	-16.81 **	48	-7.69 **	-16.88 **
150	ICMB 04222	x	IPC 811	47	-4.12 **	-6.06 **	46	-3.70	-8.08 **	46	-3.92 **	-7.07 **
151	ICMB 04222	x	IPC 1254	47	-11.00 **	-18.42 **	47	-7.39 **	-16.81 **	47	-9.22 **	-17.62 **
152	ICMB 04222	x	IPC 1268	46	-10.68 **	-17.12 **	49	-3.00	-11.82 **	47	-6.90 **	-14.48 **
153	ICMB 04222	x	IPC 1642	43	-15.00 **	-19.05 **	44	-13.43 **	-21.62 **	43	-14.21 **	-20.37 **
154	ICMB 04222	x	ICMR 356	43	-11.92 **	-13.27 **	45	-9.18 **	-16.04 **	44	-10.54 **	-14.71 **

Sl. No.	F_1 Hybrid			Rainy 2009			Summer 2010			Pooled		
	Line		Tester	F1 mean	MP Heterosis	BP Heterosis	F1 mean	MP Heterosis	BP Heterosis	F1 mean	MP heterosis	BP heterosis
155	ICMB 04222	x	ICMR 06333	46	-10.78 **	-16.51 **	46	-5.15 *	-11.54 **	46	-8.04 **	-14.08 **
156	ICMB 04222	x	ICMR 06888	43	-11.34 **	-13.13 **	45	-3.74	-7.22 *	44	-7.61 **	-10.20 **
157	ICMB 04555	x	IPC 338	49	-10.60 **	-12.61 **	55	5.77 *	-	52	-2.59 *	-5.91 **
158	ICMB 04555	x	IPC 404	47	-10.58 **	-16.22 **	46	-7.54 *	-15.60 **	46	-9.09 **	-15.91 **
159	ICMB 04555	x	IPC 536	45	-15.49 **	-18.92 **	49	-10.50 **	-10.91 **	47	-12.96 **	-14.55 **
160	ICMB 04555	x	IPC 689	48	-6.80 **	-13.51 **	52	1.96	-4.59	50	-2.44	-9.09 **
161	ICMB 04555	x	IPC 735	50	-10.31 **	-10.71 **	53	-7.02 **	-10.92 **	52	-8.65 **	-10.82 **
162	ICMB 04555	x	IPC 811	50	-4.76 **	-9.91 **	47	-9.62 **	-13.76 **	49	-7.18 **	-11.82 **
163	ICMB 04555	x	IPC 1254	49	-12.89 **	-14.04 **	50	-9.91 **	-11.50 **	50	-11.41 **	-12.78 **
164	ICMB 04555	x	IPC 1268	49	-12.61 **	-12.61 **	50	-9.59 **	-10.00 **	49	-11.11 **	-11.31 **
165	ICMB 04555	x	IPC 1642	47	-12.96 **	-15.32 **	47	-14.55 **	-15.32 **	47	-13.76 **	-14.55 **
166	ICMB 04555	x	ICMR 356	47	-10.05 **	-15.32 **	49	-9.77 **	-11.01 **	48	-9.91 **	-13.18 **
167	ICMB 04555	x	ICMR 06333	49	-10.91 **	-11.71 **	49	-7.98 **	-10.09 **	49	-9.47 **	-10.91 **
168	ICMB 04555	x	ICMR 06888	47	-10.48 **	-15.32 **	47	-8.74 **	-13.76 **	47	-9.62 **	-14.55 **
169	ICMB 04888	x	IPC 338	48	-7.25 **	-9.43 **	50	-3.41	-6.60 *	49	-5.34 **	-5.80 **
170	ICMB 04888	x	IPC 404	50	0.00	-1.98	47	-4.08	-11.32 **	48	-2.03	-6.76 **
171	ICMB 04888	x	IPC 536	44	-14.29 **	-14.71 **	48	-12.04 **	-13.64 **	46	-13.13 **	-14.15 **
172	ICMB 04888	x	IPC 689	49	0.00	-2.97	49	-3.48	-8.49 **	49	-1.76	-5.80 **
173	ICMB 04888	x	IPC 735	50	-6.10 **	-10.71 **	54	-4.89 *	-10.08 **	52	-5.48 **	-10.39 **
174	ICMB 04888	x	IPC 811	50	0.00	-0.99	49	-5.37 *	-8.49 **	49	-2.72 *	-4.83 **
175	ICMB 04888	x	IPC 1254	50	-6.98 **	-12.28 **	50	-9.59 **	-12.39 **	50	-8.29 **	-12.33 **
176	ICMB 04888	x	IPC 1268	52	-2.83 *	-7.21 **	49	-9.26 **	-10.91 **	50	-6.07 **	-9.05 **
177	ICMB 04888	x	IPC 1642	48	-6.80 **	-8.57 **	47	-13.36 **	-15.32 **	48	-10.17 **	-12.04 **
178	ICMB 04888	x	ICMR 356	46	-7.54 **	-8.91 **	46	-13.21 **	-13.21 **	46	-10.46 **	-11.11 **
179	ICMB 04888	x	ICMR 06333	47	-11.43 **	-14.68 **	48	-8.57 **	-9.43 **	47	-10.00 **	-11.27 **
180	ICMB 04888	x	ICMR 06888	44	-13.00 **	-13.86 **	46	-10.34 **	-14.15 **	45	-11.66 **	-14.01 **
181	ICMB 04999	x	IPC 338	49	-2.97 *	-7.55 **	50	2.06	-	49	-0.51	-3.90 *
182	ICMB 04999	x	IPC 404	50	3.63 *	-	48	2.70	-	49	3.17 *	-
183	ICMB 04999	x	IPC 536	46	-8.08 **	-10.78 **	49	-4.39	-10.91 **	47	-6.20 **	-10.85 **
184	ICMB 04999	x	IPC 689	50	3.66 *	-	50	4.21	-	50	3.94 **	-
185	ICMB 04999	x	IPC 735	50	-4.81 **	-11.61 **	53	-1.87	-11.76 **	51	-3.32 *	-11.69 **
186	ICMB 04999	x	IPC 811	51	4.62 **	-	49	1.03	-1.01	50	2.83 *	-
187	ICMB 04999	x	IPC 1254	50	-4.76 **	-12.28 **	49	-6.73 **	-14.16 **	49	-5.74 **	-13.22 **
188	ICMB 04999	x	IPC 1268	48	-8.21 **	-14.41 **	48	-7.32 **	-13.64 **	48	-7.77 **	-14.03 **
189	ICMB 04999	x	IPC 1642	46	-8.46 **	-12.38 **	46	-11.65 **	-18.02 **	46	-10.07 **	-15.28 **
190	ICMB 04999	x	ICMR 356	46	-5.15 **	-6.12 **	48	-5.47 *	-10.38 **	47	-5.32 **	-8.33 **
191	ICMB 04999	x	ICMR 06333	49	-4.39 **	-10.09 **	49	-2.51	-6.73 *	49	-3.47 *	-8.45 **
192	ICMB 04999	x	ICMR 06888	45	-8.72 **	-10.10 **	45	-6.25 *	-7.22 *	45	-7.49 **	-8.67 **
	Mean			47	-7.86	-11.45	49	-6.52	-11.02	48	-7.20	-10.90
	Minimum			39	-17.20	-22.22	43	-18.02	-21.62	41	-15.51	-20.37
	Maximum			55	4.62	-0.99	57	5.83	-0.94	56	3.94	-0.53
	S.E.				0.76	0.90		1.21	1.44		0.68	0.79

Correlation between MP value and hybrid performance : rainy 2009 =0.62** ; summer 2010 =0.54** ; pooled =0.60**

* = Significant at P ≤0.05; ** = Significant at P ≤0.01

Table 17. Analysis of variance for grain Fe and Zn concentration, days to 50% flower and 1000-grain mass in S_1 and half-sib progeny trial (AIMP 9290 ICMR 312) during rainy 2009 and summer 2010, Patancheru

Population	Source of variation	df	Mean square													
			Fe (mg kg^{-1})				Zn (mg kg^{-1})				1000-grain mass (g)				Days to 5	
			Rainy 2009		Summer 2010		Rainy 2009		Summer 2010		Rainy 2009		Summer 2010		Rainy 2009	
AIMP 92901	Replications	1	51.2		149.3		77.9		8.6		2.1		1.8		0.2	
	Gentypes	119	129.5	**	305.3	**	86.0	**	133.4	**	4.8	**	4.4	**	12.0	*
	S_1 progenies (S_1)	59	169.2	**	465.1	**	118.4	**	207.6	**	5.0	**	4.7	**	13.0	*
	Half-sib progenies (HS)	59	84.8	**	99.8		54.1	**	51.6		4.0	**	2.3	**	6.2	*
	S_1 vs HS	1	421.1	**	3005.5	**	58.9		580.0	**	45.3	**	112.9	**	294.8	*
	Error	119	47.0		79.1		29.9		44.7		1.1		0.5		0.9	
	C.D (5%)		13.6		17.6		10.8		13.2		2.1		1.4		1.9	
	CV (%)		15.4		14.4		12.4		11.9		9.0		6.1		2.1	
	σ^2_g		41.2		113.1		28.0		44.3		1.9		2.0		5.6	
	σ^2_p		64.7		152.7		43.0		66.7		2.4		2.2		6.0	
	h^2BS (%)		64		74		65		66		77		88		93	
ICMR 312	Replications	1	105.4		241.4		8.8		152.8		0.3		0.2		0.7	
	Gentypes	119	140.5	**	284.0	**	106.1	**	83.6	**	5.9	**	3.7	**	8.1	*
	S_1 progenies (S_1)	59	153.4	**	386.0	**	89.0	**	114.3	**	6.7	**	4.5	**	9.8	*
	Half-sib progenies (HS)	59	116.3	**	137.9	*	119.2	**	42.7		4.1	**	1.5	**	5.1	*
	S_1 vs HS	1	803.4	**	2881.5	**	340.3	**	680.7	**	62.4	**	78.5	**	82.8	*
	Error	119	41.7		84.1		29.9		32.6		1.3		0.7		0.9	
	C.D (5%)		12.8		18.2		10.8		11.3		2.2		1.7		1.9	
	CV (%)		15.4		13.6		13.8		10.4		9.0		6.9		2.0	
	σ^2_g		49.4		100.0		38.1		25.5		2.3		1.5		3.6	
	σ^2_p		70.3		142.0		53.1		41.8		3.0		1.8		4.1	
	h^2BS (%)		70		70		72		61		79		81		89	

* = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$.

Table 18. Pooled analysis of variance for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in S_1 and half-sib progeny trial (AIMP 92901 and ICMR 312) during rainy 2009 and summer 2010, Patancheru

Source of variation	df	Mean square							
		Fe (mg kg^{-1})		Zn (mg kg^{-1})		1000-grain mass (g)		Days to 50% flower	
		AIMP 92901	ICMR 312	AIMP 92901	ICMR 312	AIMP 92901	ICMR 312	AIMP 92901	ICMR 312
Environments (E)	1	35383.9	76197.2	18258.3	28330.0	0.6	16.4	49.4	15.4
Replications / E	2	100.3	148.4	43.2	150.8	1.9	0.2	1.7	0.8
Genotypes (G)	119	314.1 **	284.5 **	152.2 **	127.0 **	6.7 **	6.6 **	15.7 **	11.6 **
S_1 progenies (S_1)	59	452.8 **	364.1 **	233.8 **	148.4 **	6.8 **	7.3 **	15.7 **	13.1 **
Half-sib progenies (HS)	59	132.7 **	152.7 **	64.7 **	90.9 **	4.0 **	3.7 **	8.4 **	7.2 **
S_1 vs HS	1	2838.2 **	3363.9 **	504.3 **	991.9 **	150.7 **	140.4 **	444.7 **	185.0 **
G x E	119	120.7 **	140.0 **	67.1 **	62.7 **	2.6 **	3.0 **	3.6 **	3.1 **
S_1 x E	59	181.5 **	175.3 **	92.1 **	55.0 **	2.9 **	4.0 **	4.7 **	3.4 **
HS x E	59	51.9	101.6 **	41.0	71.1 **	2.2 **	1.9 **	2.5 **	2.9 **
S_1 vs HS x E	1	588.3 **	321.0 *	134.6	29.2	7.6 **	0.5	10.2 **	0.5
Error	238	63.0	62.9	37.3	31.3	0.8	1.0	0.9	0.8
C.D (5%)		11.1	11.1	8.5	7.8	1.3	1.4	1.3	1.2
CV (%)		14.9	14.5	12.2	11.8	7.7	8.0	2.1	1.9
σ^2_g		62.8	55.4	28.7	23.9	1.5	1.4	3.7	2.7
σ^2_p		78.5	71.1	38.1	31.7	1.7	1.7	3.9	2.9
σ^2_{ge}		28.8	38.5	14.9	15.7	0.9	1.0	1.4	1.2
$\sigma^2_{ge} / \sigma^2_g$		0.5	0.7	0.5	0.7	0.6	0.7	0.4	0.4
h^2BS (%)		80	78	75	75	88	85	94	93

* = Significant at P ≤0.05; ** = Significant at P ≤0.01.

Table 19. Estimates of progeny (S_1 and half-sib) variances and genetic components of variances for grain Fe and Zn, 1000-grain mass and days to 50% flower in two populations (AIMP 92901 and ICMR 312) in rainy 2009, summer 2010 and pooled analysis, Patancheru

Population	Variance component	Fe (mg kg^{-1})			Zn (mg kg^{-1})			1000-grain mass (g)			Days to 50% flower		
		Rainy 2009	Summer 2010	Pooled	Rainy 2009	Summer 2010	Pooled	Rainy 2009	Summer 2010	Pooled	Rainy 2009	Summer 2010	Pooled
AIMP 92901	σ^2_{S1}	61.12	193.02	97.45	44.23	81.40	49.11	1.95	2.10	1.51	6.04	3.27	3.70
	σ^2_{HS}	18.87	10.39	17.41	12.09	3.44	6.85	1.43	0.88	0.80	2.67	1.91	1.89
	σ^2_A	75.50	41.56	69.66	48.36	13.75	27.41	5.71	3.54	3.21	10.67	7.64	7.57
	σ^2_D	-57.51	605.84	111.16	-16.53	270.63	86.81	-15.06	-5.73	-6.81	-18.52	-17.47	-15.48
	σ^2_D/σ^2_A	-0.76	14.58	1.60	-0.34	19.68	3.17	-2.64	-1.62	-2.12	-1.74	-2.29	-2.05
ICMR 312	σ^2_{S1}	55.88	150.96	75.31	29.57	40.86	29.28	2.73	1.92	1.57	4.46	3.02	3.09
	σ^2_{HS}	37.31	26.94	22.45	44.66	5.06	14.91	1.43	0.39	0.67	2.11	2.14	1.60
	σ^2_A	149.25	107.74	89.81	178.65	20.26	59.63	5.72	1.55	2.68	8.45	8.57	6.39
	σ^2_D	-373.51	172.89	-57.98	-596.35	82.40	-121.39	-11.96	1.47	-4.47	-15.99	-22.22	-13.21
	σ^2_D/σ^2_A	-2.50	1.60	-0.65	-3.34	4.07	-2.04	-2.09	0.95	-1.67	-1.89	-2.59	-2.07

σ^2_{S1} and σ^2_{HS} are the variance of S_1 and half-sib progenies, respectively; σ^2A and σ^2D are the additive and dominance genetic variance, respectively.

Note: σ^2_A variance in S_1 progenies valid only when p = q = 0.5

Table 20. Analysis of variance for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in single plant selection (set I) trial, summer and rainy seasons 2009, Patancheru

Population	Source of Variation	df	Mean square							
			Fe (mg kg^{-1})		Zn (mg kg^{-1})		1000-grain mass (g)		Days to 50% flower	
			Summer 2009	Rainy 2009	Summer 2009	Rainy 2009	Summer 2009	Rainy 2009	Summer 2009	Rainy 2009
ICTP 8203	Replications	1	31.0	3.8	98.5	2.6	0.6	1.2	1.3	0.5
S_1 progenies	Progenies	39	787.7 **	468.4 **	236.1 **	169.5 **	7.1 **	5.2 **	11.1 **	13.1 **
	Error	39	150.7	205.2	64.9	60.3	0.2	0.8	1.4	0.5
	C.D (5%)		24.8	29.0	16.3	15.7	1.0	1.8	2.4	1.5
	CV(%)		11.3	19.7	9.4	12.4	3.9	7.1	2.6	1.6
	σ^2_g		318.5	131.6	85.6	54.6	3.5	2.2	4.8	6.3
	σ^2_p		393.9	234.2	118.0	84.8	3.6	2.6	5.5	6.5
	h^2 BS (%)		81	56	73	64	97	85	88	96
JBV 3	Replications	1	105.1	125.7	64.9	16.4	0.6	0.9	2.6	1.8
S_1 progenies	Progenies	39	818.6 **	190.2 **	302.0 **	143.3 **	2.4 **	2.8 **	19.8 **	9.5 **
	Error	39	57.6	50.7	52.0	62.8	0.2	0.5	1.4	0.6
	C.D (5%)		15.4	14.4	14.6	16.0	1.0	1.4	2.4	1.5
	CV (%)		10.7	16.3	11.4	18.5	5.7	8.3	2.3	1.5
	σ^2_g		380.5	69.8	125.0	40.3	1.1	1.1	9.2	4.4
	σ^2_p		409.3	95.1	151.0	71.7	1.2	1.4	9.9	4.7
	h^2 BS (%)		93	73	83	56	91	83	93	94

* = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$.

Table 21. Pooled analysis of variance for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in single plant selection (set I) trial during summer and rainy season 2009, Patancheru

Population	Source of variation	df	Mean square			
			Fe (mg kg^{-1})	Zn (mg kg^{-1})	1000-grain mass (g)	Days to 50% flower
ICTP 8203	Environment (E)	1	51396.8	21532.5	0.1	0.8
S_1 progenies	Replication / E	2	14.1	17.3	0.3	0.4
	Progenies	39	1018.1 **	325.3 **	9.5 **	18.4 **
	Progenies x E	39	238.0	80.3	2.8 **	5.8 **
	Error	78	178.0	62.6	0.5	1.0
	C.D (5%)		26.2	15.8	1.7	2.1
	C.V. (%)		14.7	10.7	5.7	2.1
	σ^2_g		210.0	65.7	2.2	4.4
	σ^2_p		254.5	81.3	2.4	4.6
	σ^2_{ge}		30.0	8.9	1.2	2.4
	σ^2_{ge}/σ^2_g		0.1	0.1	0.5	0.6
	h^2 BS (%)		83	81	95	95
JBV 3	Environment (E)	1	29604.6	16880.7	0.8	1.2
S_1 progenies	Replication / E	2	0.2	4.0	0.8	4.5
	Progenies	39	846.7 **	376.8 **	3.8 **	20.0 **
	Progenies x E	39	162.1 **	68.6	1.4 **	9.3 **
	Error	78	54.2	57.4	0.4	1.0
	C.D (5%)		15.4	15.1	1.2	1.9
	CV (%)		12.8	14.3	7.1	1.9
	σ^2_g		198.1	79.8	0.9	4.8
	σ^2_p		211.7	94.2	0.9	5.0
	σ^2_{ge}		54.0	5.6	0.5	4.2
	σ^2_{ge}/σ^2_g		0.3	0.1	0.6	0.9
	h^2 BS (%)		94	85	91	95

* = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$.

Table 22. Correlation coefficient between two seasons (summer and rainy) for grain Fe and Zn concentrations, 1000-grain mass, days to 50% flower and grain yield in single plant selection trials, Patancheru.

	Populations			
Characters	**ICTP 8203**	**JBV 3**	**AIMP 92901**	**ICMR 312**
Grain Fe (mg kg^{-1})	0.64**	0.87**	0.54**	0.36*
Grain Zn (mg kg^{-1})	0.61**	0.74**	0.71**	0.33*
1000-grain mass (g)	0.55**	0.47**	0.56**	0.45**
Days to 50% flower	0.52**	0.39*	0.71**	0.71**
Grain yield (kg ha^{-1})	-	-	0.28	0.06

* = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$.

Table 23. Correlation coefficient among S_0 plants and S_1 progenies (mean as well as replication wise) for grain Fe and Zn concentration in single plant selection trials of four populations in two seasons (summer and rainy) and pooled mean, Patancheru

Trait	Correlation between	ICTP 8203			JBV 3			AIMP 92901			ICMR 312		
		S 2009	R 2009	Pooled	S 2009	R 2009	Pooled	R 2009	S 2010	Pooled	R 2009	S 2010	Pooled
Fe concentration	S_0 and S_1 (mean)	0.69**	0.50**	0.66**	0.54**	0.62**	0.58**	0.58**	0.59**	0.66**	0.53**	0.69**	0.75**
	S_0 and S_1 (R_1)	0.66**	0.46**	-	0.46**	0.62**	-	0.37*	0.42**	-	0.45**	0.63**	-
	S_0 and S_1 (R_2)	0.60**	0.39*	-	0.59**	0.50**	-	0.60**	0.60**	-	0.47**	0.59**	-
	S_1 (R_1) and S_1 (R_2)	0.69**	0.41**	-	0.86**	0.60**	-	0.42**	0.55**	-	0.48**	0.55**	-
	S_1 (E1) and S_1 (E2)	-	-	0.64**	-	-	0.87**	-	-	0.54**	-	-	0.36*
Zn concentration	S_0 and S_1 (mean)	0.61**	0.63**	0.69**	0.64**	0.57**	0.65**	0.65**	0.69**	0.73**	0.29^{ns}	0.69**	0.61**
	S_0 and S_1 (R_1)	0.57**	0.51**	-	0.51**	0.61**	-	0.48**	0.58**	-	0.27^{ns}	0.54**	-
	S_0 and S_1 (R_2)	0.51**	0.57**	-	0.68**	0.35*	-	0.69**	0.66**	-	0.18^{ns}	0.61**	-
	S_1 (R_1) and S_1 (R_2)	0.57**	0.48**	-	0.71**	0.39*	-	0.58**	0.64**	-	0.28^{ns}	0.41**	-
	S_1 (E1) and S_1 (E2)	-	-	0.61**	-	-	0.74**	-	-	0.71**	-	-	0.33*
	Fe and Zn in S_0	0.70**			0.77**			0.87**			0.63**		

S 2009 = Summer 2009; R 2009 = Rainy 2009; S 2010 = Summer 2010; R 2010 = Rainy 2010; * = Significant at P ≤0.05; ** = Significant at P ≤0.01; ns = not significant

Table 24. Analysis of variance for grain Fe and Zn concentration, 1000-grain mass, days to 50% flower and grain yield in single plant selection (set-II) trial, rainy 2009 and summer 2010, Patancheru

Populations	Source of variation	df	Mean square																			
			Fe (mg kg^{-1})				Zn (mg kg^{-1})				1000-grain mass (g)				Days to 50% flower				Grain yield (kg/ha)			
			R 2009		S 2010		R 2009		S 2010		R 2009		S 2010		R 2009		S 2010		R 2009		S 2010	
AIMP 92901	Replications	1	94.9		61.0		0.0		7.0		0.0		0.0		3.2		3.8		30109.0		36765.0	
S_1 progenies	Progenies	39	190.8	**	468.1	**	161.4	**	267.4	**	3.8	**	5.5	**	19.6	**	14.7	**	144946.0	**	390426.0	*
	Error	39	78.8		134.4		43.0		64.9		0.7		2.1		0.9		1.0		25553.0		25262.0	
	C.D (5%)		18.0		23.5		13.3		16.3		1.7		3.0		1.9		2.1		323.3		321.5	
	C.V. (%)		17.2		15.1		14.0		12.5		8.0		13.2		2.0		2.2		9.2		6.0	
	σ^2_g		56.0		166.9		59.2		101.2		1.5		1.7		9.3		6.8		59697		182582	
	σ^2_p		95.4		234.1		80.7		133.7		1.9		2.8		9.8		7.4		72473.0		195213.0	
	h^2 (%)		59		71		73		76		81		61		95		93		82		94	
ICMR 312	Replications	1	4.9		86.6		11.8		27.1		0.0		0.8		3.2		0.6		9343.0		4485.0	
S_1 progenies	Progenies	39	146.1	**	249.7	**	62.3	*	73.1	**	3.6	**	3.7	**	11.3	**	9.1	**	291964.0	**	607048.0	*
	Error	39	52.2		71.7		35.1		30.4		0.8		1.4		1.4		0.7		19919.0		14998.0	
	C.D (5%)		14.6		17.1		12.0		11.1		1.8		2.4		2.4		1.6		285.5		247.7	
	C.V. (%)		14.5		11.1		14.1		8.8		7.9		10.1		2.4		1.7		7.7		5.0	
	σ^2_g		47.0		89.0		13.6		21.3		1.4		1.1		5.0		4.2		136023		296025	
	σ^2_p		73.1		124.8		31.2		36.5		1.8		1.8		5.7		4.6		145982.0		303524.0	
	h^2 (%)		64		71		44		58		78		62		87		93		93		98	

R 2009 = Rainy 2009; S 2010 = Summer 2010; * = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$.

Table 25. Pooled analysis of variance for grain Fe and Zn concentration, 1000-grain mass, days to 50% flower and grain yield in single plant selection (set-II) trial, during rainy 2009 and summer 2010, Patancheru

Population	Source of variation	df	Mmean square				
			Fe (mg kg^{-1})	Zn (mg kg^{-1})	1000-grain mass (g)	Days to 50% flower	Grain yield (kg/ha)
AIMP 92901	Environment (E)	1	26046.6	12208.3	4.1	21.8	31365886
S$_1$ progenies	Replication / E	2	77.1	2.0	0.0	0.3	83.0
	Progenies	39	491.1 **	360.8 **	7.3 **	29.1 **	335478.0 **
	Progenies x E	39	167.8	67.9	2.1	5.2 **	199894.0 **
	Error	78	106.6	53.9	1.4	1.0	25407.0
	C.D (5%)		20.3	14.4	2.4	2.3	324.7
	CV (%)		16.1	13.2	11.0	2.1	7.3
	σ^2_g		96.1	76.7	1.5	7.0	77517.8
	σ^2_p		122.8	90.2	1.8	7.3	83869.5
	σ^2_{ge}		30.6	7.0	0.3	2.1	87243.5
	σ^2_{ge}/σ^2_g		0.3	0.1	0.2	0.3	1.1
	h^2 BS (%)		78	85	80	97	92
ICMR 312	Environment (E)	1	28143.0	16800.0	7.7	0.1	16351248
S$_1$ progenies	Replication / E	2	76.0	0.8	0.3	1.7	40812.5
	Progenies	39	265.9 **	89.4 **	5.3 **	17.4 **	475808.0 **
	Progenies x E	39	129.9 **	45.0	2.0 *	3.0 **	423203.0 **
	Error	78	62.0	32.7	1.1	1.0	17458.0
	C.D (5%)		16.3	11.4	2.1	2.0	264.0
	CV (%)		12.5	11.0	9.1	2.1	6.1
	σ^2_g		51.0	14.2	1.0	4.1	114587.5
	σ^2_p		66.5	22.4	1.3	4.4	118952.0
	σ^2_{ge}		34.0	6.1	0.5	1.0	202872.5
	σ^2_{ge}/σ^2_g		0.7	0.4	0.4	0.2	1.8
	h^2 BS (%)		77	63	79	94	96

* = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$

Table 26 . Mean performance and realized response for grain Fe and Zn concentration and grain yield component estimated after one cycle of recurrent selection in two populations during rainy 2010, Patancheru

Population	Cycle of selection	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Days to 50% flower	Plant height (cm)	Panicle length (cm)	1000-grain mass (g)	Grain yield (kg ha^{-1})
AIMP 92901	C_0	68.3	46.3	42	187	21	13.6	2008
	C_1	70.0	50.0	43	194	22	14.2	1942
	P-value	0.82	0.45	0.42	0.30	0.05	0.05	0.22
	Realized response	1.7	3.7	0.3	6.3	1.9	0.6	-65.8
	% Gain $cycle^{-1}$	2.4	7.9	0.8	3.4	9.1	4.8	-3.3
	LSD (5%)	27.5	16.9	1.4	19.7	1.9	0.6	161.5
	C.V (%)	11.3	10.0	1.0	2.9	2.5	1.3	2.3
ICMR 312	C_0	70.7	49.3	44	193	21	12.9	2140
	C_1	76.3	52.0	43	191	23	14.7	1898
	P-value	0.27	0.50	0.23	0.58	0.14	0.05	0.50
	Realized response	5.7	2.7	-1.0	-2.5	1.5	1.8	-241.6
	% Gain $cycle^{-1}$	8.0	5.4	-2.3	-1.3	7.3	14.2	-11.3
	LSD (5%)	16.2	14.1	2.5	16.3	2.7	2.1	1262.3
	C.V (%)	6.3	7.9	1.6	2.4	3.6	4.4	17.8

Table 27. Correlation coefficient of grain Fe and Zn concentration with 1000-grain mass, flowering and grain yield in different trials for different seasons, Patancheru.

Populations	Season	Dependent traits	Zn (mg kg^{-1})	1000-grain mass (g)	Days to 50% flower	Grain yield (kg ha^{-1})
ICTP 8203 S$_1$ progenies (n = 40)	Summer 2009	Fe	0.72 **	0.07	0.07	…
		Zn		0.07	0.13	…
	Rainy 2009	Fe	0.86 **	0.20	-0.01	…
		Zn		0.22	0.00	…
	Pooled	Fe	0.80 **	0.19	-0.03	…
		Zn		0.17	0.00	…
JBV 3 S$_1$ progenies (n = 40)	Summer 2009	Fe	0.83 **	-0.07	0.21	…
		Zn		-0.01	0.17	…
	Rainy 2009	Fe	0.78 **	-0.10	0.06	…
		Zn		-0.11	0.01	…
	Pooled	Fe	0.82 **	-0.06	0.15	…
		Zn		0.00	0.09	…
AIMP 92901 S$_1$ progenies (n = 40)	Rainy 2009	Fe	0.70 **	-0.04	0.12	-0.23
		Zn		-0.01	0.13	-0.20
	Summer 2010	Fe	0.83 **	0.23	0.01	-0.43 **
		Zn		0.33 *	0.03	-0.27
	Pooled	Fe	0.78 **	0.15	0.05	-0.50 **
		Zn		0.24	0.07	-0.30
ICMR 312 S$_1$ progenies (n = 40)	Rainy 2009	Fe	0.56 **	-0.14	0.37 *	-0.32 *
		Zn		-0.34 *	0.37 *	-0.42 **
	Summer 2010	Fe	0.49 **	0.03	0.28	0.10
		Zn		0.03	0.11	0.00
	Pooled	Fe	0.43 **	-0.04	0.40 **	-0.01
		Zn		-0.13	0.27	-0.16
Line x tester (set-I) (n = 72)	Summer 2009	Fe	0.86 **	0.02	0.07	…
		Zn		-0.10	0.11	…
	Rainy 2009	Fe	0.73 **	0.08	0.28 *	…
		Zn		-0.04	0.33 *	…
	Pooled	Fe	0.84 **	0.07	0.18	…
		Zn		-0.09	0.23 *	…
Line x tester (set-II) (n = 192)	Rainy 2009	Fe	0.69 **	0.35 **	-0.15 *	…
		Zn		0.29 **	0.03	…
	Summer 2010	Fe	0.71 **	0.36 **	0.01	…
		Zn		0.22 **	-0.09	…
	Pooled	Fe	0.75 **	0.45 **	-0.07	…
		Zn		0.30 **	-0.06	…

* = Significant at $P \leq 0.05$; ** = Significant at $P \leq 0.01$

Table 28. Correlation coefficient between grain Fe and Zn concentration, and with 1000-grain mass and days to 50% flower in S_1 and half-sib (HS) progenies trial in rainy 2009, summer 2010 and pooled, Patancheru.

Correlation between	Seasons	AIMP 92901		ICMR 312	
		S_1	HS	S_1	HS
Grain Fe and Zn	Rainy 2009	0.81 **	0.69 **	0.71 **	0.78 **
	Summer 2010	0.85 **	0.76 **	0.77 **	0.69 **
	Pooled	0.86 **	0.77 **	0.77 **	0.74 **
Grain Fe and 1000-grain mass	Rainy 2009	0.32 *	0.15	0.20	0.17
	Summer 2010	0.09	-0.16	-0.19	-0.08
	Pooled	0.27 *	0.03	-0.08	0.05
Grain Zn and 1000-grain mass	Rainy 2009	0.30 *	0.29 *	0.33 *	0.30 *
	Summer 2010	0.11	-0.25	-0.17	-0.25
	Pooled	0.25	0.02	0.07	0.12
Grain Fe and days to 50% flowering	Rainy 2009	-0.01	-0.03	0.16	0.20
	Summer 2010	-0.27 *	-0.01	0.24	0.06
	Pooled	-0.17	-0.07	0.28 *	0.18
Grain Zn and days to 50% flowering	Rainy 2009	-0.03	0.06	0.04	0.15
	Summer 2010	-0.20	0.06	0.13	0.01
	Pooled	-0.15	0.04	0.13	0.04

* = Significant at P ≤0.05; ** = Significant at P ≤0.01; n = 60 for both S_1 and HS

FIGURES

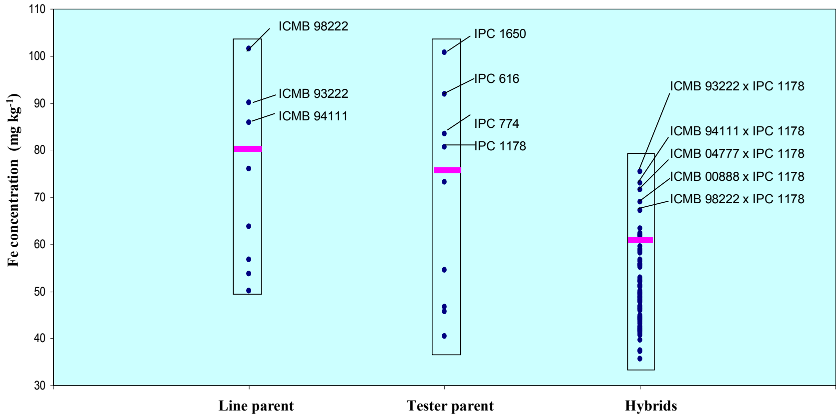


Fig 1. Range (●) and mean (▬) of grain Fe concentration (mg kg^{-1}) in parents and hybrids of line x tester (set-I) trial (mean of two seasons), Patancheru.

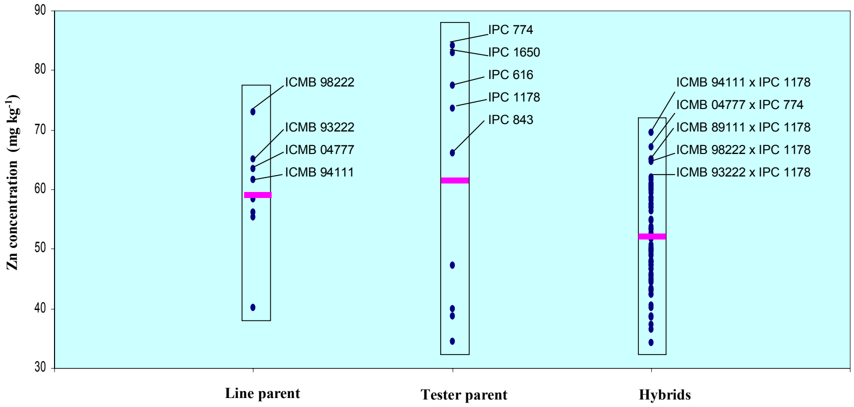


Fig 2. Range (●) and mean (▬) of grain Zn concentration (mg kg^{-1}) in parents and hybrids of line x tester (set-I) trial (mean of two seasons), Patancheru.

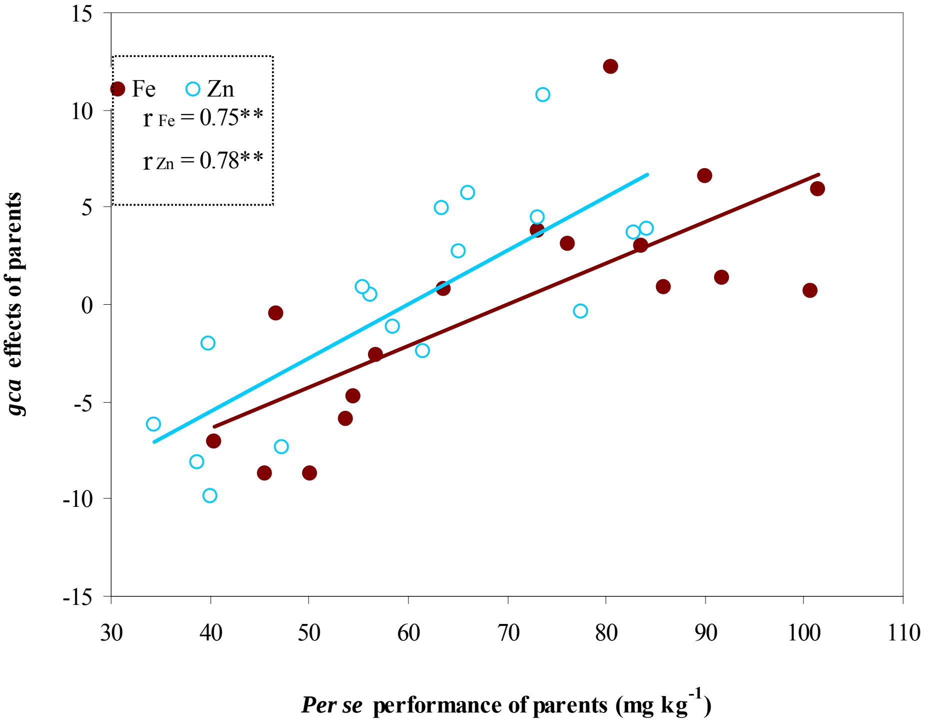


Fig 3. Relationship between per se performance of parents and their gca effects for grain Fe and Zn concentration in line x tester set - I trial (mean of two seasons).

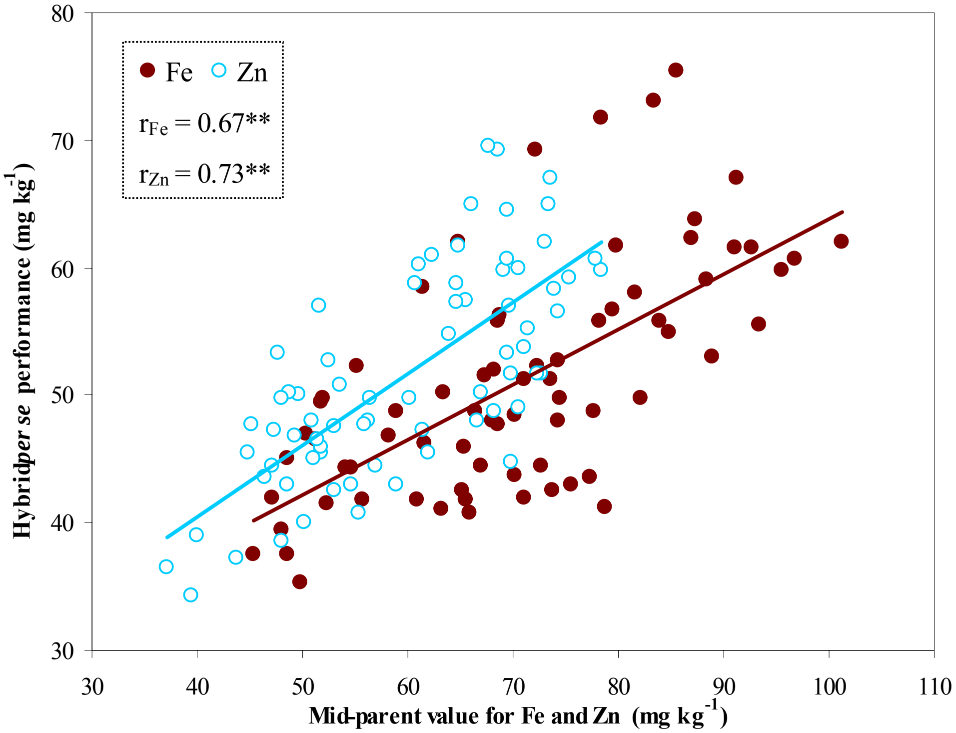


Fig 4. Relationship between mid-parent values and hybrid per se performance for grain Fe and Zn in line x tester set - I trial (mean of two seasons).

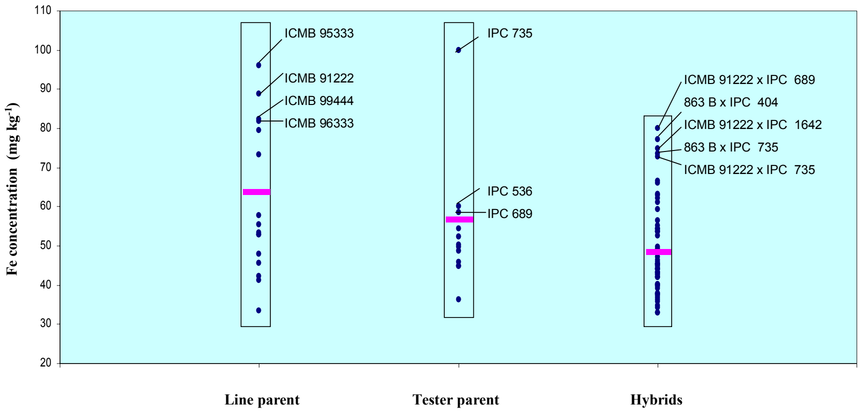


Fig 5. Range (●) and mean (▬) of grain Fe concentration (mg kg^{-1}) in parents and hybrids of line x tester (set-II) trial (mean of two seasons), Patancheru.

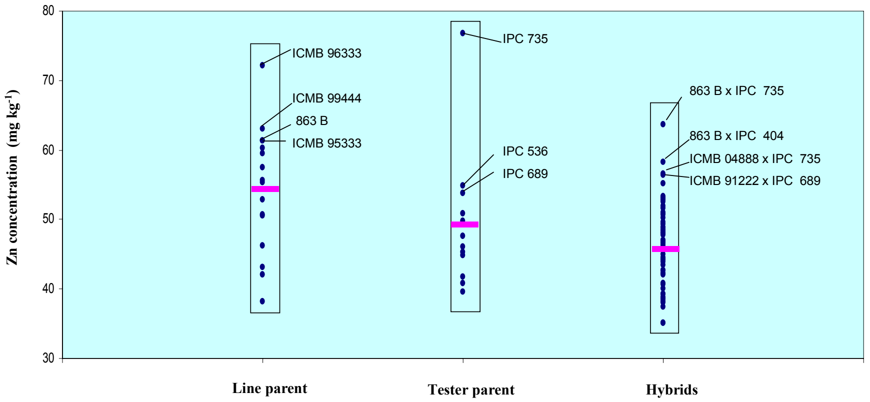


Fig 6. Range (●) and mean (▬) of grain Zn concentration (mg kg^{-1}) in parents and hybrids of Line x tester (set-II) trial (mean of two seasons), Patancheru.

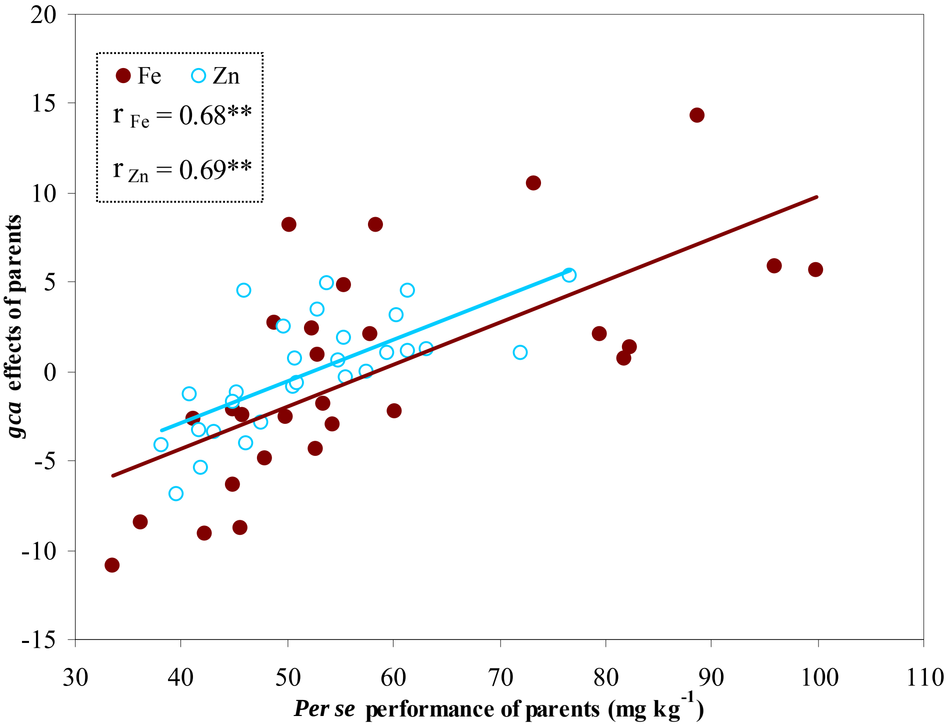


Fig 7. Relationship between per se performance of parents and their gca effects for grain Fe and Zn concentration in line x tester set - II trial (mean of two seasons).

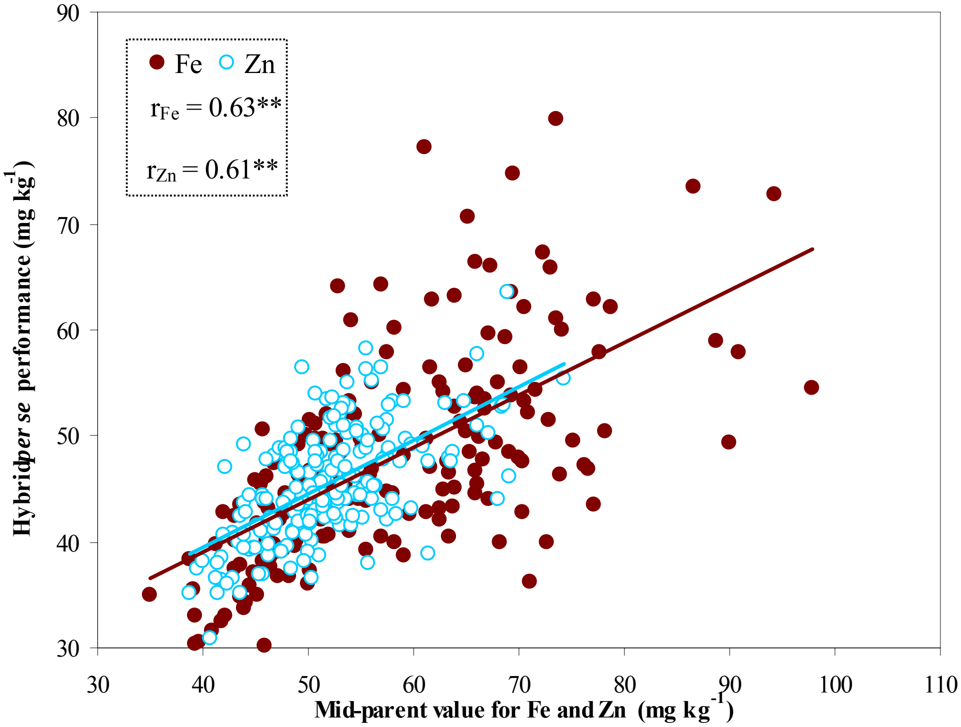
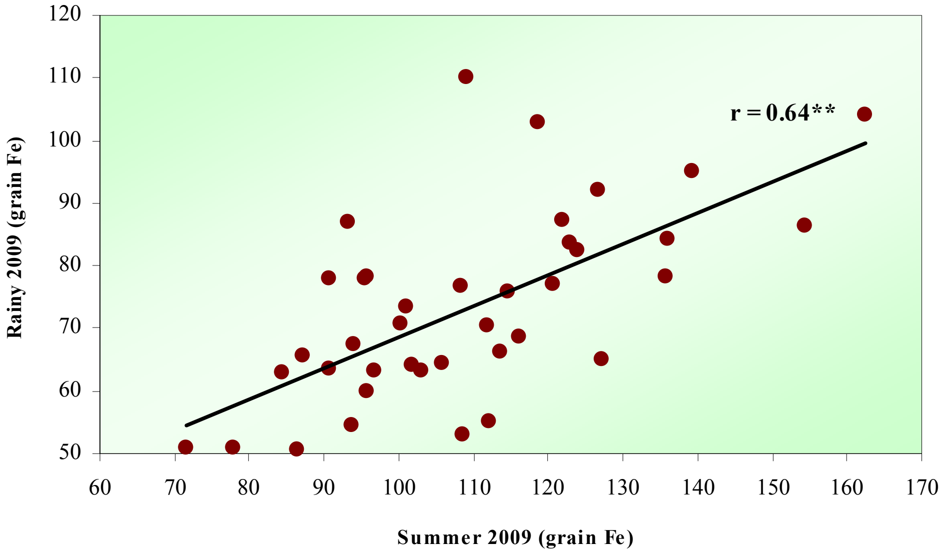


Fig 8. Relationship between mid-parent values and hybrid per se performance for grain Fe and Zn concentration in line x tester set - II trial (mean of two seasons).

A



B

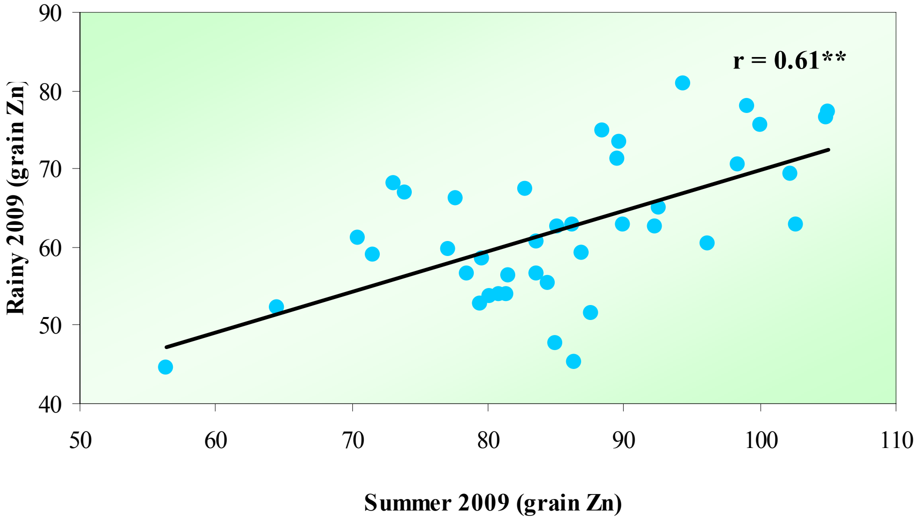
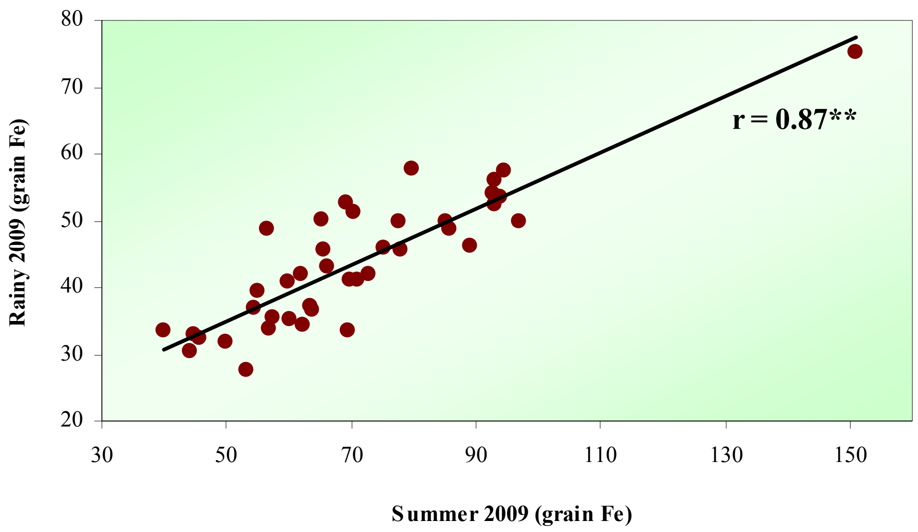


Fig 9. Relationship between summer and rainy season 2009 for grain Fe (A) and Zn (B) concentrations (mg kg-1) in ICTP 8203 S1 progeny trial, Patancheru.

A



B

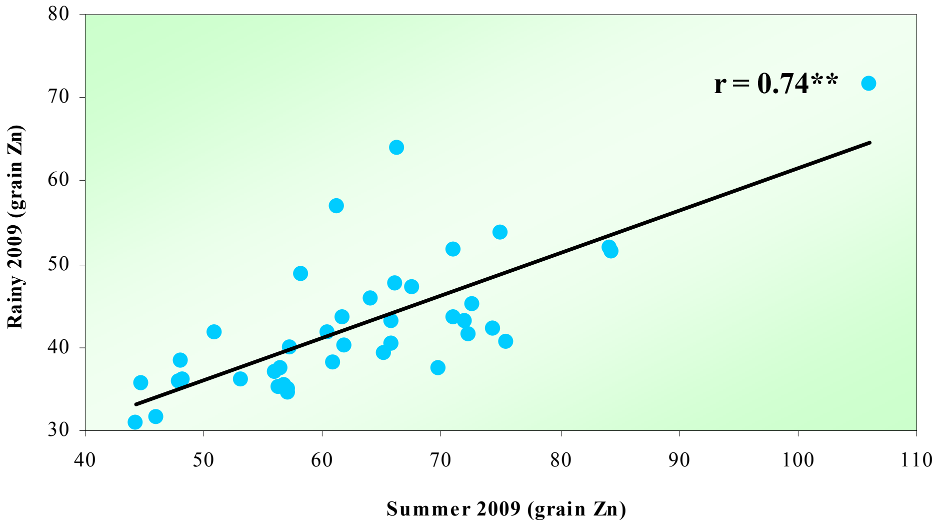


Fig 10. Relationship between summer and rainy season 2009 for grain Fe (A) and Zn (B) concentrations (mg kg-1) in JBV 3 S1 progeny trial, Patancheru

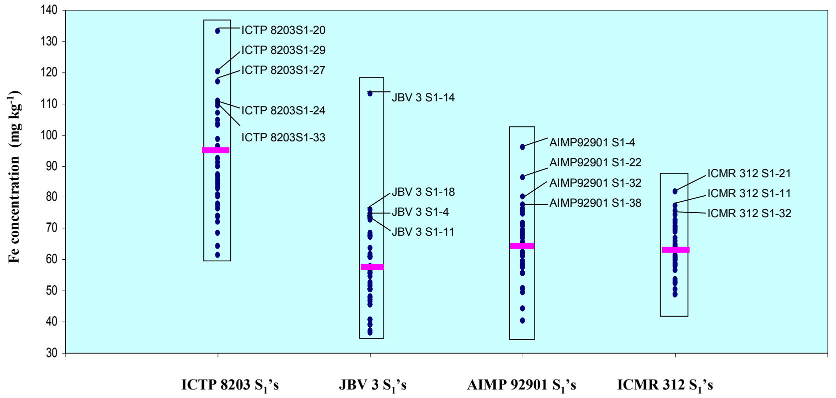


Fig 11. Range (●) and mean (▬) of grain Fe concentration (mg kg^{-1}) in S_1 progenies of different population in single plant selection trial (mean of two seasons), Patancheru.

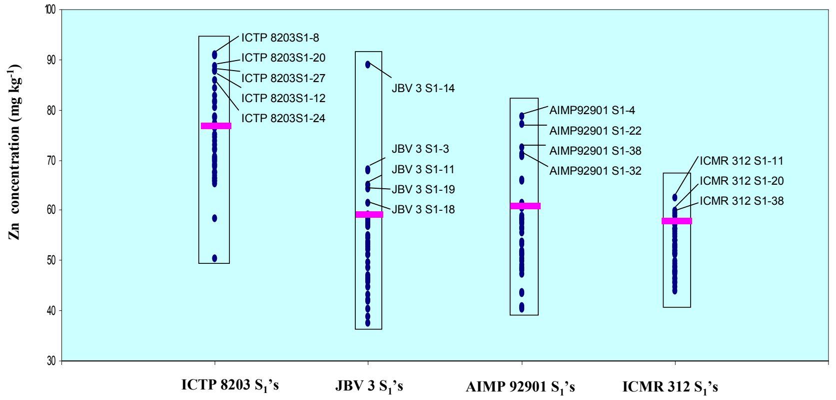


Fig 12. Range (●) and mean (▬) of grain Zn concentration (mg kg^{-1}) in S_1 progenies of different population in single plant selection trial (mean of two seasons), Patancheru.

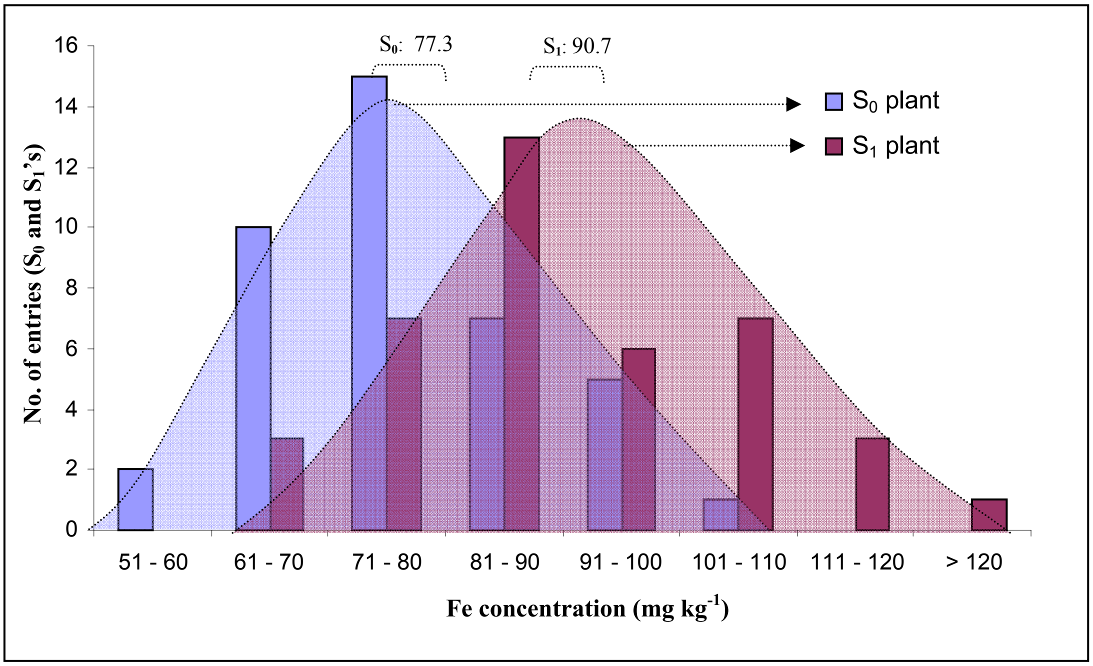


Fig 13. Frequency distribution of S_0 plant and S_1 progeny of ICTP 8203 for grain Fe concentration (S_0: rainy 2008 and S_1: mean of two seasons)

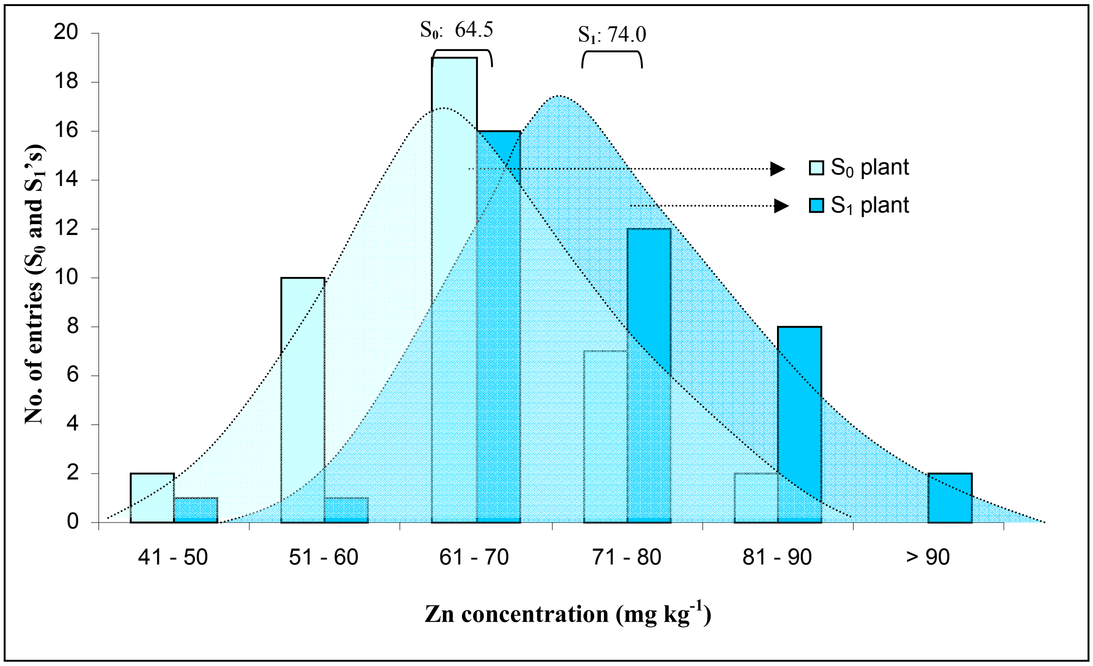
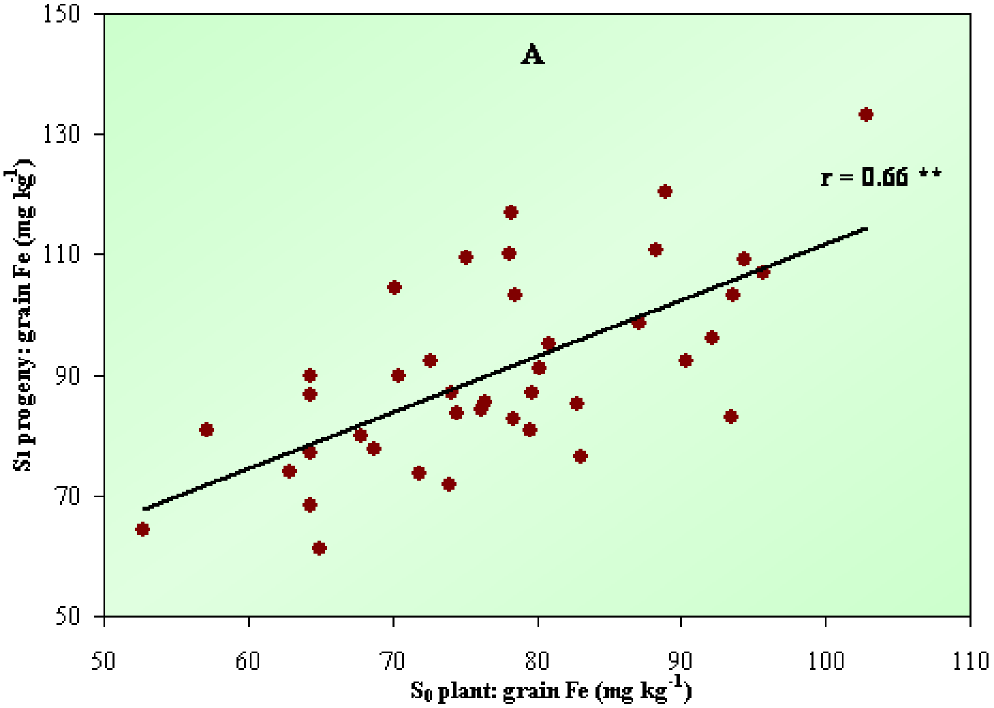


Fig 14. Frequency distribution of S_0 plant and S_1 progeny of ICTP 8203 for grain Zn concentration (S_0: rainy 2008 and S_1: mean of two seasons)



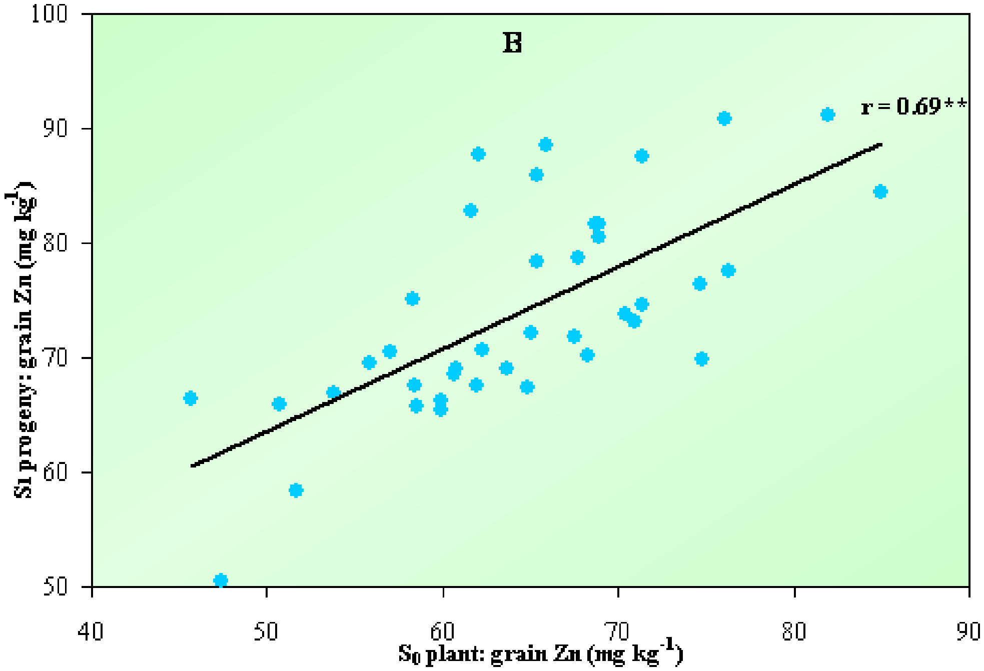


Fig 15. Correlation between S_0 plant and S_1 progenies for grain Fe (A) and Zn (B) concentration (mg kg^{-1}) in ICTP 8203 trial, Patancheru

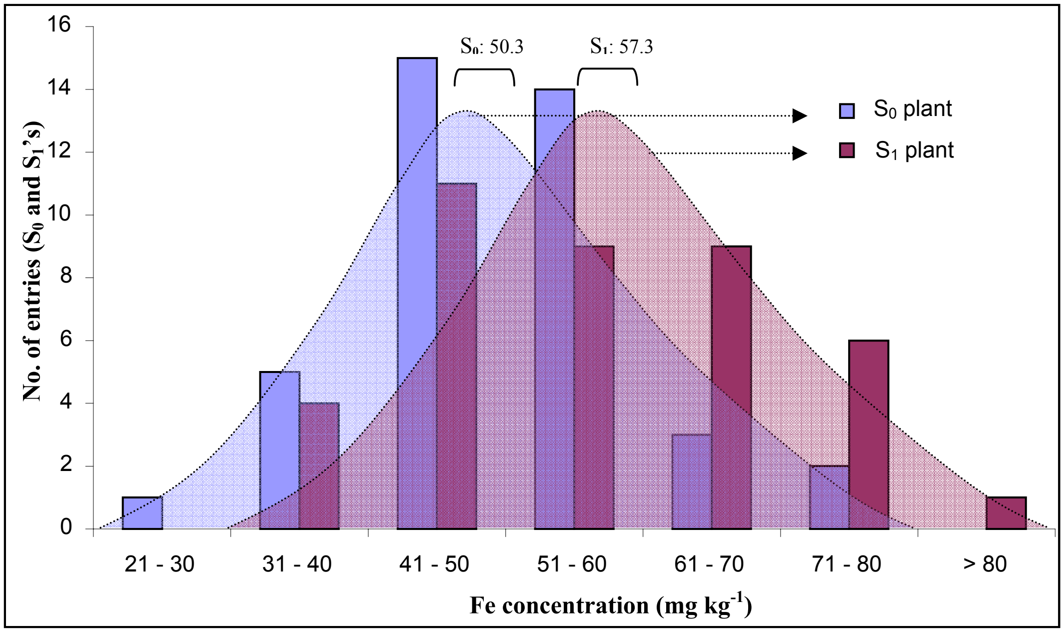


Fig 16. Frequency distribution of S_0 plant and S_1 progeny of JBV3 for grain Fe concentration (S_0: rainy 2008 and S_1: mean of two seasons)

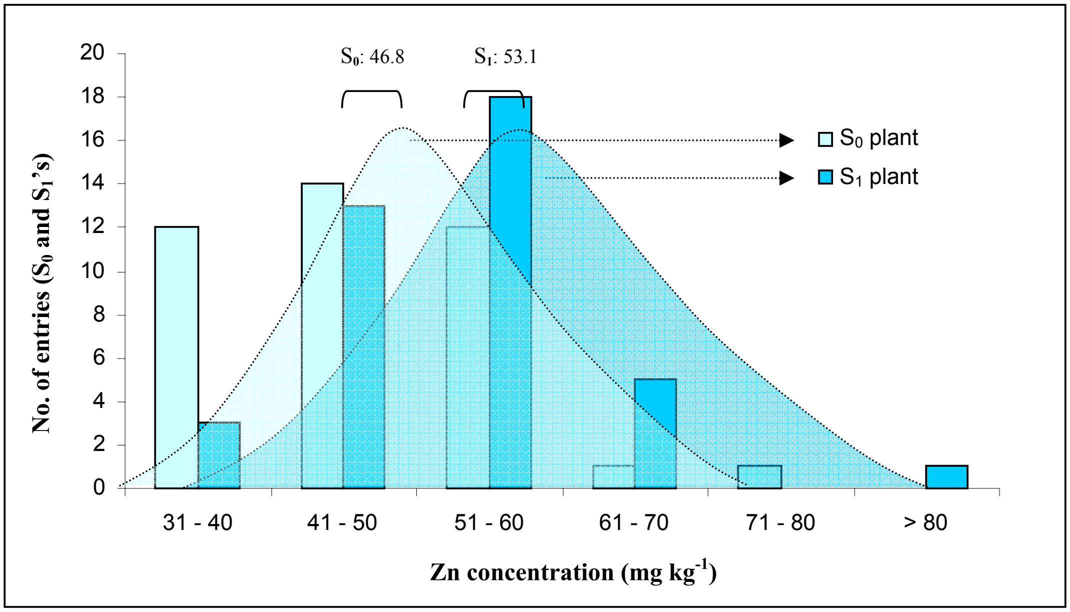
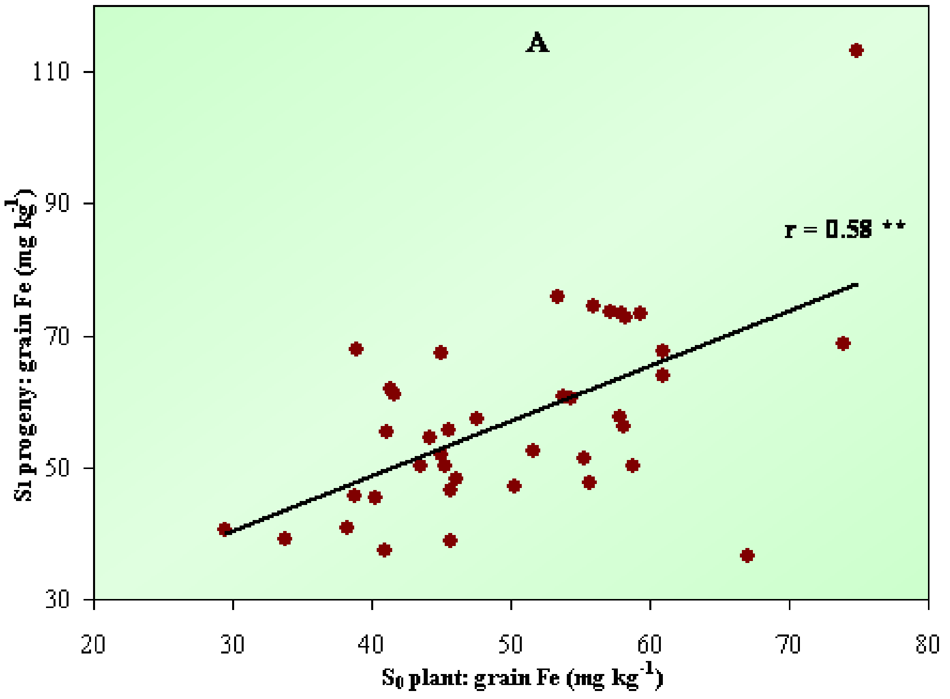


Fig 17. Frequency distribution of S_0 plant and S_1 progeny of JBV3 for grain Zn concentration (S_0: rainy 2008 and S_1: mean of two seasons)



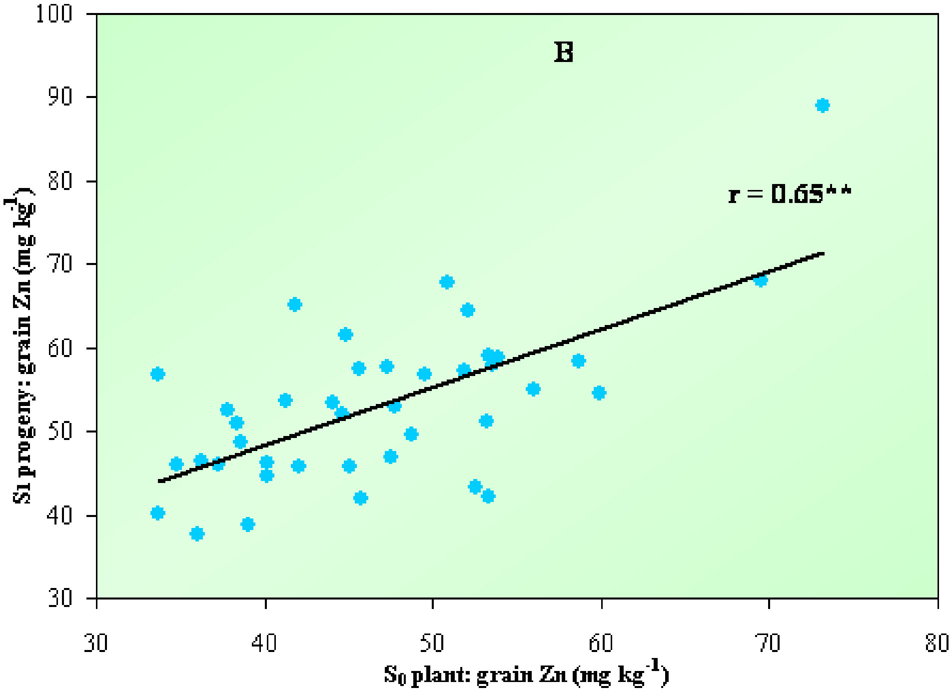


Fig 18. Correlation between S_0 plant and S_1 progenies for grain Fe (A) and Zn (B) concentration (mg kg^{-1}) in JBV3 trial, Patancheru

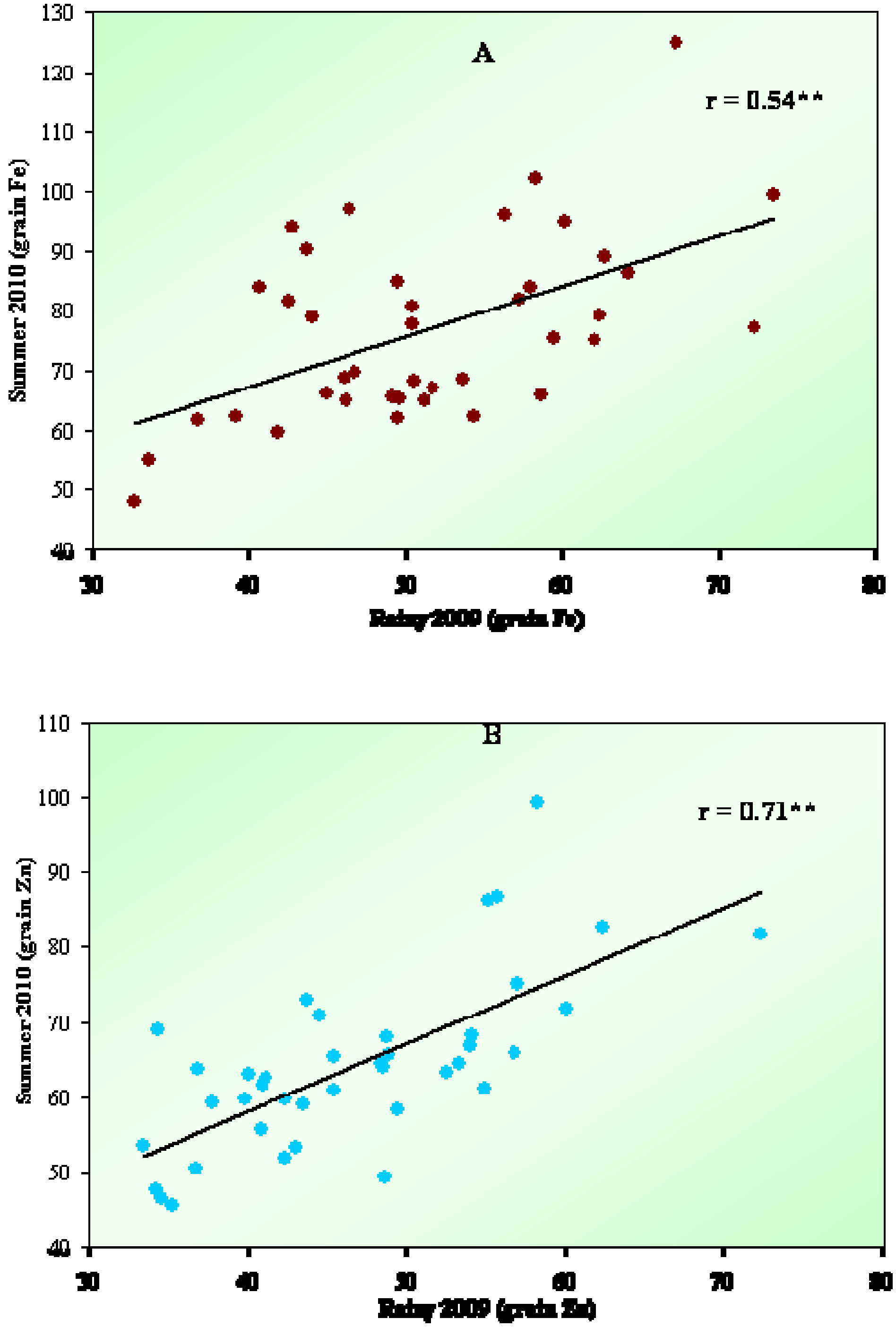
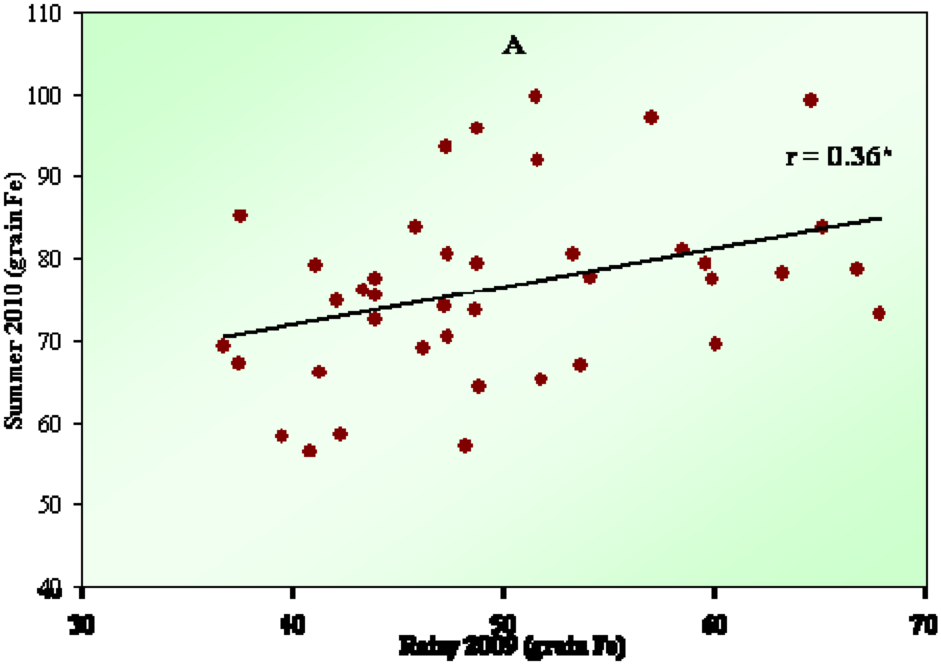


Fig 19. Relationship between rainy season 2009 and summer season 2010 for grain Fe (A) and Zn (B) concentrations (mg kg^{-1}) in AIMP 92901 S_1 progeny trial, Patancheru.



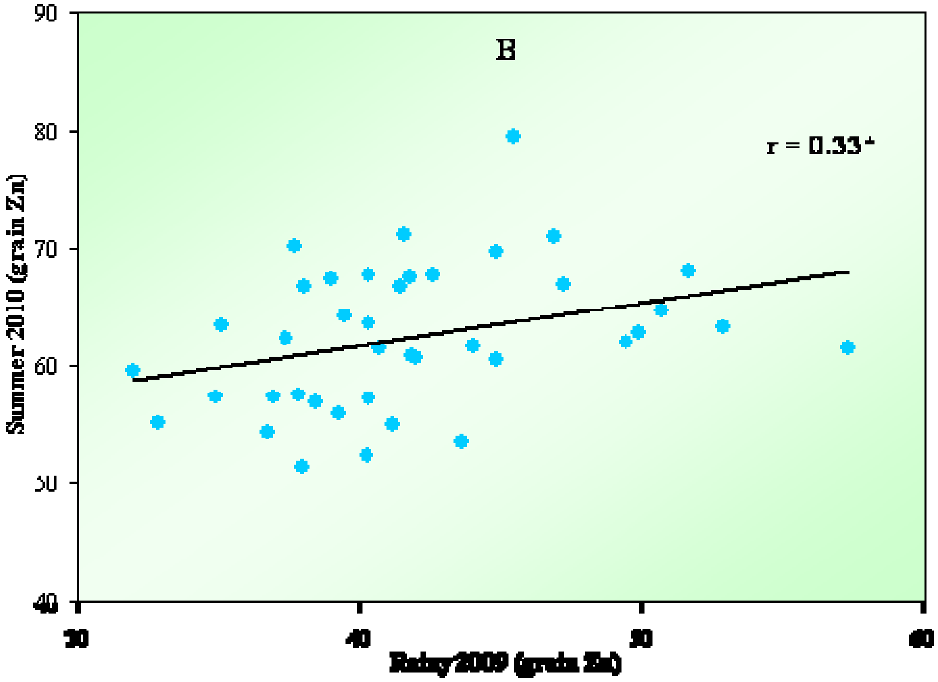


Fig 20. Relationship between rainy season 2009 and summer season 2010 for grain Fe (A) and Zn (B) concentrations (mg kg^{-1}) in ICMR 312 S$_1$ progeny trial, Patancheru

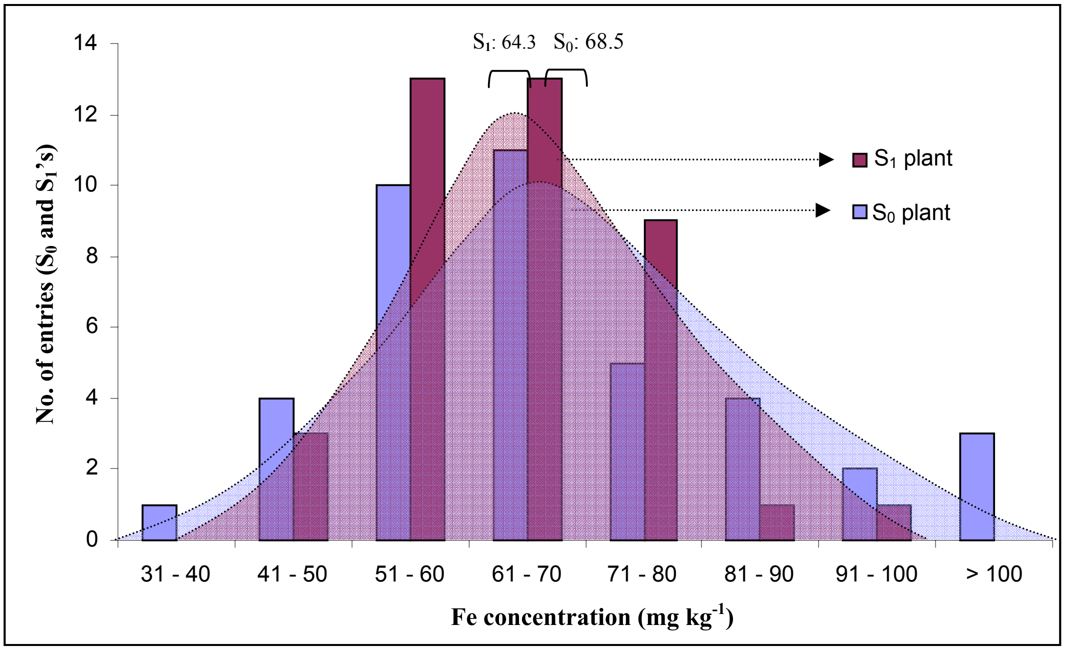


Fig 21. Frequency distribution of S_0 plant and S_1 progeny of AIMP 92901 for grain Fe concentration (S_0: summer 2009 and S_1: mean of two seasons)

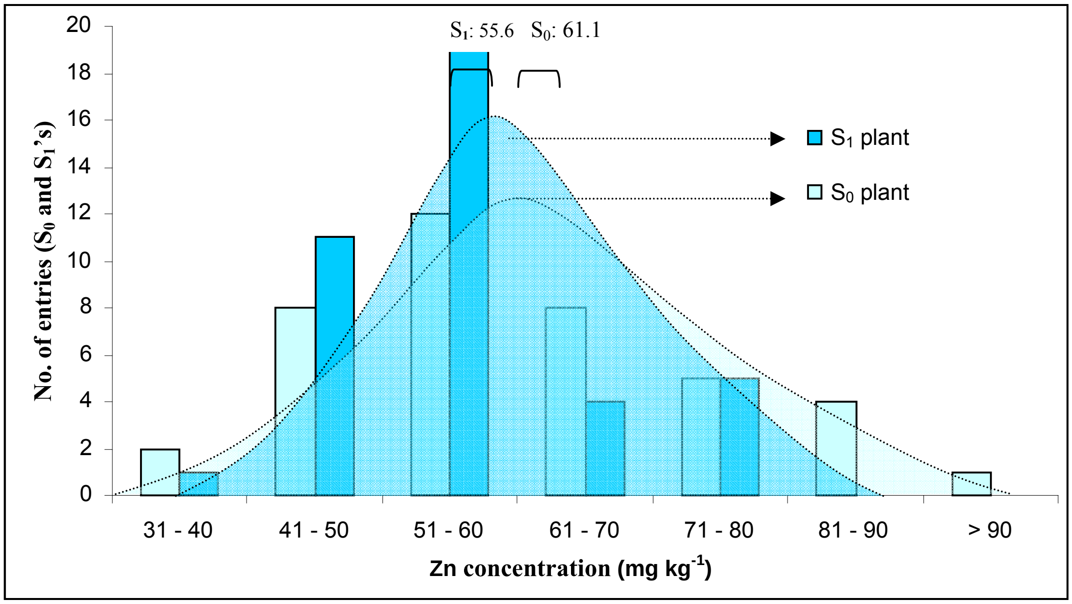


Fig 22. Frequency distribution of S_0 plant and S_1 progeny of AIMP 92901 for grain Zn concentration (S_0: summer 2009 and S_1: mean of two seasons)

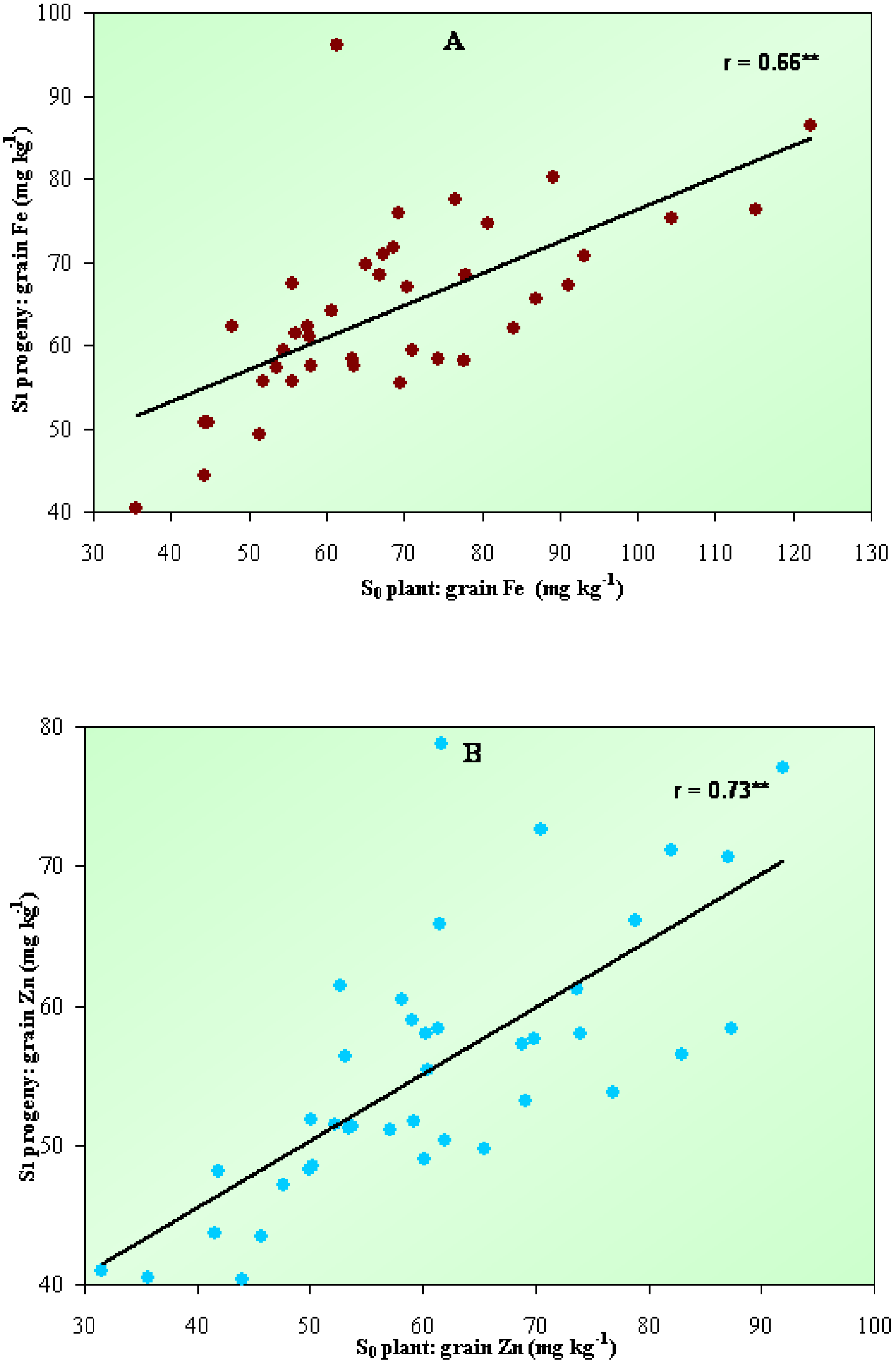


Fig 23. Correlation between S_0 plant and S_1 progenies for grain Fe (A) and Zn (B) concentration (mg kg^{-1}) in AIMP 92901 trial, Patancheru

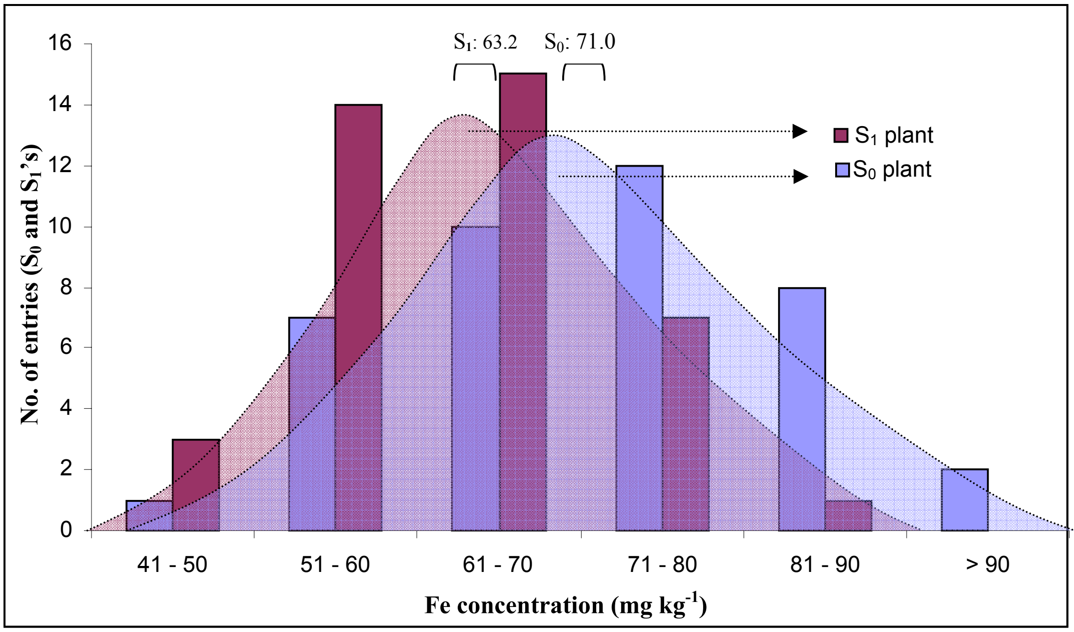


Fig 24. Frequency distribution of S_0 plant and S_1 progeny of ICMR 312 for grain Fe concentration (S_0: summer 2009 and S_1: mean of two seasons)

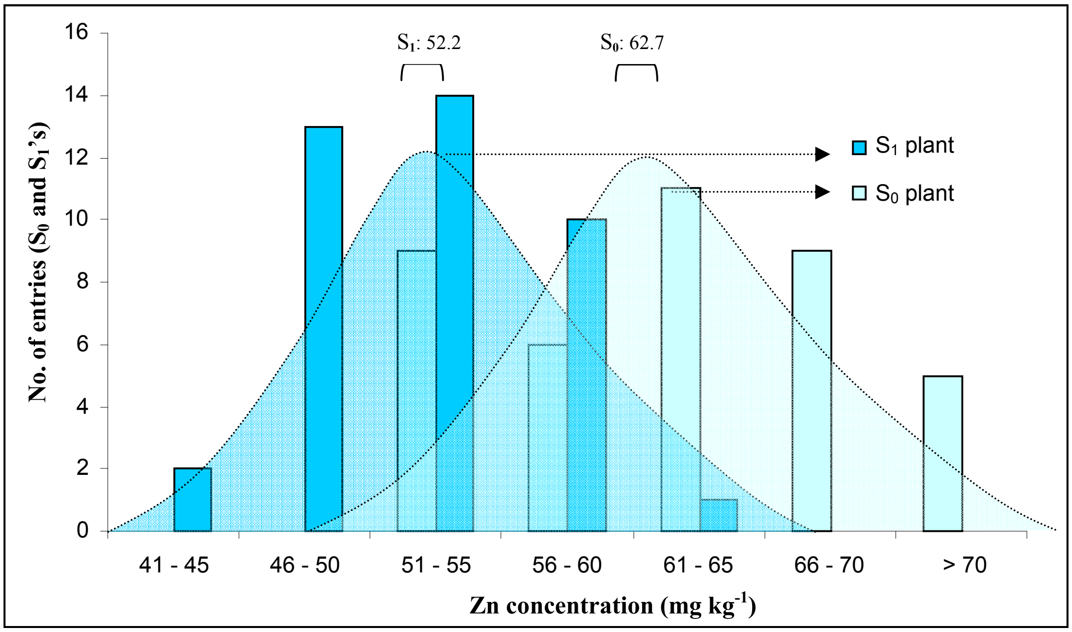


Fig 25. Frequency distribution of S_0 plant and S_1 progeny of ICMR 312 for grain Zn concentration (S_0: summer 2009 and S_1: mean of two seasons)

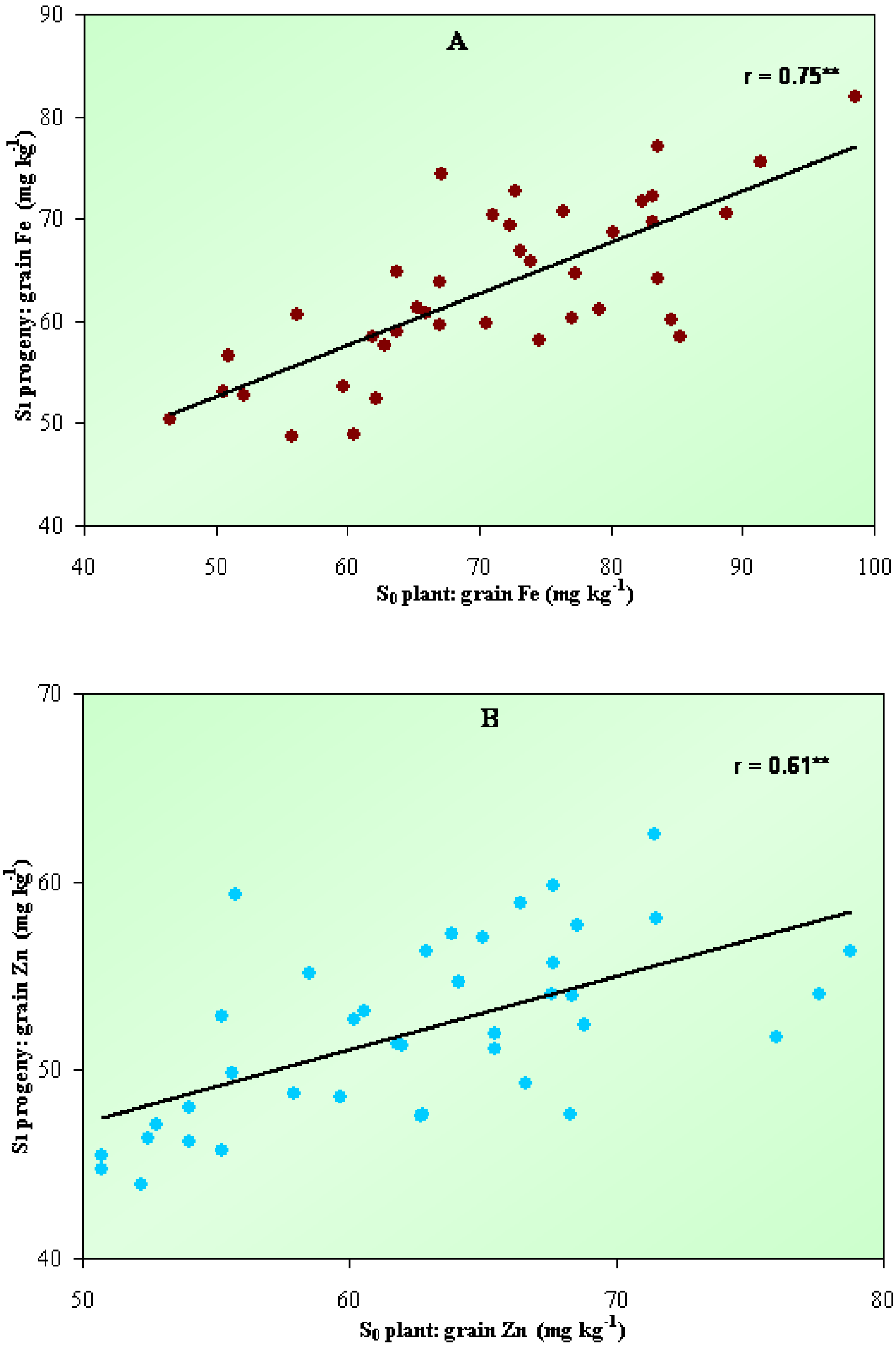


Fig 26. Correlation between S_0 plant and S_1 progenies for grain Fe (A) and Zn (B) concentration (mg kg^{-1}) in ICMR 312 trial, Patancheru

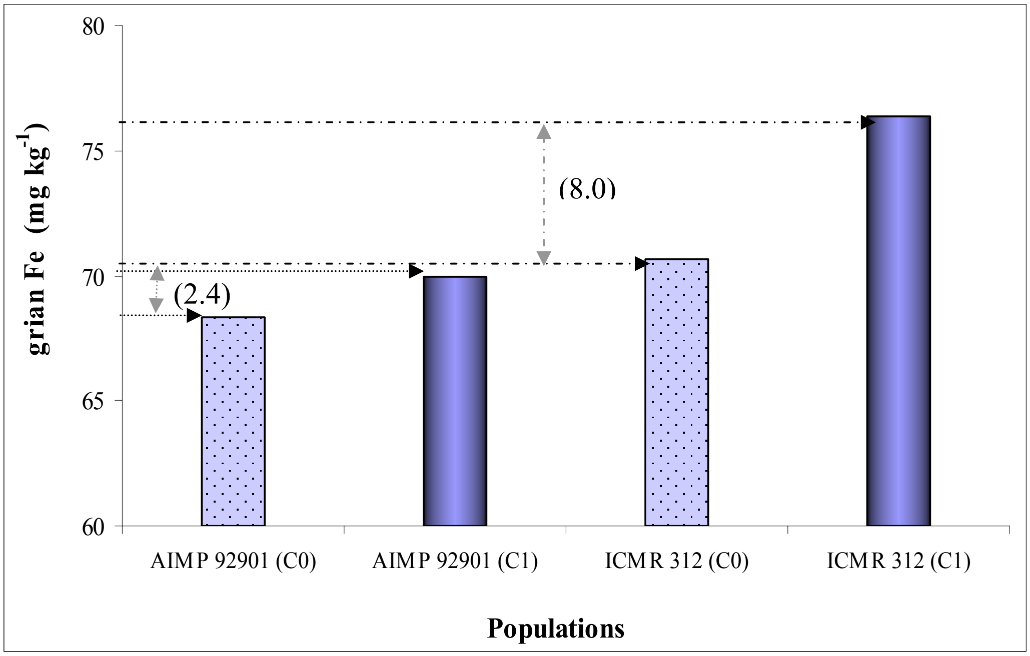


Fig 27. Frequency distributions for grain Fe concentration from cycle 0 ($C_{0:}$ dotted bar) to cycle 1 ($C_{1:}$ filled bar) of two populations (AIMP 92901 and ICMR 312). Values in the parentheses are percent of gain cycle^{-1}

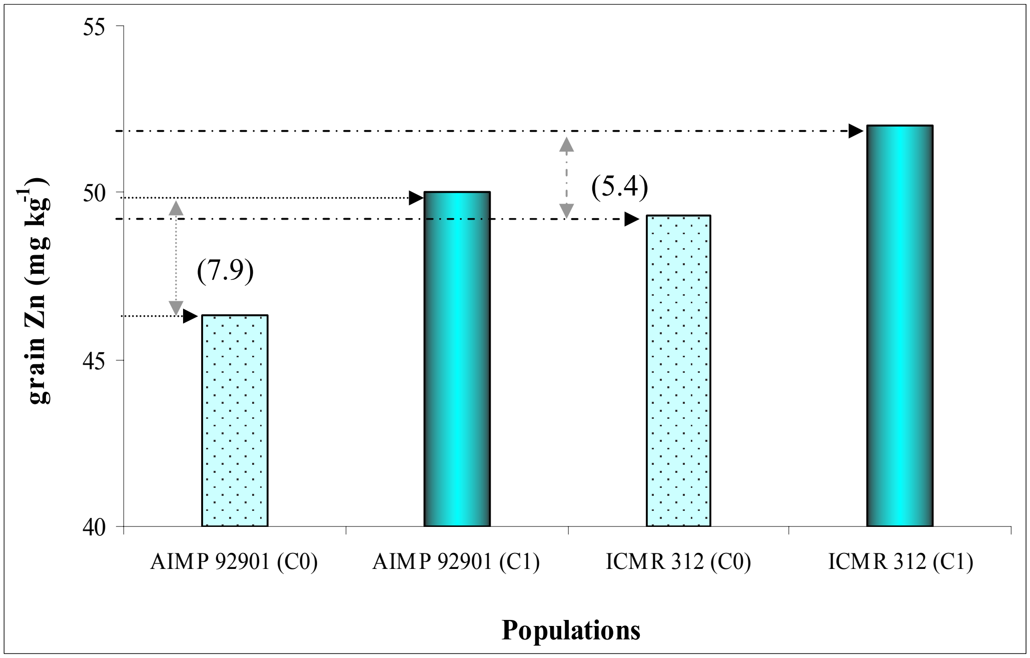


Fig 28. Frequency distributions for grain Zn concentration from cycle 0 ($C_{0:}$ dotted bar) to cycle 1 ($C_{1:}$ filled bar) of two populations (AIMP 92901 and ICMR 312). Values in the parentheses are percent of gain cycle^{-1}

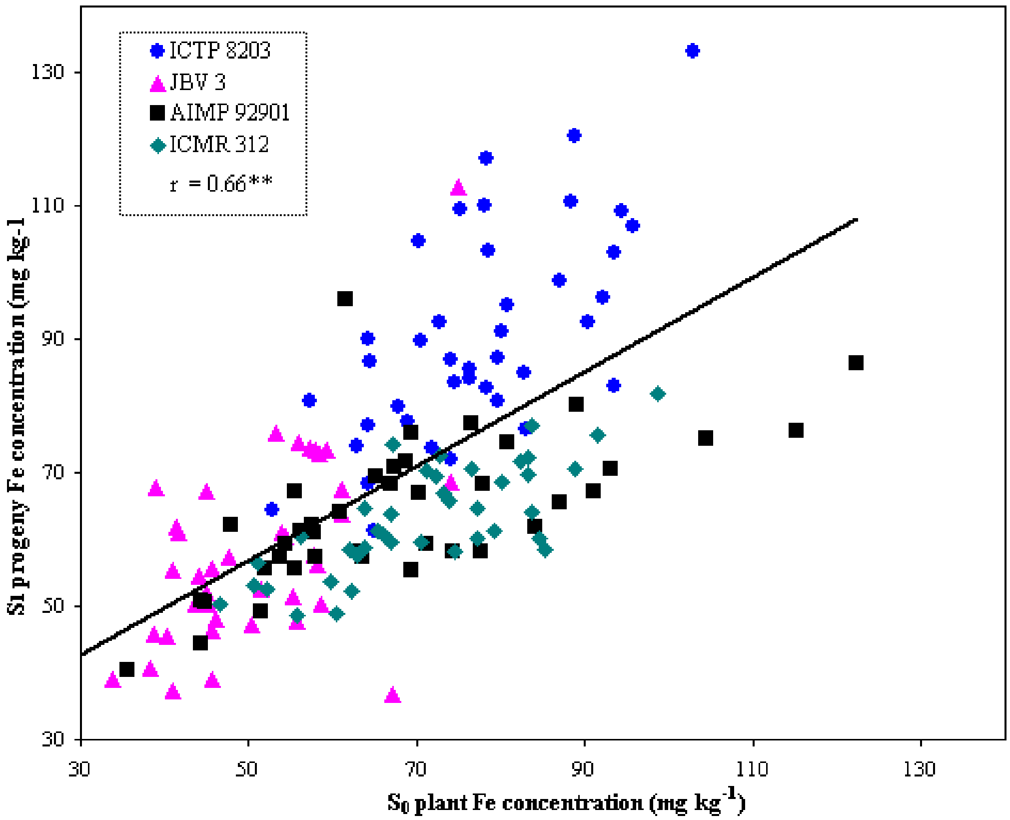


Fig 29. Relationship between S_0 plant and S_1 progenies for grain Fe concentration in four pearl millet populations (ICTP 8203, JBV 3, AIMP 92901 and ICMR 312)

APPENDICES (I to IX)

Appendix I. Weather data for each cropping season during 2008, 2009 and 2010 at ICRISAT, Patancheru

Growing Season / Year	Month	Total Rain (mm)	Temperature (^{0}C)		Relative humidity (%)		Total Evap (mm)	Solar Radiation (mj/ m2)	Bright Sunshine (Hrs)
			Min	Max	07:17 hrs	14:17 hrs			
Rainy 2008	August	72.80	21.99	30.25	92.53	66.89	73.70	16.95	5.25
	September	184.40	21.03	29.56	93.87	65.27	111.10	16.32	5.40
	October	85.40	18.79	31.01	91.29	48.26	138.90	18.32	8.12
	November	0.00	14.31	30.49	88.40	34.20	62.20	18.22	9.51
	Mean	**85.65**	**19.03**	**30.33**	**91.52**	**53.65**	**96.48**	**17.45**	**7.07**
Summer 2009	February	0.00	16.82	33.99	73.07	24.60	107.60	19.24	9.92
	March	5.80	18.44	35.39	70.94	21.65	234.10	19.03	8.65
	April	27.80	23.04	38.44	68.03	31.57	283.10	21.16	8.85
	May	5.80	24.77	40.62	62.37	35.26	231.60	22.73	9.85
	Mean	**9.85**	**20.77**	**37.11**	**68.60**	**28.27**	**214.10**	**20.54**	**9.32**
Rainy 2009	June	19.60	23.37	31.81	83.50	55.38	117.20	15.26	4.91
	July	420.20	23.07	30.98	87.32	61.39	168.90	14.64	4.83
	August	264.60	22.52	30.74	91.97	64.00	117.50	16.67	6.19
	September	60.10	20.62	30.82	91.04	53.13	94.40	15.90	7.19
	Mean	**191.13**	**22.40**	**31.09**	**88.46**	**58.47**	**124.50**	**15.62**	**5.78**
Summer 2010	February	3.00	17.72	32.98	87.52	30.10	125.10	18.01	9.08
	March	0.00	20.60	36.61	70.84	25.90	241.10	19.02	8.24
	April	5.40	24.22	39.68	64.80	24.13	313.10	21.83	9.07
	May	16.60	25.31	39.27	67.39	31.33	175.90	21.25	8.63
	Mean	**6.25**	**21.96**	**37.13**	**72.64**	**27.87**	**213.80**	**20.03**	**8.75**
Rainy 2010	August	434.90	22.38	29.60	94.10	71.57	100.90	15.83	4.67
	September	132.20	22.28	29.63	94.13	72.20	100.40	15.02	4.56
	October	108.90	20.47	29.85	94.29	58.13	103.00	15.77	6.19
	Mean	**225.33**	**21.71**	**29.70**	**94.17**	**67.30**	**101.43**	**15.54**	**5.14**

Appendix II. Variability for Fe and Zn concentration (mg kg^{-1}) in surface (0 - 30cm) soil samples during rainy (R) and summer (S) seasons 2009-2010 at the experimental field at ICRISAT - Patancheru.

Sample No.	Fe				Zn			
	S-2009	R-2009	S-2010	R-2010	S-2009	R-2009	S-2010	R-2010
1	15.8	5.6	7.3	7.6	4.8	2.3	4.1	3.6
2	14.9	5.1	5.8	7.5	5.7	2.3	4.3	3.9
3	15.7	6.7	5.4	-	5.7	2.3	4.6	-
4	15.0	-	-	-	4.7	-	-	-
Mean	15.4	5.8	6.1	7.5	5.2	2.3	4.3	3.8
Minimum	14.9	5.1	5.4	7.5	4.7	2.3	4.1	3.6
Maximum	15.8	6.7	7.3	7.6	5.7	2.3	4.6	3.9
SD (±)	0.44	0.82	1.04	0.10	0.54	0.0	0.22	0.17

The soil Fe and Zn estimated by DTPA extractable method

Appendix III. ***Per se*** **performance of parents and hybrids for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in line x tester (set-I) trial, summer and rainy season 2009, Patancheru.**

Sl. No	Entries	Fe (mg kg^{-1})			Zn (mg kg^{-1})			1000-grain mass (g)			Days to 50% flower		
		Summer	Rainy	Pooled Mean	Summer	Rainy	Pooled Mean	Summer	Rainy	Pooled Mean	Summer	Rainy	Pooled Mean
	Lines												
1	ICMB 93222	121.0	59.3	90.1	86.0	44.2	65.1	9.0	10.5	9.7	54	54	54
2	ICMB 98222	129.7	73.4	101.5	93.4	52.8	73.1	9.9	8.2	9.0	49	52	50
3	ICMB 00888	91.1	36.3	63.7	76.4	35.9	56.1	11.7	13.4	12.5	50	47	48
4	ICMB 94111	92.2	79.4	85.8	70.0	53.1	61.6	8.2	8.3	8.2	50	52	51
5	ICMB 93333	60.7	46.7	53.7	67.1	43.7	55.4	6.4	8.8	7.6	57	56	56
6	ICMB 04777	90.3	61.9	76.1	75.4	51.3	63.4	7.8	8.0	7.9	59	58	59
7	ICMB 89111	62.6	51.0	56.8	70.3	46.6	58.5	6.9	5.9	6.4	56	52	54
8	ICMB 97111	61.8	38.4	50.1	49.3	30.8	40.1	11.3	11.4	11.4	48	50	49
	Lines mean	88.7	55.8	72.2	73.5	44.8	59.1	8.9	9.3	9.1	53	52	52
	Testers												
9	IPC 1650	114.2	87.3	100.7	81.1	84.5	82.8	8.5	7.3	7.9	54	56	55
10	IPC 843	90.1	56.1	73.1	78.2	53.8	66.0	8.1	8.6	8.3	52	55	53
11	IPC 616	103.2	80.4	91.8	84.4	70.7	77.5	6.3	6.5	6.4	54	53	53
12	IPC 774	97.3	69.8	83.5	90.7	77.4	84.1	7.3	9.0	8.2	48	52	50
13	IPC 1307	54.5	38.8	46.7	47.0	32.9	39.9	6.3	7.5	6.9	61	58	59
14	IPC 1354	47.4	33.6	40.5	42.4	26.4	34.4	9.6	6.6	8.1	53	54	53
15	IPC 390	51.1	40.2	45.7	40.9	36.6	38.8	5.9	5.9	5.9	51	55	53
16	IPC 828	59.5	49.6	54.6	48.5	46.2	47.3	9.3	13.2	11.2	57	55	56
17	IPC 1178	99.3	62.0	80.6	88.1	59.2	73.6	5.7	7.3	6.5	58	57	58
	Testers mean	79.6	57.5	68.6	66.8	54.2	60.5	7.4	8.0	7.7	54	55	54
	Hybrids												
1	ICMB 93222 x IPC 1650	69.2	49.9	59.5	70.9	45.3	58.1	11.2	10.6	10.9	49	52	50
2	ICMB 93222 x IPC 843	65.7	50.5	58.1	65.7	49.6	57.6	10.0	11.4	10.7	50	51	51
3	ICMB 93222 x IPC 616	77.4	45.1	61.3	68.1	41.6	54.8	10.5	11.3	10.9	50	51	50
4	ICMB 93222 x IPC 774	76.2	48.6	62.4	69.6	43.3	56.4	14.1	15.4	14.7	48	48	48
5	ICMB 93222 x IPC 1307	66.9	44.3	55.6	63.7	41.7	52.7	10.0	12.2	11.1	54	54	54
6	ICMB 93222 x IPC 1354	55.6	36.2	45.9	62.8	37.1	50.0	11.7	14.1	12.9	50	49	49
7	ICMB 93222 x IPC 390	60.8	35.4	48.1	58.4	32.6	45.5	9.4	12.1	10.8	49	51	50
8	ICMB 93222 x IPC 828	57.5	46.7	52.1	58.5	37.5	48.0	12.5	14.1	13.3	51	52	52
9	ICMB 93222 x IPC 1178	94.0	56.8	75.4	77.2	52.2	64.7	11.3	13.2	12.3	53	52	52
10	ICMB 98222 x IPC 1650	67.1	57.0	62.0	69.8	51.3	60.5	11.7	11.5	11.6	49	51	50
11	ICMB 98222 x IPC 843	78.2	48.7	63.4	75.4	46.0	60.7	10.2	12.3	11.2	47	48	47
12	ICMB 98222 x IPC 616	73.5	48.0	60.8	76.1	42.8	59.4	9.7	11.2	10.4	49	46	48
13	ICMB 98222 x IPC 774	73.4	49.6	61.5	73.0	46.7	59.9	11.3	13.6	12.4	48	47	47
14	ICMB 98222 x IPC 1307	60.6	35.2	47.9	62.3	37.1	49.7	11.2	11.5	11.3	48	51	50
15	ICMB 98222 x IPC 1354	60.4	41.5	51.0	64.8	36.7	50.8	13.0	13.1	13.1	48	46	47
16	ICMB 98222 x IPC 390	53.9	31.1	42.5	58.3	37.4	47.8	11.8	12.6	12.2	46	48	47
17	ICMB 98222 x IPC 828	65.6	45.9	55.7	60.3	38.8	49.5	13.5	13.8	13.6	49	52	50
18	ICMB 98222 x IPC 1178	83.8	50.5	67.1	81.6	48.5	65.0	11.5	12.7	12.1	50	51	50
19	ICMB 00888 x IPC 1650	61.7	37.8	49.8	65.6	40.9	53.3	11.6	13.4	12.5	49	48	49
20	ICMB 00888 x IPC 843	67.7	36.6	52.1	76.5	44.2	60.3	11.4	13.4	12.4	48	48	48
21	ICMB 00888 x IPC 616	60.3	36.9	48.6	64.7	35.3	50.0	11.0	11.7	11.4	50	46	48
22	ICMB 00888 x IPC 774	59.6	42.7	51.1	61.3	42.3	51.8	14.0	15.5	14.7	49	44	46
23	ICMB 00888 x IPC 1307	60.1	44.1	52.1	62.7	36.9	49.8	11.1	12.2	11.7	50	49	50
24	ICMB 00888 x IPC 1354	60.4	38.8	49.6	57.7	38.0	47.8	12.7	15.7	14.2	49	46	48
25	ICMB 00888 x IPC 390	55.6	33.2	44.4	58.4	36.0	47.2	12.3	13.9	13.1	48	46	47
26	ICMB 00888 x IPC 828	55.4	42.4	48.9	55.2	36.6	45.9	13.6	15.8	14.7	50	50	50
27	ICMB 00888 x IPC 1178	94.4	43.6	69.0	78.0	45.2	61.6	12.4	14.0	13.2	53	49	51

Appendix III. Contd.,

Sl. No.	Entries	Fe (mg kg^{-1})			Zn (mg kg^{-1})			1000-grain mass (g)			Days to 50% flower		
		Summer	Rainy	Pooled Mean	Summer	Rainy	Pooled Mean	Summer	Rainy	Pooled Mean	Summer	Rainy	Pooled Mean
28	ICMB 94111 x IPC 1650	64.0	47.0	55.5	61.2	42.6	51.9	9.0	13.2	11.1	49	51	50
29	ICMB 94111 x IPC 843	69.5	43.9	56.7	68.3	41.0	54.6	9.5	11.3	10.4	48	48	48
30	ICMB 94111 x IPC 616	67.1	38.8	52.9	57.3	32.3	44.8	9.1	11.2	10.2	48	47	47
31	ICMB 94111 x IPC 774	66.0	44.3	55.1	62.9	41.1	52.0	10.6	11.2	10.9	46	46	46
32	ICMB 94111 x IPC 1307	59.3	38.1	48.7	59.7	36.2	47.9	10.5	8.9	9.7	52	50	51
33	ICMB 94111 x IPC 1354	45.4	36.9	41.1	45.9	31.2	38.5	10.6	11.9	11.2	49	47	48
34	ICMB 94111 x IPC 390	47.3	33.9	40.6	48.4	31.7	40.1	10.3	11.0	10.7	49	48	49
35	ICMB 94111 x IPC 828	49.5	38.3	43.9	52.8	33.5	43.1	12.5	12.4	12.4	51	53	52
36	ICMB 94111 x IPC 1178	84.7	61.3	73.0	82.6	56.5	69.5	10.5	12.6	11.6	52	51	51
37	ICMB 93333 x IPC 1650	52.1	34.8	43.5	69.3	50.6	59.9	9.6	10.8	10.2	53	51	52
38	ICMB 93333 x IPC 843	60.0	40.4	50.2	69.6	47.7	58.6	9.5	9.8	9.6	52	51	51
39	ICMB 93333 x IPC 616	50.7	38.3	44.5	56.5	39.3	47.9	7.9	9.1	8.5	52	50	51
40	ICMB 93333 x IPC 774	55.5	40.0	47.7	63.9	50.2	57.0	11.2	11.3	11.2	49	47	48
41	ICMB 93333 x IPC 1307	54.0	39.8	46.9	63.1	43.6	53.3	9.2	9.7	9.4	55	51	53
42	ICMB 93333 x IPC 1354	47.6	36.5	42.0	54.9	36.3	45.6	10.4	11.9	11.2	51	49	50
43	ICMB 93333 x IPC 390	44.8	26.3	35.6	54.4	34.5	44.5	10.3	11.3	10.8	50	47	48
44	ICMB 93333 x IPC 828	50.7	37.2	44.0	57.5	35.9	46.7	9.8	12.5	11.2	58	53	55
45	ICMB 93333 x IPC 1178	60.6	41.9	51.2	67.7	49.2	58.5	9.3	11.2	10.3	54	53	54
46	ICMB 04777 x IPC 1650	68.4	49.5	58.9	74.3	49.8	62.0	10.5	11.5	11.0	50	52	51
47	ICMB 04777 x IPC 843	61.0	38.6	49.8	70.1	44.5	57.3	10.0	10.6	10.3	49	52	51
48	ICMB 04777 x IPC 616	73.1	38.2	55.6	77.0	43.3	60.1	10.7	11.6	11.2	49	52	51
49	ICMB 04777 x IPC 774	79.7	44.2	62.0	83.1	51.2	67.1	10.7	10.3	10.5	50	50	50
50	ICMB 04777 x IPC 1307	72.7	44.4	58.5	72.7	41.1	56.9	10.5	9.3	9.9	56	54	55
51	ICMB 04777 x IPC 1354	58.0	35.5	46.8	62.6	37.8	50.2	11.3	10.7	11.0	51	51	51
52	ICMB 04777 x IPC 390	49.1	34.1	41.6	49.4	40.6	45.0	11.0	11.9	11.5	50	51	50
53	ICMB 04777 x IPC 828	49.8	35.0	42.4	49.8	31.3	40.6	11.8	11.6	11.7	55	55	55
54	ICMB 04777 x IPC 1178	84.4	58.6	71.5	78.1	60.7	69.4	11.2	12.9	12.0	54	55	54
55	ICMB 89111 x IPC 1650	47.7	35.2	41.4	55.8	42.0	48.9	10.5	10.6	10.6	50	51	50
56	ICMB 89111 x IPC 843	77.2	46.7	61.9	75.1	47.1	61.1	10.7	11.2	11.0	47	49	48
57	ICMB 89111 x IPC 616	64.4	40.6	52.5	61.9	36.2	49.0	9.7	10.2	10.0	51	50	50
58	ICMB 89111 x IPC 774	56.4	40.2	48.3	68.4	39.0	53.7	11.3	11.3	11.3	46	45	46
59	ICMB 89111 x IPC 1307	57.0	41.7	49.3	59.7	33.7	46.7	8.5	7.4	7.9	52	52	52
60	ICMB 89111 x IPC 1354	43.1	31.3	37.2	49.1	37.8	43.4	10.0	11.1	10.6	49	48	49
61	ICMB 89111 x IPC 390	56.2	36.3	46.2	54.2	32.1	43.1	9.7	10.4	10.0	49	46	47
62	ICMB 89111 x IPC 828	51.3	32.2	41.8	52.0	32.8	42.4	12.1	13.2	12.7	53	51	52
63	ICMB 89111 x IPC 1178	68.7	43.9	56.3	80.3	49.8	65.1	10.1	11.6	10.8	53	51	52
64	ICMB 97111 x IPC 1650	48.1	38.0	43.1	55.0	39.7	47.4	11.5	12.5	12.0	50	51	50
65	ICMB 97111 x IPC 843	53.4	39.2	46.3	56.4	38.1	47.3	10.9	10.5	10.7	49	48	48
66	ICMB 97111 x IPC 616	47.3	36.8	42.1	50.2	35.8	43.0	10.9	11.1	11.0	47	46	46
67	ICMB 97111 x IPC 774	52.5	36.1	44.3	56.4	28.5	42.5	13.8	14.1	14.0	46	45	46
68	ICMB 97111 x IPC 1307	49.0	40.6	44.8	41.3	36.2	38.8	10.9	11.7	11.3	52	51	52
69	ICMB 97111 x IPC 1354	42.9	32.1	37.5	41.9	30.9	36.4	12.7	13.6	13.1	48	48	48
70	ICMB 97111 x IPC 390	45.2	34.1	39.7	40.7	27.9	34.3	10.7	11.1	10.9	47	46	46
71	ICMB 97111 x IPC 828	49.3	33.9	41.6	41.9	32.6	37.3	12.6	14.6	13.6	49	50	49
72	ICMB 97111 x IPC 1178	50.4	33.3	41.9	53.4	35.7	44.6	10.7	12.2	11.5	51	50	50
	Hybrids mean	61.1	40.9	51.0	62.5	40.4	51.5	11.0	12.0	11.5	50	49	50
	Hybrid minimum	42.9	26.3	35.6	40.7	27.9	34.3	7.9	7.4	7.9	46	44	46
	Hybrid maximum	94.4	61.3	75.4	83.1	60.7	69.5	14.1	15.8	14.7	58	55	55
	Trial C.V. (%)	12.7	16.8	14.3	8.1	13.6	10.3	7.2	6.9	7.1	2.2	2.5	2.4
	LSD (*P* = 0.05)	16.5	14.6	11.0	10.3	11.4	7.6	1.5	1.6	1.1	2.2	2.5	1.7

Appendix IV. ***Per se*** **performance of parents and hybrids for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in line x tester trial (Set-II), rainy 2009 and summer 2010, Patancheru.**

Sl. No.	Entry	Grain Fe (mg kg^{-1})			Grain Zn (mg kg^{-1})			1000-grain mass (g)			Days to 50% flower		
		Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean
	Lines												
1	841 B	45.1	50.7	47.9	45.4	60.3	52.9	8.2	8.7	8.5	52	53	53
2	843 B	41.0	64.5	52.7	45.4	65.9	55.6	10.4	11.5	11.0	44	46	45
3	863 B	68.6	78.2	73.4	64.4	58.4	61.4	17.9	11.9	14.9	50	47	49
4	ICMB 88006	38.2	46.3	42.2	42.3	34.0	38.2	15.6	8.2	11.9	54	54	54
5	ICMB 91222	95.6	81.8	88.7	56.2	64.4	60.3	6.2	8.6	7.4	50	54	52
6	ICMB 92111	28.7	38.4	33.5	36.6	47.4	42.0	7.5	8.4	7.9	54	54	54
7	ICMB 95333	74.2	117.7	95.9	53.0	69.7	61.4	9.5	7.9	8.7	55	60	57
8	ICMB 96333	82.2	81.4	81.8	75.6	68.5	72.1	9.0	12.2	10.6	49	54	51
9	ICMB 99444	82.6	82.0	82.3	67.3	58.9	63.1	11.7	9.1	10.4	52	57	54
10	ICMB 00999	46.7	60.2	53.5	54.9	64.1	59.5	8.5	7.9	8.2	56	56	56
11	ICMB 02444	70.5	88.5	79.5	50.2	64.9	57.5	9.4	9.6	9.5	51	53	52
12	ICMB 03111	50.1	55.7	52.9	47.6	53.9	50.7	9.8	9.5	9.7	45	49	47
13	ICMB 04222	55.6	55.2	55.4	44.5	56.6	50.5	10.1	12.0	11.0	48	45	46
14	ICMB 04555	42.3	48.8	45.5	45.4	46.9	46.2	11.2	10.5	10.8	56	55	55
15	ICMB 04888	47.6	68.1	57.9	48.3	62.5	55.4	9.5	11.3	10.4	51	53	52
16	ICMB 04999	35.3	46.9	41.1	36.7	49.4	43.0	9.1	9.3	9.2	48	48	48
	Lines mean	56.5	66.5	61.5	50.9	57.9	54.4	10.2	9.8	10.0	51	52	51
	Testers												
17	IPC 338	55.1	49.7	52.4	45.9	44.6	45.2	13.8	11.8	12.8	53	50	51
18	IPC 404	40.5	57.1	48.8	43.1	56.5	49.8	13.4	13.5	13.4	49	45	47
19	IPC 536	57.0	63.4	60.2	46.4	63.2	54.8	5.5	6.5	6.0	51	55	53
20	IPC 689	50.0	67.0	58.5	49.3	58.3	53.8	14.9	12.6	13.7	48	48	48
21	IPC 735	98.6	101.0	99.8	75.0	78.4	76.7	7.1	8.4	7.8	56	60	58
22	IPC 811	42.8	47.0	44.9	39.4	39.6	39.5	11.7	10.3	11.0	50	50	50
23	IPC 1254	38.0	53.7	45.8	34.4	47.3	40.8	5.5	6.0	5.8	57	57	57
24	IPC 1268	33.3	39.2	36.3	43.5	51.6	47.5	6.0	7.0	6.5	56	55	55
25	IPC 1642	37.7	62.7	50.2	42.8	49.3	46.1	12.8	10.4	11.6	53	56	54
26	ICMR 356	39.9	68.9	54.4	42.5	59.3	50.9	8.9	11.0	10.0	49	53	51
27	ICMR 06333	42.3	47.4	44.8	42.3	41.2	41.7	13.6	12.2	12.9	55	52	53
28	ICMR 06888	43.1	56.6	49.9	41.1	48.6	44.9	7.3	7.0	7.1	50	49	49
	Testers mean	48.2	59.5	53.8	45.5	53.2	49.3	10.0	9.7	9.9	52	52	52
	Hybrids												
1	841 B x IPC 338	38.3	53.6	45.9	44.4	57.0	50.7	10.3	10.1	10.2	49	49	49
2	841 B x IPC 404	34.9	51.7	43.3	36.7	60.1	48.4	10.8	10.8	10.8	47	47	47
3	841 B x IPC 536	33.2	54.7	44.0	40.7	64.8	52.8	8.2	8.4	8.3	48	48	48
4	841 B x IPC 689	37.5	59.4	48.4	46.5	59.6	53.1	11.2	10.9	11.1	47	53	50
5	841 B x IPC 735	40.7	52.1	46.4	48.3	58.1	53.2	10.4	10.3	10.3	51	50	50
6	841 B x IPC 811	32.6	42.8	37.7	32.2	45.4	38.8	8.0	9.2	8.6	50	48	49
7	841 B x IPC 1254	27.6	52.0	39.8	38.5	57.6	48.0	8.9	8.9	8.9	49	49	49
8	841 B x IPC 1268	27.3	38.6	32.9	41.8	43.5	42.7	8.0	9.0	8.5	51	50	50
9	841 B x IPC 1642	43.1	55.3	49.2	47.4	65.5	56.4	11.6	11.0	11.3	46	47	46
10	841 B x ICMR 356	40.8	48.8	44.8	38.0	56.1	47.0	11.2	9.1	10.2	47	47	47
11	841 B x ICMR 06333	34.2	49.7	42.0	42.0	55.6	48.8	12.1	10.7	11.4	47	49	48
12	841 B x ICMR 06888	35.4	44.9	40.1	40.6	52.8	46.7	8.6	8.4	8.5	44	44	44
13	843 B x IPC 338	38.7	51.5	45.1	35.5	55.5	45.5	11.9	11.5	11.7	44	47	45
14	843 B x IPC 404	33.1	54.9	44.0	36.0	59.7	47.9	11.8	11.7	11.7	45	45	45
15	843 B x IPC 536	34.2	44.1	39.2	34.5	55.5	45.0	10.0	10.9	10.5	41	46	43
16	843 B x IPC 689	39.1	51.9	45.5	37.3	51.5	44.4	11.3	12.7	12.0	44	48	46
17	843 B x IPC 735	43.2	51.3	47.3	43.8	57.9	50.9	11.7	11.9	11.8	49	50	49
18	843 B x IPC 811	38.5	40.7	39.6	33.9	44.6	39.2	9.0	12.2	10.6	45	46	45
19	843 B x IPC 1254	39.3	49.4	44.3	40.2	48.2	44.2	11.9	10.9	11.4	46	47	46
20	843 B x IPC 1268	34.9	36.8	35.8	38.9	45.5	42.2	10.9	9.9	10.4	46	48	47
21	843 B x IPC 1642	44.1	55.2	49.7	42.0	54.2	48.1	12.2	14.6	13.4	43	44	44
22	843 B x ICMR 356	40.9	50.1	45.5	36.7	56.5	46.6	8.9	12.0	10.5	44	46	45
23	843 B x ICMR 06333	40.6	45.4	43.0	39.6	45.8	42.7	10.8	10.9	10.9	45	48	46
24	843 B x ICMR 06888	37.4	46.8	42.1	37.7	50.3	44.0	8.5	11.1	9.8	39	43	41
25	863 B x IPC 338	38.3	70.0	54.2	35.3	53.7	44.5	11.8	10.8	11.3	49	49	49

Appendix IV. Contd.,

Sl. No.	Entry	Grain Fe (mg kg^{-1})			Grain Zn (mg kg^{-1})			1000-grain mass (g)			Days to 50% flower		
		Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean
26	863 B x IPC 404	60.7	93.7	77.2	56.2	60.1	58.2	14.8	14.0	14.4	48	46	47
27	863 B x IPC 536	47.7	59.6	53.6	45.4	61.3	53.3	10.7	10.7	10.7	45	47	46
28	863 B x IPC 689	43.8	89.1	66.5	39.9	63.2	51.5	13.0	14.0	13.5	49	48	49
29	863 B x IPC 735	58.3	88.7	73.5	54.9	72.2	63.6	13.8	13.1	13.5	49	48	48
30	863 B x IPC 811	47.4	48.6	48.0	42.2	38.0	40.1	11.6	13.1	12.3	49	47	48
31	863 B x IPC 1254	35.1	50.2	42.6	35.0	42.3	38.6	10.1	11.0	10.5	52	49	50
32	863 B x IPC 1268	33.0	55.0	44.0	37.0	55.3	46.1	10.6	12.2	11.4	53	48	50
33	863 B x IPC 1642	55.5	70.3	62.9	48.8	51.6	50.2	15.5	13.9	14.7	46	45	46
34	863 B x ICMR 356	53.4	73.0	63.2	53.8	56.6	55.2	11.8	12.3	12.1	46	45	46
35	863 B x ICMR 06333	40.5	68.3	54.4	38.0	54.0	46.0	15.0	15.0	15.0	48	47	48
36	863 B x ICMR 06888	43.5	69.5	56.5	47.3	56.6	51.9	10.8	12.0	11.4	47	45	46
37	ICMB 88006 x IPC 338	38.1	46.0	42.1	35.1	41.8	38.4	12.2	10.8	11.5	50	54	52
38	ICMB 88006 x IPC 404	32.6	58.4	45.5	36.2	62.3	49.3	12.7	12.8	12.8	48	49	48
39	ICMB 88006 x IPC 536	29.6	45.2	37.4	34.3	49.9	42.1	12.7	12.0	12.3	46	50	48
40	ICMB 88006 x IPC 689	32.7	52.1	42.4	38.3	57.2	47.8	14.0	13.0	13.5	48	52	50
41	ICMB 88006 x IPC 735	28.9	43.5	36.2	34.7	49.4	42.0	12.9	12.2	12.5	51	55	53
42	ICMB 88006 x IPC 811	30.8	38.7	34.7	32.0	38.2	35.1	10.0	12.5	11.2	49	50	49
43	ICMB 88006 x IPC 1254	25.4	43.1	34.3	30.8	44.2	37.5	13.9	12.7	13.3	49	51	50
44	ICMB 88006 x IPC 1268	29.6	36.6	33.1	36.3	45.5	40.9	11.8	10.3	11.1	50	53	52
45	ICMB 88006 x IPC 1642	31.8	54.6	43.2	38.2	55.9	47.0	16.6	14.1	15.3	46	49	47
46	ICMB 88006 x ICMR 356	29.6	43.7	36.7	32.9	45.6	39.2	12.9	11.8	12.4	47	50	48
47	ICMB 88006 x ICMR 06333	34.5	41.0	37.8	35.4	41.1	38.2	15.8	14.3	15.0	48	52	50
48	ICMB 88006 x ICMR 06888	37.7	42.4	40.0	36.3	39.7	38.0	11.9	12.5	12.2	46	48	47
49	ICMB 91222 x IPC 338	55.1	69.2	62.2	43.0	58.9	50.9	12.8	11.4	12.1	48	52	50
50	ICMB 91222 x IPC 404	54.3	64.2	59.2	45.5	51.5	48.5	12.5	11.5	12.0	48	47	47
51	ICMB 91222 x IPC 536	51.2	71.1	61.1	38.2	57.9	48.1	10.7	10.0	10.3	44	46	45
52	ICMB 91222 x IPC 689	59.8	100.1	80.0	45.0	68.0	56.5	12.4	10.7	11.5	48	49	49
53	ICMB 91222 x IPC 735	66.6	78.9	72.7	52.6	53.0	52.8	11.6	11.2	11.4	48	52	50
54	ICMB 91222 x IPC 811	44.5	62.6	53.5	35.7	45.6	40.7	11.4	11.0	11.2	48	49	48
55	ICMB 91222 x IPC 1254	58.1	74.0	66.0	41.7	57.5	49.6	11.9	10.4	11.1	50	52	51
56	ICMB 91222 x IPC 1268	53.8	56.4	55.1	40.5	52.2	46.3	10.9	9.6	10.2	48	49	49
57	ICMB 91222 x IPC 1642	55.2	94.3	74.7	42.1	63.0	52.6	14.1	12.7	13.4	43	50	46
58	ICMB 91222 x ICMR 356	47.5	61.1	54.3	40.8	56.9	48.8	11.4	11.2	11.3	46	48	47
59	ICMB 91222 x ICMR 06333	45.9	59.1	52.5	37.5	49.4	43.5	14.3	12.7	13.5	48	50	49
60	ICMB 91222 x ICMR 06888	50.0	57.5	53.7	39.0	49.3	44.2	10.7	9.5	10.1	45	47	46
61	ICMB 92111 x IPC 338	30.5	44.5	37.5	28.7	41.6	35.1	9.9	10.3	10.1	51	53	52
62	ICMB 92111 x IPC 404	35.7	43.9	39.8	37.9	43.7	40.8	9.2	11.7	10.5	49	49	49
63	ICMB 92111 x IPC 536	29.2	31.0	30.1	32.3	42.6	37.5	8.6	9.1	8.9	47	49	48
64	ICMB 92111 x IPC 689	36.9	55.5	46.2	42.8	54.7	48.8	9.8	10.7	10.2	48	52	50
65	ICMB 92111 x IPC 735	31.4	64.2	47.8	40.2	59.3	49.7	9.6	10.8	10.2	51	55	53
66	ICMB 92111 x IPC 811	31.4	29.3	30.4	29.9	31.9	30.9	10.0	8.0	9.0	50	49	49
67	ICMB 92111 x IPC 1254	25.2	35.8	30.5	30.6	39.9	35.2	11.4	10.3	10.8	49	52	50
68	ICMB 92111 x IPC 1268	30.5	39.4	35.0	36.2	42.8	39.5	11.6	9.4	10.5	47	50	48
69	ICMB 92111 x IPC 1642	37.5	48.2	42.9	37.0	50.4	43.7	12.3	11.8	12.1	47	48	47
70	ICMB 92111 x ICMR 356	28.4	39.1	33.8	36.3	47.7	42.0	9.0	9.3	9.1	49	51	50
71	ICMB 92111 x ICMR 06333	32.5	38.7	35.6	36.2	36.7	36.4	10.9	11.4	11.1	49	50	50
72	ICMB 92111 x ICMR 06888	27.5	37.5	32.5	37.3	42.8	40.0	6.3	8.1	7.2	46	49	47
73	ICMB 95333 x IPC 338	43.7	76.3	60.0	42.2	55.2	48.7	11.7	10.4	11.1	50	53	51
74	ICMB 95333 x IPC 404	57.5	77.0	67.3	53.9	58.6	56.3	14.1	13.0	13.5	50	49	49
75	ICMB 95333 x IPC 536	35.0	52.1	43.6	37.2	51.0	44.1	10.5	9.6	10.0	46	50	48
76	ICMB 95333 x IPC 689	46.4	79.5	62.9	46.5	59.5	53.0	14.1	10.4	12.3	49	54	51
77	ICMB 95333 x IPC 735	50.1	58.8	54.5	46.1	46.4	46.2	11.2	11.3	11.3	50	55	53
78	ICMB 95333 x IPC 811	35.3	50.2	42.7	30.7	42.6	36.7	11.5	10.8	11.2	50	50	50
79	ICMB 95333 x IPC 1254	38.9	65.5	52.2	39.9	50.9	45.4	11.8	9.1	10.5	55	57	56
80	ICMB 95333 x IPC 1268	41.4	49.3	45.4	41.5	47.7	44.6	10.2	8.6	9.4	49	51	50
81	ICMB 95333 x IPC 1642	52.8	78.8	65.8	47.2	62.7	55.0	15.6	12.5	14.0	46	48	47
82	ICMB 95333 x ICMR 356	36.2	62.7	49.4	38.9	49.1	44.0	9.6	10.0	9.8	46	52	49
83	ICMB 95333 x ICMR 06333	37.4	57.6	47.5	39.6	47.4	43.5	13.2	11.3	12.2	49	54	52
84	ICMB 95333 x ICMR 06888	43.1	60.1	51.6	34.5	48.6	41.6	8.1	9.5	8.8	48	51	49
85	ICMB 96333 x IPC 338	52.7	66.5	59.6	43.8	51.4	47.6	12.6	11.9	12.3	46	50	48
86	ICMB 96333 x IPC 404	40.7	56.1	48.4	39.3	58.7	49.0	11.5	13.0	12.3	46	48	47
87	ICMB 96333 x IPC 536	41.1	54.9	48.0	41.0	55.0	48.0	10.0	10.1	10.1	43	49	46

Appendix IV. Contd.,

Sl. No.	Entry	Grain Fe (mg kg^{-1})			Grain Zn (mg kg^{-1})			1000-grain mass (g)			Days to 50% flower		
		Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean
88	ICMB 96333 x IPC 689	50.3	62.6	56.4	50.0	56.2	53.1	12.8	11.3	12.0	47	50	48
89	ICMB 96333 x IPC 735	50.6	65.2	57.9	47.2	63.6	55.4	12.7	12.5	12.6	50	54	52
90	ICMB 96333 x IPC 811	39.1	41.7	40.4	35.3	40.8	38.0	11.1	10.7	10.9	48	47	47
91	ICMB 96333 x IPC 1254	38.7	51.5	45.1	42.6	47.8	45.2	11.9	11.7	11.8	49	51	50
92	ICMB 96333 x IPC 1268	36.6	40.7	38.6	41.4	44.8	43.1	9.3	8.6	9.0	49	48	49
93	ICMB 96333 x IPC 1642	42.1	65.9	54.0	41.5	64.9	53.2	13.0	13.7	13.4	45	47	46
94	ICMB 96333 x ICMR 356	33.9	46.0	39.9	36.9	40.8	38.9	10.8	10.6	10.7	45	49	47
95	ICMB 96333 x ICMR 06333	44.0	49.2	46.6	42.1	43.8	43.0	11.4	10.9	11.2	48	49	49
96	ICMB 96333 x ICMR 06888	46.3	47.1	46.7	41.7	43.3	42.5	9.5	10.5	10.0	45	47	46
97	ICMB 99444 x IPC 338	52.4	61.0	56.7	41.7	45.6	43.6	10.8	10.7	10.7	49	54	51
98	ICMB 99444 x IPC 404	33.6	61.8	47.7	41.0	59.0	50.0	12.5	10.9	11.7	46	49	47
99	ICMB 99444 x IPC 536	48.8	50.0	49.4	43.3	54.5	48.9	10.1	10.5	10.3	46	49	47
100	ICMB 99444 x IPC 689	47.0	63.1	55.1	48.2	53.2	50.7	12.3	10.9	11.6	49	55	52
101	ICMB 99444 x IPC 735	49.4	68.4	58.9	47.8	57.9	52.8	15.2	10.2	12.7	46	52	49
102	ICMB 99444 x IPC 811	34.0	51.8	42.9	33.5	44.6	39.0	12.8	9.2	11.0	50	52	51
103	ICMB 99444 x IPC 1254	38.1	56.0	47.1	42.3	54.5	48.4	11.2	11.3	11.2	48	50	49
104	ICMB 99444 x IPC 1268	34.6	46.3	40.5	39.3	43.6	41.5	8.2	8.8	8.5	49	53	51
105	ICMB 99444 x IPC 1642	47.5	58.2	52.8	46.2	55.7	51.0	13.9	12.5	13.2	46	48	47
106	ICMB 99444 x ICMR 356	37.1	52.1	44.6	39.1	52.1	45.6	9.2	8.9	9.0	48	50	49
107	ICMB 99444 x ICMR 06333	47.1	52.4	49.7	42.4	48.7	45.6	12.4	10.5	11.5	49	54	51
108	ICMB 99444 x ICMR 06888	39.9	46.7	43.3	38.4	46.1	42.2	9.2	8.9	9.0	46	51	48
109	ICMB 00999 x IPC 338	39.6	53.2	46.4	43.6	49.7	46.7	10.1	9.9	10.0	51	50	50
110	ICMB 00999 x IPC 404	44.6	52.6	48.6	44.3	57.3	50.8	10.0	12.2	11.1	50	48	49
111	ICMB 00999 x IPC 536	42.9	49.8	46.4	40.9	54.5	47.7	8.7	8.7	8.7	47	50	49
112	ICMB 00999 x IPC 689	44.5	65.5	55.0	45.4	56.9	51.1	10.7	9.7	10.2	50	55	52
113	ICMB 00999 x IPC 735	44.8	49.1	46.9	40.0	48.0	44.0	10.2	10.3	10.3	54	53	53
114	ICMB 00999 x IPC 811	34.4	56.7	45.6	35.3	53.3	44.3	13.1	8.8	11.0	51	51	51
115	ICMB 00999 x IPC 1254	35.3	54.8	45.1	41.6	51.4	46.5	9.9	8.7	9.3	52	50	51
116	ICMB 00999 x IPC 1268	31.4	42.8	37.1	37.0	50.9	43.9	12.8	7.9	10.3	52	51	51
117	ICMB 00999 x IPC 1642	45.9	58.0	52.0	41.4	53.7	47.6	13.7	11.0	12.3	48	46	47
118	ICMB 00999 x ICMR 356	35.2	46.7	41.0	35.1	49.6	42.3	10.1	9.1	9.6	48	49	48
119	ICMB 00999 x ICMR 06333	43.2	49.4	46.3	38.7	47.1	42.9	12.3	10.2	11.3	51	49	50
120	ICMB 00999 x ICMR 06888	34.6	46.3	40.4	43.1	56.0	49.5	8.2	8.7	8.4	45	46	45
121	ICMB 02444 x IPC 338	42.5	57.4	50.0	35.1	51.4	43.3	11.2	11.3	11.3	46	48	47
122	ICMB 02444 x IPC 404	44.6	58.1	51.4	43.4	50.7	47.0	14.1	11.9	13.0	47	47	47
123	ICMB 02444 x IPC 536	41.7	55.1	48.4	39.2	51.3	45.2	9.7	9.3	9.5	43	48	45
124	ICMB 02444 x IPC 689	48.4	78.8	63.6	44.7	54.5	49.6	12.7	12.5	12.6	47	50	48
125	ICMB 02444 x IPC 735	36.9	61.8	49.4	39.8	60.5	50.2	12.3	11.6	12.0	50	50	50
126	ICMB 02444 x IPC 811	35.0	49.0	42.0	33.8	48.0	40.9	13.2	11.5	12.3	50	46	48
127	ICMB 02444 x IPC 1254	35.9	54.0	44.9	43.9	49.2	46.6	10.9	11.6	11.2	50	50	50
128	ICMB 02444 x IPC 1268	32.2	47.9	40.0	38.5	46.6	42.6	9.5	9.3	9.4	50	47	48
129	ICMB 02444 x IPC 1642	50.3	91.0	70.7	45.9	61.1	53.5	15.1	12.0	13.6	46	46	46
130	ICMB 02444 x ICMR 356	35.0	53.2	44.1	33.9	51.0	42.4	10.2	11.9	11.0	45	46	45
131	ICMB 02444 x ICMR 06333	36.3	49.9	43.1	35.9	40.2	38.1	13.6	13.1	13.3	48	47	47
132	ICMB 02444 x ICMR 06888	39.6	61.4	50.5	35.0	54.1	44.5	8.7	9.3	9.0	44	46	45
133	ICMB 03111 x IPC 338	41.4	62.6	52.0	41.5	53.3	47.4	11.6	11.0	11.3	46	50	48
134	ICMB 03111 x IPC 404	36.3	59.6	48.0	36.7	53.9	45.3	10.5	11.3	10.9	46	47	47
135	ICMB 03111 x IPC 536	35.7	53.8	44.7	38.2	50.0	44.1	9.6	9.9	9.7	44	47	45
136	ICMB 03111 x IPC 689	53.6	62.1	57.8	50.6	56.5	53.6	12.5	10.6	11.5	45	49	47
137	ICMB 03111 x IPC 735	36.9	63.9	50.4	36.9	60.1	48.5	9.5	9.9	9.7	46	52	49
138	ICMB 03111 x IPC 811	37.8	47.1	42.5	36.0	47.2	41.6	9.6	10.1	9.9	46	47	46
139	ICMB 03111 x IPC 1254	37.3	59.7	48.5	40.9	48.0	44.5	11.5	11.2	11.3	46	49	47
140	ICMB 03111 x IPC 1268	33.2	43.8	38.5	35.5	51.4	43.4	8.6	9.5	9.0	46	48	47
141	ICMB 03111 x IPC 1642	50.0	62.3	56.1	44.7	54.7	49.7	12.5	12.2	12.3	43	46	45
142	ICMB 03111 x ICMR 356	35.8	51.9	43.9	39.9	54.6	47.2	8.9	9.8	9.3	45	46	45
143	ICMB 03111 x ICMR 06333	45.0	54.3	49.7	36.4	46.6	41.5	11.1	11.0	11.0	46	47	46
144	ICMB 03111 x ICMR 06888	40.2	62.9	51.6	36.8	57.3	47.1	8.4	10.0	9.2	42	45	43
145	ICMB 04222 x IPC 338	51.0	55.7	53.3	41.4	45.6	43.5	12.4	12.0	12.2	46	46	46
146	ICMB 04222 x IPC 404	40.3	57.9	49.1	35.1	48.2	41.6	12.4	13.6	13.0	45	47	46
147	ICMB 04222 x IPC 536	46.9	53.1	50.0	40.1	49.1	44.6	9.3	11.4	10.4	42	47	44
148	ICMB 04222 x IPC 689	53.6	74.8	64.2	44.9	58.3	51.6	13.0	12.7	12.9	46	47	47
149	ICMB 04222 x IPC 735	48.9	66.9	57.9	37.3	58.0	47.6	13.0	11.6	12.3	47	50	48

Appendix IV. Contd.,

Sl. No.	Entry	Grain Fe (mg kg^{-1})			Grain Zn (mg kg^{-1})			1000-grain mass (g)			Days to 50% flower		
		Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean
150	ICMB 04222 x IPC 811	40.8	52.5	46.7	33.6	45.1	39.4	12.8	11.5	12.2	47	46	46
151	ICMB 04222 x IPC 1254	48.8	53.5	51.1	43.9	44.1	44.0	12.1	12.4	12.3	47	47	47
152	ICMB 04222 x IPC 1268	40.7	46.7	43.7	38.4	45.6	42.0	10.0	9.7	9.8	46	49	47
153	ICMB 04222 x IPC 1642	58.1	70.2	64.2	37.1	59.9	48.5	14.0	15.5	14.8	43	44	43
154	ICMB 04222 x ICMR 356	43.5	55.8	49.6	39.8	55.5	47.6	8.4	12.1	10.2	43	45	44
155	ICMB 04222 x ICMR 06333	43.6	59.4	51.5	36.1	43.6	39.8	13.6	13.6	13.6	46	46	46
156	ICMB 04222 x ICMR 06888	42.6	56.6	49.6	32.5	54.9	43.7	9.0	10.5	9.8	43	45	44
157	ICMB 04555 x IPC 338	35.2	45.6	40.4	34.6	39.4	37.0	11.0	10.0	10.5	49	55	52
158	ICMB 04555 x IPC 404	29.2	44.4	36.8	36.6	42.6	39.6	12.1	14.0	13.0	47	46	46
159	ICMB 04555 x IPC 536	40.5	45.5	43.0	37.8	51.3	44.6	7.8	9.3	8.6	45	49	47
160	ICMB 04555 x IPC 689	33.7	47.4	40.6	36.3	48.5	42.4	12.7	11.6	12.2	48	52	50
161	ICMB 04555 x IPC 735	38.7	41.2	39.9	43.4	51.9	47.6	10.8	11.3	11.1	50	53	52
162	ICMB 04555 x IPC 811	34.1	35.7	34.9	32.4	40.8	36.6	10.5	11.2	10.8	50	47	49
163	ICMB 04555 x IPC 1254	33.6	42.9	38.3	34.7	50.2	42.4	12.4	11.7	12.0	49	50	50
164	ICMB 04555 x IPC 1268	27.0	36.2	31.6	34.7	47.6	41.1	9.1	8.9	9.0	49	50	49
165	ICMB 04555 x IPC 1642	37.2	52.0	44.6	37.1	51.0	44.1	16.9	14.1	15.5	47	47	47
166	ICMB 04555 x ICMR 356	30.4	41.6	36.0	36.7	45.2	40.9	10.4	11.5	10.9	47	49	48
167	ICMB 04555 x ICMR 06333	33.9	49.5	41.7	33.5	45.5	39.5	12.0	11.7	11.9	49	49	49
168	ICMB 04555 x ICMR 06888	35.5	43.0	39.3	36.3	45.8	41.0	9.5	10.4	10.0	47	47	47
169	ICMB 04888 x IPC 338	35.4	62.7	49.0	31.7	53.3	42.5	12.5	12.6	12.5	48	50	49
170	ICMB 04888 x IPC 404	39.8	64.3	52.1	44.8	58.7	51.8	15.8	14.0	14.9	50	47	48
171	ICMB 04888 x IPC 536	35.3	54.0	44.6	37.7	51.0	44.3	11.2	11.6	11.4	44	48	46
172	ICMB 04888 x IPC 689	47.4	73.0	60.2	47.4	53.6	50.5	14.9	12.8	13.8	49	49	49
173	ICMB 04888 x IPC 735	52.1	72.2	62.1	54.8	60.7	57.7	11.8	11.2	11.5	50	54	52
174	ICMB 04888 x IPC 811	31.5	49.5	40.5	31.6	46.7	39.1	13.9	12.1	13.0	50	49	49
175	ICMB 04888 x IPC 1254	42.7	61.5	52.1	42.8	54.2	48.5	12.2	11.5	11.9	50	50	50
176	ICMB 04888 x IPC 1268	36.2	41.9	39.1	39.0	48.6	43.8	10.2	10.0	10.1	52	49	50
177	ICMB 04888 x IPC 1642	50.4	71.3	60.8	46.0	62.1	54.0	18.0	16.4	17.2	48	47	48
178	ICMB 04888 x ICMR 356	39.6	54.2	46.9	41.5	49.2	45.4	13.1	12.2	12.6	46	46	46
179	ICMB 04888 x ICMR 06333	41.0	51.4	46.2	43.8	51.0	47.4	12.8	12.6	12.7	47	48	47
180	ICMB 04888 x ICMR 06888	36.2	51.8	44.0	32.4	51.3	41.9	10.8	12.5	11.6	44	46	45
181	ICMB 04999 x IPC 338	38.0	56.7	47.3	34.5	51.0	42.8	9.4	9.9	9.6	49	50	49
182	ICMB 04999 x IPC 404	40.8	50.9	45.8	37.5	47.0	42.2	12.0	11.9	11.9	50	48	49
183	ICMB 04999 x IPC 536	34.7	55.6	45.2	33.9	56.4	45.2	8.7	8.9	8.8	46	49	47
184	ICMB 04999 x IPC 689	37.3	63.0	50.1	37.2	58.0	47.6	10.2	10.9	10.5	50	50	50
185	ICMB 04999 x IPC 735	44.9	61.5	53.2	47.6	51.0	49.3	10.0	10.7	10.3	50	53	51
186	ICMB 04999 x IPC 811	34.1	46.1	40.1	30.5	42.4	36.5	9.2	9.0	9.1	51	49	50
187	ICMB 04999 x IPC 1254	33.4	53.5	43.4	32.0	49.4	40.7	10.2	10.3	10.3	50	49	49
188	ICMB 04999 x IPC 1268	38.1	38.5	38.3	34.4	39.4	36.9	8.4	9.0	8.7	48	48	48
189	ICMB 04999 x IPC 1642	43.2	58.1	50.7	37.4	51.4	44.4	15.5	13.5	14.5	46	46	46
190	ICMB 04999 x ICMR 356	35.7	49.5	42.6	33.2	50.1	41.6	11.3	10.6	11.0	46	48	47
191	ICMB 04999 x ICMR 06333	36.9	48.1	42.5	30.5	41.4	36.0	8.3	11.4	9.8	49	49	49
192	ICMB 04999 x ICMR 06888	33.3	49.1	41.2	32.8	48.6	40.7	9.9	9.71	9.8	45	45	45
	Hybrids mean	40.3	55.2	47.7	39.5	51.3	45.4	11.4	11.1	11.2	47	49	48
	Hybrid minimum	25.2	29.3	30.1	28.7	31.9	30.9	6.3	7.9	7.2	39	43	41
	Hybrid maximum	66.6	100.1	80.0	56.2	72.2	63.6	18.0	16.4	17.2	55	57	56
	Trial C.V. (%)	14.3	11.9	12.9	10.9	10.2	10.5	8.7	7.6	8.2	1.8	2.7	2.3
	LSD (P = 0.05)	11.8	13.1	12.9	8.7	10.5	10.0	1.9	1.6	1.3	1.7	2.7	1.6

Appendix V (a). ***Per se*** **performance of selfed (S_1) and half-sib (HS) progenies for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in AIMP 92901, rainy 2009 and summer 2010, Patancheru.**

Progeny No.	Grain Fe (mg kg^{-1})						Grain Zn (mg kg^{-1})						1000-grain mass (g)						Days to 50% flower					
	S_1's			Half-sib			S_1's			Half-sib			S_1's			Half-sib			S_1's			Half-sib		
	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled
1	53.7	60.3	57.0	55.0	71.0	63.0	53.0	57.8	55.4	48.8	64.3	56.6	13.7	12.9	13.3	10.2	10.8	10.5	50	47	48	42	45	43
2	48.2	77.4	62.8	49.6	59.6	54.6	41.7	65.3	53.5	51.7	58.7	55.2	11.2	11.4	11.3	12.2	11.0	11.6	45	43	44	48	47	47
3	45.2	62.0	53.6	45.1	69.5	57.3	44.9	62.1	53.5	44.7	55.8	50.2	10.3	10.6	10.5	15.5	13.2	14.3	44	44	44	43	44	43
4	26.7	32.1	29.4	58.6	56.3	57.4	30.1	33.9	32.0	48.7	47.2	47.9	10.4	10.5	10.4	13.3	12.6	12.9	46	47	46	46	44	45
5	49.6	55.8	52.7	43.7	51.3	47.5	53.9	54.4	54.1	43.4	50.7	47.0	10.0	9.1	9.6	10.5	11.6	11.1	42	44	43	43	45	44
6	42.2	57.5	49.8	43.5	59.2	51.3	39.0	54.8	46.9	47.9	53.1	50.5	14.6	12.2	13.4	11.6	11.3	11.4	44	43	43	46	46	46
7	47.9	54.7	51.3	45.6	52.6	49.1	54.5	54.7	54.6	45.2	54.1	49.7	11.1	12.4	11.8	13.6	12.4	13.0	45	45	45	45	42	44
8	30.5	51.7	41.1	56.4	62.2	59.3	36.6	50.0	43.3	51.6	54.4	53.0	9.8	10.4	10.1	11.0	10.4	10.7	50	50	50	46	45	46
9	51.6	73.7	62.6	37.5	56.2	46.9	43.3	54.1	48.7	37.2	57.5	47.4	12.1	10.9	11.5	10.9	13.4	12.1	45	47	46	46	45	45
10	52.2	80.0	66.1	41.3	57.2	49.2	52.2	72.4	62.3	44.1	53.9	49.0	11.3	12.1	11.7	10.5	11.2	10.8	43	46	44	47	45	46
11	51.2	92.8	72.0	35.2	51.5	43.3	57.1	70.9	64.0	31.7	52.0	41.9	12.6	11.8	12.2	11.4	12.1	11.8	47	46	46	44	45	44
12	42.0	59.2	50.6	44.4	57.8	51.1	43.7	51.5	47.6	43.1	51.6	47.4	10.2	10.6	10.4	14.1	12.8	13.4	50	48	49	44	45	45
13	57.9	63.6	60.8	32.9	51.1	42.0	60.1	67.6	63.8	37.2	50.1	43.6	13.1	11.7	12.4	11.2	11.6	11.4	48	51	49	47	47	47
14	60.7	90.3	75.5	34.5	50.2	42.3	60.0	81.2	70.6	45.8	54.2	50.0	11.7	11.3	11.5	12.6	14.5	13.6	47	44	45	47	46	46
15	37.3	50.8	44.1	40.4	51.1	45.7	35.6	55.0	45.3	36.2	51.7	43.9	10.0	10.0	10.0	12.0	11.5	11.7	49	49	49	45	44	45
16	49.7	65.8	57.8	36.0	57.2	46.6	50.1	56.6	53.3	36.1	58.2	47.2	13.0	13.3	13.2	10.3	12.5	11.4	49	46	47	48	46	47
17	48.8	56.8	52.8	55.5	70.3	62.9	39.8	55.6	47.7	54.9	63.1	59.0	12.9	11.9	12.4	13.4	13.1	13.2	51	50	50	42	41	42
18	50.7	62.8	56.7	43.1	44.6	43.8	47.8	51.2	49.5	42.2	51.7	46.9	10.0	8.8	9.4	12.1	13.4	12.8	45	45	45	43	43	43
19	43.1	56.6	49.9	38.8	59.1	49.0	40.1	49.4	44.7	41.0	55.0	48.0	9.9	11.6	10.7	12.8	11.9	12.3	45	45	45	47	47	47
20	43.0	52.3	47.6	53.4	75.5	64.4	49.8	48.8	49.3	43.0	63.5	53.3	12.7	11.3	12.0	13.6	13.0	13.3	47	45	46	44	44	44
21	40.1	56.9	48.5	47.9	61.5	54.7	37.5	51.3	44.4	41.1	50.2	45.6	10.2	9.3	9.8	11.9	12.0	11.9	45	45	45	45	44	44
22	43.6	56.7	50.2	46.7	52.6	49.6	38.1	48.6	43.3	44.9	50.6	47.7	13.6	11.2	12.4	12.3	12.7	12.5	47	47	47	44	41	42
23	46.7	58.6	52.7	41.7	51.1	46.4	58.9	60.5	59.7	42.1	49.6	45.8	11.2	13.0	12.1	13.2	12.0	12.6	47	46	46	45	46	46
24	36.5	55.9	46.2	44.6	56.0	50.3	37.0	57.4	47.2	42.6	54.6	48.6	9.5	8.2	8.9	12.1	11.8	12.0	44	44	44	45	41	43

Appendix V (a). Contd.,

Progeny No.	Grain Fe (mg kg^{-1})						Grain Zn (mg kg^{-1})						1000-grain mass (g)						Days to 50% flower					
	S_1's			Half-sib			S_1's			Half-sib			S_1's			Half-sib			S_1's			Half-sib		
	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled
25	40.4	49.8	45.1	46.7	60.2	53.5	39.8	47.2	43.5	43.3	56.1	49.7	9.0	9.7	9.3	16.4	13.5	14.9	51	49	50	46	44	45
26	36.5	62.9	49.7	44.8	65.4	55.1	36.3	57.4	46.8	43.1	62.9	53.0	9.5	8.1	8.8	8.9	9.9	9.4	44	46	45	43	46	45
27	60.3	61.9	61.1	41.9	61.7	51.8	46.1	52.3	49.2	38.8	56.1	47.4	13.9	11.6	12.8	9.7	12.8	11.2	50	47	48	46	47	46
28	42.5	50.9	46.7	42.4	49.8	46.1	38.3	48.5	43.4	45.5	51.5	48.5	8.5	13.3	10.9	11.3	13.2	12.3	50	47	48	44	44	44
29	45.6	49.4	47.5	41.7	46.1	43.9	44.5	45.2	44.8	40.2	49.9	45.0	8.9	9.6	9.3	11.2	11.0	11.1	46	46	46	45	44	45
30	60.5	68.9	64.7	43.8	55.7	49.7	56.4	54.9	55.6	47.9	55.5	51.7	11.0	9.3	10.2	13.6	13.4	13.5	46	47	46	46	44	45
31	46.5	54.5	50.5	40.0	63.2	51.6	41.1	44.3	42.7	40.5	54.5	47.5	11.3	11.6	11.4	12.8	13.4	13.1	51	47	49	41	41	41
32	33.8	50.5	42.2	37.9	58.7	48.3	36.2	52.3	44.2	42.0	55.1	48.6	11.7	12.5	12.1	14.6	12.5	13.6	51	45	48	44	43	44
33	46.6	96.3	71.4	41.9	56.7	49.3	47.5	79.9	63.7	43.7	53.9	48.8	13.5	12.4	12.9	11.3	11.5	11.4	48	46	47	44	45	44
34	57.5	79.0	68.2	37.4	47.8	42.6	45.2	58.6	51.9	38.5	49.3	43.9	11.2	12.9	12.0	10.2	12.4	11.3	50	46	48	45	44	44
35	35.3	51.7	43.5	52.0	58.0	55.0	37.8	49.0	43.4	45.3	61.8	53.5	10.1	9.8	9.9	12.3	11.6	11.9	48	46	47	45	45	45
36	40.6	56.2	48.4	42.9	49.7	46.3	37.1	56.5	46.8	42.0	48.1	45.0	9.2	10.2	9.7	13.8	12.2	13.0	44	48	46	41	41	41
37	54.2	68.0	61.1	44.8	63.7	54.2	50.3	56.5	53.4	38.8	52.2	45.5	11.7	12.2	12.0	11.7	13.3	12.5	45	43	44	43	45	44
38	32.4	75.4	53.9	35.4	59.3	47.4	28.1	63.2	45.6	45.4	53.4	49.4	11.9	13.4	12.7	11.9	10.4	11.1	44	45	45	43	44	44
39	45.5	67.7	56.6	33.8	53.2	43.5	43.0	58.8	50.9	45.5	51.0	48.3	11.1	9.9	10.5	14.6	12.3	13.4	44	44	44	44	45	45
40	41.1	58.2	49.6	54.0	65.5	59.8	36.8	49.7	43.2	48.5	57.5	53.0	10.9	13.6	12.3	11.7	12.9	12.3	51	47	49	45	44	44
41	35.5	60.5	48.0	56.1	59.5	57.8	41.5	55.3	48.4	50.1	48.4	49.3	11.8	12.2	12.0	12.6	13.8	13.2	50	46	48	45	45	45
42	50.5	68.6	59.5	39.2	63.8	51.5	46.3	51.3	48.8	49.6	59.9	54.8	15.8	12.3	14.1	12.3	12.0	12.1	47	48	47	47	44	45
43	56.5	66.5	61.5	41.6	42.7	42.1	49.3	52.7	51.0	45.8	49.1	47.4	11.3	9.6	10.5	13.2	11.7	12.5	50	51	50	47	46	46
44	43.4	75.2	59.3	36.6	58.4	47.5	49.1	55.4	52.3	32.5	54.8	43.7	10.4	10.9	10.6	11.8	12.8	12.3	50	46	48	46	49	47
45	57.4	118.4	87.9	34.5	53.6	44.0	51.3	79.8	65.6	40.5	42.8	41.7	10.1	11.3	10.7	11.6	12.6	12.1	43	42	42	47	46	46
46	45.5	67.4	56.5	43.9	63.3	53.6	45.7	72.9	59.3	39.4	62.9	51.2	12.0	10.0	11.0	10.9	11.1	11.0	49	51	50	46	45	45
47	30.3	54.7	42.5	45.7	57.6	51.6	33.3	51.1	42.2	43.8	53.1	48.4	11.3	8.7	10.0	10.8	14.1	12.5	44	46	45	45	46	45
48	40.3	106.7	73.5	41.2	56.3	48.8	40.8	92.5	66.7	40.4	54.4	47.4	11.5	10.1	10.8	12.6	13.0	12.8	49	45	47	43	44	44
49	42.6	57.5	50.1	39.7	60.0	49.8	39.8	55.9	47.9	45.8	52.7	49.2	10.6	12.7	11.6	12.0	12.9	12.5	50	46	48	45	44	44

Appendix V (a). Contd.,

Progeny No.	Grain Fe (mg kg^{-1})						Grain Zn (mg kg^{-1})						1000-grain mass (g)						Days to 50% flower					
	S$_1$'s			Half-sib			S$_1$'s			Half-sib			S$_1$'s			Half-sib			S$_1$'s			Half-sib		
	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled
50	36.3	69.6	53.0	54.7	74.8	64.7	36.0	64.9	50.4	54.8	64.0	59.4	9.0	8.8	8.9	13.1	10.5	11.8	46	45	45	49	45	47
51	45.6	66.5	56.0	39.4	63.1	51.2	50.6	63.0	56.8	42.8	62.3	52.6	10.9	9.6	10.2	12.7	12.0	12.4	47	47	47	45	45	45
52	32.0	52.4	42.2	35.5	51.3	43.4	38.1	53.1	45.6	41.5	46.4	43.9	12.1	10.2	11.1	12.4	13.1	12.8	48	47	47	42	44	43
53	42.2	74.5	58.4	42.1	65.1	53.6	44.6	59.0	51.8	44.8	61.0	52.9	13.0	11.9	12.4	11.4	11.6	11.5	46	44	45	44	43	44
54	42.6	52.4	47.5	47.4	65.0	56.2	38.2	54.4	46.3	47.6	60.0	53.8	8.8	10.1	9.4	12.8	12.0	12.4	46	46	46	47	46	46
55	54.4	64.4	59.4	41.8	61.6	51.7	46.4	60.1	53.2	42.6	60.3	51.4	10.1	14.0	12.0	11.8	11.1	11.4	47	45	46	46	44	45
56	54.9	82.0	68.5	48.0	53.7	50.9	49.8	62.8	56.3	52.0	55.1	53.5	10.2	7.6	8.9	11.8	14.7	13.2	46	46	46	47	46	46
57	37.6	52.0	44.8	37.9	50.1	44.0	39.7	46.4	43.0	40.0	46.7	43.3	13.6	9.0	11.3	11.1	14.5	12.8	50	49	49	43	43	43
58	59.6	81.6	70.6	31.9	66.2	49.0	57.6	69.8	63.7	31.7	60.2	45.9	13.4	11.3	12.3	12.0	12.6	12.3	51	46	48	46	45	45
59	55.3	93.8	74.6	49.4	64.7	57.0	48.9	65.0	57.0	53.9	59.5	56.7	11.8	10.1	11.0	14.9	13.5	14.2	46	48	47	42	44	43
60	74.7	68.3	71.5	37.4	63.8	50.6	56.8	71.1	63.9	39.1	61.6	50.3	13.0	12.8	12.9	11.6	13.3	12.4	46	47	47	45	45	45
Mean	45.9	65.3	55.6	43.3	58.2	50.7	44.5	57.9	51.2	43.5	54.8	49.2	11.3	11.0	11.2	12.2	12.4	12.3	47	46	46	45	44	45
Minimum	26.7	32.1	29.4	31.9	42.7	42.0	28.1	33.9	32.0	31.7	42.8	41.7	8.5	7.6	8.8	8.9	9.9	9.4	42	42	42	41	41	41
Maximum	74.7	118.4	87.9	58.6	75.5	64.7	60.1	92.5	70.6	54.9	64.3	59.4	15.8	14.0	14.1	16.4	14.7	14.9	51	51	50	49	49	47

R´09 = Rainy 2009; S´10 = Summer 2010

Appendix V (b). *Per se* performance of selfed (S_1) and half-sib (HS) progenies for grain Fe and Zn concentration, 1000-grain mass and days to 50% flower in ICMR 312, rainy 2009 and summer 2010, Patancheru.

Progeny No.	Grain Fe (mg kg^{-1})						Grain Zn (mg kg^{-1})						1000-grain mass (g)						Days to 50% flower					
	S_1's			Half-sib			S_1's			Half-sib			S_1's			Half-sib			S_1's			Half-sib		
	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled
1	45.8	74.4	60.1	38.4	78.2	58.3	38.7	57.1	47.9	36.3	61.4	48.8	11.8	11.1	11.5	11.5	12.1	11.8	48	48	48	49	50	49
2	43.3	67.3	55.3	35.3	47.9	41.6	42.8	48.7	45.8	37.0	47.9	42.5	10.7	13.3	12.0	12.9	12.6	12.8	48	49	48	47	49	48
3	50.7	81.3	66.0	47.3	57.6	52.5	52.4	67.2	59.8	43.0	44.3	43.6	14.2	14.3	14.2	12.9	13.3	13.1	47	49	48	47	48	47
4	53.3	73.0	63.1	37.3	64.3	50.8	49.1	65.2	57.2	39.8	52.3	46.0	10.7	8.8	9.7	13.7	12.9	13.3	51	50	51	46	47	46
5	43.2	66.6	54.9	37.0	58.6	47.8	41.4	56.5	48.9	39.2	53.0	46.1	13.8	12.0	12.9	14.7	13.5	14.1	47	47	47	47	46	46
6	43.9	65.2	54.5	40.1	68.8	54.4	36.2	52.8	44.5	35.3	55.6	45.4	12.6	11.4	12.0	14.7	12.9	13.8	52	51	51	48	48	48
7	42.5	61.6	52.1	42.3	62.1	52.2	39.3	50.6	45.0	39.9	48.9	44.4	12.0	14.3	13.1	15.6	12.9	14.3	49	50	49	48	49	48
8	33.6	70.6	52.1	40.1	75.3	57.7	34.5	52.7	43.6	38.9	57.3	48.1	11.0	11.7	11.4	13.4	13.7	13.6	52	49	50	45	47	46
9	38.3	58.4	48.4	34.0	57.0	45.5	35.8	55.2	45.5	29.8	44.8	37.3	12.1	13.1	12.6	13.3	13.4	13.3	41	45	43	46	48	47
10	70.1	108.4	89.2	33.8	58.7	46.2	61.9	77.5	69.7	29.6	49.9	39.8	14.8	9.4	12.1	11.4	11.5	11.4	48	51	49	51	50	50
11	39.7	57.1	48.4	47.2	74.5	60.8	40.4	52.7	46.5	36.4	54.9	45.6	8.9	10.1	9.5	12.8	13.2	13.0	49	49	49	51	49	50
12	54.6	79.1	66.8	37.3	42.4	39.8	42.8	59.7	51.3	35.5	43.8	39.7	13.2	11.4	12.3	12.7	12.0	12.3	46	46	46	45	47	46
13	40.7	58.4	49.6	43.7	70.4	57.0	40.4	52.8	46.6	37.4	51.1	44.2	8.5	10.6	9.6	16.6	13.9	15.3	48	48	48	48	48	48
14	46.5	65.9	56.2	39.2	73.1	56.2	60.1	60.3	60.2	37.3	57.6	47.5	14.9	12.9	13.9	14.9	13.7	14.3	48	48	48	46	48	47
15	41.7	51.8	46.7	33.0	69.5	51.2	42.5	51.1	46.8	30.5	52.5	41.5	14.8	11.9	13.3	12.2	12.5	12.4	48	48	48	48	49	49
16	49.1	63.8	56.4	33.0	68.7	50.8	38.8	50.3	44.5	29.8	53.7	41.8	11.4	11.6	11.5	12.4	11.8	12.1	50	52	51	48	47	47
17	44.3	76.5	60.4	41.9	60.2	51.1	39.9	58.4	49.1	34.5	54.8	44.6	11.4	10.1	10.7	11.1	11.7	11.4	48	51	49	47	54	50
18	44.1	69.8	56.9	43.2	60.2	51.7	40.9	50.7	45.8	36.2	48.6	42.4	10.6	10.6	10.6	12.5	13.7	13.1	53	50	52	45	45	45
19	57.6	88.6	73.1	44.2	79.7	62.0	48.3	52.9	50.6	43.3	67.1	55.2	10.7	10.0	10.3	15.5	12.5	14.0	51	51	51	47	48	47
20	58.8	84.2	71.5	42.1	57.8	49.9	47.5	57.2	52.3	37.6	53.1	45.3	13.4	11.0	12.2	12.7	11.8	12.3	48	51	49	45	48	46
21	43.8	75.7	59.7	36.8	50.9	43.8	41.4	47.9	44.6	36.9	46.2	41.5	13.4	12.0	12.7	13.5	13.6	13.5	47	47	47	47	47	47
22	53.7	70.5	62.1	50.8	81.2	66.0	36.8	54.9	45.9	45.4	58.5	51.9	12.3	12.0	12.2	11.4	11.0	11.2	47	47	47	46	46	46
23	73.3	74.3	73.8	74.5	67.9	71.2	48.0	54.4	51.2	84.6	52.8	68.7	12.1	12.7	12.4	14.4	13.8	14.1	53	54	53	50	47	48
24	42.4	53.7	48.1	48.4	61.0	54.7	39.5	48.2	43.8	42.9	58.9	50.9	14.8	11.5	13.1	13.0	12.4	12.7	50	49	49	47	45	46

Appendix V (b). Cond.,

Progeny No.	Grain Fe (mg kg^{-1})						Grain Zn (mg kg^{-1})						1000-grain mass (g)						Days to 50% flower					
	S_1's			Half-sib			S_1's			Half-sib			S_1's			Half-sib			S_1's			Half-sib		
	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled
25	57.0	92.4	74.7	31.9	56.7	44.3	51.1	63.3	57.2	35.5	51.5	43.5	10.5	13.3	11.9	12.3	12.3	12.3	46	48	47	46	46	46
26	34.4	49.9	42.1	48.8	72.5	60.6	33.1	49.5	41.3	46.1	57.7	51.9	12.1	11.2	11.6	11.7	11.7	11.7	49	49	49	47	49	48
27	35.8	55.1	45.4	46.2	58.9	52.6	38.9	49.7	44.3	42.5	59.5	51.0	14.5	11.3	12.9	14.3	13.7	14.0	50	50	50	49	47	48
28	33.3	51.2	42.3	29.5	71.2	50.3	31.2	49.4	40.3	47.5	54.4	50.9	14.2	15.3	14.8	15.9	12.6	14.3	50	48	49	47	45	46
29	47.3	64.9	56.1	37.2	52.2	44.7	45.1	65.6	55.3	40.2	53.4	46.8	16.7	10.5	13.6	15.3	13.1	14.2	49	49	49	44	46	45
30	44.8	74.8	59.8	37.6	69.5	53.5	39.5	59.3	49.4	38.8	51.7	45.2	10.4	9.4	9.9	13.7	12.9	13.3	49	49	49	47	48	47
31	35.5	66.8	51.2	51.2	67.3	59.2	36.5	50.5	43.5	43.3	55.9	49.6	11.0	12.3	11.7	14.9	12.4	13.7	46	47	46	48	49	49
32	34.2	86.1	60.2	35.1	66.1	50.6	35.9	60.4	48.1	36.1	56.2	46.1	11.6	12.1	11.8	12.6	10.9	11.7	48	49	48	49	50	50
33	47.0	97.6	72.3	40.3	54.0	47.1	36.1	73.1	54.6	43.5	52.2	47.9	9.6	11.5	10.5	12.0	11.7	11.8	49	50	49	49	47	48
34	33.2	56.1	44.7	39.2	65.7	52.5	29.1	44.4	36.8	35.1	53.9	44.5	11.9	14.8	13.4	10.7	14.2	12.5	42	46	44	47	48	48
35	46.8	66.3	56.5	35.8	60.2	48.0	45.3	49.7	47.5	35.9	54.9	45.4	12.9	12.3	12.6	11.3	12.7	12.0	46	47	47	49	47	48
36	34.4	71.0	52.7	38.5	64.0	51.2	34.7	49.1	41.9	35.0	54.2	44.6	10.2	10.1	10.2	13.1	13.1	13.1	48	54	51	49	48	48
37	38.1	82.7	60.4	30.2	55.7	42.9	42.6	64.0	53.3	33.1	49.1	41.1	10.1	8.6	9.4	12.4	11.3	11.8	47	50	49	47	46	46
38	44.4	63.8	54.1	40.8	55.3	48.0	34.1	55.8	44.9	40.4	47.6	44.0	13.4	12.6	13.0	16.2	13.1	14.6	47	50	48	51	48	50
39	49.1	81.3	65.2	45.7	63.6	54.6	53.0	65.4	59.2	47.5	56.9	52.2	17.4	15.0	16.2	12.5	11.5	12.0	49	49	49	47	48	48
40	37.1	65.8	51.4	40.6	68.7	54.7	33.7	56.0	44.9	38.9	53.1	46.0	11.7	9.1	10.4	13.2	12.1	12.7	49	50	50	47	48	47
41	38.9	67.0	52.9	66.4	62.0	64.2	35.9	60.1	48.0	53.4	51.1	52.2	12.9	12.3	12.6	13.3	12.3	12.8	49	47	48	49	49	49
42	42.5	74.9	58.7	36.7	60.5	48.6	47.0	56.2	51.6	37.1	47.0	42.0	11.3	8.9	10.1	11.8	15.1	13.5	48	48	48	47	47	47
43	52.5	77.0	64.7	33.4	70.5	51.9	37.6	60.0	48.8	34.4	52.4	43.4	10.1	13.1	11.6	11.4	13.8	12.6	51	49	50	48	48	48
44	49.7	67.8	58.7	35.3	53.1	44.2	42.3	59.1	50.7	29.7	52.4	41.0	10.2	11.8	11.0	13.2	12.9	13.1	48	50	49	47	47	47
45	39.3	60.2	49.8	35.6	57.2	46.4	41.4	46.9	44.1	35.6	52.1	43.9	11.7	11.7	11.7	11.5	12.5	12.0	48	46	47	48	49	48
46	46.2	58.0	52.1	32.0	68.3	50.1	47.3	54.6	51.0	35.9	62.1	49.0	11.5	10.4	11.0	10.8	11.8	11.3	48	46	47	46	46	46
47	37.4	52.7	45.1	36.3	57.5	46.9	40.1	53.3	46.7	38.2	52.7	45.5	12.6	11.1	11.8	14.0	13.5	13.8	46	46	46	47	47	47
48	50.1	93.1	71.6	42.8	56.6	49.7	50.8	72.6	61.7	27.9	50.1	39.0	12.3	12.7	12.5	11.7	12.9	12.3	48	47	47	48	48	48
49	39.8	56.8	48.3	44.2	63.8	54.0	39.7	51.1	45.4	44.4	57.5	51.0	10.5	12.5	11.5	13.6	12.7	13.1	47	47	47	45	49	47

Appendix V (b). Cond.,

Progeny No.	Grain Fe (mg kg^{-1})						Grain Zn (mg kg^{-1})						1000-grain mass (g)						Days to 50% flower					
	S$_1$'s			Half-sib			S$_1$'s			Half-sib			S$_1$'s			Half-sib			S$_1$'s			Half-sib		
	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled	R´09	S´10	Pooled
50	51.4	93.4	72.4	38.1	59.0	48.6	56.5	75.6	66.1	35.2	51.8	43.5	10.9	11.6	11.2	12.7	13.9	13.3	53	51	52	44	46	45
51	32.6	63.8	48.2	38.7	63.5	51.1	39.8	61.0	50.4	37.7	50.9	44.3	12.3	10.9	11.6	11.9	11.9	11.9	48	50	49	50	50	50
52	37.4	51.3	44.3	38.2	75.2	56.7	34.1	48.4	41.2	34.9	51.3	43.1	9.6	12.2	10.9	11.8	12.1	11.9	52	50	51	47	46	46
53	42.7	64.5	53.6	35.7	69.8	52.7	41.6	53.5	47.6	37.1	58.3	47.7	13.2	9.7	11.5	12.1	12.3	12.2	48	48	48	48	48	48
54	33.5	69.9	51.7	39.1	66.9	53.0	33.2	56.9	45.1	36.4	61.0	48.7	10.6	12.5	11.6	11.7	12.6	12.1	49	48	48	48	46	47
55	35.8	92.1	63.9	39.0	55.8	47.4	32.4	72.6	52.5	34.9	49.1	42.0	11.8	10.9	11.3	14.0	13.4	13.7	51	49	50	45	47	46
56	27.1	112.5	69.8	36.9	75.1	56.0	29.4	66.0	47.7	33.8	58.2	46.0	9.0	10.4	9.7	11.0	12.2	11.6	51	49	50	48	49	48
57	42.4	62.4	52.4	29.7	56.6	43.2	40.4	52.7	46.5	36.2	51.2	43.7	10.0	10.4	10.2	13.5	11.8	12.7	47	50	48	47	48	47
58	35.6	61.9	48.8	43.6	81.0	62.3	34.8	56.5	45.6	36.8	61.2	49.0	11.5	12.5	12.0	12.1	13.0	12.5	47	49	48	45	46	45
59	38.6	74.0	56.3	38.3	60.3	49.3	40.1	59.8	50.0	39.7	50.0	44.9	13.1	10.8	11.9	14.4	13.8	14.1	48	49	48	47	45	46
60	49.2	65.2	57.2	41.3	63.8	52.5	40.4	49.7	45.0	35.9	52.3	44.1	13.7	11.7	12.7	13.9	13.1	13.5	50	52	51	46	46	46
Mean	43.8	70.7	57.2	40.2	63.7	51.9	41.1	56.8	48.9	38.5	53.4	46.0	12.0	11.6	11.8	13.0	12.7	12.9	48	49	48	47	47	47
Minimum	27.1	49.9	42.1	29.5	42.4	39.8	29.1	44.4	36.8	27.9	43.8	37.3	8.5	8.6	9.4	10.7	10.9	11.2	41	45	43	44	45	45
Maximum	73.3	112.5	89.2	74.5	81.2	71.2	61.9	77.5	69.7	84.6	67.1	68.7	17.4	15.3	16.2	16.6	15.1	15.3	53	54	53	51	54	50

R´09 = Rainy 2009; S´10 = Summer 2010

Appendix VI. ***Per se*** **performance of ICTP 8203 S_0 plant and S_1 progenies for grain Fe and Zn concentrations, days to 50% flower and 1000-grain mass in summer and rainy 2009, Patancheru.**

Sl. No	S_1 Progenies	Grain Fe (mg kg^{-1})					Grain Zn (mg kg^{-1})					1000-grain mass (g)			Days to 50 % flower		
		S_0 plant	S_1 progeny				S_0 plant	S_1 progeny				S_1 progeny			S_1 progeny		
		Rainy 2008	Summer 2009	Rainy 2009	Pooled mean	% over S_0	Rainy 2008	Summer 2009	Rainy 2009	Pooled mean	% over S_0	Summer 2009	Rainy 2009	Pooled mean	Summer 2009	Rainy 2009	Pooled mean
1	ICTP 8203 S1 - 1	64.9	71.6	51.0	61.3	-6	47.4	56.4	44.5	50.4	6	13.4	12.5	12.9	44	49	46
2	ICTP 8203 S1 - 2	79.6	94.1	67.4	80.8	1	59.9	71.6	59.1	65.3	9	13.7	14.9	14.3	46	45	45
3	ICTP 8203 S1 - 3	80.2	111.9	70.4	91.1	14	67.5	77.6	66.1	71.8	6	12.3	16.2	14.3	44	44	44
4	ICTP 8203 S1 - 4	82.7	105.9	64.4	85.1	3	67.7	92.5	65.0	78.8	16	13.4	11.9	12.7	47	47	47
5	ICTP 8203 S1 - 5	76.4	100.2	70.9	85.5	12	65.0	83.6	60.8	72.2	11	12.4	12.7	12.5	51	46	49
6	ICTP 8203 S1 - 6	64.3	86.4	50.5	68.4	6	59.9	79.5	52.8	66.2	10	10.6	10.6	10.6	49	52	51
7	ICTP 8203 S1 - 7	64.4	95.4	78.0	86.7	35	58.3	82.8	67.4	75.1	29	13.1	14.6	13.9	47	47	47
8	ICTP 8203 S1 - 8	78.6	123.0	83.5	103.3	31	81.9	105.0	77.2	91.1	11	12.7	12.9	12.8	47	44	45
9	ICTP 8203 S1 - 9	68.8	95.7	59.8	77.8	13	63.7	81.6	56.4	69.0	8	9.0	9.8	9.4	45	43	44
10	ICTP 8203 S1 - 10	74.0	94.2	49.7	71.9	-3	45.7	85.0	47.8	66.4	45	11.7	11.5	11.6	44	42	43
11	ICTP 8203 S1 - 11	79.7	101.0	73.5	87.2	9	60.7	77.2	59.8	68.5	13	12.8	12.1	12.5	44	43	44
12	ICTP 8203 S1 - 12	70.2	122.0	87.2	104.6	49	62.1	100.1	75.5	87.8	41	11.4	11.2	11.3	49	42	45
13	ICTP 8203 S1 - 13	95.7	135.9	78.2	107.1	12	74.7	89.9	62.8	76.3	2	10.2	13.2	11.7	42	43	42
14	ICTP 8203 S1 - 14	93.6	124.0	82.4	103.2	10	84.9	98.4	70.4	84.4	-1	10.0	12.2	11.1	46	47	46
15	ICTP 8203 S1 - 15	62.9	93.7	54.5	74.1	18	55.8	87.5	51.6	69.6	25	12.6	11.1	11.8	44	44	44
16	ICTP 8203 S1 - 16	70.4	113.6	66.1	89.9	28	65.4	96.2	60.5	78.3	20	12.3	12.8	12.5	48	47	47
17	ICTP 8203 S1 - 17	57.2	108.5	52.9	80.7	41	50.7	86.3	45.3	65.8	30	8.8	10.0	9.4	47	47	47
18	ICTP 8203 S1 - 18	71.8	84.4	62.8	73.6	2	51.6	64.5	52.4	58.4	13	11.1	10.6	10.8	42	43	43
19	ICTP 8203 S1 - 19	75.1	109.0	110.0	109.5	46	68.9	89.7	73.4	81.6	18	12.7	12.4	12.6	44	49	47
20	ICTP 8203 S1 - 20	102.8	162.5	104.1	133.3	30	76.1	104.9	76.6	90.8	19	12.5	12.2	12.3	45	44	44
21	ICTP 8203 S1 - 21	76.2	90.7	77.8	84.3	11	62.3	73.1	68.2	70.6	13	11.9	13.2	12.6	48	48	48
22	ICTP 8203 S1 - 22	83.0	87.2	65.7	76.4	-8	60.8	79.5	58.6	69.1	14	12.6	10.7	11.7	45	43	44
23	ICTP 8203 S1 - 23	80.8	114.7	75.9	95.3	18	70.4	85.1	62.5	73.8	5	13.2	12.4	12.8	48	46	47
24	ICTP 8203 S1 - 24	88.3	118.7	102.9	110.8	26	71.4	94.4	80.8	87.6	23	16.9	14.6	15.8	40	45	42
25	ICTP 8203 S1 - 25	64.3	93.2	86.8	90.0	40	68.7	88.4	74.8	81.6	19	14.0	12.4	13.2	48	47	47
26	ICTP 8203 S1 - 26	94.3	126.7	92.0	109.3	16	70.9	86.9	59.2	73.1	3	14.0	13.9	13.9	48	45	46
27	ICTP 8203 S1 - 27	78.2	139.2	95.0	117.1	50	65.9	99.1	78.1	88.6	34	13.3	14.3	13.8	47	45	46
28	ICTP 8203 S1 - 28	72.6	108.3	76.7	92.5	27	58.6	70.5	61.1	65.8	12	12.8	14.8	13.8	48	48	48
29	ICTP 8203 S1 - 29	88.9	154.4	86.4	120.4	36	68.9	89.5	71.3	80.4	17	12.4	11.2	11.8	49	50	49
30	ICTP 8203 S1 - 30	87.1	120.6	76.9	98.7	13	71.4	86.3	62.8	74.5	4	13.2	13.7	13.4	46	47	46

Appendix VI. Contd.,

Sl. No	S_1 Progenies	Grain Fe (mg kg^{-1})					Grain Zn (mg kg^{-1})					1000-grain mass (g)			Days to 50 % flower		
		S_0 plant	S_1 progeny				S_0 plant	S_1 progeny				S_1 progeny			S_1 progeny		
		Rainy 2008	Summer 2009	Rainy 2009	Pooled mean	% over S_0	Rainy 2008	Summer 2009	Rainy 2009	Pooled mean	% over S_0	Summer 2009	Rainy 2009	Pooled mean	Summer 2009	Rainy 2009	Pooled mean
31	ICTP 8203 S1 - 31	90.3	116.2	68.8	92.5	2	76.3	92.4	62.6	77.5	2	17.6	13.8	15.7	44	44	44
32	ICTP 8203 S1 - 32	93.5	102.9	63.1	83.0	-11	74.8	84.4	55.3	69.8	-7	15.4	13.3	14.3	47	47	47
33	ICTP 8203 S1 - 33	78.1	135.9	84.3	110.1	41	65.4	102.3	69.4	85.8	31	13.1	12.0	12.6	49	50	49
34	ICTP 8203 S1 - 34	74.1	95.7	78.4	87.0	17	57.0	73.9	66.9	70.4	23	9.9	8.3	9.1	50	52	51
35	ICTP 8203 S1 - 35	92.2	127.3	65.1	96.2	4	68.2	83.6	56.6	70.1	3	13.2	13.3	13.2	46	45	45
36	ICTP 8203 S1 - 36	74.4	112.2	55.2	83.7	12	61.6	102.6	62.9	82.7	34	11.0	13.3	12.2	48	46	47
37	ICTP 8203 S1 - 37	64.3	90.7	63.5	77.1	20	64.8	80.8	54.0	67.4	4	9.8	11.7	10.8	43	45	44
38	ICTP 8203 S1 - 38	78.4	101.7	64.0	82.8	6	62.0	81.3	53.9	67.6	9	15.5	12.8	14.1	45	46	45
39	ICTP 8203 S1 - 39	67.9	96.7	63.3	80.0	18	53.8	80.1	53.6	66.8	24	11.1	14.3	12.7	48	49	48
40	ICTP 8203 S1 - 40	52.8	77.8	50.8	64.3	22	58.4	78.4	56.6	67.5	16	14.4	14.2	14.3	46	48	47
	Mean	77.3	108.6	72.7	90.7	18	64.5	85.6	62.4	74.0	15	12.6	12.6	12.6	46	46	46
	Minimum	52.8	71.6	49.7	61.3	-11	45.7	56.4	44.5	50.4	-7	8.8	8.3	9.1	40	42	42
	Maximum	102.8	162.5	110.0	133.3	50	84.9	105.0	80.8	91.1	45	17.6	16.2	15.8	51	52	51
	CD (5%)		24.8	29.0	26.2			16.3	15.7	15.8		1.0	1.8	1.7	2.4	1.5	2.1
	CV (%)		11.3	19.7	14.7			9.4	12.4	10.7		3.9	7.1	5.7	2.6	1.6	2.1

Appendix VII. ***Per se*** **performance of JBV 3 S_0 plant and S_1 progenies for grain Fe and Zn concentrations, days to 50% flower and 1000-grain mass in summer and rainy 2009, Patancheru.**

Sl. No	S_1 Progenies	Grain Fe (mg kg^{-1})					Grain Zn (mg kg^{-1})					1000-grain mass (g)			Days to 50 % flower		
		S_0 plant	S_1 progeny				S_0 plant	S_1 progeny				S_1 progeny			S_1 progeny		
		Rainy 2008	Summer 2009	Rainy 2009	Pooled mean	% over S_0	Rainy 2008	Summer 2009	Rainy 2009	Pooled mean	% over S_0	Summer 2009	Rainy 2009	Pooled mean	Summer 2009	Rainy 2009	Pooled mean
1	JBV 3 S1 - 1	45.7	57.4	35.4	46.4	2	53.3	60.4	41.8	51.1	-4	10.3	8.1	9.2	50	53	51
2	JBV 3 S1 - 2	38.3	49.8	31.7	40.7	6	38.6	57.2	40.0	48.6	26	7.1	8.4	7.7	51	51	51
3	JBV 3 S1 - 3	61.0	77.8	49.8	63.8	5	69.5	84.2	51.9	68.1	-2	8.9	8.8	8.9	49	52	50
4	JBV 3 S1 - 4	55.9	93.1	56.0	74.5	33	44.9	71.0	51.8	61.4	37	8.7	7.8	8.3	50	50	50
5	JBV 3 S1 - 5	61.0	85.3	50.0	67.6	11	42.0	56.3	35.2	45.8	9	6.6	7.1	6.8	55	53	54
6	JBV 3 S1 - 6	47.6	72.8	41.9	57.3	20	45.1	57.1	34.6	45.8	2	7.1	8.7	7.9	55	50	52
7	JBV 3 S1 - 7	40.3	57.0	33.9	45.4	13	39.1	45.9	31.6	38.8	-1	8.2	7.9	8.0	55	54	54
8	JBV 3 S1 - 8	58.3	93.0	52.5	72.8	25	47.3	72.0	43.2	57.6	22	7.0	8.2	7.6	56	51	53
9	JBV 3 S1 - 9	29.5	53.4	27.7	40.5	37	34.8	57.1	35.0	46.0	32	7.6	8.6	8.1	56	56	56
10	JBV 3 S1 - 10	46.1	62.1	34.2	48.2	5	44.6	65.1	39.2	52.2	17	10.4	8.3	9.4	53	53	53
11	JBV 3 S1 - 11	57.2	93.9	53.5	73.7	29	50.9	84.4	51.5	67.9	33	6.9	7.1	7.0	56	53	54
12	JBV 3 S1 - 12	55.3	69.5	33.4	51.5	-7	53.5	75.4	40.6	58.0	8	8.3	8.0	8.2	49	51	50
13	JBV 3 S1 - 13	38.8	54.5	36.9	45.7	18	36.2	56.0	36.9	46.5	28	8.0	7.0	7.5	51	50	51
14	JBV 3 S1 - 14	74.9	151.0	75.2	113.1	51	73.2	106.1	71.6	88.9	21	7.2	8.9	8.1	55	49	52
15	JBV 3 S1 - 15	59.3	96.8	49.8	73.3	24	58.7	74.4	42.2	58.3	-1	9.1	9.3	9.2	51	51	51
16	JBV 3 S1 - 16	41.0	69.7	41.3	55.5	35	38.3	61.8	40.2	51.0	33	9.2	9.5	9.4	46	46	46
17	JBV 3 S1 - 17	55.7	60.2	35.2	47.7	-14	47.5	56.5	37.5	47.0	-1	10.0	12.0	11.0	48	46	47
18	JBV 3 S1 - 18	53.3	94.4	57.5	76.0	43	52.1	75.0	53.7	64.3	23	8.4	7.6	8.0	45	50	47
19	JBV 3 S1 - 19	41.6	69.4	52.6	61.0	47	41.8	66.2	63.8	65.0	56	7.7	7.2	7.4	55	51	53
20	JBV 3 S1 - 20	40.9	44.3	30.3	37.3	-9	36.1	44.3	30.9	37.6	4	7.5	7.3	7.4	49	50	50
21	JBV 3 S1 - 21	53.8	70.4	51.4	60.9	13	53.9	72.6	45.2	58.9	9	8.8	9.1	8.9	49	50	49
22	JBV 3 S1 - 22	57.8	65.4	50.1	57.7	0	44.1	58.2	48.8	53.5	21	7.6	7.5	7.6	53	53	53
23	JBV 3 S1 - 23	43.6	63.4	37.2	50.3	15	37.3	56.8	35.4	46.1	24	8.2	9.1	8.6	50	49	50
24	JBV 3 S1 - 24	44.2	66.2	43.0	54.6	24	40.2	53.2	36.1	44.6	11	8.6	9.5	9.1	51	50	50
25	JBV 3 S1 - 25	51.6	56.5	48.6	52.5	2	53.3	61.2	56.9	59.1	11	9.5	7.9	8.7	49	52	50
26	JBV 3 S1 - 26	38.9	89.2	46.2	67.7	74	33.7	72.3	41.5	56.9	69	9.0	10.1	9.5	54	53	53
27	JBV 3 S1 - 27	50.3	54.9	39.4	47.2	-6	53.3	48.2	36.1	42.1	-21	7.6	7.9	7.7	44	52	48
28	JBV 3 S1 - 28	33.7	45.6	32.4	39.0	16	33.7	44.7	35.7	40.2	19	7.5	8.2	7.8	53	49	51
29	JBV 3 S1 - 29	45.0	85.8	48.6	67.2	49	37.8	61.7	43.5	52.6	39	10.3	9.8	10.0	48	51	49
30	JBV 3 S1 - 30	58.1	70.9	41.3	56.1	-3	59.9	65.9	43.1	54.5	-9	7.6	8.4	8.0	49	46	47

Appendix VII. Contd.,

Sl. No	S$_1$ Progenies	Grain Fe (mg kg^{-1})					Grain Zn (mg kg^{-1})					1000-grain mass (g)			Days to 50 % flower		
		S$_0$ plant	S$_1$ progeny			% over S$_0$	S$_0$ plant	S$_1$ progeny			% over S$_0$	S$_1$ progeny			S$_1$ progeny		
		Rainy 2008	Summer 2009	Rainy 2009	Pooled mean		Rainy 2008	Summer 2009	Rainy 2009	Pooled mean		Summer 2009	Rainy 2009	Pooled mean	Summer 2009	Rainy 2009	Pooled mean
31	JBV 3 S1 - 31	58.7	63.8	36.8	50.3	-14	48.8	60.9	38.2	49.6	2	6.8	6.5	6.7	50	52	51
32	JBV 3 S1 - 32	45.7	44.8	33.0	38.9	-15	45.8	47.8	35.8	41.8	-9	8.0	7.0	7.5	50	49	50
33	JBV 3 S1 - 33	45.5	65.5	45.7	55.6	22	49.5	66.2	47.6	56.9	15	8.0	7.8	7.9	48	51	49
34	JBV 3 S1 - 34	67.0	39.8	33.4	36.6	-45	52.5	48.1	38.3	43.2	-18	7.7	10.6	9.2	50	49	50
35	JBV 3 S1 - 35	45.0	61.9	41.9	51.9	15	40.2	50.9	41.7	46.3	15	10.6	8.5	9.6	48	52	50
36	JBV 3 S1 - 36	54.4	75.4	45.8	60.6	11	45.6	67.5	47.3	57.4	26	8.2	7.7	8.0	54	52	53
37	JBV 3 S1 - 37	73.9	79.6	57.7	68.7	-7	56.0	64.1	45.9	55.0	-2	7.2	7.3	7.2	55	55	55
38	JBV 3 S1 - 38	58.0	92.7	54.0	73.4	27	47.7	65.8	40.3	53.1	11	9.4	8.2	8.8	47	52	49
39	JBV 3 S1 - 39	41.4	78.0	45.6	61.8	49	41.3	69.8	37.5	53.7	30	7.9	9.0	8.5	54	49	52
40	JBV 3 S1 - 40	45.2	60.0	40.7	50.4	11	51.9	71.0	43.5	57.3	10	9.2	11.1	10.2	51	49	50
	Mean	50.3	70.9	43.8	57.3	15	46.8	63.3	42.8	53.1	15	8.3	8.4	8.4	51	51	51
	Minimum	29.5	39.8	27.7	36.6	-45	33.7	44.3	30.9	37.6	-21	6.6	6.5	6.7	44	46	46
	Maximum	74.9	151.0	75.2	113.1	74	73.2	106.1	71.6	88.9	69	10.6	12.0	11.0	56	56	56
	CD (5%)		15.4	14.4	15.4			14.6	16.0	15.1		1.0	1.4	1.2	2.4	1.5	1.9
	CV (%)		10.7	16.3	12.8			11.4	18.5	14.3		5.7	8.3	7.1	2.3	1.5	1.9

Appendix VIII. ***Per se*** **performance of AIMP 92901 S_0 plant and S_1 progenies for grain Fe and Zn concentrations,1000-grain mass, days to 50% flowering and grain yield in rainy 2009 and summer 2010, Patancheru.**

Sl. No	Entry	Grain Fe (mg kg^{-1})					Grain Zn (mg kg-1)					1000-grain mass (g)			Days to 50 % flower			Grain yield (kg ha^{-1})		
		S_0 plant	S_1 progeny				S_0 plant	S_1 progeny				S_1 progeny			S_1 progeny			S_1 progeny		
		Summer 2009	Rainy 2009	Summer 2010	Pooled mean	% over S_0	Summer 2009	Rainy 2009	Summer 2010	Pooled mean	% over S_0	Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean
1	AIMP 92901 S1- 1	91.1	49.5	84.9	67.2	-26	69.9	44.6	70.7	57.6	-17	9.8	10.1	9.9	46	46	46	1403	1565	1484
2	AIMP 92901 S1- 2	60.8	50.4	77.7	64.0	5	53.4	43.5	58.9	51.2	-4	11.2	11.8	11.5	50	49	50	2005	2200	2103
3	AIMP 92901 S1- 3	66.9	62.0	74.9	68.5	2	53.2	48.6	64.1	56.3	6	11.0	10.4	10.7	43	44	43	1808	3385	2597
4	AIMP 92901 S1- 4	61.4	67.2	124.9	96.1	56	61.6	58.3	99.2	78.7	28	11.8	13.2	12.5	44	43	43	1504	2305	1905
5	AIMP 92901 S1- 5	74.4	46.8	69.7	58.3	-22	52.1	40.1	62.9	51.5	-1	9.8	11.5	10.6	52	47	49	2204	3293	2749
6	AIMP 92901 S1- 6	70.3	43.7	90.2	67.0	-5	61.3	48.7	68.1	58.4	-5	11.4	10.1	10.8	45	44	44	1464	2200	1832
7	AIMP 92901 S1- 7	69.4	44.9	66.1	55.5	-20	74.0	52.6	63.3	57.9	-22	14.3	12.2	13.2	44	45	44	2136	2591	2364
8	AIMP 92901 S1- 8	44.3	39.2	62.3	50.7	15	45.7	33.5	53.4	43.5	-5	8.9	8.8	8.9	53	50	52	2115	3283	2699
9	AIMP 92901 S1- 9	57.6	58.6	65.8	62.2	8	52.7	56.8	66.0	61.4	17	9.2	10.8	10.0	51	44	48	1957	2573	2265
10	AIMP 92901 S1- 10	47.9	40.6	83.9	62.2	30	50.1	41.2	62.5	51.8	3	11.4	9.5	10.4	44	46	45	1729	2197	1963
11	AIMP 92901 S1- 11	69.4	62.7	89.1	75.9	9	78.9	57.0	75.2	66.1	-16	11.0	10.5	10.8	48	51	49	1695	2721	2208
12	AIMP 92901 S1- 12	77.9	42.7	94.1	68.4	-12	61.9	36.9	63.7	50.3	-19	12.9	14.3	13.6	48	46	47	1275	2229	1752
13	AIMP 92901 S1- 13	44.8	41.8	59.5	50.7	13	41.9	43.0	53.2	48.1	15	9.5	11.5	10.5	51	47	49	1887	2930	2408
14	AIMP 92901 S1- 14	51.9	49.5	62.0	55.7	7	50.0	40.8	55.6	48.2	-4	12.0	10.6	11.3	45	43	44	1531	3013	2272
15	AIMP 92901 S1- 15	56.1	44.0	78.8	61.4	9	50.3	37.9	59.1	48.5	-3	10.0	11.6	10.8	44	42	43	1395	2330	1862
16	AIMP 92901 S1- 16	51.4	36.8	61.7	49.3	-4	41.5	36.8	50.5	43.7	5	10.2	10.8	10.5	45	46	45	1679	2655	2167
17	AIMP 92901 S1- 17	68.6	46.4	97.1	71.7	5	59.2	34.4	69.1	51.7	-13	11.2	10.4	10.8	47	47	47	1740	2878	2309
18	AIMP 92901 S1- 18	84.2	42.5	81.5	62.0	-26	87.0	55.1	86.2	70.7	-19	12.6	14.8	13.7	44	45	44	1731	3122	2426
19	AIMP 92901 S1- 19	93.1	62.3	79.1	70.7	-24	69.1	45.4	60.8	53.1	-23	11.0	10.4	10.7	47	48	48	1683	2183	1933
20	AIMP 92901 S1- 20	57.9	49.6	65.3	57.4	-1	60.3	54.9	61.0	57.9	-4	9.5	9.8	9.7	55	53	54	1364	3180	2272
21	AIMP 92901 S1- 21	54.4	51.7	67.1	59.4	9	43.9	35.3	45.4	40.4	-8	12.3	11.8	12.0	42	41	41	1653	2700	2177
22	AIMP 92901 S1- 22	122.3	73.5	99.4	86.4	-29	91.9	72.3	81.8	77.0	-16	8.2	10.9	9.5	53	50	52	1431	2276	1853
23	AIMP 92901 S1- 23	57.8	53.6	68.5	61.1	6	47.6	42.4	51.9	47.1	-1	10.2	9.8	10.0	47	46	47	2096	2002	2049
24	AIMP 92901 S1- 24	65.2	57.3	81.9	69.6	7	59.1	53.4	64.5	58.9	0	9.7	8.3	9.0	46	47	46	1835	3112	2473
25	AIMP 92901 S1- 25	63.5	46.1	68.9	57.5	-9	53.7	41.0	61.6	51.3	-5	11.6	13.7	12.7	43	42	42	1807	2313	2060
26	AIMP 92901 S1- 26	87.0	50.4	80.8	65.6	-25	68.7	48.8	65.7	57.3	-17	11.5	13.2	12.4	46	49	47	1213	3110	2162

Appendix VIII. Contd.,

Sl. No	Entry	Grain Fe (mg kg^{-1})					Grain Zn (mg kg-1)					1000-grain mass (g)			Days to 50 % flower			Grain yield (kg ha^{-1})		
		S_0 plant	S_1 progeny				S_0 plant	S_1 progeny				S_1 progeny			S_1 progeny			S_1 progeny		
		Summer 2009	Rainy 2009	Summer 2010	Pooled mean	% over S_0	Summer 2009	Rainy 2009	Summer 2010	Pooled mean	% over S_0	Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean
27	AIMP 92901 S1- 27	44.4	33.6	55.0	44.3	0	31.6	34.2	47.6	40.9	30	9.4	11.7	10.6	48	47	47	2221	3627	2924
28	AIMP 92901 S1- 28	67.3	58.0	84.0	71.0	6	60.5	45.4	65.4	55.4	-8	10.3	11.4	10.9	51	46	48	1672	2505	2089
29	AIMP 92901 S1- 29	35.5	32.7	48.0	40.3	14	35.7	34.6	46.4	40.5	14	11.0	11.3	11.1	46	45	46	2075	3083	2579
30	AIMP 92901 S1- 30	55.5	59.4	75.3	67.4	21	58.1	54.1	66.7	60.4	4	9.9	10.0	9.9	47	51	49	2003	2592	2297
31	AIMP 92901 S1- 31	55.6	46.1	65.1	55.6	0	57.1	42.4	59.7	51.0	-11	9.6	9.6	9.6	44	46	45	1620	2301	1960
32	AIMP 92901 S1- 32	89.1	58.3	102.0	80.2	-10	82.0	55.6	86.7	71.2	-13	12.8	12.4	12.6	48	46	47	1756	2373	2065
33	AIMP 92901 S1- 33	71.1	50.5	68.3	59.4	-16	65.5	39.8	59.6	49.7	-24	10.1	8.8	9.5	46	46	46	1581	2547	2064
34	AIMP 92901 S1- 34	63.3	54.3	62.4	58.3	-8	60.1	48.7	49.4	49.0	-18	7.4	8.9	8.2	48	46	47	1537	2912	2225
35	AIMP 92901 S1- 35	115.2	56.2	96.2	76.2	-34	87.4	43.7	73.0	58.4	-33	11.8	11.6	11.7	47	47	47	2127	2403	2265
36	AIMP 92901 S1- 36	53.7	49.1	65.7	57.4	7	61.6	60.0	71.7	65.9	7	10.9	10.1	10.5	46	46	46	1977	2951	2464
37	AIMP 92901 S1- 37	104.3	64.2	86.4	75.3	-28	82.9	48.4	64.5	56.4	-32	9.4	7.6	8.5	50	50	50	1671	2730	2200
38	AIMP 92901 S1- 38	76.6	60.1	94.9	77.5	1	70.6	62.3	82.8	72.6	3	11.2	13.6	12.4	43	43	43	1544	2312	1928
39	AIMP 92901 S1- 39	80.8	72.2	77.0	74.6	-8	73.6	54.1	68.2	61.2	-17	12.8	10.6	11.7	47	49	48	1627	2283	1955
40	AIMP 92901 S1- 40	77.7	51.2	65.0	58.1	-25	76.9	49.4	58.2	53.8	-30	10.7	13.6	12.2	49	45	47	2079	2282	2180
	Mean	68.5	51.5	77.0	64.3	-3	61.1	46.9	64.4	55.6	-6	10.7	11.1	10.9	47	46	46	1746	2631	2188
	Minimum	35.5	32.7	48.0	40.3	-34	31.6	33.5	45.4	40.4	-33	7.4	7.6	8.2	42	41	41	1213	1565	1484
	Maximum	122.3	73.5	124.9	96.1	56	91.9	72.3	99.2	78.7	30	14.3	14.8	13.7	55	53	54	2221	3627	2924
	CD (5%)		18.0	23.5	20.3			13.3	16.3	14.4		1.7	3.0	2.4	1.9	2.1	2.3	323.3	321.5	324.7
	CV (%)		17.2	15.1	16.1			14.0	12.5	13.2		8.0	13.2	11.0	2.0	2.2	2.1	9.2	6.0	7.3

Appendix IX. *Per se* performance of ICMR 312 S_0 plant and S_1 progenies for grain Fe and Zn concentrations, 1000-grain mass, days to 50% flower and grain yield in rainy 2009 and summer 2010, Patancheru.

Sl. No	Entry	Grain Fe (mg kg^{-1})					Grain Zn (mg kg^{-1})					1000-grain mass (g)			Days to 50 % flower			Grain yield (kg/ha)		
		S_0 plant	S_1 progeny				S_0 plant	S_1 progeny				S_1 progeny			S_1 progeny			S_1 plant		
		Summer 2009	Rainy 2009	Summer 2010	Pooled mean	% over S_0	Summer 2009	Rainy 2009	Summer 2010	Pooled mean	% over S_0	Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean
1	ICMR 312 S1-1	82.4	51.6	91.8	71.7	-13	66.6	35.1	63.4	49.3	-26	12.6	13.3	13.0	49	49	49	2012	2243	2128
2	ICMR 312 S1-2	46.6	42.3	58.5	50.4	8	55.2	44.0	61.6	52.8	-4	10.3	10.5	10.4	48	47	47	2004	2800	2402
3	ICMR 312 S1-3	72.3	59.5	79.3	69.4	-4	68.6	50.7	64.6	57.7	-16	11.7	11.4	11.6	49	49	49	1986	2698	2342
4	ICMR 312 S1-4	74.5	43.9	72.4	58.2	-22	77.6	40.3	67.8	54.0	-30	12.8	11.8	12.3	47	48	47	1333	2602	1968
5	ICMR 312 S1-5	80.2	59.8	77.6	68.7	-14	62.7	37.9	57.5	47.7	-24	10.7	10.9	10.8	52	53	53	2487	2650	2568
6	ICMR 312 S1-6	73.1	53.3	80.4	66.9	-9	63.9	44.8	69.6	57.2	-10	11.8	10.7	11.2	47	47	47	2060	2196	2128
7	ICMR 312 S1-7	59.8	41.3	66.0	53.6	-10	61.8	42.0	60.8	51.4	-17	11.4	13.0	12.2	45	47	46	1648	1972	1810
8	ICMR 312 S1-8	67.0	43.9	75.4	59.7	-11	57.9	40.3	57.3	48.8	-16	10.3	10.1	10.2	50	50	50	1592	2280	1936
9	ICMR 312 S1-9	88.8	67.8	73.2	70.5	-21	71.5	52.9	63.2	58.0	-19	12.0	13.0	12.5	49	47	48	2039	2000	2019
10	ICMR 312 S1-10	79.2	48.6	73.7	61.2	-23	61.9	41.8	60.8	51.3	-17	9.6	10.4	10.0	50	50	50	1795	2002	1898
11	ICMR 312 S1-11	83.6	57.0	97.2	77.1	-8	71.4	45.5	79.5	62.5	-13	11.8	9.3	10.5	54	56	55	1579	1628	1604
12	ICMR 312 S1-12	72.7	66.7	78.6	72.6	0	67.6	51.6	68.0	59.8	-12	9.2	12.1	10.6	50	48	49	1532	3497	2514
13	ICMR 312 S1-13	62.2	37.5	67.3	52.4	-16	55.2	32.0	59.5	45.8	-17	11.3	12.8	12.1	45	47	46	2188	2540	2364
14	ICMR 312 S1-14	77.1	53.6	66.9	60.3	-22	67.6	49.4	61.9	55.7	-18	11.3	12.0	11.7	51	52	52	1477	1908	1693
15	ICMR 312 S1-15	85.2	51.8	65.1	58.5	-31	68.3	38.4	56.9	47.7	-30	13.2	12.0	12.6	47	46	47	1715	2287	2001
16	ICMR 312 S1-16	56.1	47.1	74.0	60.6	8	50.7	36.7	54.3	45.5	-10	11.4	9.4	10.4	47	50	49	1760	1917	1838
17	ICMR 312 S1-17	66.0	43.9	77.6	60.8	-8	52.2	32.9	55.1	44.0	-16	12.1	12.7	12.4	49	47	48	1790	1618	1704
18	ICMR 312 S1-18	50.5	36.8	69.4	53.1	5	54.0	34.9	57.4	46.2	-14	9.7	10.9	10.3	52	50	51	2321	2722	2522
19	ICMR 312 S1-19	62.8	46.2	69.2	57.7	-8	65.4	40.3	63.6	52.0	-21	12.9	13.0	13.0	47	48	47	1417	2613	2015
20	ICMR 312 S1-20	51.0	48.8	64.4	56.6	11	55.7	57.3	61.5	59.4	7	9.2	10.3	9.7	53	51	52	1753	2750	2252
21	ICMR 312 S1-21	98.6	64.6	99.3	81.9	-17	65.0	47.3	66.8	57.1	-12	9.1	11.8	10.4	56	51	53	1051	2948	2000
22	ICMR 312 S1-22	83.2	48.8	95.8	72.3	-13	78.8	41.6	71.0	56.3	-29	10.2	11.3	10.8	50	48	49	1703	2195	1949
23	ICMR 312 S1-23	63.7	47.3	70.5	58.9	-8	50.7	38.0	51.5	44.8	-12	10.9	10.6	10.7	44	46	45	1672	2038	1855
24	ICMR 312 S1-24	84.6	41.1	79.2	60.1	-29	67.6	41.4	66.7	54.1	-20	13.3	12.9	13.1	50	50	50	2064	2663	2364
25	ICMR 312 S1-25	77.3	45.8	83.7	64.7	-16	60.1	44.8	60.5	52.7	-12	11.3	14.7	13.0	48	47	48	1612	2732	2172
26	ICMR 312 S1-26	76.4	63.1	78.3	70.7	-7	59.6	43.6	53.5	48.6	-19	9.4	11.3	10.4	53	52	52	1621	4263	2942
27	ICMR 312 S1-27	65.4	37.6	85.0	61.3	-6	68.4	37.7	70.1	53.9	-21	10.5	11.9	11.2	49	49	49	2253	2795	2524
28	ICMR 312 S1-28	67.1	65.1	83.6	74.4	11	62.7	39.2	55.9	47.6	-24	11.8	10.0	10.9	48	49	48	1947	2181	2064
29	ICMR 312 S1-29	60.5	39.5	58.3	48.9	-19	65.4	40.7	61.6	51.1	-22	11.6	12.0	11.8	49	47	48	1893	2723	2308
30	ICMR 312 S1-30	67.0	47.3	80.5	63.9	-5	60.5	39.0	67.3	53.1	-12	14.1	11.7	12.9	48	47	47	2164	1953	2059
31	ICMR 312 S1-31	83.2	58.5	80.9	69.7	-16	62.9	49.9	62.7	56.3	-10	9.9	11.8	10.9	52	51	52	1519	2218	1869
32	ICMR 312 S1-32	91.4	51.5	99.7	75.6	-17	68.8	38.0	66.8	52.4	-24	13.6	15.5	14.6	50	48	49	2173	3488	2831
33	ICMR 312 S1-33	83.6	48.8	79.4	64.1	-23	76.0	39.4	64.1	51.8	-32	11.5	12.3	11.9	48	50	49	2416	2278	2347

Appendix IX. Contd.,

Sl. No	Entry	Grain Fe (mg kg^{-1})					Grain Zn (mg kg^{-1})					1000-grain mass (g)			Days to 50 % flower			Grain yield (kg/ha)		
		S_0 plant	S_1 progeny				S_0 plant	S_1 progeny				S_1 progeny			S_1 progeny			S_1 plant		
		Summer 2009	Rainy 2009	Summer 2010	Pooled mean	% over S_0	Summer 2009	Rainy 2009	Summer 2010	Pooled mean	% over S_0	Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean	Rainy 2009	Summer 2010	Pooled mean
34	ICMR 312 S1-34	55.7	40.9	56.5	48.7	-13	52.8	36.9	57.4	47.2	-11	10.0	11.8	10.9	51	49	50	2216	2937	2576
35	ICMR 312 S1-35	70.6	43.3	76.1	59.7	-15	55.6	37.4	62.3	49.9	-10	11.5	11.6	11.5	48	53	50	2087	2428	2258
36	ICMR 312 S1-36	71.1	47.3	93.5	70.4	-1	64.1	41.7	67.6	54.7	-15	8.8	8.7	8.8	48	51	49	1992	3555	2774
37	ICMR 312 S1-37	52.1	48.3	57.1	52.7	1	54.0	41.1	54.9	48.0	-11	12.2	12.0	12.1	49	50	50	2201	2433	2317
38	ICMR 312 S1-38	63.7	60.1	69.5	64.8	2	66.4	46.9	70.9	58.9	-11	10.2	12.9	11.5	47	47	47	481	2268	1375
39	ICMR 312 S1-39	73.9	54.1	77.7	65.9	-11	52.5	40.2	52.5	46.4	-12	12.8	11.8	12.3	49	49	49	2017	1955	1986
40	ICMR 312 S1-40	61.9	42.1	74.8	58.5	-6	58.5	42.6	67.7	55.2	-6	11.3	10.9	11.1	47	47	47	1761	1930	1846
	Mean	71.0	49.9	76.4	63.2	-10	62.7	41.9	62.4	52.2	-16	11.2	11.7	11.5	49	49	49	1833	2473	2153
	Minimum	46.6	36.8	56.5	48.7	-31	50.7	32.0	51.5	44.0	-32	8.8	8.7	8.8	44	46	45	481	1618	1375
	Maximum	98.6	67.8	99.7	81.9	11	78.8	57.3	79.5	62.5	7	14.1	15.5	14.6	56	56	55	2487	4263	2942
	CD (5%)		14.6	17.1	16.3			12.0	11.1	11.4		1.8	2.4	2.1	2.4	1.6	2.0	285.5	247.7	264.0
	CV (%)		14.5	11.1	12.5			14.1	8.8	11.0		7.9	10.1	9.1	2.4	1.7	2.1	7.7	5.0	6.1

This thesis received **International Plant Nutrition Award for the best PhD research for the year 2009**

Rewarding moments……….

Media / bulletin news

ICRISAT
Science with a human face
Happenings
In-house Newsletter

International Crops Research Institute for the Semi-Arid Tropics

No. 1394 24 December 2009

Winner of international scholar award

M Govindraj, a PhD scholar, received the prestigious International Scholar Award from the International Plant Nutrition Institute (IPNI) of Georgia, USA. The certificate of recognition and cash award of $2000 was presented to him by David Rogiani, Vice-President of Canpotex, Singapore and K Mujumdar, IPNI's India Director at the 45th annual seminar on the *Fertilizer Policy for Sustainable Agriculture*. The seminar was conducted by the Fertilizer Association of India at Hotel Marriott, Hyderabad on 3 December. Govindraj is a student of Tamil Nadu Agricultural University (TNAU), Coimbatore and is doing research on *Genetics of Grain Iron and Zinc content in Pearl millet* in the HarvestPlus project. He is working under the supervision of P Shanmugasundaram (TNAU), and ICRISAT's KN Rai and KL Sahrawat.

David Rogiani presenting award to Govindraj. K Mujumdar is also present (Right)

Congratulations to Govindraj!

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BETTER CROPS–INDIA

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2009 IPNI Scholar Award Recipients Announced

The 2009 winners of the Scholar Award sponsored by the International Plant Nutrition Institute (IPNI) have been selected. The awards of US$2,000 (two thousand dollars) are available to graduate students in sciences relevant to plant nutrition and management of crop nutrients. The winners from India are **Govindaraj Mahalingam** and **Ramesh Thangavel**.

"There were many highly qualified applicants this year from a wide array of universities and fields of study," said Dr. Terry L. Roberts, IPNI President. "The academic institutions these young people represent and their advisers and professors can be proud of their accomplishments. The selection committee adheres to rigorous criterion evaluating important aspects of each applicant's academic achievements." In total, 14 (fourteen) graduate students were named to receive the IPNI Scholar Award in 2009, with the most widespread geographic distribution ever for the awards.


Govindaraj Mahalingam

Mr. Govindaraj Mahalingam began his Ph.D. program in 2007 in Plant Breeding and Genetics at Tamil Nadu Agricultural University, Coimbatore, India. His dissertation title is "Genetics of Grain Iron and Zinc Content in Pearl Millet" and the study is focused on assessing and valuating the genetic efficiency of pearl millet genotypes for the accumulation of iron and zinc content in grain. Enhancement of mineral nutrition in grain is essential to eradicate human mineral malnutrition, especially in resource-poor populations of developing nations. For the future, development of genotypes having higher nutrient use efficiency, especially for iron and zinc, is important to enable production on many soils. This research can significantly increase the mineral content of grain and enable other agronomic advantages in crop plants.


Ramesh Thangavel

Mr. Ramesh Thangavel began his Ph.D. program in 2008 in Soil Science and Agricultural Chemistry at the Indian Agricultural Research Institute (IARI) in New Delhi. His dissertation title is "Stocks and Quality of Soil Organic Matter under Different Land Use Systems in East Khasi Hills of Meghalaya." Objectives of his project include quantifying and qualifying soil organic matter stocks in different land use systems under slash and burn cultivation, and studying carbon stability mechanisms in Northeast India. For the future, this could lead to great reduction in soil erosion and much improved land use patterns.

Funding for the Scholar Award program is provided through support of IPNI member companies, primary producers of nitrogen, phosphate, potash, and other fertilizers. Graduate students attending a degree-granting institution located in any country with an IPNI program region are eligible. Students in the disciplines of soil and plant sciences including agronomy, horticulture, ecology, soil fertility, soil chemistry, crop physiology, and other areas related to plant nutrition are encouraged to apply.

Application deadline is June 30 each year. Further information and online application instructions and forms for the scholar award program can be found at the website: >www.ipni.net/scholar<.

Introduction to this Special Issue

Welcome…

You are reading the third issue of *BETTER CROPS-INDIA*, first introduced in 2007 and published by the International Plant Nutrition Institute. Following a similar style as our popular quarterly publication, Better Crops with Plant Food, this special publication is the result of considerable effort for the India Programme staff and many cooperators.

We at IPNI wish to congratulate and thank the many cooperators, researchers, government officials, farmers, industry representatives, and others who are working in a positive mode for progress in India.

Dr. Terry L. Roberts, President, IPNI

Author previous publications

Full Length Research papers:

Govindaraj, M., B. Selvi and I. Sudhir Kumar. 2011. Genetic Diversity Studies in Indigenous Pearl Millet [*Pennisetum glaucum* (L.) R. Br.] Accessions Based on Biometrical and Nutritional Quality Traits. **Indian J. Plant Genet. Resour**., 24 (2): 186 - 193.

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Govindaraj, M., K.N. Rai., P. Shanmugasundaram and A. S. Rao. 2011**.** Efficiency of single plant selection for grain iron and zinc density in pearl millet. (Submitted **European Journal of Plant Science and Biotechnology**)

Oral / Posters / Abstracts:

M.Govindaraj, B.Selvi and D.Arun prabhu. Multivariate analysis of pearl millet genotypes (*Pennisetum glaucum* (L.) R. BR.) for nutritional and yield traits. **In: International Conference on 21st Century challenges to sustainable Agri-food systems,** held at University of Agricultural Sciences, Bangalore, India on 15-17, March 2007.

M.Govindaraj, B.Selvi and D.Arun prabhu. Molecular marker studies on pearl millet (*pennisetum glaucum* (l.) r. br.) genotypes for yield and nutritional traits.**In: National 6th Biological Congress on Biotechnology: Past, Present and Future**, held at Muthayammal Educational Institutions, Rasipuram, Tamil Nadu, India on 5th and 6th January 2007.

M.Govindaraj, B.Selvi, S. Rajarethinam and P. Malarvizhi. Genetic diversity analysis for yield and quality traits in pearl millet. **In: Second National Plant Breeding Congress**, held at Tamil Nadu agricultural university, Coimbatore, India, on 1 -3 march, 2006.

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