



Genetic variability for yield and yield attributing traits in F₃ generation of rice (*Oryza sativa* L.)

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Abstract: The present investigation was carried out in the segregating population of two rice cross combinations viz., Swarna x Ranbir basmati and Swarna x BR2655. The results revealed that the appreciable genetic variability for grain iron and zinc content along with other biometrical traits. Moderate to high variability was observed for grains per panicle, grain length, L/B ratio, in Cross 1 and Cross 2 for plant height, grains per panicle, in F₃ generation. Hence, these traits need one or more generations in order to attain homozygosity. The existence of comparatively moderate variability for these traits, which could be exploited for improvement of the traits through selection in advanced generations. The high genotypic and phenotypic coefficient of variability were observed for panicle weight, grain yield kg per ha, in Cross 1 (Swarna x Ranbir basmati) and Cross 2 (Swarna x BR2655) for number of panicles per plant, panicle weight, grain yield. It indicates high variability among the lines. High heritability coupled with high genetic advance as per cent of mean were recorded for plant height, number of panicle per plant, panicle weight, number of grains per panicle, L/B ratio, grain yield kg per ha in Cross 1 (Swarna x Ranbir basmati) and Cross 2 (Swarna x BR2655) for number of panicle per plant, panicle weight, number of grains per panicle, grain yield kg per ha. This indicates scope of selection in the population, since there is a wide range of variation and additive gene action.

Key words: Iron, Zinc, Heritability, Genetic advance, XRF, GCV and PCV

Introduction

Rice is not only a major staple food item but also a way of life for the millions in India. A crop of great antiquity with nearly 10000 years of cultivation, fluctuations in its production meant famines in the past. Although such catastrophes were averted through the application of science based agriculture in the recent decades, even today the crop is overwhelmingly important for the food, nutritional and livelihood security for half the human race (Shobha Rani *et al.*, 2008). Rice is most widely consumed in one or other form by poorest to richest person. However, rice is a poor source of essential micronutrients such as iron (Fe) and zinc (Zn) (Bouis and Welch, 2010). Because of the importance of rice, FAO named the year 2004 'International Year of Rice' and the theme of that year was 'Rice is life'. The average content of iron in rice grains is 1.2 mg/100 g and zinc is 0.5 mg/100 g. However, in spite of its great importance, rice on its own is not considered as a balanced diet choice, because the majority of rice is consumed in the form of polished grains, from which the bran layer and germ (the main storage sites for essential minerals such as iron (Fe) and zinc (Zn) are removed during the milling process (Hoa and Lan, 2004). Therefore, in developing countries, where polished rice is consumed as a staple food, anemia due to iron deficiency is the most widespread nutritional disorder (White and Broadley, 2009).

Malnutrition is a growing problem in the developing world mainly in South and South-East Asia and Sub-Sahara Africa (Reddy *et al.* 2005). Over three billion people suffer from micro nutrient malnutrition (Welch and Graham, 2002). Iron deficiency may affect three billion people worldwide (Long and Buu, 2005). It is estimated that 49 per cent of the world's population is at risk for low zinc intake (Cichy *et al.*, 2005). Micronutrients are essential for balanced nutrition

in plants and animals (Welch and Graham, 1999; Graham *et al.*, 2000). Micronutrients also play vital role in abiotic stress tolerance in rice plants. Green revolution laid emphasis on increased grain yield, which led to reduced availability of micronutrients in food (Mason and Garcia, 1993; Tontisirin and Nantel., 2002 and Welch *et al.*, 1997). The genetic variation in micronutrient contents provides a basis for improving micronutrient content through breeding. However, manipulating this trait in conventional breeding is difficult, because such substantial variation is quantitatively inherited (Shiny *et al.* 1991).

The F₂ or F₃ derived lines are far from being homozygous and early generation selection relies on the assumption that the performance of a line at an early generation of selfing is predictive of its performance at homozygosity (Chahota *et al.* 2007). Empirical studies in different self pollinated crops have indicated that early generation selection is sometimes effective and sometime ineffective (Bernardo, 2003). In order to improve the yield through selection, it is essential to have a thorough knowledge on genetic variability available in the germplasm and the extent to which the desirable traits are heritable, which requires a better insight of the ancillary characters for better selection. Therefore, the present study was aimed at finding out nature and magnitude of genetic variability studies in segregating population of the rice for grain yield and other yield component traits to select the transgressive segregants for further breeding programme.

Materials and Methods

The experimental material comprised two F₃ families one derived from Swarna x Ranbir basmati cross and another from Swarna X BR 2655. Cross 1 comprising 214 F₃ families where in one of the parent Swarna is a popular high yielding semi dwarf variety derived from cross between Vasistha x Mahsuri having low

iron and zinc content (2.93 mg 100 g⁻¹ and 2.28mg 100 g⁻¹ respectively). While, Ranbir basmati possess high iron and zinc content of 4 mg/100 g and 5 mg/100 g respectively and is a selection from Basmati 370. Cross 2 comprising 234 F_3 families in which the male parent BR-2655 is high in iron and zinc content (3.50 mg 100 g⁻¹ and 3.02 mg 100 g⁻¹ respectively) in brown rice with parentage of (BR 10 x BR 4) x (BR7 x Palghar 84-3). In both the crosses Swarna is used as female parent. These two segregating populations were used as experimental material in present study for estimating grain iron and zinc content during *Kharif*, 2012 and 2013, at Agricultural Research Station (Paddy) Sirsi. The experiment was laid out in randomized block design with two replications and all the entries were allotted randomly using random number table. Sowing was carried out on 1st July, 2013 in individual row for F_2 -01-214 derived F_3 families and another F_2 -02-234 derived F_3 families. Recommended cultural operations and plant protection measures as per package of practices were taken up to ensure uniform and healthy crop stand. The iron and zinc contents of seed samples were estimated by X-ray fluorescence (XRF) spectrometry at M S Swaminathan Research Foundation, Chennai.

Observations were recorded in randomly selected five plants per family in each replication. The yield and yield components traits and grain quality characters were recorded in both the crosses (Swarna x Ranbir basmati) and (Swarna x BR-2655). The averages of the observations recorded on these five plants were considered for analysis. The characters observed for eliciting the information are morphological characters viz., Days to 50% flowering, days to maturity, plant height (cm), number of panicles per plant, panicle length (cm), panicle weight (g), number of grains per panicle, hundred seed weight (g), grain yield per plant (kg ha⁻¹), grain characters viz., grain length (mm), breadth (mm) L/B ratio, grain nutritional traits viz., Iron content (mg kg⁻¹), zinc content (mg kg⁻¹). Mean values were subjected to analysis of variance to test the significance for each character as per methodology advocated by Panse and Sukhatme (1967). PCV and GCV were calculated by the formula given by Burton and De Vane (1953), heritability by Lush (1949) and Hanson *et al.* (1956) and genetic advance i.e. the expected genetic gain were calculated by using the procedure given by Johnson *et al.* (1955) in order to estimate the genetic variation among parents and families.

Results and Discussion

A reasonable amount of differences among the genotype were observed for all the traits under study as evident from the table -1; indicating the presence of sufficient variability among the experimental materials. In the present investigation, low genotypic and phenotypic coefficient of variability was recorded for days to fifty per cent flowering for both crosses in F_3 generations. These results were in conformity with Kalaimaghal (2011) in the crosses of TRY (R) 2 x Mapillaisamba, TRY (R) 2 x Kosuvakathazhai and ADT 37 x IR68144-3B-2-2-3 of F_2 and F_3 generation. Ghosh and Deepak Sharma (2012) also reported the same results in the 10 diverse parents (3 CMS lines and 7 advance breeding lines) and 21 hybrids of rice. This low variability showed by days to fifty per cent flowering might be due to attainment of homozygosity in F_3

generation itself, since our selection pressure is basically focused on yield and maturity. Days to maturity exhibited low genotypic and phenotypic coefficient of variability in both crosses in F_3 generations, suggesting the less influence of environment for the traits days to maturity. Similar findings were reported earlier by Devi *et al.* (2006).

Plant height exhibited moderate genotypic and phenotypic coefficient of variability in Cross 2 in F_3 generations. This indicates the existence of comparatively moderate variability for this trait, which could be exploited for improvement through selection in advanced generations. These results are in consonance with earlier reports. Where in, moderate GCV and PCV for characters like plant height were reported by Shivani and Reddy (2000), Sharma and Sharma (2007), Vijayalakshmi (2008), Sathish Chandra *et al.* (2009). In this study phenotypic coefficients of variation were slightly higher than the genotypic coefficients of variation for plant height in Cross 1. This indicates the presence of environmental influence to some degree in the phenotypic expression of the characters. Iftekhharuddeula *et al.* (2001) Sabesan *et al.* (2009) and Idris *et al.* (2012) observed similar results. The trait, panicle length exhibited low genotypic and phenotypic coefficient of variability in both crosses for F_3 generations. Low variability for this trait was already reported by Kole and Hasib (2008) in induced mutants of aromatic rice in M_4 generation and Raju *et al.* (2004) in F_2 generation. This low variability was the net result of homozygosity as early as in F_3 generation. Number of panicle per plant exhibited high variability in both crosses which is in accordance with the results reported by earlier workers Michael Gomez *et al.* (2002), Thirugnana Kumar *et al.* (2006), Anilkumar *et al.* (2008). It may be due to high recombination percentage in second filial generation and this offer for further improvement of this trait through simple selection procedure. High genotypic and phenotypic coefficient recorded for panicle weight. Higher magnitude of PCV and GCV for this trait indicates presence of high degree of variability and better scope for improvement.

Moderate GCV and PCV recorded for number of grains per panicle in both the crosses in F_3 generation. Similar results were also reported by Monalisa *et al.* (2006); Kole and Hasib (2008), Nandeshwar *et al.* (2010). In the present investigation, hundred grain weight recorded low genotypic and phenotypic coefficient of variability in Cross 2. These results were in agreement with the findings of Ghosh and Deepak Sharma (2012), who observed similar results in F_1 generation. Low genotypic and phenotypic coefficient of variability was observed for grain length for Cross 2 in F_3 generation. These results were in accordance with Nandeshwar *et al.* (2010) who studied F_2 progenies which were derived from the crosses IR62 x Samba Mashuri and Kunti x Dudheswar and the report of Kumar *et al.* (2006) in F_2 generation. It indicates that there was a bottleneck for further improvement through selection. Since our selection pressure is basically focused on yield. The moderate phenotypic and genotypic co-efficients of variation were observed for grain length, L/B ratio, in Cross 1, this indicates the existence of comparatively moderate variability for these traits, which could be exploited for improvement of these traits through selection in advanced generations. These results are in consonance with earlier reports where in, moderate GCV and PCV for characters like grain

Table-1: Mean, range and genetic parameters for yield, yield related traits and micronutrients of two hundred fourteen F_3 families of Cross 1 (Swarna x Ranbir basmati)

Characters	Exp Mean next Generation	Mean	Range		GCV (%)	PCV (%)	h ² bs (%)	GA	GA as % of mean
			Minimum	Maximum					
Days to 50 per cent flowering	119.48	105.83	76.50	126.50	6.31	6.35	98.5	13.65	12.90
Days to maturity	147.88	134.41	105.00	155.00	4.93	5.00	97.2	13.47	10.02
Plant height (cm)	138.10	103.22	61.40	318.80	18.64	21.19	77.4	34.87	33.78
Panicle length (cm)	28.67	25.62	18.75	31.30	8.03	9.61	69.8	3.54	13.81
Number of panicles per plant	13.75	10.53	6.50	18.30	17.51	20.94	69.9	3.17	30.16
Panicle weight (g)	27.22	18.44	7.60	33.71	27.84	28.72	94.0	10.25	55.61
Grains per panicle	167.73	135.90	98.10	189.10	12.06	12.80	88.8	31.82	23.42
Test weight (g)	2.34	2.01	1.34	2.57	9.57	11.83	65.4	0.32	15.95
Grain Length (mm)	9.22	7.70	4.53	10.03	10.46	11.44	83.6	1.519	19.71
Grain Breadth	2.73	2.40	1.85	2.83	7.72	11.44	83.6	1.51	25.26
L/B ratio	4.00	3.20	2.10	5.73	12.73	13.48	89.2	0.79	24.77
Zinc content (mg/kg)	28.56	26.00	20.77	36.29	7.61	11.25	46.4	2.80	10.76
Iron content (mg/kg)	8.87	8.39	4.86	9.84	5.28	8.75	36.4	0.55	6.56
Grain yield (kg/ha)	839.54	512.09	148.71	994.81	33.09	35.29	88.0	327.45	63.94

Table-2: Mean, range and genetic parameters for yield, yield related traits and micronutrients of two hundred thirty four F_3 families of Cross 2 (Swarna x BR2655)

Characters	Mean	Range		GCV (%)	PCV (%)	h ² bs (%)	GA	GA as % of mean
		Minimum	Maximum					
Days to 50 per cent flowering	111.38	77.50	138.50	5.90	5.96	98.0	13.41	12.04
Days to maturity	139.91	105.50	165.50	4.83	4.87	98.1	13.78	9.85
Plant height (cm)	85.23	60.66	111.91	11.89	14.65	65.0	16.95	19.89
Panicle length (cm)	24.14	19.00	28.00	5.83	7.65	58.0	2.20	9.14
Number of panicles per plant	8.59	4.25	14.40	22.32	24.38	83.8	3.61	42.11
Panicle weight (g)	20.73	8.47	42.96	24.17	25.83	87.6	9.66	46.62
Grains per panicle	161.53	116.54	235.12	11.75	12.22	92.5	37.63	23.29
Test weight (g)	2.19	1.77	2.63	4.47	8.52	27.5	0.106	4.83
Grain Length (mm)	7.38	6.34	8.34	4.68	5.20	81.0	0.641	8.68
Grain breadth (mm)	2.40	2.10	2.83	3.91	4.43	78.0	0.171	7.12
L/B ratio	3.09	2.55	3.52	5.26	6.07	75.0	0.290	9.39
Iron content (mg/kg)	8.53	7.05	11.65	8.32	11.88	49.0	1.02	11.99
Zinc content (mg/kg)	24.18	6.15	28.75	9.18	11.96	58.9	3.51	14.52
Grain yield (kg/ha)	492.40	101.25	1353.92	38.28	40.52	89.2	366.81	74.49

length, L/B ratio, were recorded (Binodh *et al.*, 2007; Jayashree, 2007; Sabesan *et al.*, 2009).

But in case of Cross 2 grain length and L/B ratio exhibited low genotypic and phenotypic coefficient of variability. These results were in accordance with Nandeshwar *et al.* (2010) who studied F_2 progenies derived from the crosses IR62 x Samba Mashuri and Kunti x Dudheswar and the report of Kumar *et al.* (2006) in rice F_2 generation. It indicates that there was a bottleneck for further improvement through selection. Since our selection pressure is basically focused on yield. Grain size (L/B ratio) was the important trait in the micronutrient enhancement studies. Since large sized grain stores more micronutrients in the endosperm compared to small or medium sized grains (Ashok kumar *et al.* 2009). Similar findings were also reported by Kalaimaghal (2011) in cross of TRY (R) 2 x Mapillaisamba and ADT37 x IR68144-3B-2-2-3 in F_2 and F_3 generation and Kumar *et al.* (2006) in F_2 generation of rice. This character can be further improved by selection as the variability still exists in the segregants. In the present study, kernel breadth recorded low genotypic and phenotypic coefficient of variability in both the crosses. Similar findings were already have been reported

in 110 rice genotypes (Anilkumar, 2008, Umadevi *et al.*, 2010). Increase in the mean value of Cross 1 and cross 3 from F_4 to F_5 indicates that there is a shift in the mean towards positive side for quality traits due to selection intensity or selection pressure. Zinc content in present study indicated low GCV and moderate PCV in both the crosses. Similar results were reported by Habibi (2008), Olivar *et al.* (2009) and Ravindra Babu *et al.* (2012). Iron content registered low to moderate genotypic and phenotypic coefficient of variability for both the crosses in F_3 generation. These results were in parallel with the findings of Kalaimaghal (2011) who observed low to moderate GCV and PCV for iron content in the in F_2 and F_3 the cross ADT37 x IR68144-3B-2-2-3. The trait, grain yield kg per ha exhibited high genotypic and phenotypic coefficient of variability in both the crosses for F_3 generations. Such high variability trait was already reported by Gangashetty *et al.* (2013). These traits are under the influence of genetic control. Hence, this indicates the existence of wide genetic base among the genotypes taken for study and possibility of genetic improvement through selection for these traits. This was in conformity with the findings of Bastia *et al.* (2008) who reported higher PCV and GCV in upland rice for grain yield.

On the whole, co-efficient considerable amount of variability was observed for most of the traits except few traits. The close correspondence between the estimates of GCV and PCV for most of the traits indicated lesser environmental influence on the expression of these traits, which is also reflected by their high heritability values. **Heritability and genetic advance:** Heritability and genetic advance were determined to study the scope of improvement in various characters through selection. Heritability and genetic advance are important selection parameters. In the present investigation, high heritability along with low genetic advance as percentage of mean was recorded for days to fifty per cent flowering and days to maturity in both the crosses in F_3 generation, indicating non additive gene action. The high heritability is being exhibited due to favourable influence of environment rather than genotype and selection for this trait may not be rewarding (Sarawgi *et al.*, 2000). These results were in the conformity with the findings of Sanjeev Singh *et al.* (2006) in M_2 , M_3 and Kole and Hasib (2008) in M_4 generation. High heritability coupled with moderate to high genetic advance as percent of mean was recorded for plant height in both crosses. It can be contributed to favourable influence of environment rather than genotype and selection may not be rewarding. This observation is in agreement with the earlier findings of F_2 and F_3 generation (Sanjeev Kumar *et al.*, 2005, Anilkumar, 2008).

In the study of Anilkumar (2008), high heritability coupled with high genetic advance as percentage of mean was observed for number of panicles per plant in the cross of ADT 43 x IRBB 60 in F_2 and F_3 . Anbanandan *et al.* (2009) also reported the same in rice of F_3 and F_4 which is in contrast with the result of current investigation. High heritability coupled with low genetic advance as percentage of mean was recorded for number of panicle per plant in both crosses in F_3 generation. High heritability coupled with low genetic advance was recorded for both crosses, with respect to panicle weight, grain length, grain breadth, L/B ratio, and test weight. This indicates that there was low environmental influence on the expression of these characters and hence one can practice selection of high heritability and genetic advance as per cent of mean as reported by earlier workers for grains per panicle, for L/B ratio, and test weight. (Raju *et al.*, 2004, Venkata Subbaiah *et al.* 2011, Ravindra Babu *et al.*, 2012, and Gangashetty *et al.*, 2013)

High heritability with high genetic advance as percentage of mean was observed for number of grains per panicle, in both the crosses. Similar trend was observed for grain yield, in both the crosses. This suggests that there is high importance of additive gene action. These results are in agreement with reports of Venkata Subbaiah *et al.* (2011); Ravindra Babu *et al.* (2012); Ghosh and Deepak Sharma (2012). Grain iron and zinc content exhibited moderate heritability with low genetic advance as percentage of mean in both crosses. This result was in agreement with the findings of Gangashetty *et al.* (2013). High heritability coupled with high genetic advance as per cent of mean for most of the characters indicating the presence of considerable genetic variation and additive gene effects. Hence, improvement of these characters could be effective through phenotypic selection.

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References

- Anbanandan, V., Saravanan K. and Sabesan, T.: Variability, heritability and genetic advance in rice (*Oryza sativa* L.). *Int. J. Plant Sci.*, **3**: 61-63 (2009).
- Anilkumar, C. V.: Genetic analysis of economic traits in segregating population of rice (*Oryza sativa* L.). *M. Sc. (Agri.) Thesis* TNAU, Coimbatore (India) (2008).
- Ashok Kumar, A., Reddy, V. S., Belum, B., Ramaiah, Sanjan Reddy, P., Sahrawat K. L. and Upadhayaya, H. D.: Genetic variability and plant character association of grain iron and zinc in selected core collection accessions of sorghum germplasm under breeding lines. *Electron. J. ICRISAT*, **7**: 112-123 (2009).
- Bastia, D., Mishra, T. K. and Das, S. R.: Genetic variability and selection indices for grain yield in upland rice. *Oryza*, **45**: 72-75 (2008).
- Bernardo, R.: On the effectiveness of early generation selection in self pollinated crops. *Crop Sci.*, **43**: 1558-1560 (2003).
- Binodh, K., Kalaiyarasi, R. and Thiyagarajan, K.: Genetic parameter studies on grain quality traits in rice. *Madras Agric. J.*, **94**: 109-113 (2007).
- Bouis, H. E. and Welch, R. M.: Biofortification a sustainable agricultural strategy for reducing micronutrient malnutrition in the global south. *Crop Sci.*, **50**: 20-32 (2010).
- Burton, G. W. and De Vane, E. M.: Estimating heritability in tall Fescue (*Festuca arundinaceae*) from replicated clonal-material. *Agron. J.*, **51**: 515-518 (1953).
- Chahota, R.K., N. Kishore, K.C. Dhiman, T.R. Sharma and S.K. Sharma: Predicting transgressive segregants in early generation using single seed descent method derived *micro-macrosperma* gene pool of lentil (*Lens culinaris* Medikus). *Euphytica*, **156**: 305-310 (2007).
- Cichy K.A., Shana, F., Kenneth, L.G. and George, L.H.: Inheritance of seed zinc accumulation in navy bean. *Crop Sci.*, **45**: 864-870 (2005).
- Devi, S.L., Raina, F.A., Pandey, M.K. and Cole, C.R.: Genetic parameters of variation for grain yield and its components in rice. *Crop Res.*, **32**: 69-71 (2006).
- FAO.: International Year of Rice (IYR). Available from <http://en/aboutrice.htm>. Accessed on April 2, (2006) (2004)
- Gangashetty, P. I., Salimath, P.M. and Hanamaratti, N.G.: Genetic variability studies in genetically diverse non-basmati local aromatic genotypes of rice (*Oryza sativa*L.). *Rice Genomics and Genet.*, **4**: 4-8. (2013).
- Ghosh and Deepak Sharma: Genetic parameters of agro morpho physiological traits in rice (*Oryza sativa* L.). *Electron. J. Plant Breed.*, **3**: 711-714 (2012).
- Graham, R. D., Welch, R. M. and Bouis, H. E.: Addressing micronutrient malnutrition through enhancing the nutritional quality of staple food: principles, prospective and knowledge gaps. *Adv. Argon.*, **70**: 77-142 (2000).
- Habibi: Genetic variation for grain quality, protein and micronutrients in F_2 generation of BPT-5204 x HPR-14 in rice (*Oryza sativa* L.) under aerobic condition. *M. Sc. (Agri.) Thesis*, Univ. Agric. Sci., Bengaluru (India) (2008).
- Hanson, G. H., Robinson, H. F. and Comstock, R. E.: Biometrical studies on yield in segregating populations of Korean lespedera. *Agron. J.*, **48**: 268-272 (1956).
- Hoa, T. T. C. and Lan, N. T. P.: Effect of milling technology on iron content in rice grains of some leading varieties in the Mekong delta. *Omonrice*, **12**: 38-44 (2004).

- Idris, A. E., Justin, F. J., Dagash, Y. M. I. and Abuali, A. I.: Genetic variability and inter relationship between yield and yield components in some rice genotypes. *American J. Exptl. Agric.*, **2**: 233-239 (2012).
- Iftekhharuddeula, M., Hassan, S., Islam, M. J., Badshah, M. A., Islam, M. R. and Khaleda, A.: Genetic evaluation and selection criteria of Hybrid rice in irrigated ecosystem of Bangladesh. *Pakistan J. Bio. Sci.*, **4**: 790-791 (2001).
- Jayashree: Characterization of landraces, cultivars and new plant types of rice for quantitative and grain quality traits. *M. Sc. (Agri.) Thesis*, TNAU, Coimbatore (India) (2007).
- Johnson, H. W., Robinson, H. F. and Comstock, R. E.: Estimates of genetic and environmental variability in soybean. *Agron. J.*, **47**: 314-318 (1955).
- Kalaimaghal, R.: Studies on genetic variability of grain iron and zinc content in F_2 , F_3 generation of rice (*Oryza sativa* L.). *M. Sc. (Agri.) Thesis*, TNAU, Coimbatore (India) (2011).
- Kole, P.C. and Hasib, K.M.: Correlation and regression analysis in scented rice. *Madras Agric. J.*, **95**: 178-182 (2008).
- Kumar, S., A.S. Gautam and C. Chandal: Estimates of genetic parameters for quality traits in rice (*Oryza sativa* L.) in mid hills of Himachal Pradesh. *Crop Res.*, **32**: 206-208 (2006).
- Long, N.T. and Buu, B.C.: Tag genes controlling grain protein content using microsatellite markers in rice (*Oryza sativa* L.). *Omon rice.*, **13**: 67-68 (2005).
- Lush, J.L.: Inter size correlation, regression of offspring on dams as a method of estimating heritability of characters. *Proc. Amer. Soc. Anim. Pro.*, **33**: 293-301 (1949).
- Mason, J.B. and Garcia, M.: Micronutrient deficiency-the global situation. *SCN News.*, **9**: 11-16 (1993).
- Michael Gomez, S. and Rangasamy, P.: Correlation and path analysis of yield and physiological characters in drought resistant rice (*Oryza sativa* L.). *Int. J. Mendel.*, **19**: 33-34 (2002).
- Monalisa Manna, M., Narasim Ali, D. and Sasmal, B. G.: Variability, correlation and path coefficient analysis in some important traits of low land rice. *Crop Res.*, **31**: 153-156 (2006).
- Nandeshwar, B.C., Pal, S., Senapati, B.K. and De, D.K.: Genetic variability and character association among biometrical traits in F_2 generation of some Rice crosses. *Electron. J. Plant Breed.*, **1**: 758-763 (2010).
- Oliveira, G.A.L., Tan, L., Fu, Y. and Sun, C.: Genetic identification of quantitative trait loci for contents of mineral nutrients in rice grain. *J. Integr. Plant Biol.*, **51**: 84-92 (2009).
- Pansee, V. G. and Sukhatme, P. V.: Statistical Methods for Agricultural Workers. 2nd edition, ICAR, New Delhi. p. 22 (1967).
- Raju, C. H. S., Rao, M. V. B. and Sundarashanam, A.: Genetic analysis and character association in F_2 generation of rice. *Madras Agric. J.*, **91**: 66-69 (2004).
- Ravindra Babu, V., Shreya, K., Kuldeep Singh, D., Usharani, G., Nagesh, P.: Genetic variability studies for qualitative and quantitative traits in popular rice (*Oryza sativa* L.) hybrids in India, *Int. J. Sci. Res. Publ.*, **2**: 1-5 (2012).
- Reddy, B. V. S., Ramesh, S. and Longvah, T.: Prospects of breeding for micronutrients and carotene- dense- sorghums. *Int. Sorghum Millets Newsl.*, **46**: 10-14 (2005).
- Sabesan, T., Suresh, R. and Saravanan, K.: Genetic variability and correlation for yield and grain quality characters of rice grown in coastal saline low land of Tamil Nadu. *Electron. J. Plant Breed.*, **1**: 56-59 (2009).
- Sanjeev Kumar, Singh, H. B. and Sharma, J. K.: Genetic variability for morpho- physiological and some quality traits in rice (*Oryza sativa* L.). *Himachal J. Agric. Res.*, **31**: 163-165 (2005).
- Sanjeev Singh, Singh, J., Singh, R. K. and Singh, V. P.: Genetic studies on induced micro mutation population of Basmati rice in M_2 and M_3 generations. *Crop Res.*, **31**: 150-152 (2006).
- Sarawgi, A. K., Rastogi, N. K. Verma R. and Wade, L. J.: Character association in improved shallow rainfed lowland rices. *Oryza*, **37**: 217-276 (2000).
- Satish Chandra, B., Dayakar Reddy, T. and Sudheer Kumar, S.: Variability parameters for yield, its components and quality traits in rice (*Oryza sativa* L.). *Crop Res.*, **38**: 144-146 (2009).
- Sharma, A. K. and Sharma, R. N.: Genetic variability and character association in early maturing rice. *Oryza*, **44**: 300-303 (2007).
- Shiny, V. V., Sash, D. V. and Sachem, J. K. S.: Inheritance of protein per grain in rice, *Indian J. Genet.*, **51**: 214-220 (1991).
- Shivani, D. and Reddy, S. R.: Correlation and path analysis in certain rice (*Oryza sativa* L.) hybrids. *Oryza*, **37**: 183-186 (2000).
- Shobha Rani, N., Prasad, G.S.V., Subba Rao, L.V., Sudharsha, I., Manishk K. P., Babu, V.R., Ram, T., Padmavathi, G., Muralidharan, K., Pasalu, I. C. and Viraktamath, B.C.: High yielding rice varieties of India, *Technical Bulletin No. 33*, Directorate of Rice Research, Rajendranagar, Hyderabad 500 030, Andhra Pradesh, India, p.188 (2008).
- Thirugnana Kumar, S., Narassiman, R., Senthil Kumar, N., Eswaran, R., Praveen, C. and Sampath Kumar: Gene effects for grain yield and its component characters in rice (*Oryza sativa* L.). *Crop Improv.*, **34**: 19-23 (2006).
- Tontisirin, K. and Nantel, G. L.: Food based strategies to the challenges of micronutrient malnutrition in the developing world. *Prof. Nutr. Soc.*, **6**: 243-250 (2002).
- Umadevi, M., Veerabadhiran, P., Manonmani, S. and Shanmugasundaram, P.: Physico-chemical and cooking characteristics of rice genotypes. *Electron. J. Plant Breed.*, **1**: 114-123 (2010).
- Venkata Subbaiah, P., Reddi Sekhar, M., Reddy, K. H. P. and Eswara Reddy, N. P.: Variability and genetic parameters for grain yield and its components and kernel quality attributes in CMS based rice hybrids (*Oryza sativa* L.). *Int. J. Appl. Biol. & pharm. Technol.*, **2**: 603-609 (2011).
- Vijayalakshmi, B., Vijay, D., Raju, P. R. K and Satyanarayana, P. V.: Genetic divergence of qualitative and quantitative characters in lowland rice germplasm. *Crop Res.*, **36**: 212-214 (2008).
- Welch, R. M. and Graham, R. D.: A new Paradigm for world agriculture: meeting human needs. Productive, sustainable, nutritious. *Field Crops Res.*, **60**: 1-10 (1999)
- Welch, R. M. and R. D. Graham: Breeding for micronutrients in staple food crops from a human nutrition perspective. *J. Exptl. Bot.*, **55**: 353-364 (2002).
- Welch, R. M., Combs, G. F. and Duxbury, J. M.: Toward a "greener" revolution *Sci. Technol.*, **14**: 50-58 (1997).
- White, P. J. and Broadley, M. R.: Biofortifying crops with essential mineral elements. *Trends Plant Sci.*, **10**: 428-433 (2009).