Oryza Vol. 54 No. 2, 2017 (186-193)
DOI 10.5958/2249-5266.2017.00024.8

Analysis of quantitative genetic variation using aromatic and non aromatic genotypes in rice

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Received : 18 October 2016 Accepted : 22 August 2017 Published : 28 September 2017

ABSTRACT

The gene effects for grain yield and its component characters were studied using five generations viz., P_1, P_2, F_1, F_2, *and* F_3 *in ten crosses involving five aromatic and three non-aromatic varieties. Epistasis was noticed in majority of the characters for all the crosses. This study confirmed that, in addition to main effects (additive/ dominance) the non allelic interaction effects were also predominant in expression of the desirable metric traits related to yield. The nature and magnitude of gene effects differ depending on cross and quantitative trait. Hence, specific breeding strategy has to be adopted for each cross to get immediate benefit in grain yield and improve traits in rice. Based on the magnitudes of fixable genetic variation ('d' & 'i' types) and per se, pedigree selection in segregating generations with respect to crosses, BPT 5204 x Akshyadhan, Akshyadhan x NLR 145, Akshyadhan x Pusa 1121 were recommended.*

Key words: *Aromatic rice, generation mean analysis, gene effects*

INTRODUCTION

Presently, the yield potential of aromatic long and short-grain varieties is only 2.5 - 3.0 t ha^{-1} which is very low as compared to non-basmati high yielding varieties. Hence, there is a need to raise the present productivity levels to 5.5 - 6.0 t ha^{-1} which is possible through development of high yielding semi-dwarf aromatic varieties with resistance to biotic and abiotic stresses and improved productivity levels of aromatic short-grain types to replace the locally tall varieties which have got export potential. A perusal of literature indicates scanty information on the genetics of grain quality and yield components of fine grain aromatic rices particularly with respect to short grained ones. This background clearly necessitates studies in this direction towards genetic variability of yield and its components of aromatic rice, which comprises of mainly short and long grained types. In the present investigation, an attempt was made to know the genetic architecture of quantitative characters in ten crosses by involving aromatic rice varieties.

MATERIAL AND METHODS

The present investigation was carried out at Agricultural Research Station, Kampasagar, Nalgonda district of Telangana state with ten crosses developed from five aromatic (Pusa 1121, Improved Pusa Basmati, Basmati 370, Sumathi and RNR 2354) and three non-aromatic (BPT 5204, Akshyadhan and NLR 145) parents. Aromatic genotypes selected based on aroma, grain type (long slender) and elongation after cooking, where as the non aromatic parents were included considering high yield potential and wider adoptability. The purpose of crossing aromatic parents with non aromatic ones was to improve yield potential of aromatic types through genetic studies. Parents with contrast features were selected, so that there would be significant difference among generation means for the traits under consideration which is a pre-requisite for generation mean analysis. The experimental material representing five generations (P_1, P_2, F_1, F_2, and F_3) for study was planted during post rainy season 2012-13 (December - May) in the randomized block design replicating thrice. Parents and respective hybrids (F_1's) were planted in one row of 3.0 m length adopting a spacing of 20 cm between the rows and 15 cm between the plants within each row. The F_2 and F_3 generations of each cross were planted in twelve rows each with same row length and spacing. Observations were recorded on ten competitive plants in parents and F_1s, 50 in F_2 and F_3 for each set in each replication for yield and yield attributing characters *viz.*, days to 50 per cent flowering, plant height, number of productive tillers per plant, panicle length, panicle weight per plant, number of filled grains per panicle, 1000-grain weight and grain yield per plant.

RESULTS AND DISCUSSION

The mean values of five generations *viz.*, P_1, P_2, F_1, F_2 and F_3 were utilized for generation mean analysis with respect to yield associated traits to detect the epistasis and estimate 5 components (m, d, h, i and l) as per 5 parameter model.

The scaling tests C and D indicated the presence of appreciable amount of epistasis in expression of different characters under study. The characters showing significance for any of the scales (C or D or both) indicated the presence of epistasis. The significance of 'C' alone was taken as presence of dominance × dominance (l) type of non-allelic interaction and the significance of D alone was taken as additive × additive type. Existence of both additive × additive and dominance × dominance types of gene interaction was considered when C and D scales were significant. If none of the scaling tests was significant, it was considered as the absence of epistatic gene action (Mather and Jinks, 1971). Difference between generation means is a pre-requisite to proceed with the analysis of generation means. Mean values showing significant differences among five generations (P_1, P_2, F_1, F_2 and F_3) of the ten crosses with respect to eight characters have been presented in Table 1.

The five components *viz.*, mean [m], additive [d], dominance [h], additive x additive [i] and dominance x dominance [l] obtained from analysis of five populations *viz.*, parent 1, parent 2, F_1, F_2 and F_3 for eight characters of ten crosses *viz.*, BPT 5204 x Akshyadhan, BPT 5204 x Pusa 1121, BPT 5204 x Sumathi, Akshyadhan x NLR 145, Akshyadhan x Pusa 1121, NLR 145 x Sumathi, RNR 2354 x Improved Pusa Basmati, RNR 2354 x Basmati 370, Sumathi x Improved Pusa Basmati and Improved Pusa Basmati x Basmati 370 were estimated following perfect fit digenic interaction 5 parameter model and presented in Table 2 and explained below.

The individual scaling tests (C and D) and Chi-square value of joint scaling were observed to be highly significant in case of days to 50 per cent flowering revealing the inadequacy of the additive dominance model. All the crosses flowered early as compared to their respective better parent except in case of BPT 5204 x Pusa 1121 indicating predominantly the decreasing effect of dominant alleles. The dominance x dominance [l] interaction effects were negative and significant in all the crosses studied except in BPT 5204 x Akshyadhan. In all the crosses duplicate type of epistasis was prevalent as was reported by Murugan and Ganesan (2006) and Nayak et al. (2007). Direct selection in three crosses (Akshyadhan x NLR 145, RNR 2354 x Improved Pusa Basmati and Improved Pusa Basmati x Basmati 370) would be useful to evolve early lines, as the 'd' effects were negative and significant, whereas for other crosses, breeding method which exploit 'h' and 'l' type of variation would be useful.

With respect to plant stature both the tests (joint scaling as well as C, D scaling tests) revealed the presence of epistasis in its inheritance. Significant additive [d] gene effects in the crosses *viz.*, BPT 5204 x Akshyadhan, BPT 5204 x Pusa 1121, BPT 5204 x Sumathi, NLR 145 x Sumathi, RNR 2354 x Basmati 370 and Improved Pusa Basmati x Basmati 370 indicated that, selection would be rewarding to develop dwarf genotypes. Dominance [h] and dominance x dominance [l] effects for all the ten crosses were in opposite direction, indicating role of duplicated epistasis. Due to mutual cancellations of dominance effects, the 'i' type of interaction was predominant but towards undesirable positive side except in BPT 5204 x Akshyadhan.

Number of productive tillers per plant play crucial role in rice productivity. In all the crosses except in BPT 5204 x Akshyadhan simple additive and dominance model was inadequate and non-allelic

Table 1. Generation means for yield and yield contributing characters

Cross	Days to 50% flowering					Plant height (cm)					No. of productive tillers/ plant					Panicle length (cm)				
	P_1	P_2	F_1	F_2	F_3	P_1	P_2	F_1	F_2	F_3	P_1	P_2	F_1	F_2	F_3	P_1	P_2	F_1	F_2	F_3
BPT 5204 x Akshyadhan	111.0	108.0	104.0	113.0	114.0	96.8	127.7	119.0	91.0	106.0	11.8	10.3	11.8	14.3	12.7	19.8	29.3	27.1	24.5	24.5
BPT 5204 x Pusa 1121	111.0	96.3	98.0	107.0	91.0	96.8	116.3	118.0	125.0	95.0	11.8	14.5	10.4	15.1	14.4	19.8	23.6	26.5	25.0	20.9
BPT 5204 x Sumathi	111.0	108.7	98.0	113.0	106.0	96.8	137.7	118.0	119.0	61.0	11.8	9.5	9.6	12.6	22.3	19.8	26.8	26.9	24.5	18.7
Akshyadhan x NLR 145	108.0	121.0	99.0	110.0	106.0	127.7	108.5	122.0	148.0	114.0	10.3	9.7	7.8	12.1	13.3	29.3	22.7	27.2	25.0	24.4
Akshyadhan x Pusa 1121	108.0	96.3	89.0	103.0	92.0	127.7	116.3	122.0	127.0	119.0	10.3	14.5	10.9	13.4	14.5	29.3	23.6	30.4	26.5	25.4
NLR 145 x Sumathi	121.0	108.7	99.0	113.0	103.0	108.5	137.7	126.0	119.0	103.0	9.7	9.5	10.7	11.8	12.5	22.7	26.8	26.6	28.9	25.1
RNR 2354 x I.P Basmati	106.0	115.0	96.0	113.0	89.0	113.4	102.5	115.0	108.0	92.0	9.1	9.5	7.6	11.2	14.4	22.2	27.9	29.3	27.0	24.5
RNR 2354 x Basmati 370	106.0	101.0	99.0	109.0	82.0	113.4	121.2	112.0	105.0	92.0	9.1	8.5	8.1	10.5	16.0	22.2	28.5	27.4	27.4	23.5
Sumathi x I.P Basmati	108.7	115.0	93.0	104.0	93.0	137.7	102.5	130.0	123.0	103.0	9.5	9.5	9.6	13.0	14.3	26.8	27.9	32.3	27.2	26.9
I.P Basmati x Basmati 370	115.0	101.0	94.0	112.0	99.0	102.5	121.2	110.0	121.0	90.0	9.5	8.5	10.5	14.7	16.3	27.9	28.5	29.8	26.3	25.6

Cross	Panicle weight (g)					No. of filled grains/ panicle					1000 grain weight (g)					Grain yield/ plant (g)				
	P_1	P_2	F_1	F_2	F_3	P_1	P_2	F_1	F_2	F_3	P_1	P_2	F_1	F_2	F_3	P_1	P_2	F_1	F_2	F_3
BPT 5204 x Akshyadhan	2.3	3.4	4.0	2.1	2.3	137.3	167.7	189.3	92.6	109.0	12.5	25.8	20.5	20.5	18.9	16.6	28.6	42.8	22.1	23.4
BPT 5204 x Pusa 1121	2.3	1.2	3.6	1.7	1.5	137.3	44.3	147.7	68.6	84.0	12.5	23.8	20.6	20.5	16.5	16.6	11.9	32.9	19.0	16.6
BPT 5204 x Sumathi	2.3	3.1	3.6	2.3	1.1	137.3	120.0	160.0	109.3	80.0	12.5	22.4	18.6	18.6	17.3	16.6	22.4	29.7	21.0	21.7
Akshyadhan x NLR 145	3.4	2.7	4.3	2.7	2.2	167.7	97.0	166.9	103.4	85.0	25.8	18.2	24.0	24.0	23.3	28.6	16.5	28.3	25.4	22.6
Akshyadhan x Pusa 1121	3.4	1.2	3.2	1.9	1.5	167.7	44.3	107.2	63.9	54.0	25.8	23.8	28.8	28.9	26.2	28.6	11.9	27.9	18.7	17.7
NLR 145 x Sumathi	2.7	3.1	3.1	2.9	2.2	97.0	120.0	160.7	105.6	76.0	18.2	22.4	23.9	23.7	22.7	16.5	22.4	28.5	24.3	18.0
RNR 2354 x I.P Basmati	2.7	2.2	4.4	2.2	1.9	135.7	53.4	202.0	91.4	83.0	15.4	18.8	20.8	20.8	19.7	19.3	10.5	27.7	17.5	20.8
RNR 2354 x Basmati 370	2.7	3.9	4.2	2.3	1.7	135.7	124.6	200.7	128.9	85.0	15.4	21.8	18.0	17.8	18.0	19.3	24.8	28.9	20.4	20.3
Sumathi x I.P Basmati	3.1	2.2	3.9	2.0	1.4	120.0	53.4	165.7	77.9	55.0	22.4	18.8	23.6	23.5	18.3	22.4	10.5	30.1	18.0	13.9

interactions were involved in its inheritance. Higher estimates of additive [d] type component were registered with respect to the crosses, Sumathi x Improved Pusa Basmati, BPT 5204 x Akshyadhan and Improved Pusa Basmati x Basmati 370, which indicated the scope of direct selection for improvement of this trait (Thirugnana kumar et al., 2007), whereas in other crosses, heterosis exploitation would be highly effective. The negative sign of (i) for all the crosses except BPT 5204 x Akshyadhan indicated that the selection should be deferred to later generations.

Epistatic gene effects existed for panicle length also and among the interaction effects, 'i' type gene effects were positively significant in six crosses. Within these, two specific crosses *viz.*, Akshyadhan x NLR 145 and Akshyadhan x Pusa 1121 were considered as best ones from selection point of view as both 'd' and 'i' types were in positive direction with high per se performance. The epistasis was of duplicate type for seven crosses studied as was reported by Verma et al., (2006). Inter-mating programme among F_2 segregants (or) multiple crossing programme with selected segregants would help in realizing of superior genotypes with improved panicle length.

Epistatic effects were prevalent for panicle weight as per the scaling tests and Joint scaling test. The additive x additive [i] interaction effects were positive and significant for eight crosses and for remaining two crosses they were negative, for one significantly negative and for another non-significant. The dominance x dominance [l] effects was positively significant in case of seven crosses and 'h' and 'l' were opposite in five crosses. Pedigree selection would be highly rewarding incase of 4 crosses *viz.*, BPT 5204 x Pusa 1121, Akshyadhan x NLR 145, Akshyadhan x Pusa 1121, RNR 2354 x Improved Pusa Basmati and Sumathi x Improved Pusa Basmati, as their 'd' and 'i' components were significant with high per se performance with respect to panicle weight whereas, in respect of other crosses the 'd' and 'i' components had opposite signs.

Highly significant positive dominance [h] effects and dominance x dominance [l] effects were recorded for number of filled grains per panicle. Non additive gene effects were predominant over additive gene effects, indicating the existence of non fixable

Table 2. Genetic components of generation mean for yield and yield contributing characters

Cross	Scaling tests			Components				
	C	D	÷² value of JST (3 parameter) at 2 d.f	m	d	h	i	l
Days to 50 % flowering								
BPT 5204 x Akshyadhan	26.33**± 1.03	11.67**± 0.63	1051.17**	113.33**± 0.14	1.50** =± 0.17	-8.89**± 0.49	-0.39± 0.61NS	19.56**± 1.66
BPT 5204 x Pusa 1121	25.33**± 0.45	-58.00**± 0.71	16545.45**	107.33**± 0.04	7.33**± 0.19	37.56**± 0.41	57.56**± 0.47	-111.11**± 0.89
BPT 5204 x Sumathi	34.33**± 0.59	-22.33**± 0.87	4527.78**	112.67**± 0.10	1.17**±0.19	9.11**± 0.55	22.94**± 0.57	-75.56**± 1.32
Akshyadhan x NLR 145	11.67**± 0.70	-25.67**± 0.92	1347.23**	109.67**± 0.10	-6.50**± 0.24	3.56**± 0.55	6.06**± 0.53	-49.78**± 1.36
Akshyadhan x Pusa 1121	28.33**± 0.58	-41.67**± 0.46	10510.93**	102.67**± 0.10	5.83**± 0.14	19.33**± 0.30	44.17**± 0.37	-93.33**± 1.00
NLR 145 x Sumathi	22.33**± 0.80	-43.00**± 0.63	7816.59**	112.67**± 0.10	6.17**± 0.26	16.89**± 0.33	44.72**± 0.62	-87.11**± 1.10
RNR 2354 x I.P Basmati	39.33**± 0.99	-90.00**± 0.92	9869.82**	113.00**± 0.20	-4.67**± 0.18	51.56**± 0.66	57.22**± 0.71	-172.44**± 1.99
RNR 2354 x Basmati 370	29.00**± 0.54	-95.00**± 0.59	29712.06**	108.67**± 0.10	2.50**± 0.15	64.00**± 0.37	73.17**± 0.45	-165.33**± 1.05
Sumathi x I.P Basmati	8.00**± 1.04	-54.67**± 0.83	4618.52**	103.67**± 0.04	-3.33**± 0.16	23.11**± 0.60	31.11**± 0.59	-83.56**± 1.67
I.P Basmati x Basmati 370	43.21**± 0.97	-44.33**± 0.57	6130.96**	112.00**± 0.20	7.17**± 0.14	22.89**± 0.47	51.06**± 0.60	-116.44**± 1.77
Plant height								
BPT 5204 x Akshyadhan	-9.84**± 0.74	-25.01**± 0.56	1966.20**	90.94**± 0.12	-15.43**± 0.25	21.37**± 0.26	-15.83**± 0.60	-20.23** ±1.04
BPT 5204 x Pusa 1121	49.88**± 1.70	-83.57**± 0.92	9469.91**	124.62**± 0.15	-9.77**± 0.25	75.20**± 0.75	44.50**± 0.91	-177.94**± 2.52
BPT 5204 x Sumathi	6.03**± 1.08	-230.90**± 11.15	471.57**	119.33**± 0.02	-20.45**± 0.37	156.09**± 7.42	114.04**± 5.28	-315.91**±14.87
Akshyadhan x NLR 145	111.13**± 0.96	-76.53**± 0.86	19020.12**	147.90**± 0.18	9.57**± 0.20	73.58**± 0.59	88.68**± 0.65	-250.22**± 1.82
Akshyadhan x Pusa 1121	19.96**± 0.84	-20.41**± 1.26	708.26**	126.94**± 0.19	5.67**± 0.16	16.84**± 0.86	28.27**± 0.78	-53.83**±2.19
NLR 145 x Sumathi	-22.01**± 0.93	-74.11**± 0.73	13148.32**	119.01**± 0.04	-14.58**± 0.34	48.52**± 0.29	16.57**± 0.55	-69.48**± 0.96
RNR 2354 x I.P Basmati	-15.26**± 1.34	-61.52**± 1.10	3762.27**	107.58**± 0.09	5.45**± 0.48	45.29**± 0.48	49.37**± 1.04	-61.68**± 1.52
RNR 2354 x Basmati 370	-39.67**± 0.92	-76.37**± 0.97	7688.69**	104.68**± 0.01	-3.87**± 0.43	38.90**± 0.32	36.57**± 0.94	-48.93**± 0.75
Sumathi x I.P Basmati	29.05**± 1.76	-65.74**± 0.83	8779.99**	122.95**± 0.10	17.58**± 0.40	49.82**± 0.55	83.83**± 0.94	-126.38**± 2.19
I.P Basmati x Basmati 370	40.58**± 0.89	-104.87**± 0.65	62168.25**	120.99**± 0.04	-9.32**± 0.31	74.66**± 0.26	58.05**± 0.68	-193.94**± 0.92
No. of productive tillers/ plant								
BPT 5204 x Akshyadhan	11.06**± 0.52	0.09± 0.36 NS	-	14.27**± 0.12	0.75**± 0.10	2.77**± 0.07	3.29**± 0.37	-14.63**± 0.99
BPT 5204 x Pusa 1121	13.39**± 0.40	2.24**± 0.26	1122.55**	15.08**± 0.01	-1.37**± 0.10	-2.06**± 0.17	-2.00**± 0.27	-14.86**± 0.53
BPT 5204 x Sumathi	9.83**± 0.39	44.23**± 0.96	2546.32**	12.60**± 0.06	1.15**± 0.13	-28.80**± 0.62	-25.55**± 0.51	45.87**± 1.32
Akshyadhan x NLR 145	12.95**± 0.34	9.29**± 0.24	4739.57**	12.05**± 0.07	0.30**± 0.05	-6.34**± 0.19	-3.44**± 0.22	-4.87**± 0.65
Akshyadhan x Pusa 1121	6.97**± 0.54	7.03**± 0.29	1600.67**	13.43**± 0.11	-2.12**± 0.04	-4.91**± 0.27	-7.76**± 0.32	0.09± 0.99 NS
NLR 145 x Sumathi	6.65**± 0.38	7.97**± 0.51	566.54**	11.78**± 0.07	0.10± 0.09NS	-3.11**± 0.34	-4.01**± 0.30	1.76*± 0.87
RNR 2354 x I.P Basmati	10.93**± 0.24	17.73**± 0.47	3952.78**	11.20**± 0.04	-0.20**± 0.02	-11.60**± 0.32	-10.40**± 0.25	9.07**± 0.72
RNR 2354 x Basmati 370	8.62**± 0.40	25.34**± 0.65	-	10.55**± 0.09	0.28**± 0.09	-16.24**± 0.44	-14.89**± 0.37	22.29**± 1.07
Sumathi x I.P Basmati	14.69**± 0.62	6.59**± 0.45	1406.22**	13.24**± 0.14	2.10**± 0.00	-1.74**± 0.35	-1.94**± 0.43	-10.81**± 1.22
I.P Basmati x Basmati 370	20.14**± 0.49	17.98**± 1.38	1966.03**	14.69**± 0.11	0.48**± 0.09	-7.28**± 0.93	-7.66**± 0.70	-2.88± 2.00 NS

Continued....

Table 2. continued……

Cross	Scaling tests			Components				
	C	D	$\div^2$ value of JST (3 parameter) at 2 d.f	m	d	h	i	l
Panicle length								
BPT 5204 x Akshyadhan	-5.02**± 0.52	-0.11± 0.46 NS	196.15**	24.54**± 0.06	-4.75**± 0.22	1.78**± 0.12	-10.27**± 0.52	6.55**± 0.48
BPT 5204 x Pusa 1121	3.64**± 0.59	-9.82**± 0.51	1693.35**	24.98**± 0.03	-1.90**± 0.25	11.95**± 0.12	3.35**± 0.53	-17.95**± 0.47
BPT 5204 x Sumathi	0.83**± 0.56	-5.80**± 0.51	221.96**	24.52**± 0.08	-4.08**± 0.23	6.12**± 0.19	-4.16**± 0.54	-8.84**± 0.67
Akshyadhan x NLR 145	-0.01**± 0.73	-8.21**± 1.01	67.01**	24.94**± 0.13	4.85**± 0.10	8.69**± 0.71	15.17**± 0.61	-10.94**± 1.75
Akshyadhan x Pusa 1121	-7.82**± 0.27	-4.17**± 0.32	873.89**	26.47**± 0.01	2.85**± 0.12	5.50**± 0.15	7.18**± 0.17	4.86**± 0.35
NLR 145 x Sumathi	13.09**± 1.27	-6.99**± 0.62	128.82**	28.95**± 0.30	-2.05**± 0.04	8.69**± 0.62	2.74**± 0.76	-26.77**± 2.47
RNR 2354 x I.P Basmati	-0.62**± 0.22	-6.34**± 0.17	1953.64**	27.02**± 0.01	-2.85**± 0.08	8.31**± 0.07	-1.58**± 0.13	-7.63**± 0.25
RNR 2354 x Basmati 370	4.21**± 0.53	-11.55**± 0.25	2402.59**	27.43**± 0.10	-3.12**± 0.05	10.45**± 0.24	2.17**± 0.30	-21.01**± 0.93
Sumathi x I.P Basmati	-40.61**± 3.82	9.57**± 1.92	1737.74**	27.23**± 0.95	-0.57**± 0.07	-10.28**± 1.91	-14.28**± 2.34	66.92**± 7.63
I.P Basmati x Basmati 370	-10.61**± 0.26	-6.66**± 0.23	1964.56**	26.33**± 0.00	-0.27**± 0.07	4.24**± 0.14	2.14**± 0.19	5.27**± 0.38
Panicle weight								
BPT 5204 x Akshyadhan	-5.70**± 0.12	-0.77**± 0.08	3162.97**	2.07**± 0.03	-0.55**± 0.02	0.71**± 0.06	-1.54**± 0.01	6.58**± 0.02
BPT 5204 x Pusa 1121	-4.03**± 0.08	-1.05**± 0.05	-	1.72**± 0.01	0.57**± 0.02	1.90**± 0.03	1.16**± 0.05	3.97**± 0.13
BPT 5204 x Sumathi	-3.50**± 0.05	-5.55**± 0.10	6826.11**	2.29**± 0.01	-0.38**± 0.02	3.96**± 0.06	2.34**± 0.06	-2.68**± 0.13
Akshyadhan x NLR 145	-4.10**± 0.91	-131.47**± 2.29	9507.66**	2.67**± 0.01	0.42**± 0.02	2.36**± 0.06	1.91**± 0.06	1.96**± 0.12
Akshyadhan x Pusa 1121	-3.30**±0.12	-2.50**± 0.06	4395.69**	1.97**± 0.03	1.12**± 0.02	2.00**± 0.06	3.35**± 0.01	1.07**±0.21
NLR 145 x Sumathi	-0.13NS± 0.11	-2.85**± 0.25	147.51**	2.94**± 0.04	-0.25**± 0.01	2.06**± 0.18	1.38**± 0.15	-3.64**± 0.45
RNR 2354 x I.P Basmati	-5.16**± 0.03	-1.79**± 0.13	42119.01**	2.16**± 0.01	0.27**± 0.01	2.30**± 0.01	0.86**± 0.06	4.50**± 0.18
RNR 2354 x Basmati 370	-567**± 0.12	-4.51**± 0.10	2419.12**	2.34**± 0.01	-0.59**± 0.05	-2.95**± 0.04	0.90**± 0.06	1.55**± 0.12
Sumathi x I.P Basmati	1.79**± 0.15	-2.77**± 0.13	1027.53**	2.59**± 0.03	0.47**± 0.01	2.29**± 0.10	2.48**± 0.10	-1.32**± 0.31
I.P Basmati x Basmati 370	-6.66**± 0.12	-3.98**± 0.12	2994.93**	1.88**± 0.01	-0.85**± 0.05	2.53**± 0.05	-0.15NS± 0.07	3.56**± 0.15
No. of filled grains/ panicle								
BPT 5204 x Akshyadhan	-313.37**± 2.80	-55.48**± 3.29	-	92.57**± 0.41	-15.17**± 1.13	21.59**± 1.71	-45.58**± 2.39	343.86**± 4.44
BPT 5204 x Pusa 1121	-202.59**± 3.89	15.79**± 2.00	2970.30**	68.60**± 0.47	46.50**± 0.85	12.54**± 1.39	48.71**± 2.37	291.17**± 5.46
BPT 5204 x Sumathi	-140.32**± 3.32	-447.84**± 1.71	69130.53**	109.25**± 0.35	8.67**± 0.76	306.51**± 1.13	292.51**± 2.14	-410.03**± 4.48
Akshyadhan x NLR 145	4.05**± 0.18	0.86**± 0.17	584.93**	103.40**± 0.01	35.33**± 0.87	91.47**± 1.03	127.47**± 2.04	71.44**± 2.27
Akshyadhan x Pusa 1121	-171.27**± 5.35	-123.70**± 4.04	2028.77**	63.85**± 0.72	61.67**± 0.92	55.26**± 2.96	177.26**± 3.39	63.42**± 9.07
NLR 145 x Sumathi	-115.80**± 4.17	-124.27**± 3.17	5609.94**	105.63**± 1.01	-11.50**± 0.24	115.71**± 2.59	40.54**± 2.78	-11.29**± 8.76
RNR 2354 x I.P Basmati	-227.76**± 2.90	-40.12**± 2.54	6366.36**	91.39**± 0.43	41.00**± 1.03	96.12**± 1.23	70.79**± 2.62	250.19**± 4.08
RNR 2354 x Basmati 370	-145.77**± 6.50	-179.11**± 3.22	3608.34**	128.89**± 0.84	5.67**± 1.19	165.78**± 2.54	106.45**± 3.71	-44.45**± 9.67
Sumathi x I.P Basmati	-225.24**± 13.27	-59.21**± 3.10	702.91**	77.91**± 0.60	33.17**± 0.14	121.10**± 4.89	68.27**± 5.26	221.37**± 18.44
I.P Basmati x Basmati 370	-124.65**± 14.86	-85.01**± 1.93	2012.81**	70.17**± 0.42	-35.33**± 0.62	60.56**± 5.04	-34.77**± 5.65	52.86**± 19.97

continued……

Table 2. Continued.....

Cross	Scaling tests			Components				
	C	D	$\div^2$ value of JST (3 parameter) at 2 d.f	m	d	h	i	l
1000 grain weight								
BPT 5204 x Akshyadhan	2.66**± 0.49	-3.85**± 0.31	164.58**	20.51**± 0.06	-6.68**± 0.04	4.39**± 0.26	-10.36**± 0.26	-8.67**± 0.83
BPT 5204 x Pusa 1121	4.63**± 0.29	-11.36**± 0.13	7865.17**	20.50**± 0.03	-5.65**± 0.05	10.80**± 0.11	-2.95**± 0.14	-21.32**± 0.42
BPT 5204 x Sumathi	2.53**± 0.30	-2.54**± 0.22	203.56**	18.60**± 0.05	-4.87**± 0.06	3.39**± 0.15	-7.62**± 0.18	-6.76**± 0.50
Akshyadhan x NLR 145	-0.12± 0.58NS	-5.47**± 1.12	24.15**	24.02**± 0.07	6.07**± 0.09	9.43**± 0.76	15.76**± 0.59	-7.14**± 1.68
Akshyadhan x Pusa 1121	8.27**± 0.42	-2.55**± 0.22	508.60**	28.87**± 0.04	1.03**± 0.05	7.09**± 0.19	5.14**± 0.21	-14.43**± 0.64
NLR 145 x Sumathi	6.50**± 0.16	2.94**± 0.13	1642.62**	23.67**± 0.01	-2.00**± 0.06	2.81**± 0.05	-4.87**± 0.10	-4.75**± 0.18
RNR 2354 x I.P Basmati	8.31**± 0.36	4.39**± 0.27	1222.97**	20.78**± 0.07	-1.70**± 0.06	2.68**± 0.17	-4.37**± 0.21	-5.49**± 0.66
RNR 2354 x Basmati 370	7.43**± 0.40	3.31**± 0.19	950.83**	17.80**± 0.03	-3.17**± 0.04	-0.41**± 0.07	-6.15**± 0.10	1.52**± 0.25
Sumathi x I.P Basmati	-1.88**± 0.15	-0.74**± 0.11	218.74**	23.67**± 0.03	1.70**± 0.08	1.65**± 0.17	1.70**± 0.19	-2.60**± 0.42
I.P Basmati x Basmati 370	6.00**± 0.22	4.05**± 0.28	783.40**	18.97**±0.03	-1.47**±0.07	-6.13**±0.07	12.23**±0.23	-7.76**±0.15
Grain yield/ plant								
BPT 5204 x Akshyadhan	-42.38**± 0.57	4.27**± 0.15	7157.11**	22.11**± 0.02	-5.98**± 0.07	10.27**± 0.19	-21.88**± 0.23	62.20**± 0.76
BPT 5204 x Pusa 1121	-18.49**± 0.83	-0.01**± 0.54	490.95**	18.99**± 0.13	2.35**± 0.19	15.57**± 0.36	1.62**± 0.45	24.64**± 1.31
BPT 5204 x Sumathi	-14.67**± 0.35	5.93**± 0.75	1957.76**	20.97**± 0.03	-2.90**± 0.11	3.80**± 0.49	-12.20**± 0.38	27.47**± 1.04
Akshyadhan x NLR 145	-0.42± 0.07NS	-0.10**± 0.15	35.36**	25.40**± 0.01	-0.08**± 0.02	0.61**± 0.10	-0.16**± 0.08	0.43 ± 0.21NS
Akshyadhan x Pusa 1121	-21.52**± 1.00	-7.11**± 0.84	598.37**	18.69**± 0.19	8.33**± 0.20	8.75**± 0.59	17.82**± 0.63	19.22**± 1.86
NLR 145 x Sumathi	1.35**± 0.50	-15.51**± 0.31	2989.73**	24.30**± 0.03	-2.98**± 0.12	19.59**± 0.19	4.60**± 0.26	-22.48**± 0.65
RNR 2354 x I.P Basmati	-15.30**± 0.40	18.67**± 0.90	1693.56**	17.48**± 0.09	4.42**± 0.07	-2.22**± 0.61	-6.17**± 0.49	45.30**± 1.38
RNR 2354 x Basmati 370	-20.33**± 0.98	-3.69**± 0.65	715.95**	20.40**± 0.20	-2.72**± 0.08	5.93**± 0.55	-6.36**± 0.59	22.18**± 1.87
Sumathi x I.P Basmati	6.92**± 1.47	-7.20**± 0.50	209.13**	18.10**± 0.22	5.97**± 0.12	16.76**± 0.59	17.89**± 0.73	-18.83**± 2.34
I.P Basmati x Basmati 370	-39.39**± 0.79	5.08**± 1.18	2467.22**	14.03**± 0.11	-7.13**± 0.08	2.53**± 0.83	-24.22**± 0.66	59.29**± 1.97

*Significant at 5 % level, ** Significant at 1 % level genetic variation as reported by Annadurai and Nadarajan (2001) and Patil et al. (2006). Hence, scope of improvement for grains per panicle through single plant selection is limited. In certain crosses *viz.,* BPT 5204 x Sumathi and RNR 2354 x Basmati 370 in which 'i' type of interaction coupled with significant 'd' effects suggesting largely direct selection would be advantageous. The opposite signs of [h] and [l] in crosses like BPT 5204 x Sumathi, Akshyadhan x NLR 145, NLR 145 x Sumathi and RNR 2354 x Basmati 370 and same signs in six crosses indicated the presence of both duplicate and complementary epistasis, for grains per panicle (Kumar and Mani, 2010). In most of the cases, higher magnitude of heterosis followed by high inbreeding depression was experienced for grains per panicle largely due to dominance and interaction between plus dominant genes in such crosses, heterotic breeding would be highly rewarding in comparison to straight selection in segregating generations only to reap immediate benefits provided feasible male sterile lines are generated (Murugan and Ganesan, 2006; Verma et al., 2006).

For thousand kernel weight, the [d] estimates were positive in two crosses *viz.,* Akshyadhan x NLR 145 and Akshyadhan x Pusa 1121, for which, direct selection would be highly useful as also reported from studies by Dhanakodi and Subramanian (1998) and Thirugnana Kumar et al., (2007). In remaining crosses (except Sumathi x Improved Pusa Basmati), significant and positive dominance [h] effects were expressed. The interaction effects due to dominance x dominance [l] were negative and significant in all the crosses except in one *viz.*, Sumathi x Improved Pusa Basmati. The signs for dominance [h] and dominance x dominance [l] components were in opposite direction for all the crosses studied revealing the greater role of duplicate epistasis as also reported by Thirugnana Kumar et al., (2007). Among the crosses investigated, Akshyadhan x NLR 145 and Akshyadhan x Pusa 1121 were the best superior crosses from the point of recovering the homozygous lines with very high test weight, as the additive x additive [i] and additive [d] components were positive and highly significant in these two crosses. In rest of the crosses, direct selection for higher test weight may not be much fetching due to preponderance of dominance [h] effects as well as duplicate epistasis. When both additive and non additive effects are important, the use of population improvement concept may become an amenable solution. Frey (1982) explained the use of this technique in highly autogamous crop. Bi-parental mating, recurrent selection and selective diallel mating system (Jensen, 1970) might be more profitable.

Grain yield per plant is the ultimate end product resulting from the direct and interaction effects of all the yield components. Scaling tests (C and D) as well as joint scaling test indicated that simple additive - dominance model was inadequate to explain the inheritance of grain yield. The estimates of dominance [h] components were high and positive in comparison to those of additive [d] except in case of Akshyadhan x Pusa 1121 and Sumathi x Improved Pusa Basmati. Most of the crosses exhibited significant dominance x dominance (l) type of interactions for grain yield as was observed by Ganesan and Subramanian (1994). In the present study, 6 crosses registered complementary epistasis and 3 crosses exhibited duplicate epistasis, as in case of Patil et al., (2006) and Savitha and Usha Kumari (2015). The observed genetic variation for grain yield per plant was of mostly non additive type, hence direct selection for grain yield would be a futile attempt. Instead, recurrent selection and bi-parental mating would be advantageous especially in crosses like BPT 5204 x Akshyadhan, BPT 5204 x Pusa 1121 and Improved Pusa Basmati x Basmati 370 in view of predominant role of non-allelic genetic variation.

CONCLUSION

Keeping in view, the magnitudes of fixable genetic variation ('d' & 'i' types) and per se performance in F_2 generation in comparison to F1's and respective parents, immediate selection in segregating generations / intercrossing among the selected genotypes in F_2 to poolup plus genes with simultaneous advancement in certain promising crosses *viz.*, BPT 5204 x Akshyadhan, Akshyadhan x NLR 145 and Akshyadhan x Pusa 1121 is expected to be highly feasible for grain yield improvement in rice.

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