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Combining Ability Analysis for Yield, Yield Related Traits and Chlorophyll Content over Environments in Boro Rice

Kumari Priyanka* and H. K. Jaiswal

Department of Genetics and Plant Breeding, Institute of Agricultural Sciences,
Banaras Hindu University, Varanasi – 221 005, Uttar Pradesh, India

*Corresponding Author E-mail: kpriyanka.choudhary@gmail.com

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ABSTRACT

Combining ability of yield, yield related traits and chlorophyll content in Boro rice were studied employing diallel approach with 9 parents and their 36 crosses over three seasons i.e. Boro-2014, Kharif-2015 and Boro-2015. Data were recorded on days to 50% flowering, days to maturity, plant height, effective tillers/plant, panicle length, flag leaf length, flag leaf width, grains/panicle, 100 seed weight, yield/plant and chlorophyll content. Combining ability analysis revealed significant differences among GCA effects of the parents and SCA effects of the crosses for all the yield traits and chlorophyll content over the seasons. SCA effects were significant (both positive and negative) for majority of crosses for most of the traits which exhibited the importance of non-additive type of gene action. Krishna Hamsa was found to be good general combiner for yield per plant over both Boro and Kharif seasons. The crosses with good x good GCA parents could be improved through selection and pedigree method of breeding and crosses with poor x poor GCA parents could be improved through heterosis breeding.

Key words: *Boro rice, Chlorophyll content, GCA, SCA, Yield.*

INTRODUCTION

Rice is a staple crop critical to food security of billions of people around the world. There is need to increase rice production in order to meet the requirements of growing population. Hybrid rice technology is a potential strategy to increase productivity in rice which depends on selection of parental lines and their superior crosses. Diallel analysis is the best strategy for determining general combining ability and specific combining ability effects[15]. The average performance of a line in cross combinations is termed as general combining ability which relates to additive gene action. The performance of specific cross among all cross combinations is termed as specific combining ability, which relates to non-additive gene action. Estimation of combining ability is the first step in most plant-breeding programs aimed to improve yield and other related parameters[6] as it helps in the selection of suitable parents for hybridization. Therefore, the present investigation was undertaken to assess the combining ability for yield traits and chlorophyll content over seasons to avoid biasness due to other factors.

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MATERIALS AND METHODS

The present study was carried out over three seasons in three replications at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (India). Crosses were made in 9 x 9 diallel fashion excluding reciprocals to generate 36 crosses in Kharif -2014, Boro-2014 and Kharif-2015. All the parents and crosses were evaluated in Boro- 2014, Kharif-2015 and Boro-2015 for days to 50% flowering, days to maturity, plant height,effective tillers/plant, panicle length, flag leaf length, flag leaf width, grains/panicle, 100 seed weight , yield/plant and chlorophyll content. The observations were recorded as per Standard evaluation system of IRRI[8]. Chlorophyll content was measured directly in the field with the help of SPAD - 502 Chlorophyll meter (Konica Minolta) just before heading. Combining ability analysis was performed with the help of statistical software Windostat v.9.2 (Windostat Services, Hyderabad, A.P., India).

RESULTS AND DISCUSSIONS

Thirty six crosses from 9 parents were subjected to combining ability analysis following Griffing's Method II and Model I. The mean sum of squares due to general combining ability (GCA) and specific combining ability (SCA) were utilized for 'F-test' against error mean sum of squares for all the traits. The significant 'F test' for both GCA and SCA indicated sufficient differences between GCA and SCA effects of parents and crosses respectively. This indicated the importance of both additive and non-additive type of gene action in the inheritance of the traits studied. The mean squares due to GCA and SCA was highly significant for all the characters in all the three seasons (Table 1). Highly significant GCA and SCA for all the yield traits was also reported by Mohanty and Mohapatra[10], Verma and Srivastava[18], Torres and Geraldi[16], Chakraborty *et al*[5]., Rahimi *et al*[12]., Adilakshmi and Reddy[1], Ilieva *et al*[7]., Priyanka *et al.*[11] and Adilakshmi and Upendra[2], which supports the present findings.

The estimates of general combining ability (GCA) effects of parental lines and the specific combining ability (SCA) effects of thirty six crosses in the three growing seasons for studied traits are presented in Table 2 and Table 3. MTU 1010 followed by Gautam and Krishna Hamsa were found to be good general combiners for days to 50% flowering in all the three seasons as they exhibited negative and significant GCA effects. However, IR 64 showed highest negative significant GCA in boro-2015. As earliness is an important trait negative estimates of GCA effects were considered as desirable. Negative GCA effects for days to flowering was also reported by Verma and Srivastava[18]. IR 8 showed significant positive GCA effects in boro-2014, non-significant negative GCA effects in boro-2015 and non significant positive effects in kharif-2015. IR 64 showed significant positive effects in boro-2014 and negative GCA effects in boro-2015 and kharif-2015. This suggests the influence of the environment and demand inclusion of more number of genotypes and environments to select good general combiners for improvement of this trait. For days to 50% flowering, most of the crosses showed significant SCA effects. About 50% of the crosses showed significant and negative SCA effects in all the seasons indicating importance of non additive type of gene action in their per se performances. Involvement of non additive gene action for the trait was reported by Sharma *et al*[14]., and Venkatesan *et al*[17]. However, role of additive gene action for the trait was reported by Kumar *et al*[9]., and Chakraborty *et al*[5].

Gautam, MTU 1010 and Krishna Hamsa showed good combining ability towards early maturity in all the three seasons. In boro-2015, IR 64 showed good general combining ability for the trait followed by Gautam, MTU 1010 and Krishna Hamsa. Significant negative GCA is desirable for days to maturity as earliness is a desirable trait in case of rice[11]. For days to maturity, most of the crosses exhibited significant negative SCA effects over the seasons indicating involvement of non additive gene action.

Only few crosses (2-5) over the seasons showed non- significant SCA effects Similar finding was also reported by Sharma *et al*[14]., for the trait. For plant height, IR 64 followed by IR 8 and MTU 1010 exhibited negative and significant GCA effects over the seasons (boro-2014, boro-2015 and kharif-2015). These could be effectively used as a source of dwarfness in breeding programme. In rice, dwarf hybrids are desirable to avoid lodging problems. Significant negative GCA is desirable for plant height. For plant height, very few crosses (one in boro-2014, five in boro-2015 and four in kharif-2015) showed non significant SCA effects. Approximately 40-53% of crosses showed positive and significant SCA effects over seasons. Crosses with significant SCA effects for plant height indicated the preponderance of non-additive gene action in the manifestation of this trait. Approximate 40% of crosses showed negative and significant SCA effects over the seasons which suggested the importance of non-additive type of gene action for dwarfness. Sharma *et al*[14]., and Venkatesan *et al*[17]., also reported preponderance of non additive gene action for the trait. However, role of additive gene action for the trait was reported by Kumar *et al*[9]., and Chakraborty *et al*[5].

Positive and significant GCA is desirable for the trait effective tillers per plant as it contributes directly towards yield. Positive and significant GCA was observed in case of Gautam over the seasons. In boro-2014, besides Gautam IR 64 showed significant positive GCA effects whereas in boro-2015, Krishna hamsa showed significant GCA effects. In kharif-2015, MTU 1010, Krishna Hamsa and Jaya also showed significant and positive GCA. Most of the crosses showed non-significant SCA effects for the trait indicating involvement of additive type of gene action for the trait. About 20-30% crosses showed significant positive SCA effects and an equal per cent showed significant negative SCA effects across season. Chakraborty *et al*[5]., Allahgholipour *et al*[4]., reported additive type of gene action for the trait which is similar with present finding. However, Venkatesan *et al*[17]., reported non-additive type of gene action for the trait.

For panicle length, MTU 1010 showed significant positive GCA over both boro seasons. Besides this, Krishna Hamsa and Jaya showed positive and significant GCA in boro-2014, HUR 105 and Krishna Hamsa showed positive and significant GCA in boro-2015. IR 64 followed by Jaya and HUR 105 showed positive significant GCA in kharif-2015. Positive and significant GCA is desirable for panicle length. Most of the crosses showed non-significant SCA effects for the trait which revealed importance of additive gene action for the inheritance of the trait. 25 per cent of crosses showed positive significant SCA effects over seasons for panicle length. A few crosses also recorded negative significant SCA effects. These observations revealed the role of additive gene action in the determination of panicle length. Akram *et al*[3]., Torres and Geraldi[16], Chakraborty *et al*[5]., Saleem *et al*[13]., and Ilieva *et al*[7]., also reported importance of additive gene action for the trait which is in support of the present study. However, Sharma *et al*[14]., reported importance of non additive gene action for the trait.

For flag leaf length, HUR 105, HUR 36 and IR 36 showed positive and significant GCA effects in all the three seasons (boro-2014, boro-2015 and kharif-2015). About one third of the crosses (33.3 – 52.7%) showed significant negative SCA effects and an equal number of crosses showed significant positive SCA effects. Some crosses showed non-significant SCA effects indicating involvement of both additive and non additive type of gene action. However, Chakraborty *et al*[5]., reported the importance of additive gene action for the trait.

For flag leaf width, HUR 105 exhibited positive and significant GCA in boro-2015 and kharif-2015 whereas Krishna Hamsa showed highest positive and significant GCA in boro-2014. Most of the parents showed non significant GCA effects for the trait. Most of the crosses showed non-significant SCA effects indicating involvement of additive type of gene action for the trait. Only few crosses showed significant positive SCA effects whereas a few crosses showed negative significant SCA effects for the trait over seasons.

For grains per panicle, Krishna Hamsa recorded significant positive GCA over seasons (boro-2014, boro-2015 and kharif-2015). MTU 1010 exhibited highest positive and significant GCA in boro-2014. Besides Krishna Hamsa, Gautam showed highest positive and significant GCA in boro-2015 whereas HUR 36 exhibited highest positive significant GCA in kharif-2015. Positive and significant GCA is desirable for grains per panicle as it directly contributes towards yield.

Significant positive SCA effects was observed in 16.6-33.3% of crosses over seasons whereas the negative significant SCA effects ranged from 16.6-44.4% of crosses over the seasons. Some crosses showed significant SCA effects whereas some crosses showed non-significant SCA effects indicating involvement of both additive and non-additive gene action for the trait. Ilieva *et al*[7]., reported involvement of both additive and non-additive gene action for the trait. Sharma *et al*[14]., and Allahgholipour *et al*[4]., reported involvement of non-additive gene action for grains per panicle.

For 100 seed weight, positive and significant GCA was found in case of Krishna Hamsa followed by Gautam and IR 64 in boro-2014. In boro-2015, IR 8, Krishna Hamsa and Jaya exhibited positive and significant GCA whereas in kharif-2015, IR 8 followed by Jaya and Krishna Hamsa showed positive and significant GCA. Positive and significant GCA effects is desirable for the trait. Krishna Hamsa was found to be a good general combiner for the trait over three seasons. 52.7% to 69.4% of crosses showed significant positive SCA effects whereas few crosses (27.7-38.8%) showed significant negative SCA effects. Most of the crosses showed significant SCA effects over the seasons suggesting involvement of non additive gene action for this trait. Similar finding is reported by Sharma *et al*[14]., and Allahgholipour *et al*[4]. However, preponderance of additive gene action was reported by Kumar *et al*[9].

In case of yield/plant, Gautam followed by Jaya and Krishna Hamsa exhibited highest positive significant GCA in boro-2014, whereas in boro-2015, Krishna Hamsa followed by Gautam and MTU 1010 showed highest positive significant GCA. In kharif-2015, Krishna hamsa followed by Jaya exhibited highest positive significant GCA. Krishna Hamsa was found to be a good general combiner for the trait over three seasons. Significant positive GCA effects are desirable for the trait yield per plant. Gautam showed significant positive GCA effects in boro-2014 and boro-2015 but showed non significant estimates in kharif-2015 indicating the influence of the environment (year and seasons). The GCA effects behaved similarly during both boro season. 78 per cent of crosses studied showed significant SCA effects for the trait in boro-2014 and 64% in boro-2015 indicating preponderance of non additive gene action for the trait, whereas in kharif-2015, 50% of crosses showed significant SCA effects and 50% of crosses showed non-significant SCA effects indicating involvement of both additive and non additive type of gene action. Mohanty and Mohapatra[10], Sharma *et al*[14]., Venkatesan *et al*[17]., and Allahgholipour *et al*[4]., reported involvement of non additive gene action for yield per plant. However, Chakraborty *et al*[5]., reported role of additive gene action in inheritance of the trait. If the gene action is additive in nature then direct selection is possible. In case of yield per plant direct selection would be ineffective due to predominance of non additive gene action. About one third of the crosses (30.5% to 36.1%) showed positive significant SCA effects for the trait. It was observed that most of the top performers had positive SCA effects and crosses with relatively poor performance had negative SCA effects.

For chlorophyll content, Gautam recorded positive and significant GCA for the trait in all the three seasons and was best general combiner. Besides Gautam, Jaya showed positive and significant GCA in boro-2014, HUR 105 in boro-2015 and Krishna Hamsa followed by MTU 1010 in kharif-2015. Nearly 50 per cent of the crosses showed significant positive SCA effects for the trait across seasons. A significant negative SCA effect was also exhibited by some crosses. Most of the crosses showed significant SCA effects in all the three season indicating involvement of non-additive gene action for the trait.

Table 1: ANOVA for combining ability analysis for yield traits and chlorophyll content in Boro rice

SV	DF	Season	DTF	DTM	PH	ET/P	PL	FL	FW	G/P	100SW	Y/P	CC
GCA	8	B-2014	198.71***	179.74***	222.09***	3.73***	7.16***	129.13***	0.03***	301.11***	0.13***	86.48***	20.07***
		B-2015	194.04***	189.84***	229.07***	2.49***	4.98***	86.77***	0.04***	217.43***	0.19***	112.72***	20.64***
		K-2015	262.81***	241.41***	191.81***	4.46***	6.53***	88.94***	0.03***	652.66***	0.17***	25.62***	14.10***
SCA	36	B-2014	63.33***	64.51***	49.65***	3.91***	5.74***	69.09***	0.02***	1059.66***	0.12***	30.45***	11.37***
		B-2015	85.15***	92.87***	73.01***	2.29***	5.89***	59.79***	0.02***	618.12***	0.17***	45.03***	12.19***
		K-2015	43.34***	39.81***	53.53***	4.16***	7.35***	47.45***	0.03***	451.41***	0.09***	13.86***	15.57***
Error	88	B-2014	0.52	0.46	0.26	0.54	0.60	0.92	0.01	15.85	0.00	2.00	0.32
		B-2015	0.47	0.54	0.44	0.44	0.56	0.50	0.00	12.76	0.00	1.97	0.28
		K-2015	0.52	0.51	0.22	0.43	0.50	0.77	0.00	13.07	0.00	1.38	0.33

*$p \leq 0.05$; **$p \leq 0.01$;***$p \leq 0.001$; SV-Source of variation; DF – Degrees of freedom; DTF – Days to 50% flowering; DTM – Days to maturity; PH- Plant height; ET/P – Effective tillers/plant; PL- Panicle length; FL – Flag leaf length; FW- Flag leaf width; G/P-Grains/panicle; 100SW- 100 seed weight; Y/P- Yield/plant; CC- Chlorophyll content; B-2014 – Boro 2014; B-2015 – Boro 2015; K-2015 – Kharif 2015.

Table 2: Estimates of GCA effects of parental lines along with their mean performance for yield traits and chlorophyll content over seasons

	Days to 50% flowering			Days to maturity			Plant height			Effective tillers/plant		
Parent	Boro-2014	Boro-2015	Kharif -2015	Boro-2014	Boro-2015	Kharif-2015	Boro-2014	Boro-2015	Kharif-2015	Boro-2014	Boro-2015	Kharif-2015
P1	0.717***	-0.064	0.121	1.320***	0.421*	0.525*	-4.707***	-4.608***	-1.745***	-0.974***	-0.317	-0.953***
P2	3.263***	3.118***	0.970***	3.987***	3.330***	0.768***	-1.946***	-1.890***	-0.521***	-0.649**	-0.244	-0.786***
P3	0.535*	-5.246***	-0.091	-2.529***	-5.458***	-0.626**	-5.125***	-4.769***	-7.821***	0.502*	0.068	-0.341
P4	5.051***	4.845***	6.758***	4.956***	4.209***	6.495***	9.538***	10.295***	8.013***	-0.162	-0.363	0.050
P5	5.687***	6.845***	7.727***	5.259***	6.542***	7.434***	3.623***	2.528***	2.922***	-0.183	0.274	-0.341
P6	-6.343***	-3.306***	-5.364***	-4.680***	-3.549***	-5.323***	-1.953***	-1.529***	-0.905***	0.132	-0.551**	0.680***
P7	-1.313***	0.239	0.121	-0.559**	0.663**	0.222	0.408**	1.210***	0.943***	0.214	-0.272	0.408*
P8	-2.313***	-2.246***	-3.788***	-2.832***	-1.579***	-3.444***	0.857***	0.407*	-0.742***	0.147	0.504**	0.511**
P9	-5.283***	-4.185***	-6.455***	-4.923***	-4.579***	-6.051***	-0.695***	-1.644***	-0.145	0.972***	0.901***	0.771***
SE(gi) ±	0.205	0.195	0.205	0.193	0.208	0.203	0.144	0.189	0.134	0.208	0.189	0.186
SE(gi-gj)±	0.308	0.293	0.308	0.289	0.313	0.304	0.217	0.284	0.201	0.312	0.283	0.279

	Panicle length			Flag leaf length			Flag leaf width			Grains/panicle		
Parent	Boro-2014	Boro-2015	Kharif -2015	Boro-2014	Boro-2015	Kharif-2015	Boro-2014	Boro-2015	Kharif-2015	Boro-2014	Boro-2015	Kharif -2015
P1	-0.389	-0.562**	-0.254	-3.790***	-1.751***	0.351	0.032	-0.093***	0.044*	-8.879***	-0.596	-9.875***
P2	-1.158***	-0.574**	-0.772***	2.504***	1.870***	1.988***	0.062**	-0.005	0.013	2.818*	-7.081***	-6.451***
P3	-0.279	0.572**	1.109***	1.731***	-0.363	-2.843***	0.035	-0.017	0.047**	-2.879*	-3.475***	0.943
P4	-0.807***	-0.974***	-0.663**	4.798***	3.812***	4.375***	-0.080***	-0.053**	-0.032	2.758*	-0.293	17.064***
P5	0.224	0.705**	0.482*	4.498***	4.397***	3.318***	0.020	0.056**	0.050**	3.242**	-0.626	0.852
P6	1.084***	0.805***	-0.194	-3.999***	-3.466***	-4.425***	-0.032	0.126***	0.004	7.697***	-2.657*	-0.481
P7	0.754***	0.144	0.955***	-1.993***	-1.878***	-0.515*	-0.050*	-0.023	0.010	-2.879*	1.828	0.852
P8	1.002***	0.457*	0.382	-2.006***	-2.645***	-1.182***	0.044*	0.010	-0.105***	3.333**	7.313***	2.882**
P9	-0.431	-0.574**	-1.045***	-1.741***	0.025	-1.067***	-0.032	-0.002	-0.032	-5.212***	5.586***	-5.785***
SE(gi) ±	0.220	0.212	0.200	0.272	0.200	0.250	0.021	0.018	0.017	1.132	1.015	1.028
SE(gi-gj)±	0.330	0.318	0.301	0.408	0.300	0.375	0.031	0.027	0.026	1.698	1.523	1.541

*p≤0.05; **p≤0.01; P1-IR 8; P2-IR 36; P3-IR-64; P4-HUR 36; P5-HUR 105; P6-MTU 1010; P7-Jaya; P8- Krishna Hamsa; P9- Gautam

GCA cont.

	100 seed weight			Yield/plant			Chlorophyll content		
Parent	Boro -2014	Boro-2015	Kharif -2015	Boro -2014	Boro-2015	Kharif -2015	Boro -2014	Boro-2015	Kharif -2015
P1	-0.039***	0.189***	0.196***	-2.189***	-2.645***	-2.603***	-0.175	0.034	-1.370***
P2	-0.029***	-0.060***	-0.070***	-1.243**	-2.800***	-0.921**	-0.778***	-1.584***	-0.134
P3	0.076***	0.001	-0.042***	-1.107**	-2.397***	0.018	-0.899***	-0.111	-0.394*
P4	-0.188***	-0.290***	-0.178***	-4.749***	-4.145***	-1.758***	-0.523**	-1.096***	-1.109***
P5	-0.077***	-0.018***	-0.069***	-0.880*	0.576	0.533	0.153	0.340*	-0.334*
P6	0.028***	0.067***	0.009**	0.420	2.740***	0.630	-0.893***	-0.866***	0.630***
P7	-0.062***	0.035***	0.187***	3.181***	0.379	1.455***	1.174***	0.034	-0.379*
P8	0.172***	0.098***	0.029***	3.023***	5.109***	2.224***	-1.126***	0.019	0.666***
P9	0.119***	-0.023***	-0.061***	3.544***	3.182***	0.421	3.068***	3.228***	2.424***
SE(gi) ±	0.003	0.004	0.002	0.402	0.399	0.333	0.162	0.150	0.163
SE(gi-gj)±	0.005	0.006	0.004	0.603	0.599	0.500	0.243	0.225	0.244

*p≤0.05; **p≤0.01; P1-IR 8; P2-IR 36; P3-IR-64; P4-HUR 36; P5-HUR 105; P6-MTU 1010; P7-Jaya; P8- Krishna Hamsa; P9- Gautam

Table 3: Estimates of SCA effects of crosses among nine Boro rice parental lines for yield traits and chlorophyll content

Cross	Days to 50% Flowering			Days to matyrity			Plant height			Effective tillers/plant		
	Boro-2014	Boro-2015	Kharif-2015	Boro-2014	Boro-2015	Kharif-2015	Boro-2014	Boro-2015	Kharif-2015	Boro-2014	Boro-2015	Kharif-2015
P1XP2	9.509***	8.376***	7.042***	9.012***	7.079***	5.352***	-4.244***	-3.631***	-7.367***	-0.908	-1.334*	-1.476*
P1XP3	0.236	2.739***	-4.897***	0.527	3.200***	-2.255**	-2.765***	-1.619*	-0.767	0.774	0.521	-3.421***
P1 XP4	-4.279***	-8.352***	-11.412***	-4.958***	-7.800***	-12.376***	-9.929***	-13.782***	-11.834***	-1.596*	-0.116	-0.479
P1XP5	-4.248***	-5.352***	-5.715***	-3.261***	-6.133***	-4.982***	1.353**	-3.649***	-3.343***	1.925**	-0.352	0.512
P1XP6	-3.218***	-5.867***	-3.624***	-4.321***	-6.376***	-3.558***	7.628***	13.975***	4.184***	0.144	0.739	3.658***
P1XP7	9.752***	10.921***	9.891***	10.558***	10.412***	8.897***	11.235***	11.936***	9.636***	1.962**	1.127	1.397*
P1XP8	-5.915***	-2.261***	-3.200***	-3.170***	-4.012***	-2.436***	-7.781***	-9.828***	-10.013***	-1.905**	-0.416	-0.973
P1XP9	-5.945***	-3.321***	-2.533***	-5.745***	-2.345**	-3.830***	4.938***	4.424***	5.524***	0.704	-0.579	3.667***
P2XP3	5.358***	12.558***	8.921***	9.194***	13.291***	7.170***	2.474***	5.996***	3.808***	0.383	2.315***	-2.455***
P2XP4	6.176***	8.467***	10.739***	7.376***	9.624***	10.715***	2.110***	-0.867	0.775	4.947***	1.678**	-0.512
P2XP5	-5.794***	-9.533***	-8.230***	-4.927***	-9.042***	-8.558***	5.525***	6.833***	4.066***	2.701***	-0.058	1.545*
P2XP6	-8.430***	-11.382***	-7.139***	-10.655***	-12.285***	-6.800***	-6.732***	-8.410***	-7.673***	-0.081	0.033	-0.542
P2XP7	-16.794***	-18.927***	-6.958***	-17.109***	-19.164***	-7.012***	-6.693***	-9.349***	-6.088***	-2.096**	0.521	4.064***
P2XP8	3.539***	4.558***	3.285***	2.164**	3.412***	2.321**	5.692***	0.521	6.963***	-4.462***	-0.088	-0.473
P2XP9	4.509***	-0.503	3.952***	4.255***	0.745	4.594***	-4.323***	-8.661***	1.233**	-1.020	-3.519***	1.467*
P3XP4	8.903***	0.830	4.133***	3.558***	-0.921	5.776***	-10.444***	-7.988***	-7.825***	1.828**	-3.367***	2.376***
P3XP5	-3.067***	-19.170***	1.830**	-15.412***	-18.255***	-0.497	-4.862***	-8.055***	-8.134***	-2.717***	-0.737	2.800***
P3XP6	-5.703***	-1.018	-3.412***	3.194***	-0.164	-2.406***	5.847***	4.769***	-0.840	0.568	0.054	2.479***
P3XP7	-14.067***	-11.230***	-4.897***	-8.261***	-11.376***	-4.952***	-4.314***	-2.904***	-9.122***	1.719*	0.075	0.852
P3XP8	6.267***	-7.079***	-2.988***	-4.988***	-7.133***	-4.285***	-0.229	-1.067	4.596***	0.386	-1.934**	1.048
P3XP9	7.236***	1.861**	-1.321	3.436***	-4.133***	-1.679*	3.522***	-0.949	-2.067***	-2.605***	1.469*	-1.945**
P4XP5	3.418***	11.739***	5.648***	2.770***	10.412***	5.715***	7.207***	5.481***	9.033***	-2.587***	0.427	2.409***
P4XP6	-2.885***	-5.442***	-7.261***	-2.624***	-9.830***	-7.527***	-11.117***	-13.961***	-10.073***	-0.235	2.218***	0.421
P4XP7	-8.582***	-11.655***	-10.745***	-9.079***	-14.042***	-11.073***	-11.044***	-13.634***	-8.322***	1.050	0.272	-1.939**
P4XP8	-6.915***	-2.836***	-0.836	-2.806***	-1.467*	-1.406*	14.841***	12.702***	10.730***	-1.917**	-0.070	-1.176
P4XP9	-2.612***	-0.230	3.830***	0.952	-0.800	2.867***	2.125***	-0.646	3.499***	-0.741	1.299*	0.597
P5XP6	16.145***	17.558***	7.770***	16.739***	18.170***	6.867***	3.398***	2.539***	2.151***	-0.214	-3.385***	-2.821***
P5XP7	8.115***	12.012***	8.285***	9.618***	11.624***	7.988***	2.238***	1.266*	3.269***	-0.462	-2.298***	-1.748**
P5XP8	2.448***	4.830***	3.194***	4.891***	4.867***	3.655***	2.156***	5.702***	4.854***	1.871**	1.393*	2.048**
P5XP9	-13.248***	-6.230***	-8.139***	-10.018***	-7.133***	-7.739***	-5.659***	-6.879***	-7.210***	-0.920	2.030**	-0.879
P6XP7	-0.855	0.164	7.042***	-3.442***	2.048**	5.412***	7.413***	4.924***	4.263***	-2.478***	-0.407	0.864
P6XP8	0.479	4.982***	5.285***	0.830	5.291***	5.079***	4.065***	2.293***	-0.619	1.422*	0.918	0.027
P6XP9	-1.885**	-1.079	2.285**	-3.079***	-0.709	2.352***	-8.517***	-8.388***	-9.749***	0.532	-1.779	-0.400
P7XP8	-8.885***	-9.564***	-8.867***	-10.958***	-8.921***	-7.800***	-8.796***	-13.413	-9.201***	3.541***	-0.295	-1.167
P7XP9	-0.915	-1.624*	-3.533***	-2.200**	-1.588*	-1.861**	3.322***	3.872	7.936***	0.950	0.375	0.806
P8XP9	2.752***	2.861***	-1.291	4.073***	3.988***	-0.194	3.274***	4.708	1.721***	1.650*	0.299	1.536*
SE (Sij)±	0.660	0.628	0.660	0.620	0.671	0.653	0.465	0.609	0.432	0.670	0.607	0.600

*p≤0.05; **p≤0.01; P1-IR 8; P2-IR 36; P3-IR-64; P4-HUR 36; P5-HUR 105; P6-MTU 1010; P7-Jaya; P8- Krishna Hamsa; P9- Gautam

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Cross	Panicle length			Flag leaf length			Flag leaf width			Grains/panicle		
	Boro-2014	**Boro-2015**	**Kharif-2015**	**Boro-2014**	**Boro-2015**	**Kharif-2015**	**Boro-2014**	**Boro-2015**	**Kharif-2015**	**Boro-2014**	**Boro-2015**	**Kharif-2015**
P1XP2	0.393	-3.816***	-4.010***	-9.190***	-11.115***	-0.796	-0.082	-0.268***	0.058	-24.073***	-8.145*	8.497*
P1XP3	-1.986**	0.172	-1.258	2.483**	3.018***	6.735***	0.145*	-0.056	0.124*	13.958***	-3.752	-2.897
P1 XP4	-0.625	-0.049	-2.385***	-10.484***	-7.258***	-7.350***	0.060	-0.119	0.203***	-2.012	-6.267	-28.352***
P1XP5	3.178***	3.472***	1.936**	-2.417**	1.024	3.674***	0.160*	-0.028	-0.079	25.170***	19.067***	1.194
P1XP6	-0.616	-1.095	-0.988	-5.687***	-1.179	-5.850***	-0.288***	0.102	0.267***	-3.952	14.764***	-4.139
P1XP7	1.981**	2.199**	-0.504	4.474***	6.633***	-4.359***	0.063	0.050	-0.339***	-4.376	-4.388	-7.806*
P1XP8	-0.768	-0.846	-0.031	-4.078***	-0.733	-0.926	-0.164*	-0.083	-0.124*	6.079	-7.539*	7.497*
P1XP9	-1.135	-0.516	3.363***	8.022***	2.264**	6.525***	0.012	0.162**	-0.297***	-43.376***	-11.145**	-15.170***
P2XP3	-0.116	1.584*	1.093	5.722***	6.230***	-5.735***	-0.119	-0.044	-0.045	-1.406	2.733	4.679
P2XP4	-0.589	5.163***	1.366*	4.122***	5.821***	8.113***	0.196**	0.059	0.033	14.958***	-14.115***	-12.776***
P2XP5	3.647***	1.451*	2.987***	-6.211***	-2.830***	-1.962*	0.230**	0.017	-0.348***	24.473***	22.552***	5.103
P2XP6	-0.080	-0.349	1.330*	-6.381***	-2.933***	3.280***	0.081	0.047	0.097	93.018***	-13.418***	6.103
P2XP7	0.317	-3.322***	-0.919	-1.287	3.345***	0.671	-0.134	0.162**	0.191**	-47.406***	-9.903**	-18.897***
P2XP8	-0.598	0.033	-3.879***	7.362***	3.012***	1.638*	0.105	-0.004	0.106	-18.618***	-0.721	-4.594
P2XP9	-3.232***	-2.470***	-4.852***	2.362*	4.542***	3.322***	-0.119	-0.259***	0.133*	-34.073***	-7.661*	-13.594***
P3XP4	0.899	-1.182	1.518*	-6.905***	-1.145	-4.090***	0.057	0.005	0.000	-10.345**	-17.388***	-8.836*
P3XP5	-1.032	-2.961***	-0.228	-7.438***	-8.130***	-3.332***	-0.143*	-0.104	0.018	-41.164***	-38.388***	-21.624***
P3XP6	2.941***	1.772*	-0.852	7.425***	11.800***	4.344***	0.008	0.126*	-0.136*	9.048*	6.642*	-1.291
P3XP7	-3.128***	-3.934***	-3.901***	-1.114	0.612	-3.365***	-0.073	-0.225***	0.124*	17.624***	30.824***	2.709
P3XP8	1.123	0.754	-0.795	-0.099	3.179***	-1.465	0.133	0.141*	0.273***	-5.921	-14.327***	-14.321***
P3XP9	3.690***	0.918	1.199	-3.999***	-7.558***	-0.014	0.108	-0.247***	0.000	-5.709	-5.933	3.012
P4XP5	-3.938***	-3.082***	-3.988***	2.028*	4.927***	-2.417**	0.072	-0.068	0.097	-50.467***	-43.236***	-47.412***
P4XP6	-1.765	-2.282**	-1.679*	-15.208***	-14.776***	-12.441***	0.124	-0.038	0.042	-40.921***	-41.539***	-14.745***
P4XP7	-1.635*	-2.722***	-1.861**	-13.881***	-11.030***	-7.584***	-0.125	-0.089	0.036	-45.679***	-18.358***	-25.745***
P4XP8	0.950	2.066**	2.812***	-2.265*	0.970	3.150***	0.015	0.078	-0.148*	-9.891*	3.158	-2.442
P4XP9	-3.816***	-2.370**	-5.495***	7.801***	13.933***	7.035***	0.057	0.090	-0.021	-31.012***	-44.448***	-25.776***
P5XP6	0.305	3.072***	-1.092	15.125***	21.739***	17.050***	-0.276***	-0.047	0.161**	-0.406	5.461	-2.533
P5XP7	-1.265	1.133	0.327	13.353***	10.418***	4.707***	-0.058	0.102	0.155**	7.836*	-14.024***	-2.200
P5XP8	0.087	-0.446	-0.034	-1.532	2.785***	7.107***	-0.052	-0.032	-0.230***	5.624	8.158*	13.436***
P5XP9	3.953***	3.618***	4.360***	-3.965***	-3.818***	2.959***	0.124	0.047	0.197**	28.836***	36.885***	18.436***
P6XP7	3.175***	3.266***	2.702***	-4.717***	-5.085***	-6.150***	0.293***	-0.068	-0.100	-15.618***	-6.661*	1.800
P6XP8	-0.741	-1.013	-0.125	-1.435	-1.652*	8.016***	-0.001	0.199**	0.215***	-4.164	5.855	0.770
P6XP9	-0.974	-0.582	0.602	-5.502***	-4.255***	0.168	0.175*	0.111	0.042	4.048	-2.085	-3.564
P7XP8	3.323***	2.248**	-0.073	-6.508***	-0.906	0.074	-0.082	-0.253***	0.209***	23.079***	11.370**	9.436**
P7XP9	-1.377	-0.655	-2.079**	-9.675***	-7.109***	-5.875***	-0.307***	-0.041	-0.064	21.958***	1.430	1.770
P8XP9	1.875*	1.199	1.260	-5.659***	-2.642	-2.008*	-0.001	0.126*	0.052	12.079**	11.612**	10.073**
SE (Sij)±	0.708	0.683	0.647	0.876	0.644	0.805	0.068	0.059	0.055	3.641	3.267	3.307

*$p \leq 0.05$; **$p \leq 0.01$; P1-IR 8; P2-IR 36; P3-IR-64; P4-HUR 36; P5-HUR 105; P6-MTU 1010; P7-Jaya; P8- Krishna Hamsa; P9- Gautam

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Cross	100 Seed Weight			Yield/plant			Chlorophyll content		
	Boro-2014	Boro-2015	Kharif-2015	Boro-2014	Boro-2015	Kharif-2015	Boro-2014	Boro-2015	Kharif-2015
P1XP2	-0.393***	0.447***	-0.521***	-3.859**	-3.605**	-4.769***	1.630**	1.407**	0.720
P1XP3	-0.356***	-0.654***	-0.102***	-10.595***	-4.541**	-1.175	-2.948***	-3.299***	-4.419***
P1 XP4	0.368***	0.184***	0.120***	1.014	2.507	-0.733	5.376***	2.086***	1.396*
P1XP5	0.187***	0.378***	-0.549***	-0.956	4.019**	-0.757	2.800***	-0.617	-1.047
P1XP6	0.183***	0.327***	0.497***	7.044***	1.956	1.379	1.579**	1.356**	4.623***
P1XP7	-0.124***	0.526***	0.456***	-4.383**	-7.317***	-2.278*	1.745**	3.156***	1.699**
P1XP8	0.098***	-0.107***	0.137***	3.775**	-0.381	-1.415	-2.955***	-0.462	0.520
P1XP9	0.112***	-0.030	0.050***	-4.213**	1.213	6.855***	-2.482***	-7.072***	2.796***
P2XP3	-0.075***	-0.462***	-0.099***	-5.107***	-1.653	-0.390	-1.412*	-0.414	4.611***
P2XP4	0.023*	-0.214***	-0.100***	-4.532**	-0.638	1.085	1.079*	-0.996*	4.059***
P2XP5	0.378***	0.274***	0.395***	3.199*	4.007**	5.061***	1.403*	1.701**	-0.683
P2XP6	0.227***	0.102***	0.227***	8.165***	-2.690*	7.098***	-3.185***	-2.726***	-6.047***
P2XP7	0.114***	-0.049**	-0.154***	-0.162	0.071	-3.827**	6.148***	2.974***	0.796
P2XP8	0.172***	0.175***	0.310***	3.529**	-1.893	2.604*	-1.152*	-2.378***	-1.716**
P2XP9	0.113***	0.189***	0.284***	-4.892***	-4.632***	-4.893***	0.221	-1.087*	0.226
P3XP4	0.394***	0.475***	0.499***	5.365***	1.292	2.246*	-1.067*	-0.835	3.253***
P3XP5	0.439***	0.583***	-0.153***	4.929***	-2.762*	1.022	1.758**	-2.405***	-1.622**
P3XP6	0.298***	0.844***	-0.021*	-4.571**	11.941***	-1.475	1.536**	5.435***	3.281***
P3XP7	0.071***	0.004	-0.106***	5.068***	-6.832***	7.034***	2.303***	-0.099	-1.610**
P3XP8	-0.076***	-0.006	-0.018	-0.507	-3.662**	-1.602	4.070***	4.916***	3.611***
P3XP9	-0.509***	-0.879***	-0.121***	-3.228*	-8.002***	-1.599	-2.791***	-1.593**	1.953***
P4XP5	0.327***	0.284***	0.275***	3.005*	0.686	1.398	-2.385***	-3.520***	5.459***
P4XP6	0.135***	0.143***	0.164***	-10.462***	-11.878***	-5.833***	7.527***	4.486***	1.996***
P4XP7	0.412***	0.352***	0.156***	-5.522***	-1.584	-1.690	0.994	1.053*	-1.295*
P4XP8	0.034**	0.105***	0.101***	-2.898*	-0.947	0.107	3.327***	6.801***	4.693***
P4XP9	-0.102***	0.030	0.057***	-3.186*	-12.387***	-2.157	-0.100	0.892	-1.432**
P5XP6	-0.859***	-0.557***	-0.364***	-5.465***	-9.099***	-3.624**	-1.448**	-5.050***	-1.347*
P5XP7	-0.829***	-0.671***	0.001	-1.559	-6.838***	-4.715***	1.318*	0.216	6.096***
P5XP8	0.113***	0.196***	0.392***	-1.535	4.165**	5.049***	2.418***	3.732***	5.550***
P5XP9	0.227***	0.197***	0.289***	1.378	10.025***	3.752**	0.524	4.056***	0.293
P6XP7	0.353***	0.128***	0.097***	-1.592	8.232***	4.155***	-2.570***	0.756	-0.735
P6XP8	-0.078***	-0.182***	-0.002	-5.635***	2.835*	1.652	1.230*	-1.329	-1.580**
P6XP9	0.055***	0.045**	0.174***	6.911***	3.695**	2.822*	-0.597	0.362	-2.771***
P7XP8	0.018	-0.160***	-0.137***	6.105***	6.662***	4.195***	-0.370	0.338	-0.838
P7XP9	0.179***	0.104***	-0.157***	8.950***	2.689*	0.798	2.570***	4.895	5.872***
P8XP9	0.078***	0.171***	-0.026***	4.108**	12.425***	-1.639	-4.430***	-2.990	-3.941***
SE (Sij)±	0.011	0.015	0.009	1.294	1.285	1.073	0.520	0.483	0.523

*p≤0.05; **p≤0.01; P1-IR 8; P2-IR 36; P3-IR-64; P4-HUR 36; P5-HUR 105; P6-MTU 1010; P7-Jaya; P8- Krishna Hamsa; P9- Gautam

CONCLUSION

Combining ability analysis revealed significant differences among GCA effects of the parents and SCA effects of the crosses for all the yield traits and amylose content over the seasons. SCA effects were significant (both positive and negative) for majority of crosses for most of the traits which exhibited the importance of non-additive type of gene action. However, presence of at least one good general combiner as one of the parent in top five selected crosses for each trait showed importance of both additive and non-additive type of gene action. Non significant SCA effects were also observed in few of the selected five crosses indicating the importance of only additive type of gene action in those crosses. Early generation selection is possible in such crosses and such crosses can be used for improvement of component traits.

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