Analysis of Combining Abilities and Heterosis in Agriculture

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Abstract

More than three billion people, or half the world's population, rely heavily on rice as their primary source of nutrition. Thirty Asian nations, 28 American states, 41 African states, 11 European states, and 4 oceanic states grow it. Worldwide, rice is grown on around 163.46 million hectares, yielding about 718.35 million tonnes per year at an average productivity of 4.39 tonnes per hectare. India's 42.6 million hectares of rice field's account for 21.24 percent of global rice output, and its 152.6 million metric tonnes of rice are second only to China's 206.09 million metric tonnes, according to India's average productivity of 3.59 tonnes per hectare. This study examines the role of heterosis and combining talents in agriculture.

Keywords: *Combining Abilities, Heterosis, Agriculture, Rice, Cultivation*

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1. Introduction

More than half of the world's population relies on rice as their primary source of nutrition; it is the second most extensively produced cereal crop after wheat and has rich genetic reservoirs. Rice's tremendous genetic variety is partly due to the availability of more than 100,000 landraces and enhanced cultivar collections in rice germplasm across the globe. Basmati rice, a speciality rice around the world, emerged as a result of natural selection of varieties grown in different agroEco climatic conditions and continuous selection by man for his different tastes in quality and aesthetics. [1]

India has more land dedicated to rice farming than any other country and its output is second only to China's. Asia's 137 million hectares (ha) of rice fields accounts for 23.3% of India's total gross cropped area and results in an annual output of 106.1 million metric tonnes, or 25% of the country's agricultural GDP. Rice is an important part of the national food grain supply, accounting for 43 percent of the country's overall food grain output and 46 percent of the country's total cereal production. While China's productivity per acre is 5.8 tonnes, India's is just 23.80 q/ha. [2-3]

While India's rice yields are significantly lower than the global average, advances in production technology and the introduction of high-yielding, widely-adapted pure-line rice varieties over the past four decades have allowed us to meet consumer demand. However, escalating demand on account of India's expanding population has compelled us to seek for yet another quantum improvement in rice output. If India wants to meet its 115–120 million tonne rice production objective by 2320 AD, its annual rice output must increase by more than 2.0 million tonnes during the next few decades. Natural resource bases including land, labour, and water are decreasing, making this task much more difficult. In light of this difficulty, it is crucial to adopt superior pure line and hybrid varieties of rice that provide larger yields.[4-5]

One of the most practical and easily adopted methods to overcome the yield barrier, hybrid rice technology has shown to increase yields by 15-20% compared to the highest-yielding enhanced or High Yielding Varieties. About 55% of China's total rice land and 66% of China's total rice output comes from hybrid rice, making China the world leader in hybrid rice production. The increased production potential, agronomic performance, and disease resistance of hybrid rice are being heralded as the new solution to the rising hunger of the world's population.[6-7]

It is impossible to enhance a crop like rice in any characteristic by selection of better genotypes without first establishing genetic variability, correlation, and path coefficients. High-heritability, genetically-independent, or positively associated yield components are the most promising candidates for improving crop production. [8-9]

Assessing the degree of heritability in observed variability is notoriously difficult. Plant breeders often make selections for features that contribute to yield indirectly. Extensive phenotypic research has been conducted on the correlation between rice yield and its contributing features. Grain yield is a quantitative property that depends on a number of other factors working together. Because of this, selecting for yield alone may not be very rewarding unless additional qualities related to yield are included.[10]

2. Material And Methods

Materials

The weather records for the time under investigation (2021) were collected from the Lucknow, India, Hindi newspaper Dainik Jagran.

Table 1: Weekly averages of agro meteorological data during the time period under study (27 May 2021 - 11 November 2021):

Week Month^{-1}	**Temperature (^{0}C)**		**Relative Humidity %**		**Rainfall(mm)**
	Max.	**Min.**	**Max.**	**Min.**	
May 2021 Last week	34.54	21.2	93.2	48	25.70

JUNE 2021					
1st week	36.17	22.08	87.28	48	
2nd week	36.51	25.57	84.42	50	2.28
3rd week	35.72	26.38	90	54.85	1.2
4th week	34.71	26.18	96.14	63.57	3.03
JULY 2021					
1st week	33.91	26.58	93	61.71	11.04
2nd week	34.67	27.1	87.71	60.71	2.55
3rd week	34.77	26.62	91	59.57	
4th week	31.68	25.75	94.57	73.85	3.74
AUGUST 2021					
1st week	33.92	26.0	94.85	60.85	45.53
2nd week	33.52	26.02	94.57	64.28	7.25
3rd week	33.47	26.48	92.57	66	33.37
4th week	34.45	26.17	94.85	59.14	6.05
SEPTEMBER2021					
1st week	33.8	26.22	95.28	64.42	17.01
2nd week	32.85	24.28	94.57	67.42	20.46
3rd week	33.25	25.15	93.33	64.66	4.04
4th week	29.74	23.1	94.71	74.28	29.26
OCTOBER 2021					
1st week	33.27	25.12	97.14	61.85	0.04
2nd week	30.48	23.01	95.57	63	10.02
3rd week	32.45	19.65	95.85	42.28	
4th week	31.74	19.02	99.85	43.14	

NOVEMBER 2021					
1st week	30.75	16.08	98.33	33.16	
2nd week	29.7	14.8	100	34	
3rd week	27.77	12.34	99.28	31.71	
4th week	26.88	13.55	99.85	49.71	
TOTAL					222.59

Experimental Descriptions

Aromatic and non-aromatic rice genotypes/varieties suited for sodic soil was crossed with 15 lines (females) to produce 16 hybrids (F1s). Each of the three examinees would be During Kharif of 2021, a randomised full block design with three replications was used to assess the 16 F1s alongside their parents and check variations. For each replication, one seedling from each genotype (treatment) will be transplanted into a 3-meter-long plot's single row at a spacing of 15 centimetres (cm) inside the row and 20 centimetres (20 cm) between rows.

In order to continue testing in the second year, we chose the lines that had the highest values for biological yield, harvest index, productive tillers per square metre, and number of full grains per panicle. All additional agronomic and plant protection practises typical of a commercial rice crop were also used.

Observations to be recorded

The experiment was set up in a single, uniform block using a randomised full block design with three replicates for each experimental setting. Five plants were chosen at random, and their characteristics were recorded.

Data collection:

The variables examined were.

- **Days to 50% flowering:**

The number of days between planting and when half of the plants show full flag leaf emergence may be used to estimate yield.

- **Days to maturity:**

On the plot, the number of days between planting and when more than 75% of the spike turns yellow was recorded.

- **Plant height (cm):**

Five randomly chosen plants per plot had their heights measured from the soil up to the top of the panicle.

- **Number of tillers per plant:**

The average number of tillers per plant was determined by counting the number of tillers on five randomly chosen plants from each plot.

- **Number of filled grains per panicle:**

Twenty randomly chosen panicles had their full grains counted and averaged.

- **Biological yield per plant (g) :**

The average figure was calculated as bilological yield per plant (grammes) based on the final weight of the mature plant (shoot and dried leaves included).

- **Grain yield/plant (gm) :**

The total number of seeds from a plant were counted and recorded. Then, the following formula was used to determine the yield in kilogrammes per hectare:

$$\text{Grain yield/plant} = \text{seeds weight of a plant (gm)}$$

Statistical Analyses

Following are some of the statistical and genetic analysis used to the data obtained from the current study.

1. Randomised complete block design analysis of variance (ANOVA),

2. Analysing mixing skills using Line x Tester,

3. The third method involves estimating the degree to which one parent is superior to the other (heterobeltiosis) or the norm (standard heterosis).

4. Correlation Coefficient Estimation and

5. An examination of path coefficients Simple linear correlation coefficients were calculated based on seasonal mean values. The simple linear correlation coefficients between grain yields per hectare and four other traits (number of tillers per hectare, 1000-grain weight, panicle length,

and number of filled grains per panicle) were broken down into direct and indirect effects using path coefficient analysis.

3. Results

3.1 HETEROSIS

The extent to which F1 values exceed or fall short of those of the better parent (BP) and the reference variety has been used to determine the degree of heterosis. Table summarises the types and levels of heterosis by character.

Table 2 : Twelve rice varieties and their parents and hybrids are analysed for 2021 using a variance analysis

Different Traits	Replication	Treat	Parent	PvsC	Crosses	L	T.	LxT	Error
DF	2	62	17	1	44	14	2	28	124
Days to 50%	13.16	148.85	22.83	25.04	200.35	244.50	302.75	170.96	7.27
Days to Maturity	28.77	218.65	29.01	216.35	291.98	401.57	477.15	223.95	15.37
Plant Height	22.31	246.26	185.22	188.76	271.15	419.07	202.52	202.09	8.81
PBT	0.87	10.43	10.99	40.06	9.54	14.52	34.13	5.29	0.33
Panicle length (cm)	1.76	11.13	2.28	28.80	14.15	20.80	15.62	10.72	0.79
Spikelets/Panicle	128.34	2093.30	2108.32	2047.15	2088.55	4087.56	4760.10	898.23	46.04
Spikelets fertility	14.48	341.86	391.89	296.66	323.55	596.48	1495.46	103.38	6.65
Test grain weight (g.)	1.51	8.62	4.57	0.13	10.37	12.91	29.08	7.76	0.52
Biological Yield	25.36	220.25	204.35	77.24	229.65	421.75	20.23	148.55	10.02

Harvest Index	3.09	61.11	35.79	25.92	71.69	104.77	99.66	53.15	1.22
L B ratio	0.05	0.69	1.05	3.15	0.50	0.93	1.23	0.22	0.02
Yield/hill	3.86	32.68	33.52	53.21	31.88	44.43	98.35	20.86	1.56

Days to 50% flowering

Table 2021 displays the mean and standard deviation for heterosis estimations over the superior parent and standard variety. In 2021, considerable positive heterosis was seen in 18 crosses from the better parent and 15 from the standard variety. Maximum heterosis over superior parent and standard variety was shown by the L13 x T2 cross (19.06%) and the L15 x T2 cross (15.91%) in 2021.

Days to maturity

In most cases, a negative heterosis is prefered for the number of days to maturity. Therefore, the current research concluded that early maturity makes for a better parent. Table displays the heterosis mean and range for days to maturity for both the superior parent and the reference variety. estimations for heterosis in 2021 varied from -13.94% (L4 xT1) to 16.83% (L1 xT3) and -16.18% (L4 xT1) to 12.19% (L15 xT2) over the superior parent and the standard variety, respectively. In 2021, considerable negative heterosis was seen in days to maturity in 16 improved parent cross-offspring and 18 standard variety cross-offspring.

Plant Height

Dwarf rice plants are more resistant to lodging, which in turn increases their reactivity to nitrogen and production. Therefore, the current research indicates that having a dwarf parent is preferable. The table below shows the mean and range of plant height heterosis for the better parent and the standard variety. Negative heterosis for plant height was seen in just three of nine crossings with the normal variety in 2020.

Table 3 : Heterosis with the Superior Parent and the 2021 Standard Strain

Crosses	Days to 50% flowering		Days to Maturity		Plant height		EBT	
	BP	SV	BP	SV	BP	SV	BP	SV
L_1T_1	-3.24	-7.26	-3.3	-8.72	9.98	-3.25	-18.73	-27.40
L_1T_2	-2.94	-6.98	7.48	1.45	2.56	-9.77	-22.33	-22.33

L_1T_3	13.58	8.85	16.83	10.28	24.08	9.16	-6.69	-14.92
L_2T_1	7.21	4.19	5.22	-1.21	26.37	5.40	-4.91	-15.06
L_2T_2	6.52	3.52	6.35	-0.15	16.54	-2.79	-10.26	-10.26
L_2T_3	-3.63	-6.35	3.99	-2.37	10.43	-7.89	-16.43	-23.81
L_3T_1	4.24	3.61	2.04	1.85	9.08	14.98	4.44	-7.48
L_3T_2	-8.93	-9.07	-9.95	-10.05	-5.51	-5.51	-14.19	-14.19
L_3T_3	10.22	10.05	5.75	5.64	11.64	17.67	10.59	-2.03
L_4T_1	-9.55	-12.93	-13.94	-16.18	-6.73	-1.22	-11.59	-19.97
L_4T_2	-5.19	-8.74	-9.81	-12.16	-3.22	-3.22	-11.41	-11.41
L_4T_3	-10.37	-13.72	-13.47	-15.72	-10.09	-4.78	-13.31	-20.96
L_5T_1	-7.82	-8.38	-12.70	-12.85	-10.30	1.9	-11.38	-20.84
L_5T_2	8.93	11.09	7.27	7.27	16.43	16.43	1.56	1.56
L_5T_3	6.05	8.15	-2.93	-2.43	8.28	16.85	2.21	-6.81
L_6T_1	-2.22	-6.28	3.56	0.02	-2.43	10.84	-5.86	-15.9
L_6T_2	3.19	-1.09	-1.29	-4.66	9.62	9.62	-6.13	-6.13
L_6T_3	10.48	5.89	1.98	-1.5	10.17	21.73	3.89	-5.28
L_7T_1	4.47	3.84	-2.78	-3.39	11.72	12.51	6.63	-9.33
L_7T_2	3.16	3.16	-0.69	-1.31	3.64	4.37	-4.71	-4.71
L_7T_3	-5.17	-4.88	-2.12	-2.73	-0.38	0.32	-9.17	-17.18
L_8T_1	7.34	6.02	4.05	3.77	10.06	20.43	5.39	-5.86
L_8T_2	8.67	7.34	6.14	5.86	14.14	14.14	0.78	0.78
L_8T_3	-2.39	-3.59	-3.32	-3.58	-2.52	6.66	-6.39	-14.65
L_9T_1	7.73	7.08	2.54	2.36	10.80	19.66	1.21	-9.59
L_9T_2	-4.64	-4.64	-7.50	-8.49	-0.16	-0.16	-14.66	-14.66
L_9T_3	13.74	14.60	11.39	10.19	15.32	24.55	5.86	-3.48

L10T1	-9.38	-9.93	-13.46	-13.62	-8.01	0.07	-21.23	-29.63
L10T2	-5.60	-5.60	-10.53	-10.53	-1.87	-1.87	-21.51	-21.51
L10T3	-8.59	-6.69	-12.06	-11.12	-7.27	0.87	-20.17	-27.21
L11T1	-7.66	-8.22	-10.33	-11.82	-3.15	1.61	-17.42	-26.23
L11T2	14.08	14.08	10.93	9.09	17.82	17.82	-2.51	-2.51
L11T3	6.02	6.16	0.45	-1.22	8.82	14.17	-6.59	-14.84
L12T1	-5.22	-9.27	-7.88	-12.18	-5.40	6.11	-16.65	-25.55
L12T2	0.19	-4.09	-1.65	-6.24	5.02	5.02	-16.32	-16.32
L12T3	18.81	13.74	16.65	11.22	16.87	29.15	2.14	-6.87
L13T1	12.44	3.27	1.55	1.37	13.76	18.85	3.51	-7.54
L13T2	19.06	9.35	6.53	6.34	17.57	17.57	3.68	3.68
L13T3	2.4	-5.95	-6.59	-6.76	0.83	5.34	-7.93	-16.06
L14T1	-8.86	-11.65	-10.48	-13.62	-6.67	0.86	-19.26	-27.88
L14T2	-5.53	-8.43	-9.39	-12.56	-2.21	-2.21	-20.51	-20.51
L14T3	-10.69	-13.43	-13.06	-16.10	-11.01	-3.83	-22.66	-29.48
L15T1	-6.98	-7.55	-10.97	-11.13	-4.26	2.71	-15.59	-24.60
L15T2	15.91	15.91	12.19	12.19	20.22	20.22	0.38	0.38
L15T3	12.35	12.60	9.35	8.70	11.98	12.35	2.35	3.50
No. of crosses with (+) value	18	15	12	10	24	25	5	5
No. of crosses with (-) value	16	21	16	18	9	3	26	22
Range of heterosis	-10.69 to 19.06	-13.72 to 15.91	-13.94 to 16.83	-16.18 to 12.19	-11.01 to 26.37	-9.77 to 29.15	-22.66 to 10.59	-29.63 to 3.68

Crosses	Biological yield		Yield/hill	
	BP	SV	BP	SV
L_1T_1	-13.63	-8.06	-4.2	-9.31
L_1T_2	8.57	8.57	-5.76	-5.76
L_1T_3	3.36	4	7.46	-0.78
L_2T_1	-12.47	-6.82	1.8	-3.63
L_2T_2	-5.23	-5.23	0.12	0.12
L_2T_3	0.12	0.74	-3.45	-13.37
L_3T_1	3.17	11.60	-3.25	-8.41
L_3T_2	-0.89	7.21	-16.40	-16.40
L_3T_3	-7.35	0.22	1.08	-9.31
L_4T_1	6.33	14.62	-14.17	-14.54
L_4T_2	4.09	12.21	-8.20	-8.20
L_4T_3	-5.26	2.13	-17.30	-17.66
L_5T_1	6.83	13.71	-12.56	-12.23
L_5T_2	-8.70	-3.13	9.79	10.21
L_5T_3	10.08	16.80	-0.57	-0.19
L_6T_1	-11.21	-5.49	-7.50	-12.43
L_6T_2	-9.61	-4.24	-5.16	-5.16
L_6T_3	-11.29	-6.01	5.98	-4.91
L_7T_1	-18.04	-12.76	-6.31	-11.31
L_7T_2	4.43	4.43	-9.45	-9.45
L_7T_3	-4.08	-3.49	-7.72	-17.20
L_8T_1	-7.26	-1.29	5.06	-0.54
L_8T_2	-5.68	-0.17	3.25	3.25

L_8T_3	12.16	18.71	-3.72	-10.47
L_9T_1	7.45	14.38	2.4	-3.07
L_9T_2	11.09	17.06	-11.53	-11.53
L_9T_3	-5.19	-0.09	11.07	-0.35
L10T1	-10.82	-3.3	-15.52	-20.03
L10T2	-10.62	-3.08	-14.88	-14.88
L10T3	-16.13	-9.06	-12.35	-21.35
L11T1	-10.97	-5.23	-15.47	-19.98
L11T2	14.76	14.76	1.31	1.31
L11T3	4.46	5.11	-2.04	-12.11
L12T1	-5.73	0.34	-14.03	-18.62
L12T2	-3.22	-2.78	-10.73	-10.73
L12T3	11.09	11.59	8.99	-2.21
L13T1	-5.40	0.7	-2.71	-7.90
L13T2	-0.88	-0.88	0.28	0.28
L13T3	-11.22	-10.67	-9.62	-18.90
L14T1	1.82	8.39	-15.66	-20.16
L14T2	-7.92	-4	-15.93	-15.93
L14T3	6.12	10.63	-16.38	-24.97
L15T1	-21.46	-16.40	-18.88	-23.21
L15T2	-16.48	-16.48	0.11	0.11
L15T3	-14.62	-9.06	1.2	1.45
No. of crosses with (+) value	10	14	5	1

No. of crosses with (-) value	22	9	23	30
Range of heterosis	-21.46 to 14.76	-16.48 to 18.71	-18.88 to 11.07	-24.97 to 10.21

Ear bearing tillers per plant:

The average and standard deviation of heterosis over the superior parent and the gold standard variety are shown in Table. As of 2021, five improved-parent/standard-variety crossings have produced substantial positive heterosis.

In 2021, the proportion of heterosis for ear-bearing tillers varied from -22.66 (L14 x T3) to -10.59 (L3 x T3) relative to the superior parent, and from -29.63 (L10 x T1) to 3.68 (L13 x T2) relative to the baseline variety.

Biological yield:

In Table, we see the median and interquartile ranges for estimated heterosis values relative to the ideal parent and reference variety. From -21.46 (L15 x T1) to 14.76 (L11 x T2) percent, and from -19.33 (L15 x T1) to 15.19 (L11 x T2) percent, the estimated heterosis values over the better parent varied from a low of 11. During the 2021 research period, the percentage of heterosis over the standard variety varied between -16.49 (L15 x T1) and 16.62 (L9 x T2) and between -16.48 (L15 x T2) and 18.71 (L8 x T3). While in 2021, five improved-parent crosses and 14 standard-variety crossings showed strong positive heterosis.

Yield per hill:

The average and standard deviation of heterosis yield improvements over the superior parent and reference variety are shown in Table. Five 2021 crosses involving the better parent exhibited positive heterosis, while just one L5 x T2 cross did. in 2021, it went from a low of -24.97 (L14 x T3) to a high of 10.21 (L5 x T2), and a high of -18.88 (L15 x T1).

3.2 COMBINING ABILITY ANALYSIS

Variance analysis:

Table shows the results of an ANOVA on combining ability, which showed that the variances attributable to men, females, and males x females were all statistically significant for all twelve characteristics.

Table: 4: Prediction of the average line and tester combining capacity for twelve paddy characteristics in the year 2021

Line/Tester	Days to 50% flowering	Days to Maturity	Plant height	EBT	Biological yield	Yield/hill
Line						
Sarju52	-1.32	5.12**	-8.48**	-1.47**	0.33	1.78**
Nagina	0.80	2.41	-8.94**	-0.47*	-4.49**	1.64**
Jhona 349	1.82*	2.88*	1.52	1.17**	4.76**	-0.67
Magic	-10.77**	-13.81**	-10.21**	-0.68**	7.78**	-1.51**
Kuber	3.80**	0.69	4.11**	1.01**	7.30**	3.61**
Sumo	-0.09	1.44	6.37**	0.93**	-5.84**	0.89*
Shriram Reshma	1.04	0.92	-1.69	0.68**	-4.64**	-1.19**
Shriram432	3.45**	6.34**	6.06**	1.42**	4.22**	2.87**
Shriram434	5.74**	5.54**	6.97**	0.91**	8.51**	1.90**
Shriram453	-6.62**	-10.27**	-7.54**	-2.35**	-5.75**	-3.65**
Vidya295	4.16**	2.32	3.60**	-0.11	3.42**	-0.22
RHR27	0.49	1.01	5.76**	-0.44**	1.75	-0.33
Veda	2.48*	4.29**	6.23**	1.41**	-4.35**	0.35
HALCHAL	-10.18**	13.09**	-8.91**	-2.32**	3.53**	-4.29**
Super Moti	5.19**	4.68**	5.14**	0.30	16.62**	-1.18**
SE(gca line)	0.88	1.31	0.99	0.19	1.06	0.42
SE(gi-gj)line	1.25	1.85	1.40	0.27	1.49	0.59
Tester						
Pusa 169	-2.99**	-3.76**	-0.05	-0.82**	-0.77	-1.07**
PB1	1.37**	1.99**	-2.10**	0.91**	0.44	1.69**

IR24	1.62**	1.77**	2.14**	-0.09	0.33	-0.62**
SE(gca tester)	0.40	0.58	0.44	0.09	0.47	0.19
SE(gi-gj) tester	0.57	0.83	0.63	0.12	0.67	0.26

3.3 Synergistic effects of abilities

Table provides rankings of parents and crosses according to gca, sca, and per se performance. Character-by-character breakdown of the impacts of ability combinations.

Days to 50% flowering:

The value of a parent is evaluated from germination to 50% blooming based on gca effects. Magic (12.29), Halchal (10.86), and Shriram 453 (-7.03) were discovered to be strong general combiners for earlyness in 2015. This is despite the fact that general combiners with negative values are prefered. In 2021, reliable all-purpose combiners were identified as Magic (-10.77), Halchal (-10.18), and Shriram 453 (-6.62).

Pusa 169 was the only female line that showed a substantial gca impact over time (-3.35% and -2.99%), both of which are desired. While the majority of women saw beneficial results with gca, others did not. The Halchal (-12.29) and (-10.77) restore lines were evaluated for their general combinability in 2015 and 2021, respectively.

There were 13 different permutations where the negative sca effects were statistically significant. In 2015, the five best crossovers were L9 xT2 (-11.61), L3 x T2 (-9.99), L15 x T1 (-8.80), L11 x T1 (-8.38), and L5 x T1 (-8.22), in descending order of performance as measured by the sca value. Significant and positive sca effects were detected for 15 cross combinations throughout the years, with highest values of 11.21 and 11.23 in the cross L12 x T3. Fourteen cross combinations showed a significant negative sca impact in 2021, with a maximum value of -11.39 (L13 xT2).

Based on intrinsic effectiveness and the sca impact The 2015 study indicated that the best particular combination for early birth was L9 xT2 (-11.61). L13 x T2 (-11.39) was identified in 2021 as a "god-specific" cross.

Days to maturity:

The days-to-maturity metric favours general combiners with negative values. In 2015, three restores, including Halchal (-13.39), Magic (- 13.17), and Shriram 453 (-9.48), were discovered to be strong general combiners, but in 2021, only two receptors, including Magic (-13.81) and Shriram 453 (-10.27), met this criterion. Pusa 169 female lines (-3.86 and -3.76) showed the most desired substantial negative gca effects throughout time. The Halchal (-13.39) restores line was identified as having high-quality general-purpose early-maturing combiners based on per se performance and gca impacts.

Based on their per se performance and gca impacts, Halchal (-13.39) and Magic (-13.81) were discovered to be excellent particular combiners in 2021.

Plant height:

Significant and negative general combining capacity for plant height was shown by the PB-1 female line, with values of -2.62 and -2.10, respectively. On the other hand, IR-24 (1.88 and 2.14) were excellent general combiners that had a particularly beneficial impact on height. For male paternal strains, Magic (-12.05), Halchal (-9.22), Shriram 453 (-8.6), and Sarju 52 (-7.00) performed best as general combiners.

In terms of dwarfism, the year 2021 belonged to Magic (-10.21), Nagina (-8.94), Halchal (-8.91), and Sarju 52 (8.48).

L9 xT2 (-12.27), L3 xT2 (-11.99), L13 xT3 (-10.45), L15 xT1 (-9.71), and L5 xT1 (-9.47) were the top five cross combinations in 2021. Fifteen different cross combinations were shown to have a statistically significant and positive sca impact across the years, with the highest values being 12.89 and 13.07 for the cross combination L12 x T3, respectively.

In 2015 and 2021, the best particular pairings for dwarfism were L9 x T2 (-12.5 and -12.27), based on per se performance and sca impacts.

Ear bearing tillers per Plant:

Three different female lines showed statistically significant gca effects: PB-1 (1.38), IR 24 (0.46), and PB-1 (0.91), whereas Pusa 169 (-1.65) and -0.82) were the most unfavourable. In 2021, researchers saw a beneficial and strong gca impact on restorers, leading to an increase in the number of ear-bearing tillers per plant.

In 2021, Jhona 349 (1.53) was discovered to be the best general combination for ear bearing tillers per plant based on per se performance and gca impacts.The highest number of ear-bearing tillers per plant was seen in 2020, followed by 2021.

Biological Yield:

Except for Sarju 52, Halchal among pollen percent, the estimated gca impacts of all the female lines were significant in either the positive or negative direction. Pusa 169, PB-1, and IR-24 among seed parents were not statistically significant. Super Moti was the best general combiner for the year, with values of 15.93 and 16.62, and eight of the fifteen restoration orders studied showed a substantial positive gca impact. Super Moti (15.93 and 16.62) were evaluated as excellent general combiners for biological yield in 2021 based on per se performance and gca impacts.

Fourteen of the 45 possible cross-year 2021 combinations showed a statistically significant positive sca impact. Table shows that in 2021, L8 xT3 (11.52), L11 xT2 (8.60), L12 xT3 (7.47), L7 xT2 (7.21), and L5 xT3 (6.68). Good particular combiners for biological yield were identified to be L8 xT3 (11.60 and 11.52) in 2021 based on per se performance and gca impacts.

Yield/hill:

Except for IR-24, estimates of gca impacts on the seed parent were statistically significant in either the positive or negative direction throughout the research years. Kuber (3.48 and 3.61) in 2021 were the best general combiners for yield/hill based on per se performance and gca impacts. L12 x T3 (4.04 & 3.97) in 2021 were shown to be excellent particular combiners for yield per hill based on per se performance and sca impacts.

Table 5: Prediction of each line's and tester's particular combination ability for twelve paddy characters in the year 2021

Crosses	Days to 50% flowering	Days to Maturity	Plant height	EBT	Biological yield	Yield/hill
L_1T_1	-2.18	-7.97	-1.85	-0.31	-7.97	-0.55
L_1T_2	-6.27	-1.44	-6.12	-1.07	6.02	-1.88
L_1T_3	8.44	9.42	7.97	1.37	1.95	2.43
L_2T_1	6.52	3.80	6.98	1.07	-2.02	1.87
L_2T_2	1.53	-0.67	1.10	0.27	-1.77	0.63
L_2T_3	-8.05	-3.13	-8.08	-1.34	3.79	-2.50
L_3T_1	4.96	7.02	5.79	0.90	5.58	2.26
L_3T_2	-11.39	-13.08	-11.99	-2.13	0.35	-3.71
L_3T_3	6.43	6.06	6.20	1.23	-5.93	1.45
L_4T_1	1.92	1.96	1.84	0.33	5.31	0.64
L_4T_2	1.52	1.07	1.95	0.25	1.90	0.43
L_4T_3	-3.44	-3.02	-3.79	-0.58	-7.22	-1.07
L_5T_1	-8.34	-8.53	-9.47	-1.52	4.97	-3.56

L_5T_2	5.68	10.01	6.65	1.07	-11.64	2.72
L_5T_3	2.66	-1.48	2.82	0.46	6.68	0.84
L_6T_1	-2.48	6.25	-3.08	-0.49	0.55	-0.92
L_6T_2	-1.94	-5.13	-2.21	-0.34	0.48	-0.74
L_6T_3	4.41	-1.11	5.28	0.83	-1.04	1.66
L_7T_1	5.96	2.66	6.60	1.03	-7.29	1.61
L_7T_2	0.94	-0.58	0.78	0.19	7.21	-0.40
L_7T_3	-6.90	-2.08	-7.38	-1.21	0.08	-1.21
L_8T_1	5.60	5.87	6.52	0.96	-5.66	1.89
L_8T_2	2.49	2.65	2.48	0.51	-5.85	0.66
L_8T_3	-8.09	-8.52	-9.00	-1.46	11.52	-2.56
L_9T_1	4.32	4.97	4.87	0.75	4.37	1.84
L_9T_2	-11.12	-13.86	-12.27	-1.96	5.61	-4.33
L_9T_3	6.81	8.89	7.40	1.21	-9.97	2.49
L10T1	0.61	1.51	0.42	0.14	2.46	0.56
L10T2	0.33	-0.50	0.59	-0.02	1.45	-0.13
L10T3	-0.94	-1.01	-1.00	-0.12	-3.91	-0.43
L11T1	-8.56	-8.91	-9.24	-1.44	-8.47	-2.85
L11T2	8.14	10.56	8.51	1.41	8.60	2.97
L11T3	0.41	-1.65	0.73	0.03	-0.13	-0.13
L12T1	-5.88	-8.04	-7.04	-0.98	-1.70	-2.20
L12T2	-5.36	-6.62	-6.04	-0.93	-5.77	-1.77
L12T3	11.24	14.65	13.07	1.90	7.47	3.97
L13T1	3.98	5.03	4.82	0.65	4.72	1.45
L13T2	5.36	5.28	5.63	1.08	2.07	1.99

L13T3	-9.34	-10.31	-10.45	-1.72	-6.79	-3.44
L14T1	2.54	4.33	2.55	0.45	3.86	1.15
L14T2	1.22	-0.13	1.63	0.14	-8.67	0.09
L14T3	-3.76	-4.20	-4.18	-0.59	4.81	-1.24
L15T1	-8.96	-9.95	-9.71	-1.54	1.30	-3.19
L15T2	8.85	12.45	9.30	1.55	0.01	3.45
L15T3	0.11	-2.50	0.41	-0.02	-1.31	-0.26
SE(sca)	1.56	2.26	1.71	0.33	1.83	0.72
SE(sij-skj	2.20	3.20	2.42	0.47	2.58	1.02

3.4 Estimates of the contribution of individual genetic factors to variation in twelve plant traits and the size of these effects are provided.

Table displays the estimated variances (σ^2g), sca (σ^2s), and average degree of dominance (√ σ^2s/2 σ^2g) for a number of plant traits, broken down by the proportional contributions of men, females, and Females x men.

The average degree of dominance (√ σ^2s/2 σ^2g) suggested that additive and non-additive gene activity were equally important in determining the expression of the features, whereas a ratio that deviated from 1:1 indicated that (σ^2g) or (σ^2s) played a more significant role. Male lines contributed less on average throughout the years than female lines or female lines crossed with men.

For every character throughout time, the sca variance (σ^2s) was shown to be significantly larger than the gca variance (σ^2g). The number of spikelets per panicle showed the greatest variation (σ^2s) during the research years.

Furthermore, the results from dominance epistasis and other interactions for most of the characteristics throughout the years, respectively, revealed that sca variance were of higher order and was greater than unity, suggesting a large involvement of non-additive gene action.

Table 6: Estimation of components of variance, degree of Dominance,additive and dominance for twelve characters of paddy for year 2021

Characters	σ^2g (Female)	σ^2g (male)	σ^2g (Pool)	σ^2s	√ σ^2s/2 σ^2g	σ^2A	σ^2D
Days to 50%	8.171	2.929	0.447	75.592	74.698	0.894	74.698
Days to Maturity	19.735	5.627	1.079	113.077	110.919	2.159	110.919
Plant Height	24.109	0.010	1.318	83.311	80.674	2.637	80.674
Biological Yield	30.355	-2.852	1.660	55.636	52.316	3.320	52.316
Yield/hill	2.619	1.722	0.143	17.092	16.805	0.286	16.805

4. Conclusion

Variance analysis The material selected were diverse for all traits, and the crosses created substantial genetic variability, as shown by the analysis of variance, which revealed significant mean sum of squares due to genotypes for all characters and highly significant differences between parents and the resulting F1 hybrids for all traits. Annexure 1 presents the best hybrids in terms of per se performance, SCA effects, and GCA impact of their parent for the various attributes evaluated. It was found by comparing SCA effects to per se performance that crosses with favourable SCA effects also tended to have per se performance on most characteristics that was better. High mean performance and SCA impacts were used to identify sets of excellent particular combinations for additional attributes. Seed output was significantly increased in the Jhona x Pusa 169 hybrid, which came from mating two species with a large genetic difference between them. However, despite their parents' great genetic distance, the crossings of Shriram 434 x PB 1 and Halchal x IR 24 and Magic x Pusa 169 and Super Moti x Pusa 169 produce sparsely high significant negative standard heterosis for seed production. Possible explanations include competitive allele linkage for biomass and yield.

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