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# DEVELOPMENT OF HETEROTIC HYBRIDS FOR YIELD AND YIELD CONTRIBUTING TRAITS SUITABLE FOR *RABI* SEASON IN RICE (*ORYZA SATIVA* L.)

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**ABSTRACT**

Combining ability and heterosis studies was performed with40 hybrids, 14 parents and two checks (US 314 and Tellahamsa). These were evaluated at three locations (Jagtial, Rudrur and Rajendranagar) representing two agro climatic zones of Telangana during *rabi* 2020-21. Based on significant *sca* effects 16 hybrids were identified as promising for grain yield per plant. Similarly for standard heterosis, the range was from -24.48 (CMS 46A × RNR 21571) to 32.52 per cent (JMS 13A × RNR 2354) and positive significant standard heterosis exhibited by 14 hybrids for grain yield per plant over hybrid check, US 314. The hybrids, JMS 13A × RNR 2354, CMS 46A × JGL 34551, JMS 13A × ZGY 1, CMS 59A × IR 72, CMS 59A × JGL 35126 and CMS 59A × ZGY 1were expressed highly significant positive heterosis (More than 20 percent) for yield over standard checks,also showed superior performance for plant height (early & negative heterosis), number of productive tillers per plant, 1000 grain weight and head rice recovery.

***Key words :*** Rice, Hybrids, Heterosis, Heterobeltiosis and Yield.

## Introduction

Rice is the basic energy foodsource for most of the Asian people being cultivated in 165.25 mha with an annual production of 515.05 mt per annum. In India, rice cultivation spreads over the area of 47 mha with a production of 135.75 lakh tones (INDIASTAT, 2022-23). Telangana, the state named as seed hub of India has largest area (4.66 mha) under rice cultivation producing 15.87 mt with a productivity of 3406 kg /ha‘ (INDIASTAT, 2022-23).

Genetically speaking, heterosis refers to the significant increase or decrease in the $F_1$ value over the mid parent value. However, from the plant breeding point of view, increase over better parent and /or the popular commercial variety/hybrid is more relevant (Shull, 1908).

In rice heterosis was first reported by Jones (1926), who observed that some $F_1$ hybrids had more culms and higher yield than their parents. Since then several rice researchers also confirmed its occurrence for yield and yield contributing characters (Virmani, 1994). However, most of these reports were on relative heterosis and heterobeltiosis, but not on standard heterosis. It was only after the successful development and cultivation of $F_1$ rice hybrids in China in 1976 that the usefulness of standard heterosis in commercial agriculture is being considered.

The general rice breeding scheme includes evaluating a number of genotypes at various stages and testing selected ones at several locations. Information on genotype × environment interaction leads to successful evaluation of stable genotype, which could be used for general cultivation. Yield is a complex quantitative character and is greatly influenced by environmental fluctuations; hence, the selection for superior genotypes based on yield *per se* at a single location in a year may not be very effective (Shrestha *et al.*, 2012).Keeping in all the aspects, present work focused on identification of highly heterotic hybrids suitable for rabi season with high yield potential.

## Materials and Methods

### Experimental material

Experimental material for this investigation comprised 40 hybrids derived from crossing of four WA based cytoplasmic male sterile (CMS) lines and ten elite proven restorer lines at Regional Agricultural Research Station (RARS), Polasa, Jagtial located at 180 50’ 20.24" N latitude, 78056’54.20" E longitude and 249 m above mean sea level.

**Table 1 :** List of material used to study heterosis in hybrid rice.

| S. no. | Genotype | Source | Cold Reaction | Reaction to leaf blast |
|---|---|---|---|---|
| **Lines** | | | | |
| 1 | JMS 13B | RARS, Jagtial | T | R |
| 2 | CMS 23B | IRRI, Philippines | T | R |
| 3 | CMS 46B | IRRI, Philippines | T | R |
| 4 | CMS 59B | IRRI, Philippines | T | R |
| **Testers** | | | | |
| 1 | RNR 26085 | RRC, ARI, Hyderabad | T | R |
| 2 | ZGY 1 | IRRI, Philippines | T | R |
| 3 | RNR 2354 | RRC, ARI, Hyderabad | T | R |
| 4 | RNR 28359 | RRC, ARI, Hyderabad | T | R |
| 5 | RNR 21571 | RRC, ARI, Hyderabad | T | R |
| 6 | IR 72 | IRRI, Philippines | T | R |
| 7 | JGL 35126 | RARS, Jagtial | T | R |
| 8 | JGL 35047 | RARS, Jagtial | T | R |
| 9 | JGL 34551 | RARS, Jagtial | T | R |
| 10 | RNR 28411 | RRC, ARI, Hyderabad | T | R |
| **Checks** | | | | |
| 1 | US 314 | Private | - | R |
| 2 | Tellahamsa | RRC, ARI, Hyderabad | T | - |

T = Tolerant and R = Resistant.

### Experimental sites and package of practices

During *Kharif*, 2020 four CMS lines and ten testers (Tolerant to cold and resistant to blast) were planted in a crossing block with a spacing of 20 cm × 15 cm and crosses were performed in line × tester mating design to produce 40 hybrids. Three staggered sowings of the parents (females and males) were undertaken at an interval of 10 days to ensure synchronous flowering andto make crosses.

A total of 40 hybrids along with 10 restorers, 4 “B” lines of corresponding male sterile lines and 2 checks were sown at three locations *viz.*, Regional Agricultural Research Station (RARS), Polasa, Jagtial (NTZ), Regional sugarcane & Rice Research Station, Rudrur (NTZ) and Rice Research Center ARI, Rajendranagar, Hyderabad (STZ) for estimation of *per se* performanceand heterosis during *Rabi*, 2020-21.

A completely randomized block design with three replications was followed. Top dressing was given with urea and need based plant protection measures were undertaken for raising healthy seedlings. Each entry was planted in two rows of three meters length with a spacing of 20 cm × 15 cm in three replications and all the package of practices were followed to raise a healthy crop.

### Recording of observations

Five plants were selected at random from each entry in each replication to record plant height, number of productive tillers per plant and panicle length. Observations were recorded for yield and yield attributing traits at three locations. However 1000 grain weight, hulling, milling, head rice recovery, kernel length, kernel breadth and kernel length breadth ratio were recorded on random sample in each plot, whereas for days to 50% flowering the data was recorded on whole plot basis. Spikelet fertility was calculated as the ratio of filled grains per panicle to the total number of grains in a panicle and was expressed as percentage. In case of CMS lines, the observations were recorded on their respective maintainer (B) lines.

## Results and Discussion

### Analysis of variance

The mean values for days to 50% flowering, plant height, panicle length, number of productive tillers per plant, spikelet fertility (%), 1000 grain weight, hulling per cent, milling per cent, head rice recovery, kernel length, kernel breadth, kernel length-breadth ratio and grain yield per plant estimated from three locations *viz.*, Jagtial, Rudrur and Rajendranagar were subjected to pooled statistical analysis. The analysis of variance for grain yield and yield contributing characters revealed significant difference between the treatments for all the characters under study

**Table 2 :** Pooled analysis of variance for combining ability for yield and yield components in rice.

| Source of variation | DF | DFF | PH | PL | NPT | SF % | TW | H % |
|---|---|---|---|---|---|---|---|---|
| Replicates | 2 | 13.05** | 13.78** | 3.00* | 0.78 | 0.31 | 0.34 | 14.69** |
| Environments | 2 | 2647.49** | 1763.79** | 211.04** | 70.30** | 141.44** | 103.73** | 515.03** |
| Rep* Env. | 4 | 1.79 | 1.46 | 3.71** | 1.59 | 2.91 | 0.255 | 0.49 |
| Treatments | 53 | 146.29** | 428.11** | 25.32** | 18.96** | 72.41** | 65.39** | 13.79** |
| Parents | 13 | 195.71** | 657.25 | 25.89** | 30.95** | 67.26** | 101.31** | 20.32** |
| Parent vs Crosses | 1 | 991.38** | 1038.78** | 2.41 | 98.29** | 1241.92 | 192.91** | 1920.74 |
| Crosses | 39 | 108.15** | 336.08** | 25.72** | 12.93** | 44.26** | 50.14** | 11.91** |
| Line effect | 3 | 61.71 | 754.95** | 95.39** | 23.1 | 48.13 | 40.027 | 1.13 |
| Tester effect | 9 | 107.28 | 701.60** | 45.18** | 12.10 | 62.93 | 122.59** | 6.92 |
| Line* Tester effect | 27 | 113.61** | 167.69** | 11.49** | 12.08** | 37.61** | 27.12** | 14.77** |
| Env*Treat | 106 | 13.05** | 23.78** | 1.99** | 3.48** | 20.78** | 5.18** | 14.65** |
| Env* Parents | 26 | 18.66** | 15.78** | 1.95** | 3.35** | 15.36** | 5.83** | 10.63** |
| Env*Parent vs Cross | 2 | 9.88* | 42.88** | 0.36 | 2.86* | 6.39 | 12.56** | 50.12** |
| Env*Crosses | 78 | 11.25** | 25.96** | 2.042** | 3.54** | 22.96** | 4.78** | 15.081** |
| Env*Line effect | 6 | 2.57 | 68.07* | 3.54 | 3.31 | 23.37 | 3.74 | 40.88** |
| Env* Tester effect | 18 | 10.63 | 24.71 | 2.49 | 4.06 | 20.16 | 3.34 | 15.81 |
| Env*Line*Tester effect | 54 | 12.43** | 21.69** | 1.72** | 3.39** | 23.85** | 5.37** | 11.91** |
| Error | 318 | 2.260 | 2.81 | 0.703 | 0.73 | 3.38 | 0.88 | 1.27 |

*Significant at P = 0.05 level, ** Significant at P = 0.01 level.

***Table 2 contd…***

| Source of variation | DF | M% | HRR % | KL (mm) | KB (mm) | L/B ratio | GYP (g) |
|---|---|---|---|---|---|---|---|
| Replicates | 2 | 26.54** | 5.87* | 0.001 | 0.002 | 0.005 | 4.31 |
| Environments | 2 | 486.62** | 96.46** | 1.50** | 0.023** | 0.41** | 825.76** |
| Rep* Env. | 4 | 0.39 | 0.58 | 0.01 | 0.002 | 0.007 | 1.39 |
| Treatments | 53 | 15.72** | 134.36** | 1.24** | 0.11** | 0.35** | 177.43** |
| Parents | 13 | 17.12** | 21.45** | 1.93** | 0.20** | 0.49** | 20.41** |
| Parent vs Crosses | 1 | 20.74** | 33.51** | 0.11** | 0 | 0.01 | 2212.86** |
| Crosses | 39 | 15.13** | 174.58** | 1.04** | 0.08** | 0.31** | 177.58** |
| Line effect | 3 | 4.12 | 1602.37** | 6.07** | 0.29** | 2.24** | 267.15 |
| Tester effect | 9 | 19.41 | 113.71* | 1.31** | 0.17** | 0.11 | 177.56 |
| Line* Tester effect | 27 | 14.92** | 36.23** | 0.39** | 0.02** | 0.16** | 167.63** |
| Env*Treat | 106 | 19.27** | 5.43** | 0.11** | 0.02** | 0.01** | 31.39** |
| Env* Parents | 26 | 7.47** | 8.12** | 0.11** | 0.03** | 0.09** | 30.40** |
| Env*Parent vs Cross | 2 | 135.61** | 11.59** | 0.13** | 0.05** | 0.05* | 332.84** |
| Env*Crosses | 78 | 20.22** | 4.37** | 0.11** | 0.02** | 0.10** | 23.99** |
| Env*Line effect | 6 | 28.33 | 5.82 | 0.11 | 0.02 | 0.13 | 8.14 |
| Env* Tester effect | 18 | 23.01 | 2.81 | 0.09 | 0.02 | 0.08 | 36.69 |
| Env*Line*Tester effect | 54 | 18.43** | 4.73** | 0.12** | 0.03** | 0.10** | 21.53** |
| Error | 318 | 0.81 | 1.32 | 0.01 | 0.003 | 0.01 | 3.77 |

*Significant at P = 0.05 level, ** Significant at P = 0.01 level

**M%** = Milling (%), **HRR%** = Head rice recovery (%), **KL =** Kernel length (mm), **KB** = Kernel breadth (mm), **L/B =** Kernel Length Breadth Ratio, **GYP** = Grain yield per plant (g).

in pooled analysis. Significance of genotypes indicated that there was sufficient variability among the genotypes tested.

**Study of heterosis**

Heterosis or average heterosis (di), heterobeltiosis (dii) and standard heterosis (diii) is the superior performance as desirable over the mid parent, better parent and the standard checks (2 checks US 314 and Tellahamsa), respectively was estimated for 40 hybrids for thirteen characters *viz.*, days to 50 % flowering, plant height, panicle length, number of productive tillers per plant, spikelet fertility (%), 1000 grain weight, hulling per cent, milling per cent, head rice recovery, kernel length, kernel breadth, kernel length-breadth ratio and grain yield per plant for three locations *viz.*, Jagtial, Rudrur and Rajendranagar. Pooled results are presented character-wise. The negative heterosis for days to 50% flowering indicates earliness and the negative heterosis for plant height and kernel breadth indicates short stature and slender grain, respectively which are desirable, while for other characters positive heterosis values were considered to be desirable.

**Days to 50% flowering**

In pooled analysis, 29 hybrids recorded significant negative heterosis ranging from -9.38 (JMS 13A × JGL 35126) to 7.30 per cent (CMS 23A × JGL 35047) over the mid parental value. Out of 40 hybrids studied, thirty four hybrids flowered earlier than their better parents by exhibiting significant negative heterobeltiosis ranging from -13.10 (CMS 23A × RNR 26085) to 3.00 percent (CMS 23A × JGL 35047). Three hybrids exhibited significant negative standard heterosis and its range was from -3.69 (CMS 23A × RNR 26085) to 13.25 per cent (CMS 46A × RNR 26085) over the early check, Tellahamsa. Early maturity is an important trait especially for *rabi* situations, both negative and positive heterosis resulted over mid parent, better parent and standard checks. Reddy *et al.* (2012) reported significant negative mid parent and heterobeltiosis. Chouhan *et al.* (2016), Dilruba *et al.* (2018) and Gokulakrishnan *et al.* (2018) reported significant heterobeltiosis and standard heterosis in desirable direction.

**Plant height (cm)**

Short stature is one important trait in rice to withstand lodging especially under high input management, hail storm and high rainfall areas. Hence, negative heterosis is treated as desirable. Among 40 hybrids, 22 hybrids exhibited significant negative relative heterosis in pooled analysis with a range of -15.28 (JMS 13A × IR 72) to 10.76% (CMS 23A × JGL 34551). The significant negative heterobeltiosis was recorded in 33 hybrids, with a range of -17.67 (CMS 23A × RNR28411) to 6.10% (CMS 23A × JGL 35047). The significant negative standard heterosis was recorded in 21 hybrids with a range of -16.73 (CMS 23A × RNR 2354) to 10.74% (CMS 59A × RNR 26088), when compared with check, Tellahamsa. Short plant type is an important trait of a hybrid to withstand lodging and hence, heterosis in negative direction is desirable, for this trait. Both positive and negative heterosis was observed over mid parent, better parent and standard checks. Several rice researchers *viz.*, Sharma *et al.* (2013), Priyanka *et al.* (2014), Srijan (2015), Parimala (2016) and Ramesh (2016) reported negative heterosis for relative heterosis and heterobeltiosis. In case of standard heterosis, similar nature was reported by Gouri Shankar *et al.* (2010), Kumar Babu *et al.* (2010b), Priyanka *et al.* (2014), Srijan *et al.* (2015), Parimala (2016), Ramesh (2016) and Gokulakrishnan *et al.* (2018).

**Panicle length (cm)**

Hybrids generally are characterized by having larger panicles indicating their efficiency in partitioning of assimilates to reproductive parts. Significant positive and negative heterosis was exhibited over mid-parent, better parent and checks in hybrids. Analysis for this character revealed that average heterosis ranged from -10.78 (JMS 13A × IR 72) to 13.04 (CMS 59A × IR 72) per cent and heterobeltiosis ranged from -13.09 (JMS 13A × RNR26085) to 10.75 (CMS 59A × IR 72) per cent among the hybrids. Sixteen hybrids expressed significant positive average heterosis while, 11 hybrids manifested significant positive heterobeltiosis. The range of standard heterosis over best check for panicle length varied from -18.21 (JMS 13A × IR 72) to 10.84 per cent (CMS 59A × RNR 26085). Four hybrids over hybrid check (US 314) exhibited significant positive standard heterosis. These results are in accordance with Palaniraja *et al.* (2010), Dey *et al.* (2013), Priyanka *et al.* (2014), Nayak *et al.* (2015) and Ramesh (2016). Standard heterosis of both positive and negative nature was observed in their studies by Priyanka *et al.* (2014), Nayak *et al.* (2015), Chouhan *et al.* (2016), Parimala (2016), Ramesh (2016), Thorat *et al.* (2017) and Dilruba *et al.* (2018).

**Number of productive tillers per plant**

In pooled analysis, the range of average heterosis was from -34.29 (JMS 13A × RNR 26085) to 16.28 per cent (CMS 46A × RNR 21571) and two hybrids recorded significant positive heterosis. The range of heterobeltiosis was from –46.03 (JMS 13A × JGL 34551) to 12.64% (CMS 23A × RNR 26085) and one hybrid exhibited significant positive heterobeltiosis. Standard heterosis over Tellahamsa ranged from -33.33 (CMS 46A × RNR 28411) to 9.38% (JMS 13A × IR 72). One cross exhibited significant positive standard heterosis over Tellahamsa and 17 hybrids exhibited significant positive standard heterosis over hybrid check, US 314. Number of

**Table 3 :** Individual location wise and pooled estimates of heterosis, heterobeltiosis and standard heterosis for days to 50 percent flowering and plant height.

| Crosses | Pooled (DFF) | | | | Pooled (PH) | | | |
|---|---|---|---|---|---|---|---|---|
| | Heterosis | | Standard Heterosis | | Heterosis | | Standard Heterosis | |
| | MP | BP | US 314 | Tella hamsa | MP | BP | US 314 | Tella hamsa |
| JMS 13A x RNR 26085 | -7.31** | -7.55** | 1.25 | 3.00** | -7.59** | -14.81 | -4.40** | 0.08 |
| JMS 13A x ZGY 1 | -8.86** | -9.23** | 0.23 | 1.96** | 0.85 | 0.79 | -4.46** | 0.01 |
| JMS 13A x RNR 2354 | -4.24** | -5.48** | 3.51** | 5.30** | -0.49 | -2.51** | -7.71** | -3.39** |
| JMS 13A x RNR 28359 | 0.57 | -0.41 | 8.45** | 10.33** | -11.56** | -13.62** | -14.23** | -10.22** |
| JMS 13A x RNR 21571 | -5.38** | -10.03** | -1.13 | 0.58 | -11.24** | -11.64** | -15.57** | -11.62** |
| JMS 13A x IR 72 | -7.59** | -8.69** | 0.00 | 1.73* | -15.28** | -16.71** | -18.39** | -14.57** |
| JMS 13A x JGL 35126 | -9.38** | -13.03** | -4.67** | -3.02** | 0.36 | -1.32 | -3.35** | 1.18 |
| JMS 13A x JGL 35047 | -5.79** | -9.10** | -0.45 | 1.27 | -6.59** | -13.03** | -17.66** | -13.81** |
| JMS 13A x JGL 34551 | -5.45** | -7.55** | 1.94** | 3.70** | -2.05** | -4.40** | -4.94** | -0.49 |
| JMS 13A x RNR 28411 | -2.16** | -6.10** | 2.83** | 4.61** | -1.66* | -11.38** | 4.55** | 9.45** |
| CMS 23A x RNR 26085 | -6.54** | -13.10** | -5.32** | -3.69** | 2.99** | -9.24** | 1.86* | 6.63** |
| CMS 23A x ZGY 1 | -1.44* | -8.92** | 0.57 | 2.30** | -4.49** | -9.14** | -13.87** | -9.84** |
| CMS 23A x RNR 2354 | -3.22** | -9.13** | -3.06** | -1.38 | -9.81** | -12.42** | -20.45** | -16.73** |
| CMS 23A x RNR 28359 | 0.39 | -6.01** | 0.91 | 2.65** | -3.14** | -9.83** | -10.47** | -6.29** |
| CMS 23A x RNR 21571 | 5.59** | 2.87** | 1.59* | 3.34** | 1.95* | -3.38** | -7.67** | -3.35** |
| CMS 23A x IR 72 | 2.43** | -3.92** | 2.72** | 4.49** | 1.97* | -4.49** | -6.42** | -2.04* |
| CMS 23A x JGL 35126 | -1.86** | -5.29** | -4.64** | -3.00** | -10.63** | -16.27** | -17.99** | -14.15** |
| CMS 23A x JGL 35047 | 7.30** | 3.00** | 5.05** | 6.86** | 8.61** | 6.10** | -9.21** | -4.96** |
| CMS 23A x JGL 34551 | 4.63** | -0.87 | 3.74** | 5.53** | 10.76** | 3.04** | 2.45** | 7.25** |
| CMS 23A x RNR 28411 | 1.52* | -2.02** | -1.36 | 0.35 | -4.56** | -17.67** | -2.86** | 1.68 |
| CMS 46A x RNR 26085 | 3.53** | 2.18** | 11.33** | 13.25** | -5.08** | -12.90** | -2.25** | 2.33** |
| CMS 46A x ZGY 1 | -8.47** | -10.26** | -0.91 | 0.81 | -6.93** | -7.44** | -12.26** | -8.16** |
| CMS 46A x RNR 2354 | -2.93** | -3.18** | 3.28** | 5.07** | -2.70** | -4.21** | -10.21** | -6.01** |
| CMS 46A x RNR 28359 | -8.01** | -8.54** | -1.81* | -0.12 | -7.87** | -10.45** | -11.08** | -6.92** |
| CMS 46 A X RNR 21571 | 1.16 | -2.35** | 3.62** | 5.41** | -0.93 | -1.87* | -6.23** | -1.85* |
| CMS 46A x IR 72 | -5.26** | -5.61** | 0.91 | 2.65** | -6.71** | -8.73** | -10.57** | -6.39** |
| CMS 46A x JGL 35126 | -0.44 | -2.99** | 2.94** | 4.72** | -4.79** | -6.83** | -8.75** | -4.48** |
| CMS 46A x JGL 35047 | -4.58** | -6.51** | -0.11 | 1.62* | 4.24** | -2.50** | -8.60** | -4.33** |
| CMS 46A x JGL 34551 | -3.92** | -4.59** | 1.25 | 3.00** | 7.09** | 4.02** | 3.43** | 8.27** |
| CMS 46A x RNR 28411 | -3.07** | -5.55** | 0.23 | 1.96** | -3.69** | -13.58** | 1.96* | 6.73** |
| CMS 59A x RNR 26085 | -0.42 | -1.14 | 7.70** | 9.56** | -0.43 | -5.74** | 5.79** | 10.74** |
| CMS 59A x ZGY 1 | -4.94** | -6.26** | 3.51** | 5.30** | 0.01 | -2.71** | -2.46** | 2.10* |
| CMS 59A x RNR 2354 | -3.70** | -4.01** | 3.06** | 4.84** | 1.85* | -2.94** | -2.69** | 1.86* |
| CMS 59A x RNR 28359 | -2.53** | -2.53** | 4.69** | 6.50** | -3.77** | -4.23** | -3.99** | 0.51 |
| CMS 59A x RNR 21571 | -4.18** | -8.02** | -1.25 | 0.46 | -1.31 | -3.63** | -3.38** | 1.14 |
| CMS 59A x IR 72 | -6.55** | -6.75** | 0.60 | 2.34* | -1.12 | -2.24** | -1.99* | 2.59** |
| CMS 59A x JGL 35126 | -6.80** | -9.70** | -3.06** | -1.38 | -2.55** | -3.68** | -3.43** | 1.09 |
| CMS 59A x JGL 35047 | -5.90** | -8.33** | -1.59* | 0.12 | 2.40** | -7.11** | -6.87** | -2.52** |
| CMS 59A x JGL 34551 | -1.92** | -3.16** | 3.96** | 5.76** | 1.14 | 0.72 | 0.98 | 5.70** |
| CMS 59A x RNR 28411 | -6.80** | -9.70** | -3.06** | -1.38 | -8.86** | -15.71** | -0.56 | 4.10** |
| **SE** | 0.63 | 0.73 | 0.73 | 0.73 | 0.67 | 0.78 | 0.78 | 0.78 |
| **CD. 95%** | 1.17 | 1.36 | 1.36 | 1.36 | 1.34 | 1.54 | 1.54 | 1.54 |

**Table 4 :** Individual location wise and pooled estimates of heterosis, heterobeltiosis and standard heterosis for panicle length and Number of productive tillers/plant.

| Crosses | Pooled (PL) | | | | Pooled (PTP) | | | |
|---|---|---|---|---|---|---|---|---|
| | Heterosis | | Standard Heterosis | | Heterosis | | Standard Heterosis | |
| | MP | BP | US 314 | Tella hamsa | MP | BP | US 314 | Tella hamsa |
| JMS 13A x RNR 26085 | -5.50** | -13.09** | -3.60* | 12.50** | -34.29** | -45.24** | -9.21 | -28.13** |
| JMS 13A x ZGY 1 | -4.75** | -5.34** | -11.87** | 2.85 | 6.32 | -19.84** | 32.89** | 5.21 |
| JMS 13A x RNR 2354 | 0.54 | -1.98 | -8.74** | 6.50** | -5.77 | -22.22** | 28.95** | 2.08 |
| JMS 13A x RNR 28359 | 0.68 | -0.41 | -5.23** | 10.60** | -20.95** | -34.13** | 9.21 | -13.54** |
| JMS 13A x RNR 21571 | -9.79** | -10.14** | -15.68** | -1.60 | -15.35** | -27.78** | 19.74** | -5.21 |
| JMS 13A x IR 72 | -10.78** | -12.15** | -18.21** | -4.55* | -16.33** | -16.67** | 38.16** | 9.38* |
| JMS 13A x JGL 35126 | 6.43** | 4.33** | 1.11 | 18.00** | -19.07** | -30.95** | 14.47** | -9.38* |
| JMS 13A x JGL 35047 | -2.99* | -8.24** | -14.57** | -0.30 | -12.50** | -27.78** | 19.74** | -5.21 |
| JMS 13A x JGL 34551 | 3.51* | 3.35* | -3.47* | 12.65** | -3.55** | -46.03** | -10.53* | -29.17** |
| JMS 13A x RNR 28411 | 6.32** | 5.74** | -0.47 | 16.15** | -25.33** | -33.33** | 10.53* | -12.50** |
| CMS 23A x RNR 26085 | -1.75 | -12.28** | -2.70 | 13.55** | 14.62** | 12.64** | 28.95** | 2.08 |
| CMS 23A x ZGY 1 | -2.78 | -5.31** | -12.94** | 1.60 | 3.31 | -10.34* | 2.63 | -18.75** |
| CMS 23A x RNR 2354 | -2.78 | -3.49* | -14.65** | -0.40 | 0.59 | -2.3 | 11.84* | -11.46** |
| CMS 23A x RNR 28359 | -2.00 | -6.12** | -10.67** | 4.25* | 0.58 | -1.15 | 13.16** | -10.42** |
| CMS 23A x RNR 21571 | -3.98** | -7.40** | -13.11** | 1.40 | 9.09* | 7.87 | 26.32** | 0.00 |
| CMS 23A x IR 72 | -2.32 | -4.00* | -13.37** | 1.10 | -22.64** | -34.40** | 7.89 | -14.58** |
| CMS 23A x JGL 35126 | -2.37 | -7.29** | -10.15** | 4.85** | -18.18** | -19.10** | -5.26 | -25.00** |
| CMS 23A x JGL 35047 | -0.35 | -2.70 | -15.21** | -1.05 | -4.14 | -6.90 | 6.58 | -15.63** |
| CMS 23A x JGL 34551 | 2.47 | -0.96 | -7.50** | 7.95** | -16.28** | -17.24** | -5.26 | -25.00** |
| CMS 23A x RNR 28411 | -2.34 | -5.96** | -11.48** | 3.30 | -5.38 | -11.11** | 15.79 | -8.33* |
| CMS 46A x RNR 26085 | 5.35** | -6.49** | 3.73* | 21.05** | -18.56** | -19.05** | -10.53* | -29.17** |
| CMS 46A x ZGY 1 | -1.61 | -4.80** | -12.47** | 2.15 | 7.48 | -4.82 | 3.95 | -17.71** |
| CMS 46A x RNR 2354 | 7.15** | 5.67** | -6.56** | 9.05** | 5.45 | 4.82 | 14.47** | -9.38* |
| CMS 46A x RNR 28359 | 3.50* | -1.49 | -6.26** | 9.40** | -6.59 | -7.14 | 2.63 | -18.75** |
| CMS 46 A X RNR 21571 | 3.74* | -0.59 | -6.73** | 8.85** | 16.28** | 12.36** | 31.58** | 4.17 |
| CMS 46A x IR 72 | 9.84** | 7.25** | -3.21* | 12.95** | -19.23** | -32.80** | 10.53* | -12.50** |
| CMS 46A x JGL 35126 | 1.90 | -3.85* | -6.81** | 8.75** | -13.95** | -16.85** | -2.63 | -22.92** |
| CMS 46A x JGL 35047 | 8.14 | 6.28** | -8.61** | 6.65** | -11.52** | -12.05** | -3.95 | -23.96** |
| CMS 46A x JGL 34551 | 9.15** | 4.82** | -2.10 | 14.25** | -8.33* | -9.41* | 1.32 | -19.79** |
| CMS 46A x RNR 28411 | 4.71** | 0.18 | -5.70** | 10.05** | -29.67** | -35.35** | -15.79** | -33.33** |
| CMS 59A x RNR 26085 | 8.15** | -0.08 | 10.84** | 29.35** | -12.57** | -19.19** | 5.26 | -16.67** |
| CMS 59A x ZGY 1 | -2.23 | -3.33* | -9.08** | 6.10** | -11.66** | -27.27** | -5.26 | -25.00** |
| CMS 59A x RNR 2354 | -6.93** | -9.70** | -15.08** | -0.90 | -28.18** | -34.34** | -14.47** | -32.29** |
| CMS 59A x RNR 28359 | 6.93** | 6.30** | 1.16 | 18.05** | -20.22** | -26.26** | -3.95 | -23.96** |
| CMS 59A x RNR 21571 | 1.03 | 0.91 | -5.10** | 10.75** | -24.47** | -28.28** | -6.58 | -26.04** |
| CMS 59A x IR 72 | 13.04** | 10.75** | 4.16** | 21.55** | -20.54** | -28.80** | 17.11** | -7.29 |
| CMS 59A x JGL 35126 | 3.16* | 1.64 | -1.50 | 14.95** | 1.06 | -4.04 | 25.00** | -1.04 |
| CMS 59A x JGL 35047 | 10.82** | 4.33** | -1.89 | 14.50** | -13.81** | -21.21** | 2.63 | -18.75** |
| CMS 59A x JGL 34551 | 1.21 | 0.87 | -5.14** | 10.70** | -23.91** | -29.29** | -7.89 | -27.08** |
| CMS 59A x RNR 28411 | 9.97** | 9.92** | 3.47* | 20.75** | -9.09** | -9.09* | 18.42** | -6.25 |
| **SE** | 0.34 | 0.39 | 0.39 | 0.39 | 0.35 | 0.41 | 0.41 | 0.41 |
| **CD. 95%** | 0.67 | 0.78 | 0.78 | 0.78 | 0.68 | 0.78 | 0.78 | 0.78 |

productive tillers per plant directly contributes towards grain yield. In the present study, some of the hybrids recorded significant positive heterosis and heterobeltiosis. Mid parental heterosis of both positive and negative values was reported by Vanisree *et al.* (2011), Rajender Reddy *et al.* (2012), Sharma *et al.* (2013), Srijan *et al,* (2015) and Parimala (2016). Heterobeltiosis in positive direction was reported by Nayak *et al.* (2015), Chouhan *et al.* (2016) and Reddy *et al.* (2012), Ashfaq *et al.* (2013), Nayak *et al.* (2015), Srijan *et al.* (2015), Chouhan *et al.* (2016), Parimala *et al.* (2016), Ramesh (2016), Thorat *et al.* (2017) and Gokulakrishnan *et al.* (2018) reported both positive and negative standard heterosis in their studies, which were in similarity with present study suggesting methods of exploiting both additive and non-additive gene effects.

**Spikelet fertility (%)**

For this trait, the average heterosis ranged from -9.30 (CMS 46A × RNR 26085) to 3.25 per cent (CMS 23A × RNR 28359) and from -11.65 (CMS 46A × RNR 26085) to 2.99 per cent (CMS 23A × RNR 28359) for heterobeltiosis. One hybrid manifested significant positive superiority over mid parent and better parent heterosis. Threehybrids recorded significant positive standard heterosis over hybrid check, US 314 and range was from -7.20 (CMS 46A × RNR 26085) to 3.35 per cent (JMS 13A × JGL 35126). Both positive and negative standard heterosis for spikelet fertility was reported by Gouri Shankar *et al.* (2010), Kumar Babu *et al.* (2010b), Srijan *et al.* (2015), Parimala (2016), Thorat *et al.* (2017) and Gokulakrishnan *et al.* (2018), whereas negative heterosis for this trait was observed by Pandya and Tripathi (2006) and Singh *et al.* (2006b).

**1000 grain weight (g)**

Test weight is also one of the important yield contributing character in rice crop. Both positive and negative heterosis was resulted in case of test weight. The significant positive average heterosis was recorded in 30 hybrids, with range of-15.83 (JGL 13A × JGL 35126) to 36.57 per cent (JMS 23A × RNR 2354). The significant positive heterobeltiosis was recorded in 15 hybrids with heterobeltiosis range from -30.42 (JGL 13A × JGL 35126) to 19.29 per cent (CMS 23A × RNR 2354). Standard heterosis was recorded in 33 hybrids with a range from -12.90 (CMS 59A × RNR 2354) to 31.59 per cent (CMS 23A × RNR 28411) over the check, US 314 and two hybrids recorded significant heterosis over varietal check, Tellahamsa. Positive standard heterosis was reported by Nayak *et al.* (2015), Samrath Bedi and Deepak Sharma (2016), Thorat *et al.* (2017) and Gokulakrishnan *et al.* (2018).

**Hulling (%)**

The range of average heterosis was from -3.75 (CMS 46Ax ZGY 1) to 2.81 per cent (CMS 59A × RNR 26085) and 13 hybrids recorded significant positive heterosis. The range of heterobeltiosis was from -5.29 (CMS 46A × ZGY 1) to 2.59 (CMS 46A × RNR 28359). Five hybrids exhibited significant positive heterobeltiosis. Heterosis over hybrid check US 314 ranged from -2.88 (CMS 46A × RNR 26085) to 2.88 per cent (CMS 46A × RNR 28359). Six hybrids recorded significantly positive standard heterosis over hybrid check, US 314.

**Milling (%)**

Milling recovery is also one of the important physical quality parameters. The range of average heterosis was from -3.88 (CMS 46A × RNR 2354) to 3.97 per cent (JMS 13A × IR 72). Six hybrids recorded significantly positive heterosis. The range of heterobeltiosis was from -5.26 (CMS 59A × RNR 28411) to 3.97 (JMS 13A × IR 72). Five hybrids exhibited significant positive heterobeltiosis. Heterosis over hybrid and varietal checks(US 314 and Tellahamsa) ranged from -6.57 (JMS 13A × JGL 34551) to 4.95 per cent (CMS 46A × RNR 28359). Only one hybrid recorded significantly positive standard heterosis over hybrid check, US 314 whereas 19 hybrids recorded significantly positive standard heterosis over varietal check Tellahamsa.

**Head rice recovery (%)**

The average heterosis ranged from -18.07 (CMS 23A × ZGY 1) to 7.92 per cent (JMS 13A × RNR 26085) and heterobeltiosis from -19.84 (CMS 23A × ZGY 1) to 7.34 per cent (CMS 59A × JGL 35047). Sixteen hybrids exhibited significant positive average heterosis while heterobeltiosis of same type was shown by 12 hybrids. Standard heterosis ranged from -16.73 (CMS 23A × ZGY 1) to 11.84 per cent (CMS 59A × RNR 2354) over hybrid check, US 314. Significant positive standard heterosis

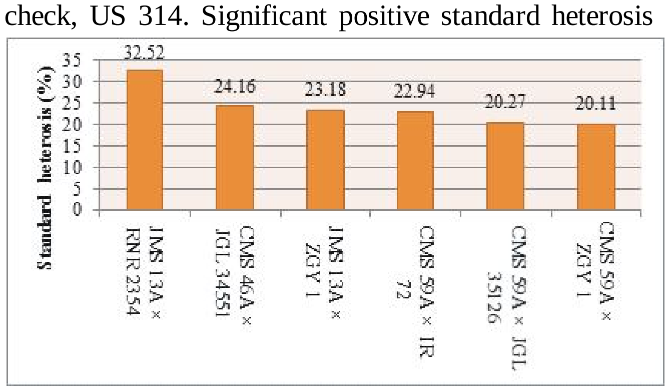


**Fig. 1 :** Pictorial representation of standard heterosis by top ranking hybrids over US 314 for grain yield per plant (g).

**Table 5 :** Individual location wise and pooled estimates of heterosis, heterobeltiosis and standard heterosis for spikelet fertility (%) and 1000 grain weight (g).

| Crosses | Pooled (SF) | | | | Pooled (TW) | | | |
|---|---|---|---|---|---|---|---|---|
| | Heterosis | | Standard Heterosis | | Heterosis | | Standard Heterosis | |
| | MP | BP | US 314 | Tella hamsa | MP | BP | US 314 | Tella hamsa |
| JMS 13A x RNR 26085 | -4.42** | -5.49** | -0.73 | -8.00** | 8.62** | -9.88** | 10.07** | -10.46** |
| JMS 13A x ZGY 1 | -6.26** | -9.64** | -0.01 | -7.34** | 28.24** | 7.02** | 28.81** | 4.84** |
| JMS 13A x RNR 2354 | -3.39** | -3.70** | -1.12 | -8.37** | 16.23** | 12.50** | -9.40** | -26.26** |
| JMS 13A x RNR 28359 | -5.49** | -7.01** | -4.52** | -11.51** | 20.05** | 2.44 | 16.74** | -4.98** |
| JMS 13A x RNR 21571 | -4.82** | -5.23** | -2.69** | -9.83** | 12.24** | -8.07** | 16.02** | -5.57** |
| JMS 13A x IR 72 | -7.85** | -9.10** | -6.67** | -13.51** | 24.72** | 11.20** | 14.35** | -6.93** |
| JMS 13A x JGL 35126 | 0.28 | -0.10 | 3.35** | -4.22** | -15.83** | -30.42** | 14.24** | -30.19** |
| JMS 13A x JGL 35047 | -5.71** | -6.50** | -2.35* | -9.51** | 31.81** | 15.79** | 23.19** | 0.27 |
| JMS 13A x JGL 34551 | -3.50** | -3.74** | -1.16 | -8.41** | 10.87** | 7.45** | -7.79** | -24.94** |
| JMS 13A x RNR 28411 | -5.28** | -6.56** | -1.39 | -8.61** | 16.70** | -4.25* | 20.30** | -2.08 |
| CMS 23A x RNR 26085 | -3.81** | -6.62** | -1.91 | -9.10** | 9.68** | 0.04 | 22.30** | -0.45 |
| CMS 23A x ZGY 1 | -6.45** | -11.42** | -1.98 | -9.16** | 12.47** | 3.37 | 24.42** | 1.27 |
| CMS 23A x RNR 2354 | -4.92** | -6.38** | -4.49** | -11.49** | 36.57** | 19.29** | 20.36** | -2.04 |
| CMS 23A x RNR 28359 | 3.25** | 2.99** | 2.36* | -5.14** | 10.43** | 4.10* | 18.63** | -3.44 |
| CMS 23A x RNR 21571 | -6.50** | -7.83** | -6.18** | -13.06** | -0.32 | -10.31** | 13.18** | -7.88** |
| CMS 23A x IR 72 | 0.32 | -0.19 | -0.29 | -7.60** | 19.30** | 18.17** | 21.52** | -1.09 |
| CMS 23A x JGL 35126 | -1.96* | -4.12** | -0.81 | -8.08** | 0.30 | -8.80** | 12.40** | -8.51** |
| CMS 23A x JGL 35047 | -4.43** | -6.97** | -2.84** | -9.96** | -0.08 | -2.67 | 3.56 | -15.71** |
| CMS 23A x JGL 34551 | 0.22 | -1.38 | 0.75 | -6.63** | 0.09 | -7.39** | -6.56** | -23.95** |
| CMS 23A x RNR 28411 | -5.73** | -8.70** | -3.64** | -10.71** | 16.18** | 4.74** | 31.59** | 7.11** |
| CMS 46A x RNR 26085 | -9.30** | -11.65** | -7.20** | -14.00** | 7.26** | 2.55 | 25.25** | 1.95 |
| CMS 46A x ZGY 1 | -5.80** | -10.51** | -0.98 | -8.23** | -3.29* | -6.89** | 12.07** | -8.78** |
| CMS 46A x RNR 2354 | -5.50** | -6.63** | -4.74** | -11.72** | 6.25** | -10.33** | -0.78 | -19.24** |
| CMS 46A x RNR 28359 | -3.97** | -4.07** | -4.46** | -11.46** | 12.14** | 10.88** | 26.36** | 2.85 |
| CMS 46 A X RNR 21571 | -5.85** | -6.87** | -5.20** | -12.15** | -1.03 | -6.83** | 17.58** | -4.30* |
| CMS 46A x IR 72 | -4.11** | -4.26** | -4.36** | -11.37** | 13.29** | 8.94** | 21.36** | -1.22 |
| CMS 46A x JGL 35126 | 0.34 | -1.53 | 1.87 | -5.59** | 5.33** | 0.27 | 23.58** | 0.59 |
| CMS 46A x JGL 35047 | -1.42 | -3.70** | 0.57 | -6.80** | 6.59** | 4.19* | 16.07** | -5.52** |
| CMS 46A x JGL 34551 | -1.42 | -2.66** | -0.55 | -7.84** | 6.71** | -5.54** | 5.23* | -14.35** |
| CMS 46A x RNR 28411 | -6.95** | -9.57** | -4.57** | -11.56** | 6.57** | 0.53 | 26.31** | 2.81 |
| CMS 59A x RNR 26085 | -0.01 | -2.84** | 2.06* | -5.42** | 5.40** | 0.20 | 22.37** | -0.39 |
| CMS 59A x ZGY 1 | -3.09** | -8.15** | 1.64 | -5.81** | 6.01** | 1.48 | 22.14** | -0.59 |
| CMS 59A x RNR 2354 | -0.72 | -2.14* | -0.16 | -7.48** | -6.06** | -20.87** | -12.90** | -29.11** |
| CMS 59A x RNR 28359 | 0.28 | 0.13 | -0.48 | -7.77** | 6.65** | 4.83* | 19.47** | -2.76 |
| CMS 59A x RNR 21571 | -2.04* | -3.33** | -1.60 | -8.81** | 3.63* | -3.00 | 22.41** | -0.36 |
| CMS 59A x IR 72 | -3.60** | -3.98** | -4.08** | -11.11** | 16.20** | 12.38** | 23.69** | 0.68 |
| CMS 59A x JGL 35126 | -3.55** | -5.58** | -2.31* | -9.47** | 1.74 | -3.70* | 18.69** | -3.40 |
| CMS 59A x JGL 35047 | -5.81** | -8.22** | -4.15** | -11.17** | 6.47** | 4.70* | 15.24** | -6.20** |
| CMS 59A x JGL 34551 | 1.36 | -0.16 | 2.01 | -5.47** | 5.34** | -6.27** | 3.17 | -16.03** |
| CMS 59A x RNR 28411 | -3.61** | -6.54** | -1.37 | -8.60** | 2.36 | -3.98* | 20.63** | -1.81 |
| **SE** | 0.73 | 0.84 | 0.84 | 0.84 | 0.39 | 0.45 | 0.45 | 0.45 |
| **CD. 95%** | 1.48 | 1.71 | 1.71 | 1.71 | 0.71 | 0.82 | 0.82 | 0.82 |

**Table 6 :** Individual location wise and pooled estimates of heterosis, heterobeltiosis and standard heterosis for Hulling (%) and Milling (%).

| Crosses | Pooled (H %) | | | | Pooled (M %) | | | |
|---|---|---|---|---|---|---|---|---|
| | Heterosis | | Standard Heterosis | | Heterosis | | Standard Heterosis | |
| | MP | BP | US 314 | Tella hamsa | MP | BP | US 314 | Tella hamsa |
| JMS 13A x RNR 26085 | 3.40** | 2.04** | 0.72 | 0.72 | 3.16** | 2.64** | -0.48 | 2.48** |
| JMS 13A x ZGY 1 | 1.00 | -1.39* | 2.16** | 2.16** | 0.57 | -1.58** | -0.32 | 2.64** |
| JMS 13A x RNR 2354 | 1.53* | 1.46* | 0.29 | 0.29 | 0.49 | -0.81 | -1.28* | 1.65** |
| JMS 13A x RNR 28359 | -0.07 | -0.72 | -0.72 | -0.72 | -0.24 | -1.45* | -2.08** | 0.83 |
| JMS 13A x RNR 21571 | -2.01** | -3.40** | -1.87** | -1.87** | -2.68** | -4.31** | -4.01** | -1.16 |
| JMS 13A x IR 72 | 0.87 | 0.00 | 0.43 | 0.43 | 3.97** | 3.97** | 0.80 | 3.80** |
| JMS 13A x JGL 35126 | 1.73** | 0.72 | 1.44* | 1.44* | 2.56** | 2.30** | -0.32 | 2.64** |
| JMS 13A x JGL 35047 | -1.59** | -2.84** | -1.59* | -1.59* | -2.75** | -4.90** | -3.53** | -0.66 |
| JMS 13A x JGL 34551 | -0.88 | -1.46* | -2.74** | -2.74** | -2.91** | -3.64** | -6.57** | -3.80** |
| JMS 13A x RNR 28411 | 0.07 | -1.42* | 0.29 | 0.29 | -0.16 | -1.91** | -1.44* | 1.49* |
| CMS 23A x RNR 26085 | 0.67 | -0.58 | -2.02** | -2.02** | -0.65 | -2.72** | -2.56** | 0.33 |
| CMS 23A x ZGY 1 | -1.07 | -3.48** | 0.00 | 0.00 | -2.15** | -2.69** | -1.44* | 1.49* |
| CMS 23A x RNR 2354 | 1.61** | 1.46* | 0.29 | 0.29 | 0.80 | 0.48 | 0.64 | 3.63** |
| CMS 23A x RNR 28359 | 1.02 | 0.29 | 0.29 | 0.29 | -1.37* | -1.76** | -1.60** | 1.32* |
| CMS 23A x RNR 21571 | -1.66** | -3.12** | -1.59* | -1.59* | -3.60** | -3.67** | -3.37** | -0.50 |
| CMS 23A x IR 72 | -1.67** | -2.58** | -2.16** | -2.16** | -0.98 | -2.56** | -2.40** | 0.50 |
| CMS 23A x JGL 35126 | 1.52* | 0.43 | 1.15 | 1.15 | 0.89 | -0.48 | -0.32 | 2.64** |
| CMS 23A x JGL 35047 | -1.37* | -2.70** | -1.44* | -1.44* | -2.86** | -3.48** | -2.08** | 0.83 |
| CMS 23A x JGL 34551 | 1.40* | 0.88 | -0.58 | -0.58 | -0.25 | -2.56** | -2.40** | 0.50 |
| CMS 23A x RNR 28411 | 1.87** | 0.28 | 2.02** | 2.02** | -1.12* | -1.28* | -0.80 | 2.15** |
| CMS 46A x RNR 26085 | -1.10 | -3.16** | -2.88** | -2.88** | -3.78** | -5.19** | -6.25** | -3.47** |
| CMS 46A x ZGY 1 | -3.75** | -5.29** | -1.87** | -1.87** | -2.80** | -3.96** | -2.72** | 0.17 |
| CMS 46A x RNR 2354 | -1.74** | -2.44** | -2.16** | -2.16** | -3.88** | -4.19** | -4.65** | -1.82** |
| CMS 46A x RNR 28359 | 2.73** | 2.59** | 2.88** | 2.88** | 2.83** | 2.58** | 1.92** | 4.95** |
| CMS 46 A X RNR 21571 | -0.07 | -0.71 | 0.86 | 0.86 | -0.24 | -0.96 | -0.64 | 2.31** |
| CMS 46A x IR 72 | -1.22* | -1.29 | -0.86 | -0.86 | -0.16 | -1.13 | -2.24** | 0.66 |
| CMS 46A x JGL 35126 | -0.50 | -0.72 | 0.00 | 0.00 | -0.57 | -1.30* | -2.40** | 0.50 |
| CMS 46A x JGL 35047 | -0.07 | -0.57 | 0.72 | 0.72 | -2.40** | -3.63** | -2.24** | 0.66 |
| CMS 46A x JGL 34551 | 0.66 | -0.72 | -0.43 | -0.43 | -0.41 | -2.11** | -3.21** | -0.33 |
| CMS 46A x RNR 28411 | -2.28** | -2.97** | -1.30 | -1.30 | -0.64 | -1.44* | -0.96 | 1.98** |
| CMS 59A x RNR 26085 | 2.81** | 1.61* | 0.00 | 0.00 | 0.83 | 0.33 | -2.72** | 0.17 |
| CMS 59A x ZGY 1 | -2.14** | -4.59** | -1.15 | -1.15 | -0.57 | -2.69** | -1.44* | 1.49* |
| CMS 59A x RNR 2354 | -0.80 | -1.02 | -2.16** | -2.16** | 0.98 | -0.32 | -0.80 | 2.15** |
| CMS 59A x RNR 28359 | 1.23* | 0.43 | 0.43 | 0.43 | 0.73 | -0.48 | -1.12 | 1.82** |
| CMS 59A x RNR 21571 | 0.00 | -1.56* | 0.00 | 0.00 | 0.24 | -1.44* | -1.12 | 1.82** |
| CMS 59A x IR 72 | 2.46** | 1.43* | 1.87** | 1.87** | 1.32* | 1.32* | -1.76** | 1.16 |
| CMS 59A x JGL 35126 | -0.87 | -2.00** | -1.30 | -1.30 | 0.08 | -0.16 | -2.72** | 0.17 |
| CMS 59A x JGL 35047 | 1.73** | 0.28 | 1.59* | 1.59* | 1.29* | -0.95 | 0.48 | 3.47** |
| CMS 59A x JGL 34551 | 2.21** | 1.76* | 0.14 | 0.14 | -2.08** | -2.81** | -5.77** | -2.97** |
| CMS 59A x RNR 28411 | -2.95** | -4.53** | -2.88** | -2.88** | -3.57** | -5.26** | -4.81** | -1.98** |
| **SE** | 0.47 | 0.54 | 0.54 | 0.54 | 0.36 | 0.42 | 0.42 | 0.42 |
| **CD. 95%** | 0.87 | 1.00 | 1.00 | 1.00 | 0.70 | 0.81 | 0.81 | 0.81 |

**Table 7 :** Individual location wise and pooled estimates of heterosis, heterobeltiosis and standard heterosis for Head rice recovery(%) and grain yield (g).

| Crosses | Pooled (HRR) | | | | Pooled (GY) | | | |
|---|---|---|---|---|---|---|---|---|
| | Heterosis | | Standard Heterosis | | Heterosis | | Standard Heterosis | |
| | MP | BP | US 314 | Tella hamsa | MP | BP | US 314 | Tella hamsa |
| JMS 13A x RNR 26085 | 7.92** | 5.21** | 11.22** | 6.45** | 5.09 | -2.89 | -18.75** | -9.29* |
| JMS 13A x ZGY 1 | 0.10 | -0.77 | 4.90** | 0.39 | 53.21** | 47.22** | 23.18** | 37.52** |
| JMS 13A x RNR 2354 | -0.77 | -0.96 | 5.10** | 0.59 | 64.58** | 58.38** | 32.52** | 47.92** |
| JMS 13A x RNR 28359 | 2.51** | 2.32* | 8.16** | 3.52** | 6.79 | 0.28 | -16.10** | -6.33 |
| JMS 13A x RNR 21571 | 2.66** | 0.58 | 6.33** | 1.76 | -6.57 | -7.41 | -22.53** | -13.51** |
| JMS 13A x IR 72 | -0.96 | -1.34 | 5.10** | 0.59 | -3.28 | -4.87 | -17.71** | -8.13* |
| JMS 13A x JGL 35126 | 1.57 | 0.00 | 5.71** | 1.17 | 36.03** | 32.08** | 17.32** | 30.98** |
| JMS 13A x JGL 35047 | 2.91** | 1.53 | 9.18** | 2.72** | 46.94** | 41.20** | 18.14** | 31.90** |
| JMS 13A x JGL 34551 | -4.14** | -6.18** | -0.81 | -5.08** | -2.36 | -4.98 | -15.98** | -6.20 |
| JMS 13A x RNR 28411 | 3.42** | 1.87* | 11.02** | 6.25** | 20.43** | 18.67** | -0.71 | 10.85** |
| CMS 23A x RNR 26085 | -6.84** | -7.32** | -6.94** | -10.94** | 14.16** | 9.91* | -15.74** | -5.93 |
| CMS 23A x ZGY 1 | -18.07** | -19.84** | -16.73** | -20.31** | 16.89** | 16.53** | -10.11** | 0.35 |
| CMS 23A x RNR 2354 | -8.04** | -10.96** | -5.51** | -9.57** | 6.39 | 5.90 | -18.06** | -8.52* |
| CMS 23A x RNR 28359 | 3.09** | 0.19 | 5.51** | 0.98 | 47.84** | 44.76** | 10.98** | 23.90** |
| CMS 23A x RNR 21571 | -16.87** | -17.71** | -16.53** | -20.12** | 8.13* | 4.50 | -14.13** | -4.13 |
| CMS 23A x IR 72 | -9.61** | -12.64** | -6.94** | -10.94** | 0.34 | -5.37 | -18.14** | -8.61* |
| CMS 23A x JGL 35126 | -17.09** | -18.33** | -16.33** | -19.92** | 5.73 | -1.51 | -12.51** | -2.33 |
| CMS 23A x JGL 35047 | -7.77** | -9.33** | -6.73** | -10.74** | 7.27 | 6.94 | -17.51** | -7.91* |
| CMS 23A x JGL 34551 | -13.73** | -14.52** | -13.47** | -17.19** | 26.10** | 17.71** | 4.09 | 16.21** |
| CMS 23A x RNR 28411 | -9.11** | -13.11** | -5.31** | -9.38** | 12.31** | 9.16* | -11.33** | -1.01 |
| CMS 46A x RNR 26085 | 0.98 | -2.10* | 4.69** | 0.20 | 21.31** | 13.54** | -7.60* | 3.16 |
| CMS 46A x ZGY 1 | -1.26 | -2.67** | 4.08** | -0.39 | 18.22** | 15.14** | -6.30 | 4.61 |
| CMS 46A x RNR 2354 | -1.15 | -1.53 | 5.31** | 0.78 | 41.45** | 37.96** | 12.28** | 25.35** |
| CMS 46A x RNR 28359 | 0.58 | -0.19 | 6.73** | 2.15* | 32.81** | 26.35** | 2.83 | 14.81** |
| CMS 46 A X RNR 21571 | 5.00** | 2.29* | 9.39** | 4.69** | -7.65* | -8.09 | -24.48** | -15.69** |
| CMS 46A x IR 72 | -1.15 | -1.34 | 5.51** | 0.98 | 0.98 | -2.00 | -15.23** | -5.36 |
| CMS 46A x JGL 35126 | -4.68** | -6.68** | -0.20 | -4.49** | 25.83** | 20.56** | 7.08* | 19.55** |
| CMS 46A x JGL 35047 | 4.09** | 2.10* | 9.18** | 4.49** | 6.90 | 4.11 | -15.27** | -5.40 |
| CMS 46A x JGL 34551 | 1.18 | -1.53 | 5.31** | 0.78 | 46.23** | 40.41** | 24.16** | 38.62** |
| CMS 46A x RNR 28411 | 0.95 | 0.00 | 8.98** | 4.30** | 10.41** | 10.30* | -10.23** | 0.22 |
| CMS 59A x RNR 26085 | 4.23** | 3.40** | 5.51** | 0.98 | 12.03** | 5.60 | -15.35** | -5.49 |
| CMS 59A x ZGY 1 | 2.87** | 1.96* | 5.92** | 1.37 | 52.71** | 49.83** | 20.11** | 34.09** |
| CMS 59A x RNR 2354 | 7.45** | 5.38** | 11.84** | 7.03** | 13.22** | 11.24** | -10.82** | -0.44 |
| CMS 59A x RNR 28359 | 7.68** | 6.01** | 11.63** | 6.84** | 40.16** | 34.32** | 7.67* | 20.21** |
| CMS 59A x RNR 21571 | 5.12** | 4.80** | 6.94** | 2.34* | 33.09** | 31.47** | 8.03* | 20.61** |
| CMS 59A x IR 72 | 3.72** | 1.53 | 8.16** | 3.52** | 47.53** | 42.13** | 22.94** | 37.26** |
| CMS 59A x JGL 35126 | 3.99** | 3.78** | 6.33** | 1.76 | 42.34** | 35.40** | 20.27** | 34.27** |
| CMS 59A x JGL 35047 | 7.77** | 7.34** | 10.41** | 5.66** | 9.98** | 7.90 | -13.50** | -3.43 |
| CMS 59A x JGL 34551 | -3.61** | -4.00** | -2.04* | -6.25** | 10.60** | 5.43 | -6.77 | 4.09 |
| CMS 59A x RNR 28411 | 0.19 | -3.00** | 5.71** | 1.17 | 37.09** | 36.19** | 10.63** | 23.51** |
| **SE** | 0.47 | 0.53 | 0.53 | 0.53 | 0.84 | 0.97 | 0.97 | 0.97 |
| **CD. 95%** | 0.92 | 1.06 | 1.06 | 1.06 | 1.66 | 1.91 | 1.91 | 1.91 |

**Table 8 :** Top ranking crosses based on per se, sca and standard heterosis of crosses for yield and its components in hybrid rice.

| Cross | Mean | SCA | Standard Heterosis | |
|---|---|---|---|---|
| | | | US 314 | Tellahamsa |
| **Days to 50% flowering** | | | | |
| CMS 23A x RNR 26085 | 92.89 | -7.78** | -5.32** | -3.69** |
| JMS 13A x JGL 35126 | 93.53 | -2.24** | -4.67** | -3.02** |
| CMS 23A x JGL 35126 | 93.56 | -1.14* | -4.64** | -3.00** |
| CMS 23A x RNR 2354 | 95.11 | -3.55** | -3.06** | -1.38 |
| CMS 59A x JGL 35126 | 95.11 | -0.96 | -3.06** | -1.38 |
| **Plant height (cm)** | | | | |
| CMS 23A x RNR 2354 | 73.16 | -7.43** | -20.45** | -16.73** |
| JMS 13A x IR 72 | 75.06 | -6.24** | -18.39** | -14.57** |
| CMS 23A x JGL 35126 | 75.74 | -6.90** | -17.99** | -14.15** |
| JMS 13A x JGL 35047 | 75.72 | -4.42** | -17.66** | -13.81** |
| JMS 13A x RNR 21571 | 77.64 | -4.68** | -15.57** | -11.62** |
| **Panicle length (cm)** | | | | |
| CMS 59A x RNR 26085 | 28.74 | 1.03** | 10.84** | 29.35** |
| CMS 46A x RNR 26085 | 26.90 | 0.13 | 3.73* | 21.05** |
| CMS 59A x RNR 28411 | 26.83 | 0.57* | 3.47* | 20.75** |
| CMS 59 A x RNR 28359 | 26.23 | 0.41 | 1.16 | 18.05** |
| JMS 13A x JGL 35126 | 26.22 | 1.79** | 1.11 | 18.00** |
| **No.of productive tillers/plant** | | | | |
| JMS 13A x IR 72 | 11.67 | 1.04** | 38.16** | 9.38* |
| JMS 13A x ZGY 1 | 11.22 | 1.43** | 32.89** | 5.21 |
| CMS 46A x RNR 21571 | 11.11 | 1.57** | 31.58** | 4.17 |
| JMS 13A x RNR 2354 | 10.89 | 0.96** | 28.95** | 2.08 |
| CMS 23A x RNR 26085 | 10.89 | 1.94** | 28.95** | 2.08 |
| **Spikelet fertility (%)** | | | | |
| JMS 13A x JGL 35126 | 86.98 | 2.27** | 3.35** | -4.22** |
| CMS 23A x RNR 28359 | 86.14 | 3.52** | 2.36* | -5.14** |
| CMS 59A x RNR 26085 | 85.89 | 2.52** | 2.06* | -5.42** |
| CMS 59A x JGL 34551 | 85.84 | 0.61 | 2.01 | -5.47** |
| CMS 46A x JGL 35126 | 85.73 | 2.06** | 1.87 | -5.59** |
| **1000 grain weight (g)** | | | | |
| CMS 23A x RNR 28411 | 26.29 | 1.08** | 31.59** | 7.11** |
| JMS 13A x ZGY 1 | 25.73 | 2.36** | 28.81** | 4.84** |
| CMS 46A x RNR 28359 | 25.24 | 0.69* | 26.36** | 2.85 |
| CMS 46A x RNR 28411 | 25.23 | -0.20 | 26.31** | 2.81 |
| CMS 46A x RNR 26085 | 25.02 | 0.53 | 25.25** | 1.95 |
| **Hulling (%)** | | | | |
| CMS 46A x RNR 28359 | 79.33 | 1.78** | 2.88** | 2.88** |
| JMS 13A x ZGY 1 | 78.78 | 1.68** | 2.16** | 2.16** |
| CMS 23A x RNR 28411 | 78.67 | 1.96** | 2.02** | 2.02** |
| CMS 59A x IR 72 | 78.56 | 1.58** | 1.87** | 1.87** |
| CMS 59A x JGL 35047 | 78.33 | 1.36** | 1.59** | 1.59** |

*Table 8 continued....*

exhibited by 26 hybrids. In case of varietal check (Tellahamsa) 13 hybrids exhibited significantly positive heterosis.

### Kernel length (mm)

For kernel length, heterosis was from -6.50 (JMS 13A × JGL 35126) to 10.39 per cent (CMS 23A × JGL 34551) and 22 hybrids recorded significant positive heterosis. The range of heterobeltiosis was from -16.48 (JMS 13A × JGL 35126) to 7.95 (CMS 23A × JGL 34551). Seven hybrids exhibited significant positive heterobeltiosis. Heterosis over hybrid check US 314ranged from -9.54 (JMS 13A × JGL 35126) to 15.41 per cent (CMS 59A × RNR 28411). A total number of 30 hybrids exhibited significant positive standard heterosis. Twenty one hybrids recorded significant positive standard heterosis over Tellahamsa.

### Kernel breadth (mm)

For this trait, heterosis ranged from -4.93 (CMS 23A × ZGY 1) to 7.36 per cent (JMS 13A × IR 72) and from -12.49 (CMS 59A × RNR 28411) to 4.72 per cent (CMS 59A × JGL 34551) for heterobeltiosis. Seven and 25 hybrids manifested significant negative superiority over mid parent and better parent, respectively. Twenty hybrids recorded significant negative standard heterosis over hybrid check, US 314and range was from -15.35 (JMS 13A × RNR 2354) to 5.73 per cent (CMS 23A × RNR 28359). Ten hybrids exhibited significant negative standard heterosis over check, Tellahamsa.

### Kernel length breadth ratio

In pooled analysis, the significant positive average heterosis was recorded in 16 hybrids, with a range of -8.67 (CMS 59A × JGL 34551) and 12.10 per cent (CMS 23A × ZGY 1). The significant heterobeltiosis was recorded in one hybrid with overall heterobeltiosis ranging from -13.26 (CMS 59A × JGL 34551) to 6.88 per cent (CMS 23A × ZGY 1). The significant positive standard heterosis was recorded in 34 hybrids with heterosis ranging from -1.68 (CMS 23A × RNR 28359) to 24.61 (CMS 59A × RNR 28411) when compared with hybrid check, US 314 and 13 hybrids exhibited significant positive standard heterosis over Tellahamsa for kernel length-breadth ratio.

### Grain yield per plant (g)

Grain yield is a complex quantitative trait governed by many genes interacting with the environment and is the product of various factors

***Table 8 continued....***

| | | | | |
|---|---|---|---|---|
| **Milling (%)** | | | | |
| CMS 46A x RNR 28359 | 70.67 | 2.06** | 1.92** | 4.95** |
| JMS 13A x IR 72 | 69.89 | 1.46** | 0.80 | 3.80** |
| CMS 23A x RNR 2354 | 69.78 | 1.23** | 0.64 | 3.63** |
| CMS 59A x JGL 35047 | 69.67 | 1.72** | 0.48 | 3.47** |
| JMS 13A x ZGY 1 | 69.11 | 0.74* | -0.32 | 2.64** |
| **Head rice recovery (%)** | | | | |
| CMS 59A x RNR 2354 | 60.89 | 1.81** | 11.84** | 7.03** |
| CMS 59A x RNR 28359 | 60.78 | -0.39 | 11.63** | 6.84** |
| JMS 13A x RNR 26085 | 60.56 | 1.92** | 11.22** | 6.45** |
| JMS 13A x RNR 28411 | 60.44 | 1.01** | 11.02** | 6.25** |
| CMS 59A x JGL 35047 | 60.11 | 0.31 | 10.41** | 5.66** |
| **Kernel length (mm)** | | | | |
| CMS 59A x RNR 28411 | 6.68 | 0.12** | 15.41** | 9.58** |
| CMS 46A x JGL 35126 | 6.58 | 0.25** | 13.64** | 7.91** |
| CMS 59A x IR 72 | 6.55 | 0.16** | 13.07** | 7.36** |
| CMS 59A x RNR 21571 | 6.53 | 0.07 | 12.86** | 7.16** |
| CMS 46A x RNR 26085 | 6.49 | 0.14** | 12.09** | 6.43** |
| **Kernel breadth (mm)** | | | | |
| JMS 13A x RNR 2354 | 1.64 | -0.09** | -15.35** | -11.71** |
| JMS 13A x JGL 34551 | 1.69 | -0.03 | -13.00** | -9.26** |
| CMS 59A x RNR 2354 | 1.71 | -0.01 | -11.63** | -7.83** |
| CMS 46A x JGL 34551 | 1.72 | -0.04* | -11.45** | -7.65** |
| JMS 13A x JGL 35126 | 1.73 | -0.08** | -11.05** | -7.23** |
| **Length/Breadth ratio** | | | | |
| CMS 59A x RNR 28411 | 3.72 | 0.20** | 24.61** | 13.42** |
| CMS 59A x ZGY 1 | 3.56 | 0.06 | 19.17** | 8.47** |
| CMS 46A x JGL 35126 | 3.54 | 0.11** | 18.35** | 7.73** |
| CMS 46A x JGL 34551 | 3.52 | 0.09** | 17.57** | 7.01** |
| CMS 59A x RNR 26085 | 3.52 | 0.01 | 17.98** | 7.39** |
| **Grain yield per plant (g)** | | | | |
| JMS 13A x RNR 2354 | 37.41 | 7.02** | 32.52** | 47.92** |
| CMS 46A x JGL 34551 | 35.06 | 6.68** | 24.16** | 38.62** |
| JMS 13A x ZGY 1 | 34.78 | 4.07** | 23.18** | 37.52** |
| CMS 59A x IR 72 | 34.71 | 6.57** | 22.94** | 37.26** |
| CMS 59A x JGL 35126 | 33.96 | 1.56* | 20.27** | 34.27** |
| CMS 59A x ZGY 1 | 33.91 | 1.89** | 20.11** | 34.09** |

called yield components. Selecting the parents based on yield alone is often misleading. Hence, thorough knowledge about relationship between yield and its contributing characters is needed for efficient selection and development of high yielding variety. For the character grain yield average heterosis and heterobeltiosis estimates ranged from -7.65 (CMS 46A × RNR 21571) to 64.58 per cent (JMS 13A × RNR 2354) and from -8.09 (CMS 46A × RNR 21571) to 58.38 per cent (JMS 13A × RNR 2354), respectively. Out of 40 hybrids studied, 28 hybrids excelled with significant positive average heterosis and 24 hybrids exhibited significant positive heterobeltiosis. With respect to heterosis over best hybrid check, US 314, the range was from -24.48 (CMS 46A × RNR 21571) to 32.52 per cent (JMS 13A × RNR 2354) and positive significant standard heterosis was exhibited by 14 hybrids. Heterosis and heterobeltiosis of positive nature was reported by Reddy *et al.* (2012), Priyanka *et al.* (2014), Mistry *et al.* (2015), Balakrishna and Satyanarayana (2015), Nayak *et al.* ,(2015), Srijan (2015), Parimala (2016), Ramesh (2016), Borah *et al.* (2017) and Vanave *et al.* (2018). Earlier rice workers *viz*., Kumar *et al.* (2010), Sateesh Kumar and Saravanan (2010), Ashfaq *et al.* (2013), Pratap *et al.* (2013), Priyanka *et al.* (2014), Seesang *et al.* (2014), Bhati *et al.* (2015), Dar *et al.* (2015), Savitha and Usha Kumara (2015), Srijan *et al.* (2015), Chouhan *et al.* (2016), Parimala (2016), Ramesh (2016), Samrath Bedi and Deepk Sharma (2016), Showkat *et al.* (2016), Srivastava and Jaiswal (2016), Galal *et al.* (2017), Premkumar *et al.* (2017), Thorat *et al.* (2017), Gokulakrishnan *et al.* (2018) and Manjunath *et al.* (2019).

Based on *per se* performance and positive *sca* effects six superior combinations for grain yield were identified, they were JMS 13A × RNR 2354, CMS 46A × JGL 34551, JMS 13A × ZGY 1, CMS 59A × IR 72, CMS 59A × JGL 35126 and CMS 59A × ZGY 1. These hybrids also excelled in mean performance, *sca* effects and heterosis for important yield deciding traits like plant height (early & negative heterosis), number of productive tillers per plant, 1000 grain weight and head rice recovery. This also indicated that these yield attributes played great role in expression of high heterosis for grain yield per plant.

Superior crosses with high disirable *per se* performance along with their *sca* effects and standard heterosis were presented in Table 8.

Heterosis for grain yield per plant is mainly because of simultaneous manifestation of heterosis for yield component traits. The hybrids, JMS 13A × RNR 2354, CMS 46A × JGL 34551, JMS 13A × ZGY 1, CMS 59A × IR 72, CMS 59A × JGL 35126 and CMS 59A × ZGY 1 which expressed highly significant positive heterosis for yield over standard checks (Fig. 1), also proved superior performance for plant height (early & negative heterosis), number of productive tillers per plant, 1000 grain weight and head rice recovery.

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