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Nature and magnitude of heterosis and inbreeding depression for grain yield and yield attributing traits in nutritional rich rice (*Oryza sativa* L.) Crosses

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Abstract
Studies on heterosis for days to 50% flowering revealed that highest magnitudes in negative direction were expressed by WGL-32100 x Ramappa, Ramappa x NH-787, RP-Bio-5478-270 x NH-787, RP-Bio-5478-166 x DRR Dhan-40 and RP-Bio-5478-176 x DRR Dhan-40, but due to a substantial increase in F_2 generation, not recommended for direct selection. The crosses MTU 1010 x Ramappa, WGL-32100 x RP-Bio-5478-185, WGL-32100 x NH-686, WGL-32100 x NH-787, Ramappa x NH-686 and Ramappa x NH-787 were recommended for selection due to high heterosis followed by low inbreeding depression for improving productive tillers per plant. Among the characters studied, 1000 grain weight registered maximum level of heterosis with highest in WGL-32100 x Ramappa, WGL-32100 x RP-Bio-5478-270, WGL-32100 x RP-Bio-5478-185, Ramappa x RP-Bio-5478-270 and WGL-32100 x RP-Bio-5478-166. It is interesting to note that, high heterosis was followed by low inbreeding depression in majority of the crosses, which indicated the presence of additive gene effects in the inheritance of this character. Therefore, for improvement of grain yield, an indirect selection for plants having higher test weight would be more advantageous. In most of the cases, the cross combination which showed high heterosis for grain yield exhibited better mean performance and also corresponding heterosis for 1000 grain weight too, which made a clear way for selection of the plants having higher test weight for ultimate improvement of grain yield per plant.

Keywords: Rice, heterosis, inbreeding depression, test weight, yield and additive gene action

Introduction
Depending upon the breeding objectives, both positive and negative heterosis is useful for crop improvement. In general, positive heterosis is desired for yield and negative heterosis for early maturity. Heterosis is expressed in three ways, depending on the criteria used to compare the performance of a hybrid. The three ways are: mid-parent, standard variety and better parent heterosis. However, from the plant breeder's view point, better parent and/or standard variety is more effective. The former is designated as heterobeltiosis (Fanseco and Peterson, 1968) [6] and the latter as standard heterosis (Virmani, 1994) [22]. From a practical point of view, standard heterosis is most important because it is aimed at developing desired hybrids superior to the existing high yielding commercial varieties.
Inbreeding depression (ID) is defined as the lowered fitness or vigor of inbred individuals compared with their non-inbred counterparts. Its converse is heterosis, the 'hybrid vigor' manifested as increased size, growth rate or other parameters resulting from the increase in heterozygosis in F_1 generation crosses between inbred lines. Inbreeding depression, the depressive effect, is the expression of traits arising from increasing homozygosity (Allard, 1960) [2]. In quantitative genetics theory, inbreeding depression and heterosis are due to non-additive gene action, and are considered to be two aspects of the same phenomenon (Mather and Jinks, 1982) [10]. Li *et al.* (1997b) [9] suggested that hybrid break down in rice was part of inbreeding depression largely related to additive epistasis. In the present study, heterosis and inbreeding depression were studied to understand the type of gene action and to identify best crosses for hybrid or varietal development.

Materials and Methods
Five parents *viz.* MTU 1010, WGL-32100, RP-Bio-5478-185, NH-686 and RP-Bio-5478-166 were selected based on contrasting characters and developed material (F_1, F_2, BC_1 and BC_2) (F_1, F_2, BC_1 and BC_2) for 3 independent crosses to study the presence of non-allelic interactions through generation mean analysis for grain yield its attributing characteristics.

1. MTU 1010 X NH - 686
2. WGL-32100 X RP-Bio-5478-166
3. RP-Bio-5478 -185 X NH-686

Variation for kernel dimensions (long slender x short bold (cross 1), medium slender x short bold (cross 2) and short bold x short bold (cross 3) and flowering duration was considered as criteria for selection of parents for generation mean analysis. The entire work (crossing and evaluation) taken up at Regional Agricultural Research Station, (RARS), Warangal, PJTSAU.

During *Kharif*, 2014 crossing programme has been taken up to get F_1 seed from these three crosses. During *Rabi* 2014-15, raising F_1's to get F_2 seed. (Simultaneous crossing of these F_1's with their respective parents to get BC_1 and BC_2 seed of three crosses. Thus, seed of six basic generations, P_1, P_2, F_1, F_2, BC_1 and BC_2 was in hand for these three crosses at the end of the season *Rabi* 2014-15 for study of generation mean analysis in addition to above work). Parents were also selfed to ensure 100% genetic purity.

During *Kharif*, 2015 P_1, P_2, F_1, F_2, BC_1 and BC_2 of 3 crosses were raised to study the generation mean analysis. The material was sown in randomized block design with three replications. Recommended cultural practices were adopted. The total number of population raised in each replication was 30 for parents and F_1, 60 for back cross generations and 300 for F_2.

The Heterosis was estimated on mid value, better parent and also on two standard checks *viz.*, BPT 5204 for grain yield, its components and quality characters, Chittimuthyalu for iron and zinc contents but for inbreeding depression amylose, iron, zinc contents and cooking quality traits were excluded. Significance of the heterosis and inbreeding depression was tested with't' test values and furnished in Table 1 to 3.

Results and Discussion

Heterosis was found to be in desirable direction and six crosses exhibited significant negative heterosis (Table 4.12). The range was from -11.04% (WGL-32100 x Ramappa) to 2.64% (MTU 1010 x NH-787). Nineteen crosses registered significant negative mid parent heterosis. The heterobeltiosis ranged from –7.95% (WGL-32100 x Ramappa) to 20.97% (MTU 1010 x RP-Bio-5478-166). Among forty five hybrids, fourteen hybrids showed significant negative heterosis and eighteen hybrids showed significant positive heterosis for this trait. All cross combinations recorded significant negative standard heterosis which was highly desirable.

To develop either hybrids or pure lines with earliness, less number of days to 50% flowering (heterosis towards negative side) has to be taken into consideration. Accordingly, seventeen F1 hybrids registered significant negative heterosis and among them highest magnitudes were expressed by WGL-32100 x Ramappa, Ramappa x NH-787, RP-Bio-5478-270 x NH-787, RP-Bio-5478-166 x DRR Dhan-40 and RP-Bio-5478-176 x DRR Dhan-40. Those crosses with highest level of negative heterosis (lesser values of F1's) have shown a substantial increase in F_2 generation, as such may not be of much use for direct selection. Whereas, the cross combination which showed significant reduction in F_1 and F_2 generations for days to 50% flowering would be highly desirable for development of early duration homozygous lines.

From these crosses, it also appeared that the parents involved in these crosses contributed earliness genes responsible for reducing number of days to 50% flowering. Significant negative heterobeltiosis was reported by Tiwari *et al*. (2011) [11] and Saidaiah *et al.* (2012) [16]. Standard heterosis of similar nature was reported by Srikrishna Latha *et al.* (2013) [19], Saidaiah *et al.* (2012) [16], Kumari Priyanka *et al.* (2014) [8] and Devi *et al.* (2015) [5].

Higher numbers of effective tiller per plant are generally associated with higher grain yield, hence is highly desirable. Therefore, the main interest would be the find out the hybrids with more number of effective tillers per plant.

The heterosis for productive tiller which is an important yield component is very high in rice as is evident from sixteen crosses registering significant values of heterosis over better parent with as much as 30% in few crosses. J.N Reddy (2004), reported higher level of heterosis (up to 84%) for number of productive tillers per plant. Negative heterosis at significant level was observed only in five crosses. Most of the hybrids manifested superiority on better parent and also maintained similar trend on standard check. Existence of significant positive heterosis for number of effective tillers per plant has been reported by Srikrishna Latha *et al.* (2013) [19], Rukmini *et al.* (2014) [15].

High heterosis followed by insignificant inbreeding depression for productive tillers per plant indicated prevalence of additive gene effects. Under these situations, direct selection for improvement of this quantitative trait would be very easy and highly remunerative. Accordingly, the crosses *viz.*, MTU 1010 x Ramappa, WGL-32100 x RP-Bio-5478-185, WGL-32100 x NH-686, WGL-32100 x NH-787, Ramappa x NH-686 and Ramappa x NH-787 were recommended for selection.

Among the 45 crosses studied, seven crosses had shown significant better performance on the respective better parents. The level of heterosis for number of grains per panicle is quite high even up to 39% and the best crosses with high level of heterosis are MTU 1010 x NH-686, RP-Bio-5478-185 x NH-686. These results are in accordance with the studies of J.N Reddy (2004) [14], Saidaiah *et al.* (2012) [16], Padmavathi *et al.* (2013) [11] and Kumari Priyanka *et al.* (2014) [8]. However, Sharma *et al*, (2013) [18] reported maximum heterosis in negative side also, probably due to involvement of best parents having full gene association with more number of grains per panicle in the crossing programme. In certain crosses, higher quantities of heterosis coupled with high *per se* performance was noticed, though the mean values of the parents are at moderate levels. In these cases, the expression of heterosis is ascribed to the presence of even partial to full dominance coupled with good dispersion of dominant plus genes in parents.

If maximum population is maintained in F_2 generation and selection is made effectively, there will be good scope to identify the transgressive segregants and develop pure homozygous lines which are as good as F1's. From this point of view, MTU 1010 x Ramappa, MTU 1010 x RP-Bio-5478-176 and MTU 1010 x NH-686 were adjudged as superior crosses. Incidentally, low inbreeding depression was noticed in these crosses. However, the standard heterosis was observed to be in the negative side for this trait in most of the crosses.

Among all the characters studied, 1000 grain weight registered maximum level of heterosis. Thirty one hybrids on mid parent and twenty on better parent manifested highest level of heterosis. However, there are certain crosses in which significant negative heterosis was noticed. Out of 45 crosses studied, 35 crosses exhibited significant positive standard heterosis over standard check variety BPT 5204.

For this character, both significant positive heterobeltiosis and standard heterosis were reported by Deoraj *et al*. (2007) [4], Akarsh Parihar and Pathak (2008) [1]. Heterosis of similar nature was reported by Gnanamalar and Vivekanandan (2013) [7], Pratap *et al*. (2013) [12] and Rukmini *et al*. (2014) [15]. Only positive standard heterosis was reported by Rukmini *et al*. (2014) [15] and Thorat *et al*. (2017) [20].

Highest level of heterosis was present in five crosses *viz.*, WGL-32100 x Ramappa, WGL-32100 x RP-Bio-5478-270, WGL-32100 x RP-Bio-5478-185, Ramappa x RP-Bio-5478-270 with maximum level up to 54% in WGL-32100 x RP-Bio-5478-166. It is interesting to note that, high heterosis was followed by low inbreeding depression in majority of the crosses, which indicates the presence of additive gene effects in the inheritance of this character. Therefore, for improvement of grain yield, an indirect selection for plants having higher test weight would be more advantageous and also assured. Raju *et al*, (2005) also reported high level of heterosis as in the case of present study and recommended pedigree method of breeding for improvement.

Heterosis for grain yield on the mid parent was exhibited by 37 hybrids whereas, on better parent only 17 hybrids were found to be significantly promising. However, the number of heterosis crosses as well as the quantum of heterosis is high on standard cheek. Heterobeltiosis ranged from 13.37 (WGL-32100 x RP-Bio-5478-166) to 45.92 (RP-Bio-5478-185 x NH-686). Several workers *viz.*, Savita Bhatti *et al*. (2015), and Thorat *et al*. (2017) [20] also reported similar trend of positive heterosis for grain yield per plant.

High heterosis was accompanied by high inbreeding depression especially for the crosses which registered more than 30% heterosis. These results are in accordance with the findings of J. N. Reddy (2004) [14] and Raju *et al.* (2005) [13]. However, in certain crosses *viz.*, WGL-32100 x Ramappa, WGL-32100 x RP-Bio-5478-166, Ramappa x DRR Dhan-40, RP-Bio-5478-270 x RP-Bio-5478-166 and RP-Bio-5478-166 x DRR Dhan-40, it was low as was reported earlier by Anil kumar and Mani (2013) [3] and Sharma *et al.* (2013) [18]. When high *per se* performance as well as hybrid vigor and higher level of inbreeding depression altogether are taken into consideration, Ramappa x RP-Bio-5478-270, RP-Bio-5478-185 x NH-686, NH-686 x NH-787 are best suitable for development of hybrids with suitable CMS system, whereas, certain cross combinations, which showed high *per se* performance with high amount of heterosis coupled with low inbreeding depression *viz.*, WGL-32100 x Ramappa, RP-Bio-5478-270 x RP-Bio-5478-185, RP-Bio-5478-185 x NH-787 were identified for direct selection.

In most of the cases, the cross combination which showed heterosis for grain yield exhibited better mean performance and also corresponding heterosis for 1000 grain weight too, which makes a clear way for selection of the plants having higher test weight for ultimate improvement of grain yield.

Studies on heterosis for days to 50% flowering revealed that highest magnitudes in negative direction were expressed by WGL-32100 x Ramappa, Ramappa x NH-787, RP-Bio-5478-270 x NH-787, RP-Bio-5478-166 x DRR Dhan-40 and RP-Bio-5478-176 x DRR Dhan-40, but due to a substantial increase in F_2 generation, not recommended for direct selection. Whereas, the crosses *viz.*, WGL-32100 x Ramappa, WGL-32100 x RP-Bio-5478-166, Ramappa x NH-787 and RP-Bio-5478-166 x NH-787 were treated as best crosses for selection due to closer range in F_1 and F_2 means. The crosses MTU 1010 x Ramappa, WGL-32100 x RP-Bio-5478-185, WGL-32100 x NH-686, WGL-32100 x NH-787, Ramappa x NH-686 and Ramappa x NH-787 were recommended for selection due to high heterosis followed by low inbreeding depression for improving productive tillers per plant. The level of heterosis for number of grains per panicle is quite high even up to 39% and the best crosses with high level of heterosis were MTU 1010 x NH-686, RP-Bio-5478-185 x NH-686. Among the characters studied, 1000 grain weight registered maximum level of heterosis with highest in WGL-32100 x Ramappa, WGL-32100 x RP-Bio-5478-270, WGL-32100 x RP-Bio-5478-185, Ramappa x RP-Bio-5478-270 and WGL-32100 x RP-Bio-5478-166. It is interesting to note that, high heterosis was followed by low inbreeding depression in majority of the crosses, which indicated the presence of additive gene effects in the inheritance of this character. Therefore, for improvement of grain yield, an indirect selection for plants having higher test weight would be more advantageous. As regard to grain yield per plant, when inbreeding depression altogether are taken into consideration, Ramappa x RP-Bio-5478-270, RP-Bio-5478-185 x NH-686, NH-686 x NH-787 were best suitable for development of hybrids with suitable CMS system, whereas, WGL-32100 x Ramappa, RP-Bio-5478-270 x RP-Bio-5478-185, RP-Bio-5478-185 x NH-787 were identified for direct selection. In most of the cases, the cross combination which showed high heterosis for grain yield exhibited better mean performance and also corresponding heterosis for 1000 grain weight too, which made a clear way for selection of the plants having higher test weight for ultimate improvement of grain yield per plant.

Table 1: Estimation of heterosis over mid parent (H_1), better parent (H_2), standard check (SH) and inbreeding depression (ID) for days to 50% flowering and plant height

Crosses	Days to 50% flowering					Plant height (cm)				
	mean	H_1	H_2	SH	ID	mean	H_1	H_2	SH	ID
MTU-1010 x WGL-32100	95.67	-2.71	7.49**	-19.83**	-0.34	93.52	-8.41*	-2.31**	-10.38*	-2.90
MTU-1010 x Ramappa	91.33	-3.69*	2.62**	-23.46**	-1.83	86.53	-15.64**	-10.5**	-17.08**	-5.40
MTU-1010 x RP-Bio-5478-270	94.33	-2.25	5.99**	-20.95**	1.41	86.26	-30.93**	-20.48**	-17.34**	7.03
MTU-1010 x RP-Bio-5478-166	97.33	-2.34	9.36**	-18.44**	0.34	110.53	-14.24**	1.90**	5.92	-3.68
MTU-1010 x RP-Bio-5478-176	96.67	-0.68	8.61**	-18.99**	-2.41	100.48	-21.95**	-7.37**	-3.71	0.42
MTU-1010 x DRR Dhan - 40	95.00	-4.04*	6.74**	-20.39**	-1.05	92.29	-27.08**	-14.92**	-11.56*	-5.15
MTU-1010 x RP-Bio-5478 -185	91.67	-0.72	3.00*	-23.18**	-0.36	118.28	4.93	9.04	13.35**	2.77
MTU-1010 x NH-686	94.33	2.35	5.99	-20.95**	-0.71	92.68	-14.95**	-14.57**	-11.18*	5.27
MTU-1010 x NH-787	97.33	2.64	9.36	-18.44**	-2.74	83.73	-22.33**	-21.84**	-19.76**	-5.91
WGL-32100 x Ramappa	92.67	-11.04**	-7.95**	-22.34**	-3.59	87.80	-8.74*	-8.29	-15.86**	8.43
WGL-32100 x RP-Bio-5478-270	102.00	-3.62*	-1.92**	-14.52**	-2.94	98.42	-16.96**	2.80**	-5.68	5.51
WGL-32100 x RP-Bio-5478-166	104.67	-3.98**	-2.79**	-12.29**	2.55	112.41	-8.25*	17.42**	7.72	-6.75
WGL-32100 x RP-Bio-5478-176	104.67	-1.88	-0.95	-12.29**	-2.23	90.93	-25.69**	-5.02**	-12.86**	2.67
WGL-32100 x DRR Dhan - 40	105.67	-2.46	-1.86	-11.45**	1.58	133.95	11.45**	39.92*	28.37**	-0.41
WGL-32100 x RP-Bio-5478 -185	102.67	0.98	7.32**	-13.96**	1.63	94.05	-11.57**	-1.76**	-9.87*	7.23

Crosses	Days to 50% flowering					Plant height (cm)				
	mean	H_1	H_2	SH	ID	mean	H_1	H_2	SH	ID
WGL-32100 x NH- 686	100.67	-0.82	5.59**	-15.64**	0.67	93.79	-8.59*	-2.03**	-10.12*	-6.48
WGL-32100 x NH- 787	103.33	-0.80	2.65*	-13.41**	-1.62	102.02	0.58	6.57	-2.23	-4.45
Ramappa x RP-Bio-5478-270	98.33	-3.91*	-2.32**	-17.60**	-1.70	106.20	-10.75**	9.85**	1.77	3.01
Ramappa x RP-Bio-5478-166	102.67	-2.69	1.99**	-13.96**	1.63	83.65	-31.99**	-13.48**	-19.84**	-5.74
Ramappa x RP-Bio-5478-176	98.67	-4.36**	-1.99**	-17.31**	-0.33	103.74	-15.55**	7.3**	-0.58	4.57
Ramappa x DRR Dhan - 40	98.00	-6.52**	-2.65**	-17.87**	-3.06	86.84	-28.03**	-10.18**	-16.78**	-8.57
Ramappa x RP-Bio-5478 -185	94.67	-3.57*	-1.05**	-20.67**	0.71	128.30	20.1**	32.7*	22.95**	-1.33
Ramappa x NH-686	99.00	1.02	3.85	-17.04**	-1.01	96.05	-6.81	-0.66**	-7.95	1.61
Ramappa x NH-787	95.33	-5.3**	-5.30**	-20.11**	-1.75	82.82	-18.72**	-14.34**	-20.63**	5.82
RP-Bio-5478-270 x RP-Bio-5478-166	103.00	-3.89**	-0.96**	-13.68**	-4.85	124.58	-14.26**	-11.83**	19.39**	-0.74
RP-Bio-5478-270 x RP-Bio-5478-176	101.33	-3.34*	-2.56*	-15.08**	-12.50**	100.42	-30.82**	-28.93**	-3.77	-4.77
RP-Bio-5478-270 x DRR Dhan - 40	105.67	-0.78	1.60	-11.45**	-4.10	104.65	-26.8**	-25.94**	0.29	4.92
RP-Bio-5478-270 x RP-Bio-5478 -185	95.67	-4.17**	0.00	-19.83**	-3.48	102.34	-20.75**	-12.5**	-1.93	4.73
RP-Bio-5478-270 x NH-686	93.33	-6.35**	-2.1**	-21.79**	-11.43**	99.02	-21.03**	-9.54**	-5.11	-23.62*
RP-Bio-5478-270 x NH-787	96.33	-5.86**	-4.3**	-19.27**	-18.34**	101.05	-18.65**	-5.67**	-3.16	2.52
RP-Bio-5478-166 x RP-Bio-5478-176	107.00	-0.93	1.26	-10.33**	-10.28**	96.46	-35.33**	-35.27**	-7.56	-6.42
RP-Bio-5478-166 x DRR Dhan - 40	102.33	-6.69**	-6.12**	-14.25**	-9.45*	153.52	4.46	6.14	47.12**	3.23
RP-Bio-5478-166 x RP-Bio-5478 -185	99.00	-3.88*	3.48**	-17.04**	-1.01	136.93	2.85	17.06*	31.22**	-5.89
RP-Bio-5478-166 x NH- 686	99.33	-3.40*	4.20**	-16.76**	-0.67	95.85	-25.92**	-12.44**	-8.15*	-26.80**
RP-Bio-5478-166 x NH-787	96.67	-8.37**	-3.97**	-18.99**	2.76	89.99	-29.81**	-16.00**	-13.76**	-7.40
RP-Bio-5478-176 x DRR Dhan - 40	98.33	-8.39**	-6.94**	-17.60**	-13.90**	145.20	-1.10	0.39	39.15**	-8.82
RP-Bio-5478-176 x RP-Bio-5478 -185	101.33	0.66	5.92*	-15.08**	-6.58	102.62	-22.83**	-12.26**	-1.66	7.10
RP-Bio-5478-176 x NH-686	98.67	-1.82	3.5**	-17.31**	-25.67**	106.08	-17.92**	-3.09**	1.66	-23.74**
RP-Bio-5478-176 x NH-787	97.33	-5.65**	-3.31**	-18.44**	-7.88*	87.60	-31.59**	-18.22**	-16.05**	-41.03**
DRR Dhan - 40 x RP-Bio-5478 -185	99.33	-2.93	3.83**	-16.76**	-13.76**	93.58	-28.45**	-19.99**	-10.32*	7.30
DRR Dhan - 40 x NH-686	98.00	-4.08**	2.8**	-17.87**	-16.33**	92.07	-27.53**	-15.89**	-11.77*	-8.45
DRR Dhan - 40 x NH-787	103.67	-1.11	2.98**	-13.12**	0.65	91.00	-27.71**	-15.05**	-12.79**	-18.18
RP-Bio-5478 -185 x NH-686	94.67	-0.87	-0.70	-20.67**	-17.25**	103.00	-9.02*	-5.9**	-1.29	-3.88
RP-Bio-5478 -185 x NH-787	98.00	-0.17	2.44	-17.87**	-2.04	99.37	-11.32**	-7.24**	-4.77	-10.35
NH-686 x NH-787	95.33	-2.72	0.0**	-20.11**	-12.24**	103.51	-4.41	-3.37	-0.80	0.49

* Significant at 5% level, ** Significant at 1% level

Table 2: Estimation of heterosis over mid parent (H_1), better parent (H_2), standard check (SH) and inbreeding depression (ID) for no. of total tillers per plant and no. of productive tillers per plant

Crosses	No. of productive tillers/plant					No. of grains/panicle				
	mean	H_1	H_2	SH	ID	mean	H_1	H_2	SH	ID
MTU-1010 x WGL-32100	11.67	12.9	2.94	-20.23**	29.67*	149.33	-1.43	-20.99**	-19.65**	4.17
MTU-1010 x Ramappa	14.80	28.70**	26.86**	1.16	5.71	204.81	43.47**	19.43**	10.20	8.59
MTU-1010 x RP-Bio-5478-270	12.41	3.44	-2.00	-15.17*	7.54	114.67	-1.96	-4.37	-38.30**	5.82
MTU-1010 x RP-Bio-5478-166	11.33	-12.14	-21.66**	-22.56**	-12.85	132.21	14.26	12.61	-28.87**	5.82
MTU-1010 x RP-Bio-5478-176	8.33	-33.77**	-39.76**	-43.06**	4.13	173.42	35.72**	22.52**	-6.69	12.80
MTU-1010 x DRR Dhan - 40	13.29	18.45*	17.26	-9.16	10.75	140.44	30.95**	23.18**	-24.44**	6.55
MTU-1010 x RP-Bio-5478 -185	9.75	0.86	-13.97	-33.36**	21.88*	141.29	26.29**	23.93**	-23.98**	7.99
MTU-1010 x NH-686	12.37	14.15	9.12	-15.45*	-1.04	193.58	52.87**	39.01**	4.15	7.92
MTU-1010 x NH-787	12.25	16.67	8.09	-16.27*	-9.26	143.25	6.63	-7.39	-22.93**	11.88
WGL-32100 x Ramappa	12.88	22.67*	10.4	-11.96	-4.59	183.46	1.78	-2.93	-1.29	5.89
WGL-32100 x RP-Bio-5478-270	10.83	-1.52	-14.47	-25.97**	-1.55	141.22	-8.57	-25.28**	-24.02**	8.90
WGL-32100 x RP-Bio-5478-166	11.57	-2.77	-20.02**	-20.92**	-1.20	147.60	-3.66	-21.9**	-20.59**	9.72
WGL-32100 x RP-Bio-5478-176	15.50	33.81**	12.05	5.95	-8.82	97.33	-41.11**	-48.5**	-47.63**	2.39
WGL-32100 x DRR Dhan - 40	10.17	-0.52	-8.46	-30.49**	27.13**	133.80	-7.56	-29.21**	-28.01**	12.26
WGL-32100 x RP-Bio-5478 -185	13.75	58.65**	47.32**	-6.02	3.77	159.61	6.86	-15.55**	-14.12**	9.58
WGL-32100 x NH- 686	13.49	37.22**	30.58**	-7.79	3.93	144.78	-11.79*	-23.4**	-22.10**	9.19
WGL-32100 x NH- 787	14.00	47.33**	44.79**	-4.31	7.69	157.40	-8.40	-16.72**	-15.31**	11.28
Ramappa x RP-Bio-5478-270	13.00	6.85	2.63	-11.14	8.33	175.30	20.31**	2.22	-5.68	2.41
Ramappa x RP-Bio-5478-166	13.17	0.77	-8.99	-9.98	1.31	151.76	5.06	-11.51*	-18.35**	5.11
Ramappa x RP-Bio-5478-176	15.46	21.23**	11.73	5.67	7.59	135.62	-13.35*	-20.92**	-27.03**	10.56
Ramappa x DRR Dhan - 40	13.33	17.1*	14.29	-8.89	21.18*	146.59	7.80	-14.52*	-21.13**	6.87
Ramappa x RP-Bio-5478 -185	16.53	27.46**	7.36	-14.35	16.20	185.09	31.63**	7.93	-0.41	11.27
Ramappa x NH-686	14.17	28.79**	21.43*	-3.14	9.00	174.59	12.37*	1.81	-6.06	12.77
Ramappa x NH-787	15.67	46.88**	34.29**	7.11	-2.06	156.04	-4.32	-9.01	-16.04**	3.08
RP-Bio-5478-270 x RP-Bio-5478-166	15.17	11.79	4.84	3.69	-8.06	118.00	-0.56	-1.60	-36.51**	2.41

RP-Bio-5478-270 x RP-Bio-5478-176	13.17	-0.63	-4.82	-9.98	-9.17	128.84	-1.44	-8.97	-30.68**	12.04
RP-Bio-5478-270 x DRR Dhan - 40	13.17	10.77	3.95	-9.98	9.75	130.66	18.57*	8.97	-29.70**	2.55
RP-Bio-5478-270 x RP-Bio-5478 -185	13.39	29.61**	5.74	-8.48	-3.46	120.11	4.61	0.17	-35.38**	7.38
RP-Bio-5478-270 x NH-686	14.20	23.45**	12.08	-2.94	14.98*	117.89	-9.02	-15.34*	-36.57**	13.89
RP-Bio-5478-270 x NH-787	13.18	18.03*	4.05	-9.91	5.10	137.47	0.13	-11.13	-26.04**	6.74

Crosses		No. of productive tillers/plant				No. of grains/panicle				
	Mean	H_1	H_2	SH	ID	Mean	H_1	H_2	SH	ID
RP-Bio-5478-166 x RP-Bio-5478-176	13.66	-3.46	-5.58	-6.63	-8.93	120.72	-6.76	-14.71*	-35.05**	1.66
RP-Bio-5478-166 x DRR Dhan - 40	13.17	2.97	-8.99	-9.98	1.31	102.07	-6.31	-13.06	-45.08**	2.52
RP-Bio-5478-166 x RP-Bio-5478 -185	9.11	-18.9*	-37.03**	-37.73**	-2.36	106.33	-6.37	-9.43	-42.79**	11.29
RP-Bio-5478-166 x NH- 686	12.39	-0.11	-14.38	-15.31*	-6.14	109.58	-14.61*	-21.3**	-41.04**	8.06
RP-Bio-5478-166 x NH-787	13.06	8.2	-9.75	-10.73	-5.84	112.67	-17.18**	-27.16**	-39.38**	3.70
RP-Bio-5478-176 x DRR Dhan - 40	13.92	11.63	0.63	-4.85	-2.86	102.97	-14.91*	-27.25**	-44.60**	7.59
RP-Bio-5478-176 x RP-Bio-5478 -185	11.37	4.18	-17.78*	-22.28**	-5.25	115.70	-7.91	-18.26*	-37.75**	15.47*
RP-Bio-5478-176 x NH-686	15.37	27.2**	11.11	5.06	-6.28	132.53	-5.60	-6.36	-28.69**	15.15*
RP-Bio-5478-176 x NH-787	10.83	-7.8	-21.69**	-25.97**	-5.83	139.40	-5.88	-9.88	-25.00**	11.76
DRR Dhan - 40 x RP-Bio-5478 -185	12.99	36.01**	16.99	-11.21	8.43	98.87	-5.93	-9.90	-46.80**	-2.56
DRR Dhan - 40 x NH-686	13.66	27.43**	22.99*	-6.63	5.24	127.87	6.67	-8.17	-31.20**	4.59
DRR Dhan - 40 x NH-787	12.20	17.46	9.84	-16.61*	-6.15	139.26	9.16	-9.97	-25.07**	4.41
RP-Bio-5478 -185 x NH-686	12.91	40.84**	24.94*	-11.76	-7.79	177.48	42.56**	27.45**	-4.51**	3.30
RP-Bio-5478 -185 x NH-787	13.67	54.72**	41.38**	-6.56	-8.87	151.79	14.81*	-1.86	-18.33**	3.56
NH-686 x NH-787	13.67	36.67**	32.26**	-6.56	13.92	174.61	18.81**	12.88*	-6.05	9.18

* Significant at 5% level, ** Significant at 1% l

Table 3: Estimation of heterosis over mid parent (H_1), better parent (H_2), standard check (SH) and inbreeding depression (ID) 1000 grain weight and Grain yield per plant

Crosses	1000 grain weight (g)					Grain yield per plant (g)				
	Mean	H_1	H_2	SH	ID	Mean	H_1	H_2	SH	ID
MTU-1010 x WGL-32100	23.41	18.1**	-6.53	48.82**	2.48	25.10	12.15*	4.61	32.11**	11.87
MTU-1010 x Ramappa	24.90	18.87**	-0.59	58.30**	7.19	29.07	26.63**	21.13**	53.00**	16.86*
MTU-1010 x RP-Bio-5478-270	19.22	-3.64	-23.26**	22.19**	7.02	21.59	13.69*	-10.02	13.63	3.80
MTU-1010 x RP-Bio-5478-166	22.65	13.93**	-9.59*	43.99**	2.12	21.88	13.26*	-8.83	15.16	4.66
MTU-1010 x RP-Bio-5478-176	20.46	1.69	-18.32**	30.07**	-1.47	22.38	9.4	-6.72	17.79*	6.57
MTU-1010 x DRR Dhan - 40	22.91	9.37*	-8.53*	45.65**	1.62	25.33	30.71**	5.56	33.32**	12.75
MTU-1010 x RP-Bio-5478 -185	21.02	1.78	-16.1**	33.63**	8.28	25.58	28.66**	6.58	34.63**	19.27*
MTU-1010 x NH-686	23.04	0.07	-8.02	46.47**	1.69	28.96	33.78**	20.67**	52.42**	13.81
MTU-1010 x NH-787	21.76	-3.02	-13.15**	38.33**	0.87	23.75	13.08*	-1.04	25.00**	5.73
WGL-32100 x Ramappa	23.19	47.49**	37.65**	47.43**	0.17	27.49	28.83**	25.48**	44.68**	6.33
WGL-32100 x RP-Bio-5478-270	20.60	39.92**	38.74**	30.96**	2.14	21.19	21.94**	2.04	11.53	9.34
WGL-32100 x RP-Bio-5478-166	22.73	55.1**	54.53**	44.50**	2.42	24.23	36.88**	16.66*	27.53**	5.20
WGL-32100 x RP-Bio-5478-176	20.16	35.33**	32.7**	28.16**	-2.73	20.27	7.57	-2.39	6.68	4.74
WGL-32100 x DRR Dhan - 40	20.73	31.83**	23.03**	31.79**	-0.82	20.48	15.3*	-1.38	7.79	4.49
WGL-32100 x RP-Bio-5478 -185	22.05	42.94**	35.7**	40.18**	5.08	23.06	26.24**	11.03	21.37**	13.14*

Crosses	1000 grain weight (g)					Grain yield per plant (g)				
	Mean	H_1	H_2	SH	ID	Mean	H_1	H_2	SH	ID
WGL-32100 x NH- 686	21.76	22.28**	3.65	38.33	-0.32	22.01	9.89	5.99	15.84*	8.45
WGL-32100 x NH- 787	20.09	16.73**	1.36	27.72	15.28*	24.42	25.95**	17.56*	28.53**	13.27*
Ramappa x RP-Bio-5478-270	22.92	44.58**	36.00**	45.71	21.47*	29.04	61.76**	32.53**	52.84**	15.01*
Ramappa x RP-Bio-5478-166	21.07	33.56**	25.06**	33.95	4.32	25.27	38.28**	15.32*	33.00**	14.56*
Ramappa x RP-Bio-5478-176	18.07	12.82*	7.26	14.88*	-3.71	21.50	10.71	-1.89	13.16	12.93
Ramappa x DRR Dhan - 40	21.12	25.32**	25.32**	34.27**	-1.09	24.84	35.48**	13.37*	30.74**	-1.13
Ramappa x RP-Bio-5478 -185	22.68	37.03**	34.58**	44.18**	13.76	23.85	26.61**	8.85	25.53**	18.83
Ramappa x NH-686	21.35	12.82**	1.68	35.73**	0.94	24.29	17.92**	10.88	27.84**	3.99
Ramappa x NH-787	21.96	19.75**	10.78*	39.61**	1.55	27.50	37.82**	25.53**	44.74**	10.91
RP-Bio-5478-270 x RP-Bio-5478-166	19.45	31.59**	30.95**	23.65**	0.67	18.74	30.92**	28.04**	-1.37	1.28
RP-Bio-5478-270 x RP-Bio-5478-176	19.13	27.39**	25.96**	21.61**	3.71	18.68	20.83*	10.36	-1.68	11.46
RP-Bio-5478-270 x DRR Dhan - 40	15.95	0.63	-5.34	1.40	1.50	18.66	29.81**	26.42**	-1.79	8.20
RP-Bio-5478-270 x RP-Bio-5478 -185	20.19	29.85**	24.27**	28.35**	1.29	20.09	35.04**	27.45**	5.74	8.51
RP-Bio-5478-270 x NH-686	13.83	-22.84**	-34.13**	-12.08	-1.59	18.78	12.87	-2.64	-1.16	10.33
RP-Bio-5478-270 x NH-787	20.45	17.97**	3.18	30.01**	1.03	19.38	21.13**	7.63	2.00	8.77

Crosses	1000 grain weight (g)					Grain yield per plant (g)				
	Mean	H_1	H_2	SH	ID	Mean	H_1	H_2	SH	ID
RP-Bio-5478-166 x RP-Bio-5478-176	19.69	31.7**	29.6**	25.17**	3.45	18.08	14.59	6.83	-4.84	1.83
RP-Bio-5478-166 x DRR Dhan - 40	14.77	-6.41	-12.36*	-6.10	1.15	18.86	28.35**	27.8**	-0.74	2.17
RP-Bio-5478-166 x RP-Bio-5478 -185	18.07	16.76**	11.22	14.88*	0.22	18.79	23.65**	19.22*	-1.11	8.83
RP-Bio-5478-166 x NH- 686	18.71	4.81	-10.89*	18.94**	2.57	18.12	6.84	-6.06	-4.63	3.48
RP-Bio-5478-166 x NH-787	16.97	-1.68	-14.36**	7.88	4.24	19.81	21.42**	10.05	4.26	0.81

RP-Bio-5478-176 x DRR Dhan - 40	18.35	14.52**	8.88	16.66*	1.31	18.41	16.23*	8.8	-3.11	2.39
RP-Bio-5478-176 x RP-Bio-5478 -185	19.40	23.42**	19.41**	23.33**	6.13	18.02	10.26	6.48	-5.16	1.00
RP-Bio-5478-176 x NH-686	17.98	-0.61	-14.35**	14.30*	2.61	22.18	22.49**	14.96	16.74*	9.33
RP-Bio-5478-176 x NH-787	18.80	7.38	-5.16	19.52**	3.14	20.61	18.04*	14.5	8.47	0.49
DRR Dhan - 40 x RP-Bio-5478 -185	19.22	16.14**	14.07*	22.19**	3.64	18.17	19.06*	15.27	-4.37	0.33
DRR Dhan - 40 x NH-686	19.77	4.49	-5.83	25.68**	3.24	18.90	10.98	-2.06	-0.53	4.55
DRR Dhan - 40 x NH-787	18.56	1.23	-6.36	17.99**	-1.78	19.86	21.21**	10.29	4.53	11.58
RP-Bio-5478 -185 x NH-686	23.93	28.51**	13.97**	52.13**	5.81	28.15	60.62**	45.92**	48.16**	15.13*
RP-Bio-5478 -185 x NH-787	22.01	22.07**	11.07*	39.92	2.04	23.76	40.75**	31.99**	25.05**	11.15
NH-686 x NH-787	23.59	15.59**	12.35*	49.97**	2.12	25.02	34.15**	29.66**	31.68**	15.71*

* Significant at 5% level, ** Significant at 1% level

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