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Heterosis study on gain yield and its components traits of Ahu rice (*Oryza sativa* L.) of Assam

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Abstract
In the present investigation conducted at Assam Agricultural University, Jorhat, Assam, studied 11 genotypes selected out of 60 genotypes on the basis of genetic divergence including landraces, maintainers of wild abortive cytoplasmic male sterile (WA CMS) lines and high yielding varieties (HYVs) and study were done for the 19 traits of ahu/aus rice of Assam. The estimates of heterosis for seedling establishment, days to 50% flowering, panicle initiation, days to maturity, culm length, panicle length, biological yield per plant, and straw yield per plant and gel consistency were mostly negative. The crosses with negative heterosis effects indicated the reduction in performance of the concerned trait but seedling height, flag leaf area, productive tillers, average panicle weight. panicle length, grains per panicle spikelet fertility grains yield per plant for biological yield per plant and harvest index showed positive and significant positive mid- and better parent Heterosis for most of crosses. Twenty-seven crosses exhibited significant positive heterosis for straw yield. The crosses, BOR*25B (18.35**), LAL*55B (29.34**), SUR*LAC (29.05**) and MAY*LAC (26.59**) showed significant positive mid-parent heterosis for grains yield per plant and better parent heterosis for grain yield per plant ranged from -10.38** (LAL*BOR) to 29.20** (88B*LUI). The crosses, namely 88B*LUI (29.20**), SUR*LAC (27.11**), 88B*55B (25.48**) and MAY*LAC (25.42**), exhibited significant positive better-parent heterosis for grains yield per plant.

Keywords: Heterosis, mid-parent heterosis, better parent heterosis, nitrogen content, Ahu rice

1. Introduction

World population is continuously exploding, food and resources are not is sufficient amount to feed the global population. To make feed the world population, there are two solution first is we have decrease the world population and second is increase the food production, but population control is not our hand therefore we focus on the on the increasing the food production by hybrid breeding and deep study of heterosis of crops.

Of the various classes of rice cultivated in Assam, upland rice cultivars of North East India are directly sown in the fields during March-April and harvested in June-July known agronomically as "*aus*/*ahu*" rice (Travis *et al.*, 2015) [30]. *Boro* rice is sown in winter (November-December) and harvested in summer (May-June), while *aus* rice is sown in summer (March-April) along with pre-monsoon rains and harvested in autumn (June-July). *Sali* or *Aman* rice is sown in the rainy season (June-July) and harvested in winter (November-December). The photoperiod insensitive *ahu* rice landraces are maintained by farmers since time immemorial and are endowed with enormous genetic variability and valuable genes for various abiotic stress tolerances as they are not subject to any selective breeding during their long history of cultivation. Recent genome sequence information identifies the *aus* subpopulation as a distinct sub-population from both *indica* and *japonica* subpopulation of *O. sativa* species (Kim *et al.*, 2016). As pointed out by Kim *et al.* (2016), the cultivated *aus* cultivars and its wild ancestor represent an underappreciated genetic resource. The *aus* cultivars are early maturing, photoperiod insensitive and drought-tolerant (Civáň *et al.*, 2015).

The term heterosis was defined by Shull (1914) [28] to indicate the superiority of the hybrids over its parents in terms of vigour, growth, yield or other characteristics that result from crossing genetically diverse individuals. Jones (1926) first reported heterosis in rice when he observed that some F_1 hybrids had more culms and higher yields than their parents. Subsequently, other workers also reported the occurrence of this phenomenon in various agronomic traits of rice such as yield, grain weight, number of grains per panicle, number of panicles per plant, plant height, and days to flowering and general plant vigour (Virmani *et al.*,

1982) [33, 34, 36]. A critical prerequisite for the successful production of hybrid varieties is that sufficient hybrid vigour (heterosis) is available through specific parental combinations so that yields of hybrids would significantly exceed those obtained from the best conventionally bred varieties available (standard heterosis). In rice, the hybrid varieties (the heterozygous F1 generation) typically display a grain yield advantage of 10–30% over their parents (Luo *et al.*, 2013) [16]. Exploiting the heterosis phenomenon in a breeding programme is one of the most efficient ways to increase grain yield to meet the demands of global food security, and the development of hybrid rice breeding is one of the most scintillating advances in agricultural genetics (Wang *et al.*, 2005).

2. Material and Method

2.1 Experimental materials

A group of 11 rice genotypes consisting of landraces, maintainers of wild abortive cytoplasmic male sterile (WA CMS) lines and high yielding varieties (HYVs) of Assam were used in the present study.

2.2 Place of work

Field experiments were conducted in the experimental field of the Instructional cum Research Farm of Assam Agricultural University, Jorhat.

2.3 Observations recorded: all the observations except seedling establishment, days to panicle initiation, 50% flowering and maturity were based on 3 random competitive plants. Observations are 1. seedling height at 21 DAS (SH), 2. leaf number at21 DAS (LN), seedling establishment at 7 DAT (SEST)

Days to panicle initiation [DPI], days to 50 per cent flowering [DFF], flag leaf area (cm^2) [FLA]:the flag leaf area was calculated at booting stage using the formula given by Yoshida (1981) as follows: Leaf area (cm^2) = 0.75 × length (cm) × width (cm) ,days to maturity [DM], culm height (cm) [CH], number of productive tillers per plant[PT], average panicle weight (g) (APW), panicle length [PL], number of filled grains per panicle [GP], spikelet fertility (%) [SF], straw yield per plant (g) [SYP], grain yield per plant (g) [GYP], biological yield per plant (g) [BYP], harvest index (%) [HI], gel consistency[GC]: the test was conducted by the method described by Cogampang *et al.* (1973) [4]. The method separates high amylose rice into hard gel consistency (26-40 mm),medium gel consistency (41-60 mm) and soft gel consistency (61-100 mm) types, amylose content (%) [AC]: amylose content was determined by using the method described by Dela Cruz and Khush (2000). Rice varieties were grouped on the basis of their amylose content into waxy (0-2%), very low (3-9%), low (10-19%), intermediate (20-25%) and high (>25%) (Kumar and Khush, 1986) [14].

2.4 Estimation of heterosis

The magnitude of heterosis in relation to mid parent, better parent and standard parent (Luit) was worked out. The estimates of heterosis were calculated as percentage increase or decrease of F_1s over the mid parent ($\overline{MP}$), better parent ($\overline{BP}$) and standard parent ($\overline{SP}$) values following the method of Turner (1953) [31] and Hayes *et al.* (1955) [10].

3. Results and Discussion

The term hybrid variety refers to the F_1 populations that are used for planting the commercial crop (Allard, 1960) [2]. The dawn of the heterosis concept in maize begins with the work of Shull (1908) [27]. The development and growth of hybrid maize are regarded as one of the plant breeders' greatest accomplishment of the twentieth century and has contributed immensely towards securing the food front. The phenomenon of heterosis or hybrid vigour has been exploited in many self, crosses and often cross-pollinated crops such as rice, mustard, maize, pearl millet, onion, sorghum, cotton, pigeon pea, and others. Rice is the staple food which provides about 35-59% of the total calorie intake of people in South and Southeast Asia. The demand for rice would be 800 million tonnes by 2020 necessitating the production of about 350 million tonnes more rice by 2020 than the current production level to feed the ever-increasing population (Virmani *et al*., 1997) [35]. Hybrid rice is a proven technology already showing its potential in meeting the challenges of increasing food production. *Hybrid rice* is the commercial *rice* crop grown from F_1 seeds of a cross between two genetically dissimilar parents. Commercially acceptable *rice hybrids* have the yield advantage of 15-20% over the best-inbred variety grown under similar conditions.

The manifestation of heterosis usually depends on genetic divergence of the parental varieties (Hallauer and Miranda, 1981). The hereditary variation in the germplasm is estimated by the assessment of morphological / phenotypic, biochemical or protein variants and DNA/RNA polymorphisms. The achievement of the hybrid rice through the exploitation of heterosis depends on the genetic divergence of the germplasm, mostly on geographic separation for the three-line hybrid rice and sub-species genetic diversity for the two-line hybrid rice.

3.1 Estimates of heterosis

Analyses of variance showing the partitioning of the treatment sum of squares into parents, hybrids and parents vs. hybrids for the various characters are presented in **T**able 1a to 2c**.** The mean squares for the parents and the hybrids were highly significant ($p < 0.01$) for all the traits indicating that the parents selected was diverse for all the traits and also resulted in the creation of substantial genetic variability in the crosses. The highly significant mean squares for Parent vs. Hybrids for all the traits except amylose content suggested that the performance of the parents' group was different from that of the hybrids group which also supported the existence of heterotic effects for the traits. Partitioning of the Treatment x Environment interaction revealed that the Parents x Environment interactions were highly significant for all the traits except seedling establishment, average panicle weight, straw yield and biological yield per plant, indicating the differential responses of the parents to the N-doses. Similarly, the performances of the hybrids were different in the 40 and 60 kg N-doses as evident from the highly significant Hybrids x Environment interactions for all the traits except seedling establishment. The mean squares for Parents vs. Hybrids* Environment were highly significant ($P < 0.01$) for days to 50% flowering, flag leaf area, filled grains per panicle, harvest index and gel consistency which indicated that the contrast between the parents' group and the hybrids group was variable with the N-doses. The degree of heterosis varied from cross to cross and from character to character. Alam *et al*. (2004) [1] in upland rice observed the varying degree of heterosis for yield and its related traits.

The estimates of heterosis for the traits under investigation expressed as an increase or decreased over the mid-parent (MP), and better-parent (BP) values are presented in Table 2a to 2f.

3.1.1 Seedling height (cm)

Mid-parent heterosis for seedling height varied from -8.48** (SUR*LAL) to 9.98** (25B*LUI). The crosses *viz*., 25B*LUI (9.98**), LAC*LUI (8.65**), BOR*88B (8.45**) and 55B*LAC (8.33**) showed significant and positive mid-parent heterosis for seedling height. Better parent heterosis for seedling height varied from -11.70** (LAL*LUI) to 10.55** (55B*LUI). The crosses 55B*LUI (10.55**), LAC*LUI (8.30**), 25B*LUI (8.25**) and BOR*88B (7.90**) exhibited significant positive better parent heterosis for seedling height.

3.1.2 Leaf number

Mid-parent heterosis for leaf number ranged from -2.00** in 97B*56B and 97B*55B to 1.25** in LAL*LUI. Better parent heterosis for number of leaves varied from -2.00** (55B*LAC, 56B*LUI, 56B*LAC, 97B*LAC, 97B*55B, 97B*56B, 88B*LUI and 25B*LUI) to 1.00** (LAL*LUI).

3.1.3 Seedling establishment (%)

Mid-parent heterosis for seedling establishment ranged from a low of -36.25** in MAY*97B to a high of 21.25** in SUR*25B. Better parent heterosis for seedling length varied from -37.50** in MAY*97B to 17.5 in SUR*25B. No one cross exhibited significant and positive better parent heterosis for seedling establishment.

3.1.4 Days to panicle initiation

Mid-parent heterosis for days to panicle initiation varied from -6.50** (LAL*MAY) to 13.75** (MAY*88B). The crosses *viz*., LAL*MAY (-6.50**), SUR*LAL (-5.50**) and SUR*BOR (-3.50**) showed significant negative mid-parent heterosis for days to panicle initiation. Better parent heterosis was the lowest in LAL*LUI (-6.00**) to the highest in MAY*88B and 56B*55B (11.25**). The crosses namely, LAL*LUI (-6.00**), SUR*BOR (-5.25**) and SUR*MAY (-5.00**) exhibited significant negative better parent heterosis for days to panicle initiation. These results corroborated the findings of Alam *et al.* (2004) [1].

3.1.5 Days to 50% Flowering

Mid-parent heterosis for days to 50% flowering varied from -5.75** (SUR*LAL) to 9.63** (LAC*LUI). The crosses, namely SUR*LAL (-5.75**), LAL*MAY (-5.25**), MAY*LAC (-4.00**) and 55B*LAC (8.33**) showed significant negative mid-parent heterosis for early flowering. Better parent heterosis for days to 50% flowering varied from -9.00** (LAL*MAY) to 11.50** (MAY*88B). The crosses *viz*., SUR*LAL (-5.75**), SUR*BOR (-5.00**), MAY*LAC (-4.75**) exhibited significant negative better-parent heterosis for days to 50% flowering. These results were in line with the findings of Alam *et al.* (2004) [1] and Sarial *et al.* (2006) [24].

3.1.6 Flag leaf area (cm^2)

Mid-parent heterosis for flag leaf area ranged from -9.90** (97B*LAC) to 19.63** (88B*56B). The crosses, 88B*56B (19.63**), BOR*MAY (13.40**), SUR*LAL (13.13**) and BOR*56B (26.28**) showed significant positive mid-parent heterosis for flag leaf area. Better parent heterosis for flag leaf area varied from -8.96** (97B*56B) to 21.60** (BOR*56B). The crosses, BOR*56B (21.60**) followed by 88B*56B (13.33**), BOR*MAY (13.25**) and BOR*88B (7.90**) exhibited significant positive better parent heterosis for flag leaf area.

3.1.7 Days to maturity

The range of mid-parent heterosis for days to maturity was from -4.88** (LAL*MAY) to 11.38** (MAY*56B). The crosses, SUR*BOR (-4.13**) and LAL*MAY (-4.88**) showed significant negative mid-parent heterosis for days to maturity. Sahu *et al.* (2017) [21, 22] and Yuga *et al.* (2018) [17] also obtained negative heterosis for maturity duration. Better parent heterosis for days to maturity varied from -7.25** (SUR*MAY) to 9.75** (MAY*56B). The crosses, SUR*MAY (-7.25**), SUR*BOR (-7.00**), LAL*MAY (-6.25**), SUR*55B (-6.00**) and SUR*97B (-5.75**) exhibited significant negative better-parent heterosis for days to maturity. Sarial *et al.* (2006) [24] also reported negative better-parent heterosis for days to maturity.

3.1.8 Culm height (cm)

Mid-parent heterosis for culm height varied from -21.11** (SUR*LAL SUR*LAL) to 45.78** (88B*55B). The crosses, 56B*LAC (-19.75**), LAL*MAY (-19.29**) and LAC*LUI (-9.03*) showed significant negative mid-parent heterosis for culm height. Better parent heterosis for culm height ranged from -25.58** (SUR*LAL) to 42.33** (88B*55B). The crosses, SUR*LAL (-25.58**), SUR*56B (-23.30**) and SUR*56B (-23.30**) exhibited significant negative better parent heterosis for culm height**.** Thorat *et al.* (2017) [29] also reported negative heterosis for culm height.

3.1.9 Productive tillers Plant^{-1}

Mid-parent heterosis for productive tillers ranged from -7.11** (LAL*MAY) to 13.18** (LAL*56B). The crosses, LAL*56B (13.18**), 97B*56B (12.79**), 25B*88B(10.60**) and LAL*55B (10.35**) accorded significant positive mid-parent heterosis for productive tillers as also reported by Faiz *et al.* (2006) [5]; Sarial *et al.* (2006) [24] and Gnanasekaran *et al.* (2006) [9] and Yuga *et al.* (2018) [17]. Better parent heterosis for productive tillers varied from -7.80** (56B*LAC) to 12.15** (97B*56B). The crosses, 55B*LUI (10.55**), LAL*56B (11.45**), 25B*88B (10.15**) and LAL*55B (10.00**) exhibited significant positive better parent heterosis for productive tillers; similar findings also reported by Joshi (2001) [12]; Alam *et al.* (2004) [1] and Thorat *et al.* (2017) [29].

3.1.10 Average panicle weight (g)

Mid-parent heterosis for average panicle weight ranged from -9.00* (SUR*25B) to 48.63** (97B*LAC). The crosses, 48.63** (97B*LAC), BOR*MAY (37.00**), MAY*55B (24.88**) and 88B*97B (24.50**) showed significant positive mid-parent heterosis for average panicle weight.

Better parent heterosis for average panicle weight ranged from -17.75** (SUR*LUI) to 41.25** (97B*LAC). The crosses *viz*., 97B*LAC (41.25**), BOR*MAY (35.25**), MAY*55B (22.25**) and 88B*97B (19.75**) exhibited significant positive better-parent heterosis for average panicle weight.

3.1.11 Panicle length (cm)

Mid-parent heterosis for panicle length varied from -8.06** (LAL*97B) to 18.35** (BOR*25B). The crosses namely, BOR*25B (9.98**), MAY*56B (6.28**), 56B*55B (6.26**) and 56B*LUI (5.79**) showed significant positive mid-parent heterosis for panicle length. Joshi (2001) [12], Alam *et al.* (2004) [1], Thorat *et al.* (2017) [29] and Yuga *et al.* (2018) [17] also reported positive heterosis for panicle length. Better parent heterosis for panicle length varied from -8.20** (LAL*97B) to 17.75** (BOR*25B). The crosses BOR*25B (17.75**), MAY*56B (5.93**), 56B*55B(5.63**) and SUR*MAY (5.43**) exhibited significant positive better parent heterosis for panicle length; as also reported by Singh *et al.* (1980) and Joshi (2001) [12].

3.1.12 Filled grains per panicle

Mid-parent heterosis for filled grains per panicle ranged from -43.95** (25B*LUI) to 173.78** (LAL*MAY). The crosses *viz*., BOR*25B (18.35**), SUR*LAC (164.83**), SUR*56B (161.18**) and LAL*LUI (87.45**) showed significant positive mid-parent heterosis for grains per panicle. Better parent heterosis for grains per panicle varied from -62.40** (25B*LUI) to 164.30** (LAL*MAY). The crosses, BOR*25B (17.75**), SUR*56B (158.43**), SUR*LAC (154.25**) and LAL*LUI (78.08**) exhibited significant positive better-parent heterosis for grains per panicle. The significant positive better parent heterosis for grains per panicle was also reported by Joshi (2001) [12], Faiz *et al.* (2006) [5], Saravanan *et al.* (2008) [23], Sharma *et al.* (2013) [25, 26], Singh *et al.* (2013) and Thorat *et al.* (2017) [29]. Significant and positive mid-parent heterosis and better parent heterosis was also in close conformity with the findings of Bansal *et al.* (2000) [3], Sarial *et al.* (2006) [24] and Rahimi *et al.* (2010) [21].

3.1.13 Spikelet fertility (%)

Spikelet fertility showed mid-parent heterosis ranging from -42.86** (88B*56B) to 22.29** (BOR*56B). The crosses, BOR*56B (22.29**), BOR*97B (16.38**), BOR*55B (15.71**) and 25B*56B (15.47**) showed significant positive mid-parent heterosis for spikelet fertility. Alam *et al.* (2004) [1] and Thorat *et al.* (2017) [29] showed similar findings. Better parent heterosis for spikelet fertility ranged from -54.05** (88B*56B) to 12.71** (25B*56B). The crosses, 25B*56B (12.71**), BOR*97B (5.82**), 25B*55B (4.82**) and SUR*MAY (4.81**) exhibited significant positive better parent heterosis for spikelet fertility. In contrast, Joshi (2001) [12] observed negative heterobeltiosis for spikelet fertility trait. Spikelet fertility (%) showing maximum positive significant heterotic effects over better-parent was also reported by Panday *et al.* (1995) [18], Panwar *et al.* (1998) [19], Ghara *et al.* (2014) [8], and Kumar and Adilakshmi (2016) [13].

3.1.14 Straw yield (g Plant^{-1})

Mid-parent heterosis for straw yield per plant ranged from -37.38** (LAL*56B) to 91.10** (88B*97B). Better parent heterosis for straw yield per plant ranged from -43.77** (LAL*56B) to 80.96** (88B*97B). Twenty-seven crosses exhibited significant positive heterosis for straw yield. The promising crosses exhibiting significant positive mid- and better-parent heterosis were 88B*97B (91.10** & 80.96**), MAY*56B (55.27** & 53.59**) and 97B*LAC (54.37** & 50.80**).

3.1.15 Grains yield (g Plant^{-1})

The range of mid-parent heterosis for grains yield per plant was from -6.82** (LAL*BOR) to 31.11** (88B*LUI). The crosses, BOR*25B (18.35**), LAL*55B (29.34**), SUR*LAC (29.05**) and MAY*LAC (26.59**) showed significant positive mid-parent heterosis for grains yield per plant. A significant positive heterosis for grain yield per plant has been reported by Virmani *et al.* (1982) [33, 34, 36], Bansal *et al.* (2000) [3], Joshi (2001) [12], Alam *et al.* (2004) [1], Veni *et al.* (2005) [32], Faiz *et al.* (2006) [5], Sarial *et al.* (2006) [24], Kunkerkar *et al.* (2012) [15], Ghara *et al.* (2014) [8], Kumar and Adilakshmi (2016) [13], Gnanamalar and Vivekanandan (2013) and Thorat *et al.* (2017) [29]. Better parent heterosis for grain yield per plant ranged from -10.38** (LAL*BOR) to 29.20** (88B*LUI). The crosses, namely 88B*LUI (29.20**), SUR*LAC (27.11**), 88B*55B (25.48**) and MAY*LAC (25.42**), exhibited significant positive better-parent heterosis for grains yield per plant. A similar finding was also reported by Sahu *et al.* (2017) [21, 22].

3.1.16 Biological yield (g plant^{-1})

The values of heterosis over mid- and better-parent for biological yield per plant ranged from -19.54** and -32.44** in LAL*BOR to 96.20** and 81.47 in 88B*97B. Some of the promising crosses were 88B*97B (96.20** & 81.47**), 97B*LAC (71.30** & 70.59**), MAY*97B (72.26** & 68.42**), 88B*55B (62.90** & 49.04**), MAY*LAC (61.89** & 58.81**) and 88B*LUI (59.13** & 40.60**) showing significant positive mid- and better-parent heterosis for biological yield per plant. Similar findings were also observed by Sarial *et al.* (2006) [24].

3.1.17 Harvest index (%)

Mid-parent heterosis for harvest index ranged from -21.13**(88B*97B) to 28.61** (LAL*55B). The crosses*viz*., LAL*55B (28.61**), LAL*56B (24.48**), LAL*LAC (24.29**) and BOR*25B (21.51**) showed significant positive mid-parent heterosis for harvest index. Better parent heterosis for harvest index ranged from -22.67** (88B*97B) to 26.60** (LAL*55B). The crosses namely, LAL*55B (26.60**), LAL*LAC(24.14**), LAL*56B (22.64**) and BOR*25B (21.04**) exhibited significant positive heterobeltiosis for harvest index. Positive and highly significant heterosis for harvest index has been reported by Virmani *et al.* (1982) [33, 34, 36], Virmani *et al.* (1984), Rahimi *et al.* (2010) [21], Dwivedi and Pandey (2012), and Kumar *et al.* (2012). Sarial *et al.* (2006) [24] reported negative heterobeltiosis for biological yield.

3.1.18 Amylose content (%)

Mid-parent heterosis for amylose content varied from -6.46**(55B*LUI) to 13.34** (25B*55B). The crosses *viz*., 25B*55B (13.34**), 25B*88B (11.15**), SUR*BOR (10.99**) and BOR*MAY (9.99**) showed significant positive mid-parent heterosis for amylose content. Better parent heterosis for amylose content that varied from -10.65** (LAL*MAY) to 11.90** (25B*55B). The crosses, 25B*55B (11.90**) followed by 25B*88B (9.20**), BOR*MAY(8.28**) and SUR*BOR (8.00**) exhibited significant and positive better parent heterosis for amylose content. Positive and highly significant heterosis for amylose content was also recorded by Gnanamalar and Vivekanandan (2013).

3.1.19 Gel consistency (mm)

Mid-parent heterosis for gel consistency varied from -38.25**(LAL*LAC) to 23.13** (MAY*56B). A positive significant mid- and better-parent heterosis for gel consistency was observed for 10 and 4 crosses, respectively. Most of the crosses exhibited significant negative heterosis for gel consistency. Better parent heterosis for gel consistency varied from -44.75** (25B*88B) to 16.50** (MAY*97B). Negative and significant heterosis for gel consistency was also observed by Gnanamalar and Vivekanandan (2013).

Table 1a: ANOVA for the seedling traits of the 11-parent diallel crosses

Source of Variations	df	Mean Squares	
		SH	LN
Blocks	1	0.03	0.02
Treatments (TREAT)	65	33.16**	0.61**
Parents (PAR)	10	39.88**	0.68**
Hybrids (HYB)	54	31.97**	0.50**
PAR vs. HYB	1	30.08**	6.01**
Error	65	1.91	0.20
Total	131	17.40	0.40
SL: Seedling length (cm); LN: Leaf number			

Table 1b: Pooled ANOVA for the 17 traits of the 11-parent diallel crosses over environments

Source of Variations	df	Mean Squares							
		SEST	DPI	DFF	FLA	DM	CH	PT	APW
Environments (ENV)	1	151.52	992.97**	1605.31**	11.50**	1052.00**	21.31	293.79**	958.37**
Blocks/ENV	2	9.85	0.76	0.47**	0.09	6.72**	11.12	5.17	20.91
Treatments (TREAT)	65	488.25**	62.59**	64.69**	139.49**	46.92**	1173.89**	95.43**	507.24**
Parents (PAR)	10	225.00**	90.22**	84.10**	115.24**	54.55**	869.13**	25.90**	189.12**
Hybrids (HYB)	54	519.33**	47.81**	47.26**	143.42**	38.59**	1172.59**	106.15**	553.66**
PAR vs.HYB	1	1442.73**	584.00**	811.53**	169.85**	420.47**	4291.93**	212.08**	1181.82**
TREAT * ENV	65	95.36	18.54**	16.68**	49.81**	16.17**	133.19**	30.24**	184.68**
PAR * ENV	10	101.36	15.12**	11.25**	96.16**	8.09**	58.57**	10.64**	43.96
HYB * ENV	54	95.99	19.51**	17.20**	37.82**	17.97**	149.49**	34.43**	213.50**
PAR vs. HYB * ENV	1	1.21	0.15	42.55**	234.08**	0.13	0.02	0.19	35.02
Error	130	82.16	2.94	2.54	0.94	3.07	20.39	2.46	25.80
Total	263	185.50	25.28	27.47	47.30	21.16	333.29	33.43	187.56

SEST: Seedling establishment (%); DPI: Days to panicle initiation; DFF: Days to 50% flowering; FLA: Flag leaf area (cm2); DM: Days to maturity; CH: Culm length (cm); PT: Productive tillers/Plant; APW: Average panicle weight (g)

Table 1c: Pooled ANOVA for the 17 traits of the 11-parent diallel crosses over environments

Source of Variations	df	Mean Squares								
		PL	GP	SF	SYP	GYP	BYP	HI	AC	GC
Environments (ENV)	1	0.21	10363.82**	110.80**	2176.20**	448.58**	4444.81**	0.02	0.10	1581.7**
Blocks/ENV	2	0.43	11.95	1.42	57.93*	4.52	25.80	5.78	14.69**	3.63
Treatments (TREAT)	65	41.17**	9046.84**	778.82**	1276.49**	383.76**	1741.81**	357.12**	53.55**	705.01**
Parents (PAR)	10	22.19**	836.38**	397.20**	528.97**	54.66**	698.34**	122.29**	42.08**	723.56**
Hybrids (HYB)	54	44.42**	10450.72**	852.12**	1358.75**	401.21**	1714.88**	399.09**	56.55**	634.78**
PAR vs.HYB	1	54.98**	15341.59**	636.60**	4309.59**	2732.63**	13631.54**	438.55**	6.10	4312.15**
TREAT * ENV	65	21.36**	709.23**	96.83**	56.73**	46.27**	124.79**	39.69**	11.64**	980.82**
PAR * ENV	10	18.72**	360.71**	18.39**	17.07	35.19**	46.47	48.16**	44.54**	819.52**
HYB * ENV	54	22.23**	778.56**	113.13**	64.52**	49.14**	141.42**	37.89**	5.68**	706.18**
PAR vs. HYB * ENV	1	0.91	450.45**	1.09	32.95	2.10	9.79	52.50**	4.03	17424.01**
Error	130	3.35	11.09	1.78	16.99	4.24	24.93	5.38	2.84	7.41
Total	263	17.12	2456.17	217.73	346.62	110.12	490.75	100.78	17.63	426.36

PL: Panicle length (cm); GP: Filled grains/Panicle; SF: Spikelet fertility (%); SYP: Straw yield/Plant (g); GYP: Grain yield/Plant (g); BYP: Biological yield/Plant (g); HI: Harvest index (%); AC: Amylose content (%); GC: Gel consistency (%)

Table 2a: Estimates of mid-parent (H_{MP}) and better-parent heterosis (H_{BP}) for the seedling traits of the 55 rice hybrids

Hybrids	Seedling height		Leaf number		Seedling establishment	
	H_{MP}	H_{BP}	H_{MP}	H_{BP}	H_{MP}	H_{BP}
SUR*LAL	-8.48**	-9.15**	-0.75	-1.00*	1.25	0.00
SUR*BOR	1.20	-3.00*	0.00	0.00	7.50	7.50
SUR*MAY	-5.68**	-6.40**	0.00	0.00	0.00	-2.50
SUR*25B	-5.63**	-11.60**	-0.50	-1.00*	21.25**	17.50
SUR*88B	5.05**	0.30	-0.50	-1.00*	12.50	7.50
SUR*97B	4.25**	0.00	-0.50	-1.00*	1.25	-2.50
SUR*56B	-4.65**	-9.25**	-0.50	-1.00*	8.75	5.00
SUR*55B	-0.13	-5.05**	-0.50	-1.00*	2.50	2.50

SUR*LAC	3.70**	-0.20	0.00	0.00	10.00	7.50
SUR*LUI	-2.05	-6.30**	0.00	0.00	-21.25**	-30.00**
LAL*BOR	6.53**	1.65	-0.75	-1.00*	1.25	0.00
LAL*MAY	-2.30	-3.70**	0.25	0.00	-11.25	-12.50
LAL*25B	-3.05*	-9.70**	-0.25	-1.00*	-15.00	-20.00*
LAL*88B	-2.63*	-8.05**	-0.25	-1.00*	-3.75	-10.00
LAL*97B	-0.93	-5.85**	-0.25	-1.00*	-17.50*	-20.00*
LAL*56B	1.58	-3.70**	-0.25	-1.00*	2.50	0.00
LAL*55B	-1.75	-7.35**	-0.25	-1.00*	11.25	10.00
LAL*LAC	-5.13**	-9.70**	0.25	0.00	1.25	0.00
LAL*LUI	-6.78**	-11.70**	1.25**	1.00*	-27.50**	-35.00**
BOR*MAY	-1.53	-5.00**	0.00	0.00	-17.50*	-20.00*
BOR*25B	5.93**	4.15**	-0.50	-1.00*	-3.75	-7.50
BOR*88B	8.45**	7.90**	-0.50	-1.00*	2.50	-2.50
BOR*97B	2.75*	2.70	-0.50	-1.00*	-8.75	-12.50
BOR*56B	4.75**	4.35**	-0.50	-1.00*	-16.25*	-20.00*
BOR*55B	-0.48	-1.20	-0.50	-1.00*	-17.50*	-17.50
BOR*LAC	0.10	-0.20	-1.00*	-1.00*	-12.50	-15.00
BOR*LUI	4.45**	4.40**	-1.00*	-1.00*	-28.75**	-37.50**
MAY*25B	2.50*	-2.75	-0.50	-1.00*	-16.25*	-22.50*
CD (5%)	2.40	2.77	0.78	0.90	15.53	17.93
CD (1%)	3.18	3.67	1.03	1.19	20.52	23.70

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

Table 2a: Contd…

Hybrids	Seedling height (cm)		Leaf number		Seedling establishment	
	H_{MP}	H_{BP}	H_{MP}	H_{BP}	H_{MP}	H_{BP}
MAY*88B	-0.72	-4.75**	-0.50	-1.00*	-5.00	-12.50
MAY*97B	-4.98**	-8.50**	-0.50	-1.00*	-36.25**	-37.50**
MAY*56B	-2.58*	-6.45**	-0.50	-1.00*	-33.75**	-35.00**
MAY*55B	3.90**	-0.30	-0.50	-1.00*	5.00	2.50
MAY*LAC	5.88**	2.70	0.00	0.00	-5.00	-5.00
MAY*LUI	4.53**	1.00	0.00	0.00	-13.75	-20.00*
25B*88B	2.48*	1.25	0.00	0.00	1.25	0.00
25B*97B	5.73**	4.00**	-1.00*	-1.00*	-22.50**	-30.00**
25B*56B	0.32	-1.05	-1.00*	-1.00*	-7.50	-15.00
25B*55B	1.65	0.60	-1.00*	-1.00*	3.75	0.00
25B*LAC	7.13**	5.05**	0.50	0.00	3.75	-2.50
25B*LUI	9.98**	8.25**	-1.50**	-2.00**	-22.50**	-35.00**
88B*97B	4.35**	3.85**	-1.00*	-1.00*	-6.25	-15.00
88B*56B	-1.70	-1.85	-1.00*	-1.00*	-11.25	-20.00*
88B*55B	1.68	1.50	-1.00*	-1.00*	-12.50	-17.50
88B*LAC	8.15**	7.30**	-0.50	-1.00*	0.00	-7.50
88B*LUI	1.25	0.75	-1.50**	-2.00**	-8.75	-22.50*
97B*56B	1.10	0.75	-2.00**	-2.00**	-2.50	-2.50
97B*55B	-3.83**	-4.50**	-2.00**	-2.00**	-3.75	-7.50
97B*LAC	-0.35	-0.70	-1.50**	-2.00**	-6.25	-7.50
97B*LUI	-0.35	-0.35	-0.50	-1.00*	-22.50**	-27.50**
56B*55B	0.57	0.25	-1.00*	-1.00*	8.75	5.00
56B*LAC	-3.45**	-4.15**	-1.50**	-2.00**	-13.75	-15.00
56B*LUI	1.45	1.10	-1.50**	-2.00**	-15.00	-20.00*
55B*LAC	8.33**	7.30**	-1.50**	-2.00**	12.50	10.00
55B*LUI	11.23**	10.55**	-0.50	-1.00*	-3.75	-12.50
LAC*LUI	8.65**	8.30**	0.00	0.00	6.25	0.00
CD (5%)	2.40	2.77	0.78	0.90	15.53	17.93
CD (1%)	3.18	3.67	1.03	1.19	20.52	23.70

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

Table 2b: Estimates of mid-parent (H_{MP}) and better-parent heterosis (H_{BP}) for the traits of the 55 rice hybrids

Cross	Days to panicle initiation		Days to 50% flowering		Flag leaf area	
	H_{MP}	H_{BP}	H_{MP}	H_{BP}	H_{MP}	H_{BP}
SUR*LAL	-5.50**	-6.00**	-5.75**	-5.75**	13.13**	11.35**
SUR*BOR	-3.50*	-5.25**	-2.25	-5.00**	-3.36**	-6.68**
SUR*MAY	-1.00	-5.00**	-0.75	-4.50**	-3.12**	-6.58**
SUR*25B	2.25	-2.00	3.13*	-1.75	3.34**	2.21*
SUR*88B	6.00**	-0.50	5.75**	-0.25	4.25**	2.56**

SUR*97B	4.13**	-1.50	3.50*	-2.00	-4.47**	-5.53**
SUR*56B	6.63**	-0.25	7.25**	0.50	4.89**	-3.11**
SUR*55B	1.88	-4.50**	2.13	-3.75*	-5.52**	-7.63**
SUR*LAC	0.00	-3.50*	1.00	-2.00	9.11**	6.90**
SUR*LUI	2.13	-1.75	4.13**	0.00	-4.33**	-6.93**
LAL*BOR	2.50	1.25	4.50**	1.75	-1.38	-2.91**
LAL*MAY	-6.50**	-10.00**	-5.25**	-9.00**	2.98**	1.30
LAL*25B	3.75*	0.00	3.38*	-1.50	5.52**	4.88**
LAL*88B	2.25	-3.75*	2.25	-3.75*	5.63**	5.54**
LAL*97B	1.63	-3.50*	1.50	-4.00*	-5.32**	-8.15**
LAL*56B	3.38*	-3.00	4.00**	-2.75	5.53**	-0.68
LAL*55B	6.88**	1.00	6.38**	0.50	-5.75**	-6.08**
LAL*LAC	3.25*	0.25	3.75**	0.75	-4.33**	-8.31**
LAL*LUI	3.63*	0.25	4.88**	0.75	-4.96**	-5.78**
BOR*MAY	5.75**	3.50*	6.00**	5.00**	13.40**	13.25**
BOR*25B	-1.75	-4.25*	0.88	-1.25	7.91**	5.73**
BOR*88B	0.75	-4.00*	2.50	-0.75	3.27**	1.64
BOR*97B	0.88	-3.00	2.00	-0.75	-7.30**	-11.68**
BOR*56B	4.38**	-0.75	6.75**	2.75	26.28**	21.60**
BOR*55B	5.63**	1.00	8.13**	5.00**	6.54**	5.33**
BOR*LAC	3.00*	1.25	5.00**	4.75**	-0.46	-5.99**
BOR*LUI	2.88	0.75	6.63**	5.25**	0.02	-0.70
MAY*25B	8.75**	8.50**	9.13**	8.00**	2.30**	-0.03
CD (5%)	2.94	3.39	2.73	3.16	1.66	1.92
CD (1%)	3.88	4.48	3.61	4.17	2.20	2.54

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

Table 2b: Contd…

Cross	Days to panicle initiation		Days to 50% flowering		Flag leaf area	
	H_{MP}	H_{BP}	H_{MP}	H_{BP}	H_{MP}	H_{BP}
MAY*88B	13.75**	11.25**	13.75**	11.50**	-4.43**	-6.20**
MAY*97B	10.63**	9.00**	12.25**	10.50**	-1.82*	-6.33**
MAY*56B	12.38**	9.50**	13.25**	10.25**	4.67**	0.13
MAY*55B	11.13**	8.75**	10.13**	8.00**	0.99	-0.36
MAY*LAC	-3.50*	-4.00*	-4.00**	-4.75**	11.46**	5.79**
MAY*LUI	-1.38	-1.50	-0.13	-0.50	6.74**	5.88**
25B*88B	3.25*	1.00	4.63**	3.50*	3.40**	2.84**
25B*97B	0.13	-1.25	1.88	1.25	4.17**	1.98*
25B*56B	3.38*	0.75	5.38**	3.50*	5.56**	-1.31
25B*55B	5.13**	3.00	6.25**	5.25**	9.25**	8.28**
25B*LAC	0.00	-0.75	1.38	-0.50	-7.00**	-10.34**
25B*LUI	-0.38	-0.75	1.50	0.75	0.40	-1.07
88B*97B	5.63**	4.75**	5.00**	4.50**	-3.44**	-6.19**
88B*56B	7.13**	6.75**	7.00**	6.25**	19.63**	13.33**
88B*55B	7.63**	7.50**	7.88**	7.75**	4.19**	3.77**
88B*LAC	3.00*	0.00	3.75**	0.75	8.19**	4.29**
88B*LUI	3.88*	1.25	4.13**	2.25	-1.12	-2.03*
97B*56B	7.50**	6.25**	6.75**	5.50**	0.09	-8.96**
97B*55B	4.50**	3.75*	4.63**	4.25**	-0.08	-3.24**
97B*LAC	3.13*	1.00	3.00*	0.50	-9.90**	-11.06**
97B*LUI	3.50*	1.75	4.13**	2.75	-0.11	-3.77**
56B*55B	11.75**	11.25**	11.63**	10.75**	10.21**	4.32**
56B*LAC	10.38**	7.00**	8.75**	5.00**	-0.07	-10.28**
56B*LUI	9.25**	6.25**	9.38**	6.75**	4.45**	-0.95
55B*LAC	7.13**	4.25*	7.38**	4.50**	-5.76**	-10.08**
55B*LUI	9.00**	6.50**	9.00**	7.25**	-2.37**	-2.86**
LAC*LUI	7.63**	7.25**	9.63**	8.50**	-2.69**	-7.50**
CD (5%)	2.94	3.39	2.73	3.16	1.66	1.92
CD (1%)	3.88	4.48	3.61	4.17	2.20	2.54

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

Table 2c: Estimates of mid-parent (H_{MP}) and better-parent heterosis (H_{BP}) for the traits of the 55 rice hybrids

Cross	Days to maturity		Culm height		Productive tillers	
	H_{MP}	H_{BP}	H_{MP}	H_{BP}	H_{MP}	H_{BP}
SUR*LAL	-3.00	-6.00**	-21.11**	-25.58**	-0.10	-2.65
SUR*BOR	-4.13**	-7.00**	25.31**	21.35**	5.18**	3.65*

SUR*MAY	-2.88	-7.25**	13.88**	8.88	-1.26	-3.78*
SUR*25B	2.00	-3.50*	15.34**	0.67	8.13**	7.75**
SUR*88B	3.88*	-2.00	41.55**	29.38**	-1.88	-2.70
SUR*97B	0.00	-5.75**	40.00**	26.63**	4.16**	3.98*
SUR*56B	5.25**	-0.75	-15.44**	-23.30**	7.55**	6.73**
SUR*55B	0.00	-6.00**	-1.28	-16.90**	-0.40	-3.30*
SUR*LAC	0.25	-3.75*	28.44**	21.83**	5.78**	3.90*
SUR*LUI	1.38	-3.00	28.04**	18.10**	8.68**	7.85**
LAL*BOR	1.13	1.00	0.83	-7.60	-3.53*	-4.55**
LAL*MAY	-4.88**	-6.25**	-19.29**	-19.83**	-7.11**	-7.15**
LAL*25B	3.00	0.50	4.55	-14.58**	2.08	-0.85
LAL*88B	2.88	0.00	-4.66	-21.30**	2.23	-1.15
LAL*97B	3.50*	0.75	5.31	-12.53**	-3.54*	-5.90**
LAL*56B	4.75**	1.75	28.03**	15.70**	13.18**	11.45**
LAL*55B	5.50**	2.50	18.14**	-1.95	10.35**	10.00**
LAL*LAC	2.75	1.75	9.65*	-1.43	0.92	0.25
LAL*LUI	3.13*	1.75	12.28**	-2.12	10.13**	8.40**
BOR*MAY	3.75*	2.25	-8.51*	-17.48**	-6.59**	-7.58**
BOR*25B	0.63	-2.00	18.43**	7.73	3.30*	1.40
BOR*88B	1.75	-1.25	36.06**	27.85**	8.65**	6.30**
BOR*97B	-0.63	-3.50*	17.64**	8.23	-6.01**	-7.35**
BOR*56B	4.38**	1.25	13.93**	10.03*	-0.23	-0.92
BOR*55B	7.38**	4.25*	22.36**	10.70*	-1.43	-2.80
BOR*LAC	3.38*	2.25	13.18**	10.53*	-3.95**	-4.30**
BOR*LUI	5.00**	3.50*	26.75**	20.78**	-0.35	-1.05
MAY*25B	8.63**	7.50**	17.61**	-2.05	5.81**	2.93
CD (5%)	3.00	3.47	7.74	8.93	2.69	3.10
CD (1%)	3.97	4.58	10.22	11.81	3.55	4.10

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

Table 2c: Contd…

Cross	Days to maturity		Culm height		Productive tillers	
	H_{MP}	H_{BP}	H_{MP}	H_{BP}	H_{MP}	H_{BP}
MAY*88B	9.75**	8.25**	14.20**	-2.97	2.64	2.45
MAY*97B	9.63**	8.25**	13.08**	-5.30	2.85	0.27
MAY*56B	11.38**	9.75**	20.56**	7.70	6.28**	5.93**
MAY*55B	10.38**	8.75**	27.28**	6.65	2.96	1.98
MAY*LAC	-2.38	-2.75	22.16**	10.55*	1.29	0.38
MAY*LUI	0.75	0.75	22.41**	7.47	0.24	-0.50
25B*88B	2.63	2.25	3.26	0.77	-2.51	-3.38
25B*97B	1.25	1.00	2.41	1.13	-3.55*	-5.45**
25B*56B	2.00	1.50	-1.95	-8.75	3.35*	2.33
25B*55B	4.75**	4.25*	11.24**	10.28*	2.74	1.08
25B*LAC	1.50	0.00	8.83*	0.77	4.06*	3.83*
25B*LUI	-0.88	-2.00	4.43	-0.30	0.79	0.72
88B*97B	3.88*	3.75*	20.98**	19.78**	0.04	-2.73
88B*56B	4.88**	4.75**	4.59	0.27	1.76	1.60
88B*55B	5.63**	5.50**	45.78**	42.33**	4.60**	3.80*
88B*LAC	2.88	1.00	0.34	-5.23	3.48*	2.38
88B*LUI	2.75	1.25	0.44	-1.80	5.35**	4.43*
97B*56B	5.75**	5.50**	-4.49	-10.00*	0.72	-2.20
97B*55B	1.75	1.50	8.18*	5.93	1.81	-1.75
97B*LAC	2.75	1.00	5.36	-1.40	-0.79	-2.45
97B*LUI	3.38*	2.00	14.01**	10.58*	-1.39	-3.23
56B*55B	7.25**	7.25**	7.46	-0.30	6.26**	5.63**
56B*LAC	6.50**	4.50*	-19.75**	-21.00**	-0.59	-1.85
56B*LUI	6.88**	5.25**	2.30	0.22	5.79**	4.70*
55B*LAC	7.25**	5.25**	-1.66	-10.68*	-0.70	-2.60
55B*LUI	5.63**	4.00*	5.66	-0.02	0.72	-1.00
LAC*LUI	9.63**	9.25**	-9.03*	-12.35**	-1.18	-1.35
CD (5%)	3.00	3.47	7.74	8.93	3.14	3.62
CD (1%)	3.97	4.58	10.22	11.81	4.15	4.79

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

Table 2d: Estimates of mid-parent (H_{MP}) and better-parent heterosis (H_{BP}) for the traits of the 55 rice hybrids

Cross	Average panicle weight		Panicle length		Filled grains per panicle	
	H_{MP}	H_{BP}	H_{MP}	H_{BP}	H_{MP}	H_{BP}
SUR*LAL	2.88	-1.00	-1.84	-4.70*	63.55**	63.30**
SUR*BOR	1.50	-4.50	-0.18	-1.60	-15.10**	-30.35**
SUR*MAY	7.25	-0.50	5.58**	5.43**	-14.83**	-24.55**
SUR*25B	-9.00*	-12.25*	0.42	-0.40	-23.13**	-31.95**
SUR*88B	22.50**	17.75**	3.51*	3.48	-18.13**	-28.80**
SUR*97B	-6.25	-6.25	-0.95	-3.68*	-19.05**	-24.35**
SUR*56B	-2.50	-2.50	3.23*	3.03	161.18**	158.43**
SUR*55B	10.38*	0.00	1.61	0.78	72.03**	70.65**
SUR*LAC	5.38	-2.00	-3.29*	-4.35*	164.83**	154.25**
SUR*LUI	-13.75**	-17.75**	0.76	-0.13	51.28**	41.65**
LAL*BOR	-0.38	-2.50	-3.36*	-4.80**	86.00**	71.00**
LAL*MAY	22.63**	18.75**	-1.74	-4.45*	173.78**	164.30**
LAL*25B	-2.63	-3.25	-2.34	-4.38*	82.13**	73.05**
LAL*88B	8.63	7.75	-3.30*	-6.20**	0.97	-9.45**
LAL*97B	21.13**	17.25**	-8.06**	-8.20**	2.35	-2.70
LAL*56B	-10.88*	-14.75**	0.59	-2.48	-16.00**	-19.00**
LAL*55B	2.50	-4.00	-0.25	-3.95*	43.68**	42.55**
LAL*LAC	6.75	3.25	-4.40**	-6.20**	30.13**	19.80**
LAL*LUI	-7.88	-8.00	-2.10	-4.08*	87.45**	78.08**
BOR*MAY	37.00**	35.25**	4.90**	3.63*	25.10**	19.58**
BOR*25B	9.00*	6.25	18.35**	17.75**	53.28**	29.20**
BOR*88B	-0.75	-2.00	1.09	-0.38	11.58**	7.00*
BOR*97B	21.00**	15.00**	-2.40	-3.70*	-6.25*	-16.20**
BOR*56B	0.00	-6.00	2.50	0.88	-5.35	-23.35**
BOR*55B	7.38	3.00	1.56	-0.70	-11.33**	-25.20**
BOR*LAC	6.38	5.00	4.46**	4.10*	6.98*	2.30
BOR*LUI	-3.00	-5.00	4.41**	3.88*	30.78**	25.15**
MAY*25B	0.75	-3.75	1.55	0.88	15.35**	-3.20
CD (5%)	8.70	10.05	3.14	3.62	5.71	6.59
CD (1%)	11.50	13.28	4.15	4.79	7.54	8.70

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

Table 2d: Contd…

Cross	Average panicle weight		Panicle length		Filled grains per panicle	
	H_{MP}	H_{BP}	H_{MP}	H_{BP}	H_{MP}	H_{BP}
MAY*88B	5.61**	2.28	-4.00	-7.00	-34.15**	-35.10**
MAY*97B	6.65**	4.33**	1.00	-6.75	-3.28	-7.70*
MAY*56B	3.16*	1.48	4.50	-3.25	9.98**	-2.50
MAY*55B	-2.94*	-3.33*	24.88**	22.25**	54.50**	46.15**
MAY*LAC	9.46**	8.83**	9.63*	9.25	46.05**	45.20**
MAY*LUI	8.46**	6.78**	-3.50	-7.25	-9.40**	-9.50**
25B*88B	10.60**	10.15**	-8.75*	-10.25*	25.75**	6.25
25B*97B	6.89**	6.33**	-8.25	-11.50*	41.65**	27.53**
25B*56B	2.90*	1.70	4.00	0.75	10.83**	4.75
25B*55B	-2.68	-5.95**	18.63**	11.50*	11.25**	1.05
25B*LAC	7.00**	4.75**	-5.38	-9.50	-11.45**	-30.85**
25B*LUI	-0.20	-1.40	13.50**	12.75*	-43.95**	-62.40**
88B*97B	0.69	-0.32	24.50**	19.75**	13.63**	8.25*
88B*56B	5.35**	3.70*	-3.75	-8.50	-40.03**	-53.45**
88B*55B	9.53**	5.80**	2.13	-3.50	36.30**	27.00**
88B*LAC	5.30**	2.60	-4.63	-7.25	-11.70**	-11.80**
88B*LUI	4.50**	2.85	18.25**	17.50**	11.85**	10.80**
97B*56B	12.79**	12.15**	-11.00*	-11.00*	37.93**	29.88**
97B*55B	1.01	-1.70	3.13	-7.25	-38.18**	-42.10**
97B*LAC	-3.96**	-5.65**	48.63**	41.25**	28.03**	22.75**
97B*LUI	3.09*	2.45	-1.00	-5.00	64.83**	60.50**
56B*55B	-3.63**	-5.70**	6.88	-3.50	-2.22	-6.35
56B*LAC	-6.75**	-7.80**	13.38**	6.00	-30.83**	-44.15**
56B*LUI	-1.80	-1.80	4.25	0.25	-38.13**	-50.50**
55B*LAC	-6.65**	-7.68**	18.00**	15.00**	-33.80**	-43.00**
55B*LUI	-4.68**	-6.75**	13.88**	7.50	-34.45**	-42.70**
LAC*LUI	2.83*	1.78	-2.63	-6.00	30.80**	29.85**
CD (5%)	2.69	3.10	8.70	10.05	5.71	6.59
CD (1%)	3.55	4.10	11.50	13.28	7.54	8.70

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

Table 2e: Estimates of mid-parent (H_{MP}) and better-parent heterosis (H_{BP}) for the traits of the 55 rice hybrids

Cross	Spikelet fertility		Straw yield per plant		Grain yield per plant	
	H_{MP}	H_{BP}	H_{MP}	H_{BP}	H_{MP}	H_{BP}
SUR*LAL	-1.47	-4.52**	8.74*	-2.23	10.64**	8.94**
SUR*BOR	9.04**	1.03	20.99**	19.36**	10.70**	8.85**
SUR*MAY	-15.31**	-23.45**	22.62**	19.73**	6.72**	5.94**
SUR*25B	-1.58	-1.68	40.24**	38.83**	13.51**	11.94**
SUR*88B	-1.39	-9.71**	32.98**	20.25**	10.13**	7.38**
SUR*97B	-25.62**	-28.17**	-13.64**	-16.23**	3.74*	1.41
SUR*56B	-7.67**	-10.54**	-9.11*	-13.68**	24.31**	22.93**
SUR*55B	8.23**	3.75**	-1.19	-3.31	1.39	-1.86
SUR*LAC	8.50**	2.75*	1.44	0.47	29.05**	27.11**
SUR*LUI	7.01**	0.57	6.01	1.64	4.01*	3.17
LAL*BOR	8.63**	-2.43	-12.72**	-22.06**	-6.82**	-10.38**
LAL*MAY	-27.01**	-32.09**	-21.55**	-29.62**	5.71**	3.22
LAL*25B	7.96**	4.81**	-9.53**	-19.09**	-4.02*	-7.30**
LAL*88B	-7.11**	-12.39**	4.33	-19.36**	22.20**	17.74**
LAL*97B	4.65**	4.16**	-4.69	-18.25**	3.99*	3.37
LAL*56B	7.23**	1.32	-37.38**	-43.77**	15.01**	14.68**
LAL*55B	-0.12	-1.56	-16.75**	-25.60**	29.34**	24.38**
LAL*LAC	-4.13**	-6.84**	-20.37**	-30.36**	18.98**	15.32**
LAL*LUI	-9.82**	-13.21**	-19.28**	-25.87**	14.62**	12.06**
BOR*MAY	7.58**	-8.56**	13.14**	11.87**	9.71**	8.64**
BOR*25B	-38.80**	-46.71**	-17.70**	-17.92**	12.01**	11.73**
BOR*88B	7.16**	-9.17**	43.02**	28.66**	6.50**	5.59**
BOR*97B	16.38**	5.82**	23.92**	19.70**	0.08	-4.10*
BOR*56B	22.29**	17.14**	8.65*	5.70	-2.88	-6.11**
BOR*55B	15.71**	3.21*	10.17**	9.69*	8.53**	7.14**
BOR*LAC	13.80**	0.03	1.24	0.59	-0.55	-0.64
BOR*LUI	14.39**	-0.06	-2.52	-5.27	-0.51	-1.52
MAY*25B	6.59**	-1.64	-0.57	-2.06	4.36*	3.57
CD (5%)	2.29	2.64	7.06	8.15	3.53	4.08
CD (1%)	3.02	3.49	9.33	10.77	4.66	5.39

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

Table 2e: Contd…

Cross	Spikelet fertility		Straw yield per plant		Grain yield per plant	
	H_{MP}	H_{BP}	H_{MP}	H_{BP}	H_{MP}	H_{BP}
MAY*88B	-34.45**	-34.64**	30.86**	15.24**	2.18	0.20
MAY*97B	0.89	-4.70**	2.31	-3.18	22.15**	19.04**
MAY*56B	-10.29**	-21.29**	55.27**	53.59**	16.99**	14.83**
MAY*55B	-18.84**	-22.49**	-1.92	-2.70	3.99*	1.53
MAY*LAC	-2.59*	-4.97**	35.31**	33.39**	26.59**	25.42**
MAY*LUI	4.40**	2.71*	24.52**	23.04**	4.91**	4.85*
25B*88B	-33.04**	-41.47**	10.19**	-3.94	9.92**	8.74**
25B*97B	2.31*	-0.34	9.44**	5.44	9.94**	6.05**
25B*56B	15.47**	12.71**	2.54	-0.63	6.98**	4.03
25B*55B	9.41**	4.82**	0.08	-0.63	7.88**	6.20**
25B*LAC	-9.57**	-15.43**	6.04	5.61	2.02	1.64
25B*LUI	9.46**	2.92*	11.11**	8.14	2.78	2.06
88B*97B	1.10	-4.67**	91.10**	80.96**	5.59**	0.50
88B*56B	-42.86**	-54.05**	12.96**	-4.34	-2.49	-6.63**
88B*55B	0.52	-3.32*	37.41**	22.57**	25.97**	25.48**
88B*LAC	-3.32**	-5.89**	38.28**	24.57**	2.67	1.87
88B*LUI	-4.92**	-6.80**	28.51**	11.41**	31.11**	29.20**
97B*56B	-16.36**	-21.77**	20.89**	13.73**	20.23**	19.29**
97B*55B	-35.29**	-37.23**	5.78	1.07	-1.16	-6.74**
97B*LAC	-38.34**	-41.55**	54.37**	50.80**	16.93**	12.65**
97B*LUI	-10.50**	-14.39**	1.46	-5.50	7.32**	4.14*
56B*55B	-2.51*	-9.86**	6.85	4.39	5.79**	1.16
56B*LAC	-10.12**	-18.74**	14.73**	11.13**	-3.56*	-6.89**
56B*LUI	-7.80**	-17.11**	25.79**	25.59**	-6.57**	-8.80**
55B*LAC	-4.27**	-5.54**	6.74	5.60	0.57	-0.73
55B*LUI	-0.52	-2.48	15.92**	13.67**	4.98**	2.58
LAC*LUI	-12.24**	-12.93**	-0.77	-4.17	0.63	-0.47
CD (5%)	2.29	2.64	7.06	8.15	3.53	4.08
CD (1%)	3.02	3.49	9.33	10.77	4.66	5.39

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

Table 2f: Estimates of mid-parent (H_{MP}) and better-parent heterosis (H_{BP}) for the traits of the 55 rice hybrids

Cross	Biological yield per plant		Harvest index		Amylose content		Gel consistency	
	H_{MP}	H_{BP}	H_{MP}	H_{BP}	H_{MP}	H_{BP}	H_{MP}	H_{BP}
SUR*LAL	19.39**	6.71	4.57*	2.24	-6.19**	-9.35**	-4.75*	-10.25**
SUR*BOR	31.69**	31.47**	2.20	-0.54	10.99**	8.00**	-36.13**	-38.75**
SUR*MAY	29.34**	27.22**	0.08	-1.85	2.13	0.85	-17.75**	-23.00**
SUR*25B	53.75**	53.59**	-1.39	-3.66	-1.54	-2.40	-13.13**	-14.75**
SUR*88B	42.63**	27.63**	-6.83**	-11.62**	5.91**	4.83**	7.75**	-3.25
SUR*97B	-9.90*	-10.16*	12.63**	9.38**	-2.63	-3.03	-22.75**	-32.50**
SUR*56B	16.71**	10.75*	20.80**	20.30**	-3.03*	-3.45*	19.88**	1.75
SUR*55B	0.20	-0.93	2.21	-2.14	0.88	0.30	-9.00**	-12.50**
SUR*LAC	31.56**	30.59**	20.21**	17.72**	-4.05**	-4.05*	-12.00**	-12.25**
SUR*LUI	10.03*	6.50	1.49	-1.21	-3.04*	-4.88**	-20.13**	-20.25**
LAL*BOR	-19.54**	-32.44**	-2.57	-2.97	-1.25	-7.40**	-34.38**	-42.50**
LAL*MAY	-15.84**	-26.40**	14.37**	13.97**	-6.21**	-10.65**	-6.50**	-17.25**
LAL*25B	-13.56**	-26.40**	-0.70	-0.77	-3.23*	-7.25**	-16.63**	-20.50**
LAL*88B	26.05**	-1.62	12.46**	5.34*	-3.90**	-5.98**	-15.50**	-32.00**
LAL*97B	-0.70	-13.64**	4.51*	-1.08	-3.29*	-6.85**	-7.00**	-22.25**
LAL*56B	-15.93**	-22.65**	24.48**	22.64**	-3.44*	-6.18**	-11.38**	-35.00**
LAL*55B	12.60**	-1.21	28.61**	26.60**	-3.31*	-5.90**	-23.00**	-32.00**
LAL*LAC	-1.39	-15.03**	24.29**	24.14**	3.66*	0.50	-38.25**	-44.00**
LAL*LUI	-4.66	-13.81**	19.73**	19.37**	-3.83**	-5.15**	-21.63**	-27.25**
BOR*MAY	22.85**	20.51**	4.14*	3.33	9.99**	8.28**	-25.13**	-27.75**
BOR*25B	-5.68	-5.74	21.51**	21.04**	2.85	0.73	-32.25**	-36.50**
BOR*88B	49.03**	34.25**	-11.24**	-18.76**	1.65	-2.43	-5.88*	-14.25**
BOR*97B	24.00**	23.96**	-7.73**	-13.72**	9.39**	6.80**	10.38**	3.25
BOR*56B	5.77	-0.41	-5.16*	-7.40**	1.09	-2.33	8.00**	-7.50**
BOR*55B	18.71**	17.80**	4.49*	2.87	2.51	-1.05	-23.63**	-24.50**
BOR*LAC	0.69	-0.05	-1.02	-1.28	1.71	-1.28	-28.13**	-30.50**
BOR*LUI	-3.03	-6.79	0.61	0.57	-0.60	-5.43**	-11.00**	-13.50**
MAY*25B	3.79	1.51	4.54*	4.21	5.16**	4.75**	-1.38	-8.25**
CD (5%)	8.56	9.88	3.98	4.59	2.89	3.33	4.67	5.39
CD (1%)	11.31	13.05	5.25	6.07	3.81	4.40	6.16	7.12

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

Table 2f: Contd…

Cross	Biological yield per plant		Harvest index		Amylose content		Gel consistency	
	H_{MP}	H_{BP}	H_{MP}	H_{BP}	H_{MP}	H_{BP}	H_{MP}	H_{BP}
MAY*88B	32.55**	15.44**	-11.12**	-17.84**	-3.14*	-5.50**	-3.50	-9.25**
MAY*97B	24.46**	22.08**	14.75**	9.58**	0.90	0.02	21.00**	16.50**
MAY*56B	72.26**	68.42**	-2.29	-3.72	4.65**	2.95	23.13**	10.25**
MAY*55B	2.07	-1.17	4.93*	2.51	6.25**	4.40*	-14.75**	-16.50**
MAY*LAC	61.89**	58.81**	7.91**	7.35**	-0.07	-1.35	-4.50	-9.50**
MAY*LUI	29.43**	28.02**	-2.76	-3.53	-0.16	-3.28	13.38**	8.25**
25B*88B	19.63**	4.80	1.68	-5.38*	11.15**	9.20**	-32.13**	-44.75**
25B*97B	19.38**	19.28**	4.45*	-1.07	3.26*	2.80	8.13**	-3.25
25B*56B	9.53*	3.41	5.24*	3.47	-2.11	-3.40*	-6.50**	-26.25**
25B*55B	7.96	6.99	7.70**	5.61*	13.34**	11.90**	1.88	-3.25
25B*LAC	8.06	7.25	-0.06	-0.28	0.44	-0.42	-23.08**	-24.95**
25B*LUI	13.89**	10.20*	-0.71	-1.14	0.07	-2.63	-26.50**	-28.25**
88B*97B	96.20**	81.47**	-21.13**	-22.67**	-1.66	-3.15	8.50**	7.25**
88B*56B	9.99*	-10.97*	-10.22**	-15.51**	-5.66**	-6.33**	3.38	-3.75
88B*55B	62.90**	49.04**	4.39*	-4.75*	0.59	0.08	-10.50**	-18.00**
88B*LAC	40.46**	26.44**	-12.55**	-19.83**	-2.21	-3.30	-23.00**	-33.75**
88B*LUI	59.13**	40.60**	8.87**	1.38	-3.43*	-4.18*	-4.13	-15.00**
97B*56B	26.39**	20.17**	17.96**	14.22**	-1.15	-1.98	8.38**	0.00
97B*55B	4.62	3.75	-2.53	-10.13**	-2.13	-3.10	-24.00**	-30.25**
97B*LAC	71.30**	70.59**	-4.03*	-9.77**	2.48	2.08	-23.50**	-33.00**
97B*LUI	8.78*	4.99	5.59**	-0.36	-2.14	-4.38*	2.38	-7.25**
56B*55B	12.63**	5.55	2.93	-0.93	4.10**	3.95*	-2.63	-17.25**
56B*LAC	11.17*	4.25	-7.60**	-9.59**	-3.38*	-3.80*	-14.38**	-32.25**
56B*LUI	19.21**	16.78**	-11.91**	-14.11**	-2.26	-3.68*	-8.00**	-26.00**
55B*LAC	7.30	7.14	-1.53	-3.40	2.63	2.05	-16.75**	-20.00**
55B*LUI	20.90**	16.24**	0.11	-1.54	-6.46**	-7.73**	-36.13**	-39.50**
LAC*LUI	-0.14	-4.64	0.90	0.69	0.14	-1.70	-21.38**	-21.50**
CD (5%)	8.56	9.88	3.98	4.59	2.89	3.33	4.67	5.39
CD (1%)	11.31	13.05	5.25	6.07	3.81	4.40	6.16	7.12

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

4. Conclusion

Significant negative heterosis could result due to the presence of dominant loci for the traits acting in different directions and thus, cancel the positive and negative effects leading to no or negative heterosis. The crosses showing no heterosis indicated that the parents involved in the crosses did not differ in gene frequencies for the trait in question (Falconer, 1989) [6]. The estimates of heterosis for seedling establishment, days to 50% flowering, panicle initiation, days to maturity, culm length, panicle length, biological yield per plant, and straw yield per plant and gel consistency were mostly negative. The crosses with negative heterosis effects indicated the reduction in performance of the concerned trait. For heterosis to occur, any of three genetic effects *viz*., dominance, overdominance and epistasis at loci governing a quantitative trait is necessary and also sufficient, with their various individual contribution to heterosis which depends on the mating system, the traits investigated and the genetic material used (Fievet *et al*., 2018) [7].

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