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Heterosis in Oat (*Avena sativa* L.) for various Agro-Morphological, Yield and Quality Traits

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ABSTRACT: The objective of the present study was to estimate the level of heterosis for different agro-morphological, yield attributing and quality traits in oat. A total of 40 F_1 hybrids along with parents and standard check PLP-1 were evaluated in RBD with three replications during *Rabi* 2018-19. Analysis of variance revealed significant differences among parents, genotypes and hybrids for almost all the traits indicating sufficient genetic variability in the material. UPO-130 × JPO-46 showed promising heterosis for green fodder yield and seed yield. HJ-8 × JPO-46 exhibited desirable acid detergent fibre, neutral detergent fibre and highest β-glucan content. Based on mean performance, heterosis studies and resistance to powdery mildew, cross combinations KRR-AK-26 × JPO-46, Kent × JPO-46 and PLP-14 × UPO-30 were found best and can be expected to throw transgressive segregants. Thus, these hybrids can be further evaluated at multilocation trials and commercially exploited through heterosis breeding.

Keywords: Oat, heterosis, heterobeltiosis, ADF, NDF and β-glucan.

INTRODUCTOIN

Oat (*Avena sativa* L.) is one of the most important dual-purpose cereal crop of the genus *Avena* belonging to family Poaceae. It is grown worldwide largely as a winter crop and supplemented with other legumes like berseem and lucerne. It ranks sixth in world production among cereals and a rich source of anti-oxidants like α-tocopherol, α-tocotrienol and avenanthramides including the soluble fiber β-glucan (Oliver *et al.,* 2010; Ahmad and Zaffar 2014). Oat has high protein content of about 11–15% due to higher proportion of lysine and lower levels of prolamine (Rodehutscord *et al.,* 2016). From human health point of view, consumption of oat grains lowers the risk of cardiovascular diseases and inhibits bad cholesterol leading to increase in its demand in global food market (Tiwari *et al.*, 2011; Devi 2018). Hence, it has been often referred to as “Supergrain” as it serves as excellent source of various nutritional features (Varma *et al.,* 2016; Premkumar 2017). As fodder, the quality of the forage primarily depends upon both digestible and indigestible fractions. Both acid detergent fibre (ADF) and neutral detergent fibre (NDF) refers to indigestible portion and digestible portion respectively, are key constituents in fixing forage quality. Moreover, low ADF and NDF content is preferred for better digestibility and higher forage intake.

Most of the grain and forage yield traits are quantitative in nature and the choice of parents for hybridization and selection of desirable genotypes for direct use as a parent in hybridization plan is a challenging task for a breeder. Improvement in forage production involves maximum utilization of heterosis providing scope for developing high yielding dual-purpose, multi-cut with good regeneration capacity and disease resistant oat cultivars. Disease management in oat is of paramount importance as powdery mildew (*Blumeria graminis* f. sp. *avena*) causes huge qualitative and quantitative losses severely affecting both green fodder yield and seed yield (Banyal *et al.*, 2016). Although heterosis being ubiquitous, it does not mean it occurs in every cross between two parents and also not necessarily always from good parents (Liu *et al.,* 2021). Therefore, information on the extent of heterosis, is rather essential to identify potential cross combinations which can be further exploited through inter varietal hybridization programme. Oat is a self-pollinated crop therefore hybrids development is not a good alternate for the development of yield potential cultivars however hybridization between diverse parent followed by individual plant selection and selfing till to generate homozygous progenies are the basic steps to develop potential cultivar. Therefore, exploitation of heterosis and identification of transgressive segregants are most crucial and are the reasons that plant breeding works.

In India, oat breeding has not received much attention due to narrow regionally adapted genetic base of cultivated gene pool. Moreover, growing food scarcity for both human and livestock with ever rising population and shrinking land for agriculture use has led to intensified efforts towards more efficient forage research and production, for which it is imperative to identify promising hybrids (Sood *et al.* 2016). While planning any breeding programme, selection of diverse parents leads to higher heterotic effects and probability of getting desirable transgressive. However, the selection of suitable parents chiefly depends on the predominance of the genes for the additive effect due to heterosis and heterobeltiosis to obtain superior hybrids (Beche *et al.* 2013). With this vision, estimation of heterosis and heterobeltiosis effects was undertaken to identify the potential cross combinations in oat expressing high hybrid vigour.

MATERIAL AND METHODS

Experimental material and site. The experimental material for the investigation comprises of 40 F_1 hybrids for their use in hybridization programme to obtain desired recombinants or transgressive segregants. These hybrids along with parents and standard check *i.e.* PLP-1 were evaluated in RBD with three replications during *Rabi* 2018-19 at the Experimental Fodder Farm of the Department of Genetics and Plant Breeding, CSK HPKV, Palampur (HP). Each entry was raised in two rows of 1.25 m length with 30 cm row to row and 20 cm plant to plant distance. Parental materials are maintained at Fodder Section of the Department of Genetics and Plant Breeding, CSK HPKV, Palampur, Himachal Pradesh, India.

Field study and data evaluation. Data was recorded for different agro-morphological, yield attributing and quality traits *viz.,* days to 50% flowering (50%F), plant height (PH), leaves per plant (NOL), tillers per plant (NOT), leaf stem ratio (LSR), flag leaf area (FLA), green fodder yield per plant (GFY), dry matter yield per plant (DMY), days to 75% maturity (75%M), biological yield per plant (BY), seed yield per plant (SY), 100-seed weight (100-SW), harvest index (HI), crude protein yield-fodder per plant (CPY-F), crude protein content-seed (CP-S), acid detergent fibre (ADF), neutral detergent fibre (NDF), β-glucan content (BG) and reaction to powdery mildew (*Blumeria graminis* f. sp. *avenae)* under natural epiphytotic conditions (Mayee and Datar 1986). Quality traits such as ADF (%) and NDF (%) was determined by the method given by Van Soest (1991) and Van Soest and Snifftn (1984) respectively. The crude protein content for each genotype was analyzed following Micro-Kjeldhal Method (AOAC 1970). BG (%) was determined *via* alkali extraction (AE) method (Wood *et al.,* 1977) and Congo Red (CR) estimation method given by Semedo *et al.,* (2015). Mid parental (MP) heterosis, heterobeltiosis (BP) and economic heterosis (EC) were estimated and tested by using the standard formulae (Turner 1953; Hayes *et al.,* 1955).

RESULTS AND DISCUSSION

Analysis of variance for the experimental design revealed significant differences among the genotypes, parents and hybrids for all the traits studied. Thus, it can be seen that abundant variability is present among genotypes, parents as well as their F_{1s}' for almost all the traits undertaken for the investigation, providing opportunity for the improvement through suitable breeding approaches. In heterosis breeding, the main goal is to attain a quantum jump in the performance for certain traits over and above the average performance of otherwise straightbred parents. Heterosis has been increasingly applied in crop improvement and breeding programmes for nearly a century, with the objective of developing higher yielding, more vigorous and better performing cross combinations (Fu *et al* 2014). The magnitude of mid parent heterosis, heterobeltiosis and standard heterosis is discussed below for different agro-morphological, yield and yield attributing and quality traits.

Agro-morphological traits. For 50% F (Table 1), four cross combinations *viz.,* KRR AK 26 × JPO 46, KRR AK 26 × PLP 1, KRR AK 15 × JPO 46 and Kent × JPO 46 exhibited significant negative heterosis over the mid parent and sixteen cross combinations showed significant negative heterobeltiosis values (Table 1). Out of six cross combinations, cross HJ 8 × HFO 52 exhibited highest desirable negative heterosis over the check PLP-1 up to the extent of -6.22%.

The magnitude of heterosis for mid parent and better parent for *p*H (Table 1) ranged from -22.29% to 33.13% and -23.20% to 20.91% respectively. Eleven cross combinations showed significant mid parent desirable positive heterosis while over better parent, only two cross combinations *viz.* HJ 8 × JPO 46 and UPO 130 × HFO 52 showed significant beneficial positive heterosis. Over standard check PLP-1, sixteen cross combinations showed significant positive desirable economic heterosis while maximum beneficial heterosis was exhibited by cross JPO 36 × UPO 30 to the extent of 22.63%. Although, HJ 8 × JPO 46 was found common for mid parent (17.15%), better parent (13.90%) and standard check PLP 1 (21.31%) for plant height.

For FLA (Table 1), the magnitude of heterosis for mid-parent ranged from -48.20% to 64.33% and better parent ranged from -58.52% to 53.00%. Nineteen cross combinations showed significant desirable mid parental positive heterosis while for better parent, eleven cross combinations showed significant desirable positive values of heterosis. Over standard check PLP-1 ranged from -23.15% to 130.40%, thirty-two cross combinations exhibited significant desirable positive economic heterosis, of which Kent × UPO 30 showed maximum beneficial standard heterosis.

Eighteen cross combinations exhibited for 75%M (Table 1) significant desirable negative heterosis over the mid parent and twenty-six cross combinations expressed significant desirable negative heterobeltiosis. The magnitude of heterosis for mid-parent and over better parent ranged from -5.96% to 3.44% and -8.87% to 3.01% respectively. Significant desirable negative heterosis was observed for nine cross combinations when tested against standard check PLP-1. Although, HJ 8 × HFO-52, KRR AK 26 × PLP 1, PLP 14 × UPO 30, KRR AK 15 × HFO-52, UPO 130 × HFO-52 and K 353 × HFO-52 were found common for mid parent, better parent and standard check PLP-1 for early maturity.

Table 1: Magnitude of heterosis (%) over mid parent (MP), better parent (BP) and economic heterosis (EC) over standard check PLP-1.

Crosses/ Traits	50%F			PH			FLA			75%			NOL			NOT		
	MP	BP	EC	MP	BP	EC	MP	BP	EC	MP	BP	EC	MP	BP	EC	MP	BP	EC
EC-528865 × JPO-46	-1.79	-7.58 *	1.15	3.84	1.17	13.59 *	-8.51 *	-12.10 *	62.86 *	-2.91 *	-8.87 *	0.00	21.64*	1.08	21.01 *	27.18 *	10.74	22.79 *
EC-528865 × PLP-1	1.99	0.23	0.23	14.07 *	7.83	21.07 *	22.18 *	-3.13	65.39 *	3.44 *	1.50 *	1.50 *	4.33	-4.26	14.62	43.74 *	30.95 *	30.95 *
EC-528865 × UPO-30	0.81	-1.59	-0.23	-22.29 *	-23.20 *	-13.77 *	1.32	-11.08 *	51.81 *	2.49 *	0.75	0.37	-10.37	-17.88*	18.11	-7.80	-23.78 *	-4.08
EC-528865 × HFO-52	1.93	0.95	-2.53 *	11.73 *	-0.68	11.51	17.05 *	9.99 *	87.79 *	0.19	-0.38	-3.00 *	-12.53*	-22.92*	21.01 *	-10.17	-18.90	-17.24
HJ-8 × JPO-46	-0.45	-7.16 *	1.61	17.15 *	13.90 *	21.31 *	-22.62 *	-23.61 *	45.25 *	-0.55	-7.17 *	1.87 *	-18.75*	-38.95*	-3.77	-44.44 *	-44.79 *	-38.78 *
HJ-8 × PLP-1	4.85 *	2.07	2.07 *	12.51 *	12.17	12.85 *	-13.08 *	-33.68 *	26.09 *	2.88 *	0.37	0.37	-4.89	-22.27*	22.52 *	12.01	7.14	17.35
HJ-8 × UPO-30	-0.59	-3.86 *	-2.53 *	12.99 *	8.33	18.79 *	24.44 *	4.41	98.52 *	0.77	-1.50 *	-1.87 *	-22.58*	-25.97*	16.69	-23.50 *	-28.46 *	-9.97
HJ-8 × HFO-52	-0.97	-0.97	-6.22 *	11.13	3.79	4.43	18.84 *	6.34	102.19 *	-1.17 *	-2.31 *	-4.87 *	-17.64*	-17.80*	29.56 *	-18.01 *	-20.81 *	-13.27
KRR-AK-26 × JPO-46	-6.36 *	-6.95 *	1.84	-0.29	-8.02	15.94 *	-25.01 *	-35.99 *	18.60 *	-5.96 *	-8.53 *	0.37	31.06*	-1.45	54.97 *	-2.24	-4.93	11.56
KRR-AK-26 × PLP-1	-4.98 *	-8.53 *	-1.15	-13.74 *	-22.65 *	-2.50	43.62 *	26.61 *	65.90 *	-3.31 *	-5.05 *	-1.50 *	-10.84	-27.07*	14.68	-21.44 *	-27.25 *	-14.63
KRR-AK-26 × UPO-30	-1.65	-4.69 *	3.00 *	-15.27 *	-20.78 *	-0.15	-0.20	-1.01	29.71 *	0.55	-1.44 *	2.25 *	-18.95*	-22.41*	22.01 *	0.42	-2.97	22.11 *
KRR-AK-26 × HFO-52	2.05	-4.26 *	3.46 *	0.77	-14.70 *	7.51	-13.17 *	-18.69 *	22.07 *	1.68 *	-1.44 *	2.25 *	-34.99*	-35.05*	2.14	-3.88	-10.14	5.44
PLP-14 × JPO-46	1.34	-4.21 *	4.84 *	1.30	-0.17	6.32	-36.41 *	-37.34 *	16.10 *	-2.52 *	-7.51 *	1.50 *	13.77	-8.60	19.37	5.12	-5.52	4.76
PLP-14 × PLP-1	3.62 *	2.30	2.30 *	10.30	8.48	12.18	-18.23 *	-36.38 *	14.41	1.13 *	0.37	0.37	-7.27	-18.14*	6.92	-4.69	-10.20	-10.20
PLP-14 × UPO-30	-1.51	-3.41 *	-2.07 *	-1.40	-4.20	5.04	23.98 *	6.43	91.41 *	-3.21 *	-3.76 *	-4.12 *	-17.44*	-21.23*	13.30	-38.19 *	-47.38 *	-33.78 *
PLP-14 × HFO-52	4.32 *	2.84 *	0.23	17.57 *	8.42	12.12	3.98	-4.61	71.56 *	1.72 *	1.14 *	-0.37	-25.82*	-32.05*	6.67	24.64 *	16.33	18.71
KRR-AK-15 × JPO-46	-2.72 *	-5.89 *	3.00 *	-10.21	-11.50	-5.74	-48.20 *	-58.52 *	-23.15 *	-4.71 *	-6.83 *	2.25 *	8.70	-21.84*	41.38 *	12.50	9.25	28.57 *
KRR-AK-15 × PLP-1	0.46	-0.68	1.61	-16.34 *	-17.74 *	-14.90 *	-15.68 *	-20.02 *	-10.85	-1.65 *	-3.93 *	0.75	13.12*	-12.17*	58.87 *	10.62	2.31	20.41 *
KRR-AK-15 × UPO-30	1.13	0.68	3.00 *	-12.17 *	-14.65 *	-6.41	-22.40 *	-27.66 *	-6.74	0.37	-2.14 *	2.62 *	-9.09	-18.40*	47.60 *	-16.20 *	-18.92 *	2.04
KRR-AK-15 × HFO-52	1.52	-2.25	-0.00	-9.83	-16.85 *	-13.98 *	-4.65	-16.93 *	24.71 *	-2.59 *	-6.07 *	-1.50 *	0.97	-5.70	70.57 *	20.74 *	12.72	32.65 *
JPO-36 × JPO-46	0.00	-2.53 *	6.68 *	-1.44	-5.08	9.16	11.98 *	-16.54 *	54.63 *	-1.91 *	-3.41 *	5.99 *	13.11	-15.83*	36.60 *	33.45 *	19.94	32.99 *
JPO-36 × PLP-1	1.24	-0.67	3.23 *	-3.34	-9.65	3.91	58.48 *	51.28 *	51.28 *	-0.54	-3.52 *	2.62 *	0.71	-18.62*	32.08 *	-2.17	-7.82	-7.82
JPO-36 × UPO-30	0.79	-0.44	3.46 *	9.17	6.63	22.63 *	56.52 *	33.44 *	72.04 *	-1.45 *	-4.58 *	1.50 *	-5.49	-10.87	44.65 *	14.29	-2.70	22.45 *
JPO-36 × HFO-52	-0.93	-5.32 *	-1.61	5.07	-7.58	6.29	15.93 *	-6.93	39.73 *	-2.21 *	-6.34 *	-0.37	-27.27*	-28.46*	16.10	21.43 *	13.33	15.65
Kent × JPO-46	-2.39 *	-5.47 *	3.46 *	7.61	6.33	16.00 *	-34.81 *	-40.76 *	9.77	-3.89 *	-7.17 *	1.87 *	8.72	-21.57*	40.38 *	3.79	-1.11	21.09 *
Kent × PLP-1	1.25	0.00	2.53 *	1.20	-3.02	5.80	33.00 *	10.40 *	67.25 *	0.37	-0.73	1.50 *	-4.06	-25.23*	33.84 *	-15.29	-23.06	-5.78
Kent × UPO-30	1.47	0.90	3.46 *	5.86	5.60	15.79 *	64.33 *	52.09 *	130.40 *	0.56	-0.73	1.50 *	-10.93*	-19.68*	43.77 *	-12.33	-13.51	8.84
Kent × HFO-52	2.57 *	-1.35	1.15	23.21 *	10.92	21.01 *	-16.07 *	-16.44 *	26.58 *	0.56	-1.83 *	0.37	-26.47*	-30.99*	23.52 *	-31.82 *	-37.50	-23.47 *
UPO-130 × JPO-46	1.92	-4.84 *	4.15 *	27.39 *	6.34	13.25 *	28.56 *	4.26	93.18 *	-1.79 *	-6.48 *	2.62 *	74.66*	43.02*	77.74 *	18.90 *	6.13	17.69
UPO-130 × PLP-1	3.78 *	1.15	1.15	28.63 *	10.17	10.17	63.83 *	53.00 *	76.31 *	0.75	0.37	0.37	7.12	-3.34	20.13 *	11.27	4.08	4.08
UPO-130 × UPO-30	3.52 *	0.23	1.61	29.40 *	6.77	17.07 *	23.68 *	17.11 *	50.99 *	1.32 *	1.13 *	0.75	2.28	-4.68	37.11 *	20.45 *	1.89	28.23 *
UPO-130 × HFO-52	2.55 *	2.43	-2.76 *	33.13 *	20.91 *	5.59	9.85 *	-2.91	45.76 *	-2.10 *	-3.02 *	-3.75 *	-12.34*	-21.47*	23.27 *	21.22 *	12.33	14.63
K-353 × JPO-46	2.58 *	-3.79 *	5.30 *	1.79	-2.69	13.65 *	-24.72 *	-38.85 *	13.29	-2.33 *	-6.83 *	2.25 *	15.10*	-11.14	29.43 *	-13.61	-21.07	5.78
K-353 × PLP-1	4.71 *	2.53 *	2.53 *	4.51	-3.01	13.28 *	31.84 *	22.89 *	42.20 *	2.06 *	1.87 *	1.87 *	-2.30	-17.62*	20.00 *	-9.88	-21.32*	5.44
K-353 × UPO-30	4.91 *	2.05	3.46 *	7.55	4.26	21.77 *	-4.05	-8.96	17.37 *	3.01 *	3.01 *	2.62 *	-38.65*	-39.03*	-11.19	-7.59	-10.41	20.07 *
K-353 × HFO-52	1.81	1.20	-3.00 *	4.02	-9.10	6.17	29.65 *	14.79 *	72.33 *	-1.14 *	-2.26 *	-2.62 *	-10.37	-13.60*	35.64 *	-10.95	-21.57*	5.10
EC-605834 × JPO-46	0.66	-4.21 *	4.84 *	-7.65	-8.60	-2.66	-0.83	-20.11 *	48.03 *	-1.42 *	-5.46 *	3.75 *	38.98*	4.33	64.91 *	5.61	-0.54	24.83 *
EC-605834 × PLP-1	1.74	1.15	1.15	-10.45	-12.30 *	-8.52	-7.45	-12.86	-1.32	0.37	0.00	0.75	-10.02	-26.55*	16.10	8.30	-2.71	22.11 *
EC-605834 × UPO-30	2.42 *	1.14	2.53 *	9.40	6.74	17.04 *	58.50 *	48.86 *	91.92 *	1.68 *	1.12 *	1.87 *	-16.59*	-20.34*	25.91 *	-9.07	-9.19	14.29
EC-605834 × HFO-52	2.14	0.00	-1.15	5.39	-3.19	0.98	-34.32 *	-42.39 *	-13.51	-0.57	-2.23 *	-1.50 *	-16.47*	-16.76*	31.57 *	13.60	2.98	29.25 *
S.E. ±	**1.54**	**1.77**	**1.42**	**6.03**	**6.96**	**6.66**	**1.76**	**2.03**	**2.05**	**0.81**	**0.94**	**0.93**	**2.20**	**2.54**	**2.61**	**0.86**	**0.99**	**0.95**

(*Significant at 5% level of significance)

Yield and yield attributing traits. Six cross combinations expressed significant desirable positive mid parent heterosis for NOL (Table 1) while only one cross showed significant positive heterobeltiosis value. The magnitude of heterosis for mid-parent and over better parent ranged from -38.65% to 74.66% and -39.03% to 43.02% respectively. Out of the twenty-seven cross combinations, cross UPO 130 × JPO 46 showed highest beneficial positive heterosis over standard check PLP-1 and found common for mid parent (74.66%), better parent (43.02%) and standard heterosis (77.74) for leaves per pant.

For NOT (Table 1), EC 528865 × PLP 1 was found common for mid parent (43.74%), better parent (30.95%) and standard heterosis (30.95%). Nine cross combinations showed significant desirable positive mid parental heterosis while only one cross combination showed significant desirable positive heterobeltiosis. The magnitude of heterosis for this trait over check PLP-1 ranged from -38.78% to 32.99% and of which, fourteen cross combinations showed significant desirable positive values of heterosis.

The range of heterosis for mid parent, better parent and standard check PLP 1 for LSR (Table 2) varied from -10.91% to 16.83%, -29.32% to 12.38% and -11.34% to 45.36% respectively. For mid parent, six cross combinations showed significant desirable positive heterosis while only cross combination UPO 130 × PLP 1 showed significant desirable positive heterobeltiosis. UPO 130 × PLP 1 was found common for mid parent (16.83%), better parent (12.38%) and standard heterosis (21.65%) while KRR AK 26 × HFO 52 and K 353 × HFO 52 among other thirty cross combinations showed highest beneficial economic heterosis (45.36%) over standard check PLP-1.

The magnitude of heterosis for mid-parent, better parent and standard check PLP-1 for GFY (Table 2) ranged from -24.53% to 89.81%, -35.64% to 73.01% and -34.83% to 44.30% respectively. For mid parent, thirteen cross combinations showed significant desirable positive heterosis while seven cross combinations showed significant and desirable positive heterobeltiosis. Against standard check PLP-1, fourteen cross combinations showed significant and desirable positive economic heterosis. UPO-130 × JPO-46 (44.30%), KRR-AK-26 × JPO-46 (27.92%) and Kent × PLP-1 (26.15%) exhibited maximum desirable heterosis for green fodder yield per plant.

For DMY, the extent of heterosis for mid-parent (Table 2) varied from -28.33% to 104.98% and twelve cross combinations showed significant and desirable positive heterosis value. For heterobeltiosis, the magnitude of heterosis ranged from -38.17% to 65.72% and seven cross combinations showed significant and desirable positive heterosis. Against standard check PLP-1, eleven cross combinations exhibited significant desirable positive economic heterosis up to the extent of 65.52% (UPO 130 × JPO 46).

For mid-parent and better parent, magnitude of heterosis for BY (Table 2) varied from -5.90% to 35.21% and -10.50% to 30.52% respectively. Twenty-two cross combinations showed significant desirable mid parental positive heterosis while nine cross combinations showed significant and desirable positive heterobeltiosis. The magnitude of heterosis over check PLP-1 ranged from -9.21% to 24.95%. Ten cross combinations exhibited significant desirable positive economic heterosis. PLP 14 × JPO 46 (24.95%) and Kent × UPO-30 (19.45%) showed maximum desirable standard heterosis for biological yield per plant.

The extent of heterosis for mid-parent for SY (Table 2) ranged from -17.12% to 36.25% and sixteen cross combinations exhibited significant desirable positive heterosis. For heterobeltiosis, the magnitude of heterosis varied from -28.54% to 36.18 and eight cross combinations showed significant desirable positive heterosis over better parent. Against standard check PLP-1, the magnitude of heterosis ranged from -6.39% to 44.88% (HJ 8 × UPO 30) and seventeen cross combinations showed significant and desirable positive economic heterosis. For seed yield per plant, both HJ-8 × UPO-30 (44.88%) and EC-528865 × HFO-52 (40.45%) showed highest standard economic heterosis.

The magnitude of heterosis (Table 2) for mid-parent, better parent and standard check PLP-1 for 100-SW ranged from -31.03% to 41.38%, -34.33% to 26.94% and -27.15% to 59.54%. For mid parent, twelve cross combinations showed significant desirable positive heterosis while six cross combinations showed significant desirable positive heterobeltiosis. Among fifteen cross combinations, HJ-8 × PLP-1 showed highest significant desirable positive heterosis against check PLP-1.

For mid parent, the magnitude of heterosis for HI (Table 3) ranged from -22.07% to 24.05% and six cross combinations showed significant and desirable positive heterosis. The extent of heterosis over better parent varied from -28.14% and only two cross combinations exhibited significant desirable positive heterosis. The magnitude of heterosis over check PLP 1 ranged from -17.65% to 33.80% and fifteen cross combinations showed significant and desirable positive economic heterosis while HJ 8 × UPO 30 exhibited maximum standard heterosis for harvest index.

Quality traits. The extent of heterosis for mid parent, better parent and economic heterosis for CPY-F (Table 3) ranged from -25.73% to 108.06%, -28.72% to 63.89% and -25.03% to 80.13% respectively. For mid parent, fourteen cross combinations showed significant and desirable positive heterosis while seven cross combinations showed significant and desirable positive heterobeltiosis values. Over standard check PLP 1, fourteen cross combinations showed significant and desirable positive economic heterosis. Cross combinations *viz.*, HJ 8 × PLP 1, KRR AK 26 × JPO 46, PLP 14 × HFO-52, UPO 130 × JPO 46, UPO 130 × UPO 30, K 353 × UPO 30 and EC 605834 × UPO 30 were found common for mid parent, better parent and standard heterosis, among which UPO 130 × JPO 46 showed highest crude protein yield-fodder (%).

Table 2: Magnitude of heterosis (%) over mid parent (MP), better parent (BP) and economic heterosis (EC) over standard check PLP-1.

Crosses/ Traits	LSR			GFY			DMY			BY			SY			100-SW		
	MP	BP	EC	MP	BP	EC	MP	BP	EC	MP	BP	EC	MP	BP	EC	MP	BP	EC
EC-528865 × JPO-46	5.83	4.10	30.93 *	8.07	-12.14 *	0.28	14.75	2.78	29.48 *	17.54 *	2.57	14.65 *	-4.18	-19.02 *	11.78 *	-12.75 *	-22.17 *	-1.36
EC-528865 × PLP-1	5.12	-4.24	16.49 *	37.36 *	17.75 *	17.75 *	27.35 *	27.16 *	27.16 *	5.05	-0.48	11.24 *	-17.12 *	-28.54 *	-1.36	28.34 *	14.81 *	45.49 *
EC-528865 × UPO-30	-1.99	-7.52	26.80 *	-24.53 *	-35.64 *	-34.83 *	-28.33 *	-30.50 *	-26.23	-4.70	-7.66	3.21	-1.79	-13.05 *	20.02 *	-1.57	-16.87 *	5.35
EC-528865 × HFO-52	-6.67	-13.14 *	22.68 *	13.74	3.16	-26.30 *	10.34	-13.32	-13.58	0.29	-2.44	9.05	12.80 *	1.75	40.45 *	-10.50 *	-11.55 *	14.78 *
HJ-8 × JPO-46	2.07	0.82	26.80 *	-3.56	-16.94 *	-5.20	-5.03	-18.07	3.21	9.23 *	3.50	-3.67	9.11	3.46	9.95	20.45 *	7.84	35.53 *
HJ-8 × PLP-1	6.48	-3.36	18.56 *	10.08	0.43	0.43	29.70 *	24.10	24.10	7.02	3.31	3.31	-2.77	-5.64	0.28	41.38 *	26.94 *	59.54 *
HJ-8 × UPO-30	-5.56	-10.53 *	22.68 *	2.36	-7.14	-5.97	12.48	4.66	11.09	9.86 *	3.70	8.71	36.25 *	36.18 *	44.88 *	39.17 *	17.93 *	48.22 *
HJ-8 × HFO-52	7.81	0.73	42.27 *	28.54 *	9.59	-9.62	32.79 *	7.76	-1.53	5.94	-0.38	5.29	0.41	-1.73	9.08	-1.76	-3.31	25.47 *
KRR-AK-26 × JPO-46	5.06	0.00	39.18 *	10.73 *	9.42	27.92 *	21.32 *	16.51	46.77 *	7.10	5.28	-9.21	4.66	-1.04	5.80	8.45	-1.90	-2.52
KRR-AK-26 × PLP-1	0.86	-13.33 *	20.62 *	-23.23 *	-28.79 *	-16.74 *	-15.39	-21.22	-8.63	14.30 *	6.43	6.43	-2.47	-5.62	0.90	-1.45	-11.11	-11.11
KRR-AK-26 × UPO-30	0.75	0.00	39.18 *	5.80	-1.28	15.42 *	4.69	0.25	16.27	-0.07	-8.93 *	-4.54	8.24	7.98	15.44 *	21.37 *	16.57 *	1.78
KRR-AK-26 × HFO-52	3.68	2.92	45.36 *	-8.50	-31.49 *	-19.91 *	1.75	-24.15 *	-12.03	5.09	-4.58	0.85	19.05 *	16.85 *	29.71 *	5.24	-14.78 *	10.59
PLP-14 × JPO-46	6.52	-19.67 *	1.03	-0.87	-19.75 *	-8.40	10.78	-4.03	20.89	35.21 *	23.08 *	24.95 *	23.83 *	22.12 *	19.67 *	9.52	4.82	13.94 *
PLP-14 × PLP-1	8.18	-11.34	-11.34	17.76 *	0.49	0.49	20.60	15.95	15.95	-0.35	-1.09	0.41	16.87 *	15.69 *	15.69 *	-0.85	-4.82	3.46
PLP-14 × UPO-30	-3.59	-29.32 *	-3.09	-10.38	-23.92 *	-22.96 *	-13.97	-19.58	-14.65	12.33 *	10.56 *	15.90 *	-0.93	-4.84	1.24	14.33 *	3.09	12.05
PLP-14 × HFO-52	10.55	-19.71 *	13.40 *	89.81 *	73.01 *	22.26 *	104.98 *	65.72 *	52.92 *	-1.82	-3.76	1.71	-8.15	-13.53 *	-4.02	-17.01 *	-23.75 *	-1.05
KRR-AK-15 × JPO-46	-3.11	-10.66 *	12.37	4.74	0.11	14.26 *	-4.42	-14.22	8.06	15.40 *	6.11	5.35	2.07	-9.59 *	11.65 *	13.33 *	11.93	14.05 *
KRR-AK-15 × PLP-1	3.00	0.00	6.19	-7.09	-8.90	-5.22	-2.32	-2.39	-2.25	-5.90	-6.24	-6.24	-3.27	-12.47 *	8.09	0.73	-0.21	1.68
KRR-AK-15 × UPO-30	5.93	-6.02	28.87 *	-10.08	-11.28	-7.70	13.00	9.81	16.55	-1.50	-4.10	0.53	-10.78 *	-16.95 *	2.55	26.09 *	17.08 *	19.29 *
KRR-AK-15 × HFO-52	2.50	-10.22 *	26.80 *	23.44 *	-3.78	0.11	27.81	0.23	0.38	-2.75	-5.70	-0.33	1.52	-3.61	19.03 *	-3.17	-13.57 *	12.16
JPO-36 × JPO-46	-10.91 *	-19.67 *	1.03	-7.93	-19.03 *	-7.59	5.22	-7.32	16.75	19.89 *	16.23 *	3.12	18.01 *	14.97 *	9.54	4.50	-3.27	-3.88
JPO-36 × PLP-1	-4.62	-5.10	-4.12	-16.28 *	-21.89 *	-21.89 *	-15.30	-17.02	-17.02	4.51	-1.39	-1.39	6.91	1.76	1.76	8.92	0.52	0.52
JPO-36 × UPO-30	-8.23	-20.30 *	9.28	0.16	-7.09	-5.92	19.15	13.43	20.39	10.65 *	2.14	7.08	12.80 *	4.30	10.97	27.68 *	25.69 *	9.75
JPO-36 × HFO-52	5.53	-9.49 *	27.84 *	27.50 *	6.57	-7.72	46.98 *	17.10	12.34	14.66 *	5.45	11.45 *	20.77 *	9.54	21.59 *	-11.10 *	-26.58 *	-4.72
Kent × JPO-46	-0.45	-9.02	14.43 *	-19.09 *	-28.28 *	5.92	-27.16 *	-38.17 *	11.63	19.39 *	10.82 *	7.80	11.49 *	7.29	10.56	4.67	4.07	4.61
Kent × PLP-1	6.06	3.96	8.25	1.86	-14.58 *	26.15 *	11.82	-13.12	56.84 *	14.61 *	13.05 *	13.05 *	-1.66	-3.11	-0.16	-12.18 *	-12.41	-11.95
Kent × UPO-30	1.71	-10.53 *	22.68 *	-2.38	-17.72 *	21.51 *	-8.55	-27.39 *	31.08 *	18.21 *	13.95 *	19.45 *	5.36	3.71	10.34	12.95 *	5.53	6.08
Kent × HFO-52	6.72	-7.30	30.93 *	16.51 *	-18.81 *	19.91 *	-0.39	-34.49 *	18.27	12.17 *	7.70	13.83 *	-12.53 *	-15.67 *	-6.39	-8.78	-19.06 *	5.03
UPO-130 × JPO-46	13.66 *	5.74	32.99 *	58.61 *	26.43 *	44.30 *	70.15 *	31.40 *	65.52 *	30.13 *	26.63 *	5.49	25.98 *	23.58 *	22.40 *	-25.61 *	-28.24 *	-23.27 *
UPO-130 × PLP-1	16.83 *	12.38 *	21.65 *	49.14 *	25.14 *	25.14 *	61.80 *	36.39 *	36.39 *	13.25 *	1.26	1.26	-0.90	-1.37	-1.37	-13.48 *	-16.27 *	-10.48
UPO-130 × UPO-30	15.97 *	3.76	42.27 *	40.24 *	17.08 *	18.56 *	52.98 *	25.92 *	33.65 *	2.17	-10.50 *	-6.18	9.59 *	5.80	12.56 *	-24.99 *	-31.86 *	-27.15 *
UPO-130 × HFO-52	10.74 *	-2.19	38.14 *	28.99 *	19.80 *	-18.75 *	41.63*	29.59	-11.11	21.93 *	6.44	12.49 *	-2.45	-7.70	2.45	0.18	-8.64	18.55 *
K-353 × JPO-46	4.56	3.28	29.90 *	3.63	-1.18	12.79 *	-1.82	-7.81	16.14	31.73 *	30.52 *	8.73	7.63	6.27	3.87	11.87 *	-5.33	35.85 *
K-353 × PLP-1	9.26	-0.84	21.65 *	-6.94	-8.53	-5.30	14.49	9.00	20.56	25.26 *	13.85 *	13.85 *	11.31 *	10.05	10.05	-1.51	-16.44 *	19.92 *
K-353 × UPO-30	-1.59	-6.77	27.84 *	10.17	8.96	12.81 *	31.22 *	28.56 *	42.20 *	14.48 *	1.89	6.81	19.33 *	14.47 *	21.79 *	-4.54	-23.23 *	10.17
K-353 × HFO-52	10.16 *	2.92	45.36 *	-10.63	-30.21 *	-27.75 *	16.00	-12.15	-2.83	10.98 *	-1.58	4.02	16.23 *	9.28	21.31 *	-31.03 *	-34.33 *	-5.77
EC-605834 × JPO-46	9.43	-4.92	19.59 *	1.53	-3.02	10.69	-2.94	-4.69	20.06	14.10 *	9.25	-0.53	30.86 *	28.18 *	27.34 *	8.58	1.47	16.04 *
EC-605834 × PLP-1	10.16	6.19	6.19	-23.41 *	-24.86 *	-21.92 *	-22.18 *	-29.04 *	-13.84	-3.64	-7.96	-7.96	9.02	8.67	8.67	14.23 *	7.06	22.43 *
EC-605834 × UPO-30	3.14	-13.53 *	18.56 *	21.45 *	19.90 *	24.59 *	33.62 *	25.21*	52.04 *	-1.43	-7.91	-3.46	2.30	-1.08	5.24	-1.25	-12.92 *	-0.42
EC-605834 × HFO-52	10.13 *	-8.76	28.87 *	7.97	-15.80 *	-12.51 *	17.67	-13.58	4.94	0.60	-6.37	-1.04	9.48 *	3.74	15.15 *	-1.33	-7.19	20.44 *
S.E. ±	**0.02**	**0.02**	**0.02**	**8.76**	**10.11**	**9.55**	**3.54**	**4.09**	**4.04**	**4.04**	**4.66**	**4.88**	**1.13**	**1.30**	**1.30**	**0.18**	**0.20**	**0.21**

(*Significant at 5% level of significance)

For CP-S (Table 3), thirty-five cross combinations showed significant desirable mid parental positive heterosis and five cross combinations showed significant desirable positive heterosis over better parent. For mid parent and better parent, magnitude of heterosis ranged from -1.49% to 13.70% and -12.85% to 7.57% respectively. Against standard check PLP-1, the level of heterosis ranged from -8.58% to 14.28% and seventeen cross combinations showed significant and desirable positive standard heterosis. HJ 8 × HFO 52, EC 528865 × PLP 1 and KRR AK 15 × PLP 1 exhibited highest crude protein content-seed (%).

The magnitude of heterosis for mid-parent, better parent and standard heterosis for ADF (Table 3) ranged from -35.47% to 52.89%, -41.28% to 51.03% and -37.45% (to 24.80% respectively. Ten cross combinations exhibited significant and desirable negative mid parental heterosis while seventeen cross combinations exhibited significant desirable negative heterobeltiosis. UPO 130 × HFO 52 (-37.45%), Kent × UPO-30 (-31.53%) and HJ-8 × JPO-46 (-29.42 %) showed lowest desirable acid detergent fibre content over standard check PLP-1.

For mid-parent, the level of heterosis for NDF (Table 3) varied from -26.09% to 31.72% and nine cross combinations exhibited significant desirable negative heterosis. The magnitude of heterosis over better parent ranged from -30.10% to 19.95% and significant desirable negative heterobeltiosis was observed for twelve cross combinations. Against check PLP 1, HJ 8 × UPO 30 (-29.60%), PLP-14 × JPO-46 (-28.26%) and UPO-130 × PLP-1 (-26.47%) exhibited lowest neutral detergent fibre.

The magnitude of heterosis for mid-parent and better parent for BG (Table 3) ranged from -9.21% to 21.81% and -23.58% to 13.37% respectively. Twenty-six cross combinations showed significant and desirable positive mid parental heterosis while seven cross combinations showed significant desirable positive heterobeltiosis. The magnitude of heterosis over check PLP-1 ranged from 2.47% (KRR AK 26 × UPO 30) to 74.89% (PLP 14 × JPO 46). Out of thirty-five cross combinations, PLP 14 × JPO 46 (74.89%), HJ 8 × JPO 46 (70.96%), HJ 8 × HFO 52 (70.29%), PLP 14 × HFO 52 (70.29%) and Kent × JPO 46 (68.50%) showed significant desirable positive and highest values of β-glucan content against standard check PLP-1.

Disease reaction. The reaction of parents and hybrids to powdery mildew incidence (*Blumeria graminis* f. sp. *avenae)* under field conditions (Table 4) was graded using visual observations on a scale of 0 to 9 (Mayee and Datar 1986).

Among parents, KRR-AK-26, JPO-46 and PLP-1 showed resistance to the disease with severity and rating value of 1 amongst the experimental material. Singh (2018) also found PLP-1 as resistant to powdery mildew. Among crosses, three hybrids KRR-AK-26 × JPO-46, KRR-AK-26 × PLP-1 and KRR-AK-15 × PLP-1 were found resistant to powdery mildew, whereas twenty-one cross combinations were found to be moderately resistant to the pathogen. Earlier workers Aung *et al.* 1976; Sebesta *et al.* 2000; Yu and Hermann 2006, have also stated similar observations and concluded that the inheritance was monogenic and dominant.

CONCLUSION

Comparative studies of all 40 F_1 hybrids revealed higher values in relation to parents. However, none of the hybrids exhibited desired standard heterosis, relative heterosis and heterobeltiosis for all the traits. Among all the traits, HJ-8 × UPO-30 showed highest SY followed by KRR-AK-26 × HFO-52 and PLP-14 × JPO-46. For GFY, EC-528865 × PLP-1 and PLP-14 × HFO-52 showed highest positive heterosis. HJ-8 × JPO-46 and UPO-130 × PLP-1 exhibited desirable ADF and NDF for quality fodder intake while HJ-8 × JPO-46, HJ-8 × HFO-52 and KRR-AK-26 × PLP-1 showed highest BG among all the 40 hybrid combinations. Overall, UPO-130 × JPO-46 showed promising heterosis among all 40 F_1 cross combinations for GFY, SY and CPY-F as compared to check PLP-1, whereas KRR-AK-26 × JPO-46 showed significant beneficial heterosis for 50%F, GFY and CPY-F. Therefore, based on mean performance, heterosis studies and resistance to powdery mildew under epiphytotic conditions, cross combinations KRR-AK-26 × JPO-46, Kent × JPO-46 and PLP-14 × UPO-30 were found best and showed promising results for different agro-morphological, yield attributing and quality traits. However, it is suggested that multiple crosses between potential lines and testers involved in the crosses may be attempted so that the transgressive segregants could be identified in the later generations of such crosses. Thus, these hybrids can be evaluated at multilocation trials and further commercially exploited through heterosis breeding programmes. The results from this present investigation will be extremely beneficial in formulating studies related to identification of potential cross combinations and designing future hybridization breeding programs for oat improvement.

Table 3: Magnitude of heterosis (%) over mid parent (MP), better parent (BP) and economic heterosis (EC) over standard check PLP-1.

Crosses/ Traits	HI			CPY-F			CF-S			ADF			NDF			BG		
	MP	BP	EC	MP	BP	EC	MP	BP	EC	MP	BP	EC	MP	BP	EC	MP	BP	EC
EC-528865 × JPO-46	-18.08 *	-21.10 *	-2.56	16.02	4.37	30.60 *	5.82 *	-1.50	-1.5	-9.64 *	-25.02 *	-10.64 *	12.85 *	-2.29	0.28	-4.71	-22.05 *	21.30 *
EC-528865 × PLP-1	-20.58 *	-28.14 *	-11.25	27.87 *	18.62	38.70 *	5.41 *	5.30 *	5.52 *	-11.50 *	-18.62 *	-3.01	12.37 *	-1.62	-1.62	7.27	6.73	6.73
EC-528865 × UPO-30	3.49	-5.67	16.51 *	-25.54 *	-26.04	-25.03	9.20 *	2.98	2.98	7.46 *	-9.01 *	8.43 *	-12.62 *	-23.24 *	-23.84 *	5.55	4.43	5.61
EC-528865 × HFO-52	12.94 *	4.59	29.18 *	12.23	-11.25	-11.25	5.81 *	3.80	7.91 *	-16.67 *	-27.80 *	-13.96 *	-1.30	-8.84 *	-19.19 *	19.68 *	2.25	42.83 *
HJ-8 × JPO-46	0.16	0.03	14.41	4.87	-7.65	15.56	-1.49	-12.85 *	-2.39	-17.34 *	-23.42 *	-29.42 *	-23.16 *	-27.64 *	-25.74 *	8.27 *	6.72 *	70.96 *
HJ-8 × PLP-1	-9.37	-14.96 *	-2.99	44.10 *	30.76 *	52.89 *	1.56	-3.79	7.76 *	-13.17 *	-16.57 *	-16.57 *	1.73	-3.02	-3.02	2.63	-16.66 *	33.52 *
HJ-8 × UPO-30	24.05 *	17.29 *	33.80 *	20.96	17.32	18.93	9.43 *	-2.00	9.76 *	24.18 *	17.76 *	8.53 *	-25.85 *	-29.05 *	-29.60 *	21.24 *	-1.12	58.41 *
HJ-8 × HFO-52	-5.31	-8.97	3.84	34.89 *	8.61	3.47	5.83 *	2.03	14.28 *	-2.57	-5.12 *	-12.55 *	9.99 *	8.77 *	-1.40	13.57 *	6.30 *	70.29 *
KRR-AK-26 × JPO-46	-2.37	-6.22	16.45 *	25.41 *	22.40 *	60.88 *	9.62 *	4.47	-0.65	19.83 *	9.96 *	-13.55 *	7.59 *	-2.56	0.00	10.84 *	-0.22	55.27 *
KRR-AK-26 × PLP-1	-14.92 *	-23.20 *	-4.64	-12.28	-17.12	8.94	5.12 *	2.44	2.65	25.33 *	3.82	3.82	2.05	-6.49	-6.49	19.92 *	8.10 *	34.64 *
KRR-AK-26 × UPO-30	7.38	-2.36	21.24 *	12.74	-0.16	31.23 *	7.19 *	3.54	-1.53	7.92 *	-3.16	-19.98 *	9.41 *	0.62	-0.17	-9.19 *	-17.73 *	2.47
KRR-AK-26 × HFO-52	12.81 *	4.22	29.41 *	-1.16	-28.72 *	-6.31	5.19 *	0.71	4.69 *	2.23	-10.46 *	-21.79 *	-12.04 *	-14.71 *	-24.40 *	9.89 *	3.93	45.18 *
PLP-14 × JPO-46	-8.56	-15.74 *	-3.62	9.53	-1.01	23.87	6.71 *	6.09 *	-8.58 *	32.87 *	21.33 *	-4.62 *	-26.09 *	-30.10 *	-28.26 *	7.44 *	2.90	74.89 *
PLP-14 × PLP-1	17.31 *	15.21 *	15.21 *	12.01	4.41	22.08	6.05 *	-1.91	-1.71	32.44 *	9.24 *	9.24 *	-19.70 *	-23.11 *	-23.11 *	9.72 *	-12.86 *	48.09 *
PLP-14 × UPO-30	-11.87	-14.13	-12.72	-13.77	-13.9	-12.72	5.86 *	3.79	-8.02 *	25.58 *	12.15 *	-7.33 *	-20.13 *	-23.24 *	-23.84 *	21.09 *	-3.43	64.13 *
PLP-14 × HFO-52	-6.44	-10.37	-5.66	108.06 *	63.89 *	65.62 *	4.57 *	-4.88 *	-1.12	29.86 *	13.22 *	-1.10	-3.26	-4.77	-12.87 *	9.99 *	0.20	70.29 *
KRR-AK-15 × JPO-46	-11.28 *	-14.97 *	6.09	-1.75	-10.34	12.2	9.44 *	0.54	3.45	38.60 *	32.31 *	4.02 *	10.73 *	-0.98	1.62	14.30 *	2.52	59.53 *
KRR-AK-15 × PLP-1	2.69	-7.50	15.41 *	-0.19	-6.03	9.88	6.09 *	4.70 *	7.73 *	5.74 *	-9.34 *	-9.34 *	4.73	-5.26	-5.26	15.55 *	4.54	29.15 *
KRR-AK-15 × UPO-30	-8.58	-17.05 *	3.50	14.8	13.75	17.46	11.52 *	3.78	6.78 *	0.07	-6.68 *	-22.89 *	16.00 *	5.30	4.48	4.59	-4.90	17.49 *
KRR-AK-15 × HFO-52	4.13	-4.01	19.76 *	26.25	-1.32	1.89	4.96 *	4.43	8.55 *	4.42 *	-5.06 *	-17.07 *	-3.37	-7.58	-18.07 *	8.43 *	2.17	42.71 *
JPO-36 × JPO-46	-1.91	-7.14	6.21	9.21	3.11	29.02	13.70 *	3.12	9.17 *	31.33 *	19.92 *	-5.72 *	15.47 *	-1.31	1.29	17.21 *	2.81	59.98 *
JPO-36 × PLP-1	2.06	0.97	3.18	-15.35	-17.45	-3.47	6.21 *	3.37	9.44 *	41.81 *	16.97 *	16.97 *	8.23 *	-6.49	-6.49	18.93 *	10.12 *	29.26 *
JPO-36 × UPO-30	1.76	1.49	3.71	29.54 *	23.84	37.64 *	8.81 *	-0.06	5.81 *	13.74 *	1.58	-16.06 *	7.81 *	-6.54	-7.27	21.81 *	13.37 *	33.07 *
JPO-36 × HFO-52	5.30	3.76	9.22	52.55 *	16.18	29.13	3.58	2.65	8.67 *	4.28	-9.08 *	-20.58 *	31.72 *	19.95 *	6.32	9.11 *	0.40	40.25 *
Kent × JPO-46	-6.57	-9.96	2.99	-24.09 *	-36.88 *	19.14	8.73 *	3.33	-1.15	34.50 *	32.18 *	7.63 *	2.38	-0.16	2.46	11.33 *	8.29 *	68.50 *
Kent × PLP-1	-14.07 *	-16.53 *	-11.45	17.03 *	-5.24	78.86 *	3.98	1.62	1.83	-4.59 *	-13.45 *	-13.45 *	0.00	-1.23	-1.23	-2.09	-17.76 *	20.96 *
Kent × UPO-30	-10.91	-12.77	-7.46	-0.33	-23.40 *	44.58 *	7.25 *	3.30	-1.18	-16.52 *	-17.13 *	-31.53 *	-11.66 *	-12.41 *	-13.09 *	-9.21 *	-23.40 *	12.67 *
Kent × HFO-52	-22.07 *	-22.37 *	-17.65 *	4.00	-31.98 *	28.39	6.58 *	2.33	6.37 *	8.74 *	5.06 *	-8.23 *	8.87 *	3.90	1.34	6.49 *	3.81	52.69 *
UPO-130 × JPO-46	-3.72	-8.41	16.06 *	85.39 *	43.95 *	80.13 *	11.50 *	7.57 *	-0.29	20.61 *	4.81 *	11.65 *	-2.41	-11.78 *	-9.46 *	20.69 *	-1.87	52.69 *
UPO-130 × PLP-1	-13.89 *	-22.97 *	-2.39	73.67 *	38.22 *	61.62 *	6.29 *	2.3	2.51	-16.87 *	-19.42 *	-14.16 *	-19.61 *	-26.47 *	-26.47 *	11.98 *	10.54 *	10.54 *
UPO-130 × UPO-30	5.43	-5.00	20.38 *	68.56 *	41.80 *	43.74 *	7.48 *	5.12 *	-2.57	15.82 *	2.83	9.54 *	8.19 *	-0.69	-1.47	6.38	4.43	5.61
UPO-130 × HFO-52	-21.36 *	-28.01 *	-8.79	45.66 *	34.04	-7.26	5.76 *	0.03	3.98 *	-35.47 *	-41.28 *	-37.45 *	21.98 *	18.06 *	4.64	10.45 *	-6.26	30.94 *
K-353 × JPO-46	-18.11 *	-19.91 *	-4.18	2.10	-6.22	17.35	5.89 *	0.93	-4.04 *	-1.39	-2.62	-21.49 *	2.46	-4.58	-2.07	-8.91 *	-10.22 *	43.83 *
K-353 × PLP-1	-11.57	-18.83 *	-2.88	15.28	9.26	27.76	5.23 *	2.53	2.74	24.51 *	12.45 *	12.45 *	1.28	-4.53	-4.53	-5.90 *	-23.58 *	22.42 *
K-353 × UPO-30	3.40	-4.38	14.41	34.59 *	32.43 *	38.70 *	7.69 *	4.03	-1.09	52.89 *	51.03 *	24.80 *	0.63	-4.79	-5.54	-3.05	-20.92 *	26.68 *
K-353 × HFO-52	3.99	-2.27	16.94 *	21.24	-5.72	-1.26	1.76	-2.58	1.27	26.00 *	21.15 *	5.82 *	-2.72	-2.78	-13.82 *	2.88	-3.71	54.26 *
EC-605834 × JPO-46	15.03 *	12.44	28.61 *	-1.61	-5.43	28.29	9.87 *	2.87	1.59	-6.09 *	-8.59 *	-24.10 *	-3.21	-12.00 *	-9.68 *	19.88 *	2.52	59.53 *
EC-605834 × PLP-1	12.91 *	8.14	18.11 *	-25.73 *	-30.85 *	-6.2	5.23 *	4.47	4.69 *	32.53 *	21.29 *	21.29 *	6.08	-2.41	-2.41	9.48 *	4.26	15.25 *
EC-605834 × UPO-30	3.52	-0.07	9.14	42.06 *	24.11 *	68.35 *	5.57 *	0.15	-1.09	39.64 *	39.30 *	15.66 *	8.80 *	0.45	-0.34	-2.22	-6.39	3.48
EC-605834 × HFO-52	8.80	6.83	16.68 *	15.90	-17.21	12.3	4.77 *	2.16	6.19 *	20.80 *	17.82 *	2.91	9.37 *	6.50	-5.60	13.89 *	2.01	42.49 *
S.E. ±	1.43	1.66	1.60	0.40	0.47	0.47	0.23	0.27	0.22	0.59	0.68	0.65	1.90	2.19	2.42	0.12	0.13	0.14

(*Significant at 5% level of significance)

Table 4: Reaction of parents and hybrids to powdery mildew incidence on a scale of 0 to 9 (Mayee and Datar 1991).

Parents/Crosses	Severity	Rating	Disease Reaction	Crosses	Severity	Rating	Disease Reaction
EC 528865	10	3	Moderately Resistant	**PLP 14 × PLP 1**	6	**3**	Moderately Resistant
HJ 8	80	9	Highly susceptible	**PLP 14 × UPO 30**	7	**3**	Moderately Resistant
KRR AK 26	1	1	Resistant	**PLP 14 × HFO-52**	16	**7**	Susceptible
PLP 14	8	3	Moderately Resistant	**KRR AK 15 × JPO 46**	8	**3**	Moderately Resistant
KRR AK 15	10	3	Moderately Resistant	**KRR AK 15 × PLP 1**	1	**1**	Resistant
JPO 36	22	5	Moderately Susceptible	**KRR AK 15 × UPO 30**	4	**3**	Moderately Resistant
Kent	20	5	Moderately Susceptible	**KRR AK 15 × HFO-52**	20	**5**	Moderately Susceptible
UPO 130	55	9	Highly susceptible	**JPO 36 × JPO 46**	14	**5**	Moderately Susceptible
K 353	40	7	Susceptible	**JPO 36 × PLP 1**	10	**3**	Moderately Resistant
EC 605834	8	3	Moderately Resistant	**JPO 36 × UPO 30**	8	**3**	Moderately Resistance
JPO 46	1	1	Resistant	**JPO 36 × HFO-52**	34	**7**	Susceptible
PLP 1	1	1	Resistant	**Kent × JPO 46**	7	**3**	Moderately Resistant
UPO 30	6	3	Moderately Resistant	**Kent × PLP 1**	10	**3**	Moderately Resistant
HFO 52	35	7	Susceptible	**Kent × UPO 30**	15	**5**	Moderately Susceptible
EC 528865 × JPO 46	6	3	Moderately Resistant	**Kent × HFO-52**	44	**7**	Susceptible
EC 528865 × PLP 1	8	3	Moderately Resistant	**UPO 130 × JPO 46**	10	**3**	Moderately Resistant
EC 528865 × UPO 30	6	3	Moderately Resistant	**UPO 130 × PLP 1**	18	**5**	Moderately Susceptible
EC 528865 × HFO-52	18	5	Moderately Susceptible	**UPO 130 × UPO 30**	42	**7**	Susceptible
HJ 8 × JPO 46	22	5	Moderately Susceptible	**UPO 130 × HFO-52**	78	**9**	Highly susceptible
HJ 8 × PLP 1	20	3	Moderately Resistant	**K 353 × JPO 46**	36	**7**	Susceptible
HJ 8 × UPO 30	65	7	Susceptible	**K 353 × PLP 1**	22	**5**	Moderately Susceptible
HJ 8 × HFO-52	88	9	Highly susceptible	**K 353 × UPO 30**	6	**3**	Moderately Resistant
KRR AK 26 × JPO 46	1	1	Resistant	**K 353 × HFO-52**	28	**7**	Susceptible
KRR AK 26 × PLP 1	1	1	Resistant	**EC 605834 × JPO 46**	10	**3**	Moderately Resistant
KRR AK 26 × UPO 30	5	3	Moderately Resistant	**EC 605834 × PLP 1**	8	**3**	Moderately Resistant
KRR AK 26 × HFO-52	8	3	Moderately Resistant	**EC 605834 × UPO 30**	10	**3**	Moderately Resistant
PLP 14 × JPO 46	8	3	Moderately Resistant	**EC 605834 × HFO-52**	22	**5**	Moderately Susceptible

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Conflict of Interest. None.

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