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Heterosis for fodder and seed yield traits in common oat (*Avena sativa* L.)

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Abstract

The manifestation of heterosis has brought an economic revolution to the agricultural production and seed sector in the last few decades. The present research was examined to estimate the comparative performance of newly developed F_1 crosses of oat with commercially used modern oat cultivars in North-western Himalayan regions. Forty hybrids were developed using 10 female and 4 male parental lines of oat during *Rabi*, 2021-22. These crosses were evaluated in Randomized Complete Block design with three replications along with 3 checks during *Rabi* 2022-23 at CSK Himachal Pradesh Agricultural University, Palampur. Thirteen seed and fodder yield traits were analyzed for heterosis. The oat hybrids showed heterotic superiority up to -9.50% for earliness, 36.79% higher number of leaves, 67.51% higher number of tillers and 44.38% increment in plant height over the best commercial check. For green fodder yield and dry matter yield, heterosis was observed up to 117.78% and 141.94%, respectively. The magnitude of heterosis for seed yield per plant over the best check HJ-8 ranged from -26.68% to 44.49%. Conclusively, based upon earliness, high seed yield, plant height and fodder yield per plant, five cross combinations viz., PO-1×JHO-851, OS-6×HFO-114, PO-1×UPO-212, JHO-813×JHO-851 and OS-377×JHO-851 were adjudged to be the best.

Keywords: Oat, Heterosis, Green fodder yield, Seed yield

Oat (*Avena sativa* L.) is one of the most important nutricereal fodder crop grown during *Rabi* season in many parts of the country including North Western, Central, and extending up to the parts of Eastern India (Kumar *et al*. 2022; Sood *et al*. 2022). In India, oat is cultivated in Himalayan states like Punjab, Haryana, Uttar Pradesh, Madhya Pradesh, Kashmir, Himachal Pradesh, some parts of Maharashtra and Uttarakhand (Kumar *et al*. 2022). Cultivation of oat offers numerous benefits, including nutritional value, versatility, adaptability to different growing conditions, and contributions to soil health and sustainability (Sanadya *et al*. 2023). These factors contribute to oats' status as an important cereal crop worldwide. Oats are a highly nutritious grain and are commonly incorporated into the human diet in various forms due to their versatility and health benefits. For human food oat groat is desired, which is high in protein, β-glucan and low in oil, whereas high oil and low β-glucan with the high protein is desired for livestock feed to maximize the energy (Peterson *et al*., 2005 and Sood *et al*., 2022). Ongoing research and innovations in oat breeding and agronomy could contribute to improved productivity and resilience in the face of environmental challenges (Sanadya *et al*., 2024).

Heterosis, commonly known as hybrid vigor, plays a crucial role in crop production. Exploitation of heterosis has been recognized as an essential tool in providing the breeders means for improving yield and related attributes of different crops (Sood *et al*. 2022). Oats are an essential cereal crop globally, valued for their nutritional content and versatility. Heterosis plays a vital role in oat crop improvement by enhancing yield potential, genetic diversity, disease resistance, grain quality, and overall stability. Incorporating hybridization techniques into oat breeding programs contributes to sustainable agricultural practices and ensures the continued success of oat cultivation in meeting global food and nutrition demands.

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Identification of parents and elite cross-combinations with high yield and other related traits is the major objective(s) of any breeding programme (Lata *et al*. 2023). 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 (Kumar *et al*. 2022 and Rana *et al*. 2021). In oat, heterosis has been reported by several researchers *viz.,* Vishwakarma *et al*. 2010; Kapoor and Bajaj, 2013; Mishra *et al*. 2014 and Dumlupinar *et al*., 2015. Top of FormAnother important aspect from the practical point of view, which needs consideration, is the identification of potential cross combinations with respect to seed yield and its related traits and superior recombinants in the segregating generations based on their heterotic performance and combining ability (Sharma *et al*. 2007). Recently, a considerable attention has been paid to increase the yield potential by the possible use of heterosis in autogamous crops. Taking the importance of heterosis in consideration, the present research was undertaken to determine the heterotic potential of newly developed oat cross combinations.

Materials and Methods

The experiment comprised 40 F_1 hybrids developed by crossing 10 female lines with 4 male lines during *Rabi* 2021-22. The detail of parents and checks used in the present study is given in Table 1. These crosses along with three commercial checks *viz*., HJ-8, Kent and PLP-24 were evaluated in Randomized Complete Block design with three replications during *Rabi*, 2022-23.

Each entry was raised in two rows of 1.7 m length with 30 cm row to row and 10 cm plant to plant distance. One row was utilized for recording fodder yield while another one was used for seed yield. The crop was raised following the recommended package of practices under irrigated conditions. The location of experiment is situated in the mid-hill zone of Himachal Pradesh (Zone-II) and represents humid sub-temperate climate with high average annual rainfall (2500 mm per annum). Data were recorded for thirteen agro-morphological and fodder yield traits *viz.,* days to 50% flowering, number of leaves per plant, number of tillers per plant, flag leaf area (cm^2), leaf:stem ratio, plant height (cm), green fodder yield per plant (g), dry matter yield per plant (g), days to 75% maturity, biological yield per plant (g), seed yield per plant (g), harvest index (%) and 100-seed weight (g). Observations for days to 50% flowering and days to 75% maturity were recorded on plot basis while for remaining traits five randomly tagged plants were selected and averaged them for analysis and interpretation.

Data was analyzed to estimate of heterosis over best commercial check (selected based on mean performance) and tested the significance of heterosis for all traits studied. The 't' calculated values for heterosis over standard check (SC) were compared

Table 1. Oat genotypes used in the study

S. No.	Female Genotypes	Source	S. No.	Male Genotypes	Source
1.	OS-6	CCS HAU, Hisar	**1.**	PLP-1	CSKHPKV, Palampur
2.	RO-19	MPKV, Rahuri	**2.**	UPO-212	GBPUAT, Pantnagar
3.	PO-1	NBPGR, New Delhi	**3.**	HFO-114	CCS HAU, Hisar
4.	EC-608834	NBPGR, New Delhi	**4.**	JHO-851	IGFRI, Jhansi
5.	JPO-29	JNKVV, Jabalpur			
6.	JHO-813	IGFRI, Jhansi	**Checks**		
7.	RO-11-1	MPKV, Rahuri	**1.**	HJ-8	CCS HAU, Hisar
8.	OS-377	CCS HAU, Hisar	**2.**	Kent	PAU, Ludhiana
9.	OS-403	CCS HAU, Hisar	**3.**	PLP-24	CSKHPKV, Palampur
10.	TRS-106	NBPGR, New Delhi			

with 't' tabulated values at error degree of freedom at 5% of level of significance. The 't' calculated ≥ 't' tabulated values were marked significant and an asterisk (*) was put on per cent values. The standard heterosis was estimated as per the procedure suggested by Liang *et. al*. (1971).

Results and Discussion

The analysis of variance for the experimental design revealed that mean sum of squares due to genotypes were significant for all the thirteen agro-morphological traits. This indicated the presence of sufficient genetic variability among the studied genotypes (Table 2).

The estimation of heterosis would be useful to judge the best hybrid combinations for exploitation of superior hybrids (Al-Juhaishi *et al*. 2020; Garkoti and Pandey 2022). The heterosis responses in oat are not well defined. The difficulty of crossbreeding for producing large numbers of F_1 seeds prompted most researchers to compare the performance of the F_1 hybrid and their parents in space-grown populations (Murphy 1966). In the present study, three check varieties *viz.,* HJ-8, Kent and PLP-24 were used to calculate standard heterosis (economic heterosis) of forty newly developed oat crosses for seed and fodder yield traits. The values of heterosis (%) for all the studied traits are given in Table 3 and Figure 1.

The magnitude of heterosis for days to 50% flowering over the best check (PLP-24) ranged from -9.50% to 10.00%. The significant negative heterotic

Table 2. Analysis of variance for various agro-morphological traits

	Source of variance		Replication	Genotypes	Error
S. No.	**Traits**	**d.f.**	**2**	**56**	**112**
1.	Days to 50% flowering		9.8	111.56*	13.71
2.	Number of leaves per plant		31.03	1428.54*	26.27
3.	Number of tillers per plant		2.39	36.01*	0.65
4.	Flag leaf area		15.28	578.90*	8.56
5.	Leaf:stem ratio		0.0001	0.013*	0.001
6.	Plant height		1.6	1936.92*	10.38
7.	Green fodder yield per plant		12.87	11159.41*	136.87
8.	Dry matter yield per plant		1.58	759.03*	12.08
9.	Days to 75% maturity		93.81	118.65*	19.67
10.	Biological yield per plant		27.27	1878.26*	66.89
11.	Seed yield per plant		2.69	129.34*	7.1
12.	Harvest index		8.17	62.27*	12.61
13.	100 seed weight		0.001	1.76*	0.01

*** Significant at P d≤ 0.05**

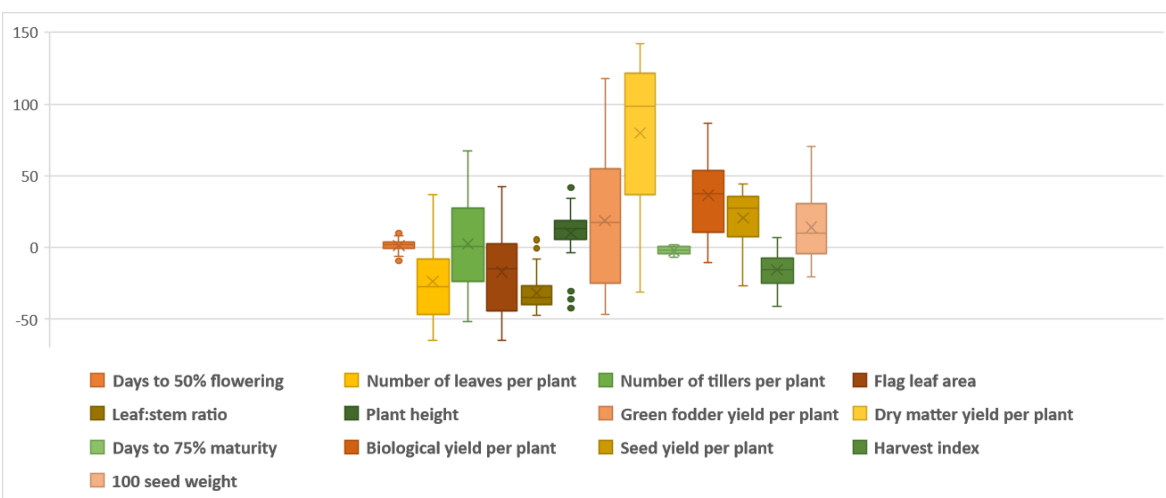

Figure 1- Box plot representation of heterosis magnitude for 13 yield traits

Table 3. Estimates of standard heterosis (%) over best check for various agro-morphological traits

Traits	DTF (PLP-24)	NOL (Kent)	NOT (Kent)	FLA (PLP-24)	LSR (Kent)	PH (PLP-24)	GFY (Kent)	DMY (Kent)	DTM (HJ-8)	BYP (HJ-8)	SYP (HJ-8)	HI (Kent)	SW (HJ-8)
OS-6×PLP-1	0.75	-65.10*	-50.89*	-3.42	-27.27*	-0.89	-16.48*	99.08*	-3.68	6.16	17.35*	3.98	41.74*
OS-6×UPO-212	-9.50*	23.88*	59.05*	9.52	-41.67*	18.89*	64.81*	126.24*	-3.86	1.85	6.40	-0.75	15.79*
OS-6×HFO-114	1.50	8.63	51.05*	-12.52*	-14.39*	16.79*	106.52*	139.07*	-5.33*	5.9	16.95*	4.96	40.26*
OS-6×JHO-851	8.25*	36.79*	67.51*	0.50	-31.06*	12.46*	71.38*	130.09*	-2.57	35.62*	28.25*	-11.17	2.59
RO-19×PLP-1	2.50	-28.73*	-1.82	-9.66	-47.73*	18.69*	-40.78*	3.14	-4.78*	5.47	-26.68*	-34.70*	4.99*
RO-19×UPO-212	3.75	-9.20	-6.03	-37.92*	-25.00*	17.78*	37.59*	116.30*	-4.41*	-4.83	-14.40	-15.40*	-4.25
RO-19×HFO-114	6.25*	27.98*	52.56*	-43.30*	-43.18*	25.68*	76.48*	141.94*	0.00	2.88	-14.40	-21.70*	-4.71*
RO-19×JHO-851	7.50*	-7.57	18.22*	-12.71*	-39.39*	8.66*	58.91*	127.35*	-0.55	46.95*	38.23*	-11.46	-20.50*
PO-1×PLP-1	1.75	-11.85*	18.25*	27.56*	-35.61*	44.38*	68.92*	134.92*	-5.51*	74.66*	33.74*	-27.91*	9.23*
PO-1×UPO-212	4.00	-20.62*	-12.16*	-8.13	-40.15*	26.90*	-26.76*	73.98*	-6.25*	51.77*	41.15*	-12.79	1.20
PO-1×HFO-114	0.25	-60.52*	-45.44*	-36.04*	-26.52*	5.62*	-35.31*	33.81*	-6.07*	45.75*	21.51*	-21.58*	-10.34*
PO-1×JHO-851	2.25	27.20*	39.41*	42.57*	-47.73*	32.22*	88.50*	134.10*	-4.04	86.70*	44.49*	-27.00*	18.28*
EC608834×PLP-1	1.00	14.04*	48.53*	-38.95*	-32.58*	20.06*	48.04*	107.41*	-2.94	60.80*	40.04*	-17.33*	3.79
EC608834×UPO-212	-6.75*	-16.78*	25.04*	-54.07*	-45.45*	13.22*	32.88*	119.26*	-1.47	55.64*	37.30*	-16.64*	-20.22*
EC608834×HFO-114	0.25	-35.53*	-27.25*	-47.84*	-34.09*	14.44*	28.09*	99.93*	1.65	27.33*	-0.59	-26.34*	4.71*
EC608834×JHO-851	-1.00	-26.32*	-18.16*	-20.07*	-35.61*	15.07*	37.17*	97.65*	1.29	38.18*	18.36*	-19.25*	-15.79*
JPO-29×PLP-1	-6.75*	-26.32*	4.61	-50.88*	-21.21*	34.50*	-33.36*	-6.31	-2.21	33.78*	-5.08	-32.24*	-5.17*
JPO-29×UPO-212	-4.50*	-35.09*	12.12*	-56.54*	-37.12*	41.72*	-20.60*	35.85*	-0.92	62.61*	28.65*	-24.74*	23.18*
JPO-29×HFO-114	10.00*	4.61	31.86*	-16.30*	-35.61*	-3.50	5.59	51.51*	1.10	-3.31	9.90	6.65	-11.54*
JPO-29×JHO-851	-3.75	-18.42*	36.44*	-49.75*	-38.64*	-3.64	-2.14	112.38*	-0.18	54.34*	10.98	-32.41*	-7.02*
JHO-813×PLP-1	1.50	-42.54*	-30.25*	-16.69*	-10.61*	9.80*	-38.93*	88.04*	0.55	34.75*	34.78*	-5.99	5.91*
JHO-813×UPO-212	2.50	-22.37*	4.61	20.31*	-40.15*	10.18*	48.93*	110.36*	-0.18	31.35*	38.58*	-0.26	60.30*
JHO-813×HFO-114	3.25	-23.68*	11.37	-44.66*	-33.33*	-1.98	38.93*	102.47*	1.29	80.68*	31.71*	-31.23*	70.27*
JHO-813×JHO-851	-3.50	-20.06*	2.33	-2.59	-41.67*	14.49*	38.60*	95.29*	-4.41*	36.33*	29.71*	-10.71	16.53*

RO-11-1×PLP-1	1.00	-58.78*	-51.53*	-42.13*	-36.36*	8.29*	8.00	75.20*	0.18	-5.37	-1.22	-1.81	6.93*
RO-11-1×UPO-212	2.50	-39.47*	-27.25*	-60.95*	-46.21*	11.89*	14.1	113.59*	1.29	30.72*	-17.75*	-40.93*	-7.48*
RO-11-1×HFO-114	3.75	-58.22*	-27.25*	-36.64*	-34.85*	21.58*	-44.24*	-11.26	0.55	58.03*	31.29*	-20.89*	45.89*
RO-11-1×JHO-851	6.00*	-47.37*	-9.03	-38.46*	-25.76*	13.22*	20.54*	90.06*	0.00	68.63*	39.81*	-21.68*	-1.94
OS-377×PLP-1	-6.25*	-59.64*	-24.25*	-65.22*	-28.03*	5.24*	-46.57*	-31.27*	-6.43*	38.73*	35.50*	-8.01	-6.56*
OS-377×UPO-212	-8.25*	-35.52*	4.61	-48.56*	-40.15*	13.22*	-45.28*	-16.81	-3.49	43.53*	26.55*	-17.13*	10.53*
OS-377×HFO-114	2.50	-39.47*	-9.06	-55.64*	-41.67*	3.57	-13.14	39.01*	-4.41*	23.24*	10.94	-15.25*	30.75*
OS-377×JHO-851	4.25	30.26*	54.59*	32.07*	-34.09*	18.35*	117.78*	136.37*	-7.17*	69.73*	26.62*	-29.86*	10.06*
OS-403×PLP-1	2.75	-44.73*	-27.28*	2.75	-30.30*	16.43*	56.20*	116.60*	-6.07*	42.68*	14.15	-24.69*	12.47*
OS-403×UPO-212	2.5	15.79*	28.22*	-4.18	-39.39*	14.44*	8.02	90.93*	-5.15*	4.57	0.77	-9.49	11.17*
OS-403×HFO-114	2.75	-43.42*	-15.85*	37.68*	-40.91*	12.72*	74.68*	124.49*	0.55	33.28*	31.32*	-7.70	42.66*
OS-403×JHO-851	0.25	-30.26*	9.12	27.44*	-32.58*	11.33*	51.53*	122.66*	1.29	30.28*	34.74*	-2.97	45.71*
TRS-106×PLP-1	-0.75	-47.37*	-18.13*	22.52*	-8.33	-36.45*	14.49	97.58*	-4.04	-10.37	2.12	6.89	30.01*
TRS-106×UPO-212	0.75	-54.60*	-13.64*	-13.24*	-15.15*	-42.25*	-19.94*	28.95*	-0.18	52.38*	38.20*	-14.71	30.47*
TRS-106×HFO-114	1.75	-47.36*	-21.16*	23.64*	5.30	-30.47*	-43.06*	-26.90*	1.1	50.57*	42.03*	-11.6	44.04*
TRS-106×JHO-851	6.00*	-60.52*	-45.44*	-3.3	-0.76	-39.82*	-43.09*	-28.63*	0.55	48.63*	33.81*	-15.37*	36.01*
SE ±	2.08	3.02	0.45	1.74	0.01	1.89	7.16	2.14	2.62	5.01	1.63	2.01	0.06

DTF: Days to 50% flowering, NOL: Number of leaves per plant, NOT: Number of tillers per plant, FLA: Flag leaf area, LSR: Leaf:stem ratio, PH: Plant height, GFY: Green fodder yield per plant, DMY: Dry matter yield per plant, DTM: Days to 75% maturity, BYP: Biological yield per plant, SYP: Seed yield per plant, HI: Harvest index, SW: 100 seed weight

* Significant at P d" 0.05; check variety in parenthesis represent the best check for the particular trait.

values are desirable for this trait showcasing the genotypes' ability for early flowering. Six cross combinations *viz.,* OS-6×UPO-212 (-9.50%), OS-377×UPO-212 (-8.25%), EC608834×UPO-212 (-6.75%), JPO- 29×PLP-1 (-6.75%), OS-377×PLP-1 (-6.25%) and JPO-29×UPO-212 (-4.50%) exhibited significant and desirable negative heterosis. The range of heterosis for number of leaves per plant over check variety Kent was -65.10% to 36.79%. Seven cross combinations *viz.,* OS-6×JHO-851 (36.79%), OS-377×JHO-851 (30.26%), RO-19×HFO-114 (27.98%), PO-1×JHO-851 (27.20%), OS-6×UPO-212 (23.88%), OS-403×UPO-212 (15.79%) and EC608834×PLP-1 (14.04%) exhibited significant and desirable positive heterosis value over Kent.

For number of tillers per plant it was ranged from -51.53% to 67.51% over the best check i.e. Kent. Fourteen cross combinations *viz.,* OS-6×JHO-851(67.51%), OS-6×UPO-212 (59.05%), OS-377×JHO-851 (54.59%), RO-19×HFO-114 (52.56%), OS-6×HFO-114 (51.05%), EC608834×PLP-1 (48.53%), PO-1×JHO-851 (39.41%), JPO-29×JHO-851 (36.44%), JPO-29×HFO-114 (31.86%), OS-403×UPO-212 (28.22%), EC608834×UPO-212 (25.04%), PO-1×PLP-1 (18.25%), RO-19×JHO-851 (18.22%) and JPO-29×UPO-212 (12.12%) showed significant and desirable positive heterosis for this character. The range of heterosis for flag leaf area over the best check i.e. PLP-24 was -65.22% to 42.57%. Highest value of heterosis for this trait was recorded for cross PO-1×JHO-851 (42.57%), followed by OS-403×HFO-114 (37.68%), OS-377×JHO-851 (32.07%) and PO-1×PLP-1(27.56%).

The range of heterosis for leaf:stem ratio over the best check i.e. Kent was recorded from -47.73% to 5.30%. None of the cross combination exhibited significant and desirable positive heterosis value over Kent. For plant height, it was ranged from -42.25% to 44.38%. Thirty-one cross combinations exhibited significant and desirable positive heterosis value over PLP-24. The cross PO-1×PLP-1 (44.38%) showed highest heterosis for plant height, followed by JPO-29×UPO-212 (41.72%), JPO-29×PLP-1 (34.50%) and PO-1×JHO-851 (32.22%).

Green fodder yield per plant is an important character to increase the fodder productivity. The extent of heterosis for green fodder yield per plant over the best check Kent ranged from -46.57% to 117.78%. Twenty cross combinations found significantly higher heterosis value for this trait. The cross OS-377×JHO-851 (117.78%) exhibited highest value of heterosis, followed by OS-6×HFO-114 (106.52%), PO-1×JHO-851 (88.50%) and RO-19×HFO-114 (76.48%). The heterosis for dry matter yield per plant over the best check i.e. Kent ranged from -31.27% to 141.94% (RO-19×HFO-114). Thirty-three cross combinations exhibited significant and desirable positive heterosis value over best check Kent. The study also compared heterosis values with previous research findings by Kapoor and Singh (2017) and Chauhan *et al*. (2018) which reported positive heterosis for green fodder yield and dry matter yield, corroborating the current findings.

For days to 75% maturity, it was ranged from -7.17% to 1.65% over HJ-8. Twelve combinations *viz*., OS-377×JHO-851 (-7.17%), OS-377×PLP-1 (-6.43%), PO-1×UPO-212 (-6.25%), PO-1×HFO-114 (-6.07%), OS-403×PLP-1 (-6.07%), PO-1×PLP-1 (-5.51%), OS-6×HFO-114 (-5.33%), OS-403×UPO-212 (-5.15%), RO-19×PLP-1 (-4.78%), RO-19×UPO-212 (-4.41%), JHO-813×JHO-851 (-4.41%) and OS-377×HFO-114 (-4.41%) exhibited significant and desirable negative heterosis value over HJ-8. The value of heterosis for biological yield per plant over the best check i.e. HJ-8 ranged from -10.37% to 86.70%. Thirty cross combinations showed significant higher value for this character. The cross PO-1×JHO-851 (86.70%) exhibited highest heterosis, followed by JHO-813×HFO-114 (80.68%), PO-1×PLP-1 (74.66%) and OS-377×JHO-851 (69.73%).

The extent of heterosis for seed yield per plant over the best check i.e. HJ-8 ranged from -26.68% to 44.49%. Twenty-six cross combinations exhibited significant and desirable positive heterosis and maximum value was recorded for cross PO-1×JHO-851 (44.49%), followed by TRS-106×HFO-114 (42.03%), PO-1×UPO-212 (41.15%), EC608834×PLP-1 (40.04%) and RO-11-1×JHO-851 (39.81%). Vishwakarma et al. (2010) and Rana et al. (2021) also reported almost similar range of standard heterosis for this trait.

None of the cross combination exhibited significant and desirable positive heterosis value over Kent for harvest index. The range of heterosis for harvest index was ranged from -40.93% to 6.89%. For 100 seed weight, twenty-four cross combinations exhibited significantly higher magnitude of heterosis over best check HJ-8. It was ranged from -20.50% to 70.27% for this character. The cross JHO-813×HFO-114 (70.27%) showed highest value, followed by JHO-813×UPO-212 (60.30%), RO-11-1×HFO-114 (45.89%) and OS-403×JHO-851 (45.71%). Thukral and Verma (2003) while studying heterosis in five crosses of oat observed that the range of heterosis varied substantially among various crosses and characters. Overall, based on the superiority over the best check varieties, five cross combinations *viz.,* PO-1×JHO-851, OS-6×HFO-114, PO-1×UPO-212, JHO-813×JHO-851 and OS-377×JHO-851 were desirable for earliness, seed yield, fodder yield, and plant height, suggesting their potential utility in future oat improvement programs. These findings contribute to the understanding of hybrid vigor in oat breeding programs and offer potential avenues for improving productivity and performance in oat cultivars.

Conclusion

The exploitation of heterosis is extremely effective method for the genetic improvement of different traits. Any of a multitude of genetic phenomena known to influence qualitative or quantitative characters is expected to influence heterosis but over the years that dispersion of completely or incompletely dominant genes and over-dominance along with some contributions of non-allelic interactions have been the main causes of heterosis. In the present study, the magnitude of heterosis in studied traits was recorded up to 141.94%, indicated the importance of heterosis in future breeding programs. Many genotypes showed the trait specific enhancement for heterosis value providing the scope to study the genetic inheritance pattern of individual trait in oat. Based upon earliness, high seed yield, plant height and fodder yield per plant, five cross combinations *viz*., PO-1×JHO-851, OS-6×HFO-114, PO-1×UPO-212, JHO-813×JHO-851 and OS-377×JHO-851 were found promising in the present investigation can be evaluated in multi-location trials and further exploited through heterosis breeding. The identified cross combinations also offer promising avenues for oat improvement and warrant further investigation and utilization in breeding programs aiming to enhance oat productivity and resilience.

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