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Heterosis for economic traits in single cross-hybrids of radish (*Raphanus sativus* L.)

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Abstract

Field experiments were conducted during 2016-18 to estimate the heterosis for economic traits in radish (*Raphanus sativus* L.). The significant differences of mean squares among parents and hybrids for various traits of economic importance indicated the presence of sufficient variation. Heterosis was observed to the tune of 22.6% for root length followed by 22.4% for root weight, 21.5% for marketable yield, 19.6% for shoot weight, 11.7% for shoot length, 8.3% for days to maturity, 7.5% for number of leaf, 6.4% for root diameter and lowest -1.6% for days to first harvesting. The parents namely VRRAD-201 & VRRAD-4 as female and VRRAD-90, VRRAD-216 & VRRAD-89 as male were found to be superior general combiner and promising. However, for marketable yield best five specific cross-combinations were VRRAD-201×VRRAD-150 (78.8 t/ha) followed by VRRAD-201×VRRAD-216 (76.0 t/ha), VRRAD-201×VRRAD-90 (75.8 t/ha), VRRAD-201×VRRAD-89 (72.6 t/ha) and VRRAD-4×VRRAD-150 (69.9 t/ha). In F_1, leaf and root shape showed dominance pattern as Lyrate > Entire > Sinuate type leaf and Cylindric > Triangular type root, respectively. Keeping in view the importance of marketable yield, usefulness of CMS line and consumers' preference altogether three most promising F_1 hybrids i.e. VRRAD-201×VRRAD-150, VRRAD-201×VRRAD-216 and VRRAD-201×VRRAD-90 have the potential for commercialization.

Key words: Heterosis, Radish, Hybrid, CMS line, Hybrid vigour

Introduction

Radish (*Raphanus sativus* L., 2n=2x=18), Brassicaceae family, is an important salad vegetable grown throughout year globally for fleshy edible roots (hypocotyls) which are eaten as crunchy salad, cooked or preserved by salting, pickling, canning and drying. Also, soft leaves are cooked as a leafy vegetable. It has numerous categories, varying in leaf division incision (lyrate, sinuate, entire, lacerate), root colour (white, red, purple), size (small, medium, big), shape (triangular or iciclical, cylindric, apically bulbous, elliptic) and period of maturity (short, medium, long). Coloured radishes are good source of anthocyanins/polyphenols and have nutraceutical, colorant and anti-oxidative properties (Singh et al. 2016, Singh et al. 2017, Koley et al. 2017). The use of F_1 hybrid seed of many vegetable has increased manifold during the past two decades in India and many countries. Heterosis or hybrid vigour is of direct interest for development and commercialization of F_1 hybrids in vegetable crops, including root vegetable which is being triggered by use of various types of genetic emasculation techniques (Singh 2016). First hybrid radish was developed by Frost (1923) who observed that the crosses between selfed lines were very vigorous and usually exceeded the better-parent in root size and other characters. Cytoplasmic male sterility (CMS) was first identified in a cultivar of Japanese radish by Ogura (1968) popularly known as Ogura-CMS, and thereafter it has been transferred into various backgrounds of different Brassica vegetables. Significantly higher yield, long sized roots and earliness were observed in the hybrids of radish (Singh et al. 1970, Singh et al. 1986). Although it is the most important salad crop in India, yet it is unfortunate that none of the radish hybrid by public institution is available on public domain in this country till date because of less priority or ignorance for research in this crop. Keeping in view of the importance and advantage of hybrids, heterosis for economic traits over mid-parent, better-parent and standard check utilizing CMS lines in radish is reported in this study.

Materials and Methods

The parental lines were selected on the basis of variability for leaf morphology and root shape, consumers' preference and practical applicability in heterosis breeding. Four female lines (VRRAD-198, VRRAD-201, VRRAD-4 and VRRAD-116); and six male lines

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(VRRAD-89, VRRAD-90, VRRAD-150, VRRAD-84, VRRAD-94 and VRRAD-216) were the basic biological materials for field experimentation. Kashi Shweta (VRRAD-90) was used as standard check. Two female lines i.e. VRRAD-198 and VRRAD-201 were Ogura-CMS developed at ICAR-IIVR, Shahanshahpur-221305, Varanasi, UP. Parents were crossed in line × tester mating design during 2016-17 to obtain the adequate amount of F_1 hybrid seed. The standard procedure of hand emasculation and pollination was followed to produce the seeds of 24 single cross F_1 hybrids. Twenty stecklings of all ten parents were transplanted and caged before flowering with 24 × 24 mesh size UV stabilized nylon-net. Appropriate sized buds, likely to open within the next 24-48 hr, on the female parents were opened and were pollinated in the morning by using the previously bagged mixed pollen from at least 18-20 plants of male parent. The siliques were harvested 50-60 days after pollination, air dried for 3-5 days and hand threshed individually. Finally, seed of single cross F_1 hybrids were kept in moisture proof envelope for further evaluation.

Seed of 24 F_1 hybrids along with 10 parents including check variety (34 genotypes) were sown at ICAR-IIVR, Shahanshahpur-221305, Varanasi, UP during winter season of 2017-18. Experimental field is located at 25°10’55” N latitude and 82°52’36” E longitude with an altitude of 85 m above the mean sea level, and receives an annual rainfall of 1050-1100 mm. The recommended packages of practices were followed to raise the crop (Singh and Karmakar 2015). Seed of each entry was sown at 1.0-1.5 cm interval in double row of 7-8 cm apart and 25-28 cm wide ridge with the spacing of about 65 cm between each pair of ridges. Each genotype comprises two ridges of 6.00 m long and triplicated in a randomized block design for heterosis study. The horticultural traits of economic importance such as gross plant weight (g), root weight (g), root length (cm), shoot length (cm), root diameter (cm), number of leaf, shoot weight (g), days to first harvesting, days to maturity and marketable yield (q/ha) were recorded at fresh marketable stage. Heterosis is the magnitude of differences in mean performance between the F_1 hybrids and their mid-parent, better-parent or standard check. Analyses of variance for parents and hybrids; and heterosis over mid-parent, better-parent and standard check for each trait were carried out using software, INDOSTAT.

Results and Discussion

Mean squares due to parents (Female and Male), hybrids and parents *vs*. hybrids were observed to be highly significant for all traits except days to first harvest and days to maturity for parents *vs*. hybrids. The significance of mean squares shows the existence of sufficient amount of variation among parents and hybrids which is prerequisite to harness the hybrid vigour through heterosis/hybrid breeding. Heterosis over mid-parent, better-parent and standard check summarized for gross plant weight, root weight, root length, shoot length and root diameter in Table-1, and for number of leaf, shoot

Table 1: Heterosis for gross plant weight, root weight, root length, root diameter and shoot length in radish

Hybrid	Gross plant weight			Root weight			Root length			Root diameter			Shoot length		
	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)
VRRAD-198× VRRAD-89	17.7 **	16.5 **	15.5 **	18.8 **	18.0 *	9.5	17.0 *	12.1	13.1	3.9	2.2	-24.4 **	8.5	-4.9	6.5
VRRAD-198× VRRAD-90	23.1 **	22.5 **	22.5 **	22.3 **	17.9 *	17.9 *	23.5 **	23.0 **	24.1 **	8.4	-5.7	-5.7	14.6 *	5.6	5.6
VRRAD-198× VRRAD-150	21.1 **	16.5 **	24.9 **	23.2 **	7.2	34.5 **	22.1 **	21.8 **	23.5 **	6.5	-1.9	-12.8	13.5 *	6.3	2.5
VRRAD-198× VRRAD-84	10.2 *	6.8	5.9	12.0	9.1	1.3	10.2	5.7	6.6	-1.1	-2.2	-26.0 **	1.8	-10.3	-0.9
VRRAD-198× VRRAD-94	12.5 **	10.9 *	9.9 *	11.2	9.4	5.1	12.2	10.7	11.7	1.4	-10.2	-13.8 *	3.7	-3.7	-5.5
VRRAD-198× VRRAD-216	20.9 **	20.8 **	20.0 **	22.1 **	18.8 *	16.7 *	20.0 **	18.9 *	20.0 *	5.3	-6.8	-10.6	11.9	5.2	0.7
VRRAD-201× VRRAD-89	28.9 **	22.2 **	32.5 **	29.8 **	18.8 **	31.0 **	28.5 **	16.0 *	33.1 **	13.4 *	3.8	-10.6	19.8 **	15.1 *	28.9 **
VRRAD-201× VRRAD-90	32.7 **	27.6 **	38.3 **	35.7 **	29.4 **	42.7 **	35.3 **	26.6 **	45.3 **	18.8 **	10.6	10.5	26.1 **	24.1 **	28.1 **
VRRAD-201× VRRAD-150	33.4 **	32.6 **	43.8 **	36.5 **	28.2 **	60.9 **	34.6 **	26.8 **	45.5 **	18.7 **	17.6 **	3.3	25.9 **	21.8 **	25.6 **
VRRAD-201× VRRAD-84	22.3 **	13.7 **	23.3 **	25.2 **	12.5	24.1 **	21.4 **	9.7	25.9 **	6.5	0.0	-13.8 *	13.0 *	9.3	20.7 **
VRRAD-201× VRRAD-94	23.2 **	16.4 **	26.2 **	26.4 **	18.3 **	30.4 **	24.1 **	15.2 *	32.2 **	9.8	4.24	0.1	16.3 **	13.4 *	17.1 *
VRRAD-201× VRRAD-216	33.5 **	27.49 **	38.7 **	33.3 **	26.0 **	39.0 **	31.1 **	22.2 **	40.2 **	16.1 **	10.17	5.7	22.5 **	18.0 **	21.8 **
VRRAD-4× VRRAD-89	22.1 **	21.5 **	19.1 **	24.2 **	22.0 **	15.9 *	22.2 **	13.0	22.9 **	6.9	0.1	-17.9 **	13.7 *	3.7	16.1 *
VRRAD-4× VRRAD-90	27.7 **	26.4 **	26.4 **	29.8 **	26.5 **	26.5 **	27.3 **	22.2 **	32.8 **	12.5 *	2.4	2.4	19.9 **	15.3 *	15.3 *
VRRAD-4× VRRAD-150	24.3 **	19.0 **	27.6 **	26.5 **	11.1	39.5 **	24.4 **	20.2 **	30.7 **	8.1	4.6	-8.1	15.9 *	13.5	9.4
VRRAD-4× VRRAD-84	13.4 **	10.6 *	8.4	14.3 *	10.1	4.5	14.1 *	5.7	14.9	-1.0	-4.9	-21.9 **	5.9	-2.8	7.3
VRRAD-4× VRRAD-94	16.7 **	15.7 **	13.4 **	17.7 **	17.0 *	12.4	16.8 *	11.2	20.9 **	2.3	-5.1	-8.9	8.1	4.9	3.0
VRRAD-4× VRRAD-216	25.4 **	24.6 **	23.8 **	27.6 **	25.4 **	23.2 **	25.1 **	19.5 **	29.9 **	9.6	1.7	-2.4	16.6 *	14.6 *	9.7
VRRAD-116× VRRAD-89	14.7 **	13.6 **	10.2 *	16.6 *	15.2	8.1	18.8 **	15.9 *	12.5	4.5	-6.3	-15.5 **	10.2	-0.2	11.8
VRRAD-116× VRRAD-90	21.9 **	19.0**	18.9 **	20.2 **	16.5 *	16.5 *	20.9 **	19.1 *	19.1 *	7.7	2.4	2.4	12.0	6.8	6.8
VRRAD-116× VRRAD-150	20.5 **	13.7 **	22.0 **	20.8 **	5.6	32.6 **	21.7 **	19.2 *	20.8 **	7.8	6.3	-4.1	12.3	9.1	5.1
VRRAD-116× VRRAD-84	10.9 *	9.7	4.4	9.3	5.8	-0.6	9.1	6.5	3.5	-4.9	-12.6 *	-21.1 **	-1.3	-10.1	-0.7
VRRAD-116× VRRAD-94	11.4 *	10.7 *	6.7	12.1	10.9	6.5	11.4	10.7	8.9	-2.2	-5.1	-8.9	2.1	-1.8	-3.6
VRRAD-116× VRRAD-216	18.0 **	15.5 **	14.8 **	18.0 **	15.4 *	13.3	19.7 **	18.5 *	17.5 *	4.8	1.7	-2.4	10.9	8.0	3.4
Parental Mean		248.9 g			166.6 g			22.3 cm			3.5 cm			35.9 cm	
Hybrid Mean		302.4 g			203.9 g			27.3 cm			3.7 cm			40.1 cm	
Heterosis Mean (%)		21.5			22.4			22.6			6.4			11.7	
Heterosis Range (%)	10.2 to 33.5	6.8 to 32.6	4.4 to 43.8	9.3 to 36.5	5.6 to 29.4	-0.6 to 60.9	9.1 to 35.3	5.7 to 26.8	3.5 to 45.5	-4.9 to 18.8	-12.6 to 17.6	-26.0 to 10.5	-1.3 to 26.1	-10.3 to 24.1	-5.5 to 28.9

MPH: Mid-parent heterosis, BPH: Better-parent heterosis, SH: Standard heterosis, *: $P<0.05$, **: $P<0.01$

weight, days to first harvesting, days to maturity and marketable yield in Table-2. Heterosis for various traits of economic importance was observed to the tune of 22.6% for root length followed by 22.4% for root weight, 21.5% for marketable yield and gross plant weight, 19.6% for shoot weight, 11.7% for shoot length, 8.3% for days to maturity, 7.5% for number of leaf, 6.4% for root diameter and lowest -1.6% for days to first harvesting (Table 1 and Table 2). This indicates that there is ample opportunity to develop hybrids for better root length, higher marketable yield and suitable for early harvest. Hawlader and Mian (1986) reported heterobeltiosis for root length (0.46-71.60%), root diameter (1.76 to 38.05%), root weight (37.57 to 165.76%), plant weight (30.00-146.87%), leaf number (0.21-48.71%) and leaf length (0.32-39.73%). Furthermore, Kutty and Sirohi (2003) also found better-parent heterosis maximum for shoot weight followed by yield, root weight, root diameter, leaf number and root length in radish.

Significantly higher heterosis for gross plant weight was observed in 24 hybrids over mid-parent (10.2-33.5%), 22 hybrids over better-parent (10.6-32.6%) and 20 hybrids over standard check (9.9-43.8%) indicating that there is enough scope to increase plant biomass through heterosis. The result is conformity with the findings of Singh et al. (1986). Among 24 hybrids, significantly positive heterosis was expressed for root weight in 14 hybrids over better-parent (15.4 to 29.4%) and in 15 hybrids over standard check (15.9 to 60.9%). This corroborates with finding of Hawlader and Mian (1986). Root length is one of the most important traits in radish breeding possessed substantially greater amount of heterosis over better-parent (15.2 to 26.8%) and over standard check (17.5 to 45.5%), respectively in 15 and 17 hybrid combinations. Best hybrids for root length were VRRAD-201×VRRAD-150 (45.5%), VRRAD-201×VRRAD-90 (45.3%) and VRRAD-201×VRRAD-216 (40.2%). Hawlader and Mian (1986) also reported heterobeltiosis for root length in radish. Moreover, significant standard heterosis (15.3 to 28.9%) for shoot length was reported only in eight hybrids which was maximum in VRRAD-201×VRRAD-89 followed by VRRAD-201×VRRAD-90, VRRAD-201×VRRAD-150, VRRAD-201×VRRAD-216, VRRAD-201×VRRAD-84, VRRAD-201×VRRAD-94, VRRAD-4×VRRAD-89 and VRRAD-4×VRRAD-90. Among all the parents, VRRAD-201 reveals better heterosis for shoot length.

Among 24 hybrids, only eight hybrid combinations involving two male parents having lyrate type of leaf shape (VRRAD-89 and VRRAD-84) showed negative heterosis (-13.8 to -26.0%) for root diameter revealing that inclusion of lyrate leaf genotype as one of the parent in hybrid development would be helpful in breeding of hybrid cultivar with thinner root. Furthermore, considerably positive heterosis was found for number of leaf in 10 hybrids over standard check and 5 hybrids over better-parent which ranged from 10.0 to 22.3% and 9.1 to 20.1%, respectively. Negative heterosis is desirable trait for days to first harvest for getting an early crop, and only -1.6% heterosis was realized among all 24 hybrids. Overall across all hybrids vs. parents, 21.5% of heterosis for marketable yield was realized which was significantly higher in all 24 hybrids over

Table 2: Heterosis for leaf number, shoot weight, days to first harvest, days to maturity and marketable yield in radish

Hybrid	Leaf number			Shoot weight			Days to first harvest			Days to maturity			Marketable yield		
	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)	MPH (%)	BPH (%)	SH (%)
VRRAD-198× VRRAD-89	3.4	-0.7	-11.6 **	15.9 *	13.9	27.5 **	-5.1	-3.1	-4.9	4.3	8.5	4.7	17.7 **	16.5 **	15.5 **
VRRAD-198× VRRAD-90	9.9 *	3.89	3.9	24.4 **	17.8 *	31.8 **	1.0	2.0	0.1	10.9 **	13.0 **	9.0 *	23.1 **	22.5 **	22.5 **
VRRAD-198× VRRAD-150	6.6	1.6	-0.3	15.9	-5.8	5.4	-1.8	-0.5	-4.9	7.8 *	8.9	2.9	21.1 **	16.5 **	24.9 **
VRRAD-198× VRRAD-84	-0.2	-6.9	-4.2	7.1	3.1	15.4	-8.2 *	-5.7	-7.4	0.8	4.9	1.3	10.2 *	6.8	5.9
VRRAD-198× VRRAD-94	2.2	-5.6	-0.9	14.7	7.0	19.8 *	-6.1	-4.36	-6.1	3.2	6.3	2.5	12.5 **	10.9 *	9.9 *
VRRAD-198× VRRAD-216	6.7	-2.9	5.5	18.7 *	13.3	26.8 **	-2.0	-0.7	-2.5	7.7 *	8.7	4.9	20.9 **	20.8 **	20.0 **
VRRAD-201× VRRAD-89	12.4 **	1.6	2.9	27.4 **	25.3 **	35.5 **	3.3	6.6	2.3	13.5 **	18.8 **	13.3 **	28.9 **	22.2 **	32.5 **
VRRAD-201× VRRAD-90	20.9 **	20.1 **	21.7 **	26.4 **	23.6 *	29.4 **	11.3 **	13.6 **	9.0 *	22.3 **	25.2 **	19.4 **	32.7 **	27.5 **	38.3 **
VRRAD-201× VRRAD-150	18.8 **	16.9 **	18.5 **	24.8 **	4.1	8.9	9.4 **	9.6 *	4.8	20.2 **	20.7 **	14.1 **	33.3 **	32.6 **	43.8 **
VRRAD-201× VRRAD-84	7.8 *	6.9	10.03 *	16.9 *	16.2	21.6 *	-1.1	2.9	-1.3	8.8 *	13.9 **	8.6 *	22.3 **	13.6 **	23.3 **
VRRAD-201× VRRAD-94	9.3 *	7.4	12.6 **	16.5 *	12.2	17.5	0.5	3.6	-0.6	10.4 **	14.4 **	9.1 *	23.2 **	16.4 **	26.2 **
VRRAD-201× VRRAD-216	16.5 **	12.5 **	22.3 **	33.7 **	31.8 **	37.9 **	6.9 *	9.6 *	5.22	17.5 **	19.3 **	13.8 **	33.5 **	27.9 **	38.7 **
VRRAD-4× VRRAD-89	6.7	-5.8	0.6	18.3 *	16.2	25.6 **	-1.9	-1.6	0.0	7.8 *	9.8 *	14.6 **	22.1 **	21.5 **	19.1 **
VRRAD-4× VRRAD-90	12.7 **	9.1 *	16.5 **	23.5 **	21.0 *	26.1 **	3.6	4.5	4.5	13.9 **	18.6 **	18.6 **	27.6 **	26.4 **	26.4 **
VRRAD-4× VRRAD-150	9.9 **	5.5	12.6 **	18.6 *	-0.9	3.3	1.1	4.3	-0.3	11.1 **	19.1 **	12.6 **	24.3 **	18.9 **	27.6 **
VRRAD-4× VRRAD-84	0.9	-0.9	5.8	11.8	11.4	16.1	-7.2 *	-6.3	-4.7	2.0	3.9	8.4	13.4 **	10.6 *	8.4
VRRAD-4× VRRAD-94	2.1	1.2	8.1	14.6	10.6	15.3	-6.1	-6.1	-4.6	3.2	6.1	8.5	16.7 **	15.7 **	13.4 **
VRRAD-4× VRRAD-216	11.1 **	10.1 *	19.7 **	21.4 **	19.9 *	24.9 **	2.0	2.4	3.3	12.2 **	17.8 **	15.8 **	25.4 **	24.6 **	23.8 **
VRRAD-116× VRRAD-89	1.7	-9.8 *	-4.5	11.1	5.8	14.4	-6.6 *	-5.9	-5.3	2.6	4.4	5.2	14.7 **	13.6 **	10.2 *
VRRAD-116× VRRAD-90	7.5 *	4.6	10.7 *	25.3 **	23.9 *	23.9 *	-1.0	-0.7	-0.7	8.7 *	9.2 *	9.3 *	21.9 **	18.9 **	19.0 **
VRRAD-116× VRRAD-150	6.0	2.1	8.1	19.6 *	2.6	0.4	-2.4	0.1	-4.3	7.3	10.9 *	4.8	20.5 **	13.7 **	22.0 **
VRRAD-116× VRRAD-84	-2.6	-3.9	1.6	13.9	10.8	14.7	-10.4 **	-9.0 *	-8.5 *	-1.5	0.2	1.1	10.9 *	9.7	4.4
VRRAD-116× VRRAD-94	-0.2	-0.6	5.2	10.0	9.5	7.0	-8.3 *	-7.7 *	-7.2	0.7	1.4	2.3	11.4 *	10.7 *	6.7
VRRAD-116× VRRAD-216	5.3	3.9	12.9 **	17.9 *	15.7	17.6	-3.0	-2.9	-2.3	6.4	7.8	6.0	18.0 **	15.5 **	14.8 **
Parental Mean	10.3			82.3 g			49.8			71.5			54.5 t/ha		
Hybrid Mean	11.1			98.5 g			49.0			77.5			66.1 t/ha		
Heterosis Mean (%)	7.5			19.6			-1.6			8.3			21.5		
Heterosis Range (%)	-2.6 to 20.9	-9.8 to 20.1	-4.5 to 21.7	7.1 to 33.7	-5.8 to 31.8	0.4 to 37.9	-10.4 to 11.3	-9.0 to 13.6	-8.5 to 9.0	-1.5 to 22.3	0.2 to 25.2	1.1 to 19.4	10.2 to 33.5	6.8 to 32.6	4.4 to 43.8

MPH: Mid-parent heterosis, BPH: Better-parent heterosis, SH: Standard heterosis, *: $P<0.05$, **: $P<0.01$

Table 3: Hybrid effects for three economically important traits (root weight, root length and marketable yield) in radish

Parent	VRRAD-89	VRRAD-90	VRRAD-150	VRRAD-84	VRRAD-94	VRRAD-216	Hybrid Mean (Female)	Parent Mean (Female)	Heterotic effects of female parent (%)
Root weight (cm)									
VRRAD-198	184.1	198.2	226.1	170.2	176.6	196.1	191.9	156.1	22.9
VRRAD-201	220.2	239.8	270.4	208.5	219.2	233.7	232.0	185.4	25.1
VRRAD-4	194.7	212.6	234.4	175.7	188.9	207.1	202.2	159.6	26.7
VRRAD-116	181.7	195.8	222.8	167.0	179.0	190.5	189.5	157.8	20.1
Hybrid Mean (Male)	195.2	211.6	238.4	180.4	191.0	206.8	203.9	164.7	23.8
Parent Mean (Male)	153.9	168.1	210.9	147.8	161.5	165.1	–	–	–
Heterotic effects of male parent (%)	26.8	25.9	13.0	22.0	18.2	25.3	–	–	–
Root length (cm)									
VRRAD-198	25.0	27.5	27.3	23.6	24.7	26.6	25.8	22.3	15.5
VRRAD-201	29.5	32.2	32.2	27.9	29.3	31.0	30.3	24.4	24.3
VRRAD-4	27.2	29.4	28.9	25.4	26.8	28.8	27.8	24.1	15.3
VRRAD-116	24.9	26.4	26.7	22.9	24.1	26.0	24.2	21.5	12.4
Hybrid Mean (Male)	26.7	28.9	28.8	25.0	26.2	28.1	27.3	23.3	16.9
Parent Mean (Male)	20.5	22.1	22.4	20.5	22.8	21.9	–	–	–
Heterotic effects of male parent (%)	30.2	30.3	28.4	21.7	15.2	28.1	–	–	–
Marketable yield (t/ha)									
VRRAD-198	63.3	67.1	68.5	58.0	60.2	65.8	63.8	54.3	17.5
VRRAD-201	72.6	75.8	78.8	67.5	69.1	76.0	73.3	59.4	23.4
VRRAD-4	65.3	69.3	69.9	59.4	62.1	67.8	65.6	53.7	22.2
VRRAD-116	60.4	65.2	66.8	57.2	58.5	62.9	61.8	52.2	18.5
Hybrid Mean (Male)	65.4	69.3	71.0	60.5	62.5	68.1	66.1	54.9	20.5
Parent Mean (Male)	53.2	54.8	58.8	51.0	52.8	54.4	–	–	–
Heterotic effects of male parent (%)	22.9	26.5	20.8	18.7	18.3	25.1	–	–	–

mid-parent (10.2-33.5%), in 22 hybrids over better-parent (10.6-32.6%) and in 20 hybrids over standard check (9.9-43.8%) indicating that there is sufficient opportunity to develop hybrids for cultivation in radish (Table 2). The result is conformity with the findings of Singh et al. (1970) and Singh et al. (1986). Best hybrids for marketable yield possessing >25% of standard heterosis were VRRAD-201×VRRAD-150 (43.8%) followed by VRRAD-201×VRRAD-216 (38.7%), VRRAD-201×VRRAD-90 (38.3%), VRRAD-201×VRRAD-89 (32.5%), VRRAD-4×VRRAD-150 (27.6%), VRRAD-4×VRRAD-90 (26.4%) and VRRAD-201×VRRAD-94 (26.2%). Hybrid effects for economically important traits such as root weight, root length and marketable yield were calculated to find the better female and male parents, and also promising hybrid combinations (Table 3). The following parents were found to be superior general combiner such as VRRAD-4 & VRRAD-201 as female and VRRAD-89, VRRAD-90 & VRRAD-216 as male for root weight; VRRAD-201 & VRRAD-198 as female and VRRAD-90, VRRAD-89 & VRRAD-150 as male for root length; and VRRAD-201 & VRRAD-4 as female and VRRAD-90, VRRAD-216 & VRRAD-89 as male for marketable yield. Conclusively, VRRAD-201 & VRRAD-4 as female and VRRAD-90, VRRAD-216 & VRRAD-89 as male parents are promising to harness the heterotic potential in radish. Female parent VRRAD-201, being CMS line, has advantage over VRRAD-4 in cost-effective seed production of F_1 hybrid. Quantitative traits of best female line 'VRRAD-201' (Ogura-CMS) during 2016-17 and 2017-18 were recorded as 275.0 & 268.3 g gross plant weight, 190.0 & 185.4 g root weight, 26.0 & 25.4 cm root length, 38.4 & 37.5 cm shoot length, 3.6 & 3.5 cm root diameter, 10.7 & 10.4 number of leaf, 52.4 & 47.8 days to first root harvest, 60.2 and 58.7 t/ha marketable yield, 38.1 & 35.8 days to 50% flowering, 381.6 & 405.2 pods/plant, 4.2 & 4.3 seed/pod and 13.3 & 12.8 g of 1000 seed weight, respectively. Moreover, economic parameters of its maintainer 'VRRAD-202' during 2016-17 and 2017-18 were realized correspondingly as 270.0 & 264.1 g gross plant weight, 182.5 & 178.5 g root weight, 24.3 & 23.8 cm root length, 37.1 & 36.6 cm shoot length, 3.7 & 3.6 cm root diameter, 11.1 & 10.9 number of leaf, 52.9 & 49.7 days to first root harvest, 591 and 578 q/ha marketable yield, 31.5 & 30.1 days to 50% flowering, 362.1 & 381.6 pods/plant, 4 number of seed/pod, and 12.2 & 11.9 g of 1000 seed weight. Furthermore, for marketable yield, best five specific cross-combinations were realized in VRRAD-201×VRRAD-150 (78.8 t/ha) followed by VRRAD-201×VRRAD-216 (76.0 t/ha), VRRAD-201×VRRAD-90 (75.8 t/ha), VRRAD-201×VRRAD-89 (72.6 t/ha) and VRRAD-4×VRRAD-150 (69.9 t/ha).

In India, radishes are grown throughout the year under varying climate conditions. In terms of consumers' preference, leaf shape, root colour, root shape and taste

Table 4: Leaf division incision (Leaf shape) and root shape of parents and F_1 hybrids in radish

Parent with leaf morphology and root shape		VRRAD-89 (L, T)	VRRAD-90 (S, T)	VRRAD-150 (E, T)	VRRAD-84 (L, T)	VRRAD-94 (S, T)	VRRAD-216 (E, T)
VRRAD-198*	(S, T)	L, T	S, T	E, T	L, T	S, T	E, T
VRRAD-201*	(S, T)	L, T	S, T	E, T	L, T	S, T	E, T
VRRAD-4 (L, C)		L, C	L, C	L, C	L, C	L, C	L, C
VRRAD-116	(E, T)	L, T	E, T	E, T	L, T	E, T	E, T

Leaf division incision (L: Lyrate, S: Sinuate, E: Entire);
Root shape (T: Triangular with tapering end, C: Cylindric with blunt end); *CMS line

are the main quality parameters and are key points in making purchasing decision. The most preferred leaf shape is Entire > Sinuate > Lyrate e” Lacerate; while among various root shape, the liking is for Triangular e” Cylindric > Spherric > Elliptic; and bright-white roots having moderate flavour. Leaf shape (Entire, Sinuate, Lyrate) and root shape (Triangular, Cylindric) of different parents and hybrids were presented in this study (Table 4) which reflects following dominance pattern: Lyrate > Entire > Sinuate leaf shape and Cylindric > Triangular root shape in F_1 progeny. In conclusion, keeping in view the importance of marketable yield, usefulness of CMS line as well as consumers' preference following three F_1 hybrids namely VRRAD-201×VRRAD-150, VRRAD-201×VRRAD-216 and VRRAD-201×VRRAD-90 are most promising.

Ikjk'k

मूली में आर्थिक रूप से महत्वपूर्ण संघटकों में संकर ओज का मूल्यांकन के लिए वर्ष 2016–18 में प्रक्षेत्र परीक्षण किया गया। विभिन्न घटकों के लिए पितृ एवं संकर के मध्य सार्थक वर्गमाध्य से स्पष्ट हुआ कि इनमें पर्याप्त विविधता मौजूद है जो ओज प्रजनन के लिए आवश्यक है। सबसे अधिक संकर ओज 22.6 प्रतिशत जड़ की लम्बाई के लिए तदोपरांत जड़भार के लिए 22.4 प्रतिशत, बाजार योग्य उपज के लिए 21.5 प्रतिशत, पर्णभार के लिए 19.6 प्रतिशत, पर्ण लम्बाई के लिए 11.7 प्रतिशत, परिपक्वता के लिए 8.3 प्रतिशत, पत्ती की संख्या के लिए 7.5 प्रतिशत, जड़ मोटाई के लिए 6.4 प्रतिशत एवं न्यूनतम –1.6 प्रतिशत प्रथम बार जड़ निकालने के लिए पाया गया। मादा पितृ के रूप में वी.आर.आर.ए.डी.–201 एवं वी.आर.आर.ए.डी.–4 तथा नर पितृ के रूप में वी.आर.आर.ए.डी.–90, वी.आर.आर.ए.डी.–216 एवं वी.आर.आर.ए.डी.–89 श्रेष्ठ सामान्य संयोजक के रूप में पहचान की गयी जबकि बाजार योग्य उपज हेतु श्रेष्ठ पांच संकर जैसे वी.आर.आर.ए.डी.–201×वी.आर.आर.ए.डी.–150 (78.8 टन/हे), वी.आर.आर.ए.डी.–201×वी.आर.आर.ए.डी.–216 (76.0 टन/हे), वी.आर.आर.ए.डी.–201×वी.आर.आर.ए.डी.–90 (75.8 टन/हे), वी.आर.आर.ए.डी.–201×वी.आर.आर.ए.डी.–89 (72.6 टन/हे) एवं वी.आर.आर.ए.डी.–4×वी.आर.आर.ए.डी.–150 (69.9 टन/हे) को उत्तम पाया गया। एफ–1 पीढ़ी में पर्ण प्रारूप एवं जड़ के आकार का प्रभाव क्रमशः लीरेट > इंटायर > सिनुएट पर्ण प्रारूप तथा सिलिंड्रिक > ट्राईएंगुलर आकार वाले जड़ के रूप में पाया गया। बाजार योग्य उपज, कोशिका द्रव्यी नरबंध्यता की उपयोगिता, उपभोक्ता की पसंद, आदि की दृष्टिकोण से तीन प्रोन्नत संकर–संयोजनों जैसे वी.आर.आर.ए.डी.–201×वी.आर.आर.ए.डी.–150, वी.आर.आर.ए.डी.–201×वी.आर.आर.ए.डी.–216 एवं वी.आर.आर.ए.डी.–201×वी.आर.आर.ए.डी.–90 को व्यवसायिक स्तर पर उत्पादित किया जा सकता है।

References

Frost HB (1923) Heterosis and dominance of size factors in *Raphanus*. Genetics 8: 116-153.

Hawlader MSH and Mian MAK (1997) Self-incompatibility studies in local cultivars of radish. (*Raphanus sativus* L.) grown in Bangladesh. Euphytica 96: 311-315.

Koley TK, Khan Z, Oulkar D, Singh BK, Maurya A, Singh B and Banerjee K (2017) High resolution LC-MS characterization of phenolic compounds and the evaluation of antioxidant properties of a tropical purple radish genotype. Arabian J Chem doi: https://doi.org/10.1016/j.arabjc.2017.11.007.

Kutty CN and Sirohi PS (2003) Exploitation of hybrid vigour in radish (*Raphanus sativus* L.). Indian J Hort 60(1): 64-68.

Ogura H (1968) Studies on the new male sterility in Japanese radish, with special reference to the utilization of this sterility towards the practical raising of hybrid seeds. Mem Fac Agric Kagoshima Univ 6: 39-78.

Singh B, Gupta VP and Gupta PK (1986) Heterosis studies in radish (*Raphanus sativus* L.). Indian J Hort 43(3): 242-247.

Singh BK (2016) Development of hybrids and hybrid seed production in root vegetables. In: Principles and Production Techniques of Hybrid Seeds in Vegetables (Singh B, Pandey S, Singh N, Manimurugan C, Devi J and Singh PM Eds). Training Manual No. 67, ICAR-IIVR, Varanasi, UP, pp 126-142.

Singh BK and Karmakar P (2015) Improved production technology for root crops. In: Improved Production Technologies in Vegetable Crops (Singh N, Roy S, Karmakar P, Chaurasia SNS, Gupta S and Singh B Eds.). IIVR Training Manual No. 59, Varanasi, pp. 120-133.

Singh BK, Koley TK, Karmakar P, Tripathi A, Singh B and Singh M (2017) Pigmented radish (*Raphanus sativus* L.): genetic variability, heritability and inter-relationships of total phenolics, anthocyanins and antioxidant activity. Indian J Agric Sci 87(12): 1600-1606.

Singh BK, Koley TK, Singh B and Singh PM (2016) Colourful radishes for healthier salad. ICAR News: A Science Techno Newsl 22(2): 12.

Singh JP, Gill HS and Tewari RN (1970) Studies on hybrid vigour in radish (*Raphanus sativus* L.). Indian J Hort 27(3): 167-175.