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Unleashing the genetic potential of CMS-based F_1 hybrids of radish (*Raphanus sativus* L.) to winter and summer temperature

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Abstract

Field experiments were conducted during 2018-20 to estimate the heterosis 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. Economic heterosis for various traits of economic importance were observed during winter and summer seasons to the tune of -23.9–15.8% & 3.4–41.8% for days to first harvest, -30.2–32.4% & 5.9–95.8% for root length, -15.3–16.5% & -7.3–24.5% for leaf length, -23.1–30.0% & -9.3–85.1% for root weight, -32.9–39.6% & -18.1–36.4% for leaf weight, -5.3–9.7% & -15.8–40.4% for harvest index, and -24.2–33.6% & 1.8–42.8%, respectively for marketable yield. Realizing the importance of marketable root as well as consumers' preference for sinuate/entire leaf shape during summer; the most promising CMS-based F_1 hybrids are VRRAD-12×VRRAD-213, VRRAD-11×VRRAD-213, VRRAD-201×VRRAD-213, VRRAD-13×VRRAD-213 & VRRAD-12×VRRAD-200 for winter season cultivation; and VRRAD-201×VRRAD-200, VRRAD-198×VRRAD-200 & VRRAD-13×VRRAD-200 for summer season cultivation at high temperature (28.5-43.4 °C). Furthermore, the following parents are the best combiners for harnessing the heterotic potential such as VRRAD-12 & VRRAD-201 as female and VRRAD-213 & VRRAD-200 as male for winter season; and VRRAD-201 & VRRAD-19 as female and heat tolerant line VRRAD-200 as male parent for summer season.

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

Introduction

Radish (*Raphanus sativus* L.) is an important salad vegetable grown worldwide for fleshy edible roots (hypocotyls) which is eaten fresh as crunchy salad, cooked as vegetable or preserved by salting, pickling, canning and drying. The soft leaves are also cooked as a leafy vegetable or used for chutney preparation. It has numerous kinds, varying in leaf division incision (lyrate, sinuate, entire, lacerate), root colour (white, red, purple, black, yellow), size (small, medium, big), shape (triangular or iciclical, cylindric, apically bulbous, elliptic) and period of maturity (short, medium, long). Coloured radishes, especially red, purple & black 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. 2020). The increasing trend for use of F_1 hybrids of many vegetables has increased manifold during the past three decades in India and many countries.

Heterosis is of direct interest for development and commercialization of F_1 hybrids in vegetable crops, including radish 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. First ever from Public Sector in India; four Ogura-CMS lines of radish (VRRAD-11, VRRAD-13, VRRAD-198 and VRRAD-201) have been developed through back-crossing at ICAR-IIVR, Varanasi, UP (Singh et al. 2018, Singh 2020).

The breeding for heat tolerance is of major importance in radish. Heat tolerance is the ability of the plant to grow and produce economic yield under high temperatures. The adverse effects of heat stress can be mitigated by developing crop plants with improved thermo-tolerance using various breeding approaches, including heterosis breeding. In India, following varieties have been developed having tolerance/resistance to heat

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stress (38-43°C) such as Pusa Chetki, Kashi Mooli-40 and Chetki group lines. Significantly higher yield, long sized roots and earliness were observed in the hybrids of winter radish (Singh et al. 1970, Singh et al. 1986, Singh et al. 2018); nevertheless, information on heterotic potential of winter and summer radish is very meagre. Although, radish is the most important salad crop grown throughout year in India, yet it is unfortunate that none of the radish hybrid is available on open domain for cultivation by public institutions till date because of less priority/ ignorance for research on this crop. Keeping in view of the importance and advantage of hybrids in radish especially in summer, heterosis for economic traits utilizing CMS lines during winter and summer seasons is compared in this study.

Materials and Methods

Ten parental lines were selected on the basis of variability for leaf morphology (Lyrate, Sinuate, Entire) and root shape (Tapering, Cylindrical), suitability to season (Winter, Summer), consumers' preference and practical applicability in heterosis breeding (CMS line as female parent); and details are provided in Table 1. Six female parents (F), all CMS lines, i.e. VRRAD-13, VRRAD-201, VRRAD-198, VRRAD-19, VRRAD-11 & VRRAD-12; and four male lines (M) i.e. Pusa Chetki, VRRAD-150, VRRAD-200 & VRRAD-213 were the basic biological materials for crossing and experimentation. VRRAD-13 is a CMS line in the background of national check variety Kashi Sweta. Two popular cultivars i.e. Kashi Sweta (ICAR-IIVR, Varanasi) and Pusa Chetki (ICAR-IARI, New Delhi) were used as standard check for trial in winter and summer seasons, respectively. All the parents were crossed in line×tester mating design during 2018-19 to get sufficient amount of F_1 hybrid seeds.

The standard procedure of hand pollination was followed to produce the seeds of 24 single-cross F_1 hybrids. Twenty stecklings of all ten parents were transplanted and caged with 24×24 mesh sized UV stabilized nylon-net before flowering. Freshly opened flowers of female lines were pollinated in the morning by using mixed pollen from at least 18-20 plants of previously caged male parents. 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 F_1 hybrids along with parents including check variety/hybrid were sown at ICAR-IIVR, Shahanshahpur-221305, Varanasi, UP during summer 2019 and winter 2019-20. 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. During root development of radish, the meteorological parameters of ICAR-IIVR, Varanasi, UP was recorded Tmin 28.5 °C (25.0-32.0 °C), Tmax 43.4 °C (41.0-46.0 °C), RHmin 30% and RHmin 60%, and sunshine exposure of 8.2 hr during mid-May to mid-June 2019; nevertheless Tmin 9.1 °C (5.0-14.0 °C), Tmax 23.3 °C (21.0-27.0 °C), RHmin 38% and RHmax 90%, and 5.5 hr sunshine exposure during December 2019 (Table 2).

In both seasons, seeds of each entry (hybrids, parents, check variety) were 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 this study. The traits of economic importance such as days to first harvesting, root length (cm), shoot length (cm), gross plant weight (g), root weight (g), shoot weight (g), harvest index (%) and marketable yield (q/ha) were recorded at fresh marketable stage. Analyses of variance for parents and hybrids; and heterosis over standard check for each trait were carried out using software, INDOSTAT.

Results and Discussion

During both seasons, 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. The significance of mean squares shows the existence of sufficient amount of variation among parents and their hybrids which is prerequisite to harness the heterotic effects.

Days-to-harvest (maturity) is a trait of economic importance. Shorter period of maturity is due to faster plant growth which reduces the cost of production and makes the hybrid/variety more economical. Negative heterosis for days to first harvest is desirable. The best performing hybrids were VRRAD-19× Pusa Chetki (-23.9%), VRRAD-198× Pusa Chetki (-21.2%), VRRAD-201× Pusa Chetki (-20.9%), VRRAD-13× Pusa Chetki (-18.6%) and VRRAD-19×VRRAD-150 (-17.9%) during winter season; and VRRAD-19×VRRAD-150 (3.4%), VRRAD-19×Pusa Chetki (3.8%), VRRAD-13× Pusa Chetki (3.9%), VRRAD-19×VRRAD-200 (7.8%) and VRRAD-198×Pusa Chetki (10.5%) during summer season (Table-3 and Table 4). Moreover, the heterotic effects of parents was minimum for Pusa Chetki (-15.0 & 13%) and VRRAD-19 (-13.0 & 8.9%) respectively during winter and summer seasons. Hence, these two parents Pusa Chetki and VRRAD-19 can be used in breeding programme for earliness trait.

Table 1: Details of basic experimental materials

S. No.	Genotype	Leaf division incision (Leaf morphology)	Root shape
Female (CMS) parent*			
1	VRRAD-13	Sinuate	Triangular with tapering end
2	VRRAD-201	Sinuate	Triangular with tapering end
3	VRRAD-198	Sinuate	Triangular with tapering end
4	VRRAD-19	Entire	Triangular with tapering end
5	VRRAD-11	Lyrate	Cylindrical with blunt end
6	VRRAD-12	Lyrate	Cylindrical with blunt end
Male parent			
7	Pusa Chetki	Sinuate	Cylindrical with blunt end
8	VRRAD-150	Entire	Triangular with tapering end
9	VRRAD-200	Sinuate	Triangular with tapering end
10	VRRAD-213	Lyrate	Triangular with tapering end

*All are CMS lines developed at ICAR-IIVR, Varanasi, UP

The heterosis for root length, one of the most important traits, ranged from -30.2 to 32.4% and 5.9 to 95.8% during winter and summer seasons, respectively. Most promising 5 hybrids were VRRAD-12×VRRAD-213 (32.4%), VRRAD-11×VRRAD-213 (27.3%), VRRAD-201×VRRAD-213 (20.5%) and VRRAD-13×VRRAD-213 (19.3%) during winter; and VRRAD-201×VRRAD-200 (95.8%), VRRAD-13×VRRAD-200 (88.9%), VRRAD-198×VRRAD-200 (88.9%), VRRAD-198×VRRAD-213 (80.2%), VRRAD-201×VRRAD-213 (78.6%) during summer season. The heterotic effects of parents for root length was maximum for VRRAD-12 (12.1%) & VRRAD-213 (19.4%) and minimum for Pusa Chetki (-17.6%) & VRRAD-19 (-7.9%) during winter; and during summer it was maximum for VRRAD-201 (63.4%) & VRRAD-200 (69.9%) and minimum for Pusa Chetki (15.7%) & VRRAD-11 (26.3%). Therefore, it reveals that root length can be increased significantly by using following parents such as VRRAD-12, VRRAD-213 & VRRAD-200 for winter; and VRRAD-200 & VRRAD-201 for summer season. Moreover, economic heterosis for leaf length and leaf weight was observed -15.3 to 16.5% & -32.9 to 39.6% during winter and -7.3 to 24.5% & -18.1 to 36.4% during summer season, respectively (Table-3 and Table 4). In radish, moderate heterosis for leaf length and leaf weight is desirable for proper root development and higher yield.

Table 2: Meteorological parameters of ICAR-IIVR, Varanasi, UP during root development of radish

Meteorological parameters	Root development period	
	mid-May to mid-June 2019 (Summer)	December 2019 (Winter)
Minimum temperature (Tmin)	28.5 °C (25.0-32.0 °C)	9.1 °C (5.0-14.0 °C)
Maximum temperature (Tmax)	43.4 °C (41.0-46.0 °C)	23.3 °C (21.0-27.0 °C)
Minimum relative humidity (RHmin)	30%	38%
Maximum relative humidity (RHmin)	60%	90%
Sunshine exposure	8.2 hr	5.5 hr

Economic heterosis for gross plant weight among 24 cross-combinations during winter and summer seasons ranged from -24.2 to 33.6% and 1.8 to 42.8%, respectively. Five best performing cross-combinations were VRRAD-12×VRRAD-213 (33.6%) followed by VRRAD-11×VRRAD-213 (31.2%), VRRAD-201×VRRAD-213 (24.3%), VRRAD-13×VRRAD-213 (21.5%) and VRRAD-12×VRRAD-200 & VRRAD-12×VRRAD-200 (21.4%) during winter; and VRRAD-201×VRRAD-200 (42.8%), VRRAD-201×VRRAD-213 (32.2%), VRRAD-198×VRRAD-200 (30.6%), VRRAD-198×VRRAD-213 (29.6%) and VRRAD-13×VRRAD-200 (29.5%) during summer season. The result is conformity with the findings of Singh et al. (1986) and Singh et al. (2018) in winter crop. Furthermore, the most heterotic parents were VRRAD-213, VRRAD-200, VRRAD-12 & VRRAD-201 during winter, and VRRAD-200, VRRAD-213, VRRAD-201 & VRRAD-19 during summer (Table-3 and Table 4). Therefore, three lines VRRAD-200, VRRAD-213 and VRRAD-201 could be used in breeding of hybrids suitable for both seasons.

During winter and summer period, the economic heterosis for root weight varied from -23.1 to 30.0% and -9.3 to 85.1%, respectively indicating that there is greater scope of increasing root weight of summer genotypes through heterosis breeding. Heterosis for root weight was found to be higher in following cross combinations: VRRAD-12×VRRAD-213 (30.0%), VRRAD-11×VRRAD-213 (28.5%), VRRAD-201×VRRAD-150 (22.0%), VRRAD-201×VRRAD-213 (21.4%) & VRRAD-12×VRRAD-150 (18.9%) during winter season, and VRRAD-201×VRRAD-200 (85.1%), VRRAD-19×VRRAD-200 (75.9%), VRRAD-198×VRRAD-200 (71.7%), VRRAD-13×VRRAD-200 (69.8%) & VRRAD-201×VRRAD-213 (35.7%) during

Table 3: Economic heterosis (%, Kashi Sweta as check) and heterotic effects (%) of parents for plant growth and marketable yield of radish during winter season

Hybrids/Parents	Days to first harvest	Root length	Leaf length	Gross plant weight	Root weight	Leaf weight	Harvest index	Marketable yield
Hybrids				**Economic heterosis**				
VRRAD-13× Pusa Chetki	-18.6**	-17.8*	0.0	-18.4*	-15.6*	-23.2**	3.4	-18.4*
VRRAD-13×VRRAD-150	-6.0	3.0	1.3	6.3	14.4*	-7.6	7.6	6.3
VRRAD-13×VRRAD-200	6.2	7.7	6.1	21.4**	18.2*	26.8**	-2.6	21.4**
VRRAD-13×VRRAD-213	10.7*	19.3**	5.7	21.5**	17.6*	28.1**	-3.2	21.5**
VRRAD-201×Pusa Chetki	-20.9**	-12.1*	-3.0	-15.9*	-12.8*	-21.3*	3.7	-15.9*
VRRAD-201×VRRAD-150	-15.1*	-8.9	4.4	12.6	22.0*	-3.6	8.4*	12.6
VRRAD-201×VRRAD-200	3.3	12.3*	4.4	17.7*	16.9*	19.0*	-0.6	17.7*
VRRAD-201×VRRAD-213	15.8*	20.5**	3.9	24.3**	21.4*	29.2**	-2.3	24.3**
VRRAD-198× Pusa Chetki	-21.2**	-27.5**	-0.5	-21.2**	-18.6*	-25.7**	3.3	-21.2**
VRRAD-198×VRRAD-150	-11.7*	1.3	2.8	-1.5	8.1	-18.1*	9.7*	-1.5
VRRAD-198×VRRAD-200	3.1	5.3	0.0	13.4*	9.5	20.1*	-3.4	13.4*
VRRAD-198×VRRAD-213	2.8	13.4*	16.5**	20.0*	14.9*	28.9**	-4.3	20.0*
VRRAD-19× Pusa Chetki	-23.9**	-30.2**	5.5	-23.3**	-20.0*	-29.2**	4.4	-23.3**
VRRAD-19×VRRAD-150	-17.9**	-6.2	-15.3**	-20.4**	-13.1*	-32.9**	9.1*	-20.4**
VRRAD-19×VRRAD-200	-6.1	1.3	-3.9	10.1	11.7	7.4	1.4	10.1
VRRAD-19×VRRAD-213	-4.0	3.4	3.6	12.9	8.0	21.3*	-4.3	12.9
VRRAD-11×Pusa Chetki	-4.0	-11.0	-5.6	-24.2**	-23.1*	-26.2**	1.5	-24.2**
VRRAD-11×VRRAD-150	-2.6	5.1	5.5	8.9	16.1*	-3.6	6.6	8.9
VRRAD-11×VRRAD-200	11.3*	13.0*	0.7	16.4*	10.2	27.1**	-5.3	16.4*
VRRAD-11×VRRAD-213	13.3*	27.3**	11.7*	31.2**	28.5**	36.0**	-2.1	31.2**
VRRAD-12× Pusa Chetki	-1.2	-7.2	1.4	-21.0**	-19.9*	-22.9*	1.4	-21.0*
VRRAD-12×VRRAD-150	-5.1	6.5	2.8	12.5*	18.9*	1.3	5.7	12.5*
VRRAD-12×VRRAD-200	8.5	16.8**	3.6	21.4**	17.2*	28.5**	-3.4	21.4**
VRRAD-12×VRRAD-213	15.8*	32.4**	-0.7	33.6**	30.0**	39.6**	-2.6	33.6**
Heterosis Mean	-2.8	2.9	2.1	5.8	6.7	4.1	1.3	5.8
Heterosis Range	-23.9 to 15.8	-30.2 to 32.4	-15.3 to 16.5	-24.2 to 33.6	-23.1 to 30.0	-32.9 to 39.6	-5.3 to 9.7	-24.2 to 33.6
Female parent				**Heterotic effects**				
VRRAD-13	-1.9	3.0	3.3	7.7	8.6	6.0	1.3	7.7
VRRAD-201	-4.2	3.0	2.4	9.7	11.9	5.8	2.3	9.7
VRRAD-198	-6.7	-1.9	4.7	2.7	3.5	1.3	1.3	2.7
VRRAD-19	-13.0	-7.9	-2.5	-5.2	-3.3	-8.3	2.7	-5.2
VRRAD-11	4.5	8.6	3.1	8.1	7.9	8.3	0.2	8.1
VRRAD-12	4.5	12.1	1.8	11.6	11.5	11.7	0.3	11.6
Male parent				**Heterotic effects**				
Pusa Chetki	-15.0	-17.6	-0.4	-20.7	-18.3	-24.7	2.9	-20.7
VRRAD-150	-9.7	0.1	0.3	3.1	11.1	-10.7	7.9	3.1
VRRAD-200	4.4	9.4	1.8	16.7	14.0	21.5	-2.3	16.7
VRRAD-213	9.1	19.4	6.8	23.9	20.1	30.5	-3.1	23.9

*&**: Significant at $P<0.05$ and $P<0.01$, respectively

summer season. This corroborates with finding of Hawlader and Mian (1986), Kutty and Sirohi (2003), and Singh et al. (2018) for winter crop. Moreover, the greater heterotic effects of parents for root weight was analysed for VRRAD-213, VRRAD-200, VRRAD-201 & VRRAD-12 during winter, and VRRAD-200, VRRAD-201, VRRAD-19 & VRRAD-198 during summer season. Moreover, economic heterosis for harvest index was significantly positive only in 3 and 5 cross-combinations during winter and summer seasons such as VRRAD-198×VRRAD-150, VRRAD-19×VRRAD-150 & VRRAD-201×VRRAD-150, and VRRAD-19×VRRAD-200, VRRAD-198×VRRAD-200, VRRAD-13×VRRAD-200, VRRAD-201×VRRAD-200 & VRRAD-201×VRRAD-150, respectively. The parents VRRAD-150 & VRRAD-19 with entire leaf shape during winter and VRRAD-200 during summer season contributing towards higher harvest index and thereby improving root to leaf ratio in radish.

However, five best performing F_1 hybrids for marketable yield were VRRAD-12×VRRAD-213 (33.6%) followed by VRRAD-11×VRRAD-213 (31.2%), VRRAD-201×VRRAD-213 (24.3%), VRRAD-13×VRRAD-213 (21.5%) and VRRAD-12×VRRAD-200 & VRRAD-13×VRRAD-200 (21.4%) during winter season (9.1-23.3 °C temperature); and VRRAD-201×VRRAD-200 (42.8%), VRRAD-201×VRRAD-213 (32.2%), VRRAD-198×VRRAD-200 (30.6%), VRRAD-198×VRRAD-213 (29.6%) & VRRAD-13×VRRAD-200 (29.5%) during

Table 4: Economic heterosis (%, Pusa Chetki as check) and heterotic effects (%) of parents for plant growth and marketable yield of radish during summer season

Hybrids/Parents	Days to first harvest	Root length	Leaf length	Gross plant weight	Root weight	Leaf weight	Harvest index	Marketable yield
Hybrids				**Economic heterosis**				
VRRAD-13× Pusa Chetki	3.9	17.0*	-7.3	2.7	6.4	-0.5	3.6	2.7
VRRAD-13×VRRAD-150	16.3*	57.2**	-0.5	17.1*	20.6*	14.1*	3.0	17.1*
VRRAD-13×VRRAD-200	13.8*	88.9**	10.1*	29.5**	69.8**	-5.0	31.1**	29.5**
VRRAD-13×VRRAD-213	41.7**	77.5**	6.3	29.4**	28.7**	30.1**	-0.6	29.4**
VRRAD-201× Pusa Chetki	13.2*	19.3*	7.2	6.4	7.2	5.8	0.7	6.4
VRRAD-201×VRRAD-150	16.3*	59.8**	14.0*	18.7*	29.3**	9.6	8.9*	18.7*
VRRAD-201×VRRAD-200	18.8*	95.8**	2.6	42.8**	85.1**	6.6	29.6**	42.8**
VRRAD-201×VRRAD-213	41.8**	78.6**	14.7*	32.2**	35.7**	29.2**	2.6	32.2**
VRRAD-198× Pusa Chetki	10.5	16.4*	-0.4	4.5	3.7	5.2	-0.7	4.5
VRRAD-198×VRRAD-150	17.5*	56.3**	10.9*	17.6*	26.5*	10.0	7.5	17.6*
VRRAD-198×VRRAD-200	13.9*	88.9**	0.3	30.6**	71.7**	-4.6	31.5**	30.6**
VRRAD-198×VRRAD-213	39.1**	80.2**	10.9*	29.6**	32.2**	27.4**	2.0	29.6**
VRRAD-19× Pusa Chetki	3.8	23.3*	8.0	10.3	14.8*	6.3	4.2	10.3
VRRAD-19×VRRAD-150	3.4	49.5**	19.2**	19.4*	26.4*	13.3	5.9	19.4*
VRRAD-19×VRRAD-200	7.8	73.2**	18.3**	25.3**	75.9**	-18.1*	40.4**	25.3**
VRRAD-19×VRRAD-213	20.4**	62.8**	19.3**	28.7**	28.0*	29.3**	-0.6	28.7**
VRRAD-11× Pusa Chetki	20.4**	5.9	1.9	1.8	-7.2	9.5	-8.8*	1.8
VRRAD-11×VRRAD-150	26.3**	27.8**	8.6	12.1	-3.3	25.3**	-13.8**	12.1
VRRAD-11×VRRAD-200	31.3**	33.2**	13.2*	17.7*	20.9*	15.1*	2.6	17.7*
VRRAD-11×VRRAD-213	33.3**	38.3**	17.1**	18.9*	2.5	33.0**	-13.8**	18.9*
VRRAD-12× Pusa Chetki	26.1**	12.4	6.6	3.7	-9.3	14.8*	-12.5*	3.7
VRRAD-12×VRRAD-150	28.8**	32.8**	10.9*	11.0	-1.4	21.7*	-11.2*	11.0
VRRAD-12×VRRAD-200	35.0**	39.0**	21.3**	20.4**	22.7*	18.4*	1.9	20.4**
VRRAD-12×VRRAD-213	26.1**	25.9**	24.5**	20.1**	1.1	36.4**	-15.8**	20.1**
Heterosis Mean	21.2	48.3	9.9	18.8	24.5	13.9	4.1	18.8
Heterosis Range	3.4 to 41.8	5.9 to 95.8	-7.3 to 24.5	1.8 to 42.8	-9.3 to 85.1	-18.1 to 36.4	-15.8 to 40.4	1.8 to 42.8
Female parent				**Heterotic effects**				
VRRAD-13	18.9	60.1	2.1	19.7	31.4	9.7	9.3	19.7
VRRAD-201	22.5	63.4	9.6	25.0	39.3	12.8	10.5	25.0
VRRAD-198	20.2	60.4	5.4	20.6	33.5	9.5	10.1	20.6
VRRAD-19	8.9	52.2	16.2	20.9	36.3	7.7	12.5	20.9
VRRAD-11	27.8	26.3	10.2	12.7	3.2	20.7	-8.4	12.7
VRRAD-12	29.0	27.5	15.8	13.8	3.3	22.8	-9.4	13.8
Male parent				**Heterotic effects**				
Pusa Chetki	13.0	15.7	2.7	4.9	2.6	6.8	-2.3	4.9
VRRAD-150	18.1	47.2	10.5	16.0	16.4	15.7	0.1	16.0
VRRAD-200	20.1	69.9	11.0	27.7	57.7	2.1	22.9	27.7
VRRAD-213	33.7	60.6	15.4	26.5	21.4	30.9	-4.4	26.5

*&**: Significant at $P<0.05$ and $P<0.01$, respectively

summer temperature of 28.5–43.4 °C. Furthermore, the most heterotic parents having better combining ability during winter and summer seasons were VRRAD-12 (F), VRRAD-201 (F), VRRAD-213 (M) & VRRAD-200 (M); and VRRAD-201 (F), VRRAD-19 (F), VRRAD-200 (M) & VRRAD-213 (M), respectively.

Quantitative traits of best one of the best Ogura-CMS lines VRRAD-12 for consecutively three years 2017-18, 18-19 and 19-20 were observed as 45.7, 42.2 & 38.5 days to first root harvest, 273.5, 261.3 & 246.5 g gross plant weight, 190.3, 172.4 & 152.6 g root weight, 24.8, 23.1 & 22.4 cm root length, 37.5, 39.1 & 44.8 cm shoot length, 3.6, 3.7 & 3.4 cm root diameter, 11.3, 11.0 & 10.5 number of leaf, 60.2, 59.5 and 66.4 q/ha marketable yield, 41.6, 37.8 & 43.1 days to 50% flowering, 410.3, 391.6 & 426.8 pods/plant, 3.7, 3.8 & 3.8 seed/pod, and 12.9, 13.5 & 13.9 g of 1000 seed weight. Moreover, economic parameters of another CMS line VRRAD-201 during 2017-18, 18-19 and 19-20 were found as 47.8, 42.4 & 36.8 days to first root harvest, 268.3, 252.3 & 215.4 g gross plant weight, 185.4, 164.8 & 134.8 g root weight, 25.4, 23.5 & 21.6 cm root length, 37.5, 38.6 & 40.2 cm shoot length, 3.5, 3.2 & 3.1 cm root diameter, 10.4, 10.5 & 10.1 number of leaf, 58.7, 56.4 & 58.0 t/ha marketable yield, 35.8, 37.1 & 36.1 days to 50% flowering, 405.2, 399.1 & 218.9 pods/plant, 4.3, 4.1 & 4.5 seed/pod and 12.8, 13.0 & 13.6 g of 1000 seed weight, respectively.

In India, radish is grown throughout the year under varying climate conditions to meet the market demand.

Table 5: Leaf division incision (Leaf shape) and root shape of parents and F_1 hybrids in radish

Parent with leaf morphology and root shape	Pusa Chetki (S, T)	VRRAD-150 (E, T)	VRRAD-200 (S, T)	VRRAD-213 (L, T)
VRRAD-13* (S, T)	S, T	E, T	S, T	L, T
VRRAD-201* (S, T)	S, T	E, T	S, T	L, T
VRRAD-198* (S, T)	S, T	E, T	S, T	L, T
VRRAD-19* (E, T)	E, T	E, T	E, T	L, T
VRRAD-11* (L, C)	L, C	L, C	L, C	L, C
VRRAD-12* (L, C)	L, C	L, C	L, C	L, C

*All are CMS lines developed at ICAR-IIVR, Varanasi, UP;
Leaf division incision i.e. Leaf morphology (L: Lyrate, S: Sinuate, E: Entire);
Root shape (T: Triangular with tapering end, C: Cylindricar with blunt end)

In terms of consumers' preference; leaf shape, root colour and root shape are the main economic traits. Generally, the most preferred leaf shape is Entire > Sinuate > Lyrate > Lacerate; root shape preference is for Triangular > Cylindric > Spherric > Elliptic; and desirable root colour is White > Coloured along with moderate taste. Leaf shape (Entire, Sinuate, Lyrate) and root shape (Triangular, Cylindric) of different 10 parents and 24 hybrids are elucidated (Table 5) which reflects following dominance pattern in F_1 progeny: Lyrate > Entire > Sinuate leaf shape and Cylindric > Triangular root shape.

In conclusion, altogether keeping in view the importance of marketable root, and consumers' preference for sinuate/entire leaf shape during summer; the following are most promising CMS-based F_1 hybrids such as VRRAD-12×VRRAD-213 (72.8 t/ha), VRRAD-11×VRRAD-213 (71.5 t/ha), VRRAD-201×VRRAD-213 (67.7 t/ha), VRRAD-13×VRRAD-213 (66.2 t/ha) & VRRAD-12×VRRAD-200 (66.1 t/ha) for winter season cultivation; and VRRAD-201×VRRAD-200 (41.6 t/ha), VRRAD-198×VRRAD-200 (38.1 t/ha) & VRRAD-13×VRRAD-200 (37.8 t/ha) for summer season cultivation at high temperature (28.5-43.4 °C). Additionally, the following promising parents VRRAD-12 & VRRAD-201 as female and VRRAD-213 & VRRAD-200 as male for winter season; and VRRAD-201 & VRRAD-19 as female and heat tolerant line VRRAD-200 as male parent for summer season are the best combiners for harnessing the heterotic potential in radish.

सारांश

मूली में संकर ओज ज्ञात करने के लिये वर्ष 2018–19 में प्रक्षेत्र प्रयोग किया गया। पित्रों एवं संकरों के लिये मध्य वर्ग विविधता के आर्थिक महत्व वाले गुणों के लिये पाया गया जिससे प्रचुर विविधता होने का संकेत मिलता है। जाड़े एवं ग्रीष्म काल में विविध गुणों के लिये आर्थिक ओज तुड़ाई के प्रथम दिन हेतु 23.9–15.8 प्रतिशत एवं 3.4–41.8 प्रतिशत; जड़ की लम्बाई हेतु –30.2–32.4 प्रतिशत एवं –5.9–95.8 प्रतिशत; पत्ती की लम्बाई हेतु –15.3–16.5 प्रतिशत एवं –7.3–24.5 प्रतिशत; जड़ भार हेतु –23.1–30.0 प्रतिशत एवं –9.3–85.1 प्रतिशत; पत्ती भार हेतु –32.9–39.6 प्रतिशत 18.1–36.4 प्रतिशत; तुड़ाई गुणांक हेतु –5.3–9.7 प्रतिशत एवं 15.8–40.4 प्रतिशत तथा बाजार योग्य उपज हेतु 24.2–33.6 प्रतिशत एवं 1.8–42.8 प्रतिशत क्रमशः पाया गया। बाजार योग्य जड़ों का महत्व एवं उपभोक्ता की पसन्द को देखते हुए ग्रीष्म काल में लहरदार/पूर्ण पत्ती; कोशिकद्रव्यी नर बन्धता आधारित संकरों जैसे –वीआरआरएडी –12 X वीआरआरएडी –213, वीआरआरएडी –11 X वीआरआरएडी –213, वीआरआरएडी –201 X वीआरआरएडी –213, वीआरआरएडी –13 X वीआरआरएडी –213 तथा वीआरआरएडी –12 X वीआरआरएडी –2000 एवं शरद काल हेतु वीआरआरएडी –201 X वीआरआरएडी –200, वीआरआरएडी –198 X वीआरआरएडी –200 तथा वीआरआरएडी –13 X वीआरआरएडी –213 ग्रीष्म काल के उच्च तापमान (28.5–43.4 डिग्री सेन्टीग्रेड) हेतु उपयुक्त पाया गया। संकर ओज के क्षमता को प्राप्त करने हेतु सबसे उपयुक्त संयोजक वीआरआरएडी –12 व वीआरआरएडी –201 मादा तथा वीआरआरएडी –213 व वीआरआरएडी –200 नर पित्र जाड़े के लिए; वीआरआरएडी –201 व वीआरआरएडी –19 मादा व तापमान सहनशील साईन वीआरआरएडी –200 नर पित्र ग्रीष्म काल के लिए उत्तम पाये गये।

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 (2020) High resolution LC-MS characterization of phenolic compounds and the evaluation of antioxidant properties of a tropical purple radish genotype. Arabian J Chem 13(1): 1355-66.

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 (2020) Radish (*Raphanus sativus* L.): Breeding for higher yield, better quality and wider adaptability. In: (Eds)., pp –.

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, 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 Sci Techno Newsl 22(2): 12.

Singh BK, Singh PM and Singh B (2018) Heterosis for economic traits in single cross-hybrids of radish (*Raphanus sativus* L.). Veg Sci 45(1): 45–49.

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