RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
55 (3) 796-809, 2023
http://doi.org/10.54910/sabrao2023.55.3.16
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

GENETIC DIVERSITY OF DIFFERENT RADISH (*RAPHANUS SATIVUS* L.) CULTIVARS UNDER THE BASTAR PLATEAU OF CHHATTISGARH, INDIA

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SUMMARY

The presented study, held at the Research cum Instructional Farm of the College of Horticulture and Research Station, Jagdalpur, Chhattisgarh, India, ran during the *Rabi* season of 2021, to investigate superior radish cultivars for selection having high yield potential and better quality root for Bastar plateau. The experiment, laid out in randomized block design (RBD), had 15 treatments and three replications. Observing high genotypic and phenotypic coefficient of variation was for the following traits: dry and fresh weights of roots, plants, and leaves; root and leaf yields; days to 50% germination; the diameter and length of the root, North-South and East-West spread of the plant; plant height, and the number of leaf plant^{-1}, having recorded significant heritability and high genetic advance. Similarly, high heritability showed for root yield and fresh and dry weights of roots. Moderate heritability levels appeared for the traits, *viz*., the plant's dry weight and the root diameter. The genetic gain resulted high for characters, *viz*., root yield and fresh and dry weights of roots. High heritability followed by high genetic advance indicates that selection may be effective for improving such characteristics. Root yield (t ha^{-1}) exhibited a highly significant positive correlation with the fresh weight of the plant at the phenotypic and genotypic levels, followed by dry weight of roots, dry weight of the plant, East-West spread of the plant, the diameter of the root, and leaf yield plot^{-1}. The fresh weight of roots had the maximum positive direct effect on root yield in the genotypic path, followed by the dry weight of roots and the plant, the East-West spread of the plant, the diameter of the root, and leaf yield in radish. The selection of these characters can benefit in improving the yield of radishes.

Keywords: radish, path coefficient, root yield, genotypic, phenotypic and correlation

Key findings: The results indicated that a genetic variation of *Raphanus sativus* L. can further serve the species' conservation, characterization, and usefulness for future breeding purposes. Cultivars exhibiting higher yield potential and desirable qualities may undergo testing in different agro-climatic locations.

Citation: Thakur NK, Singh KP, Singh B, Shukla R, Khemraj, Haldar P (2023). Genetic diversity of different radish (*Raphanus sativus* L.) cultivars under the Bastar plateau of Chhattisgarh, India. *SABRAO J. Breed. Genet.* 55(3): 796-809. http://doi.org/10.54910/sabrao2023.55.3.16.

Communicating Editor: Prof. D.P.S.T.G. Attanayaka

Manuscript received: December 27, 2022; Accepted: May 17, 2023.

INTRODUCTION

Radish (*Raphanus sativus* L.) comes from the Latin word *"radix."* It is one of the most necessary root crops of the family Cruciferae, with a chromosome number 2n = 2x = 18 originating from Central and Western China and India. India is the second-largest producer of horticulture after China. Remarkable progress has occurred in area expansion, resulting in higher production of radish over the last few decades (Thakur *et al.,* 2022). During 2019–2020, the area under vegetables was 10.35 million ha, producing 191.76 MT. In India, growing radish was over 0.212 million ha in 2019–2020, with an annual production of 3.107 MT (Anonymous, 2020b).

It is mainly grown in West Bengal, Bihar, Uttar Pradesh, Karnataka, Punjab, Maharashtra, and Assam, India. According to the Directorate of Horticulture and Farm Forestry, Chhattisgarh (2020), the area and production of white radish in Chhattisgarh were 0.0134 million ha and 0.244 MT, respectively (Anonymous, 2020a). However, in Bastar, reports of commercial cultivation are yet to exist. The genetic improvement of the crop depends on the amount of genetic variability present in the population, and the germplasm serves as a valuable source of base population, providing the possibility for wide variability (Vavilov, 1951).

The role of genetic variation in a crop is critical in selecting the best genotypes for rapidly improving yield and desirable horticultural characteristics, as well as, in choosing the most suitable parents for breeding programs (Singh *et al*., 2015; Bazargaliyeva *et al*., 2023). Genetic variability study helps understand the nature of variation in different horticultural traits, both quantitative and qualitative. Variations may result from environmental and genetic factors, mutations, or attacks by any biological agents (Singh, 2020).

Genetic variation is essential in a given germplasm and a fundamental necessity for crop improvement, as it provides more opportunities for selection to implement an efficient and productive breeding program. It is, therefore, essential to know the amount of genetic variability available, and the efficacy of selecting depends on the magnitude of genetic variability present in the given germplasm set collected from indigenous and exotic sources. Further, the extent of heritability helps the breeder to identify the traits for easy selection.

Genetic advance explains the degree of the gain obtained in a given character under a particular selection pressure. Estimates of heritability with genetic advances are more reliable and meaningful. The correlation studies help the breeder know about the types of association between the various traits in a given three germplasm sets. The path coefficient analysis helps determine the direct and indirect effect of the different horticultural traits on the dependent character, like yield. Radish is a root and leafy vegetable suitable for tropical and temperate climates. The leaves and roots are consumed raw as salad and cooked as vegetables (Thamburaj and Singh, 2005).

A preference of consumers exists for typical temperate types, which mature early and are sweet in taste, small, less pungent, and fit in multiple cropping. There is a need to maximize yield and other traits through the genetic restructuring of temperate radishes. Kumar *et al.* (2012) evaluated the performance of new temperate-type radish genotypes in India. However, the horticultural specification required in temperate radishes leaves breeders with the problem of crop improvement with limited variability. Studies on genetic divergence will help identify promising diverse genotypes, which may benefit combination and heterosis breeding. Hence, the study's objective mainly focused on selecting a remarkable radish variety with high yield potential and better-quality roots suitable for the Bastar plateau of Chhattisgarh, India.

MATERIALS AND METHODS

The field experiment on radish proceeded during the *Rabi* season in 2021–2022 at the College of Horticulture and Research Station, Jagdalpur, in the Bastar region of Chhattisgarh, India. The location map of the study site appears in Figure 1. The study area locates between 17°45' and 20°34' N latitude and 80°15' to 82°15' E longitude. The area elevation ranges from 550 to 1200 m above mean sea level. A subtropical monsoon type of climate occurs in the study area. Summer, monsoon, and winter are the reported three different seasons. From these, the southwest monsoon lies between June to mid-September, while winter and summer vary from October to February and March to mid-June. For the past 50 years, maximum annual rainfall occurs in between June and September, with 1200–1600 mm of average yearly rainfall. The experiment laid out in a randomized block design (RBD) had 15 treatments and three replications. The 15 radish cultivars used in the study as treatments were: T_1: Pusa Chetki, T_2: Pusa Mridula, T_3: Pusa Shweta, T_4: Pusa Gulabi, T_5: Pusa Jamuni, T_6: Kashi Hans, T_7: Kashi Muli 40, T_8: Kashi Lohit, T_9: Chinese Pink, T_{10}: MRH111, T_{11}: Snow White, T_{12}: Mino Early, T_{13}: Ivory White, T_{14}: R-30, and T_{15} (check): Palak Patta. Table 1 shows the source of different treatments used in this study.

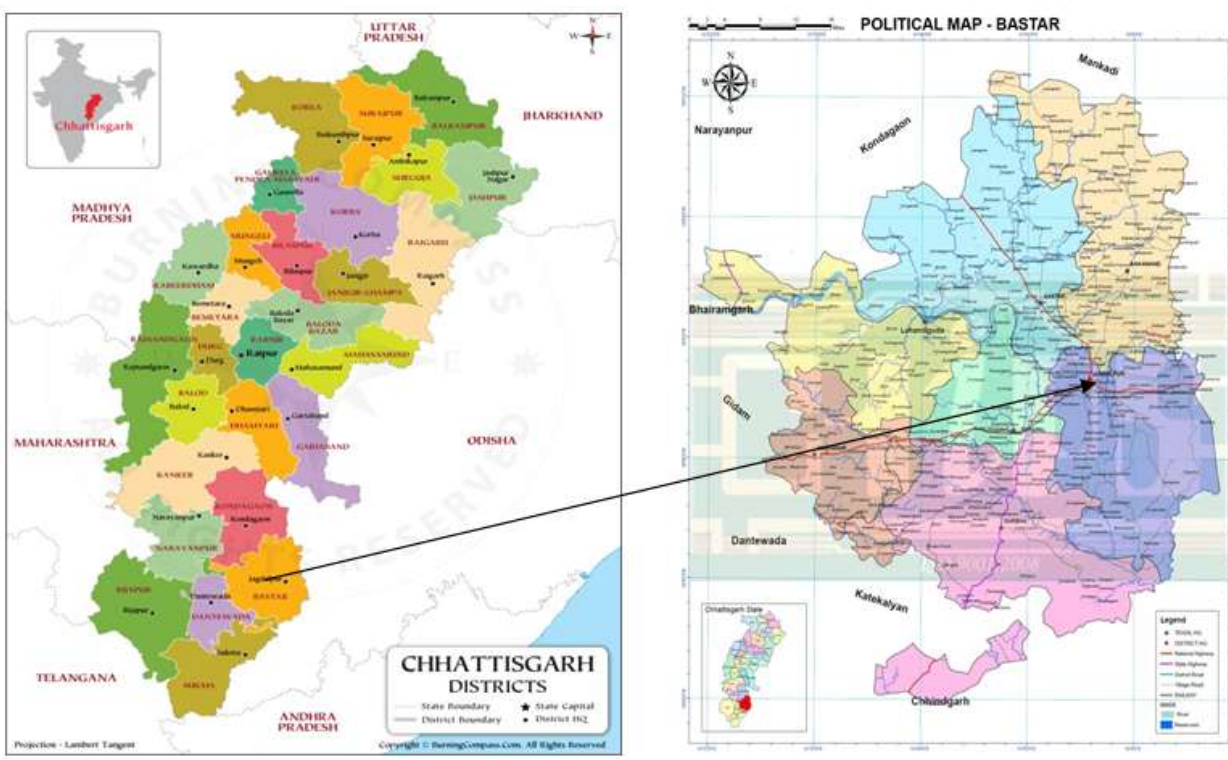

Figure 1. The location map of the study site.

Table 1. Treatment details and their sources.

Treatments		Treatments Details	Source
T_1	:	Pusa Chetki	IARI, New Delhi
T_2	:	Pusa Mridula	IARI, New Delhi
T_3	:	Pusa Shweta	IARI, New Delhi
T_4	:	Pusa Gulabi	IARI, New Delhi
T_5	:	Pusa Jamuni	IARI, New Delhi
T_6	:	Kashi Hans	IIVR, Varanasi
T_7	:	Kashi Muli – 40	IIVR, Varanasi
T_8	:	Kashi Lohit	IIVR, Varanasi
T_9	:	Chinese Pink	Agro seeds
T_{10}	:	MRH-111	Dhanya veg seeds
T_{11}	:	Snow white	Advanta golden seeds
T_{12}	:	Mino early	Sungro seeds
T_{13}	:	Ivory white	Syngenta
T_{14}	:	R-30	Agro seeds
T_{15}	:	Palak Patta (check)	Manyata seeds

Soil samples collected at a depth of 0–15 cm underwent drying in the shade at room temperature and processing to pass through a 2-mm sieve in the laboratory. The soil of the experimental block was inceptisols. Sowing followed on 27 October. The ridges and furrow opening in a bed size measured 20 cm × 10 cm, with a spacing of 20 cm kept between the ridges. The seed was dibbled at 10 cm spacing. Fertilization took place as recommended, adopting all the necessary cultural practices. Recorded observation of vital aspects, such as days to 50% germination, plant height (cm), number of leaves plant^{-1}, East-West (E-W) and North-South (N-S) spreads of the plant (cm), fresh and dry weights of leaves and roots (g), the diameter and length of roots (cm), root: shoot ratio, days to harvest, leaf yield (kg plot^{-1}) (t ha^{-1}), and root yield (kg plot^{-1}) (t ha^{-1}) progressed on five random plants from each replication.

The analysis of variance by statistical analysis followed the procedure devised by Gomez and Gomez (1984). Phenotypic and genotypic coefficients of variation in percentage calculations were according to Burton and Devane (1953). The estimates of PCV and GCV gained labels as low (<10%), moderate (10%–12%), and high (>20%), according to Sivasubramanian and Madhavamenon (1973). Heritability in the broad sense (H^2b) calculation used the Hansen *et al.* (1956) formula, defined as the proportion of genotypic variance to the total variance (phenotypic variance). The broad sense heritability estimates consisted as low (>50%), moderate (50%–70%), and high (<70%), as suggested by Robinson (1966). Genetic Advance (GA) computation followed the method given by Johnson *et al.* (1955). Correlation coefficient analysis measures all possible combinations between various characters at genotypic (g), phenotypic (p), and environmental levels using the formula suggested by Miller and Naismith (1958). The genotypic correlation coefficients were further partitioned into direct and indirect effects with the help of path coefficient analysis, as suggested by Wright (1921) and elaborated by Dewey and Lu (1959). After calculating values of the path coefficient, *i.e.*, the 'C' vector, it helped obtain path values for residual (R). The residual effect computation used a formula from Singh and Chaudhary (1985).

RESULTS AND DISCUSSION

Coefficients of variability

Table 2 depicts that the phenotypic coefficient of variation was higher in magnitude than the genotypic coefficient of variation for all the characters under study. However, the differences between PCV and GCV values for all the characters were lower in magnitude, which

Table 2. Estimates of genotypic and phenotypic coefficients of variation, heritability, and genetic advance for various traits of radish.

No	Traits	Range		Mean	Coefficients of variability (%)		Heritability (%)	Genetic advance (mean %)
		Min.	Max.		GCV	PCV		
1	Days to 50% germination	10.67	6.33	8.50	11.82	17.93	43.47	16.05
2	Plant height (cm)	23.68	37.69	31.86	7.90	15.36	26.41	8.36
3	Number of leaves plant^{-1}	9.80	13.33	11.52	7.63	14.79	26.63	8.12
4	East-West spread of the plant (cm)	20.90	33.43	28.20	8.31	15.46	28.91	9.21
5	North-South spread of the plant (cm)	28.10	46.50	40.72	9.95	15.80	39.70	12.92
6	Fresh weight of leaves (g)	71.29	109.59	86.01	10.66	18.02	34.98	12.99
7	Dry weight of leaves (g)	8.00	11.00	9.05	7.95	14.80	28.84	8.80
8	Fresh weight of the plant (g)	149.91	254.93	197.15	9.96	17.56	32.16	11.63
9	Dry weight of the plant (g)	17.42	30.28	23.43	11.10	18.12	37.51	14.00
10	Leaf yield (kg plot^{-1})	3.56	5.48	4.30	11.24	17.30	42.20	15.04
11	Diameter of the root (cm)	3.14	5.65	4.18	11.76	16.48	50.98	17.30
12	Length of the root (cm)	16.28	31.03	26.17	11.02	16.45	44.88	15.21
13	Fresh weight of roots (g)	72.81	153.75	118.61	20.22	24.25	69.53	34.73
14	Dry weight of roots (g)	9.32	19.68	15.19	20.03	24.48	66.97	33.77
15	Root yield (kg plot^{-1})	3.64	7.69	5.91	20.56	24.07	72.98	36.18

indicated that the contribution of the environment was relatively less in governing the various traits. Discussions on the observations recorded concerning phenotypic and genotypic coefficients follow under specified headings:

Phenotypic coefficient of variation

The data presented in Table 2 indicated a wide range of phenotypic variability in the experimental materials. The phenotypic coefficient of variation (PCV) ranged from 15.36% to 24.48%. High PCV existed for the traits, *viz*., dry weight of root (24.48%), fresh weight of root (24.25%), root yield (24.07%), dry weight of plant (18.12%), and fresh weight of plant (17.56%). Ullah *et al*. (2010) also observed high PCV values for identical traits in radishes. Moderate PCV resulted for the fresh weight of leaves (18.02%), days to 50% germination (17.93%), leaf yield (17.30%), the diameter of root (16.48%), length of root (16.45%), N-S spread of the plant (15.80%), E-W spread of the plant (15.46%), plant height (15.36%), dry weight of leaves (14.80%), and the number of leaves plant^{-1} (14.79%). Kumar *et al*. (2012) and Madaik (2020) also reported similar results.

Genotypic coefficient of variation

The genotypic coefficient of variation (GCV) is the amount of variation in the population which is due to the genetic component. In the experimental material, a wide range of GCVs surfaced for characters under study, ranging from 7.90% to 20.56%. A high GCV showed in characters, *viz*., root yield (20.56%), fresh weight of roots (20.22%), and dry weight of roots (20.03%). Similar observations with high GCV also came from Roopa *et al*. (2018). Moderate GCV appeared for dry weight of plant (11.10%), fresh weight of plant (9.96%), days to 50% germination (11.82%), diameter of root (11.76%), leaf yield (11.24%), length of root (11.02%), and fresh weight of leaves (10.66%). Similar findings of moderate GCV resulted from a study by Mallikarjunarao *et al.* (2015). However, low GCV emerged for the horticultural traits, *viz*., N-S spread of the plant (9.95%), E-W spread of the plant (8.31%), dry weight of leaves (7.95%), plant height (7.90%), and the number of leaves plant^{-1} (7.63%). These findings are similar to the results of Singh (2020).

Heritability

Heritability acts as an indicator of the level of genetic variation that parents can pass on to offspring. High heritability displayed by a character allows a breeder to make the exact selection on a single plant to enhance a specific trait of interest whereas, if the heritability is on the lower side, then the breeder has to rely on the progeny testing to make a selection based on desirable progenies. The heritability estimate (broad sense) varied from 26.41% to 72.98% for different characters under study (Table 2). High heritability estimates came about for root yield (72.98%), fresh weight of roots (69.53%), and dry weight of roots (66.97%). Noted moderate heritability levels were for the traits, dry weight of the plant (37.51%) and diameter of root (50.98%). Inversely, low heritability levels showed for the traits, *viz*., fresh weight of plant (32.16%), length of root (44.88%), days to 50% germination (43.47%), leaf yield (42.20%), N-S spread of the plant (39.70%), fresh weight of leaves (34.98%), E-W spread of the plant (28.91%), dry weight of leaves (28.84%), number of leaves plant^{-1} (26.63%), and plant height (26.41%). Sivathanu *et al*. (2014) reported related results.

Genetic advance

The estimates of the genetic advance calculation as a percentage of the mean during the presented investigation were for 15 radish cultivars. The heritability estimates alone cannot help determine the genetic potential of any horticultural trait. High heritability estimates coupled with high genetic advance as a percentage of the mean suggest that the corresponding feature has additive genes mainly controlling it, and selection in such a scenario can be fully effective. Genetic advance (expressed as a percent of the population mean) was low to high and ranged from 8.12% to 36.18% for different characters under study (Table 2). The genetic gain appeared high for characters, *viz*., root yield (36.18%), fresh weight of roots (34.73%), and dry weight of roots (33.77%). Mallikarjunarao *et al*. (2015) reported similar results for high genetic advances. The moderate genetic gain resulted in the fresh weight of the plant (20.51%), the diameter of the root (17.30%), days to 50% germination (16.05%), length of the root (15.21%), leaf yield (15.04%), dry weight of the plant (14.00%), fresh weight of leaves (12.99%), and N-S spread of the plant (12.92%). In contrast, observed low outputs emerged for the horticultural traits, *viz*., E-W spread of the plant (9.21%), dry weight of leaves (8.80%), plant height (8.36%), and the number of leaves plant^{-1} (8.12%). Hence, the highest heritability followed by high genetic advance indicates that selection may be effective for improving such characteristics. The presented results follow the findings of Singh (2020).

Correlation coefficient analysis

After acquiring knowledge about the available genetic variation in the experimental material, one must learn about the association between different characters within a species. Since most of the traits of economic value in crop plants rely on one or the other characteristics, the degree of expression of one character increases or decreases as another character increases or decreases and vice versa. Some of the horticultural traits can directly and positively correlate with marketable root yield per plant; hence, selecting these traits provides an opportunity for crop improvement. In plant breeding, in general, working out two types of correlations include genotypic and phenotypic correlations. The description of both correlations derived from the current study involved 15 radish cultivars, as presented in Table 3.

Genotypic and phenotypic correlations

The inherent or heritable association between two variables is known as the genotypic correlation. This type of correlation may be either due to the pleiotropic action of genes due to linkage, or both. The phenotypic correlation is a directly observed association between the two variables. It includes genetic and environmental effects, and therefore differs under different ecological conditions.

Table 3. Genotypic and phenotypic coefficients of correlation among different morphological traits of radish.

Traits		PH	NL	EWSP	NSSP	DR	LR	FWL	FWR	DWL	DWR	FWP	DWP	LY	R Y
DTG	P	-0.024	0.074	0.399**	0.359*	-0.031	0.122	0.058	-0.117	0.141	-0.087	-0.117	-0.070	0.143	-0.119
	G	0.393**	0.951**	0.998**	0.993**	-0.178	0.396**	0.660**	-0.222	0.526**	-0.248	-0.030	-0.118	0.529**	-0.220
PH	P	1.000	0.284	0.271	0.324*	-0.433**	0.428**	0.303*	0.347*	0.346*	0.349*	0.521**	0.529**	0.236	0.317*
	G	1.000	0.349*	0.910**	0.847**	-0.738**	0.896**	0.438**	0.847**	0.639**	0.846**	0.910**	0.857**	0.532**	0.880**
NL	P		1.000	0.210	0.347*	-0.149	0.213	0.137	-0.114	0.026	-0.096	-0.023	-0.070	0.073	-0.106
	G		1.000	0.855**	0.820**	-0.352*	0.175	0.351*	0.085	0.673**	0.066	0.167	0.193	0.435**	0.077
EWSP	P			1.000	0.469**	-0.242	0.453**	0.331*	0.018	0.334*	0.002	0.149	0.089	0.297*	0.041
	G			1.000	0.952**	-0.732**	0.912**	0.785**	0.157	0.872**	0.175	0.360*	0.369*	0.811**	0.134
NSSP	P				1.000	-0.347*	0.381**	0.277	0.185	0.346*	0.201	0.293	0.250	0.168	0.153
	G				1.000	-0.952**	0.944**	0.180	0.359*	0.126	0.345*	0.417**	0.435**	0.316*	0.388**
DR	P					1.000	-0.315*	0.025	-0.376*	-0.082	-0.387**	-0.361*	-0.383**	0.057	-0.322*
	G					1.000	-0.674**	0.168	-0.557**	0.229	-0.549**	-0.553**	-0.538**	0.129	-0.600**
LR	P						1.000	0.111	0.364*	0.190	0.420**	0.329*	0.418**	0.141	0.377*
	G						1.000	0.296*	0.787**	0.273	0.741**	0.976**	0.875**	0.249	0.777**
FWL	P							1.000	-0.079	0.716**	-0.103	0.295*	0.203	0.794**	-0.111
	G							1.000	-0.278	0.953**	-0.256	-0.099	-0.095	0.911**	-0.247
FWR	P								1.000	-0.073	0.921**	0.795**	0.861**	-0.083	0.970**
	G								1.000	-0.240	0.971**	0.998**	0.996**	-0.264	0.971**
DWL	P									1.000	-0.080	0.306*	0.233	0.759**	-0.118
	G									1.000	-0.233	-0.093	-0.102	0.992**	-0.191
DWR	P										1.000	0.810**	0.875**	-0.122	0.940**
	G										1.000	0.881**	0.816**	-0.230	0.912**
FWP	P											1.000	0.905**	0.228	0.788**
	G											1.000	0.956**	-0.006	0.993**
DWP	P												1.000	0.213	0.868**
	G												1.000	-0.091	0.945**
LY	P													1.000	-0.092
	G													1.000	-0.255

*: 5% level of significance, **: 1% level of significance, DTG – Days to 50% germination, DR – Diameter of root (cm), DWR - Dry weight of roots, PH – Plant height (cm), LR – Length of the root (cm), FWP- Fresh weight of the plant, NL – Number of leaves plant^{-1}, FWL - Fresh weight of leaves, DWP - Dry weight of the plant, EWSP–East-West spread of the plant (cm), FWR- Fresh weight of roots, RY – Root yield (kg plot^{-1}), NSSP–North-South spread of the plant (cm), DWL - Dry weight of leaves, LY - Leaf yield (kg plot^{-1}).

The character-wise discussion of the various genotypic and phenotypic correlations observed in the study of assorted genotypes of radish is as follows:

Days to 50% germination

Days to 50% germination demonstrated positive and highly significant genotypic and phenotypic correlations with E-W spread of the plant (0.998 and 0.399), N-S spread of the plant (0.993 and 0.359), number of leaf plant^{-1} (0.951 and 0.074), and leaf yield plant^{-1} (0.529 and 0.143). Nagar (2016) obtained similar results in radish research.

Plant height

Plant height showed a positive and highly remarkable genotypic and phenotypic correlation with the traits, *viz*., E-W spread of the plant (0.910 and 0.271), length of root (0.896 and 0.428), fresh weight of plant (0.910 and 0.521), dry weight of plant (0.857 and 0.529), and root yield plant^{-1} (0.880 and 0.317). However, plant height had a negative and highly significant correlation with the diameter of the root (-0.738 and -0.433). These findings corroborate those of Kaur *et al*. (2017).

Leaves plant^{-1}

The number of leaves plant^{-1} had a positive and highly substantial correlation with the E-W spread of the plant (0.855 and 0.210), N-S spread of the plant (0.820 and 0.347), and dry weight of leaves (0.673 and 0.026) at the genotypic and phenotypic levels. The results confirm the research findings of Chakraborty and Barman (2016) in radish.

East-West spread of plant

The plant spread is an influential trait in radishes. A positive and highly considerable correlation of E-W spread of the plant showed with N-S spread (1.216 and 0.469), length of root (0.912 and 0.453), and dry weight of leaves (0.334 and 0.872) at genotypic and phenotypic levels, respectively. These findings align with the results of Singh (2020).

North-South spread of plant

Noted positive and highly significant associations of N-S spread of the plant were with the traits, *viz*., length of root (0.944 and 381), dry weight of plant (0.435 and 0.250), fresh weight of plant (0.417 and 0.293), fresh weight of roots (0.359 and 0.185), and root yield plot^{-1} (0.388 and 0.153). The results validate the findings of Jabal *et al*. (2015) in radish.

Fresh weight of leaves

Fresh weight of leaves showed a positive and highly relevant association with the dry weight of leaves (0.953 and 0.716), leaf yield plant^{-1} (0.911 and 0.794), and E-W spread of plant (0.785 and 0.331) at genotypic and phenotypic levels, respectively. Singh (2020) gave similar findings in radishes.

Dry weight of leaves

A highly significant and positive association of the crucial horticultural trait, i.e., dry weight of leaves resulted in leaf yield plot^{-1} (0.992 and 0.759), fresh weight of leaf (0.953 and 0.716), and E-W spread of the plant (0.872 and 0.334) at genotypic and phenotypic levels, respectively. These research findings followed those obtained by Chapagain *et al.* (2010) in radish.

Fresh weight of the plant

A positive and notable correlation of the fresh weight of the plant appeared with the dry weight of the plant (0.956 and 0.905), plant height (0.910 and 0.521), and N-S spread of the plant (0.417 and 0.293) at genotypic and phenotypic levels, respectively. However, the character showed a significant positive association (0.993 and 0.788) with root yield plant^{-1}, suggesting that the trait considerably contributed to the economic attribute, with an increase in one having an increasing effect on other characters. These research findings support those obtained by Roopa *et al.* (2018) in radish.

Dry weight of the plant

The dry weight of the plant had a highly positive and meaningful connection with the characteristics, *viz.,* fresh weight of root (0.996 and 0.861), fresh weight of plant (0.956 and 0.905), length of root (0.75 and 0.418), and N-S spread of the plant (0.435 and 0.250) at genotypic and phenotypic levels, respectively. However, the feature showed a significant positive association (0.945 and 0.868) with root yield plant^{-1} at genotypic and phenotypic levels, respectively. These results verify those by Ullah *et al.* (2010) in a radish study.

Leaf yield plot^{-1}

Leaf yield plot^{-1} had a highly positive and sizable association with the traits, *viz.,* dry weight of leaves (0.992 and 0.759), fresh weight of leaves (0.911 and 0.794), E-W spread of the plant (0.811 and 0.297), and plant height (0.532 and 0.236). The research findings agree with the results from Singh (2020) in radish.

Diameter of root

The diameter of the root is a vital attribute since it contributes to the yield. A positive and highly relevant correlation of the root diameter showed with the other horticultural traits, *viz*., fresh weight of leaves (0.168 and 0.025) and leaf yield plot^{-1} (0.129 and 0.057) at genotypic and phenotypic levels. These outcomes are similar to the findings of Nagar *et al.* (2016).

Length of root

Highly remarkable and positive associations of the length of root resulted in the characters, *viz*., fresh weight of plant (0.976 and 0.329), dry weight of plant (0.875 and 0.418), and dry weight of roots (0.741 and 0.420) at genotypic and phenotypic levels, respectively. These findings confirm those obtained by Kaur *et al.* (2017).

Fresh weight of roots

The fresh weight of roots showed a positive and highly significant association with the characteristics, *viz*., fresh weight of plant (0.998 and 0.795) and dry weight of plant (0.996 and 0.861) at genotypic and phenotypic levels, respectively. Moreover, the trait displayed a significant positive connection (0.971 and 0.970) with root yield plant^{-1} at genotypic and phenotypic levels, suggesting that the increase in the character also leads to an upsurge in the economic feature (root yield plot^{-1}). Kaur *et al.* (2017) also acquired similar results in their radish study.

Dry weight of roots

The dry weight of roots had a positive and notable correlation with the fresh weight of the plant (0.881 and 0.810), dry weight of the plant (0.816 and 0.875), and root yield plant^{-1} (0.912 and 0.940) at genotypic and phenotypic levels, respectively. The presented research findings agree with past results obtained in radish (Sivathanu *et al.,* 2014).

Root yield plot^{-1}

Root yield plot^{-1} had a positive and considerable association with the characteristics, *viz.,* fresh weight of plant (0.933 and 0.788), plant height (0.880 and 0.317), length of root (0.777 and 0.377), N-S spread of the plant (0.388 and 0.153), and E-W spread of the plant (0.134 and 0.041) at genotypic and phenotypic levels, respectively. Chapagain *et al.* (2010) observed relatively similar results in radishes.

Path coefficient analysis (genotypic level)

The correlation coefficients provide information about the combination of different traits among themselves, while the path coefficient analysis gives a better insight into the cause of the association. It tells the effect of a character individually and in conjunction with other features on the dependent one, which is of economic value. It allows for partitioning of correlation coefficients into direct and indirect effects of the traits, contributing to the dependent variable. Root yield plot^{-1} was taken as a dependent variable in the current study, with the rest attributes considered as independent variables. The study results concerning direct and indirect effects on root yield plot^{-1} at the genotypic level are in Table 4. The discussion about various direct and indirect influences of the 14 independent traits on the dependent trait, root yield plot^{-1}, is as follows:

Days to 50% germination

A negative direct effect resulted in root yield plot^{-1} through days to 50% germination (-0.0394). Maximum indirect effects showed through the fresh weight of the plant (0.0046), followed by fresh weight of roots (0.0045), dry weight of roots (0.0034), dry weight of the plant (0.0028), the diameter of the root (0.0012), and plant height (0.0010). However, the maximum negative indirect effects occurred in the E-W spread of the plant (-0.0157), N-S spread of the plant (-0.0142), leaf yield plot^{-1} (-0.0057), dry weight of leaves (-0.0056), length of root (-0.0048), and the number of leaf plant^{-1} (-0.0029). The days to 50% germination gave a negative direct effect on the dependent trait root yield plot^{-1}. Similar results came from Singh (2020).

Plant height

A negative direct effect appeared for root yield plot^{-1} over plant height (**-**0.0359), which suggests that the selection for less plant height will lead to an increase in the root yield plot^{-1}. Although, positive indirect effects of the plant height were with attributes, *viz*., root diameter (0.0155) and days to 50% germination (0.0009). In contrast, a high negative indirect effect over the dependent character root yield plot^{-1} showed through the dry weight of the plant (-0.0190), fresh weight of the plant (-0.0187), length of the root (-0.0153), dry weight of roots (-0.0125), dry weight of leaves (-0.0124), fresh weight of roots (-0.0123), N-S spread of the plant (-0.0116), fresh weight of leaves (-0.0109), the number of leaf plant^{-1} (-0.0102), E-W spread of the plant (-0.0097), and leaf yield plant^{-1} (-0.0085), indicating similar results obtained by Kaur *et al*. (2017).

Leaves plant^{-1}

The trait number of leaves plant^{-1} recorded a positive direct effect (0.0205) on the root yield plot^{-1}. The reported highest positive indirect effects by other characteristics on dependent ones were through N-S spread of the plant (0.0071), followed by plant height (0.0058), length of the root (0.0044), E-W spread of the plant (0.0043), fresh weight of leaves (0.0028), leaf yield plant^{-1} (0.0015), days to 50% germination (0.0014), and dry weight of leaves (0.0005). It suggested that the selection through average root weight with leaves with the given trait, number of leaves plant^{-1}, could help increase the root yield plot^{-1} in radish. On the other hand, the highest negative indirect effect emerged through the diameter of the root (-0.0031), followed by the fresh weight of roots (-0.0023), dry weight of roots (-0.0020), dry weight of the plant (-0.0014), and fresh weight of the plant (-0.0005). Jabal *et al*. (2015) also observed the positive direct effect on the root yield through the number of leaves plant^{-1}.

East-West spread of plant

The E-W spread of the plant had a positive direct effect on the vital and dependent horticultural trait root yield plot^{-1} (0.1048). Meanwhile, a positive indirect effect occurred via N-S spread of the plant (0.0492), length of root (0.0475), days to 50% germination (0.0418), dry weight of leaves (0.0351), fresh weight of leaves (0.0347), leaf yield plant^{-1} (0.0311), plant height (0.0285), number of leaf plant^{-1} (0.0220), fresh weight of the plant (0.0156), dry weight of the plant (0.0093), fresh weight of roots (0.0019), and dry weight of roots (0.0003). But, detecting a negative indirect effect over the root diameter emerged

Table 4. Path analysis (direct and indirect) effect of different morphological characters on root yield plot^{-1} in radish.

Traits	DTG	PH	NL	EWSP	NSSP	DR	LR	FWL	FWR	DWL	DWR	FWP	DWP	LY	GCCRY
DTG	-0.0394	0.0009	0.0014	0.0418	-0.0047	-0.0021	-0.0024	-0.0047	-0.0709	-0.0133	-0.0211	0.0021	-0.0156	0.0090	-0.220
PH	0.0010	-0.0359	0.0058	0.0285	-0.0042	-0.0303	-0.0083	-0.0244	0.2097	-0.0326	0.0851	-0.0094	0.1172	0.0148	0.880**
NLPP	-0.0029	-0.0102	0.0205	0.0220	-0.0045	-0.0105	-0.0041	-0.0111	-0.0689	-0.0024	-0.0233	0.0004	-0.0157	0.0046	0.077
EWSP	-0.0157	-0.0097	0.0043	0.1048	-0.0061	-0.0169	-0.0088	-0.0267	0.0110	-0.0314	0.0006	-0.0027	0.0198	0.0185	0.134
NSSP	-0.0142	-0.0116	0.0071	0.0492	-0.0131	-0.0243	-0.0074	-0.0223	0.1121	-0.0325	0.0491	-0.0053	0.0555	0.0105	0.388**
DR	0.0012	0.0155	-0.0031	-0.0253	0.0045	0.0700	0.0061	-0.0020	-0.2276	0.0077	-0.0943	0.0065	-0.0850	0.0036	-0.600**
LR	-0.0048	-0.0153	0.0044	0.0475	-0.0050	-0.0221	-0.0194	-0.0090	0.2202	-0.0178	0.1026	-0.0060	0.0927	0.0088	0.777**
FWL	-0.0023	-0.0109	0.0028	0.0347	-0.0036	0.0018	-0.0022	-0.0806	-0.0480	-0.0673	-0.0251	-0.0053	0.0451	0.0496	-0.247
FWR	0.0045	-0.0123	-0.0023	0.0019	-0.0024	-0.0264	-0.0071	0.0064	0.6045	0.0069	0.2248	-0.0144	0.1910	-0.0052	0.971**
DWL	-0.0056	-0.0124	0.0005	0.0351	-0.0046	-0.0057	-0.0037	-0.0577	-0.0441	-0.0940	-0.0195	-0.0055	0.0516	0.0475	-0.191
DWR	0.0034	-0.0125	-0.0020	0.0003	-0.0026	-0.0271	-0.0081	0.0083	0.5571	0.0075	0.2440	-0.0147	0.1940	-0.0076	0.912**
FWP	0.0046	-0.0187	-0.0005	0.0156	-0.0038	-0.0253	-0.0064	-0.0238	0.4806	-0.0288	0.1977	-0.0181	0.2006	0.0142	0.993**
DWP	0.0028	-0.0190	-0.0014	0.0093	-0.0033	-0.0268	-0.0080	-0.0164	0.5208	-0.0219	0.2134	-0.0164	0.2217	0.0133	0.945**
LY	-0.0057	-0.0085	0.0015	0.0311	-0.0022	0.0040	-0.0027	-0.0640	-0.0500	-0.0714	-0.0298	-0.0041	0.0473	0.0625	-0.255

Residual effect: 0.02819, Diagonal and bold underlined figures show direct effect on root yield. DTG – Days to 50% germination, DR – Diameter of root (cm), DWR - Dry weight of roots, PH – Plant height (cm), LR – Length of the root (cm), FWP- Fresh weight of the plant, NL – Number of leaves plant^{-1}, FWL - Fresh weight of leaves, DWP - Dry weight of the plant, EWSP–East-West spread of the plant (cm), FWR- Fresh weight of roots, RY – Root yield (kg plot^{-1}), NSSP–North-South spread of the plant (cm), DWL - Dry weight of leaves, LY - Leaf yield (kg plot^{-1}).

(-0.0253). The selection for plant spread could help increase the root yield plot^{-1}. Similar findings came from Madaik (2020).

North-South spread of plant

A negative direct effect on root yield plot^{-1} showed through the N-S spread of the plant (-0.0131). However, positive indirect effects resulted via the root diameter (0.0045). The observed maximum negative indirect impact over the dependent trait was through the E-W spread of the plant (-0.0061), followed by the length of the root (-0.0050), dry weight of leaves (-0.0046), number of leaf plant^{-1} (-0.0045), plant height (-0.0042), fresh weight of the plant (-0.0038), fresh weight of leaves (-0.0036), dry weight of the plant (-0.0033), dry weight of roots (-0.0026), and leaf yield plant^{-1} (-0.0022). Likewise, Nagar *et al.* (2016) also reported comparable results.

Fresh weight of leaves

A negative direct effect occurred on the root yield plot^{-1} by the independent trait, fresh weight of leaves **(-**0.0806). The maximum positive indirect effect was with the dry weight of roots (0.0083) and fresh weight of roots (0.0064). Contrastingly, maximum negative indirect effects came out through the leaf yield plant^{-1} (-0.0640), followed by the dry weight of leaves (-0.0577), E-W spread of the plant (-0.0267), plant height (-0.0244), fresh weight of the plant (-0.0238), N-S spread of the plant (-0.0223), dry weight of the plant (-0.0164), number of leaf plant^{-1} (-0.0111), length of the root (-0.0090), days to 50% germination (-0.0047), and root diameter (-0.0020). Study findings agree with those from Ullah *et al*. (2010).

Dry weight of leaves

The dry weight of leaves (-0.0940) gave a negative direct effect on root yield plot^{-1}. However, negative indirect effects surfaced via leaf yield plant^{-1} (-0.0714), fresh weight of leaves (-0.0673), plant height (-0.0326), N-S spread of the plant (-0.0325), E-W spread of the plant (-0.0314), fresh weight of the plant (-0.0288), dry weight of the plant (-0.0219), root length (-0.0178), days to 50% germination (-0.0133), and the number of leaf plant^{-1} (-0.0024). Yet, maximum positive indirect effects came about through the root diameter (0.0077), followed by the dry weight (0.0075) and fresh weight (0.0069) of roots. Chapagain *et al.* (2010) observed that the independent trait, dry weight of leaves, showed a negative direct effect on root yield.

Fresh weight of the plant

The fresh weight of the plant is an essential character from an economic point of view, having a negative direct effect on root yield plot^{-1} (-0.0181). The maximum negative indirect impacts were with the dry weight of the plant (-0.0164), dry weight (-0.0147) and fresh weight (-0.0144) of roots, plant height (-0.0094), root length (-0.0060), dry weight (-0.0055) and fresh weight (-0.0053) of leaves, leaf yield plant^{-1} (-0.0041), and E-W spread of the plant (-0.0027). In contrast, the maximum positive indirect effects occurred through the root diameter (0.0065), days to 50% germination (0.0021), and the number of leaf plant^{-1} (0.0004). The results corroborate with those of Ullah *et al.* (2010).

Dry weight of the plant

The dry weight of the plant had a negative direct effect on the root yield plot^{-1} (-0.2217). The maximum positive indirect effects came from the traits, *viz*., fresh weight of the plant (0.2006), dry weight (0.1940) and fresh weight (0.1910) of roots, plant height (0.1172), length of root (0.0927), N-S spread of the plant (0.0555), leaf yield plant^{-1} (0.0473), dry weight (0.0516) and fresh weight (0.0451) of leaves, and E-W spread of the plant (0.0198). Inversely, the maximum negative indirect influences showed through the root diameter (-0.0850), number of leaf plant^{-1} (-0.0157), and days to 50% germination (-0.0156). Sivathanu *et al.* (2014) reported relatively similar results.

Leaf yield plant^{-1}

Leaf yield plant^{-1}, an influential characteristic from an economic point of view, had a positive direct effect on the dependent trait, root yield plot^{-1} (0.0625). The maximum positive indirect effects were the fresh weight (0.0496) and dry weight (0.0475) of leaves, E-W spread of the plant (0.0185), plant height (0.0148), fresh weight (0.0142) and dry weight (0.0133) of the plant, N-S spread of the plant (0.0105), days to 50% germination (0.0090), root length (0.0088), number of leaves plant^{-1} (0.0046), and root diameter (0.0036). However, the maximum negative direct effects were with traits, dry weight (-0.0076), and fresh weight (-0.0052) of roots. Mallikarjunarao *et al*. (2015) stated that the independent trait, the dry weight of leaves, showed a positive direct effect on root yield.

Diameter of the root

The root diameter affected a negative direct effect over the dependent character, root yield plot^{-1} (-0.0700). The maximum positive indirect impact occurred via leaf yield plant^{-1} (0.0040), followed by the fresh weight of leaves (0.0018). Meanwhile, the extreme negative indirect effect came through plant height (-0.0303), followed by dry weight of roots (-0.0271), dry weight of the plant (-0.0268), fresh weight of roots (-0.0264), fresh weight of the plant (-0.0253), N-S spread of the plant (-0.0243), root length (-0.0221), E-W spread of the plant (-0.0169), and the number of leaves plant^{-1} (-0.0105). Jabal *et al*. (2015) revealed comparable results.

Length of the root

The length of the root revealed a negative direct effect on root yield plot^{-1} (**-**0.0194). However, negative indirect effects resulted with the E-W spread of the plant (-0.0088), plant height (-0.0083), dry weight of roots (-0.0081), dry weight of the plant (-0.0080), N-S spread of the plant (-0.0074), fresh weight of roots (-0.0071), fresh weight of the plant (-0.0064), number of leaf plant^{-1}(-0.0041), dry weight of leaves (-0.0037), leaf yield plant^{-1} (-0.0027), days to 50% germination (-0.0024), and fresh weight of leaves (-0.0022). The root diameter (0.0061) had a positive indirect effect on root yield. Kaur *et al*. (2017) reported matching results.

Fresh weight of roots

A positive direct effect on root yield plot^{-1} appeared via the fresh weight of roots (0.6045). However, positive indirect effects emerged via the dry weight of roots (0.5571), dry weight (0.5208), and fresh weight (0.4806) of the plant, root length (0.2202), plant height (0.2097), and N-S spread (0.1121) and E-W spread (0.0110) of the plant. A negative indirect effect resulted with the root diameter (-0.2276), days to 50% germination (- 0.0709), number of leaf plant^{-1} (-0.0689), leaf yield plant^{-1} (-0.0500), and fresh weight (-0.0480) and dry weight (-0.0441) of leaves. Related findings came from Madaik (2020).

Dry weight of roots

The dry weight of roots impacted a positive direct effect on the dependent trait via dry weight of roots (0.2440). The maximum positive indirect effects resulted from the fresh weight of roots (0.2248), dry weight (0.2134), and fresh weight (0.1977) of the plant, length of the root (0.1026), plant height (0.0851), N-S spread (0.0491), and E-W spread (0.0006) of the plant, and days to 50% germination (0.0211). However, maximum negative indirect effects showed through the root diameter (-0.0943), leaf yield plant^{-1} (-0.0298), fresh weight of leaves (-0.0251), number of leaf plant^{-1} (-0.0233), and dry weight of leaves (-0.0195). The results conform to the findings of Nagar *et al.* (2016).

CONCLUSIONS

Analysis of variance for most characters in the presented study was highly significant. A high magnitude of genotypic and phenotypic coefficients of variation occurred for the traits, *viz*., dry weight and fresh weight of roots, root yield (kg plot^{-1}), and the dry and fresh weights of the plant. High heritability coupled with genetic advance resulted in root yield (kg plot^{-1}), fresh and dry weights of roots, dry and fresh weights of the plant, root diameter and length, days to 50% germination, and leaf yield (kg plot^{-1}), indicating that these parameters can successfully benefit genetic improvement of radish. According to the studies regarding the correlation and path analysis of root traits, the results revealed that fresh and dry weights of roots, fresh and dry weights of the plant, and root diameter showed significant positive and direct effects on yield and its component features in radish. The selection of these attributes might be beneficial for improving the productivity of radishes.

ACKNOWLEDGMENTS

Thanks to the Dean, K.D. College of Horticulture and Research station, for granting necessary permissions during the study period. The authors humbly offer their hearty thanks to the members of the advisory committee, Shri R.R. Kanwar (Department of Genetic and Plant Breeding, SGCARS, Jagdalpur) and Dr. D.P. Singh (Department of Agricultural Statistics, SGCARS, Jagdalpur).

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