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RESEARCH ARTICLE

Inter character association and path analysis studies for yield and related components in red cabbage (*Brassica oleracea* var. *capitata* F. *rubra*)

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Abstract

In the present study, screening of twenty-eight genotypes of red cabbage was carried out to understand character association and path coefficient analysis for yield and its related horticultural traits. The objective was to assess the degree of association between pairs of characters at genotypic and phenotypic levels and thereby collating the direct and indirect effects of the characters. Correlation and path analysis were performed in ten economic traits viz. days to 50 % marketable maturity, number of non-wrapper leaves, head compactness, gross head weight, net head weight, polar diameter, equatorial diameter, stalk length, core length and vitamin C content. Estimates of correlation coefficient revealed that net head weight had significant positive correlation with gross head weight (0.79 and 0.80), vitamin C content (0.45 and 0.87), days to 50 % marketable maturity (0.40 and 0.66), core length (0.33 and 0.59), polar diameter of head (0.30 and 0.40) and head compactness (0.20 and 0.38) at phenotypic and genotypic levels respectively. Meanwhile, path coefficient analysis indicated that vitamin C had the highest positive indirect effects on net head weight followed by gross head weight and number of non-wrapper leaves whereas positive direct effects were exerted by head compactness, core length and polar diameter, thus giving an idea of focusing on these traits for improvement in red cabbage.

Keywords: correlation; direct effects; path coefficient; red cabbage, yield

Introduction

Demand driven cultivation of exotic vegetables is a desirable choice for growers due to shifting dietary tastes because it offers a stable market and a strong export value (1). Red cabbage is a significant exotic vegetable crop that is farmed in both temperate and tropical climates worldwide. It is identified as one of the distinctive sources of natural anthocyanins, possessing good nutritional value and positive effects on human health because it is rich in micronutrients and some phytochemicals including oligosaccharides, minerals, vitamins and some bioactive compounds such as high levels of anthocyanins, flavonols and glucosinolates (2-4). This crop has also been recognized as modern multitasker's dream food for the various benefits that it provides to the consumers (5).

Genetic heterogeneity is a decisive factor for crop species to generate novel and promising genotypes, providing the foundational material for breeders to select and enhance desirable traits (6). Red cabbage displays significant variability, evident in the various sizes, shapes and maturation periods of its heads, underscoring the opportunities for genetic improvement (7). The growing popularity of red cabbage, attributed to its versatility, year-round availability and affordability, has increased the significance of breeding initiatives aimed at the genetic improvement of this crop (8). Currently, there are only a limited number of red cabbage cultivars that have been approved for commercial cultivation by farmers in the country (9), due to suboptimal adaptability to diverse climate, insufficient targeted breeding and seed development efforts. Consequently, significant potential exists to create new red cabbage varieties that exhibit the desired horticultural qualities and adaptability to various agro -climatic conditions.

The success of any breeding programme requires an understanding, research and selection of the genetic variability of potential yield-contributing traits, their interactions and how the yield is related to these factors (10). To improve the plant holistically, it is crucial to assess the relative contributions of genetic and environmental factors to variability. Moreover, the nature and extent of correlations between yield attributes and the significance of both direct and indirect effects of each component trait on yield is also essential. Selection may benefit by understanding the degree to which yield is correlated with its constituent parts and how they interact with one another (11).

For serving this purpose, correlation and path coefficient analysis are the most suitable statistical approaches. Correlation coefficient assesses the link between several economic traits and identifies the component character that can serve as the basis for selection in order to increase yield (12). But when correlations are broken down into their constituent parts using route analysis to ascertain the relative importance of the several characteristics that contribute to correlation, the implications of correlation research become clearer. Path coefficient analysis separates the correlation coefficients into the components of direct and indirect effects and ascertains the direct and indirect influence of independent factors on the dependent variable (13). Hence, this information of inter-relationships among the various yield components and their direct and indirect effects on yield are of utmost importance in breeding of any crop, which has been worked out in the present study to assess per se performance of various genotypes of red cabbage.

Materials and Methods

This investigation was conducted at the Research Farm of Department of Vegetable Science, Dr YS Parmar University of Horticulture and Forestry, Nauni-Solan, Himachal Pradesh, India. Geographically, the place was located at an altitude of 1270 m above mean sea level lying between 35.5˚N latitude and 77. 8˚E longitude. The farm area falls in the mid hill zone of Himachal Pradesh (India) (Fig. 1). The soil structure of the research farm is characterized as granular or crumb type with sandy loam to clay loam texture, comprising of sand (44.87 %), silt (31.12 %) and clay (24.01 %) with pH ranging from 6.85-7.04. The climate of the location was sub humid, sub temperate with mild summers and cool winters. Mean temperature during the cropping season

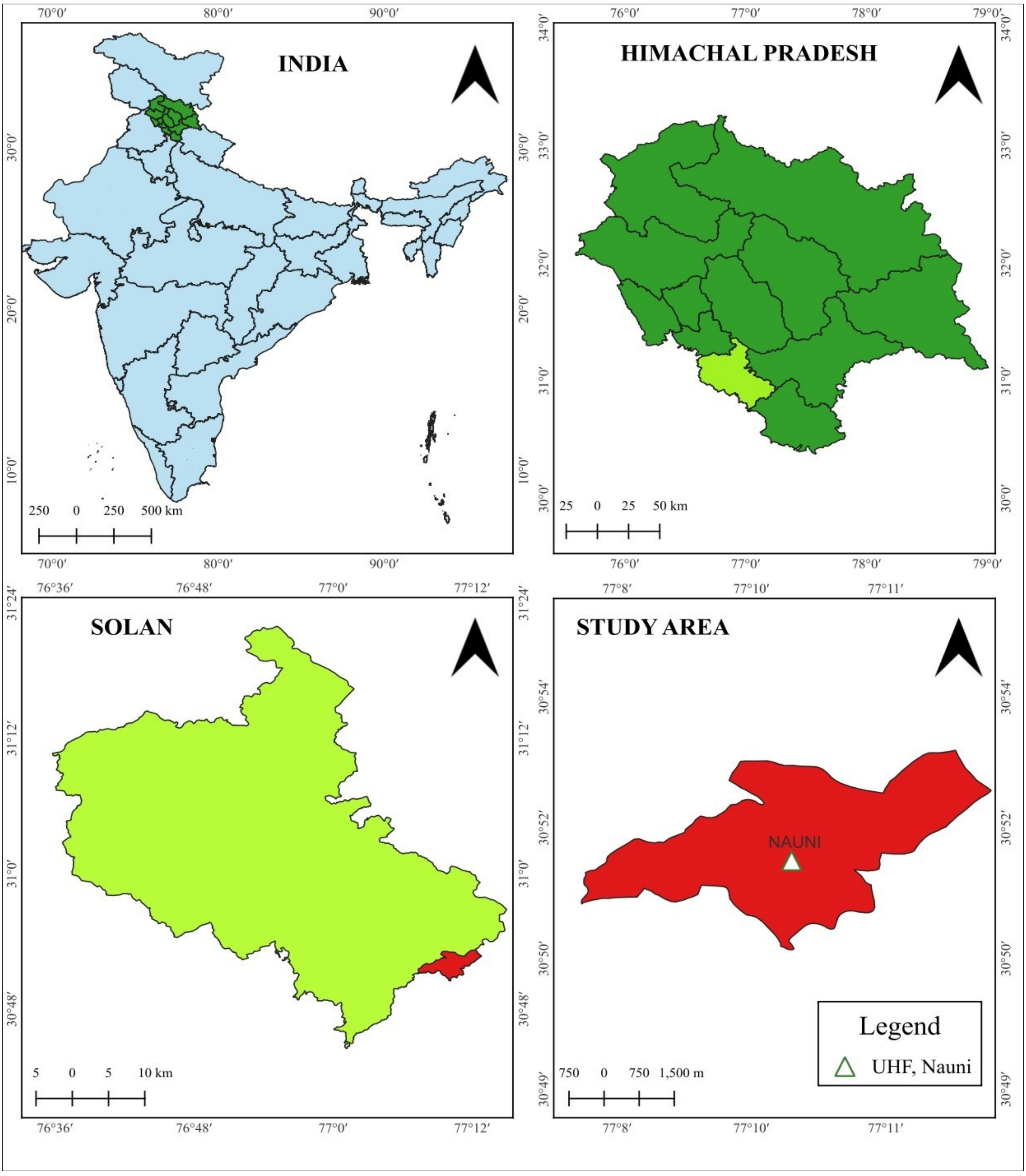

Fig. 1. Graphical representation of the study area- UHF, Nauni.

varied from 8.8 °C to 21.7 °C while the relative humidity varied from 50-76 %. The total rainfall during growing season varied from 21.6 to 224.5 mm, most of which was received in month of September.

The material used for the investigation comprised of twenty-eight genotypes of red cabbage including check cultivar Kinner red. The seeds of twenty-seven exotic genotypes of red cabbage were procured from Horticultural Research International, Wellesbourne (UK) while those of check cultivar 'Kinner Red' were obtained from Department of Vegetable Science, Dr YS Parmar University of Horticulture and Forestry, Nauni Solan (HP) India. The list of the genotypes and their sources is given in Table 1.

The experiment was laid out in randomized block design (RBD) with three replications including sixteen seedlings of each genotype planted per plot. The plants were nourished with a recommended 150 q/ha of well decomposed farmyard manure (FYM) and fertilizer dose of 480 kg N, 315 kg P_2O_5 and 45 kg K_2O per hectare as calcium ammonium nitrate, single-superphosphate and muriate of potash (14). At the time of field preparation full quantity of FYM, along with full dose of P_2O_5, K_2O and half dose of N were thoroughly mixed in the soil The remaining half of nitrogen was applied four weeks after transplanting as top dressing. All the other cultural practices i.e. irrigation, weeding and disease-pest control procedures for commercial red cabbage production have been followed to raise the healthy crop stand as recommended in the Package of Practices for Vegetable crops published by Directorate of Extension, Dr YSP UHF, Nauni (15). The harvesting of heads was also carried out manually at the marketable stage.

The observations were recorded on five randomly selected plants having compact heads from each plot in each replication and their means were worked out for further statistical analysis. The genotypic and phenotypic correlation coefficient were calculated using the method given by Al-Jibouri et al. (16) while, the path coefficient analysis of different traits with net head weight was carried out by following the method suggested by Dewey and Lu (17). Finally, the statistical analysis was carried out for each observed character under study viz. days to 50 % marketable maturity, number of non-wrapper leaves, gross and net head weight, polar and equatorial diameter, stalk and core length, head compactness and vitamin C content using MS-Excel and OPSTAT software.

Results and Discussion

Correlation coefficient

Yield is a complex product being predisposed by several interdependent quantitative characters. Selection for yield may not be effective unless the other yield components influencing it directly or indirectly are taken into consideration. Numerous other correlated traits are impacted concurrently when selection pressure is applied to improve any feature that is strongly connected with yield (18). Therefore, information regarding the association of characters with yield and among themselves gives an insight to the plant breeder for improvement in the crop through selection along-with providing a clear understanding of the contribution in respect of establishing the association by genetic and non-genetic factors. To ascertain the relationships between yield and the other examined traits, correlation coefficients were computed. In general, correlation analysis quantifies the strength and direction of the relationship between two traits. The correlation coefficient (r) is generally interpreted as:

r => 0 → Directly proportional (Positive correlation)

r =< 0 → Inversely proportional (Negative correlation)

Table 1. List of genotypes of red cabbage used in the experiment alongwith their source(s)

S.N.	Genotype	Source(s)
1	EC 889989	Horticulture Research International, Wellesbourne, UK
2	EC 889990	Horticulture Research International, Wellesbourne, UK
3	EC 889991	Horticulture Research International, Wellesbourne, UK
4	EC 889992	Horticulture Research International, Wellesbourne, UK
5	EC 889993	Horticulture Research International, Wellesbourne, UK
6	EC 889994	Horticulture Research International, Wellesbourne, UK
7	EC 889995	Horticulture Research International, Wellesbourne, UK
8	EC 889996	Horticulture Research International, Wellesbourne, UK
9	EC 889997	Horticulture Research International, Wellesbourne, UK
10	EC 889998	Horticulture Research International, Wellesbourne, UK
11	EC 889999	Horticulture Research International, Wellesbourne, UK
12	EC 890000	Horticulture Research International, Wellesbourne, UK
13	EC 890001	Horticulture Research International, Wellesbourne, UK
14	EC 890002	Horticulture Research International, Wellesbourne, UK
15	EC 890003	Horticulture Research International, Wellesbourne, UK
16	EC 890004	Horticulture Research International, Wellesbourne, UK
17	EC 890005	Horticulture Research International, Wellesbourne, UK
18	EC 890006	Horticulture Research International, Wellesbourne, UK
19	EC 890007	Horticulture Research International, Wellesbourne, UK
20	EC 890008	Horticulture Research International, Wellesbourne, UK
21	EC 890009	Horticulture Research International, Wellesbourne, UK
22	EC 890010	Horticulture Research International, Wellesbourne, UK
23	EC 890011	Horticulture Research International, Wellesbourne, UK
24	EC 890012	Horticulture Research International, Wellesbourne, UK
25	EC 890013	Horticulture Research International, Wellesbourne, UK
26	EC 890014	Horticulture Research International, Wellesbourne, UK
27	EC 890015	Horticulture Research International, Wellesbourne, UK
28	Kinner Red	Department of Vegetable Science, UHF, Nauni Solan HP (India)

r = 0 → No correlation

Simple correlation coefficients calculated among the examined traits are shown in Table 2. Mean performances of all the genotypes for various characters have also been depicted through graphs (Fig. 2-11). In most of the traits, genotypic correlation coefficient was found to be higher than the corresponding phenotypic correlation coefficient which signified strong hereditary association among the traits due to genetic factors such as linkage and/or pleiotropic effects along with less influence of the environment in the expression of the characters under the study. These findings also align with the previous investigations (19, 20). The analysis of correlation revealed that at the phenotypic level, net head weight was significantly and positively associated with gross head weight (0.79), vitamin C content (0.45), days to 50 % marketable maturity (0.40), core length (0.33), polar diameter (0.30) and head compactness (0.20). Gross head weight, in turn, showed positive correlations with number of non-wrapper leaves (0.43), days to 50 % marketable maturity (0.33), equatorial diameter (0.29), polar diameter (0.35) and core length (0.29). Vitamin C content was positively related to number of non-wrapper leaves (0.65), days to 50 % marketable maturity (0.54), core length (0.49) and gross head weight (0.33). Equatorial diameter exhibited positive correlations with polar diameter (0.38), gross head weight (0.29) and number of non-wrapper leaves (0.27), while polar diameter was positively associated with gross head weight (0.35) and core length (0.30).

At the genotypic level, net head weight showed significant positive correlations with vitamin C content (0.87), gross head weight (0.80), days to 50 % marketable maturity (0.66), core length (0.59), head compactness (0.38) and polar diameter (0.04). Gross head weight was positively associated with number of non-wrapper leaves (0.69), days to 50 % marketable maturity (0.55), core length (0.52) and vitamin C content (0.63). Vitamin C content exhibited positive correlations with number of non-wrapper leaves (0.75), days to 50 % marketable maturity (0.60), gross head weight (0.63) and equatorial diameter (0.21). Core length was positively correlated with polar diameter (0.44), gross head weight (0.52) and days to 50 % marketable maturity (0.41). Stalk length showed

Table 2. Genotypic (G) and phenotypic (P) correlation coefficients among the characters in the red cabbage genotypes

Characters		NWL	HC	GHW	PD	ED	SL	CL	VIT C	NHW
DTFMM	G	0.39*	0.11	0.55*	0.14	0.25*	0.34*	0.41*	0.60*	**0.66***
	P	0.37*	0.06	0.33*	0.12	0.15	0.33*	0.38*	0.54*	**0.40***
NWL	G		0.14	0.69*	-0.10	0.43*	0.25*	0.16	0.75*	**0.77***
	P		0.16	0.43*	-0.04	0.27*	0.23*	0.14	0.65*	**0.44***
HC	G			-0.02	0.31*	0.25*	0.12	0.12	0.19	**0.38***
	P			0.04	0.01	-0.01	0.07	0.08	0.10	**0.20***
GHW	G				0.02	0.04	0.07	0.52*	0.63*	**0.80***
	P				0.35*	0.29*	0.04	0.29*	0.33*	**0.79***
PD	G					0.05	0.15	0.44*	0.09	**0.04***
	P					0.38*	0.11	0.30*	0.07	**0.30***
ED	G						0.66*	0.18	0.38*	**-0.20**
	P						0.42*	0.11	0.21*	**0.17**
SL	G							-0.19	0.21*	**0.03**
	P							-0.17	0.20	**0.01**
CL	G								0.54*	**0.59***
	P								0.49*	**0.33***
VIT C	G									**0.87***
	P									**0.45***

Where,

DTFMM = Days to 50 % marketable maturity, NWL = Number of non-wrapper leaves, HC = Head compactness, GHW = Gross head weight, NHW = Net head weight, PD = Polar diameter of head, CL = Core length, VIT C = Vitamin C content

*Significant at 5 % level of significance

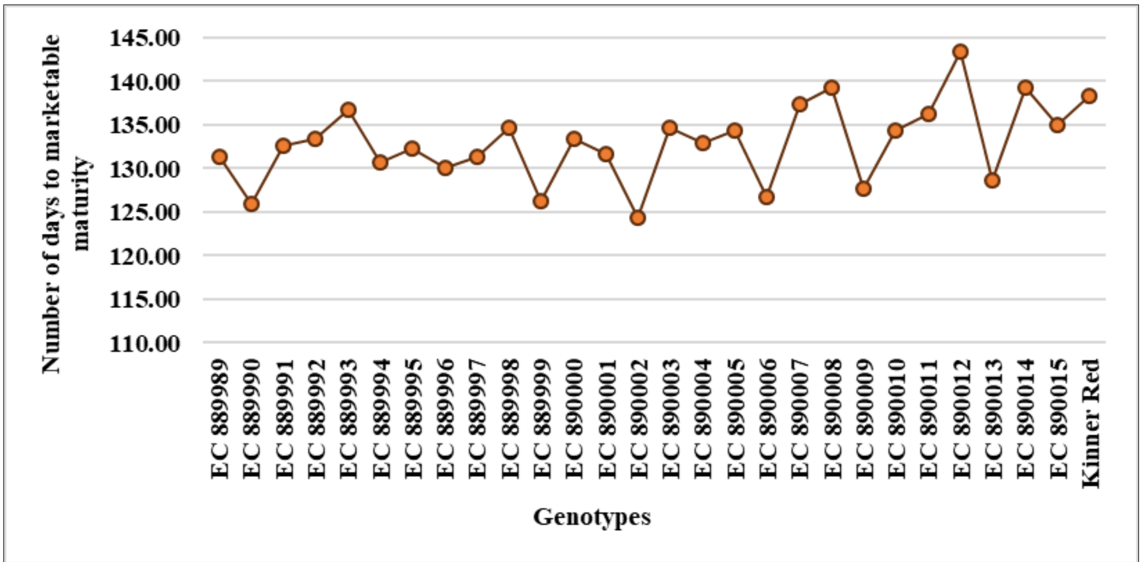

Fig. 2 Graphical representation of mean performance of red cabbage genotypes for days to fifty per cent marketable maturity (DTFMM).

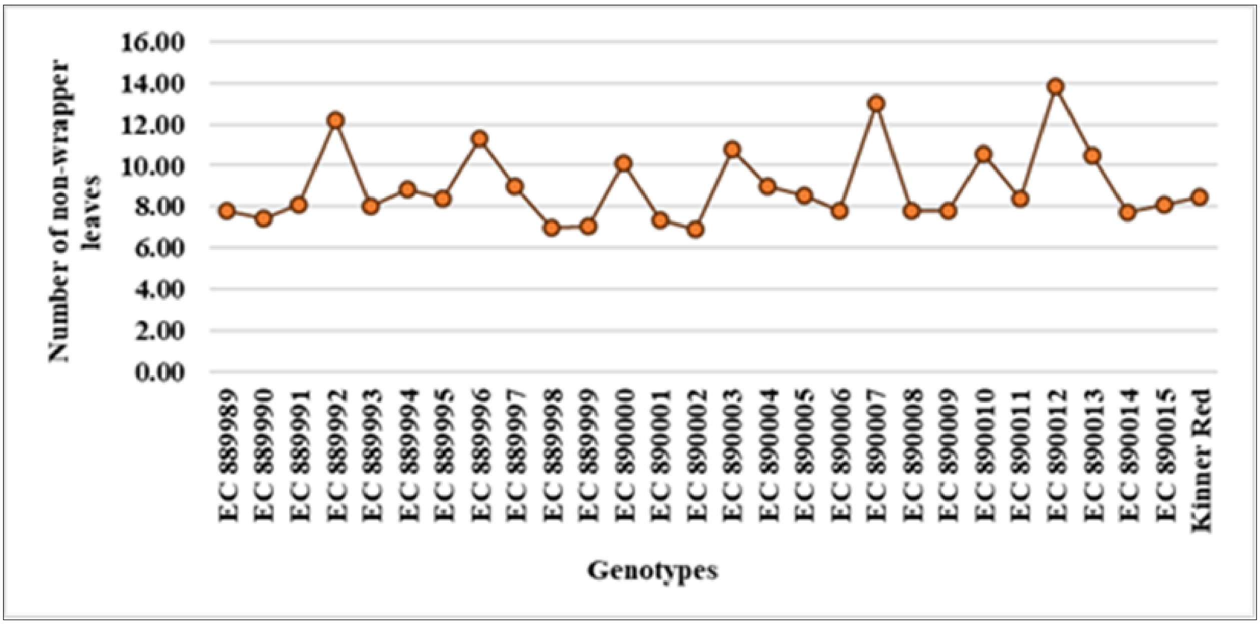

Fig. 3. Graphical representation of mean performance of red cabbage genotypes for number of non-wrapper leaves (NWL).

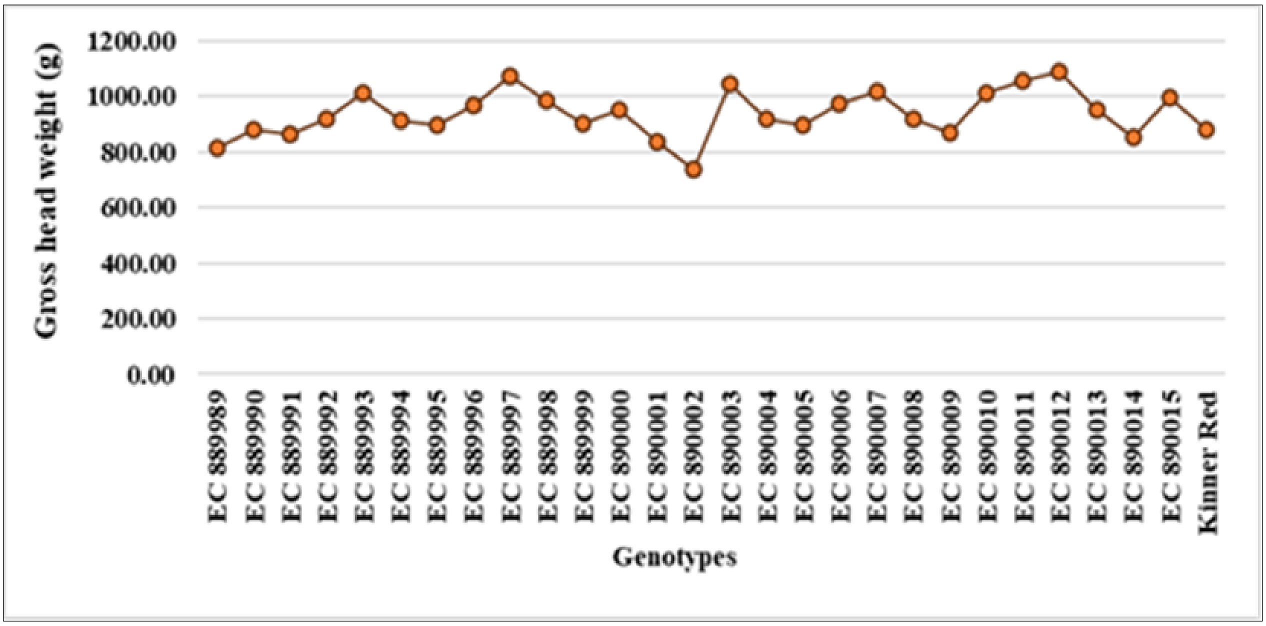

Fig. 4. Graphical representation of mean performance of red cabbage genotypes for gross head weight (GHW).

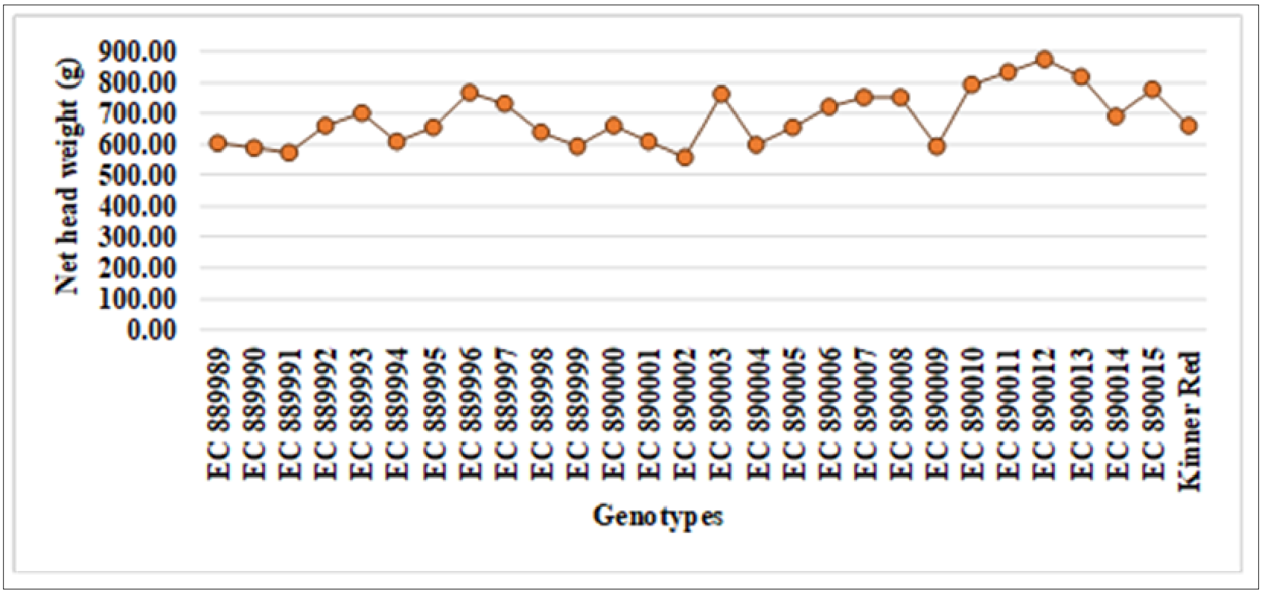

Fig. 5. Graphical representation of mean performance of red cabbage genotypes for net head weight (NHW).

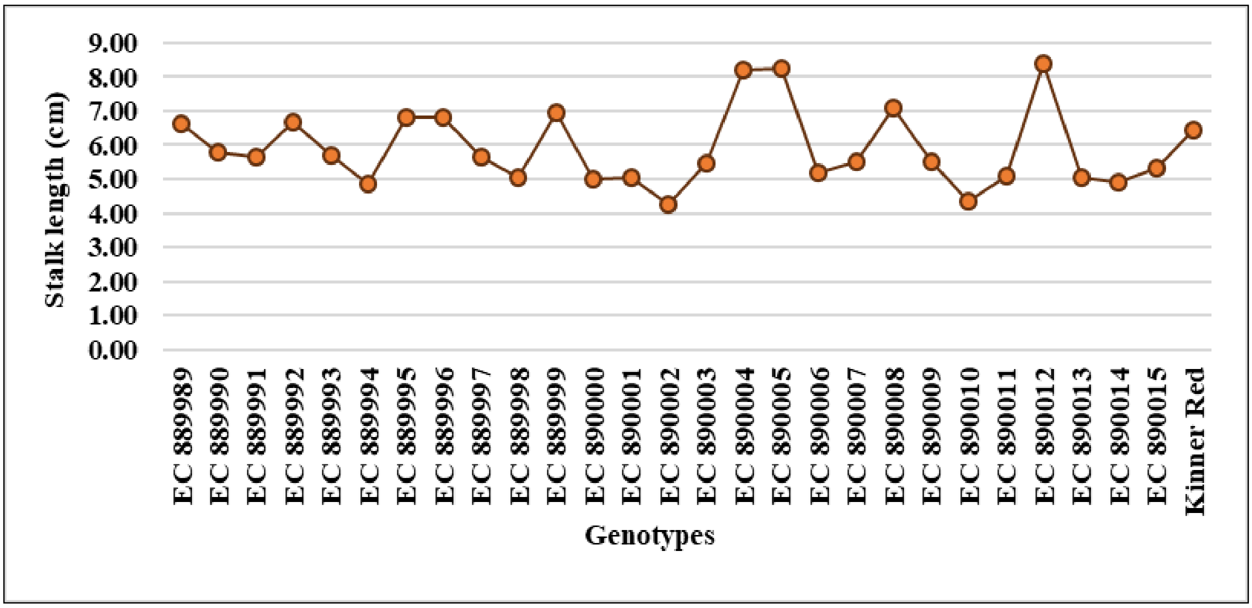

Fig. 6. Graphical representation of mean performance of red cabbage genotypes for stalk length (SL).

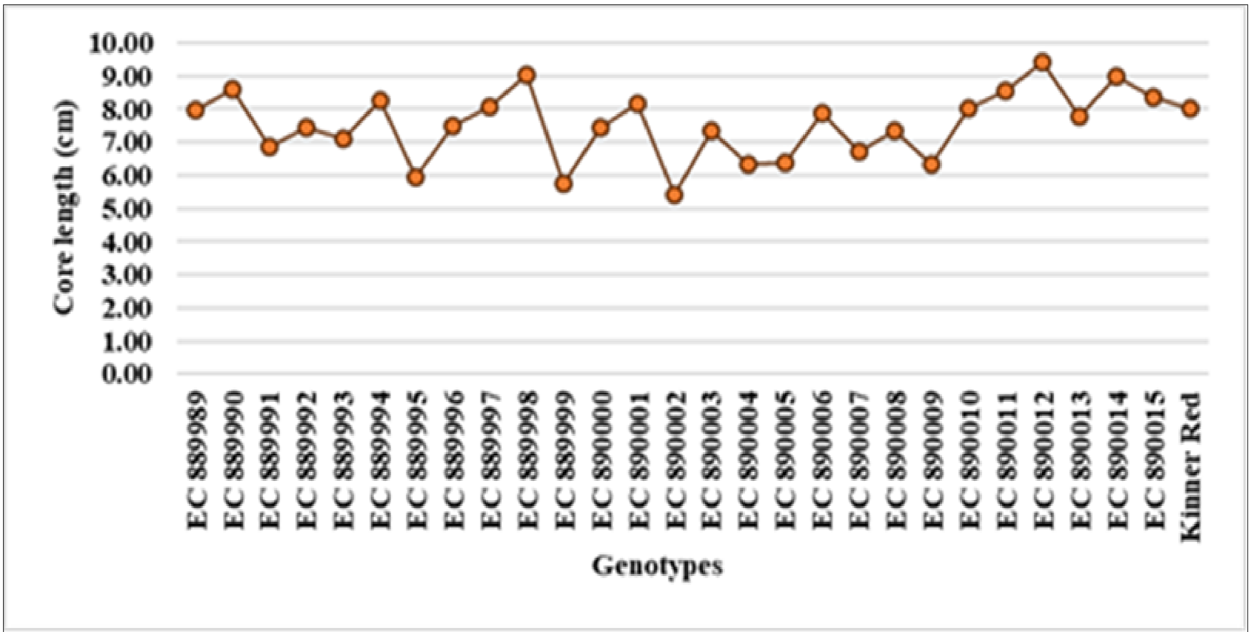

Fig. 7. Graphical representation of mean performance of red cabbage genotypes for core length (CL).

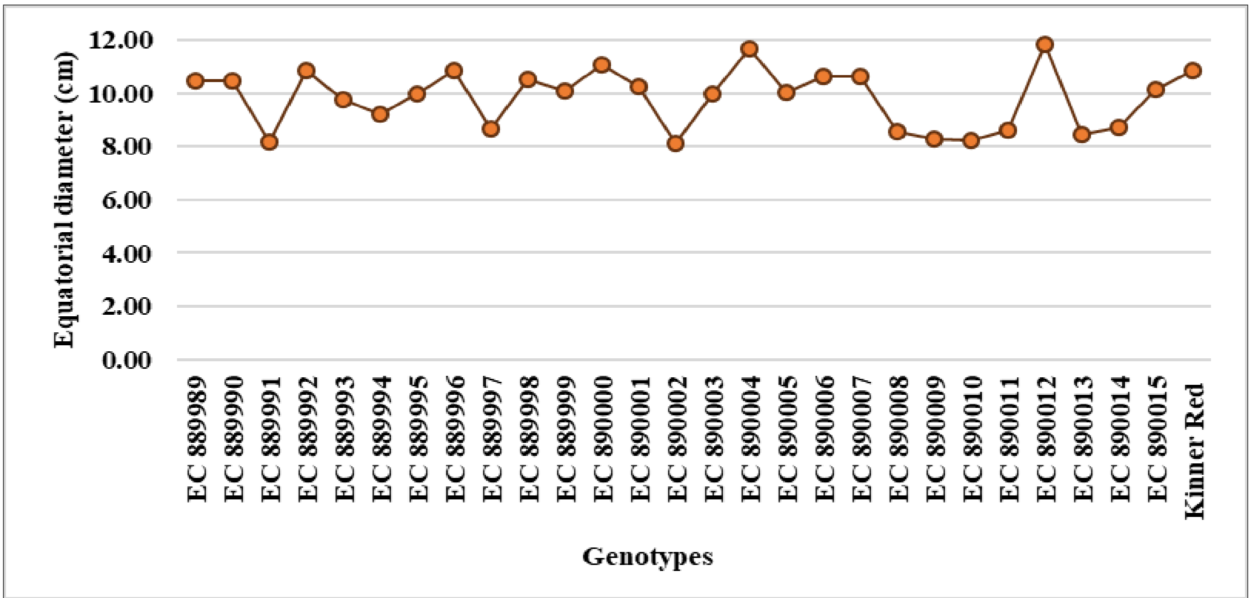

Fig. 8. Graphical representation of mean performance of red cabbage genotypes for equatorial diameter (ED).

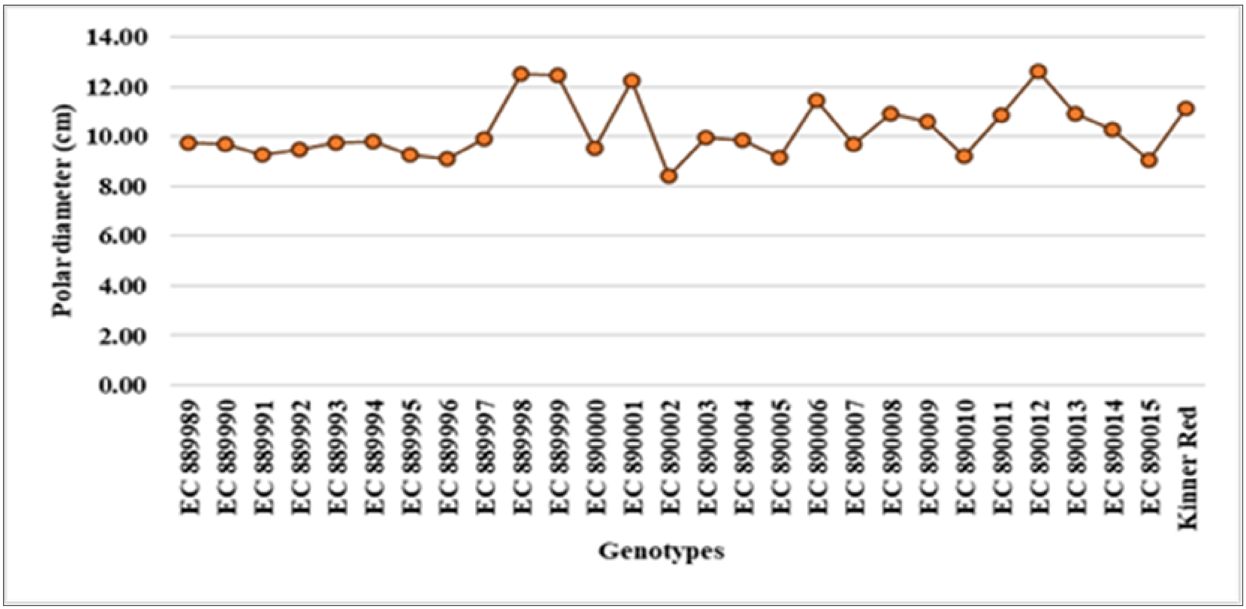

Fig. 9. Graphical representation of mean performance of red cabbage genotypes for polar diameter (PD).

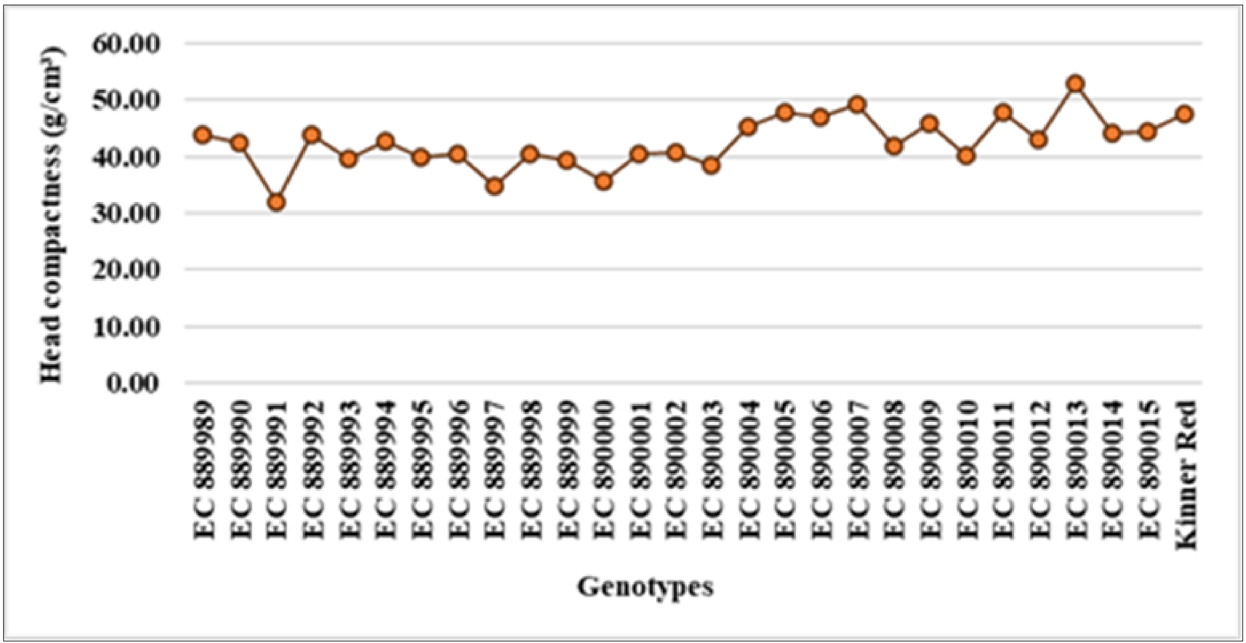

Fig. 10. Graphical representation of mean performance of red cabbage genotypes for head compactness (HC).

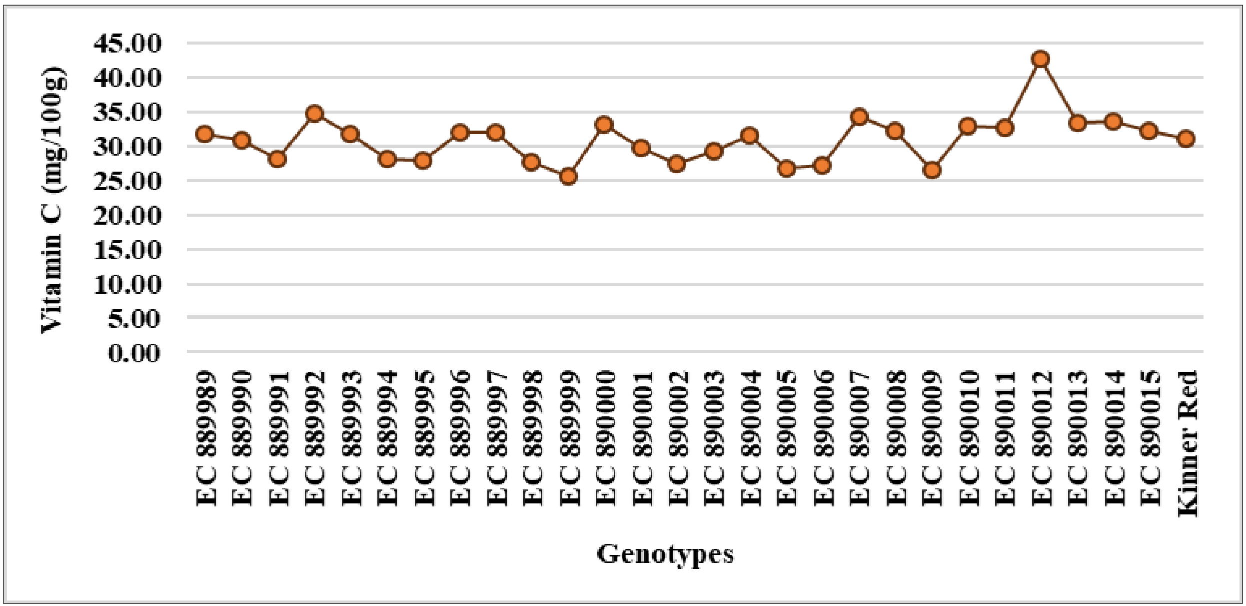

Fig. 11. Graphical representation of mean performance of red cabbage genotypes for vitamin C content (Vit C).

positive associations with equatorial diameter (0.66), days to 50 % marketable maturity (0.34) and number of non-wrapper leaves (0.25). Equatorial diameter was positively correlated with number of non-wrapper leaves (0.43), days to 50 % marketable maturity (0.25) and head compactness (0.25) while, polar diameter exhibited a positive correlation with head compactness (0.31).

Similar correlation studies of marketable yield with various other horticultural traits at phenotypic and genotypic levels in cabbage had also been reported in previous investigations (12, 21-25). It can be inferred that the phenotypic correlation was inferior to genotypic correlation and the characters namely, gross head weight, vitamin C, non-wrapper leaves, days to 50 % marketable maturity, core length, head compactness and polar diameter had positive and significant correlations with net head weight. These traits, through their contributions towards greater biomass allocation, higher physiological efficiency, larger head structure and more compactness confirmed their authenticity for further improvement in red cabbage.

Path coefficient

Correlation coefficients indicate only the general association between any two characters without possible causes of such association (26). The degree of relationship between the yield and components can be ascertained in part by using path coefficient analysis, which also gives a better understanding of the cause and effect of the relationship between various characters (27). As a result, the correlation coefficient was divided into the direct and indirect effects of various characters on yield using the route coefficient analysis. In general interpretation of path coefficient, if a trait has a high direct effect on yield (path coefficient close to or greater than its correlation value), it is a primary selection criterion and if a trait has a low direct effect but a high correlation with yield, its impact is likely to be indirect (mediated through other traits). Meanwhile, a trait with low direct effect and high indirect trait influences yield through another character.

The data pertaining to path coefficient analysis with net head weight as a dependent variable had been presented in Table 3 which revealed that head compactness (0.359) had maximum positive direct effect on net head weight followed by core length (0.343), polar diameter (0.335), gross head weight (0.249), number of non-wrapper leaves (0.226), vitamin C content (0.223) and days to 50 % marketable maturity (0.161). These seven characters also showed significant positive correlation with net head weight thereby, indicating their direct selection for yield improvement in red cabbage. Similar findings have also been reported for compactness of head (28) while, in contrary, the maximum negative direct effects for gross head weight (-0.054) were observed earlier (24). Moreover, head compactness also recorded maximum positive indirect effects via vitamin C content (0.043), core length (0.042), number of non-wrapper leaves (0.033), days to 50 % marketable maturity (0.018) and negative indirect effects via polar diameter of head (-0.104) and gross head weight (-0.005). The results also revealed that gross head weight exhibited maximum positive effects to net head weight via core length (0.179) followed by number of non-wrapper leaves (0.156), vitamin C content (0.141), days to 50 % marketable maturity (0.090) and negative effects mainly via polar diameter of head (-0.006) and head compactness (-0.007). Positive indirect effects via equatorial diameter of head, while negative indirect effects via polar diameter of head, days to marketable maturity was also reported (29). Rai et al. Negative indirect effects of gross head weight via polar and equatorial diameter of heads and days to maturity was also observed in previous studies. The residual effect at the genotypic level was found to be -0.037.

Conclusion

The results in the present study indicated that net head weight had significant positive association with vitamin C content, gross head weight, polar diameter of head, core length, stalk length, number of non-wrapper leaves, head compactness, days to 50 % marketable maturity at both genotypic and phenotypic levels of correlation while, it had negative significant association with equatorial diameter at genotypic level. Similarly, path coefficient analysis revealed that the high positive direct effects towards net head weight were contributed by core length, polar diameter of head, gross head weight, number of non-wrapper leaves, vitamin C content and days to 50 % marketable maturity. Therefore, these findings might facilitate the selection of traits to enhance yield and associated characters in red cabbage, thereby expediting the breeding process for the development of high-performance cultivars of red cabbage.

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Table 3. Estimates of direct and indirect effects of the different characters on net head weight of red cabbage genotypes

Characters	DTFMM	NWL	HC	GHW	PD	CL	VIT C	GCCNHW
DTFMM	**0.161**	0.089	0.041	0.139	-0.047	0.142	0.134	**0.66***
NWL	0.064	**0.226**	0.053	0.173	0.034	0.054	0.168	**0.77***
HC	0.018	0.033	**0.359**	-0.005	-0.104	0.042	0.043	**0.38***
GHW	0.090	0.156	-0.007	**0.249**	-0.006	0.179	0.141	**0.80***
PD	0.023	-0.022	0.111	0.005	**0.335**	0.153	0.020	**0.04***
CL	0.066	0.036	0.044	0.130	-0.149	**0.343**	0.121	**0.59***
VIT C	0.097	0.169	0.069	0.157	-0.031	0.187	**0.223**	**0.87***

Where,

DTFMM = Days to 50 % marketable maturity, NWL = Number of non-wrapper leaves, HC = Head compactness, GHW = Gross head weight, NHW = Net head weight, PD = Polar diameter of head, CL = Core length, VIT C = Vitamin C content and GCCNHW = Genotypic correlation coefficient with net head weight (* *Diagonal figures represent the direct effects*)

Residual effect: **-0.037**

Authors' contributions

ND carried out the research work in the field and the lab and drafted the manuscript. RK carried out the framework of the research and SB performed the statistical analysis. All authors read and approved the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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