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Original Research Article

Prediction of genetic variability and character contribution using path analysis in turmeric (*Curcuma longa* Linn.) germplasm

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ABSTRACT

Seventeen genetic stocks of *Curcuma longa* L. were evaluated for nature and amount of genetic variability, associations and path analysis for six economic traits, namely plant height (cm), oil content in leaf (%), oil content in fresh rhizome (%), fresh rhizome weight (kg/plot), 1,8 cineole and *p*-cymene-8-ol in the essential oil of leaves. Phenotypic coefficient of variance (PCV) was higher than genotypic coefficient of variance (GCV) for all the traits in the study indicating high influence of environmental factors for these traits. Path coefficient study showed the largest direct contribution to rhizome yield was plant height, while other traits were negative; but their direct contribution via oil content in leaf and rhizome was remarkable. All traits expressed medium to high heritability in broad sense in percent ($\hat{h}^2_{(BS)}$%), low to medium genetic advance and positive correlations. The correlation coefficients between traits expressed that rhizome oil content and 1,8 cineole were highly significant and positively correlated with plant height and 1,8 cineole at genotypic and phenotypic level, respectively. Overall, based on mean performance and other elite genetic/selection parameters, the accession ST-1 (UNK) (51.30 kg/plot) followed by ST-3 (9) (36.00 kg/plot) and ST-2 (4) (29.80 kg/plot) were the best for fresh rhizome yield; accession AMT-3 (1.50%) for essential oil content in leaf followed by ST-2 (4) (1.40%) and ST-3 (9) (1.30%); for essential oil content in rhizome, the accession TUR-1 UNK (0.73%) followed by AM-2 and TUR-13 (0.66%) were found very promising. Therefore, these accessions may be exploited for commercial production and/or exploitation.

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1. Introduction

Turmeric (*Curcuma longa* L.), family Zingiberaceae, comprises of about 80 species. It grows up to the height of 100 to 175 cm, with white, bright yellow to dark orange aromatic rhizomes based on curcumin content. It is a sub-tropical/tropical perennial rhizomatous plant, widely cultivated in warmer parts of the world, mainly in Asia, South America and Australia (Lal et al., 2017a; Mohammadhosseini et al., 2017; Mohammadhosseini et al., 2019). It was valued mainly as a spice for food and a natural dye for clothing until recently, when it was discovered to be a potential source of new drugs for a variety of diseases (Elvira and Dionisio-Sese, 2014). India is the world's largest producer (93.3%), consumer and exporter (approximately 90%) of turmeric, cultivating it on 150,000 ha. (Sasikumar, 2005; Lal et al., 2017a; Mohammadhosseini, 2017). It is reckoned that Indians consume between 80 and 100 mg turmeric extract per day and the annual consumption is about 480,000 tons (Majumdar and Ghosh, 2013; Nunes and Miguel, 2017). India is leading in production and exportation of turmeric in the world, almost all states of India especially Tamil Nadu, Andhra Pradesh, West Bengal,

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Fig. 1. Origin of seventeen accessions of turmeric in 16 states of India.

Maharashtra, Bihar, Kerala and North-Eastern states produce turmeric. It can be grown in diverse tropical conditions from temperature ranges of 20-35 ºC and sea level to 1500 m.s.l. However, it can be grown on different types of soils, but it thrives the best in well-drained sandy and clay loam soils (pH range 4.5-7.5) having good organic status. The curcumin is the main biologically active phytochemical compound of turmeric with wide range of therapeutic effects. In recent years, pharmacological properties and actions of curcumin have been widely researched and its beneficial effects have been well-established (Govindarajan, 1980; Gupta et al., 2016; Gupta et al., 2017; Camilo et al., 2017).

Turmeric was originally valued mainly as a spice for its colouring properties and aroma in food, natural dye for wool and cotton fabrics (Anandraj and Sudarshan, 2011), in pharmacy, confectionary, food industry as well as in paints and varnishes, until recently when it was discovered as a source of drugs for various diseases. The rhizomes of *Curcuma* species including *Curcuma longa* L were used as indigenous medicine (Angel et al., 2014), due to their pharmacological properties such as anti microbial (Wilson et al., 2005), anti-diarrheal (Owolabi et al., 2012), anticancer (Upadhyay et al., 2013; Elvira and Dionisio-Sese, 2014), anti-tumor and anti-inflammatory properties (Chandra and Gupta, 1972; Jang et al., 2001; Lantz et al., 2005). Rhizomes are rich in phenolics, identified as curcuminoids, mainly curcumin (diferuloyl methane) is biologically active phytochemical compound of turmeric having antibiotic properties. Traditionally, turmeric is an inexpensive and indigenous beauty aid in cosmetics. In Indian system of medicine, turmeric is being used as blood purifier, carminative, stomachic, antiseptic and vermicide. Wound healing antiseptic property of turmeric is well-known to Indians since ancient times.

In the leaf oil of turmeric, 1,8-cineole a monoterpene type of plant compound found mostly in the essential oils of turmeric leaf. 1,8-Cineole gives off a cool and a camphor-like odor. More mature turmeric plants have less 1,8-cineole than younger ones. Other herbs, fruits and spices that contain 1,8-cineole include basil, bay leaf, cardamom, chamomile, chaste- tree, damiana, eucalyptus, gotukola, lavender, lime, mint, oregano,rosemary, saffron, savory and tarragon (Chandra and Gupta, 1972; Sato et al., 2007). 1,8-Cineole is a remarkable chemical component offering strong therapeutic properties that has been well researched. It has strong healing potential. These properties suggest that using these oils during a cold or flu would help reduce pain, mucus and headaches. They also help kill bacteria and viruses. They can reduce swelling (great for sinus infections), muscle spasms and spastic coughing. Many of these offer healthful benefits, too, whether used as a spice or as an herbal remedy, e.g. for acne, thinning hair or stress relief, aphrodisiac, or in aromatherapy. 1,8-Cineole is a naturally fungicidal compound. Researchers have shown that 1,8-cineole may help protect against liver damage and other diseases. It does so by stimulating the body to produce more detoxifying liver enzymes. These enzymes are proteins that neutralize toxins that might otherwise lead to cancer and other conditions. Gelomyrtol® forte, a combination of the turmeric compounds involving 1,8-cineole, α-pinene and limonene effectively treats chronic bronchitis. Based on its chemical structure, experts suggest that 1,8-cineole is highly likely to effectively stimulate bile flow from the liver to the gallbladder and then to the intestines, relieve pain, treat liver disorders and prevent abnormal muscle movements such as in Parkinson's disease. It also serves a critical role to maintain regular heartbeat, inhibit high cholesterol, treat multiple sclerosis, etc. (Sato et al., 2007). On the other hand, the compound *p*-cymene-8-ol is a naturally occurring aromatic organic compound occurred in the essential oil of the leaves of curcuma. It is

Table 1
Origin/place of collection and mean performance of seventeen accessions of turmeric.

S. No.	Accession's code	Origin/place of collection in India	Plant height (cm)	Oil content in dry leaf (%)	Oil content in fresh rhizome (%)	P-cymene-8-ol (%) in dry leaf oil	1,8 cineole (%) in dry leaf oil	Fresh weight of rhizome (kg)
1	TUR-2	Udaipur, Rajasthan	132.20	1.20	0.46	0.24	0.15	5.10
2	TUR-11	Indaur, Madhya Pradesh	136.40	1.10	0.56	0.14	0.50	3.10
3	AMT-3	CSIR -CIMAP, Lucknow , UP	130.00	1.50	0.60	0.04	0.09	2.50
4	TUR-12	Haldwani, Uttarakhand	153.73	0.60	0.63	0.09	0.20	6.40
5	TUR-8(1)	Kozhikode, Kerala	140.20	0.70	0.44	20.96	3.73	3.40
6	TUR-1UNK	Muzaffarpur, Bihar	162.40	0.50	0.73	2.38	4.03	6.10
7	AM-2	Jorhat, Assam	175.80	0.50	0.66	21.67	6.41	7.10
8	TUR-5	Chennai, Andhra Pradesh	144.80	1.10	0.62	8.14	9.82	3.30
9	TUR-13	Phagawara, Punjab	163.80	0.30	0.66	24.57	4.50	7.00
10	TUR-8(2)	Junagarh, Gujarat	135.00	1.20	0.51	25.36	4.46	3.60
11	TUR-6	Puri, Odessa	140.40	0.80	0.55	20.95	13.15	4.80
12	TUR-10	Krishnanagar, West Bengal	129.80	0.80	0.46	22.42	5.48	3.00
13	TUR-4	Bangluru, Karnataka	131.00	0.90	0.53	23.48	4.98	6.40
14	TUR-3	Renukot, Uttar Pradesh	121.00	0.90	0.46	0.17	0.40	3.20
15	ST-1 (UNK)	Palampur, Himachal Pradesh	168.20	0.30	0.60	0.28	0.14	51.30
16	ST-2 (4)	Shilong, Meghalaya	103.40	1.40	0.36	0.23	0.39	29.80
17	ST-3(9)	Jummu, J. and K.	119.60	1.30	0.46	0.26	0.64	36.00
18	Range		103.40-175.80	0.30-1.50	0.36-0.73	0.04-25.36	0.15-13.15	2.50-51.30
19	CD (5%)		16.86	0.24	7.17	2.58	2.19	1.91
20	CD (1%)		23.06	0.33	0.098	3.53	2.99	2.62
21	CV %		7.31	16.70	0.072	15.61	38.42	10.91

classified as an alkylbenzene related to a monoterpene. Its structure consists of a benzene ring para-substituted with a methyl group and an isopropyl group. For the use of monoterpenes and especially *p*-cymene-8-ol, in food products, data from the literature showed that essential oils and plant extracts, containing various phytochemicals including *p*-cymene can be used as a fungicide or herbicide as well as an insecticide agent (Sato et al., 2007).

Turmeric is a cross-pollinated, sterile and triploid species. It is vegetatively/clonally propagated using its underground rhizomes; several studies have shown the existence of inter-specific and inter-varietal genetic variation in DNA content and RAPD analysis (Nayak et al., 2006). The genetic variability in this crop is very high in nature; therefore, the study of genetic variability and association as well as path analysis for various morpho-economic and secondary metabolite traits in the turmeric accessions is a prelude to further potential crop improvement. As the selection and development of variety depends on existing and induced genetic variability, therefore our main objective was to examine genetic variation and associations for a number of traits among genotypes in order to understand genetic associations and character's contribution of various yield components toward the turmeric rhizome yield of better quality.

2. Experimental

2.1. Plant material

More than hundred collections of turmeric (*Curcuma longa* L.) were made from different places of India. Removing duplicates, seventeen accessions belonging to sixteen states of India containing Rajasthan, Madhya Pradesh, Uttar Pradesh, Uttarakhand, Kerala, Bihar; Assam, Andhra Pradesh, Punjab, Gujarat, Odessa, West Bengal, Karnataka, Himachal Pradesh, Meghalaya, Jummu And Kashmir were included in this study (Table 1, Fig. 1). The collections were grown in randomized block design (RBD) with three replications during summer season in years 2013-2014 at the research farm of the CSIR-Central Institute of Medicinal and Aromatic Plants, Lucknow, 226 015, U.P. (India). Each treatment consisted of single row 4 m long and 50 cm apart with a distance of 50 cm space. The experimental location at the institute research farm was located at 26.5° N latitude and 80.50° E longitude and 120 m above the mean sea level. The climate is semiarid/subtropical in

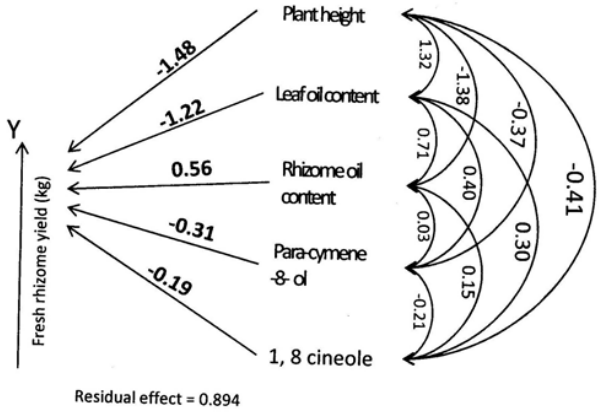

Fig. 2. Path diagram among six traits of seventeen accessions of *Curcuma longa* L.

nature. All the accessions of turmeric received normal field operations, irrigation and application of fertilizers (60 kg N_2, 30 kg P_2O_5 and 30 kg K_2O per hectare).

2.2. Data collection

In order to know the range of variation and genetic associations in different genetic accessions, the morpho-metric data was recorded on seventeen accessions of turmeric (*Curcuma longa* L.) for the six economic important traits, namely plant height (cm), oil content in dry leaf (%), oil content in fresh rhizome (%), fresh rhizome weight (kg/plot), 1,8 cineole and *p*-cymene-8-ol in the essential oil of dry leaves of the plants. The chemical composition of the dry rhizome powder and fresh rhizome oil were also worked out but not included for genetic study in this manuscript.

2.3. Isolation of essential oils

Fresh rhizomes were sliced and washed with water and used for distillation. The dry leaves also distilled for essential oil in a Clevenger apparatus (Clevenger, 1928). The duration of hydro-distillation of the fresh rhizomes was 10 h and for dry leaves 3 h. After collection of essential oils, the oils stored at 4-5 ºC temperature until analysis. Anhydrous sodium sulfate also added to free samples from moisture.

2.4. Analysis of essential oils

The instrument Variance CP3800 carried out the gas chromatography and mass spectroscopy (GC-MS) analysis. For MS, CPC18CB fused silica column 30×0.32 mm×1 µm cell thickness were used, oven temperature was 60 to 220 ºC at the rate of 3 ºC per min, 220 ºC to hold. Injector temperature 280 ºC, detector temperature 290 ºC, split ratio 1:30 and hydrogen as a carrier gas with a flow rate of 1mL/min. Compounds were identified by comparing the retention indices of the peaks with literature values computer matching against the NBS and Wiley libraries spectra. Identification of constitutes was based on retention data of reference compounds. Extraction and fractionation of curcuminoids were done using method suggested by Sandur et al. (2007). The crude curcuminoids were then purified by precipitation with petroleum ether. The precipitate was removed by filtration through Whatman filter paper no. 2 and dried at 60 ºC. The curcuminoids were further fractionated by silica gel 60 column chromatography using first $CHCl_3$ and then $CHCl_3$/methanol with increasing polarity to yield pure fractions of CUR, DMC and BDMC. The fractions were collected and spotted on thin-layer chromatography (TLC) aluminum sheets coated with silica gel 60 F254. Fractions that showed the same pattern on TLC were pooled and the organic solvent was removed to obtain the powder form. The identity and purity of each curcuminoids were verified using TLC, high-performance liquid chromatography (HPLC), infrared (IR), mass spectrometry and nuclear magnetic resonance (NMR) analyses. The purity of curcumin, DMC and BDMC by HPLC analysis was in the range of 95.0-99.0%.

2.5. Statistical analysis

Statistical software CSIR-CIMAP 0.3 version was used for statistical analysis. The data for all the six characters

Table 2
ANOVA of seventeen genetic stocks of *Curcuma longa* L.

S. No.	Traits	Replications df=2	Treatments df=16	Error df=32	CD		CV
			MS		(at 5%)	(at 1%)	(%)
1	Plant height (cm)	276.38	1097.62**	105.509	16.86	23.06	7.31
2	Oil content in dry leaf	0.12	0.42**	0.022	0.24	0.33	16.70
3	Oil content in fresh rhizome	0.01	0.03**	0.002	0.07	0.10	7.99
4	P-cymene-8-ol (%) in the dry leaves	2.92	373.74**	2.478	2.58	3.53	15.61
5	1,8 cineole (%) in the dry leaves	2.07	43.38**	1.782	2.19	2.99	38.42
6	Fresh weight of rhizome (kg)	5.78	600.60**	1.366	1.91	2.62	10.91

**= p<0.01; CD= Critical difference; CV= Coefficient of variance; df= Degree of freedom; ANOVA= Analysis of variance; MS=mean sum of squares.

Table 3

Genotypic (r_g), phenotypic (r_p), environmental correlation (r_e) and co-heritability in broad sense (co-$H_{(B)}$) among six traits of *Curcuma longa* L.

Traits		Plant height (cm)	Oil content in dry leaf (%)	Oil content in fresh rhizome (%)	P-cymene-8-ol (%)in dry leaf oil	1,8 cineole (%)in dry leaf oil	Fresh weight of rhizome (kg)
Plant height (cm)	r_g	-	-0.886**	0.930**	0.247	0.278	-0.0081
	r_p		-0.718**	0.707**	0.221	0.219	-0.011
Oil content in dry leaf (%)	r_e	-0.023	-	-0.578*	-0.329	-0.244	-0.081
	co-$H_{(B)}$	0.994		-0.535*	-0.311	-0.176	-0.080
Oil content in fresh rhizome (%)	r_e	-0.139	-0.307	-	0.05	0.267	-0.178
	co-$H_{(B)}$	1.040	-0.909		0.10	0.218	-0.158
P-cymene-8-ol (%) in dry leaf	r_e	0.118	-0.181	-0.125	-	0.679**	-0.378*
	co-$H_{(B)}$	0.963	0.969	1.184		0.634**	-0.376*
1,8 cineole (%) in the dry leaves	r_e	-0.049	0.286	-0.076	0.04	-	-0.367*
	co-$H_{(B)}$	1.037	1.207	1.049	0.997		-0.351*
Fresh weight of rhizome (kg)	r_e	-0.109	-0.172	9.124	-0.222	-0.247	-
	co-$H_{(B)}$	0.614	0.932	1.019	0.993	0.980	

*, **= p<0.05 and p<0.01, respectively

were subjected to path coefficient and correlation analysis (Dewey and Lu, 1959; Lal et al., 2013) based on the Panse and Sukhatme (1967) and Singh and Chaudhary (1979) standard methods.

3. Results and Discussion

3.1. Analysis of variance (ANOVA), critical difference (CD) and critical variance (CV) percent

The study of analysis of variance (ANOVA), critical difference (CD) and critical variance (CV) percent among seventeen accessions of *Curcuma longa* L. for six characters revealed highly significant differences (p<0.01) leading to considerable genotypic and phenotypic variability (Tables 2-6 and Fig.s 2-3). The variations among the mean, critical difference ($CD_{5\%}$ and $CD_{1\%}$), critical variance (CV%) and range of seventeen accessions were very high for the all six traits as depicted by ranges for plant height (103-40-175.80 cm; $CD_{5\%}/CD_{1\%}$ 16.86 and 23.06%; CV 7.31%), oil content in leaf (0.30-1.50%; $CD_{5\%}/CD_{1\%}$ 0.24 and 0.33%; CV 16.70%), oil content in rhizome (0.36-0.73%; $CD_{5\%}/CD_{1\%}$ 7.13 and 0.098%; CV 0.072%), *p*-cymene-8-ol content (0.04-25.36%; $CD_{5\%}/CD_{1\%}$ 2.58 and 3.53%; CV 15.61%), 1,8 cineole content (0.15-13.15%; $CD_{5\%}/CD_{1\%}$ 2.19 and 2.99%; CV 38.42%) and fresh rhizome yield (2.50-51.30 kg/plot; $CD_{5\%}/CD_{1\%}$ 1.91 and 2.62%; CV=10.91%), respectively.

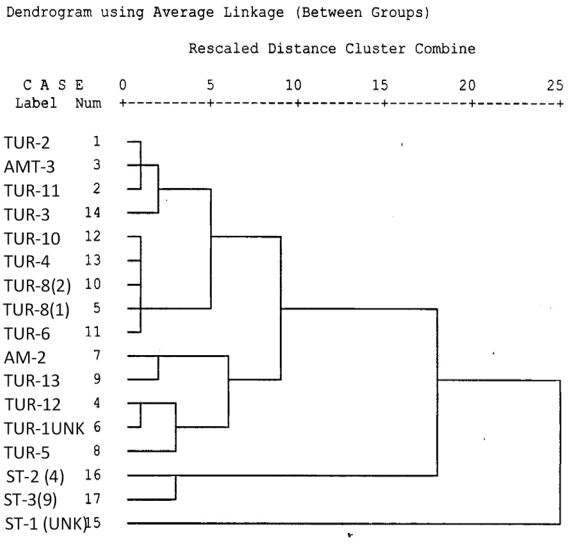

Fig. 3. Dendrogram using average linkage between groups of turmeric accessions.

3.2. Chemical compositions of dry powder of rhizomes and fresh rhizome essential oil

Chemical compositions of dry powder of rhizomes of seventeen accessions of turmeric (*Curcuma longa* L.) of one year crop for CUR=Curcumin; DMC=demethoxycurcumin; bisDMC= bisdemethoxycurcumin and curcumin content (%) are also worked out and presented in Table 7. The range for curcumin, DMC=demethoxycurcumin, Bis DMC=bisdemethoxycurcumin and curcumin contents were found to be 0.49-0.66%, 0.21-0.34%, 0.07-0.16% and 0.03-0.39%, respectively. Essential oil composition of fresh rhizome oil of the seventeen accession of turmeric also worked out and presented in Table 8 for the essential oil components. The ranges for these compounds were as α-terpionolene (0.946-18.563%); *ar*-turmerone (traces-41.220%); α-turmerone (1.215-14.730%); β-turmerone (2.023-20.541%); *ar*-curcumine (traces-8.027%); β-myrecene (trace-84.05%) and gingiberene (traces-4.25%) (see Table 8).

3.3. Correlations, co-heritability in broad sense and path analysis

The values of genotypic correlation (r_g) were higher in most of the traits than phenotypic correlation (r_p). The correlation coefficient among the six traits revealed that plant height (cm) was positively and highly significantly associated with both oil content (%) in rhizome (0.930; 0.707), *p*-cymene-8-ol (%) was also positive and significantly correlated with 1,8-cineole

Table 4

Estimates of elite genetic parameters of six different traits of *Curcuma longa* L.

Parameters and traits	Plant height (cm)	Oil content in leaf (%)	Oil content in fresh rhizome (%)	*p*-cymene-8-ol (%) in dry leaf oil	1,8 cineole (%) in dry leaf oil	Fresh weight of rhizome (kg)
GEN variation$\hat{\sigma}^2_g$	330.70	0.13	0.01	123.75	13.87	199.74
PHE variation$\hat{\sigma}^2_p$	436.21	0.15	0.01	126.23	15.65	201.11
GCV	12.94	40.79	17.47	110.34	107.17	131.94
PCV	14.87	44.08	19.21	111.44	113.85	132.39
GA	28.40	0.64	0.16	22.46	6.80	28.92
GA over mean (%)	20.50	72.05	29.27	222.79	197.70	268.86
Heritability (h^2_{BS}) %	76.00	86.00	82.00	98.00	89.00	99.00

$\hat{\sigma}^2_g$, $\hat{\sigma}^2_p$- genotypicand phenotypic variance; GCV and PCV= genotypic and phenotypic coefficient of variance; ^h (BS) = Heritability in broad sense; GA= genetic advance.

(%) (0.679; 0.634) at both genotypic and phenotypic level, hence selection of one trait changes the nature of other trait in a positive way. However, plant height (cm) was negatively and significantly correlated with oil content (%) in leaf (-0.886; -0.718). Similarly, oil content (%) in the dry leaf was also significantly and negatively correlated with oil content (%) in fresh rhizome (-0.578;-0.535) at the both genotypic and phenotypic levels. *p*-cymene-8-ol (%) and 1,8-cineole (%) were also negatively and significantly correlated with plant height at both genotypic and phenotypic levels. Better plant height (cm) coupled with high *p*-cymene-8-ol (%), 1,8 cineole (%) and fresh rhizome yield (kg/plot) are of great economic importance (Sato et al., 2007). Hence, these traits were found to be good criteria for selection. These traits were also strengthening by high values of co-heritability in broad sense. Since the increases in one of the character contributions will be coupled by the increasing trend in its co-heritable character (Table 3).

Nevertheless, besides correlations, the path coefficient study revealed that the largest direct contribution to fresh rhizome yield (kg/plot) was rhizome oil content (%) (0.56). Direct contribution of other traits to the fresh rhizome yield (kg/plot) was negative, but their indirect contribution was largest via leaf oil content (%) which was the highest followed by rhizome oil content(%) (0.71) and *p*-cymene-8-ol (%) (0.40) (Table 4). The least indirect contribution for rhizome oil content through plant height (cm) was -1.38.

3.4. Genotypic, phenotypic coefficients of variation, heritability and genetic advance

The genotypic and phenotypic coefficients of variation (GCV and PCV) were largest for fresh weight of rhizome(kg/plot) and 1,8 cineole (%) followed by *p*-cymene-8-ol (%) (Tables 4-5, Fig.s 2-6).The phenotypic coefficients of variance (PCV) among accessions for these traits were high as compared to genotypic coefficient of variance (GCV) for all traits, thereby emphasizing narrow scope of selection for improvement of these traits. Our results had shown little difference with previous results (Chandra and Gupta, 1972; Mishra et al., 2015; Lal et al., 2017a, 2017b; Lal et al., 2018a, 2018b) where genotypic coefficient of variances were higher than phenotypic coefficients of variance. High heritability ($\hat{h}^2_{BS}$) was expressed by all these traits for all characters except medium heritability for the plant height (76%). The low genetic advance in percent (GA) was expressed by oil content in rhizome (0.16%), oil content in leaf (0.64%), 1,8 cineole (6.80%)

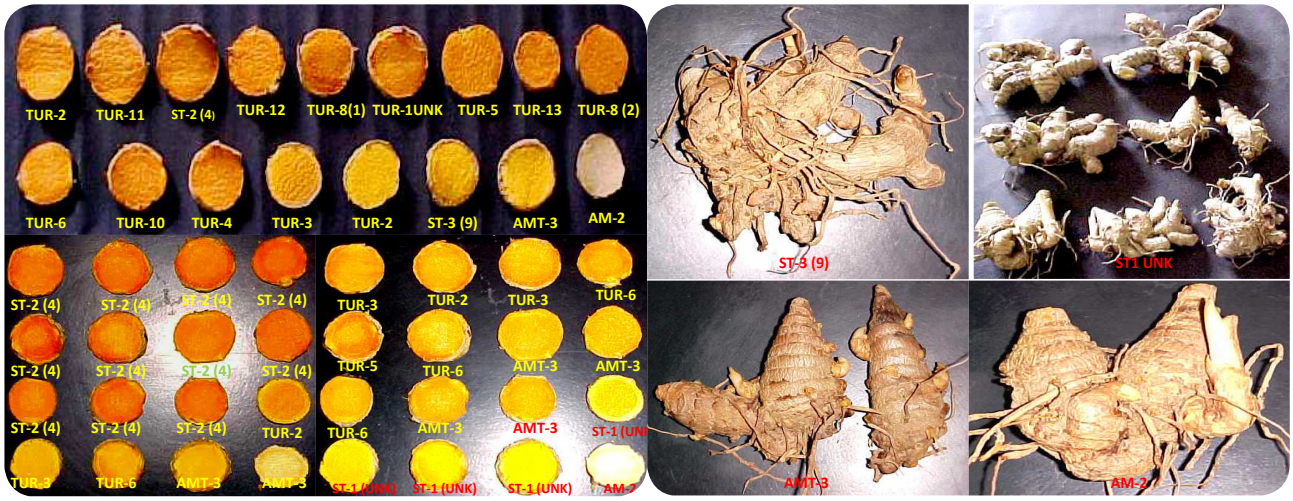

Fig. 4. Rhizomes of *Curcuma longa* L. showing variability in morphology, size, thickness of rhizome and colour variation in transverse sections.

Table 5

Direct (bold) and Indirect effects of yield traits on rhizome yield of *Curcuma longa* L.

Traits	Plant height (cm)	Oil content in dry leaf (%)	Oil content in fresh rhizome (%)	*p*-cymene-8-ol (%) in dry leaf oil	1,8 Cineole (%) in dry leaf oil	r_g (Fresh rhizome yield (kg/plot)
Plant height (cm)	**-1.48**	1.08	0.52	-0.08	-0.053	-0.008
Oil content in dry leaf	1.32	**-1.22**	-0.33	0.10	0.047	-0.08
Oil content in fresh rhizome	-1.38	0.71	**0.56**	-0.016	-0.05	-0.18
P-cymene-8-ol (%) in the dry leaves	-0.37	0.40	0.03	**-0.31**	-0.13	-0.38
1,8 cineole (%) in the dry leaves	-0.41	0.30	0.15	-0.21	**-0.19**	-0.37

Residual effect = 0.894.

Table 6

Average linkage between groups of seventeen accessions of *Curcuma longa* L.

Stage	*Cluster Combined		Coefficients	Stage Cluster First Appears		Next Stage
	*Cluster 1	*Cluster 2		Cluster 1	Cluster 2	
1	1	3	11.753	0	0	3
2	12	13	14.389	0	0	4
3	1	2	31.726	1	0	8
4	10	12	32.491	0	2	5
5	5	10	87.451	0	4	7
6	4	6	95.192	0	0	11
7	5	11	139.291	5	0	12
8	1	14	149.474	3	0	12
9	7	9	156.108	0	0	13
10	16	17	300.963	0	0	15
11	4	8	315.813	6	0	13
12	1	5	640.848	8	7	14
13	4	7	768.216	11	9	14
14	1	4	1144.162	12	13	15
15	1	16	2360.823	14	10	16
16	1	15	3387.783	15	0	0

*-Correspond to the number by order in Table 1.

Table 7

Chemical composition of seventeen accessions of turmeric (*Curcuma longa* L.).

Parameters	CUR		DMC		Bis DMC		CUR content (%)
Sample Code RT	Area	Rf	Area	Rf	Area	Rf	
STD	0.54	12463.7	0.24	6751.7	0.08	9660.8	95
TUR-2	0.59	2157.7	0.26	1046.7	0.10	2468.1	0.08
TUR-11	0.65	2763.2	0.23	2360.2	0.09	3043.4	0.11
AMT-3	0.51	750.9	0.21	607.2	0.08	1334.2	0.03
TUR-12	0.49	1607.7	0.21	1279.3	0.07	2465.3	0.06
TUR-8(1)	0.49	943.2	0.21	1228.2	0.08	2611.4	0.04
TUR-1UNK	0.50	2917.1	0.21	2133.6	0.08	3052.7	0.11
AM-2	0.53	10144.5	0.22	5462.9	0.08	6040.1	0.39
TUR-5	0.55	4519.3	0.23	2685.5	0.08	4015.9	0.17
TUR-13	0.58	6172.2	0.26	4406.9	0.10	5519.4	0.31
TUR-8(2)	0.66	1197.7	0.34	1397.4	0.16	2198.2	0.05
TUR-6	0.62	3010.9	0.31	2465.9	0.16	3863.5	0.13
TUR-10	0.60	4087.6	0.29	3610.6	0.14	4799.2	0.18
TUR-4	0.59	5496.3	0.28	3693.2	0.13	5020.2	0.24
TUR-3	0.57	1870.2	0.27	2056.8	0.13	3512.6	0.09
ST-1 (UNK)	0.55	1672.2	0.28	1965.6	0.13	3480.8	0.07
ST-2 (4)	0.53	1505.7	0.24	1626.6	0.11	2447.9	0.08
ST-3(9)	0.53	764.5	0.24	1017.1	0.11	1607.7	0.03
Range	0.49-0.66	-	0.21-0.34	-	0.07-0.16	-	0.03-0.39
Mean ± S.E.	0.56±0.013	-	0.25 ± 0.010	-	0.11 ± 0.008	-	0.13 ± 0.026
SD	0.05	-	0.04	-	0.03	-	0.01

Dry powder of rhizomes used for chemical analysis, one year crop; CUR=Curcumin; DMC=demethoxycurcumin; Bis DMC=bisdemethoxycurcumin; S.E. Standard error; SD=Standard deviation

Table 8

Essential oil composition of fresh rhizome oil of the seventeen accession of turmeric.

Accession	α-Terpionolene	*ar*-Turmerone	α-Turmerone	β-Turmerone	*ar*-Curcumine	Gingiberene	β-Myrecene
TUR-2	16.537	25.924	12.931	15.884	-	2.102	-
TUR-11	12.882	28.790	13.616	18.043	3.26	0.288	-
AMT-3	18.563	21.868	11.131	16.146	-	0.224	-
TUR-12	13.379	28.388	13.176	17.521	-	2.179	-
TUR-8(1)	10.130	27.580	13.428	19.486	-	0.190	-
TUR-1UNK	9.060	29.668	14.549	17.250	-	2.380	-
AM-2	5.279	27.767	14.730	15.460	8.027	0.190	-
TUR-5	10.958	23.659	13.264	20.068	2.456	1.810	-
TUR-13	9.120	28.874	13.817	20.541	0.188	0.286	-
TUR-8(2)	12.261	28.570	13.726	16.678	0.456	2.875	-
TUR-6	8.069	29.735	14.389	17.461	0.158	2.640	-
TUR-10	6.158	30.201	14.599	17.768	0.123	2.680	-
TUR-4	8.946	35.996	13.339	7.341	-	4.250	-
TUR-3	5.324	41.220	14.168	8.707	-	0.041	-
ST-1 (UNK)	0.946	-	1.215	2.023	-	-	84.05
ST-2 (4)	1.586	17.293	10.995	14.198	-	4.070	-
ST-3(9)	8.122	21.231	1.512	8.502	3.540	2.850	-
Range	0.946-18.563	Traces-41.220	1.215-14.730	2.023-20.541	Traces-8.027	Traces-4.25	Trace-84.05

- = Traces

and medium for fresh weight of rhizome (kg/plot) (28.92%), plant height (cm) (28.40%) and *p*-cymene-8-ol (22.46%), respectively. Genetic advance over mean in percentage was found for fresh weight of rhizome (kg/plot) (268.86%) followed by *p*-cymene-8-ol (222.79%) and 1,8 cineole (197.70%) and the lowest for plant height 20.50% (Tables 4-5).

3.5. Estimation of morphological and chemical diversity

The high genetic diversity in the accessions was also confirmed by Dendrogram (Fig.s 3-5). Hierarchical cluster analysis may be due to the use of different set of materials used for such type of study using average linkage between groups of the *Curcuma longa* L. accessions (Table 6; Fig.s 3-6 (a) and 6 (b)). Chemical compositions of dry powder of rhizomes of seventeen accessions of turmeric (*Curcuma longa* L.) for CUR=Curcumin; DMC=demethoxycurcumin; Bis DMC=bisdemethoxycurcumin and curcumin content (%) are also worked out and presented in Table 7. The range was for curcumin 0.49-0.66; DMC=demethoxycurcumin 0.21-0.34; Bis DMC=bisdemethoxycurcumin 0.07-0.16 and curcumin content 0.03-0.39 (%). Likewise, the essential oil composition of fresh rhizome oil of the seventeen accession of turmeric also worked out and presented in Table 8 for the essential oil components. The ranges for these compounds were as α-terpionolene (0.946-18.563%); *ar*-turmerone (traces-41.220%); α-turmerone (1.215-14.730%); β-turmerone (2.023-20.541%); *ar*-curcumine (traces-8.027%); β-myrecene (trace-84.05%) and gingiberene (traces-4.25%) (Table 8), respectively.

Fig. 5. Variations in plantand leaf morphology and veins colour in the accessions of *Curcuma longa* L.

Regarding the fact that the development of high yielding varieties and genetic improvement of any crops is dependent upon the nature and amount of existing genetic variability, genetic variation for six traits of seventeen genetic accessions were examined in order to understand genetic variability, genotypic, phenotypic, environmental associations and contribution of various yield components towards the rhizome yield of better quality in *Curcuma longa* L. Genotypic and phenotypic coefficient of variations were largest for fresh rhizome yield followed by *p*-cymene-8-ol. Path coefficient study revealed that the largest direct contribution to fresh rhizome yield was that of oil content in rhizome. Direct contributions of other traits to fresh rhizome yield were negative; but their indirect contribution was large via oil content in leaf, oil content in rhizome followed by *p*-cymene-8-ol. All these traits expressed medium to high heritability ($\hat{h}^2_{(BS)}$%) and low to medium genetic advance and positive correlations.

In nutshell, based on the mean performance, characters associations, path analysis and other allied genetic parameters, accession No. 15 ST-1 (UNK) (51.30 kg/plot) followed by 17 ST-3 (9) (36.00 kg/plot) and 16 ST-2 (4) (29.80 kg/plot) were the best for fresh rhizome yield; for essential oil content in leaf, the accession No. 3 AMT-3 (1.50%) followed by 16 ST-2 (4) (1.40%) and ST-3 (9) 17 (1.30%); for essential oil content in rhizome, the accession No. 6 (TUR-1 UNK) 0.73% followed by 7 AM-2 and 9 TUR-13 0.66% were found promising accessions

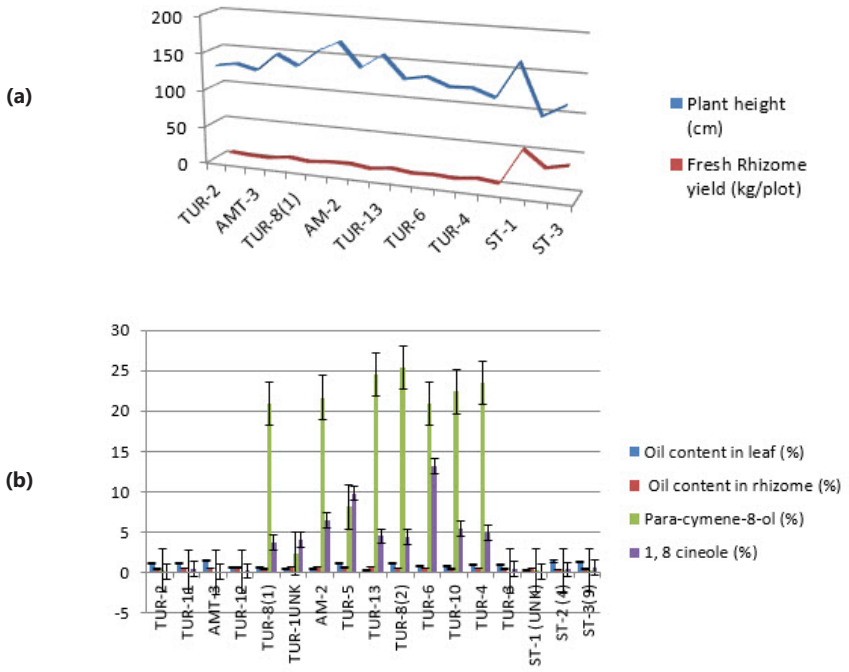

Fig. 6. Graphical representation of mean performance of different characters of *Curcuma longa* L.; plant height (cm) and rhizome yield (fresh rhizome yield (kg/plot), (b) Leaf oil content, rhizome oil content, p-cymene-8-ol and 1,8 cineole.

for further exploitation.

4. Concluding remarks

Seventeen accessions of turmeric were evaluated for nature and amount of genetic variability, path coefficients and associations in the six traits. All the traits showed high heritability, the highest being for fresh weight of rhizome (99%) except medium for plant height (76%) and oil content in rhizome (82%). Based on mean performance and other elite genetic/selection parameters, the accession ST-1 (UNK) (51.30 kg/plot) followed by ST-3 (9) (36.00 kg/plot) and ST-2 (4) (29.80 kg/plot) were the best for fresh rhizome yield; accession AMT-3 (1.50%) for essential oil content in leaf followed by ST-2 (4) (1.40%) and ST-3 (9) (1.30%); for essential oil content in rhizome, the accession TUR-1 UNK (0.73%) followed byAM-2 and TUR-13 (0.66%) were found to be good yielder. Therefore, these accessions may be exploited for commercial production/exploitation.

Conflict of interest

The authors declare that there is no conflict of interest.

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