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Physio-Biochemical basis of Yield and Quality Variation in Turmeric (*Curcuma longa* L.) Genotypes

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A B S T R A C T

A set of 17 genotypes of turmeric *Curcuma longa* L. of N.D.U.A&T Kumarganj Faizabad were assessed for variation in morphological features, leaf and rhizome essential oil content, yield and quality, curcumin content in rhizome and curcumin yield and potential for curcumin extraction from rhizomes, following their distillation for essential oil extraction. Large variability was recorded in all the features studied. The genotypes demonstrated wide variation in the contents of γ-terpenene, 1, 8-cineole and ρ-cymene in the leaf essential oils and of pinene, myrcene, Ar-curcumene and turmerones in the rhizome essential oils. There were some genotypes which were highly deficient in one or more terpenoids in their leaf and/or rhizome essential oil. The leaf oils of the accessions NDH-7, NDH-8, NDH-9, and NDH-45 were deficient in ρ-cymene and Ar-turmerones, Ar-curcumene and Ar-turmerone, Ar-turmerone and β-turmerone, Ar-curcumene and Ar-turmerone and β-turmerone and Ar-curcumene and all turmerones, respectively. The rhizome essential oil of the genotype NDH-14 was highly rich in turmerones and that of NDH-98 was deficient in turmerones, respectively. The genotypes NDH-88, NDH-108 and NDH-118 were identified as high yielding elite resource for both curcumin and leaf oil. The possibility of profitable extraction of curcumin from the essential oil extracted rhizomes was demonstrated.

Introduction

Curcuma longa L. turmeric plant, domesticated in India, is widely cultivated for the production of turmeric powder, which is widely used as spice and food colouring agent and as the resource for curcumin, the main phenolic compound in turmeric. Used in traditional and Ayurvedic medicines as *haldi* for centuries, curcumin has proven properties of antioxidant and anti-inflammatory agent and induces apoptosis in a variety of cancer cells (Khanna, 1999; Kunnumakkara *et al.*, 2008; Liang *et al.*, 2009; Lin *et al.*, 2008; Moon *et al.*, 2008; Pisano *et al.*, 2008; Srimal, 1997). Recently curcumin has been found to be anti-depressive and hypolipidimic (Bhutani *et al.*, 2009; Jang *et al.*, 2008). Since curcumin is quite safe and exhibits therapeutic efficacy against a variety of clinical conditions, the use of turmeric is expected to expand worldwide. In this context, the available genetic resources

of *C. longa* require to be evaluated for the identification of most productive lines for direct use and for recombining the favourable characters in them by conventional, genetic engineering and other biotechnological plant breeding tools. This study compares the morphological and chemical features of 17genotypes of *C. longa* collected in India and identifies some unique and useful lines.

Materials and Methods

The experiment was carried out on a crop of 17genotypes of *C. longa* land races. The genotypes had been collected from various parts of the rural areas of northern India Uttar Pradesh, Kerala and Bihar. These genetic resources were being maintained in the gene bank. Figure 1 depicts the features of a typical *C. longa* plant.

Growth conditions

Using well formed rhizomes genotypes were sown row-wise on raised ridges in the experimental farm of ND University of Agriculture and Technology Kumarganj Faizabad in early March. The ridge to ridge distance was 70 cm and rhizome to rhizome distance was kept at 30 cm. The field plot used had sandy loam soil containing NPK as 70, 12 and 150 kg/ha, respectively, organic carbon at 0.25% and pH 7.8. The fertilizers were applied at the time of sowing at the rate of 80 kg/ha phosphorus, 60 kg/ha potash and 100 kg/ha urea. Another dose of urea at the equal rate was applied two months after sowing of the rhizomes. The design of the planting was randomized block with three replications.

Observation methodology

The crop was allowed to grow for about 38 weeks and harvested in late December. Three randomly chosen plants were harvested for each genotype per replication. The root system was washed in running water. The observations on the morphological features and organ yields were recorded on single plants, which included height and number of leaves and rhizomes. The leaves and rhizomes were separated and weighed to obtain their fresh weights. The chemical characterization of leaves and rhizomes was done on the replication-wise pools of three plants per genotype. For this purpose, the pools of leaves and rhizomes were cut into small pieces separately to draw random samples for analysis.

Essential oil estimation and characterization

The samples of leaves and rhizomes were hydro-distilled in Clevenger's type apparatus at 65ºC for3h to estimate per cent essential oil content. The genotype- and replication-wise oil yields of leaves and rhizomes per plant were calculated by multiplying per cent oil content, specific gravity 0.9 and the average weight of leaves or rhizome material per plant divided by 100. The oil samples were analyzed for the contents of major terpenoids using gas liquid chromatography. The GC analysis on the neat oil samples was accomplished on HP-5890 Series-II gas chromatograph using a 3m x 3mm SS column packed with 3% AT-1000 on 80/100 supelcoport and FID as detector. Oven temperature was programmed from 100ºC to 220ºC @ 5º/min with initial and final temperature hold of 2 and 5 min, respectively. Nitrogen gas was used as carrier @ 30 ml/min: injector and detector temperatures were set at 200ºC and 240ºC, respectively. Data were processed in HP-339G Series III integrator.

Estimation of curcumin content

The percent curcumin content was detected in the freshly harvested rhizomes as well as in the rhizome material left over following essential oil extraction by hydro-distillation.

The procedure of Gupta *et al.,* (1999) was followed after minor modifications (Gupta *et al.,* 1999). For each curcumin extraction, in the airdried and powdered 0.2 g rhizome sample 10 ml of acetone was added and incubated for 12h, filtered and the filtrate was evaporated. The residue extract was re-dissolved in 2 ml of acetone for quantification. The curcumin was estimated by thin layer chromatography. The TLC was performed on a pre-activated (100ºC) silica gel TLC plate $^{60}F_{254}$ 10 x 10 cm. Samples and standards were applied to the plate as 6mm wide bands with an automatic TLC applicator Linomate IV under N_2 flow (Camag, Muttenz, Switzerland), 10 mm from the bottom of the plate at a delivery speed of the syringe 10 s/µL.

The application parameters were identical for the analyses performed. The plate was developed using mobile phase chloroform : methanol :: 95 : 5 and the spots were scanned at 366 nm using the absorption/ reflection detection mode; RF of curcumin was 0.69.

Results and Discussion

Wide variability was observed in the genotypes for all the characters studied (Table 1, 2 and 3). The salient features of the variability are described below.

Leaf

Number of leaves borne on turmeric plant is indicative of its vigour. It will be seen from Table 1 that the genotypes produced 2 to 85 leaves on their plants (mean = 21.8). The fresh weight of leaves varied between 15 g and 4.3 kg (mean = 0.8 kg). The oil content in the fresh leaves varied between 0.05% and 0.83% (mean = 0.48%) and the essential oil yield varied between 0.1 and 28 g per plant (mean = 3.67g). Considering all the genotypes together, it will be seen from Table 4 that the leaf mass was highly correlated with plant height with (r = 0.62). Further, the leaf oil yield had strong correlation with leaf mass (r = 0.91).

The leaf essential oil from the genotypes also differed widely in the composition (Table 2). The known major terpenoids of turmeric leaf oil namely a-pinene, g -terpinene, 1,8-cineole, r-cymene, Ar-curcumene, Ar-turmerone, a-turmerone, b-turmerone were present in almost all the genotypes, althoughtoextents. The contents of g-different terpinene, 1,8-cineoleandr-cymenedemonstrated very large variability, the range of the concentration of g-terpinene was from 0.8 to 62.8% (mean = 11.8%) and that of 1,8-cineole was from 0.01 to 35.5% (mean = 14.5%) and variation ranged from 0.01 to 78.1% for r-cymene (mean = 21.1%).

The range of α-pinene, Ar-curcumene and turmerone(s) was relatively lower; the concentrations of these terpenoids ranged from 0.01 to 17.4% (mean= 3.0%). Their order of occurrence in terms of increasing concentrations was α-pinene<β- turmerone<α-turmerone<Ar-curcumene<Ar-turmerone. The pooled concentration of the three turmerone(s) varied from 0.03 to 18.2% (mean = 9.8%) among all the genotypes. It is noteworthy that the concentrations of the α-pinene, Ar-curcumene and Ar-turmerone were very low (< 0.01%) in the essential oil of the genotype designated as NDH-7.

The concentration of Ar-curcumene and all the three turmerones was also observed to be very low in the genotype NDH-98. In the genotype NDH-18 essential oil, concentrations of Ar-turmerone and β-tumerone were low and in the essential oil of NDH-45, the concentrations of Ar-curcumene, Ar-turmerone and β-turmerone were low. The genotypes NDH-79 and NDH-108 were very low in concentration of ɑ-cymene and Ar-turmerone, respectively.

Rhizome

The genotypes also demonstrated high level of variability for the rhizome characters (Table 1). The number of rhizomes per plant varied from 1 to 129 (mean = 31.5) in the genotypes. The rhizome yield per plant varied from 21 g to 3.5 kg (mean = 736 g). The oil and curcumin contents in the rhizome varied from 0.05 to 1.4 % (mean = 0.57%) and 0.33 to 1.55% (mean = 0.80%), respectively. The oil and curcumin yields varied from 0.1 to 19.9 g (mean = 3.6g) and 0.2 to 31.0g per plant (mean = 6.0g), respectively. The correlations between rhizome mass on one hand and curcumin yield on the other hand and that between rhizome oil yield and curcumin yield were positive and highly significant (Table 4). Interestingly, the correlation between leaf oil yield and rhizome curcumin yield was also positive and significant. The leaf mass was highly positively correlated with rhizome mass (Table 4). Previous work has identified α-pinene, β-pinene, myrcene, 1,8-cineole, γ-terpinene, ρ-cymene, linalool, Ar-curcumene, zingiberene, Ar- turmerone, β-turmerone and β- turmerone as the major terpenoids in the rhizome essential oil. The genotypes demonstrated enormous variability in the contents of these compounds in the essential oil (Table 3).

The α- pinene, myrcene, Ar-curcumene, Ar-turmerone and β-turmerone concentrations varied from 0.01 to 45.1% (mean = 9.3%), 0.01 to 45.7% (mean = 3.6%), 0.13 to 34.8% (mean = 4.1%), 0.01 to 39.4% (mean = 11.7%), 0.01 to 34.3% (mean = 6.7%), respectively. The variation in the contents of α-pinene, 1,8-cineole, γ-terpinene, ρ-cymene, and zingiberene was relatively lower. The concentrations of these terpenoides varied from 0.01 to 14.4% with mean values ranging from 0.5 to 3.1%. There was more compositional variation in the rhizome essential oils as compared to leaf essential oils. The α-pinene, β-pinene, myrcene, 1,8-cineole, β-terpinene, ρ-cymene, linalool, zingiberene, Ar-turmerone, α-turmerone and β-turmerone concentrations was very low in the rhizome oils of a total of 23, 22, 31, 29, 41, 27, 1, 1, 1, 1 and 1 out of 17 genotypes, respectively.

Recovery of curcumin from hydro-distilled rhizomes

The hydro-distilled rhizomes of all the genotypes were extracted for curcumin. The curcumin contents of the fresh and hydro-distilled rhizomes were compared genotype wise. The results presented in Table 5 show that curcumin is extractable from the hydro-distilled rhizomes to different extents in different genotypes. Whereas in rhizomes of many genotypes with < 50% of curcumin present in fresh rhizomes was extractable from hydro -distilled rhizomes, in the other genotypes such as NDH-98 and NDH-74, bulk of the curcumin (> 80%) that was present in the fresh rhizomes was extractable from the hydro-distilled rhizome counterparts.

Identification of genotyeps for high curcumin and leaf oil yields

In Figure 2, the genotypes are plotted as metroglyphs with curcumin yields on one hand and leaf oil yield on the other hand. The concentrations of γ-terpinene, 1,8-cineole, ρ-cymene of the leaf oil and per cent content of oil, α-pinene and turmerone contents of the rhizomes are depicted as bars on the metroglyphs. This analysis identified the genotypesNDH-18, NDH-98, NDH-74 and NDH-7 as high yielding resources for curcumin on the one hand and leaf oil on the other hand. The leaf oils of these genotypes were relatively rich in ρ-cymene, pinene(s) and turmerones.

Table.1 Variation in essential oil yield characters of leaves and rhizomes of turmeric *Curcuma longa*

S.No.	Genotypes	Plant height (cm)	Leaf Number	Leaf Mass (g)	Leaf Oil content %	Leaf Oil yield (g)	Rhizome Number	Rhizome Mass (g)	Rhizome Oil content %	Rhizome Oil yield (g)	Rhizome Curcumin content %	Rhizome Curcumin yield (g)
1	2	3	4	5	6	7	8	9	10	11	12	13
1.	NDH-7	155	27	420	0.05	0.2	62	669	0.55	3.3	0.88	5.9
2.	NDH-8	200	44	2160	0.15	2.9	83	2000	0.25	4.5	0.68	13.6
3.	NDH-9	154	28	950	0.65	5.6	20	740	0.40	2.7	0.86	6.4
4.	NDH-14	159	37	1560	0.15	2.1	57	1970	0.33	5.9	0.78	15.4
5.	NDH-18	100	11	145	0.55	0.7	12	304	0.58	1.6	0.91	2.8
6.	NDH-45	182	56	3565	0.75	24.1	73	2690	0.36	8.7	1.01	27.2
7.	NDH-53	150	51	1210	0.55	6.0	34	792	0.35	2.5	0.73	5.8
8.	NDH-64	157	19	920	0.75	6.2	36	845	0.35	2.3	0.74	6.3
9.	NDH-74	152	39	1010	0.60	5.5	33	839	0.35	0.9	0.81	6.8
10.	NDH-79	151	62	2714	0.75	18.3	53	2495	0.35	7.9	0.83	20.7
11.	NDH-86	170	81	4145	0.75	28.0	117	3181	0.30	9.6	0.90	31.0
12.	NDH-88	162	42	1030	0.70	6.5	35	1277	0.35	4.0	1.02	13.0
13.	NDH-98	149	92	4330	0.55	1.6	14	3550	0.73	5.5	0.75	29.4
14.	NDH-108	152	32	1055	0.60	5.7	38	1084	0.30	2.9	0.87	9.4
15.	NDH-118	172	16	665	0.60	3.6	19	595	0.40	2.1	0.96	5.7
16.	Prabha(National check)	155	25	512	0.75	3.5	16	3428	0.73	5.6	0.83	31.2
17.	RajiendraSoni (National check)	177	51	1400	0.75	9.5	41	3113	0.71	5.8	1.0	33.5
	Range											
	Min	100	11	665	0.05	0.2	12	304	0.25	0.9	0.68	2.8
	Max	200	92	4300	0.75	28.0	117	3550	0.73	8.7	1.02	33.5
	Mean	147	21.8	800	0.48	3.67	31.5	736.6	0.57	3.60	0.80	6.03
	±S.E.	±3.4	±1.9	±111	±0.02	±0.59	±2.84	±78.6	±0.03	±0.47	±0.03	±0.71

Table.2 Percentage composition of major terpenoids in leaf essential oil of different genotypes of turmeric *Curcuma longa*

S.No.	Genotypes	% terpenoid							
		-pinene	-terpinene	1,8-cineole	-cymene	Ar-curcumene	Ar-turmerone	-turmerone	-turmerone
1	2	3	4	5	6	7	8	9	10
1.	NDH-7	3.22	2.29	26.46	25.98	3.58	3.38	4.99	1.69
2.	NDH-8	2.70	1.18	4.13	0.10	1.55	3.14	1.90	0.85
3.	NDH-9	1.00	1.79	10.51	27.20	6.04	0.01	0.83	4.00
4.	NDH-14	2.11	3.36	10.15	11.96	2.18	2.59	0.51	1.19
5.	NDH-18	2.00	11.27	13.21	23.45	3.60	7.28	0.76	2.95
6.	NDH-45	1.80	6.00	0.01	31.25	4.84	9.19	1.95	3.80
7.	NDH-53	1.59	2.71	5.12	7.03	1.56	2.38	2.44	3.75
8.	NDH-64	1.37	2.65	11.39	30.08	6.07	9.47	2.25	4.33
9.	NDH-74	1.37	3.88	11.43	29.13	5.77	9.88	2.14	4.39
10.	NDH-79	1.33	3.06	9.57	27.61	5.81	8.62	2.57	4.80
11.	NDH-86	1.53	3.73	12.09	32.01	4.92	8.22	1.73	2.90
12.	NDH-88	1.89	45.53	8.29	9.06	0.64	2.20	0.39	1.28
13.	NDH-98	1.27	32.97	13.27	29.14	6.15	10.37	2.60	5.19
14.	NDH-108	0.01	18.45	6.38	14.14	0.01	0.01	4.08	8.95
15.	NDH-118	1.55	3.39	11.38	29.00	4.81	7.22	0.65	2.98
16.	Prabha(National check)	1.48	5.61	9.77	28.46	4.63	9.51	2.37	4.46
17.	RajiendraSoni (National check)	1.49	5.37	9.48	29.08	4.08	8.09	1.95	4.38
	Range								
	Min	0.01	2.29	0.01	0.10	0.01	0.01	0.39	0.85
	Max	3.22	45.53	26.46	30.08	6.07	10.37	4.99	8.95
	Mean	1.82	11.84	14.50	21.07	3.54	5.28	1.86	2.65
	±S.E.	±0.10	±1.74	±0.84	±1.22	±0.28	±0.36	±0.15	±0.20

Table.3 Per cent composition of major terpenoides in rhizome essential oil of different genotypes of turmeric *Curcuma longa*

S.No.	Genotypes	% terpenoid											
		-	-	Myr-	1,8-	g-terpi-	p-	lina-	Ar-	zingi-	Ar-	-	
		pinene	pinene	cene	cineole	nene	cymene	lool	curcu-	berene	turme-	turme-	
									mene		rone	rone	
1	2	3	4	5	6	7	8	9	10	11	12	13	
1.	NDH-7	0.20	6.38	0.01	2.86	0.70	0.47	1.18	2.16	2.29	5.59	7.96	
2.	NDH-8	2.98	0.38	0.94	0.01	0.01	0.01	1.48	1.69	2.84	3.80	8.34	
3.	NDH-9	0.55	0.01	41.78	7.02	1.03	1.97	0.24	1.19	0.95	7.51	9.55	
4.	NDH-14	0.01	0.01	45.67	9.57	1.20	1.68	0.23	1.35	0.82	5.25	7.70	
5.	NDH-18	0.32	14.13	2.13	0.04	0.01	0.17	1.08	4.08	1.93	3 6.68	1 3.45	
6.	NDH-45	0.60	0.01	20.91	3.46	0.43	0.55	0.28	1.71	1.24	1 0.86	1 4.41	
7.	NDH-53	0.49	20.01	2.38	0.41	0.45	0.21	0.31	1.99	1.23	14.11	1 5.83	
8.	NDH-64	1.01	32.96	0.01	7.72	0.95	1.61	0.40	1.10	1.66	5.77	1 0.81	
9.	NDH-74	1.42	41.67	9.08	0.92	8.80	0.01	0.22	0.96	0.77	1 6.22	7.87	
10.	NDH-79	1.17	45.05	7.70	1.10	1.92	1.70	0.32	1.33	0.92	2 1.30	8.51	
11.	NDH-86	0.88	20.80	5.53	0.31	7.06	0.01	0.31	1.13	0.13	6.67	1 3.83	
12.	NDH-88	0.33	10.98	0.01	4.36	8.66	0.01	0.29	0.30	1.21	1 8.96	1 5.01	
13.	NDH-98	5.93	0.01	0.01	0.01	0.01	0.01	1.42	0.91	0.01	3 2.22	1 9.49	
14.	NDH-108	1.26	40.20	0.01	6.74	1.05	2.18	0.22	1.15	0.83	7.35	9.57	
15.	NDH-118	0.43	14.47	0.01	5.08	0.75	0.89	0.25	1.40	0.98	6.94	1 1.65	
16.	Prabha(National check)	0.01	13.62	0.01	5.20	12.80	0.01	0.37	0.17	1.25	1 4.04	1 3.25	
17.	RajiendraSoni (National check)	0.80	33.61	4.84	1.03	2.27	1.53	1.55	1.41	1.06	1 5.76	8.19	
	Range												
	Min	0.01	0.01	0.01	0.01	0.01	0.01	0.22	0.30	0.01	3.80	7.70	3.80
	Max	5.93	45.05	45.67	9.57	8.80	2.18	1.55	4.08	2.84	36.68	19.49	34.28
	Mean	0.52	9.26	3.62	1.46	1.17	0.95	1.85	4.08	3.14	11.66	8.80	6.66
	±S.E.	±0.10	±1.23	±0.84	±0.24	±0.28	±0.19	±0.24	±0.56	±0.29	±0.94	±0.49	±0.57

Fig.1 Features of *Curcuma longa* plants. A= Rhizomes; B = Inflorescence; C = Whole plant; D= Plantation

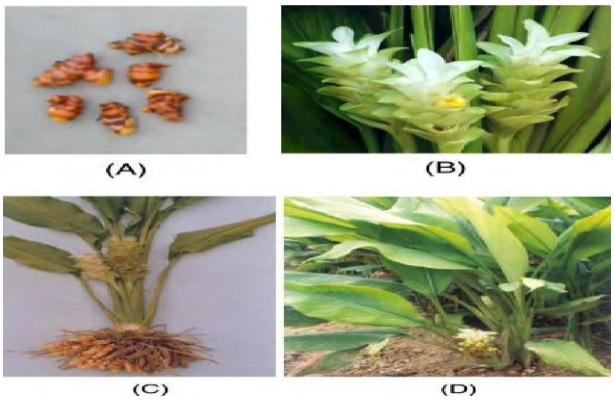
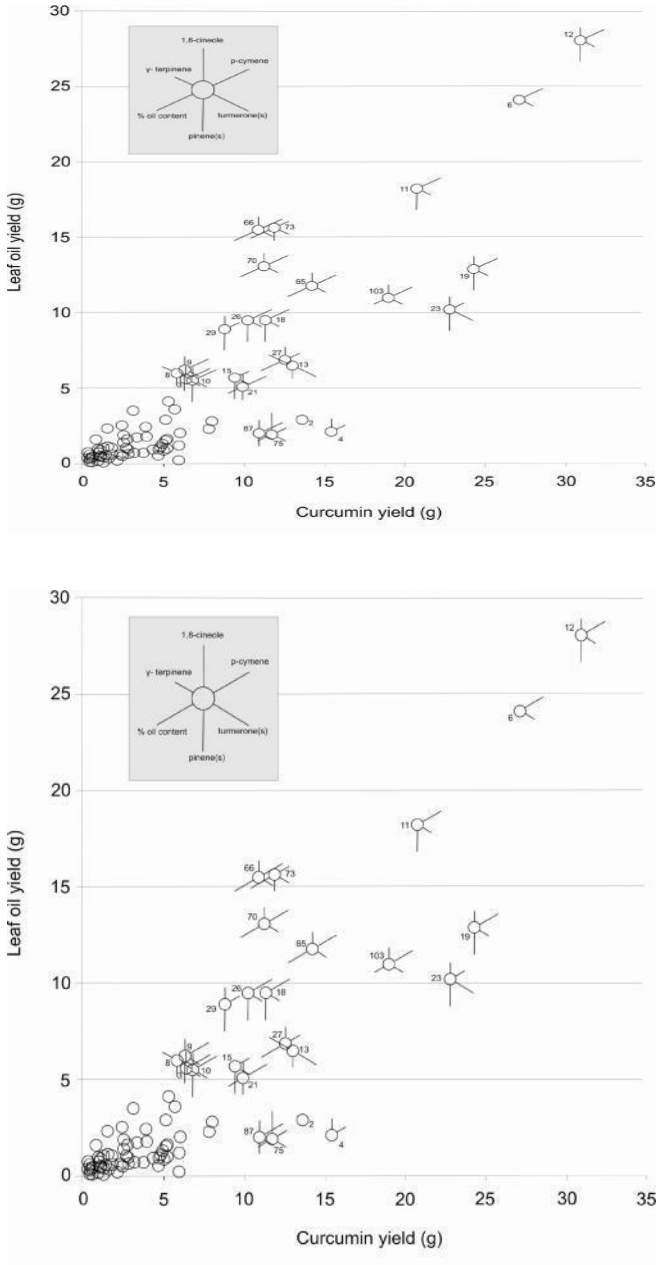


Fig.2 Genotypes of turmeric *Curcuma longa* represented as metroglyphs depicting genotype wise variation in chemical characteristics of rhizomes and leaves



The results of the comparative analysis of economic characters of turmeric *C. longa* genetic resources from northern India described above demonstrate very large variability among the genotypes. This is commensurate with the belief that *C. longa* was domesticated into a crop in the Asian region, more particularly in India.

In an earlier study, *C. longa* cv. Prabha (National check) which is cultivated widely in Southern India was characterized for the yields of rhizomes and leaves and their essential oils (Bansal *et al.*, 2002). Several genotypes of the present study out yielded this cultivar and some of the other cultivars grown in India and other parts of Asia (Dixit *et al.*,

2000; Nandi, 1991; Panigrahi *et al.*, 1987; Paramasivam *et al.*, 2009; Pathana *et al.*, 1988; Philip and Nair, 1983; Rama Rao and Rao, 1994; Randhawa and Mahey, 1988). The yields of rhizomes of *C. longa* (cv Roma) and other varieties have been reported earlier in the range of 100 g to 700 g. In this study, 22 genotypes yielded rhizomes in more than 1 kg quantity per plant. In the present experiment, the yield of rhizomes in cv Prabha (National check) was 1.9 kg. Six genotypes namely NDH-7, NDH-9, NDH-18, NDH-45, NDH-79 and NDH-98 gave rhizome yield of > 2 kg/plant. Among these the genotype NDH-18 gave a rhizome yield of 3.5kg/plant. The genotype NDH-98, produced 4.1 kg leaf biomass per plant which is marginally less than 4.3 kg biomass produced by plants of Rajendra Sonia (National check) However, the genotype NDH-7, proved superior to genotypes NDH-45, in terms rhizome oil yield (18.2 g/plant for NDH-74. Some other genotypes recorded roughly similar yields of essential oils from leaves and rhizomes, e.g. NDH-18 (15.6 g from leaves vs 17.0 g oil from rhizomes). Although the correlation coefficients in the 17 genotypes between leaf oil yield and rhizome oil yield, leaf oil yield and curcumin yield, rhizome oil yield and curcumin yield were positive and significant, yet some of the genotypes showed large differences between the characters found highly correlated on the population basis. Clearly the genetic resources of *C. longa* studied here offer potential for breeding varieties of *C. longa* for better yields of rhizomes rich in curcumin and essential oils capable of producing large biomass of leaves rich in essential oil making them resource not only of rhizomes but also of leaf essential oil.

The leaf and rhizome essential oils of different genotype demonstrated large variability in their terpenoid composition. There were several genotypes in which one of the terpenoids could be identified as a major component for leaf and rhizome essential oil since it was present in excess of 30% of the total terpenoids. Such genotypes could be called as chemotypes of the concerned terpenoid component. The genotype NDH-14, and NDH-18 would thus be termed as myrcenechemotypes because their rhizome essential oils contained 41.8 and 45.7% myrcene, respectively. The genotypes NDH-45, NDH-79, NDH-18, NDH-74 produced rhizome essential oils that were richer than 30% in ß-pinene, making them ß-pinenechemotypes. The genotype NDH-98 was a Ar-curcumene chemotype as its rhizome oil contained Ar-curcumene @ 35%. The genotype NDH-86, NDH-64 and NDH-53 proved to be Ar-turmerone chemotypes. The genotype NDH-14, NDH-18, NDH-45, NDH-74, NDH-79, Prabha and R.Sonia which could be termed as turmerone(s) rich chemotypes because their rhizome essential oils contained Ar-, α-, and β- turmerone in >30% contents. Generally, the turmerones comprised a marker of turmeric essential oils. Surprisingly, the turmerone content in the rhizome essential oils of NDH-53 was negligible (0.03%). This accession perhaps represents a natural mutation of one or more steps involved in turmerone biosynthesis in rhizomes. This conclusion is supported by the observation that turmerones are also deficient in leaf essential oil of this genotype. The α- and β-pinene, myrcene, 1, 8-cineole, γ-terpinene, ρ-cymene, linalool, zingiberene, Ar-turmerone, α- turmerone and β-turmerone had been identified as major components of rhizome essential oil on the basis of previous work (Garg *et al.*, 1999; Jantan *et al.*, 1999; Marongiu *et al.*, 2002; Nigam and Ahmad, 1991; Sharma *et al.*, 1997). Indeed these together comprised more than 1/3 terpenoid components in the rhizome essential oil of the large majority of genotypes studied, however, there are some genotype, e.g. NDH-9, NDH-53, NDH-64, NDH-88 and NDH-108 in which the above listed terpenoids did not

constitute even 1/3 of the total terpenoid composition of the rhizome essential oil. The rhizomes of all the genotypes contained curcumin though to different extents.

The richness of specific terpenoids in the leaf essential oil could also be the criteria for identification of chemotypes among genotypes. In this regard, the genotypes NDH-98, Prabha, R.Sonia, NDH-74 and NDH-18 appeared as γ-terpinenechemotypes since their leaf essential oil contained concerned compound γ-terpinene in 32.8 to 62.8% concentrations. The genotype NDH-98 and NDH-18 proved to be 1,8-cineole chemotypes because their leaf essential oil contained 1,8-cineole in 34.9% and 35.5% concentrations, respectively.

An interesting question answered in this work was whether the rhizomes could be extracted for both essential oil and curcumin, first for essential oil and subsequently for curcumin. The results ascertained the feasibility of such technology on the rhizome of some of the genotypes. The genotype NDH-74 and NDH-98 proved to be amenable for the dual production from the rhizome.

Concluding Remarks

Following is the outcome in the form of new knowledge and materials from the evaluation of 17 genetic resources of *C. longa* in the present study. The γ-terpinene, 1,8-cineole and ρ-cymene are present in the leaf essential oil in high amounts and pinene(s), myrcene, Ar-curcumene and turmerones in the rhizome essential oil. Turmerones and/or curcumene in the rhizomes are the markers for *C. longa*. There exist in *C. longa*, γ- terpinene, 1,8-cineole and ρ-cymene chemotypes on account of their richness in leaf essential oils and β-pinene, myrcene, Ar- curcumene and turmeronechemotypes for their high concentrations in the rhizomes essential oil.

There are genotypes which hyper-yield leaf essential oil and curcumin rich rhizomes. Perusal of direct selection among the genetic resources and genetic manipulation via mutagenesis, transgenesis and conventional plant breeding procedures have potential for cultivar development to obtain products of defined chemical composition.

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