Proc Indian Natn Sci Acad **80** No. 1 March 2014 pp. 143-156

Research Paper

Variation in Yield of Curcumin and Yield and Quality of Leaf and Rhizome Essential Oils among Indian Land Races of Turmeric *Curcuma longa* L.

J R BAHL[1*], R P BANSAL[1], S N GARG[1], M M GUPTA[1], VIKRAM SINGH[1], R GOEL[2] and S KUMAR[3]
[1]*Central Institute of Medicinal and Aromatic Plants, Kukrail Picnic Spot Road, PO-CIMAP, Lucknow 226 015, India*
[2]*KIET School of Pharmacy, 13th Milestone, Ghaziabad-Meerut Road, Ghaziabad 201 206 (UP), India*
[3]*National Institute of Plant Genome Research, Aruna Asaf Ali Marg, New Delhi 110 067, India* and
SKA Institution for Research, Education and Development, 4/11, Sarv Priya Vihar, New Delhi

(Received 23 May 2013; Accepted 29 August 2013)

A set of 84 accessions of turmeric *Curcuma longa* L. collected from various geographical locations in northern India 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 accessions 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 accessions which were highly deficient in one or more terpenoids in their leaf and/or rhizome essential oil. The leaf oils of the accessions CH-2 and CH-3, CH-15, CH-38, CH-40 and CH-53 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 accession CH-14 was highly rich in turmerones and that of CH-99 was deficient in turmerones, respectively. The accessions CH-6, CH-11 and CH-19 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.

Key Words: *Curcuma longa*; Haldi; Genetic Variability; Morphological Characterization; Essential Oil; Chemotypes

1. 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

**Author for Correspondence: E-mail: jr.bahl@cimap.res.in; jrbahl@yahoo.com*

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 84 accessions of *C. longa* collected in India and identifies some unique and useful lines.

2. Material and Methods

The experiment was carried out on a crop of 84 accessions of *C. longa* land races. The accessions had been collected from various parts of the rural areas of northern India in the states of Haryana, Uttrakhand, Uttar Pradesh and Bihar by visiting the farmers' fields and the krishi Vigyan Kendras, over the period of 2000 to 2008. These genetic resources were being maintained in the gene bank of the institute by single rhizome vegetative propagation. The specimen(s) of the accession are deposited in the institute's herbarium vide the Voucher No. 11128. Fig. 1 depicts the features of a typical *C. longa* plant.

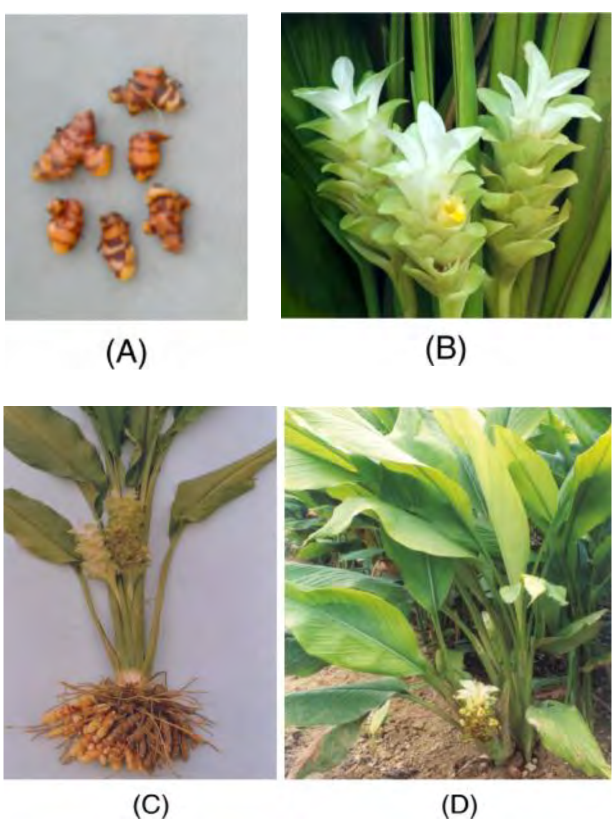

Fig. 1: Features of *Curcuma longa* plants. A= Rhizomes; B = Inflorescence; C = Whole plant; D= Plantation

(a) Growth Conditions

Using well formed rhizomes the accessions were sown row-wise on raised ridges in the experimental farm of CIMAP at Lucknow 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 two replications.

(b) 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 accession 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 accession. For this purpose, the pools of leaves and rhizomes were cut into small pieces separately to draw random samples for analysis.

(c) Essential Oil Estimation and Characterization

The samples of leaves and rhizomes were hydro-distilled in Clevenger's type apparatus at 65ºC for 3h to estimate per cent essential oil content. The accession- 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. The constituents were identified by comparing their GC retention time with those of the standard samples as well as of the components of other essential oils which had been identified earlier by matching their GC/MS fragmentation patterns with those reported in the literature and the library established in CIMAP.

(d) 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 air dried 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.

3. Results

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

(a) Leaf

Number of leaves borne on turmeric plant is indicative of its vigour. It will be seen from Table 1 that the accessions 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 accessions 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 accessions 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 accessions, although to different extents. The contents of g-terpinene, 1,8-cineole and r-cymene demonstrated 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 < ß-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 accessions. 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 accession designated as CH-15. The concentration of Ar-curcumene and all the three turmerones was also observed to be very low in the accession CH-53. In the accession CH-38 essential oil, concentrations of Ar-turmerone and ß-tumerone were low and in the essential oil of CH-40, the concentrations of Ar-curcumene, Ar-turmerone and ß-turmerone were low. The accessions CH-2 and CH-3 were very low in concentration of ρ-cymene and Ar-turmerone, respectively.

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

S.No.	Accession	Plant height (cm)	Leaf					Rhizome				
			Number	Mass (g)	Oil content %	Oil yield (g)	Number	Mass (g)	Oil content %	Oil yield (g)	Curcumin content %	Curcumin yield (g)
1	2	3	4	5	6	7	8	9	10	11	12	13
1.	CH-1	155	27	420	0.05	0.2	62	669	0.55	3.3	0.88	5.9
2.	CH-2	200	44	2160	0.15	2.9	83	2000	0.25	4.5	0.68	13.6
3.	CH-3	154	28	950	0.65	5.6	20	740	0.40	2.7	0.86	6.4
4.	CH4	159	37	1560	0.15	2.1	57	1970	0.33	5.9	0.78	15.4
5.	CH-5	100	11	145	0.55	0.7	12	304	0.58	1.6	0.91	2.8
6.	CH-6	182	56	3565	0.75	24.1	73	2690	0.36	8.7	1.01	27.2
7.	CH-8	150	51	1210	0.55	6.0	34	792	0.35	2.5	0.73	5.8
8.	CH-9	157	19	920	0.75	6.2	36	845	0.35	2.3	0.74	6.3
9.	CH-10	152	39	1010	0.60	5.5	33	839	0.35	0.9	0.81	6.8
10.	CH-11	151	62	2714	0.75	18.3	53	2495	0.35	7.9	0.83	20.7
11.	CH-12	170	81	4145	0.75	28.0	117	3550	0.30	9.6	0.90	31.0
12.	CH-13	162	42	1030	0.70	6.5	35	1277	0.35	4.0	1.02	13.0
13.	CH-14	149	8	330	0.55	1.6	14	354	0.33	1.1	0.75	2.7
14.	CH-15	152	32	1055	0.60	5.7	38	1084	0.30	2.9	0.87	9.4
15.	CH-16	172	16	665	0.60	3.6	19	595	0.40	2.1	0.96	5.7
16.	CH-17	155	25	512	0.75	3.5	16	372	0.40	1.3	0.83	3.1
17.	CH-18	177	51	1400	0.75	9.5	41	1129	0.35	3.6	1.0	11.3
18.	CH-19	186	33	2207	0.65	12.9	59	2315	0.33	6.9	1.05	24.3
19.	CH-20	135	13	295	0.20	0.5	13	245	0.65	1.4	0.95	2.3
20	CH-21	186	28	1262	0.45	5.1	50	1320	0.60	7.1	0.75	9.9
21.	CH-22	176	36	520	0.20	0.9	53	785	0.65	4.6	0.75	5.10
22.	CH-23	190	48	1880	0.60	10.2	52	1630	0.35	5.1	1.14	22.8
23.	CH-24	153	31	470	0.65	2.8	33	1070	0.30	2.9	0.75	8.0
24.	CH-25	97	7	110	0.67	0.7	2	102	0.66	0.6	0.33	0.3
25.	CH-26	159	32	1400	0.75	9.5	32	1070	0.45	4.3	0.95	10.2
26.	CH-27	180	58	2550	0.30	6.9	56	1475	1.05	13.9	0.85	12.5
27.	CH-28	100	28	402	0.55	2.0	12	525	0.36	1.7	1.15	6.0
28.	CH-29	183	29	1415	0.70	8.9	29	1010	0.05	3.2	0.87	8.8
29.	CH-30	123	18	210	0.60	1.1	26	358	0.56	1.8	1.49	5.3
30.	CH-31	110	8	165	0.70	1.0	6	193	0.32	0.6	0.62	1.2
31.	CH-32	147	13	185	0.40	0.7	12	239	0.96	2.1	1.55	3.7
32.	CH-33	112	22	232	0.60	1.3	25	586	0.66	3.5	0.83	4.9
33.	CH-34	105	18	170	0.60	0.9	16	406	0.37	1.4	1.07	4.3
34.	CH-36	100	5	63	0.72	0.4	8	122	0.36	0.4	1.2	1.5
35.	CH-38	148	4	45	0.20	0.1	2	45	0.66	0.3	0.9	0.4
36.	CH-39	88	4	35	0.40	0.13	32	300	0.80	2.2	1.60	4.8
37.	CH-40	127	5	105	0.24	0.2	6	77	0.50	0.3	0.35	0.3
38.	CH-42	172	14	400	0.15	0.5	26	475	0.76	3.3	0.38	1.8
39.	CH-43	115	7	118	0.50	0.5	22	206	0.80	1.5	0.51	1.1
40.	CH-45	200	17	1025	0.25	2.3	27	700	1.00	6.3	1.11	7.8
41.	CH-46	117	7	162	0.65	1.0	3	185	0.36	0.6	0.63	1.2
42.	CH-47	146	3	90	0.20	0.2	9	157	0.79	1.1	0.58	0.9
43.	CH-49	167	29	450	0.15	0.6	67	968	0.30	2.6	0.49	4.7

Table 1 contd ...

1	2	3	4	5	6	7	8	9	10	11	12	13
44.	CH-50	121	17	125	0.83	0.9	7	121	0.54	0.6	0.88	1.1
45.	CH-52	146	3	75	0.21	0.2	7	90	0.48	0.4	0.50	0.5
46.	CH-53	100	7	45	0.63	0.3	1	45	1.09	0.4	0.95	0.4
47.	CH-55	175	24	316	0.15	0.4	25	452	0.45	1.8	0.35	1.6
48.	CH-57	177	24	560	0.20	1.0	44	996	0.48	4.3	0.47	4.7
49.	CH-58	180	12	540	0.60	2.9	20	460	1.4	5.8	1.12	5.1
50.	CH-59	153	28	460	0.55	2.3	22	440	0.78	3.1	0.34	1.5
51.	CH-60	157	6	135	0.15	0.2	19	403	0.20	0.7	0.51	2.1
52.	CH-61	152	19	547	0.50	2.5	57	720	0.53	3.4	0.33	2.4
53.	CH-62	131	8	150	0.77	1.0	9	202	0.34	0.6	0.83	1.7
54.	CH-63	137	16	274	0.60	1.5	19	274	0.65	1.6	0.34	0.9
55.	CH-64	92	28	840	0.32	2.4	23	330	0.90	2.7	1.19	3.9
56.	CH-65	175	39	2380	0.55	11.8	64	1845	1.20	19.9	0.77	14.2
57.	CH-66	200	85	4300	0.40	15.5	129	1870	1.08	18.2	0.58	10.9
58.	CH-67	150	9	295	0.35	0.9	21	411	0.40	1.5	0.69	2.8
59.	CH-68	110	8	210	0.50	1.0	36	676	0.43	2.6	0.72	4.9
60.	CH-69	130	12	98	0.55	0.5	10	224	0.56	1.1	0.80	1.8
61.	CH-70	172	36	3230	0.45	13.1	49	1670	1.00	15.0	0.67	11.2
62.	CH-71	121	16	420	0.40	1.5	39	715	0.63	4.1	0.71	5.1
63.	CH-72	142	12	281	0.75	1.9	35	457	0.68	2.8	0.55	2.5
64.	CH-73	192	19	3160	0.55	15.6	65	1750	1.08	17.0	0.68	11.9
65.	CH-74	182	28	970	0.47	4.1	45	775	0.98	6.8	0.68	5.3
66.	CH-75	195	8	1420	0.15	1.9	75	1495	0.65	8.8	0.78	11.7
67.	CH-76	151	4	375	0.50	1.7	50	763	0.65	4.5	0.43	3.3
68.	CH-78	132	2	58	0.20	0.1	12	96	0.41	0.6	0.56	0.5
69.	CH-79	132	4	15	0.57	0.1	23	282	0.91	1.0	0.44	1.2
70.	CH-80	127	9	90	0.40	0.3	3	74	0.91	0.6	0.80	0.6
71.	CH-82	130	10	171	0.55	0.9	16	225	0.95	1.9	0.54	1.2
72.	CH-83	157	7	125	0.20	0.2	12	114	0.53	0.5	1.09	1.2
73.	CH-85	104	16	65	0.33	0.2	12	102	0.13	0.1	0.90	0.9
74.	CH-86	100	7	70	0.62	0.4	2	62	1.00	0.6	0.84	0.5
75.	CH-87	159	21	905	0.25	2.0	43	1163	0.23	2.4	0.94	10.9
76.	CH-88	111	7	170	0.50	0.8	6	147	0.57	0.8	0.89	1.3
77.	CH-90	132	7	39	0.16	0.1	7	77	0.83	0.6	0.80	0.6
78.	CH-91	155	5	162	0.50	0.7	21	303	0.7	1.9	1.01	3.1
79.	CH-93	123	45	192	0.80	1.4	19	236	0.3	0.6	1.04	2.5
80.	CH-95	87	26	39	0.60	0.2	1	21	0.38	0.1	0.92	0.2
81.	CH-97	94	4	51	0.60	0.3	6	51	0.63	0.3	0.74	0.4
82.	CH-99	200	6	305	0.15	1.2	13	604	0.08	0.4	0.98	5.9
83.	CH-103	205	34	3310	0.37	11.0	101	2380	0.73	15.6	0.80	19.0
84.	CH-104	167	8	490	0.40	1.8	55	490	0.60	2.7	0.80	3.9
	Range											
	Min	87	2	15	0.05	0.1	1	21	0.05	0.1	0.33	0.2
	Max	205	85	4300	0.83	28.0	129	3550	1.40	19.9	1.55	31.0
	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 accessions of turmeric *Curcuma longa*

S.No.	Accession	% terpenoid							
		α-pinene	γ-terpinene	1,8-cineole	ρ-cymene	Ar-curcumene	Ar-turmerone	α-turmerone	ß-turmerone
1	2	3	4	5	6	7	8	9	10
1.	CH-1	3.22	2.29	26.46	25.98	3.58	3.38	4.99	1.69
2.	CH-2	2.70	1.18	4.13	0.10	1.55	3.14	1.90	0.85
3.	CH-3	1.00	1.79	10.51	27.20	6.04	0.01	0.83	4.00
4.	CH-4	2.11	3.36	10.15	11.96	2.18	2.59	0.51	1.19
5.	CH-5	2.00	11.27	13.21	23.45	3.60	7.28	0.76	2.95
6.	CH-6	1.80	6.00	0.01	31.25	4.84	9.19	1.95	3.80
7.	CH-8	1.59	32.97	5.12	7.03	1.56	2.38	2.44	3.75
8.	CH-9	1.37	2.65	11.39	30.08	6.07	9.47	2.25	4.33
9.	CH-10	1.37	3.88	11.43	29.13	5.77	9.88	2.14	4.39
10.	CH-11	1.33	3.06	9.57	27.61	5.81	8.62	2.57	4.80
11.	CH-12	1.53	3.73	12.09	32.01	4.92	8.22	1.73	2.90
12.	CH-13	1.89	45.53	8.29	9.06	0.64	2.20	0.39	1.28
13.	CH-14	1.27	2.71	13.27	29.14	6.15	10.37	2.60	5.19
14.	CH-15	0.01	18.45	6.38	14.14	0.01	0.01	4.08	8.95
15.	CH-16	1.55	3.39	11.38	29.00	4.81	7.22	0.65	2.98
16.	CH-17	1.48	5.61	9.77	28.46	4.63	9.51	2.37	4.46
17.	CH-18	1.49	5.37	9.48	29.08	4.08	8.09	1.95	4.38
18.	CH-19	1.65	4.04	11.39	31.16	4.95	7.92	0.37	2.86
19.	CH-20	2.31	9.18	20.66	30.13	0.32	3.67	1.09	4.01
20	CH-21	1.49	2.92	15.92	28.30	5.25	9.18	1.85	3.78
21.	CH-22	3.38	3.11	30.81	19.54	2.20	3.03	1.53	5.69
22.	CH-23	1.71	40.96	11.91	11.56	1.44	2.73	0.60	0.70
23.	CH-24	1.58	3.51	9.75	27.38	5.19	8.38	2.64	4.73
24.	CH-25	2.25	27.30	14.54	9.31	1.80	5.93	0.76	2.88
25.	CH-26	1.31	3.23	9.00	24.40	4.10	8.68	2.30	4.41
26.	CH-27	0.38	0.84	12.27	15.81	5.27	7.17	1.75	4.75
27.	CH-28	1.12	2.70	14.91	26.81	4.13	9.65	1.19	3.64
28.	CH-29	1.71	3.60	12.82	32.33	5.20	8.09	0.34	2.96
29.	CH-30	1.97	2.80	14.92	27.91	6.35	8.91	1.82	3.52
30.	CH-31	1.01	1.80	11.04	25.77	5.72	10.87	0.77	4.22
31.	CH-32	1.37	2.30	13.95	18.37	1.27	8.97	2.83	4.43
32.	CH-33	1.32	2.64	13.09	23.85	4.63	9.01	2.53	3.77
33.	CH-34	1.65	4.44	12.23	32.37	4.71	9.85	0.50	3.54
34.	CH-36	2.11	56.94	8.70	10.88	0.67	0.96	0.38	0.11
35.	CH-38	3.60	10.40	24.69	28.68	1.81	0.01	3.49	0.01
36.	CH-39	0.68	5.41	9.93	33.07	17.38	0.44	0.41	0.51
37.	CH-40	3.60	18.40	24.69	28.68	0.01	0.01	3.49	0.01
38.	CH-42	1.78	5.97	23.10	4.38	8.26	1.39	5.01	2.99
39.	CH-43	1.48	3.91	17.61	30.24	3.76	8.43	1.53	2.47
40.	CH-45	1.97	1.42	27.14	2.19	5.70	1.70	4.80	9.13
41.	CH-46	1.31	2.88	13.70	27.83	5.65	9.90	2.14	4.43
42.	CH-47	3.02	2.15	28.74	5.22	1.20	3.73	1.41	1.34

Table 2 contd ...

1	2	3	4	5	6	7	8	9	10
43.	CH-49	3.57	3.16	34.86	18.02	0.42	2.66	0.91	0.04
44.	CH-50	2.05	58.65	8.69	10.82	0.55	2.19	1.23	0.35
45.	CH-52	3.75	2.48	24.87	15.82	6.70	3.42	5.78	1.78
46.	CH-53	0.36	3.38	8.01	78.09	0.01	0.01	0.01	0.01
47.	CH-55	2.74	7.98	26.52	25.71	0.36	1.79	1.38	0.42
48.	CH-57	2.59	2.51	26.50	23.73	5.29	1.24	4.04	0.90
49.	CH-58	1.09	3.45	13.10	14.81	2.54	4.98	1.22	2.57
50.	CH-59	1.10	11.02	13.48	17.48	2.63	5.86	1.40	1.98
51.	CH-60	2.54	2.77	31.91	2.88	7.93	1.09	4.95	1.88
52.	CH-61	0.86	2.64	2.16	26.70	3.72	8.07	2.04	3.60
53.	CH-62	2.24	52.81	10.63	11.62	0.79	1.54	0.34	0.28
54.	CH-63	0.81	2.20	10.45	21.40	3.63	7.97	2.45	3.80
55.	CH-64	1.15	13.38	2.41	15.60	1.88	0.25	4.84	1.11
56.	CH-65	1.30	3.59	16.16	29.53	3.75	8.16	1.68	3.01
57.	CH-66	1.03	3.22	15.44	27.84	4.78	8.16	1.96	3.92
58.	CH-67	1.12	28.05	14.79	17.45	1.49	5.01	1.00	1.88
59.	CH-68	0.72	1.96	15.60	24.58	3.99	8.05	1.55	3.34
60.	CH-69	2.08	25.51	13.99	9.50	1.83	5.65	1.01	2.52
61.	CH-70	0.96	3.55	15.29	27.55	4.86	9.48	2.02	4.85
62.	CH-71	0.88	32.78	13.11	8.74	1.53	3.07	0.92	0.66
63.	CH-72	0.94	2.75	2.17	25.80	4.00	8.02	1.89	3.23
64.	CH-73	1.77	3.68	2.92	11.07	1.23	3.48	0.66	0.52
65.	CH-74	3.13	2.83	12.26	26.50	4.37	8.21	1.72	3.38
66.	CH-75	1.56	4.58	29.77	11.57	5.32	3.52	5.28	1.84
67.	CH-76	0.28	2.77	21.29	20.52	2.55	6.60	1.56	2.93
68.	CH-78	3.73	2.53	35.50	2.69	0.71	3.15	4.68	1.71
69.	CH-79	3.73	15.66	12.54	29.48	3.04	4.12	0.84	1.47
70.	CH-80	2.59	39.09	18.91	10.74	2.07	2.67	0.42	0.79
71.	CH-82	0.54	1.44	12.81	0.01	3.84	7.57	1.49	2.08
72.	CH-83	3.55	6.84	22.66	17.28	5.83	3.35	3.61	1.55
73.	CH-85	2.31	56.99	8.65	11.31	0.74	1.10	0.20	0.23
74.	CH-86	2.99	37.21	10.22	10.25	1.95	2.96	0.48	0.80
75.	CH-87	1.56	3.60	12.47	29.92	4.64	7.19	1.37	3.30
76.	CH-88	1.57	8.53	14.37	28.38	4.03	6.66	0.92	2.69
77.	CH-90	3.14	15.51	23.71	24.75	2.59	2.87	3.41	1.47
78.	CH-91	0.83	38.85	12.20	21.50	0.76	2.36	1.19	0.26
79.	CH-93	2.53	35.15	11.21	12.06	1.66	2.82	0.41	0.67
80.	CH-95	2.78	3.31	10.45	9.06	2.65	3.52	0.60	1.19
81.	CH-97	2.45	62.82	8.53	11.07	0.23	0.59	0.15	0.07
82.	CH-99	1.55	3.45	2.15	31.43	5.09	8.44	1.95	3.65
83.	CH-103	2.12	2.87	19.21	29.08	4.12	6.95	0.82	2.92
84.	CH-104	1.03	2.74	16.05	27.49	4.59	8.90	2.11	4.36
	Range								
	Min	0.01	0.84	0.01	0.01	0.01	0.01	0.01	0.01
	Max	3.75	62.82	35.50	78.09	17.38	10.87	5.78	9.13
	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 accessions of turmeric *Curcuma longa*

S.No.	Accession	% terpenoid											
		α-pinene	β-pinene	Myrcene	1,8-cineole	g-terpinene	p-cymene	linalool	Ar-curcumene	zingiberene	Ar-turmerone	α-turmerone	β-turmerone
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	CH-1	0.20	6.38	0.01	2.86	0.70	0.47	1.18	2.16	2.29	5.59	7.96	5.18
2.	CH-2	2.98	0.38	0.94	0.01	0.01	0.01	1.48	1.69	2.84	3.80	8.34	4.98
3.	CH-3	0.55	0.01	41.78	7.02	1.03	1.97	0.24	1.19	0.95	7.51	9.55	5.07
4.	CH-4	0.01	0.01	45.67	9.57	1.20	1.68	0.23	1.35	0.82	5.25	7.70	4.22
5.	CH-5	0.32	14.13	2.13	0.04	0.01	0.17	1.08	4.08	1.93	36.68	13.45	4.81
6.	CH-6	0.60	0.01	20.91	3.46	0.43	0.55	0.28	1.71	1.24	10.86	14.41	5.94
7.	CH-8	0.49	20.01	2.38	0.41	0.45	0.21	0.31	1.99	1.23	14.11	15.83	6.62
8.	CH-9	1.01	32.96	0.01	7.72	0.95	1.61	0.40	1.10	1.66	5.77	10.81	6.91
9.	CH-10	1.42	41.67	9.08	0.92	8.80	0.01	0.22	0.96	0.77	16.22	7.87	5.67
10.	CH-11	1.17	45.05	7.70	1.10	1.92	1.70	0.32	1.33	0.92	21.30	8.51	3.80
11.	CH-12	0.88	20.80	5.53	0.31	7.06	0.01	0.31	1.13	0.13	6.67	13.83	11.97
12.	CH-13	0.33	10.98	0.01	4.36	8.66	0.01	0.29	0.30	1.21	18.96	15.01	19.52
13.	CH-14	5.93	0.01	0.01	0.01	0.01	0.01	1.42	0.91	0.01	32.22	19.49	16.95
14.	CH-15	1.26	40.20	0.01	6.74	1.05	2.18	0.22	1.15	0.83	7.35	9.57	4.88
15.	CH-16	0.43	14.47	0.01	5.08	0.75	0.89	0.25	1.40	0.98	6.94	11.65	4.96
16.	CH-17	0.01	13.62	0.01	5.20	12.80	0.01	0.37	0.17	1.25	14.04	13.25	18.59
17.	CH-18	0.80	33.61	4.84	1.03	2.27	1.53	1.55	1.41	1.06	15.76	8.19	4.53
18.	CH-19	0.36	28.04	8.17	0.56	11.42	0.01	0.25	0.92	1.06	13.98	10.40	9.65
19.	CH-20	0.05	0.79	0.01	0.01	0.01	0.34	6.24	12.30	8.26	12.98	2.99	2.94
20	CH-21	0.38	12.91	1.44	0.22	0.60	0.40	0.35	2.21	1.78	7.20	3.34	5.65
21.	CH-22	0.05	0.01	0.01	1.41	0.01	0.33	8.03	12.88	7.75	5.42	2.41	2.63
22.	CH-23	0.93	27.34	5.19	0.67	1.00	0.92	0.29	1.60	1.21	26.68	8.22	6.54
23.	CH-24	0.75	22.24	3.93	0.48	0.89	0.56	0.29	1.83	1.44	6.35	8.45	4.82
24.	CH-25	0.01	3.60	0.31	0.01	0.01	0.04	3.16	6.22	4.31	33.36	6.08	4.62
25.	CH-26	1.03	32.64	4.16	0.72	1.54	1.18	0.32	1.79	1.42	9.19	11.97	5.64
26.	CH-27	2.27	7.21	2.57	0.01	0.52	0.37	2.01	3.18	2.88	4.82	2.75	3.36
27.	CH-28	0.28	16.52	3.22	0.01	0.45	0.67	0.26	1.50	1.02	5.96	7.79	3.39
28.	CH-29	0.57	20.45	2.77	0.55	0.84	0.64	0.35	2.07	1.66	5.11	3.73	2.83
29.	CH-30	0.57	20.73	4.00	0.50	0.95	1.25	0.36	2.54	1.82	7.00	8.70	7.18
30.	CH-31	0.28	13.76	0.01	3.16	0.42	0.63	0.11	1.90	1.17	5.87	4.06	3.83
31.	CH-32	0.01	1.16	1.03	0.01	0.01	0.12	5.85	9.58	6.13	24.90	7.70	3.59
32.	CH-33	0.01	0.01	0.01	0.38	0.01	0.01	6.79	12.83	7.87	21.94	5.96	3.02
33.	CH-34	0.01	11.39	1.46	0.01	0.01	0.01	0.30	1.94	1.42	11.78	18.23	7.64
34.	CH-36	0.19	4.72	1.67	1.98	0.57	2.55	0.59	0.45	0.93	17.18	19.11	15.96
35.	CH-38	0.01	0.01	0.65	0.01	0.01	2.07	0.80	7.83	7.46	4.44	6.68	4.64
36.	CH-39	0.01	0.01	0.01	0.66	0.01	4.54	2.94	5.02	4.86	6.95	5.19	8.64
37.	CH-40	0.01	0.01	0.01	4.44	0.01	0.01	6.18	3.27	6.20	4.07	4.01	16.69
38.	CH-42	0.34	18.23	3.24	0.32	0.14	0.01	0.72	34.83	2.30	5.84	8.05	6.64
39.	CH-43	0.14	4.64	5.30	0.18	1.05	0.86	1.83	2.70	2.39	4.04	1.22	2.67
40.	CH-45	0.02	0.01	2.50	0.01	0.01	1.10	7.42	10.52	6.54	2.65	3.91	1.51
41.	CH-46	0.46	19.23	3.73	0.01	0.47	0.76	0.02	1.77	1.83	5.48	4.13	3.81

Table 3 contd ...

1	2	3	4	5	6	7	8	9	10	11	12	13	14
42.	CH-47	0.07	1.05	0.01	0.01	0.01	0.50	6.89	11.29	7.07	19.64	5.52	3.38
43.	CH-49	0.08	2.68	0.01	0.01	0.01	0.26	4.94	6.41	5.10	18.07	6.93	6.10
44.	CH-50	0.01	3.14	0.78	0.85	0.01	0.01	0.26	0.77	2.10	2.07	4.44	8.01
45.	CH-52	0.01	7.61	0.01	0.01	0.01	1.70	5.57	8.23	6.66	13.07	4.64	3.69
46.	CH-53	2.54	0.01	0.16	0.01	0.01	7.22	0.35	3.13	4.18	5.28	6.51	5.50
47.	CH-55	0.01	0.85	0.01	0.01	0.01	0.01	6.52	10.92	6.49	8.91	4.49	2.94
48.	CH-57	0.01	0.10	0.01	0.68	0.01	0.01	4.07	11.56	5.39	22.92	7.45	4.68
49.	CH-58	0.01	0.01	0.01	0.07	0.01	2.62	3.73	8.46	6.24	12.67	14.29	4.84
50.	CH-59	0.15	5.13	2.35	0.01	0.01	0.01	1.01	2.74	1.49	14.46	13.52	5.01
51.	CH-60	0.01	0.01	0.01	0.42	0.01	0.01	2.48	9.19	4.59	20.32	10.57	7.91
52.	CH-61	0.68	18.95	7.39	0.29	1.71	1.06	2.23	2.75	2.31	9.01	8.85	4.26
53.	CH-62	0.07	22.95	0.01	5.96	0.53	1.37	0.18	1.94	1.23	6.34	13.04	4.50
54.	CH-63	0.25	8.14	0.01	4.98	0.02	0.23	0.13	2.16	1.50	35.84	13.24	8.84
55.	CH-64	0.43	1.56	0.01	0.01	0.01	10.10	3.22	21.03	14.38	5.95	6.01	1.55
56.	CH-65	0.17	0.01	6.78	2.33	0.33	0.14	2.05	2.97	2.83	6.33	12.82	4.15
57.	CH-66	0.16	4.86	1.18	0.01	0.01	0.01	1.83	2.85	2.72	7.25	13.34	3.86
58.	CH-67	4.44	0.01	0.01	0.01	0.01	0.01	0.20	2.56	8.94	7.15	7.62	6.96
59.	CH-68	0.01	6.60	4.12	0.01	0.01	0.03	0.02	2.71	2.02	39.37	13.76	8.86
60.	CH-69	0.03	4.43	0.75	0.01	0.01	0.01	1.21	3.01	2.80	5.74	6.56	5.37
61.	CH-70	0.01	9.47	0.01	3.40	0.01	0.10	1.67	2.12	2.28	10.08	12.42	5.05
62.	CH-71	0.03	12.76	9.46	0.18	1.04	0.59	1.30	0.70	1.54	8.12	11.11	4.01
63.	CH-72	0.22	5.83	2.89	0.09	0.69	0.40	1.47	2.57	2.33	4.46	1.17	4.34
64.	CH-73	0.01	13.08	0.01	5.22	0.01	0.58	1.89	2.55	2.39	8.47	11.21	4.03
65.	CH-74	0.01	0.01	3.78	0.14	0.51	0.01	0.37	5.82	6.52	6.45	5.02	7.49
66.	CH-75	0.01	0.01	1.43	0.01	0.01	0.01	5.89	7.36	6.03	18.74	6.71	0.73
67.	CH-76	0.27	7.85	4.72	0.43	0.01	0.01	1.28	1.88	2.06	8.67	12.96	5.48
68.	CH-78	0.31	0.37	0.01	5.55	0.01	0.72	4.96	3.99	6.37	12.80	6.60	8.76
69.	CH-79	0.01	0.01	29.54	4.54	0.75	2.93	0.20	1.34	1.31	6.08	12.39	10.56
70.	CH-80	0.32	0.01	0.84	1.79	0.01	7.39	0.79	0.13	1.76	4.20	4.94	20.82
71.	CH-82	0.09	5.13	3.68	0.01	0.41	0.11	1.31	1.84	2.04	18.27	14.28	5.24
72.	CH-83	0.38	4.04	0.01	0.01	0.01	0.33	5.14	4.33	7.58	3.32	7.46	2.12
73.	CH-85	0.06	0.79	4.57	0.01	10.17	0.01	0.01	1.34	2.36	4.10	12.57	34.28
74.	CH-86	0.01	0.01	1.67	0.01	4.35	0.01	2.41	2.04	1.70	17.93	1.88	2.46
75.	CH-87	0.85	25.36	4.54	0.54	1.02	0.13	0.19	1.48	1.05	10.29	13.85	7.77
76.	CH-88	0.30	22.25	4.39	0.67	2.80	1.38	0.37	1.89	1.13	5.79	13.06	5.33
77.	CH-90	0.01	0.01	0.01	0.59	0.01	0.01	4.69	2.55	5.32	4.26	4.29	9.41
78.	CH-91	0.19	0.01	4.46	3.01	0.01	0.44	1.16	1.89	2.40	29.00	13.98	12.91
79.	CH-93	0.57	14.75	3.48	0.32	4.57	1.38	0.39	1.14	0.71	3.69	4.74	7.64
80.	CH-95	0.01	0.01	0.01	1.68	0.01	5.28	0.01	0.14	1.81	10.70	1.69	2.53
81.	CH-97	1.26	0.38	0.01	1.08	0.01	0.01	0.77	0.21	1.92	13.01	7.35	16.10
82.	CH-99	2.73	0.01	0.01	5.15	0.01	0.01	0.25	2.29	2.71	0.01	0.01	0.01
83.	CH-103	0.01	0.01	1.00	0.01	0.01	0.18	6.29	10.51	6.99	15.31	3.79	2.73
84.	CH-104	0.07	7.68	3.69	0.01	0.01	0.10	0.30	2.92	1.88	12.67	12.91	6.95
	Range												
	Min	0.01	0.01	0.01	0.01	0.01	0.01	0.13	0.01	0.01	0.01	0.01	0.01
	Max	5.93	45.05	45.67	9.57	12.80	10.10	8.03	34.83	14.38	39.37	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

(b) Rhizome

The accessions 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 accessions. 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 accessions 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 84 accessions, respectively. CH-99 was the only accession in which all the three turmerones were present in very low concentrations. An accession designated as CH-14 had very low contents of β-pinene, myrcene, 1,8-cineole, γ-terpinene, ρ-cymene, and zingiberene. The concentrations of all the turmerones together varied from 0.03 to as 68.7%. Thus oils of the CH-14 and CH-99 were contrasting by containing 68.7% turmerones in the former and 0.03% in the latter.

(c) Recovery of Curcumin from Hydro-Distilled Rhizomes

The hydro-distilled rhizomes of all the accessions were extracted for curcumin. The curcumin contents of the fresh and hydro-distilled rhizomes were compared accession wise. The results presented in Table 5 show that curcumin is extractable from the hydro-distilled rhizomes to different extents in different accessions. Whereas in rhizomes of many accessions with ≤ 50% of curcumin present in fresh rhizomes was extractable from hydro-distilled rhizomes, in the other accessions such as CH-9 and CH-39, bulk of the curcumin (≥ 80%) that was present

Table 4: Coefficients of correlation between character pairs in turmeric *Curcuma longa*

S.No.	Character	Leaf mass (g)	Leaf oil yield (g)	Rhizome mass (g)	Rhizome oil yield (g)	Curcumin yield (g)
1.	Plant height (cm)	0.62**[a]	0.48**	0.64**	0.60**	0.58**
2.	Leaf mass (g)	0.91**	0.92**	0.87**	0.86**	
3.	Leaf oil yield (g)		0.87**	0.70**	0.87**	
4.	Rhizome mass (g)			0.76**	0.96**	
5.	Rhizome oil yield (g)			0.66**		

a = **, significant at P= 0.01

in the fresh rhizomes was extractable from the hydro-distilled rhizome counterparts.

(d) Identification of Accessions for High Curcumin and Leaf Oil Yields

In Fig. 2, the accessions 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 accessions CH-6, CH-11, CH-12 and CH-19 as high yielding resources for curcumin on the one hand and leaf oil on the other hand. The leaf oils of these accessions were relatively rich in ρ-cymene, pinene(s) and turmerones.

4. Discussion

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 accessions. This is commensurate with the belief that *C. longa* was domesticated into a crop in the Asian region, more particularly in India.

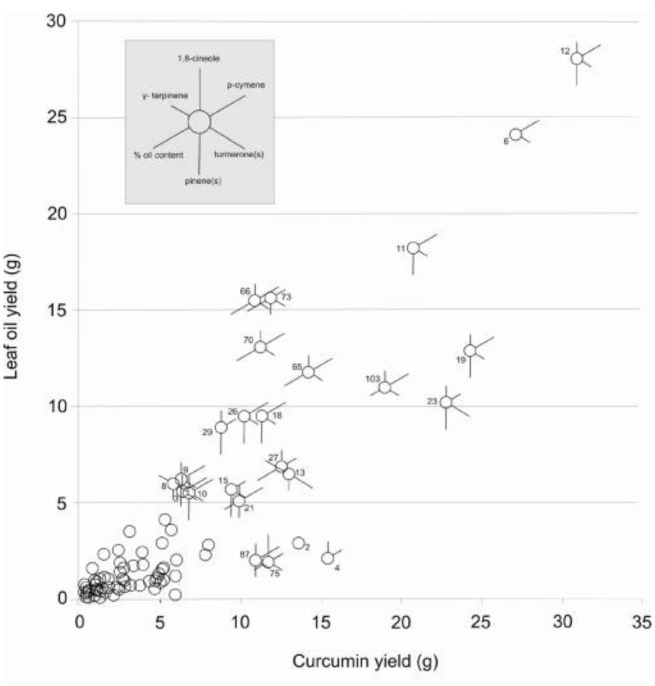

Fig. 2: Accessions of turmeric *Curcuma longa* represented as metroglyphs depicting accession wise variation in chemical characteristics of rhizomes and leaves

In an earlier study, *C. longa* cv. Roma which is cultivated widely in northern India was characterized for the yields of rhizomes and leaves and their essential oils (Bansal *et al.* 2002). Several accessions 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 accessions yielded rhizomes in more than 1 kg quantity per plant. In the present experiment, the yield of rhizomes in cv Roma (CH-66) was 1.9 kg. Six accessions namely CH-2, CH-6, CH-11, CH-12, CH-19 and CH-103 gave rhizome yield of $\geq$2 kg/plant. Among these the accession CH-12 gave a rhizome yield of 3.5kg/plant. The accession CH-12 produced 4.1 kg leaf biomass per plant which is marginally less than 4.3 kg biomass produced by plants of CH-66 (cv Roma). However, the accession CH-66 proved superior to accession CH-12 in terms rhizome oil yield (18.2 g/plant for CH-66 (cv Roma) vs 9.6 g/plant for CH-12, but inferior to accession CH-12 in leaf oil yield (15.5 g/plant vs 28.0 g/plant in CH-12) and curcumin yield from the rhizome (10.9 g/plant vs 31.0 g/plant for CH-12). Some other accessions recorded roughly similar yields of essential oils from leaves and rhizomes, e.g. CH-73 (15.6 g from leaves vs 17.0 g oil from rhizomes). Although the correlation coefficients in the 84 accessions 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 accessions 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.

Table 5: Relationship between curcumin content in fresh rhizomes and corresponding content in rhizomes distilled for essential oil

% content in rhizomes distilled for essential oil	% Content in rhizomes			
	<0.50	0.51-0.75	0.76-1.00	>1.00
<0.20	CH 25, CH 57, CH 59	CH 14, CH 22, CH 66, CH 70	CH 3, CH 18, CH 29, CH 33, CH 62, CH 65, CH 69	CH 45, CH 58, CH 64
0.21-0.60	CH 49	CH 47, CH 60 CH 71, CH 72	CH20	
0.61-0.80		CH 9		
>0.81				CH 39

The leaf and rhizome essential oils of different accessions demonstrated large variability in their terpenoid composition. There were several accessions 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 accessions could be called as chemotypes of the concerned terpenoid component. The accessions CH-3 and CH-4 would thus be termed as myrcene chemotypes because their rhizome essential oils contained 41.8 and 45.7% myrcene, respectively. The accessions CH-9, CH-10, CH-11, CH-15 and CH-26 produced rhizome essential oils that were richer than 30% in β-pinene, making them β-pinene chemotypes. The accession CH-42 was a Ar-curcumene chemotype as its rhizome oil contained Ar-curcumene @ 35%. The accessions CH-5, CH-14 and CH-68 proved to be Ar-turmerone chemotypes. The CH-5, CH-6, CH-8, CH-11, CH-12, CH-13, CH-14, CH-17, CH-19, CH-23, CH-25, CH-32, CH-33, CH-34, CH-36, CH-57, CH-59, CH-60, CH-63, CH-68, CH-82, CH-85, CH-87, CH-91, CH-97 and CH-104 were accessions which could be termed as turmerone(s) rich chemotypes because their rhizome essential oils contained Ar-, α-, and β-turmerone in $\geq$30% contents. Generally, the turmerones comprised a marker of turmeric essential oils. Surprisingly, the turmerone content in the rhizome essential oils of CH-99 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 accession. 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 accessions studied, however, there are some accessions, e.g. CH-2, CH-27, CH-43, CH-90, CH-95 and CH-99 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 accessions contained curcumin though to different extents. The curcumin content of the rhizome was as low as 0.3% in the accession CH-25 and four times in the accessions CH-64; it was 1.5% in CH-32. Although the rhizome essential oil of accession CH-99 was deficient in turmerones, yet it was rich in curcumin at 1% concentration. It emerges that presence of turmerone and/or curcumin should be taken as characteristic(s) of the turmeric rhizomes of *C. longa.*

The richness of specific terpenoids in the leaf essential oil could also be the criteria for identification of chemotypes among accessions. In this regard, the accessions CH-8, CH-13, CH-23, CH-36, CH-50, CH-62, CH-71, CH-80, CH-85, CH-86, CH-91, CH-93 and CH-97 appeared as γ-terpinene chemotypes since their leaf essential oil contained concerned compound γ-terpinene in 32.8 to 62.8% concentrations. The accessions CH-49 and CH-78 proved to be 1,8-cineole chemotypes because their leaf essential oil contained 1,8-cineole in 34.9% and 35.5% concentrations, respectively. The accessions CH-9, CH-12, CH-19, CH-20, CH-29, CH-34, CH-43, CH-53, CH-79 and CH-99 were identified as ρ-cymene chemotypes. The leaf essential oil of accession CH-53 had 78% ρ-cymene concentration and was deficient in Ar-curcumene and turmerones. Contrastingly the leaf essential oil of CH-2 was deficient in ρ-cymene, although it contained the other terpenoid components listed as major components. The leaf essential oils of most the accessions were relatively richer in ρ-cymene. On the basis of the profiles of leaf essential oil of 84 accessions, it is concluded that ρ-cymene, 1,8-cineole and γ-terpinene are the principal components that define the quality of leaf oil.

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 accessions. The accessions CH-39 and CH-9 proved to be amenable for the dual production from the rhizome.

5. Concluding Remarks

Following is the outcome in the form of new knowledge and materials from the evaluation of 84 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 turmerone chemotypes for their high concentrations in the rhizomes essential oil.

There are accessions 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.

6. Acknowledgements

Grateful thanks are due to the Council of Scientific and Industrial Research, New Delhi for grant of Emeritus Scientist Scheme. Thanks are also due to the Indian National Science Academy, New Delhi for a Senior Scientist Scheme to Professor Sushil Kumar.

References

Bansal R P, Bahl J R, Garg S N, Naqvi A A and Kumar S Differential chemical composition of the essential oil of the shoot organs, rhizomes and rhizoids in the turmeric *Curcuma longa* L. grown in Indo-Gangetic plains *Pharma Biol* **40** (2002) 384-389

Bhutani M K, Bishnoi M and Kulkarni S K Anti-depressant like effect of curcumin and its combination with piperine in unpredictable chronic stress-induced behavioural, biochemical and neurochemical changes *Pharma Biochem Behav* **92** (2009) 39-43

Dixit D, Srivastava N K and Kumar R Intraspecific variation in yield capacity of turmeric *Curcuma longa* with respect to metabolic translocation and partitioning of ^{14}C photoassimilate into essential oil and curcumin *J Med and Arom Pl Sci* **22/23** (2000) 269-274

Garg S N, Bansal R P, Gupta M M and Kumar S Variation in the rhizome essential oil and curcumin contents and oil quality in the land races of turmeric *Curcuma longa* of north Indian plains *Flav Fragr J* **14** (1999) 315-318

Gupta A P, Gupta M M and Kumar S Simultaneous determination of curcuminoids in *Curcuma* samples using high performance thin layer chromatography *J Liq Chromed and Rel Technol* **22** (1999) 1561-1569

Jang E, Choi M, Jung U J, Kim M, Kim H, Jeon S, Shin S, Seong C and Lee M Beneficial effects of curcumin on hyperlipidemia and insulin resistance in high-fat-fed hamsters *Metabolism* **57** (2008) 1576-1583

Jantan I B, Ahmad A S, Ali N A M, Ahmad A R and Ibrahim H Chemical composition of the rhizome oils of four *Curcuma* species from Malaysia *J Essen Oil Res* **11** (1999) 719-723

Khanna N M Turmeric-Nature's precious gift *Curr Sci* **76** (1999) 1351-1356

Kunnumakkara A B, Anand P and Aggarwal B B Curcumin inhibits proliferation, invasion, angiogenesis and metastasis of different cancers through interaction with multiple cell signaling proteins *Cancer Lett* **269** (2008) 199-225

Liang G, Shao L, Wang Y, Zhao C, Chu Y, Xiao J, Zhao Y, Li X and Yang S Exploration and synthesis of curcumin analogues with improved structural stability both *in vitro* and *in vivo* as cytotoxic agents *Bioorg Med Chem* **17** (2009) 2623-2631

Lin S, Huang H, Yang J, Wu J, Hsai T, Lin C, Lin C, Kuo C, Wood W G and Chung J DNA damage and endoplasmic reticulum stress meditated curcumin-induced cell cycle arrest and apoptosis in human lung carcinoma A-549 cells through the activation caspases cascade- and mitochondrial-dependent pathway *Cancer Lett* **272** (2008) 77-90

Marongiu B, Poreedda S, Caredda A, Gioannis B D and Piras A Supercritical CO_2 extraction of curcumin and essential oil from the rhizomes of turmeric (*Curcuma Longa* L.) *JEOBPS* **5** (2002) 144-153

Moon D, Kim M, Lee H, Choi Y H, Park Y, Heo M and Kim G Curcumin attenuates ovalbumin-induced airway inflammation by regulating nitric oxide *Biochem and Biophys Res Commun* **375** (2008) 275-279

Nandi A Genetic variability in turmeric (*Curcuma longa*) *Indian J Agril Sci* **61** (1991) 941-942

Nigam M C and Ahmed A *Curcuma longa*: Terpenoid composition of its essential oil *Indian Perfumer* **35** (1991) 255-257

Panigrahi U C, Patro G K and Mohanty G C Package of practices for turmeric cultivation in Orissa *Indian Farming* **37** (1987) 4-6

Paramasivam M, Poi R, Banerjee H and Bandyopadhyay A High performance thin layer chromatographic method for quantitative determination of curcuminoids in *Curcuma longa* germplasm *Food Chem* **113** (2009) 640-644

Pathana N K, Arya P S and Singh M Variability studies in turmeric (*Curcuma longa* L.) *Indian J Agril Res* **22** (1988) 176-178

Philip J and Nair P C S Morphological and yield characters of turmeric types *Indian Cocoa Arecanut Spices J* **6** (1983) 61-67

Pisano M, Cossu S, Sassu I, Pagnan G, Fabbri D, Dettori M A, Palmieri G, Delogu G, Ponzoni M and Rozzo C New curcumin analogues show enhanced antitumour activity in malignant melanoma cells *European J Cancer* **6** (2008) 90

Rama Rao M and Rao D V R (1994) Genetic resources of turmeric, In: Advances in Horticulture Plantation and Spice crops, Part 1 (Eds: Chanda KL and Rethinam P), pp 131-149, Malhotra Publication, New Delhi.

Randhawa G S and Mahey R K (1988) Advances in the agronomy and production of turmeric in India. In: Herbs, Spices and Medicinal Plants. Recent Advances in Botany, Horticulture and Pharmacology (Eds: Cracker LE and Simon JE) pp 71-101, Oryx, New York

Sharma R K, Mishra B P, Sarma T C, Bordoloi A K and Pathak M G Essential Oils of *Curcuma longa* L. from Bhutan *J Essen Oil Res* **9** (1997) 589-592

Srimal R C Turmeric: a brief review of medicinal properties. *Fitoterapia* **LXVIII** (1997) 483-493.