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Agroclimatic zone based metabolic profiling of turmeric (*Curcuma Longa* L.) for phytochemical yield optimization

I. Sriram Sandeep[a], Ananya Kuanar[a], Abdul Akbar[a], Basudeba Kar[a], Suryasnata Das[a], Antaryami Mishra[b], Parshuram Sial[c], Pradeep Kumar Naik[d], Sanghamitra Nayak[a], Sujata Mohanty[a,*]

[a] *Centre of Biotechnology, Siksha O Anusandhan University, Bhubaneswar, Odisha, India*
[b] *Department of soil science, OUAT, Bhubaneswar 751003, Odisha, India*
[c] *High Altitude Research Station, Pottangi, Koraput, 764039 Odisha, India*
[d] *Dept. of Biotechnology, Guru GhasidasVishwavidyalaya, A Central University, Koni, Bilaspur 495 009, Chhattisgarh, India*

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ABSTRACT

Curcuma longa L. belonging to the family Zingiberaceae is an important spice and medicinal plant. Despite an ever growing interest and commercial importance of curcumin and *Curcuma* essential oil, it is still not clear as to the nature and mode of influence the different soil and environmental factors have on the production and quality of curcumin, leaf and rhizome essential oil of this species. The present report deals with ‘Surama’, a high yielding turmeric cultivar that was cultivated at nine agroclimatic zones with an objective to analyse the effects the different soil and environmental parameters have on product optimization as well the quality of curcumin and essential oil contents. Variation in curcumin (1.5–5%), leaf (0.37–0.8%) and rhizome oil (0.45–0.7%) were recorded across all the zones. Gas chromatography mass spectrometry (GCMS) analysis of leaf and rhizome essential oil for different experimental zones showed wide variation in their quantity and quality. It was found that for curcumin content, most sensitive factors were; the altitude, soil pH, nitrogen and Potassium content. In contrast, the temperature and phosphorous content were found critical for leaf essential oil while, nitrogen, phosphorous and potassium contents were the key quantitative and qualitative determinants for rhizome essential oil. This study provides essential experimental data that could find effective use in yield optimization and managing varying environmental parameters of this important species for high and quality yield of curcumin, rhizome and leaf essential oil. Identification and critical analysis of sensitive/determinant agro-climatic factors are significant for commercial exploitation as well value addition of turmeric products especially with high alpha phellandrene and tumerone content.

1. Introduction

Turmeric (*Curcuma longa* L.*)* of the family Zingiberaceae is known worldwide for its multipurpose use in medicine, cosmetics, food flavour and textile industries. With regular cultivation, mainly in the states of Odisha, Andhra Pradesh, Tamil Nadu, Assam, Maharashtra and Kerala, India is world’s largest turmeric producer (94%) with about 78% share of world turmeric export (Nayak et al., 2006). Odisha is the second largest producer in India. Indian turmeric owing to its high curcumin content is of great demand in developed countries like U.S.A, U.K. and Japan (Muthusamy, 2013). It has been used for centuries as edible dye and in traditional medicines to treat numerous diseases (Anandaraj and Sudharshan, 2011; Sharma et al., 2005). The primary biologically active constituent and the principal curcuminoid of turmeric is the polyphenol curcumin(Prasad et al., 2014). Curcumin has potent anti-inflammatory (Gupta et al., 2012, 2013), anti carcinogenic (Frank et al., 2003) and antioxidant (Masuda et al., 1993) properties while, the essential oil and oleoresin of turmeric possess anti-microbial and wound healing (Srimal, 1994), hypoglycemic (Honda et al., 2006), paracitidal (Haddad et al., 2011) and larvicidal properties(Ajaiyeoba et al., 2008).

Biosynthesis and accumulation of plant secondary metabolites are largely influenced by various environmental and edaphic factors (Morison and Lawlor, 1999) as the secondary metabolites confer protections as well as adaptive advantage against

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* Corresponding author.
E-mail address: sujatamohantyils@gmail.com (S. Mohanty).

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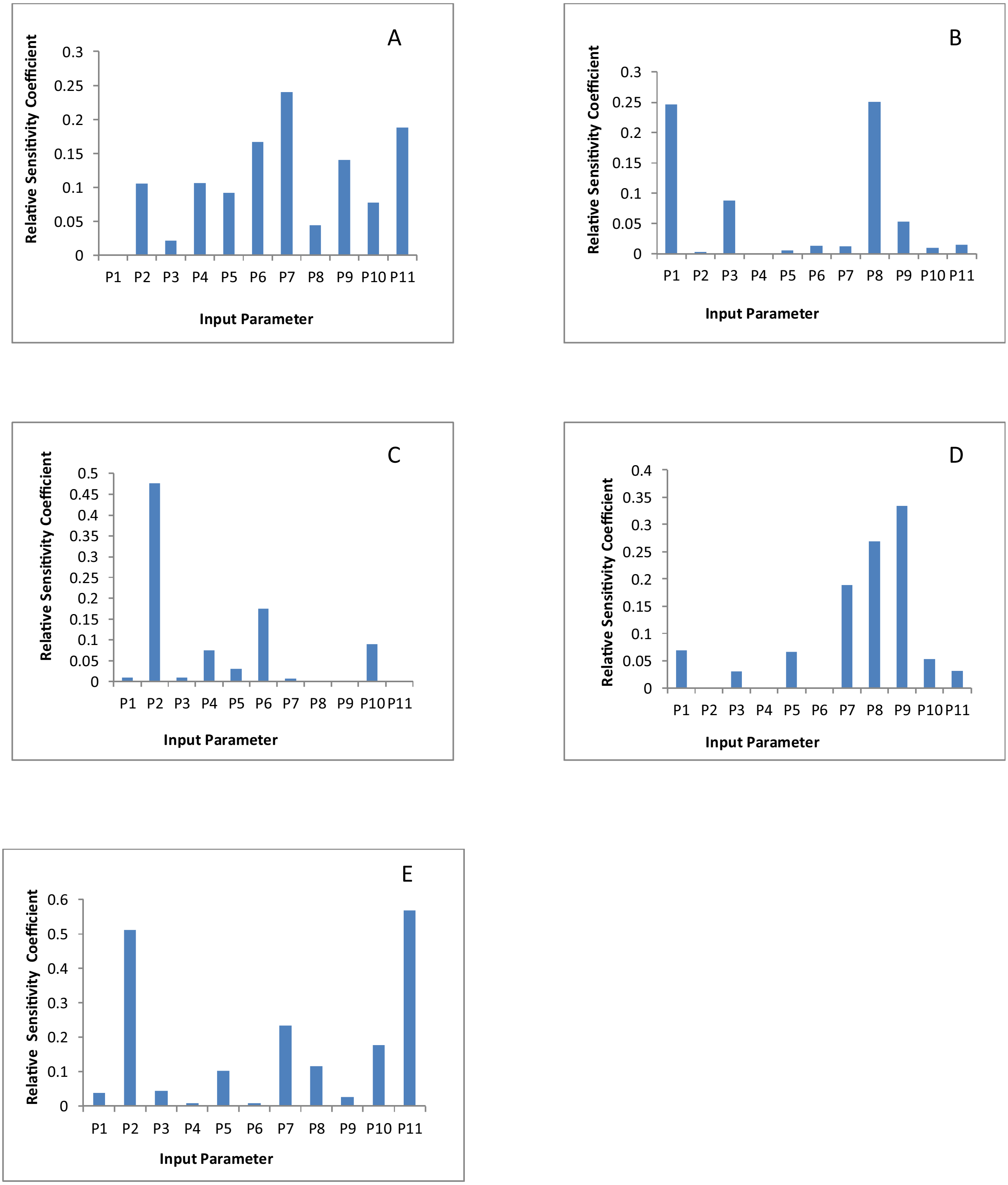

Fig. 1. (A) Relative Sensitivity Coefficient of different soil and environmental parameters for curcumin yield. (B) Relative Sensitivity Coefficient of different soil and environmental parameters for leaf essential oil yield**.** (C) Relative Sensitivity Coefficient of different soil and environmental parameters for alpha-phellandrene (leaf oil) content. (D) Relative Sensitivity Coefficient of different soil and environmental parameters for rhizome essential oil yield. (E) Relative Sensitivity Coefficient of different soil and environmental parameters for tumerone (rhizome oil) content.
P1—Max Temp, P2—Min Temp, P3—Max Humidity, P4—Min Humidity, P5—Avg Rainfall, P6—Altitude, P7—Nitrogen, P8—Phosphorous, P9—Potassium, P10—Organic Carbon, P11—pH.

environmental stresses. The major problem associated with turmeric cultivation in India is the high degree of variation in their phytoconstituents with varying agroclimatic zones (Mohanty, 1979; Rama Rao and Rao, 1994). The same cultivars grown in different agroclimatic zones yield differential percentage of curcumin, essential oil and oleoresin. This problem is more apparent when a high curcumin yielding cultivar is cultivated in places other than its place of origin where the curcumin percentage falls remarkably, thus affecting their commercial potential. Though there are several reports on prevalence of wide variation in phytoconstituents of turmeric (Philip and Nair, 1986; Pujari et al., 1987; Lee et al., 2014), reports on range of variation with regard to a particular genotype is very rare (Anandaraj et al., 2014). Detailed analyses of phytoconstituents of turmeric grown at different agroclimatic zones are not yet reported. Hence, the phytoconstituent percent in rhizome and leaf of a high yielding promising cultivar of turmeric need to be quantified by growing at different agroclimatic zones after release from their place of origin. Thus the present study was started with the cultivation of a high yielding turmeric cultivar "Surama" at nine different agroclimatic zones with the specific objective to study the effect of various soil and environment parameters on rhizome yield, curcumin and essential oil content. Further the differential variation in phytoconstituents (quantity and quality) were analysed to standardize the parameters for ensuring high curcumin and essential oil yield as well as to select suitable agroclimatic zones for large scale cultivation of these elite turmeric cultivars for yield optimization and possible value addition of desired secondary metabolites.

2. Materials and methods

2.1. Plant materials collection and plantation at different agroclimatic zones

'Surama', a high yielding turmeric variety released from High Altitude Research Station (HARS) Pottangi, Koraput, Odisha, which is a regular cultivar in the state as well as allover India was chosen for our experiment. Rhizomes were collected from HARS, Koraput during March–April (2011–2012) and were planted at nine different agro-climatic zones of Odisha such as East & South Eastern Coastal Plain, Mid Central Table Land, Eastern Ghat High Land, North Eastern Ghat, North Eastern Coastal Plain, North Central Plateau, Western Central Table Land, North Western Plateau and South Eastern Ghat. Field experiments were conducted across all the zones for analysis of rhizome yield, essential oil and curcumin content for three consecutive years (2011–2014). The study was conducted on private lands with due permission from the owners. The experimental fields containing 100 plants per cultivar were maintained by local farmers at all geographical areas for three successive years along with the information of environmental factors for all agroclimatic zones (Table 1).

2.2. Quantitative analysis of soil samples

The soil samples, collected in triplicate from all nine agroclimatic zones were air dried to a constant weight and then sieved through a 2-mm mesh. The fine soil particles were used for nutrient analysis. The pH and electrical conductivity (EC) was determined in 1:2 soils: water suspension after equilibration for 30 min with intermittent stirring. Organic carbon (OC) content was determined by Wet digestion procedure of Walkley and Black as outlined in soil chemical analysis (Jackson, 1973). Available nitrogen (N) was determined by using alkaline $KMnO_4$ method (Subbiah and Asija, 1956). Available potassium (K) was determined by NH_4OAc digestion and estimated by atomic flame photometer. Phosphorous (K) content was determined by Perchloric acid digestion (Olsen and Sommers, 1982).

2.3. Collection of leaf and rhizome samples for extraction of essential oil

In each cropping season, leaf and rhizome samples were collected from the cultivated fields for the extraction of essential oils. The essential oil from the leaves and rhizomes were extracted by hydrodistillation using Clevenger's apparatus (Guenther, 1972). For the extraction of leaf oil, fresh leaves were collected and were carefully washed and sliced in-to pieces. The sliced leaves (100 g) were taken in a flask to which distilled water is added. Then the flask was heated to 30–40° C and after 4–5 h the oil was collected in an eppendorf tube. Essential oil extraction from the harvested rhizomes was also carried out. The sliced pieces of rhizomes (100 g) were taken in the flask and heated to a temperature of 60–80° for 6–8 h after which the oil was collected.

2.4. Estimation of curcumin

The rhizome samples were collected during February-March from each agroclimatic zones for extraction of curcumin. The collected rhizomes were cleaned, cut in-to fine pieces and were allowed to dry for 4–5 days. The pieces were allowed to dry in a minimum of light for prevention of curcumin damage by light. After complete drying, the dried pieces were grinded using mortar and pestle to obtain the powder. Estimation of curcumin was done following the standard (American Spice Trade Association) ASTA method (Method no.1.09, 1997). The absorption maxima of curcumin was measured at 425 nm and was compared with 98% pure curcumin. The method was repeated three times and the mean value was recorded for data analysis.

2.5. GC–MS analysis of rhizome and leaf oil

GC and GC–MS analysis of leaf and rhizome essential oil of Surama was done each year in three replicates covering all the studied geographical zones. The component identification was achieved by the GC–MS analysis using HP 6890 series GC (Hewlett-Packard, USA) coupled with a mass selective detector (MSD), HP 5973 series (Hewlett-Packard). Helium was used as a carrier gas. The sample was injected in splitless mode in a column HP5 phenyle methyl siloxane [25 μm (film thickness) × 320 μm (internal diameter) × 30 m (length of column)]. Mass spectra were acquired over a 40–400 atomic mass unit range. Temperature programming was: initial temperature 60 °C, ramping rate 3 °C, final temperature 243 °C, run time 61 min. Compounds were identified by comparing the mass spectral data with those in the NIST library provided with software and commercially available data.

2.6. Statistical analysis

Multivariate analysis was done between curcumin content and soil nutrients, environmental factors and altitude using statistical software Statistica version 9.0. The effect of each variable factor was assessed by applying the brute — force approach. Initially the QSAR equation was developed by taking a single factor that had the highest correlation with the metabolite yield. To this equation, the second best factor was added one by one and evaluated the effect of adding. The best equation was taken on the basis of statistical parameters such as squared regression coefficient (r^2) and leave-one-out cross-validated regression coefficient (q^2). The cross-validated regression coefficient (q^2) was calculated by the following equation

$$q2 = 1 - \frac{PRESS}{TOTAL} = 1 - \frac{\sum_{i=1}^{n}\left(y_{\exp} - y_{pred}\right)}{\sum_{i=1}^{n}\left(y_{\exp} - \bar{y}\right)}$$

where y_{pred}, y_{exp} and $\bar{y}$ were the predicted, experimental and mean values of experimental activity respectively. The accuracy of the prediction of QSAR equation was validated by F value and r^2 value. Euclidian distance matrix (EDM) was calculated using Tanimoto similarity coefficient (TSC) with the help of statistical software Darwin 6.0.3 EDM = 1 − TSC.

Table 1
Description of environmental conditions at different agroclimatic zones (Per year).

ZoneNo	Zone	Geographical coordinates	Temperature (°C)		Humidity (%)		Average Rainfall (mm)	Altitude (m)
			Max	Min	Max	Min		
1	East & South Eastern Coastal Plain	20.27°N; 85.84°E	45	14	83	57	330	45
2	Mid Central Table Land	20.27°N; 85.52°E	44	15	82	55	341	36
3	Eastern Ghat High Land	18.82°N; 82.72°E	34	8	80	60	490	870
4	North Eastern Ghat	18.8°N; 84.2°E	44	18	81	59	350	145
5	North Eastern Coastal Plain	21.49°N; 86.93°E	36	15	83	57	330	90
6	North Central Plateau	21.38°N; 85.35°E	45	10	79	58	279	480
7	Western Central Table Land	21.17°N; 83.35°E	47	5	85	60	288	171
8	North Western Plateau	20.47°N; 84.23°E	40	5	81	54	270	200
9	South Eastern Ghat	18.35°N; 81.90°E	46	14	80	56	300	178

Table 2
Analysis of soil parameters from different agroclimatic zones.

Zone No	Zone	N (kg/h)		P (kg/h)		K (kg/h)		Organic carbon (%)		p.H	
		Mean ± S.E		Mean ± S.E		Mean ± S.E		Mean ± S.E		Mean ± S.E	
1	East & South Eastern Coastal Plain	140	0.01	147.82	0.01	280	0.05	0.695	0.001	6.6	0.003
2	Mid Central Table Land	201	0.01	35	0.01	257.5	0.03	1.2	0.01	6.3	0.003
3	Eastern Ghat High Land	112	0.03	57.57	0.01	314.5	0.03	1.44	0.01	6.23	0.003
4	North Eastern Ghat	200	0.01	64.13	0.01	933	0.03	1.0	0.003	7.04	0.003
5	North Eastern Coastal Plain	200	0.03	123.6	0.03	780	0.05	2.12	0.003	6.68	0.005
6	North Central Plateau	272.5	0.01	61.2	0.05	1976.7	0.05	3.688	0.001	5.8	0.005
7	Western Central Table Land	143.7	0.01	153.8	0.03	653	0.01	0.965	0.001	7.6	0.003
8	North Western Plateau	118.7	0.03	44.53	0.05	619.75	0.05	0.48	0.03	6.67	0.005
9	South Eastern Ghat	215	0.01	81.8	0.03	323	0.01	1.796	0.001	7	0.003
Mean		178.1		85.49		681.9		1.48		6.65	
S.E		17.6		14.86		180.98		0.33		0.22	

3. Results

3.1. Analysis of soil parameters from all the experimental zones

Soil Nitrogen (N), Phosphorous (P), Potassium (K), and Organic Carbon (OC) was determined in soil samples collected from all the agroclimatic zones. Available nitrogen content in soil varied from 112 to 272.5 kg/ha, phosphorous from 35 to 153.8 kg/ha and potassium from 257.5 to 1976.7 kg/ha. Organic Carbon which plays a critical role in plant secondary metabolite biosynthesis varies from 0.48 to 3.68% in the soil samples of North Western Plateau and North Central Plateau respectively. Soil samples from North Central Plateau were rich in N, K and OC in comparison to other agroclimatic zones. In Western Central Table Land the soils were rich in phosphorous content (Table 2).

3.2. Analysis of growth and yield parameters at different agroclimatic zones

Growth and yield data for two successive generations (2012–2014) and from all the experimental fields at different agroclimatic zones were recorded (Table 3). The results showed significant difference in plant height, tiller number, leaf number, leaf length, leaf breadth and rhizome yield. Effect of environment and soil was well reflected on growth and rhizome yield at different agroclimatic zones. In Eastern Ghat High Land plant height was highest (138.4 cm) and in North Central Plateau lowest height was recorded (52.5 cm). Height of plant varied from 52 to 138 cm with an average of 96.7 cm. Tiller, leaf number and length was highest and lowest in Eastern Ghat High Land and Mid Central Table Land respectively. Tiller number ranged from 5.3–2.4 with an average of 3.28 per plant. Number of leaves per plant was 8.2–3.7 with an average of 5.9. Average number of leaf length was found to be 56.46 cm ranging from 65.2–49.8 cm. Leaf breadth was highest (16.6 cm) at South Eastern Ghat and lowest (10.2 cm) in Mid Central Table Land with an average of 13 cm. Rhizome yield also varied between 734.2–284.2 g in all the zones with an average of 452.86 g. Yield of rhizome was recorded highest in Eastern Ghat High Land and the lowest in North Eastern Coastal Plain.

3.3. Phytoconstituent analysis

Analysis of curcumin, leaf and rhizome oil of samples from each experimental zone was done up-to two generations (2012–2014). Percentage of curcumin varied from 1.5–5% with an average of 3.4% and the highest among the rhizome samples from Eastern Ghat High Land, from where the Surama variety was released. The lowest curcumin content was recorded from Mid Central Table Land. Leaf and rhizome essential oil content was also varies in all the zones with the change of environment and soil content. Leaf oil was highest (0.8%) in North Eastern Coastal Plain and lowest (0.37%) in North Eastern Ghat with an average percentage of 0.5%. Rhizome oil content varied from 0.7–0.45% with an average of 0.57%. Percentage of rhizome oil was highest at South Eastern Ghat (0.7%) followed by East and South Eastern Coastal Plain (0.68%), Eastern Ghat High Land (0.65%) and North Eastern Coastal Plain (0.64%) (Table 4).

3.4. GC/MS profile of leaf and rhizome oil

GC/MS chromatogram of leaf oil collected from all experimental zones showed wide variation in their constituents. Alpha-phellandrene was the major constituents in all the zones (26.99–67-64%) except Mid Central Table Land, North Eastern Ghat and North Western Plateau where the major constituents were 4–carene (44.84%), beta–phellandrene (48.72%) and γ-terpinene (47.83%) respectively (Table 4). Effect of soil and environment on different agroclimatic zones were clearly marked out owing to the presence of unique phytoconstituents. Alpha terpineol and Isomaltol were unique to East and South Eastern Coastal Plain. In North Eastern Ghat, (Z,E)-alpha farnesene, benzyl ether and 3, 5-dimethyl cyclohexane were found which were absent in all other zones. Isoeugenol and Isoborneol were the marker compounds in

Table 3
Growth and yield of *Curcuma longa* (Surama) at different agroclimatic zones.

Zone No	Zone	Height (cm)	Mean ± S.E	Tiller (number)	Mean ± S.E	Number of Leaves	Mean ± S.E	Leaf length (cm)	Mean ± S.E	Leaf breadth (cm)	Mean ± S.E	Rhizome yield (g)	Mean ± S.E
1	East & South Eastern Coastal Plain	124.9	1.51	2.7	0.15	5.7	0.15	55.2	0.37	13.4	0.24	436	6.8
2	Mid Central Table Land	92.2	1.39	2.4	0.16	3.7	0.15	49.8	0.48	10.2	0.37	333	5.5
3	Eastern Ghat High Land	138.4	1.16	5.3	0.15	8.2	0.19	65.2	0.37	15.8	0.37	734.2	6.6
4	North Eastern Ghat	85.4	0.84	3.3	0.15	6.1	0.27	54	0.54	12	0.31	398.4	6.0
5	North Eastern Coastal Plain	62.7	0.91	2.5	0.16	4	0.14	57	0.31	13.6	0.24	284.2	9.8
6	North Central Plateau	52.5	0.62	3.5	0.16	5.6	0.16	51.4	0.24	10.6	0.39	335.4	6.4
7	Western Central Table Land	85.1	0.76	3.3	0.15	6.8	0.13	59.6	0.5	14.4	0.24	399.2	5.5
8	North Western Plateau	122.4	1.13	3	0.25	5.4	0.16	50.4	0.24	10.4	0.24	525	5.7
9	South Eastern Ghat	107.3	1.49	3.6	0.16	7.7	0.26	65.1	0.24	16.6	0.24	630.4	6.7
Mean		96.7		3.28		5.9		56.46		13		452.86	
S.E		9.64		0.3		0.5		1.99		0.74		49.8	

Table 4
Curcumin, leaf and rhizome essential oil with major constituents of Surama cultivated at differentagroclimatic zones.

ZoneNo	Zone	Curcumin (%)	Mean ± S.E	Leaf oil(%)	Mean ± S.E	Major constituents	Rhizome oil(%)	Mean ± S.E	Majorconstituents
1	East & South Eastern Coastal Plain	4.2	0.002	0.52	0.003	Alpha−Phellandrene(26.99)	0.68	0.003	Tumerone (46.97)
2	Mid Central Table Land	1.5	0.003	0.39	0.001	(+)-(4)-Carene (44.84)	0.46	0.002	Tumerone (56.42)
3	Eastern Ghat High Land	5	0.001	0.53	0.001	Alpha−Phellandrene(67.64)	0.65	0.003	Tumerone (49.1)
4	North Eastern Ghat	3.1	0.003	0.37	0.003	Beta-Phellandrene (48.72)	0.48	0.003	Tumerone (49.42)
5	North Eastern Coastal Plain	1.8	0.001	0.8	0.003	Alpha−Phellandrene(23.48)	0.64	0.002	Tumerone (54.34)
6	North Central Plateau	2.5	0.002	0.4	0.003	Alpha−Phellandrene(54.26)	0.45	0.002	Tumerone (51.43)
7	Western Central Table Land	3.9	0.003	0.5	0.002	Alpha−Phellandrene(64.27)	0.57	0.002	Tumerone (40.08)
8	North Western Plateau	3.4	0.002	0.47	0.001	γ-Terpenine (47.83)	0.55	0.003	Tumerone (42.01)
9	South Eastern Ghat	5	0.001	0.58	0.002	Alpha−Phellandrene(55.43)	0.7	0.001	Tumerone (43.87)
Mean		3.4		0.5			0.57		
S.E		0.42		0.04			0.03		

Table 5
Distribution of phytochemotypes of Leaf oil at different agroclimatic zones.

Compound	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Alpha –Phellandrene	26.99	41.76	67.64	0.49	23.48	54.26	64.27	29.11	55.43
(+)-(4)- Carene	21.39	44.84	1.83	19.61	–	12.17	4.84	–	–
Beta –phellandrene	19.56	–	–	48.72	–	–	–	–	–
α-Terpinolene	0.15	–	15.52	–	14.08	–	7.56	15.1	11.75
γ-Terpenine	14.37	–	13.34	2.48	2.63	2.33	2.22	47.83	–
Eucalyptol	8.17	7.79	–	7.62	–	–	–	–	–
Tumerone	1.47	–	–	1	0.78	0.94	0.82	1.46	–
Beta – Pinene	1.52	0.34	–	2.32	1.82	0.55	1.59	–	–
(+)-3- Carene	1.37	–	–	–	–	–	13.62	–	–
o-Cymene	–	–	–	–	–	18.79	–	–	–
1,2 dimethyl cyclohexane	0.25	–	–	–	–	–	–	–	–
Prenol	0.33	–	–	–	–	–	–	–	–
E-Fenehene	–	–	–	–	–	2.52	–	1.79	–
Thymol	0.18	–	–	–	–	–	–	–	–
L-α Terpineol	0.61	–	–	–	–	–	–	–	–
Isomaltol	0.44	–	–	–	–	–	–	–	–
Caryophyllene	0.16	–	–	–	0.46	–	–	–	–
(E)-β – Famesene	0.66	0.8	1.67	2.12	1.27	1.4	1.69	2.59	–
Zingiberene	0.38	–	–	0.2	–	–	–	0.15	–
α- Farnesene	0.35	–	–	0.82	0.47	–	0.61	1.5	–
β-Farnesene	0.21	–	–	0.14	–	–	–	–	–
Trans-nerolidol	0.15	–	–	–	–	–	–	–	0.2
Curlone	0.52	–	–	0.37	–	–	–	0.47	–
Isoeugenol	–	–	–	–	2.61	–	–	–	–
Isoborneol	–	–	–	–	–	–	0.75	–	–
3-Carene	–	4.47	–	2.31	–	–	–	–	–
p-cymene	–	–	–	8.31	–	–	–	–	29.59
3,5 dimethyl cyclohexane	–	–	–	0.34	–	–	–	–	–
Benzyl ether	–	–	–	0.51	–	–	–	–	–
Acetylcyclopentanone	–	–	–	0.71	–	0.99	–	–	3.03
(Z,E)-Alpha Farnesene	–	–	–	0.13	–	–	–	–	–
1,3,8-p- Menthatriene	–	–	–	–	10.79	–	–	–	–
Alpha-thujene	–	–	–	–	34.16	–	–	–	–
Total (%)	99.23	100	100	98.2	92.55	93.95	97.97	100	100

Table 6
Distribution of phytochemotypes of Rhizome oil at different agroclimatic zones.

Compound	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8	Zone 9
Eucalyptol	2.01	2.01	2.01	1.38	3.66	–	–	–	2.41
Terpinolene	–	1.54	0.98	–	–	–	0.62	–	–
Curcumene	1.16	1.16	–	–	–	–	–	–	–
Caryophyllene	–	–	2.09	–	–	–	–	–	–
Alpha- Phellandrene	3.94	–	–	–	5.38	–	–	5.06	4.11
Alpha-curcumene	–	3.48	2.88	2.39	0.99	0.98	1.02	3.93	1.37
Alpha –cedrene	–	–	–	6.23	–	–	–	–	–
Beta-bisabolene	–	2.64	1.04	1.41	1.28	–	–	3.13	0.64
Beta- farnesene	–	–	–	5.93	–	–	–	–	–
γ- Terpinene	–	–	–	0.4	–	–	–	–	–
Fenchene	–	–	–	4.6	–	–	–	–	–
Tumerone	46.97	56.42	49.1	49.42	54.34	51.43	40.08	42.01	43.87
Curlone	12.85	16.21	18.27	12.55	25.95	18.69	20.78	19.34	20.83
Geranyltiglate	–	–	–	1.09	–	–	–	–	–
Zingiberene	1.19	1.19	4.21	–	0.98	1.8	1.1	4.87	1.86
Beta- sesquiphellandrene	0.88	–	3.26	–	–	1.4	1.4	4.71	2.06
p-cymene	0.57	0.87	0.67	–	–	–	2.09	–	–
Dihydrocurcumene	–	–	–	–	–	–	1.83	–	–
Ethyltetramethylcyclopentadiene	1.97	–	–	–	–	–	3.98	–	–
1,4 dimethyl 2 ethyl benzene	6.02	–	–	–	–	–	–	–	–
3-ethyl-o-xylene	–	–	–	–	–	6.47	–	–	–
6-(p-Tolyl)-2-methyl-2-heptenol	–	–	–	–	–	–	9.76	–	–
1,5-dimethyl-2-pyrollcarbonitrile	–	–	–	–	–	–	–	–	6.72
Isodurene	–	–	–	–	–	–	–	–	0.87
2,4 dihydroxybenzoic acid	2.08	–	–	–	–	–	–	–	–
1,3 dimethyl 2 ethyl benzene	1.21	–	–	–	–	–	–	–	–
Total(%)	80.85	85.52	84.51	85.4	92.58	80.77	82.66	83.05	84.74

samples from North Eastern Coastal Plain and Western Central Table Land respectively while ortho cymene was present among the North Central Plateau samples only. Transnerolidol was found in East and South Eastern Coastal Plain and South Eastern Ghat (Table 5).

GC MS chromatogram of rhizome essential oil from all the experimental zones showed tumerone as the major constituent which varied from 40.08% to 56.42% (Table 4). Highest percentage of tumerone (56.42%) was reported from Mid Central Table Land followed by North Eastern Coastal Plain (54.34%) whereas the lowest

Table 7
Statistical assessment of quantitative structure − activity relationship (QSAR) equation with change in curcumin content at different agroclimatic zones.

No ofDescriptors	QSAR Equation	r^2	q^2	PRESS	Fvalue
1	CURCUMIN = 0.608 − 0.357 N	0.25	0.18	1.97	14.06
2	CURCUMIN = 0.402 + 0.407 PH −0.289 N	0.43	0.37	1.51	16.4
3	CURCUMIN = 0.383 + 0.399 PH −0.281 N+ 0.0411 Alt	0.44	0.34	1.57	10.9
4	CURCUMIN = 0.366 + 0.364 PH −0.191 N − 0.136 K2O + 0.100 Alt	0.45	0.32	1.63	8.22
5	CURCUMIN = 0.318 + 0.262 Min hum + 0.296 PH −0.264 N − 0.119 K + 0.0093 Alt	0.55	0.44	1.34	9.88
6	CURCUMIN = 0.347 + 0.266 Min hum −0.052 MINTEM + 0.293 PH −0.246 N- 0.124 K2O −0.014 Alt	0.56	0.43	1.35	8.12
7	CURCUMIN = 0.336 + 0.257 Min hum + 0.020 AVGRAIN −0.049 MINTEM + 0.308 PH −0.244 N −0.110 K2O −0.015 Alt	0.56	0.4	1.41	6.78
8	CURCUMIN = 0.300 + 0.408 Min hum −0.365 AVGRAIN + 0.159 MINTEM −0.086 PH + 0.956 O.C −0.477 N −1.14 K2O + 0.319 Alt	0.65	0.5	1.19	8.47
9	CURCUMIN = −0.283 −0.191 Min hum + 0.352 AVGRAIN + 0.350 MINTEM + 0.093 PH+ 0.153 O.C + 0.081 N + 0.721 P2O5 −0.508 K2O + 0.683 Alt	0.82	0.71	0.68	18.75
10	CURCUMIN = −1.29 + 0.703 Max hum −0.805 Min hum + 1.11 AVGRAIN + 0.837 MINTEM + 0.355 PH + 0.692 O.C + 0.212 N + 0.731 P2O5 −0.393 K2O + 1.19 Alt	0.85	0.73	0.64	19.21
11	CURCUMIN = −1.05 + 0.726 Max hum −0.762 Min hum + 0.907 AVGRAIN −0.266 MAXTEMP + 0.872 MINTEM + 0.401 PH + 0.718 O.C −0.034 N + 0.751 P2O5 −0.147 K2O + 1.07 Alt	0.85	0.72	0.66	17.43

Table 8
Statistical assessment of quantitative structure — activity relationship (QSAR) equation with change in leaf essential oil content at different agroclimatic zones.

No ofDescriptors	QSAR Equation	r^2	q^2	PRESS	Fvalue
1	LEAF OIL = 0.270 + 0.130 P	0.01	0	3.85	0.83
2	LEAF OIL = 0.624 − 0.729 Max Temp + 0.477 P	0.46	0.37	2.32	18.02
3	LEAF OIL = 0.535 + 0.421 Max hum − 0.740 Max Temp + 0.240 P	0.58	0.48	1.89	19.46
4	LEAF OIL = 0.512 + 0.540 Max hum − 0.853 Max Temp + 0.252 P + 0.190 K	0.6	0.49	1.88	15.42
5	LEAF OIL = 0.548 + 0.541 Max hum − 0.817 Max Temp − 0.133 PH + 0.274 P + 0.151 K	0.61	0.48	1.9	12.55
6	LEAF OIL = 0.677 + 0.716 Max hum −1.10 Max Temp + 0.294 PH + 0.0302 P + 0.677 K −0.484 Altitude	0.85	0.8	0.73	36.39
7	LEAF OIL = 0.379 + 0.568 Max hum −0.707 Max Temp −0.082 PH + 0.593 N + 0.148 P −0.263 K −0.046 Altitude	0.9	0.86	0.49	49.94
8	LEAF OIL = 0.228 + 0.683 Max hum −0.559 Max Temp −0.201 PH + 0.505 O.C + 0.617 N −0.0084 P −0.798 K + 0.103 Altitude	0.92	0.88	0.43	52.54
9	LEAF OIL = 1.31 + 0.695 Max hum −0.812 Avg Rainfall−1.60 Max Temp −0.0077 PH + 0.308 O.C −0.169 N + 0.207 P + 0.290 K −0.370 Altitude	0.996	0.99	0.02	904.36
10	LEAF OIL = 1.30 + 0.601 Max hum −0.724 Avg Rainfall −1.47 Max Temp −0.111 Min Temp − 0.0071 PH + 0.114 O.C −0.0059 N + 0.219 P + 0.276 K −0.394 Altitude	0.998	0.993	0.01	1518.89
11	LEAF OIL = 1.36 + 0.569 Max hum + 0.0352 Min hum −0.771 Avg Rainfall −1.47 Max Temp − 0.133 Min Temp − 0.0223 PH + 0.0962 O.C −0.0210 N + 0.215 P + 0.268 K −0.422 Altitude	0.998	0.996	0.01	1362.81

Table 9
Statistical assessment of quantitative structure − activity relationship (QSAR) equation with change in alpha phellandrene content at different agroclimatic zones.

No ofDescriptors	QSAR Equation	r^2	q^2	PRESS	Fvalue
1 2	A-PHELLANDRENE = 0.845 −0.547 Min Temp	0.35	0.27	3.08	23.49
	A-PHELLANDRENE = 1.10 −0.772 Min Temp −0.294 Altitude	0.44	0.37	2.66	17.04
3	A-PHELLANDRENE = 1.01 −0.787 Min Temp + 0.343 O.C −0.319 Altitude	0.54	0.47	2.26	16.07
4	A-PHELLANDRENE = 0.930 + 0.377 Min hum −0.862 Min Temp + 0.288 O.C −0.472 Altitude	0.67	0.61	1.65	20.52
5	A-PHELLANDRENE = 0.711 + 0.203 Min hum + 0.477 Avg Rainfall −0.721 Min Temp + 0.481 O.C − 0.352 Altitude	0.8	0.76	0.99	31.75
6	A-PHELLANDRENE = 0.438 + 0.138 Min hum + 0.739 Avg Rainfall + 0.281 Max Temp −0.680 Min Temp + 0.492 O.C −0.294 Altitude	0.82	0.78	0.92	30.64
7	A-PHELLANDRENE = 2.13 −1.58 Max hum + 1.18 Min hum −0.312 Avg Rainfall + 0.491 Max Temp −1.73 Min Temp −0.887 O.C −1.37 Altitude	0.96	0.951	0.2	148.5
8	A-PHELLANDRENE = 2.20 −1.55 Max hum + 1.20 Min hum −0.426 Avg Rainfall + 0.370 Max Temp −1.67 Min Temp −0.740 O.C −0.149 N −1.38 Altitude	0.967	0.952	0.2	131.28
9	A-PHELLANDRENE = 1.67 −1.41 Max hum + 1.00 Min hum −0.047 Avg Rainfall + 0.645 Max Temp −1.56 Min Temp −0.544 O.C + 0.151 N −0.361 K −1.07 Altitude	0.97	0.958	0.17	131.23
10	A-PHELLANDRENE = 1.66 −1.31 Max hum + 1.15 Min hum −0.119 Avg Rainfall + 0.773 Max Temp −1.60 Min Temp −0.164 O.C + 0.0381 N −0.351 P −0.658 K −1.14 Altitude	0.99	0.99	0.03	644.51
11	A-PHELLANDRENE = 1.61 −1.27 Max hum + 1.10 Min hum −0.066 Avg Rainfall + 0.756 Max Temp −1.57 Min Temp + 0.0392 PH −0.155 O.C+ 0.0374 N −0.346 P −0.603 K −1.12 Altitude	0.9	0.9	0.03	580.31

Table 10
Statistical assessment of quantitative structure – activity relationship (QSAR) equation with change in rhizome essential oil content at different agroclimatic zones.

No ofDescriptors	QSAR Equation	r^2	q^2	PRESS	Fvalue
1 2	RHIZOME OIL = 0.668 −0.764 K	0.4	0.35	3.85	28.74
	RHIZOME OIL = 0.502 + 0.417 P −0.703 K	0.51	0.46	3.18	22.6
3	RHIZOME OIL = 0.396 + 0.510 N + 0.399 P −1.05 K	0.63	0.58	2.49	23.85
4	RHIZOME OIL = 0.735 −0.830 Max Temp + 0.340 N + 0.853 P −0.569 K	0.88	0.86	0.83	77.49
5	RHIZOME OIL = 1.23 −0.566 Avg Rainfall −1.33 Max Temp + 0.109 N + 1.01 P −0.436 K	0.92	0.9	0.54	101.66
6	RHIZOME OIL = 1.27 −0.644 Avg Rainfall −1.33 Max Temp + 0.467 O.C −0.0495 N + 0.894 P −0.734 K	0.94	0.92	0.43	111.36
7	RHIZOME OIL = 1.28 −0.654 Avg Rainfall −1.33 Max Temp −0.0148 PH+ 0.468 O.C −0.0543 N + 0.899 P −0.737 K	0.94	0.92	0.46	93.06
8	RHIZOME OIL = 1.38 −0.301 Max hum −0.675 Avg Rainfall −1.30 Max Temp −0.0266 PH + 0.133 O.C + 0.0245 N + 1.10 P −0.671 K	0.96	0.943	0.34	115.45
9	RHIZOME OIL = 1.54 −0.375 Max hum + 0.181 Min hum −0.944 Avg Rainfall −1.32 Max Temp −0.186 PH + 0.324 O.C −0.098 N + 1.05 P −0.962 K	0.962	0.945	0.32	108.65
10	RHIZOME OIL = 1.56 −0.376 Max hum + 0.186 Min hum −0.957 Avg Rainfall −1.34 Max Temp −0.183 PH + 0.322 O.C −0.113 N + 1.05 P −0.946 K −0.010 Altitude	0.965	0.942	0.34	95.01
11	RHIZOME OIL = 1.31 −0.194 Max hum + 0.027 Min hum – 0.781 Avg Rainfall −1.36 Max Temp + 0.147 Min Temp −0.115 PH + 0.478 O.C −0.109 N + 1.07 P −0.905 K + 0.124 Altitude	0.96	0.93	0.36	85.53

Table 11
Statistical assessment of quantitative structure – activity relationship (QSAR) equation with change in tumerone content at different agroclimatic zones.

No ofDescriptors	QSAR Equation	r^2	q^2	PRESS	Fvalue
1	TUMERONE = 0.878 – 0.825 PH	0.55	0.52	1.69	54.56
2	TUMERONE = 0.717 + 0.277 Min Temp −0.768 PH	0.66	0.63	1.3	41.81
3	TUMERONE = 0.778 + 0.356 Min Temp −0.810 PH −0.218 N	0.71	0.67	1.16	34.57
4	TUMERONE = 0.850 + 0.243 Min Temp −0.838 PH −0.356 O.C + 0.054 N	0.75	0.7	1.04	30.5
5	TUMERONE = 0.856 + 0.303 Min Temp −0.661 PH −0.154 O.C −0.091 N −0.329 P	0.84	0.8	0.69	43.05
6	TUMERONE = 0.949 −0.137 Avg Rainfall + 0.295 Min Temp −0.723 PH −0.170 O.C −0.141 N −0.332 P	0.85	0.81	0.66	38.52
7	TUMERONE = 0.653 + 0.462 Max hum −0.0162 Avg Rainfall + 0.439 Min Temp −0.645 PH + 0.373 O.C −0.364 N −0.662 P	0.91	0.87	0.43	53.63
8	TUMERONE = 0.439 + 0.263 Max hum + 0.317 Avg Rainfall + 0.426 Max Temp + 0.250 Min Temp −0.638 PH −0.128 O.C + 0.056 N −0.637 P	0.92	0.88	0.39	56.12
9	TUMERONE = 0.382 + 0.199 Max hum + 0.407 Avg Rainfall + 0.620 Max Temp + 0.154 Min Temp −0.662 PH −0.132 O.C + 0.213 N −0.698 P −0.213 K	0.93	0.88	0.39	52.99
10	TUMERONE = −0.118 + 0.845 Max hum −0.739 Min hum + 1.13 Avg Rainfall + 0.0986 Max Temp + 0.552 Min Temp + 0.0481 PH −0.267 O.C + 0.0223 N −0.525 P + 1.23 K	0.98	0.97	0.08	243.25
11	TUMERONE = – 0.201 + 0.884 Max hum −0.781 Min hum + 1.19 Avg Rainfall + 0.121 Max Temp + 0.581 Min Temp + 0.0559 PH −0.234 O.C + 0.053 N −0.523 P + 1.20 K + 0.047 Altitude	0.9	0.9	0.08	215.86

was recorded from Western Central Table Land (40.08%). Twenty six constituents were identified from across all the zones with some constituents, unique to a particular zone. For example, 1,4 dimethyl 2 ethyl benzene and 1,3 dimethyl 2 ethyl benzene were only found in the rhizome oil of plants cultivated at East and South Eastern Coastal Plain. Likewise, Caryophyllene was the marker compound for Eastern Ghat High Land collections. In North Eastern Ghat alpha cedrene, beta farnesene, γ-terpinene, fenchene and geranyl tiglate were found in the samples which were absent in all other zones. Dihydrocurcumene was only reported from Western Central Table Land (Table 6).

3.5. *Effect of environment and soil on curcumin content*

The environmental factors like maximum and minimum temperature, maximum and minimum humidity and average rainfall at different agroclimatic zones were recorded during the experiment from 2011 to 2014 (Table 1). It revealed a wide range of variation among the entire agroclimatic zones. The maximum temperature varied from 34 to 47 °C and the minimum temperature varied from 5 to 18 °C. Percentage of humidity varied from maximum 79–85% to minimum 54–60%. Average rainfall varied from 270 to 490 mm across all experimental zones. The variation in curcumin content was positively correlated with humidity, rainfall, altitude, soil nitrogen, soil potassium and pH. The most sensitive factor for curcumin was soil nitrogen followed by soil pH and altitude (Fig. 1A). Multivariate analysis of all the factors with respect to curcumin content from the entire experimental zone showed combined effect with $r = 0.92$ at $p \leq 0.001$. By applying the‘brute force’approach it was found that, the value increased with the addition of each variable factor (r^2 and q^2) up to 10th factor (Table 7). Soil p.H was the limiting factor for alpha phellandrene yield (Fig. 2C).

). Maximum humidity was the limiting factor for curcumin yield (Fig. 2A).

3.6. *Effect of environment and soil on leaf essential oil and alpha phellandrene content*

Essential oil content of leaf samples collected from all the zones varied from 0.37 to 0.8%. Percentage of leaf oil was positively correlated with temperature and soil phosphorous whereas negatively correlated with humidity, rainfall, altitude and soil nitrogen,

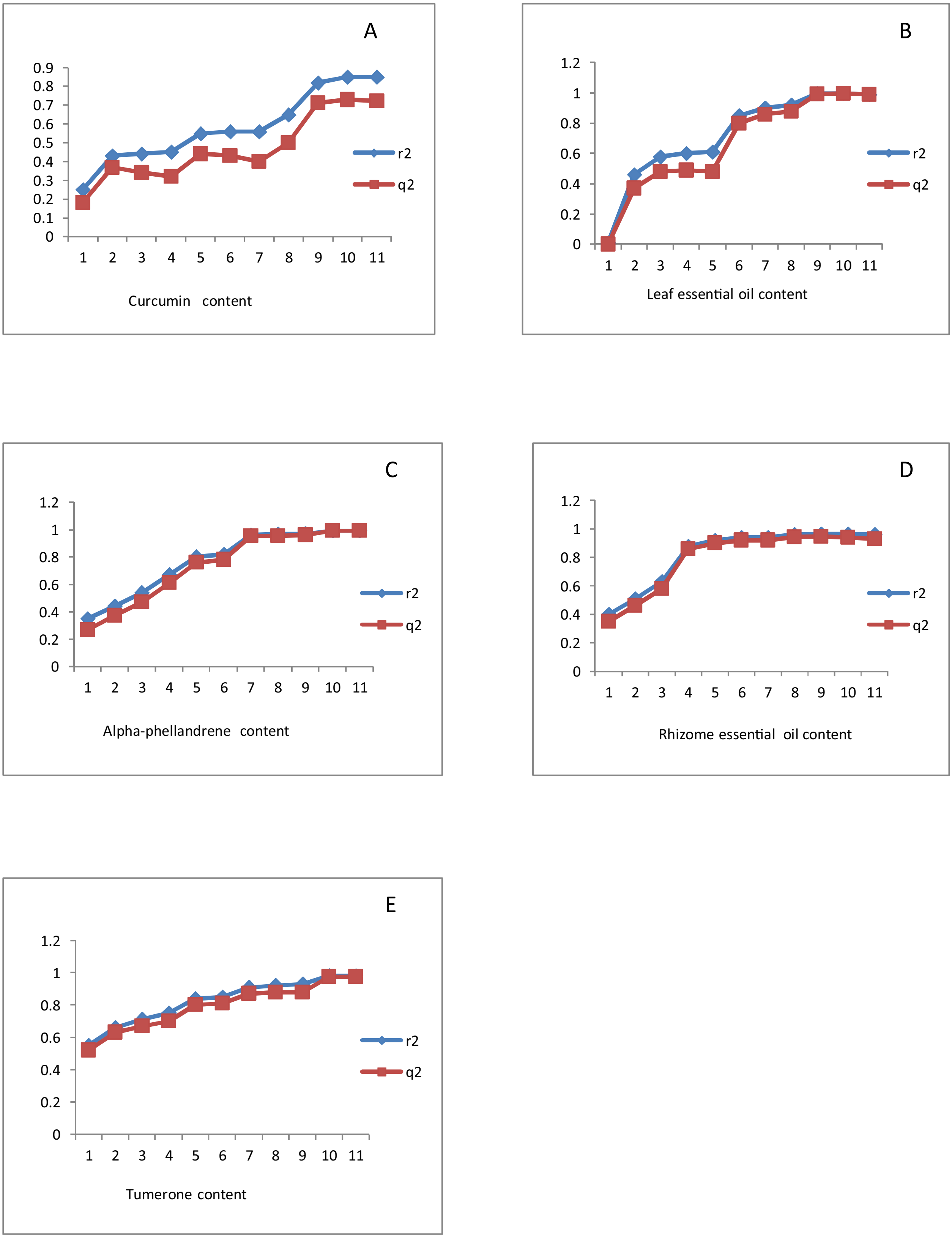

Fig. 2. (A) r^2/q^2 plot against the MLR equation for curcumin content. (B) r^2/q^2 plot against the MLR equation for leaf essential oil yield. (C) r^2/q^2 plot against the MLR equation for alpha-phellandrene (leaf essential oil) content. (D) r^2/q^2 plot against the MLR equation for rhizome essential oil yield. (E) r^2/q^2 plot against the MLR equation for tumerone (rhizome essential oil) content.

pH. Relative sensitivity of all factors when plotted against the leaf essential oil showed maximum temperature and soil phosphorous as the most sensitive factors (Fig. 1B). Thus multivariate analysis of all the factors with respect to leaf essential oil from the entire experimental zone showed clearly a marked and combined effect with $r = 0.99$ at $p \leq 0.001$. The linear regression equation was

Table 12
Euclidian distance matrix coefficient among nine agroclimatic zones for leaf oil chromatogram.

	Zone 1	Zone 2	Zone 3	Zone 4	Zone5	Zone 6	Zone 7	Zone 8	Zone 9
Zone 1	0								
Zone 2	0.77	0							
Zone 3	0.76	0.62	0						
Zone 4	0.55	0.66	0.78	0					
Zone 5	0.66	0.78	0.66	0.73	0				
Zone 6	0.75	0.63	0.6	0.65	0.66	0			
Zone 7	0.59	0.66	0.5	0.66	0.5	0.53	0		
Zone 8	0.63	0.84	0.6	0.65	0.57	0.61	0.53	0	
Zone 9	0.86	0.9	0.75	0.85	0.85	0.83	0.84	0.83	0

Zone 1- East & South Eastern Coastal Plain, Zone 2- Mid Central Table Land, Zone 3- Eastern Ghat High Land, Zone 4- North Eastern Ghat, Zone 5- North Eastern Coastal Plain, Zone 6- North Central Plateau, Zone 7- Western Central Table Land, Zone 8- North Western Plateau, Zone 9- South Eastern Ghat.

Table 13
Euclidian distance matrix coefficient among nine agroclimatic zones for rhizome oil chromatogram.

	Zone 1	Zone 2	Zone 3	Zone 4	Zone5	Zone 6	Zone 7	Zone 8	Zone 9
Zone 1	0								
Zone 2	0.6	0							
Zone 3	0.62	0.27	0						
Zone 4	0.84	0.64	0.66	0					
Zone 5	0.64	0.4	0.45	0.58	0				
Zone 6	0.71	0.63	0.54	0.76	0.55	0			
Zone 7	0.62	0.53	0.46	0.82	0.69	0.54	0		
Zone 8	0.78	0.6	0.63	0.63	0.28	0.77	0.84	0	
Zone 9	0.62	0.53	0.46	0.66	0.3	0.54	0.66	0.5	0

Zone 1- East & South Eastern Coastal Plain, Zone 2- Mid Central Table Land, Zone 3- Eastern Ghat High Land, Zone 4- North Eastern Ghat, Zone 5- North Eastern Coastal Plain, Zone 6- North Central Plateau, Zone 7- Western Central Table Land, Zone 8- North Western Plateau, Zone 9- South Eastern Ghat.

derived (Table 8) with all the factors and brute force analysis was done. The r^2 and q^2 value increased up to 10th factor and minimum temperature was the limiting factor for leaf essential oil yield (Fig. 2B). Variation range in alpha phellandrene content in leaf essential oil was 23.48–67.64% across all the experimental zones. Factors like minimum temperature, altitude, humidity and organic carbon on analysis exhibited a positive effect on alpha phellandrene percentage. Thus the most sensitive factor for alpha phellandrene was the minimum-temperature parameter across all zones (Fig. 1C). Combined effect of all factors was confirmed at $r = 0.99$ statistically significant at $p \leq 0.001$. By applying a brute force approach it was found that, the value increased with the addition of each variable factor (r^2 and q^2) up to 10th factor (Table 9

3.7. *Effect of environment and soil on rhizome essential oil and tumerone content*

Percentage of rhizome essential oil varied from 0.45–0.7% at different agroclimatic zones. Environmental and soil nutrients were crucial for essential oil yield and among them soil nitrogen, phosphorous and potassium contents were positively correlated with rhizome oil. The most sensitive factor was potassium (Fig. 1D). Multivariate analysis of all the parameters showed that combined effect was more important than the individual factors. The result was statistically significant at $r = 0.98$ and $p \leq 0.001$. Major constituent of rhizome essential oil was tumerone across all the zones which ranged between 40.08 and 56.42%. Factors like minimum temperature, nitrogen and phosphorous content as well as soil pH were positively correlated but the most sensitive factor for tumerone was soil pH (Fig. 1E). Combination of all soil and environmental parameters again proved to be more important than the individual factors for tumerone content through multivariate analysis with $r = 0.99$ and $p \leq 0.001$. With the help of brute force approach linear regression equations were developed for rhizome oil and tumerone content (Tables 10 and 11). The r^2 and q^2 value increased up to 10th factor and minimum humidity was the limiting factor for rhizome oil and tumerone respectively (Fig. 2D, E).

3.8. *Pairwise comparative analysis among different zones*

Pairwise comparison in respect to leaf and rhizome essential oil among all the nine agroclimatic zones was performed using Euclidian dissimilarity coefficient. Towards this end- GC MS chromatogram data at different zones were used. The dissimilarity matrix values for leaf and rhizome essential oil was given in (Table 12 and Table 13). Zone 2 and Zone 9 showed highest values of 0.9 (distantly related) with respect to leaf essential oil composition, whereas the lowest value of 0.5 was recorded between zone 3 and 7. Similarly for rhizome essential oil dissimilarity matrix value was highest (0.84) between zone 1 and 4 and zone 4 and 7. Lowest value (0.27) was between zone 2 and 3.

4. Discussion

The present study was conducted for metabolic profiling of a high yielding turmeric cultivar (Surama) at different agroclimatic zones. Besides, the study also covered a comprehensive analysis of the effect of various soil and environment parameters on its essential oil yield and curcumin content. Though selection of genotypes by means of rhizome and curcumin yield has been reported (Anandaraj et al., 2014), a detailed, ready-to-use phytochemical profiling of a specific turmeric cultivar subjected to a multi-agroclimatic-zone trial has remained unexplored till date and to the best of our knowledge this is the first ever study of this kind.

Phytochemicals, found naturally in plants has always evoked scientific and public interest for their medicinal, culinary and economical importance. The demand for quality turmeric products world over has triggered the production of this species many fold in India. But production with a proportionate quality is the key to enhance its export potential. There is ever increasing demand for value added products of turmeric like curcumin, oleoresin and essential oil in the global market. Prevalence of wide variability among the existing cultivars of turmeric in respect of total yield and quality was reported by several workers (Mohanty, 1979; Rama Rao and Rao, 1994; Pujari et al., 1987; Philip et al., 1982; Philip, 1983). There are many turmeric varieties i.e. Surama, Roma, Ranga and Rashmi which were released from HARS, Pottangi, Odisha that are cultivated and exported from India. These cultivars were cultivated at different places for production of rhizome without having any knowledge whatsoever on the effect the different soil nutrients and environment parameters have on the quantity and quality of the phytoconstituents. It has been noted that many medicinal and aromatic plants have higher phytoconstituent percentage in their original habitat than other cultivated areas. Environmental factors and soil nutrients plays a critical role in the productivity of these plants. There are many reports regarding effect of temperature, light, rainfall and soil nutrient on plant secondary metabolite production (Mølmannet al., 2015; Tayade et al., 2013; Hassiotis et al., 2014; Hou et al., 2010; Løvdal et al., 2010; Singh et al., 2013). But, a detailed and a targeted analysis of variation in phytoconstituents like curcumin, leaf and rhizome essential oil with their volatile components with respect to different cultivation zones is special to the present report.

Environment plays a crucial role in production of secondary metabolites (Anandaraj et al., 2014; Tayade et al., 2013; Payyavula et al., 2012; Alam and Naik, 2009). In the present study a pronounced — differential growth pattern was observed at different cultivation zones. In the Eastern Ghat High Land, from where the cultivar was released was reported to have high rhizome yield (734.2 g), highest plant height (138.4 cm) and tiller number (5.3). As the cultivar was released basing upon the high yield hence it showed high growth factors at its original habitat. Besides Eastern Ghat High Land, South Eastern Ghat was most suitable for cultivation of Surama for rhizome yield where the rhizome yield was 630.4 g. This may be due to some common environmental factors like temperature, humidity and rainfall at these two zones. Leaf and rhizome essential oil content varied at different experimental areas due to difference in environmental factors. In North Eastern Coastal Plain the leaf essential oil yield was double (0.8%) to that in other zones. Rhizome oil yield was quite similar at different areas but among them East and South Eastern Coastal Plain (0.68%), Eastern Ghat High Land(0.65%), North Eastern Coastal Plain(0.64%) and South Eastern Ghat (0.7%) were best suitable for turmeric cultivation especially for rhizome essential oil yield. Variation in rhizome essential oil and curcumin content and oil quality of 27 accessions was reported by Garg et al. (1999). They collected the rhizomes from different areas of North Indian Plains taking two varying factors like genotype and environmental parameters into account. Thus it became very difficult to analyse the effect of environment on a large number of various genotypes cultivated at different trial zones. In the present study therefore, a single genotype (cultivar Surama) was cultivated at different environmental zones due to which effect of environment was clearly seen with respect to variation in growth and phytochemical yield.

Anandaraj et al. (2014) reported genotype and environment interaction by planting eleven cultivars at 10 different zones for analysis of oil yield and curcumin basing on which they selected stable genotypes with respect to different environmental conditions. In our experiment, same cultivar was taken for optimization of parameter for high yield of curcumin and essential oil content at different agro-climatic zones. This will be helpful for selection of specific agroclimatic zones for higher phytochemical yield. A detailed analysis of leaf and rhizome essential oil showed differential metabolic expression at different zones. Alpha phellandrene in leaf essential oil was higher at Eastern Ghat High Land (67.64%) and Western Central Table Land (64.27%) whereas tumerone was found higher in the rhizome samples at Mid Central Table Land (56.42%) and North Eastern Coastal Plain (54.34%). Singh et al. (2013) though reported variation in volatile constituents of collected turmeric accessions from different agroclimatic zones for selection of some suitable cultivar, this study too was based on several different genotypes.

Soil nutrients like nitrogen, phosphorous, potassium and organic carbon has important role in secondary metabolite production. Soil organic matter content is the source for plant metabolism and resistance/adaptation against biotic and abiotic stresses. Variation in secondary metabolite production with varying soil nutrients has been reported in other plants (Alam and Naik, 2009; Ramakrishna and Ravishankar, 2011). In our study altitude, soil nitrogen, potassium and pH were positively correlated to the curcumin content. This report is in agreement with Khartikeyan et al. (2012) who reported a positive effect of potassium on curcumin yield. Li et al. (2011) reported change in volatile constituents in turmeric essential oil grown at different geographical locations with different soil types. Effect of soil nutrients on essential oil yield was well marked in the present study due to high sensitivity of soil N, P, K on essential oil production. Though soil nutrients are negatively correlated with alpha phellandrene content but for tumerone, the soil pH was the most sensitive factor. Taken together, these results suggest that the change in curcumin and essential oil content of turmeric at different agroclimatic zones may not be due to any individual factors but may be more due to a combined effect of soil and environmental factors.

5. Conclusion

In the present study, differential effect of environmental and soil parameters were analysed for factor optimization and selection of suitable agroclimatic zones for cultivation of selective turmeric varieties with high secondary metabolite contents. The results would also be useful while selecting agro-climate-zone-specific elite genotypes/cultivars based on high secondary metabolite production indices. Besides, the present report bears immense potential for future soil management programmes undertaken not only for yield optimization and commercialization but also for value addition of turmeric products like curcumin, essential oil rich in alpha phellandrene and tumerone.

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