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Comprehensive assessment of phytometabolites and health benefits of Geographical Indication turmeric in India

Dona Ann Jose, N M Bhabhina, N K Leela, M Vishudha, S Aarthi & D Prasath*

ICAR-Indian Institute of Spices Research, Kozhikode, 673012, Kerala, India.
**E mail: dprasath@gmail.com*

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Abstract

The interest and demand for the Geographical Indication (GI) turmeric have increased significantly in recent years as research unfolds their unique benefits. Still, their comprehensive and comparative metabolite profile remains to be analysed in detail from a nutritional perspective. This investigation reports phytochemical constituents, nutraceuticals, and bioactivities of four GI turmeric (Erode turmeric, Kandhamal haldi, Waigaon turmeric and Sangli turmeric) in India. The results revealed considerable differences in major quality parameters *viz.,* essential oil (4.00-5.60%), oleoresin (8.36-18.12%) and curcuminoids (2.23-5.50%). Among the GIs, Waigaon turmeric was superior in terms of quality parameters and rhizome traits. The Erode turmeric contained significantly high protein (4.64%) and several minerals (K, Ca, Fe and Mg). The IC_{50} values of DPPH scavenging assays (160.72 – 194.25 μg ml^{-1}) and α-glucosidase inhibitory assays (126.50 – 146.57 μg ml^{-1}) ensured the potent antioxidant and anti-diabetic activities of GI turmeric. The GC-MS profile of essential oil unveiled six major compounds such as, ar-turmerone, β-sesquiphellandrene, α-zingiberene, α-curcumene, α-turmerone, and curlone. The brightest yellow colour was observed in Sangli turmeric and dark orange in Waigon turmeric, based on L*, a* and b* values. All the four GI turmeric varieties are good sources of spice for people to consume but Waigaon turmeric was found to be superior among them.

Keywords: antidiabetic, antioxidant, colour, *Curcuma longa*, curcumin, geographical indication

Introduction

Turmeric (*Curcuma longa* L.) is one of the commercial crops, which is being slowly and steadily recognised for a plethora of pharmaceutical and nutraceutical properties. As a part of dietary intake, its rhizome, even at lower quantities over lengthy time-periods, has proved to be highly beneficial for general health (Huiying *et al*. 2021 & Prasath *et al.* 2019). When it comes to the medicinal value, the most prominent component is the lipophilic polyphenol substance, curcumin. Volatile oil, minerals, vitamins, carbohydrates, and proteins which are derived from the plant have manifold nutritional benefits and is much renowned for its medicinal values (Shubha *et al.* 2021).

Geographical indication (GI) is the reputation given to a crop on the basis of a specific location and for the explicit characters acquired due

to that geographical origin. The GIs could generate value additions at the end of the value chains for consumers and retailers (Cei *et al*. 2018). Though it is not general, some countries have significant market size for GIs, and some GI products have a decisive role in both domestic and export markets (Torok *et al.* 2020). Since the quality is influenced by the geographical location of production, there is a straight relation connecting the product and its original place of production (Kishore 2018).

In India, as on date four turmeric locations have secured the recognition of GIs which are Waigaon turmeric, Erode turmeric, Kandhamal haldi and Sangli turmeric. The Waigaon turmeric is traditionally cultivated in Samudrapur tehsil of Wardha district, Maharashtra, India. It grows rain fed and its rhizomes have distinct dark orange colour (GI journal 2021). The Sangli turmeric is produced in Sangli district of Maharashtra, India. The distinguishable geographical specialities and weather conditions in Sangli translates into the production of high-quality rhizomes in huge quantities (GI journal 2018). The Erode turmeric grown all over Erode district of Tamil Nadu is renowned for its distinct aroma and flavour and is a much sought-after variant in the national and international markets. It stands out from the rest in the market based on its size, appearance, colour, and slightly bent fingers (GI journal 2021). The Kandhamal haldi is produced in Kandhamal district of Odisha, India. The rhizomes are relatively loose and bold (GI journal 2018).

A comprehensive profiling of quality and nutraceuticals of these GI turmeric is necessary for improving their value and export potential. Our results provide a detailed comparative assessment of the phytoconstituents such as curcuminoids, proximates and minerals in these four GI turmeric in India. In addition, the antioxidant and antidiabetic efficacy were also explored by *in vitro* analysis. This study documents the health benefits associated with the unexploited high-quality turmeric types in India.

Materials and methods

Morphological parameters of the collected rhizomes

The fresh rhizomes of four GI turmeric were collected from the respective defined geographical locations in India *viz.,* Erode turmeric from the Erode district in Tamil Nadu; Sangli turmeric and Waigaon turmeric from Maharashtra and Kandhamal haldi from Odisha. Among the GI turmeric, Erode and Waigon are medium in duration (~200 days) whereas, Sangli and Kandhamal are long duration (~240 days) types. The rhizomes were cleaned and their length (cm), girth (cm), internodal length (cm) and weight (g) of each primary and secondary rhizomes were recorded. Subsequently the fresh rhizomes were washed and cured at ICAR- Indian Institute of Spices Research, Kozhikode, Kerala (Anandaraj *et al*. 2014). The dried rhizomes were powdered and used for further analysis.

Quantification of oleoresin (OR) and curcuminoids

Standard ASTA (American Spice Trade Association) method 11.0 was followed for the extraction of OR by cold percolation method. Total curcuminoids present in the turmeric rhizome powder was estimated by ASTA method 18.0. The extract was measured in a Shimadzu UV spectrophotometer at 425 nm, using acetone as blank. Quantification of individual curcuminoids (bisdemethoxycurcumin, demethoxycurcumin and curcumin) was performed by HPLC (Shimadzu with PDA detector SPD-M20A) with C-18 column with acetonitrile and water as solvents. The elution was performed using isocratic elution (0-15 min) with a flow rate 0.6 ml min^{-1} and 0.4 ml min^{-1} for acetonitrile and water respectively at ambient temperature, with UV detection at 425 nm. The linearity of the method was checked by injecting a series of 1 mg ml^{-1} of standard solutions of bisdemethoxycurcumin (BDMC), demethoxycurcumin (DMC) and curcumin. Standard calibration curve was plotted by concentration versus peak area.

Essential oil profile

Essential oil (EO) collected from the dried turmeric rhizomes by hydrodistillation method was subjected to GC-MS analysis. Volatile compounds were estimated using Shimadzu GC system equipped with MS detector with helium as the carrier gas (flow rate 1 ml min^{-1}). Rt X-5 column was used for the identification. The injector port and the detector temperatures were set at 260 °C and 250 °C respectively, with a split ratio of 1:40. The compounds were confirmed using NIST and WILEY Library as reference.

Determination of nutritional composition

Nutritional composition (proximate and minerals) of turmeric samples were determined by approved methods (AOAC 2005; Sadasivam and Manickam 2008) and standard procedures with slight modifications. Protein, carbohydrate, ash, and fat were estimated from turmeric rhizome powder. Protein was assayed by the method of Lowry *et al*. (1951). Carbohydrate was analysed following anthrone method (Alberto *et al.* 2008). Extraction with petroleum ether using Soxhlet apparatus was used to estimate fat content (Sera *et al*. 2019). The ash content was determined by incinerating the sample using a muffle furnace at 650-700° C (Monick *et al.* 2018).

The minerals, potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), manganese (Mn), iron (Fe), zinc (Zn) and lead (Pb) were analysed by Varian fast sequential atomic absorption spectrometer (Model AA240FS) equipped with graphite tube atomizer. Phosphorus and nitrogen were determined using Vanadomolybdate method and Kjeldhal's method respectively with spectrophotometer, according to the protocol of AOAC (2005). To determine the quantity of phosphorus, the absorbance was read at 470 nm.

Antioxidant and antidiabetic assay analysis

Antioxidant activities of the methanolic extracts of dried rhizome powder were evaluated by 2, 2 – diphenyl -1-picrylhydrazyl (DPPH) radical scavenging activity. The protocol of Sharif *et al*. (2010) was followed with slight modifications. The stock solutions and working standards of sample extracts were prepared in methanol. Five different concentrations of the sample was taken in test tube and 1 ml of 0.04% (w/v) methanol solution of 2,2-diphenyl-1-picrylhydrazyl (DPPH) was added followed by 30 min of dark incubation. Using a UV spectrophotometer, the absorbance was measured at 517 nm. DPPH scavenging activity was expressed as the concentration of a sample required to decrease DPPH absorbance by 50% (IC_{50}). This value can be graphically determined by plotting the absorbance (the percentage of inhibition of DPPH radicals) against the log concentration of DPPH and determining the slope of the nonlinear regression.

Percentage DPPH radical scavenging activity was calculated by the following equation

$$\text{\% DPPH radical scavenging activity} = \frac{A_{control} - A_{test}}{A_{control}} \times 100$$

Where, $A_{control}$ - Absorbance of control reaction (containing all reagents except the test compound) and A_{test} - The absorbance of the test compound.

Similarly, antidiabetic activity was performed by α-glucosidase enzyme inhibition assay of methanolic extracts. The α-glucosidase activity was determined by measuring the absorbance at 405 nm against blank. The α-glucosidase inhibitory activity was calculated by the following equation (Fatemeh, 2020).

$$\text{\% } \alpha\text{-glucosidase enzymatic activity} = \frac{A_{control} - A_{test}}{A_{control}} \times 100$$

Where, Ac - Enzymatic activity absorbance without sample and At - enzymatic activity absorbance with sample. IC_{50} values were obtained from the equation plotted by the % α-glucosidase enzymatic activity against extract concentration.

Colour traits of turmeric powder

Precise chromic parameters of turmeric rhizome powder were done using Color meter (HunterLab). Colour meter was calibrated and standardised for its reflectance and absorbance

with white and black plate respectively. L*, a* and b* values were recorded, and mean values were used for statistical analysis. L* specifies brightness to lightness of the sample where value 0-50 indicates darkness/ brightness and value from 51-100 indicates lightness. Positive and negative values of a* point to redness and greenness respectively. Similarly, positive, and negative values of b* indicates yellowness and blueness of the sample (Kumaresh *et al.* 2020). The collective measurement of all three parameters are required to completely describe the rhizome color.

Statistical analysis

Data collected from laboratory experiments were subjected to analysis of variance (ANOVA) to determine the significance of the study. Duncan's multiple range test (DMRT) was applied to determine the significant variations. All experiments were carried out in triplicate and expressed as mean. The results were analysed to least significant difference and differences were considered significant at P value of < 1% (SAS, 2011).

Results and discussion

The GIs in India is protected by Geographical Indications of Goods (Registration and Protection) Act, 1999. It guarantees sole right to a particular place, region, locality, or country to utilize the name for a product with certain characteristics that corresponds to their specific location. Even though GI registration is not a mandatory, the registration can provide preferable legal safeguarding to smooth action on infringement of the protected product (Ravindran and Mathew 2009).

The rhizome characters *viz.,* length, girth, internodal length, and weight of the primary and secondary rhizomes of four GI turmeric are depicted in Table 1. The results revealed that, length (13.70 cm), girth (9.46 cm) and weight (65.63 g) of primary rhizomes were significantly high in Waigaon turmeric. Weight of secondary rhizome (20.02 g) was also found to be high in Waigaon turmeric. Length of secondary rhizome (6.78 cm) was high in Kandhamal haldi which was on par with Waigaon turmeric (6.34 cm). Internodal length (1.40 cm) was found to be high in Kandhamal haldi which was on par with Waigaon turmeric (1.26 cm). Though the length of secondary rhizomes of Erode

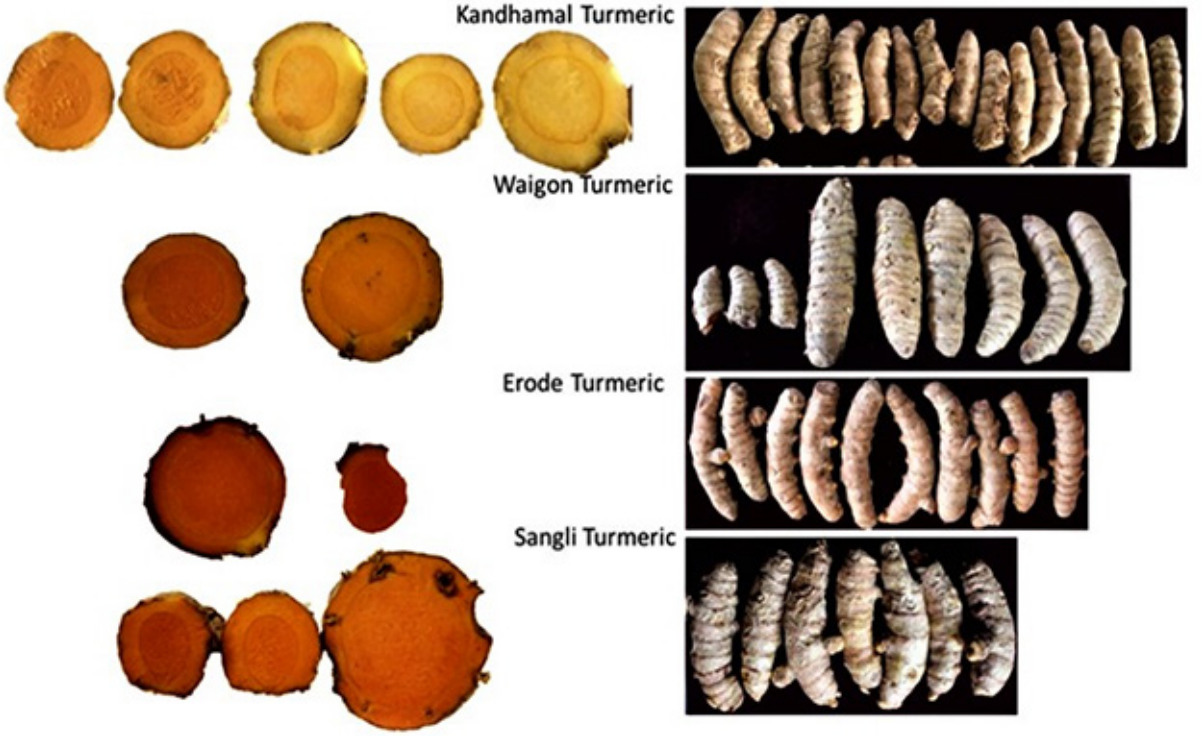

Fig. 1. Variability for the rhizome characters in Indian GI turmeric

Table 1. Rhizome characters of GI turmeric genotypes

Genotype	Primary length (cm)	Primary girth (cm)	Internodal length (cm)	Secondary length (cm)	Secondary girth (cm)	Weight of primary (g)	Weight of secondary (g)
Erode turmeric	8.80^{C}	6.24^{C}	0.90^{B}	5.66^{B}	4.56^{C}	20.14^{D}	9.14^{C}
Kandhamal haldi	10.46^{B}	7.88^{B}	1.40^{A}	6.78^{A}	5.18^{B}	36.31^{B}	10.72^{B}
Sangli turmeric	11.06^{B}	9.16^{A}	1.00^{B}	3.92^{C}	6.88^{A}	27.91^{C}	8.35^{D}
Waigaon turmeric	13.70^{A}	9.46^{A}	1.26^{A}	6.34^{AB}	5.60^{B}	65.63^{A}	20.02^{A}
Mean	11.01	8.19	1.14	5.68	5.56	37.50	12.06
CV (%)	6.92	8.03	13.38	8.94	6.35	1.70	3.83

turmeric was recorded on par with Waigaon turmeric, all other characters were found to be lowest in Erode turmeric. The growth and yield of the turmeric rhizomes greatly depends on the location specific planting methods, climatic conditions and soil fertility (Preetham *et al*. 2018).

The secondary metabolites of turmeric (OR and curcuminoids) are presented in Table 2. Waigaon turmeric was found to have significantly high OR (18.12%) and total curcuminoids (5.50%). The high OR content might be due to its high oil and high carbohydrate contents. The curcumin value of Erode turmeric was on par with Waigaon turmeric. Low curcuminoid (2.23%) turmeric Kandhamal haldi showed considerable OR (10.87 %). The lowest OR was recorded in Sangli turmeric (8.36%). Turmeric OR contain both curcuminoids and EO (Honda *et al.* 2006). In the present study, the variation in EO and curcuminoids were reflected in OR content of the Kandhamal haldi and Sangli turmeric. Turmeric with high curcumin and OR has been of great demand for industrial extraction of curcumin.

Table 2. OR and curcuminoids content of four different GI turmeric powders

Genotype	OR (%)	Curcuminoids (%)
Erode turmeric	13.20^{B}	5.26^{A}
Kandhamal haldi	10.87^{C}	2.23^{C}
Sangli turmeric	8.36^{D}	3.75^{B}
Waigaon turmeric	18.12^{A}	5.50^{A}
Mean	12.64	4.18
C V (%)	2.72	7.22
S E (d)	0.217	0.191

Quantification of individual curcuminoids by using HPLC showed curcumin was high in all GIs compared to DMC and BDMC (Fig 2). Among the fractions, curcumin ranged from 0.89% - 3.16 %; BDMC from 1.21% - 0.41% and DMC from 1.06-0.34%. The values were in the same trend as observed in spectrophotometry determination for curcumin content. Noticeably high BDMC was observed in Waigaon turmeric compared to other samples. The variations in the BDMC, DMC and CUR among the genotypes were based on many reasons, such as the variety, geographic location, cultivation as well as post-harvest processing conditions (Anandaraj *et al.* 2014; Aarthi *et al.* 2020).

The proximate composition, ash, carbohydrate, protein, and fat of four GI turmeric were compared and summarized in Table 3. Results showed Kandhamal haldi recorded significantly high ash content (14.31%) followed by Erode turmeric (13.96 %) which was on par with Sangli turmeric (13.72%). Turmeric ash, a measure of quality/grade of the material is the

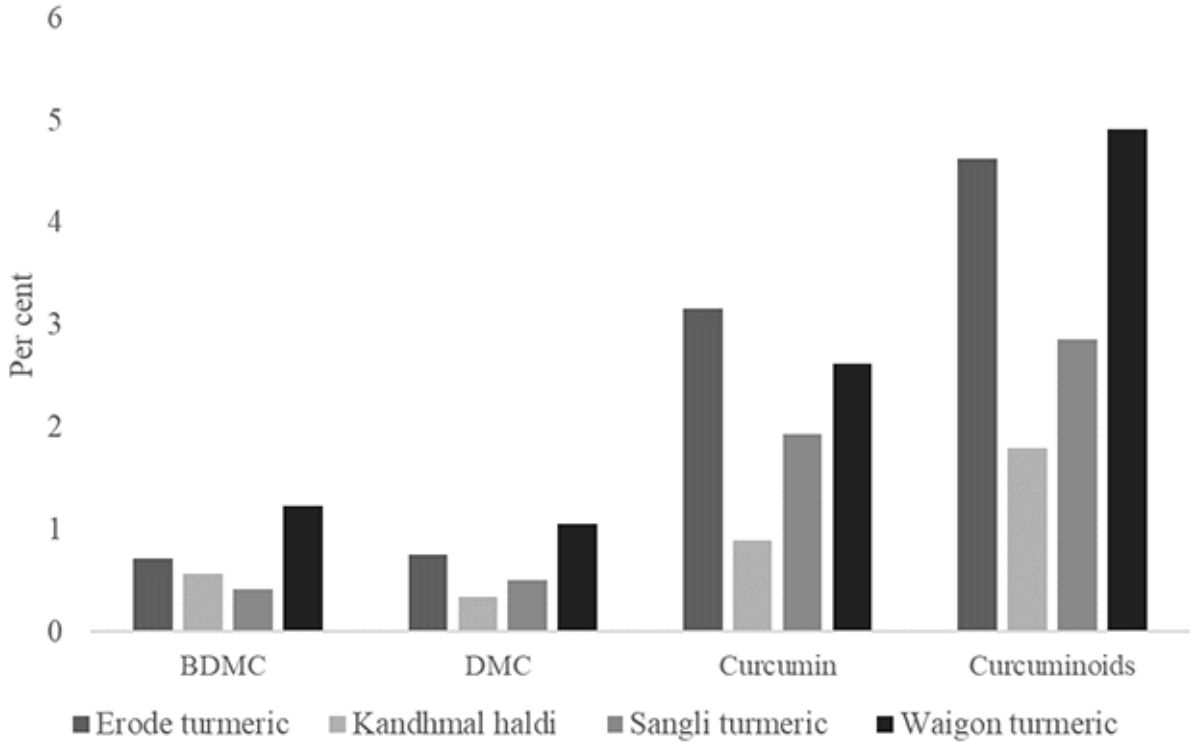

Fig. 2. Curcuminoid profile of four GI turmeric in India

inorganic residue left after complete burning. High ash value is the indication of inorganic compounds such as carbonates, phosphates and silicates (Nagarnaik *et al.* 2015). Lowest ash content observed in high curcuminoid Waigaon turmeric (12.16%) attributed its high quality.

Carbohydrate was notably high in Waigaon turmeric (73.71 %) and minimum in Erode turmeric (37.63 %). Erode turmeric recorded significantly high protein (4.64 %) followed by Kandhamal haldi (3.96 %) and Waigaon turmeric (3.61 %) which were on par and Sangli turmeric recorded the lowest protein content (2.61 %). Significantly high fat (9.16 %) was found in Sangli turmeric and the least in Erode turmeric (4.83%). Nisar *et al.* (2015) reported similar protein (6.47 ± 0.17 %), fat (2.7 ± 0.14 %), fibre (4.80 ± 0.13 %) and ash (3.49 ± 0.09 %) content in turmeric verities. All the four GI turmeric genotypes were found to be good source of protein and carbohydrate.

Analysis of mineral constituents of four GI turmeric (Table 4) showed that N (1.75 %), Mn

Table 3. Proximate composition of four different GI turmeric genotypes

Genotype	Ash (%)	Carbohydrate (%)	Protein (%)	Fat (%)
Erode turmeric	13.96^{AB}	37.63^{D}	4.64^{A}	4.83^{D}
Kandhamal haldi	14.31^{A}	49.55^{B}	3.96^{B}	5.81^{C}
Sangli turmeric	13.72^{B}	47.73^{C}	2.61^{C}	9.16^{A}
Waigaon turmeric	12.16^{C}	73.71^{A}	3.61^{B}	6.77^{B}
Mean	13.54	52.15	3.71	6.64
C V (%)	3.17	0.46	10.15	0.23
S E (d)	0.272	0.151	0.238	0.010

(91.50 ppm) and Zn (28.00 ppm) were high in Waigon turmeric. The phosphorus content of all the types were found to be at par. Significantly, high amount of K (3.19 %), Ca (0.50 %), Fe (251.50 ppm) and Mg (0.45 %) were found in Erode turmeric. The data obtained are in close proximity with the report of Mushtaq *et al.* (2019). Though the result could not highlight a specific GI turmeric with a considerable presence of all of these minerals, each variant is found to be consisting of one or two of the minerals in abundance. The report paves the way to select the most suitable GI turmeric keeping in mind the desired nutritional and mineral supplements. The variations in the values of mineral compositions of GI turmeric can be attributed to genotype, environment, agro-climatic conditions, and cultivation practices. Studies also reported the influence of environments and the variety on bioactivities and chemical compositions of turmeric (Khadija *et al*. 2021).

Table 5 highlights the EO and its GC-MS fingerprints. Among the four turmeric varieties, EO was found to be maximum in Waigaon turmeric (5.60 %) and minimum in Kandhamal haldi (4.00 %). Erode turmeric and Sangli turmeric had 4.80 % EO. Each EO was subjected to GC-MS analysis to estimate corresponding volatile constituents and a total of 22 major volatile components were identified. EO of turmeric mostly comprised of terpenes. The major components identified were aromatic-turmerones (ar-tumerones) (41.3 %), β-sesquiphellandrene (11.61 %), *α*-zingiberene (8.76 %), *α*-turmerone (15.15 %) and curlone (17.7 %). In addition, few other minor compounds were also identified. Naz *et al*. (2010) reported ar-turmerone (25.3 %), *α*-tumerone (18.3 %) and curlone (12.5 %) as the major components. Shiyou (2011) reported significant variations in EO compositions of different turmeric varieties and turmerones were considered as marker compounds for the rhizome quality (Shiyou *et al.* 2011). All the four GI turmeric varieties had >30 % turmerones. Also, high curcuminoid Erode turmeric recorded 41.3 % turmerone. The unique combination of EO-curcumin in turmeric will enhance anti-inflamatory efficacy by improving disease activity index compared to standard curcumin (Shusuke *et al*. 2017).

DPPH free-radical scavenging activity assay is one of the most common methods for investigating the antioxidant activities of plant products (Mushtaq *et al*. 2019) (Table 5). Antioxidants present in turmeric scavenge DPPH radical by contributing hydrogen atoms leading to a non-radical state with yellow colour (Akter *et al.* 2019). Though Erode and Waigaon turmeric recorded high curcuminoids, Waigaon turmeric showed the highest antioxidant activity with lowest IC_{50} (160.72 μg ml^{-1}) and Erode turmeric showed the lowest antioxidant activity with highest IC_{50} (194.25 μg ml^{-1}) value. The antioxidant activity of turmeric is not only contributed by curcuminoids but also by other compounds such as phenolics,

Table 4. Major minerals present in powders of four different GI turmeric varieties

Genotype	N (%)	P** (ppm)	K (%)	Ca (%)	Cu** (ppm)	Fe (ppm)	Mg (%)	Mn (ppm)	Zn (ppm)
Erode turmeric	0.87^{C}	0.41	3.19^{A}	0.50^{A}	5.00	251.50^{A}	0.45^{A}	39.63^{C}	12.25^{C}
Kandhamal haldi	0.80^{D}	0.45	2.81^{B}	0.08^{B}	5.50	210.50^{B}	0.10^{C}	57.25^{B}	19.63^{B}
Sangli turmeric	1.14^{B}	0.41	2.77^{B}	0.10^{B}	4.63	204.25^{B}	0.19^{B}	84.50^{A}	27.13^{A}
Waigaon turmeric	1.75^{A}	0.45	2.48^{C}	0.11^{B}	6.63	134.25^{C}	0.17^{B}	91.50^{A}	28.00^{A}
Mean	1.14	0.43	2.81	0.20	5.44	200.13	0.23	68.22	21.75
C V (%)	3.34	10.65	5.19	12.51	24.49	14.37	13.94	9.14	11.41
S E(d)	0.024	0.029	0.092	0.016	0.842	18.182	0.020	3.942	1.570

**=Non-significant

Table 5. Total EO yield and GC-MS composition of four GI turmeric genotypes

EO yield (%)		Waigaon turmeric	Erode turmeric	Sangli turmeric	Kandhamal haldi
		5.60	4.80	4.80	4.00
Compound	AI value	% composition			
α-phellandrene	1002	0.68	1.54	0.83	1.53
O-cymene	1022	0.2	0.47	0.48	0.65
Limonene	1024	0.07	0.16	0.13	0.18
Eucalyptol	1026	1.07	0.54	0.91	1.12
α-terpinolene	1086	0.11	0.26	0.15	0.06
α-terpineol	1186	0.12	0.04	0.07	0.07
α-santalene	1416	_	0.08	0.77	0.67
β-caryophyllene	1417	0.48	0.38	0.66	0.47
α-trans bergamotene	1432	0.07	0.06	0.35	_
γ-elemene	1434	_	_	_	0.43
β-farnesene	1440	0.45	0.15	0.68	0.44
α-caryophyllene	1452	0.29	0.02	0.34	0.23
α-acoradien	1464	0.1	_	0.04	0.03
α-curcumene	1479	2.24	2.37	4.9	3.07
γ- curcumene	1481	0.36	0.15	0.19	0.15
α-zingiberene	1493	7.4	2.46	8.76	5.52
β-bisabolene	1505	1.14	0.58	1.85	1.13
β-sesquiphellandrene	1521	8.86	2.77	11.61	7.83
Germacrene B	1559	_	_	1.68	1.75
α-turmerone	1595	15.15	6.58	8.38	7.49
ar-tumerone	1668	32.44	41.3	30.25	36.9
Curlone	1705	15.28	17.7	12.11	14.66

diarylheptanoids, phenylpropenoids, and terpenes to an extent (Gonzalez *et al.* 2012). The IC_{50} value of standard antioxidant ascorbic acid (152.48 μg ml^{-1}) was close to the value with that of the four GI turmeric samples, indicating that all the four are efficient and can be used as powerful natural antioxidants.

The potent antidiabetic activity of four GI turmeric is also evident the (Table 6). α -Glucosidase inhibitory activity was high in Waigaon turmeric (126.50 μg ml^{-1}) and low in Sangli turmeric (146.57 μg ml^{-1}). Standard acarbose showed IC_{50} value 265.71 μg ml^{-1}. Reports reveal that curcuminoids and ar-turmerone constitute have blood-glucose-lowering activity (Arun *et al*. 2003). The antidiabetic activity of these turmeric extracts indicates their solid protective role against lifestyle disease, diabetes mellitus and their promising use as medicine in the pharmaceutical industry.

Visual colour differences of four GI turmeric powder are depicted in Table 7. The colour of the turmeric rhizomes is mainly due to the curcumin content (Zorka *et al*. 2017). In the present study, the colour values of the samples ranged from L* (52.48 - 45.68), a* (24.77- 21.59) and b* (63.69 – 58.89). L*, a* and b* values of all the samples were positive, indicating the absence of any blue or green colour (Kumaresh *et al*. 2020). Highest L* (lightness) (52.48) and b* (yellowness) (63.69) were recorded in low curcuminoid Sangli turmeric and the visible colour of the same was bright yellow.

Table 6. Antioxidant and anti-diabetic activity of four GI turmeric genotypes

Genotype	DPPH scavenging activity (IC_{50} in μg ml^{-1})	α -Glucosidase inhibitory activity (IC_{50} in μg ml^{-1})
Erode turmeric	194.25^{A}	144.78^{B}
Kandhamal haldi	183.72^{B}	137.46^{C}
Sangli turmeric	178.79^{C}	146.57^{A}
Waigaon turmeric	160.72^{D}	126.50^{D}
Mean	179.37	138.83
C V (%)	0.35	0.19
S E (d)	0.078	0.166

Table 7. Colour measurements of four GI turmeric powders

Genotype	L*	a*	b*
Erode turmeric	51.14^{B}	21.59^{C}	59.81^{B}
Kandhamal haldi	48.66^{C}	22.25^{B}	59.35^{BC}
Sangli turmeric	52.48^{A}	22.24^{B}	63.69^{A}
Waigaon turmeric	45.68^{D}	24.77^{A}	58.89^{C}
Mean	49.49	22.71	60.44
C V (%)	0.17	0.21	0.62
S E(d)	0.053	0.030	0.236

L* specifies brightness to lightness of the sample where value 0-50 indicates darkness/brightness and value from 51-100 indicates lightness. Positive and negative values of a* point to redness and greenness respectively. Similarly, positive, and negative values of b* indicates yellowness and blueness of the sample.

The lowest L* and highest a* values for high curcuminoid Waigaon turmeric suggests that the colour of the turmeric rhizomes may be considered as dark orange. Turmeric genotype with dark orange colour exhibited better antioxidant potential (Kumaresh *et al.* 2020). Our results agree with their study and we also obtained better antioxidant activity for high curcuminoid Waigaon turmeric. In addition to curcumin, next colour giving content in turmeric is mainly BDMC. Waigaon turmeric had remarkably high BDMC and OR compared to other GI turmeric varieties.

Conclusion

This study documents a comprehensive profile of the phytochemical quality (EO, OR and curcumin), nutraceuticals (proximates and minerals) and *in vitro* bioactivities (antioxidant and antidiabetic activities) of four distinct GI turmeric rhizomes in India. Among the four GIs, dark orange coloured Waigaon turmeric recorded high EO (5.60 %), OR (18.12 %) and CUR (5.50 %). In addition, carbohydrate (73.71 %), N (1.75 %), Mn (91.50 ppm) and Zn (28.00 ppm) were also high in Waigaon turmeric. Moreover, Waigaon turmeric exhibited high DPPH scavenging activity (IC_{50} = 160.72 μg ml^{-1}) and high α- glucosidase inhibitory activity (IC_{50} = 126.50 μg ml^{-1}). With respect to rhizome traits also Waigaon turmeric stands superior among four GI turmeric. The curcumin content of Erode turmeric (5.26 %) was on par with Waigaon turmeric. It had high protein (4.64 %) and several minerals (K, Ca, Fe and Mg). Comparatively high fat (9.16 %) was observed in Sangli turmeric. Total turmerones (ar-turmerone, α-turmerone and curlone), the principal flavouring compounds in turmeric constitute 50-65 % in the EO of four GI turmeric varieties. These findings could be useful for identification of source-based GI turmeric and to understand their superior quality and health benefits.

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