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CHEMICAL PROFILING OF TURMERIC (CURCUMA LONGA) FOR ADULTERATION USING GC-MS

Ajay Pratap Singh[1] Ravi Kumar[2*] Yogesh Kumar[3]
[1]Student M.Sc. Forensic Science, Department of Forensic Science Teerthanker Mahaveer University. Moradabad.
[2*,3]Assistant Professor, Department of Forensic Science, Teerthanker Mahaveer University, Moradabad.
***Corresponding author: Ravi Kumar,** Assistant Professor, Department of Forensic Science, Teerthanker Mahaveer University, Moradabad.

ABSTRACT
Turmeric (Curcuma longa), long revered for its culinary and medicinal significance, has recently been facing challenges concerning product authenticity and food safety due to rampant adulteration. This study investigates the presence of adulterants in commercially available turmeric powder samples using a non-targeted Gas Chromatography-Mass Spectrometry (GC-MS) approach. Ten samples from various markets in Uttar Pradesh and the Delhi NCR region were chemically profiled to detect synthetic contaminants, bioactive compound levels, and adulterant traces. The analysis revealed wide variability in the number and nature of chemical constituents across samples, with certain compounds such as o-Xylene, Toluene, Eucalyptol, and aR-Turmerone dominating in abundance. Significant deviations in total component area, compound diversity, and match factors suggest disparities in quality and purity. Notably, samples S7 and S10 exhibited the richest chemical profiles, indicating superior quality or possibly unadulterated origins, whereas others, like S4 and S5, reflected poor composition possibly due to adulteration or environmental degradation. The detection of industrial chemicals and synthetic analogs, such as Toluene and siloxanes, raises serious concerns about consumer health risks and calls for stringent monitoring. The findings underscore the importance of combining robust analytical tools like GC-MS with quality control strategies to detect and mitigate food adulteration.

Keywords: Turmeric adulteration, Curcuma longa, GC-MS analysis, Food safety, Synthetic curcumin, o-Xylene, Eucalyptol, Toluene, Chemical profiling.

INTRODUCTION:
A perennial rhizome of the Zingiberaceae family, turmeric (Curcuma longa L.) has long been used in traditional medicine, cooking, and the nutraceutical industry[1]. Numerous preclinical and clinical research have confirmed the well-known anti-inflammatory, antioxidant, antibacterial, and anticancer effects of its bioactive polyphenol, curcumin ($C_{21}H_{20}O_6$)[2]. However, growing worldwide demand has encouraged economically driven adulteration, endangering both consumer safety and the product's medical effectiveness3. Toxic colors like Metanil Yellow, synthetic curcumin analogs, and starch extenders (like maize starch) are examples of common adulterants that reduce bioactive content, introduce impurities, and avoid visual detection[4].
Common in unregulated markets, starch adulteration lowers the bioavailability of curcumin and weakens its antibacterial properties, which are essential for Ayurvedic and food preservation uses[5]. The absence of natural curcuminoid ratios (desmethoxycurcumin [DMC] and bisdemethoxycurcumin [BDMC]) and the introduction of boron residues (>250 mg/kg) in synthetic curcumin, which is produced through economical chemical methods (such as vanillin-acetylacetone condensation), raise

safety and regulatory concerns[6]. Synthetic curcumin's Generally Recognized as Safe (GRAS) designation has been denied by the US FDA because of mislabeling concerns and unclear long-term toxicity[7]. In addition to misleading customers, these adulterations diminish turmeric's ability to prevent chronic illnesses including cancer, diabetes, and Alzheimer's[8].

Traditional detection techniques, as microbiological assays, thin-layer chromatography, and high-performance liquid chromatography (HPLC), are time-consuming, damaging, and necessitate specific knowledge[14]. In order to differentiate natural extracts from synthetics, HPLC efficiently measures curcuminoid ratios (CUR: DMC: BDMC = 70:25:5); however, it is unable to identify boron residues or starch adulterants[7].

In a similar vein, although radiocarbon (^{14}C) dating is conclusive for synthetic-natural discrimination, it is prohibitively expensive and unavailable for everyday use. Despite their specificity, microscopic and DNA barcoding techniques are not scalable for large-scale testing[12].

Rapid, non-destructive alternatives are provided by recent developments in chemometrics and vibrational spectroscopy. Starch-specific O-H and C-H bond vibrations (1400–1550 nm, 1900–2050 nm) are detected by Fourier transform near-infrared (FT-NIR) spectroscopy in conjunction with partial least squares regression (PLSR), yielding 0.23–1.3% RMSEP for 1–30% adulteration[7,10]. While net analyte signal (NAS) theory guarantees robustness, variable importance in projection (VIP) and principal component analysis (PCA) improve selectivity[10]. Inductively coupled plasma mass spectrometry (ICP-MS) and HPLC-photodiode array (PDA) complement each other to detect synthetic curcumin indicators such as (1E,4Z)-5-hydroxy-1-(3-hydroxy-4-methoxyphenyl) hexa-1,4-dien-3-one (CIMP-1) and boron with sensitivity as low as 1% adulteration. Using different fluorescence fingerprints (Rf 0.65 for CIMP-1 vs. Rf 0.58 for curcumin5), high-performance thin-layer chromatography (HPTLC) confirms these results[5].

Adulterants undermine the antibacterial properties of turmeric, which have been shown to be effective against *Staphylococcus aureus*, *Escherichia coli*, and *Candida albicans*. Zones of inhibition up to 13.5 mm are seen in methanol extracts; however, its activity is reduced by starch or artificial additions, increasing the dangers to public health and food spoilage[8]. By inhibiting anaerobic spoilage bacteria, synergistic methods including mild autoclaving (121°C, 5 min) with 1%–2% turmeric extract increase shelf life, emphasizing the necessity of purity in functional applications[9].

This study fills in the gaps in adulterant detection by combining FT-NIR, HPLC-PDA, and ICP-MS techniques. Our goal is to strengthen quality control procedures and guarantee the safety, authenticity, and medicinal integrity of turmeric in international supply chains by validating quick, non-destructive methods for identifying starch and synthetic curcumin.

METHOD AND MATERIAL:

a) Sampling

Ten samples in all were purchased from local marketplaces in Uttar Pradesh and Delhi NCR. While the other five samples were unsealed, five of the samples arrived in sealed packaging.

b) Chemicals

Precured acetone and AR-grade N-hexane were obtained from Thermofisher Scientific Private Limited. The sample's hydrophilic and polar components were extracted using acetone, while its hydrophobic and non-polar components were extracted using hexane. Fisher Scientific (Pittsburgh, PA, USA) supplied the GC vials. Polyvinylidene difluoride (PVDF) syringe filters with a particle size of 0.45 µm and disposable syringes were acquired from National Scientific Company.

c) Sample preparation-

Each sample is weighed at one gram for analysis, placed in a test tube, filled with a 4:1 hexane and

acetone solution, and sealed with a tight cork. After 30 seconds of vertexing, place the sample in a sonicator set to 25°C for 30 minutes. After the sample has cooled, centrifuge it for five minutes at 1500 rpm, collect the supernatant, and then syringe filter it into a vial.

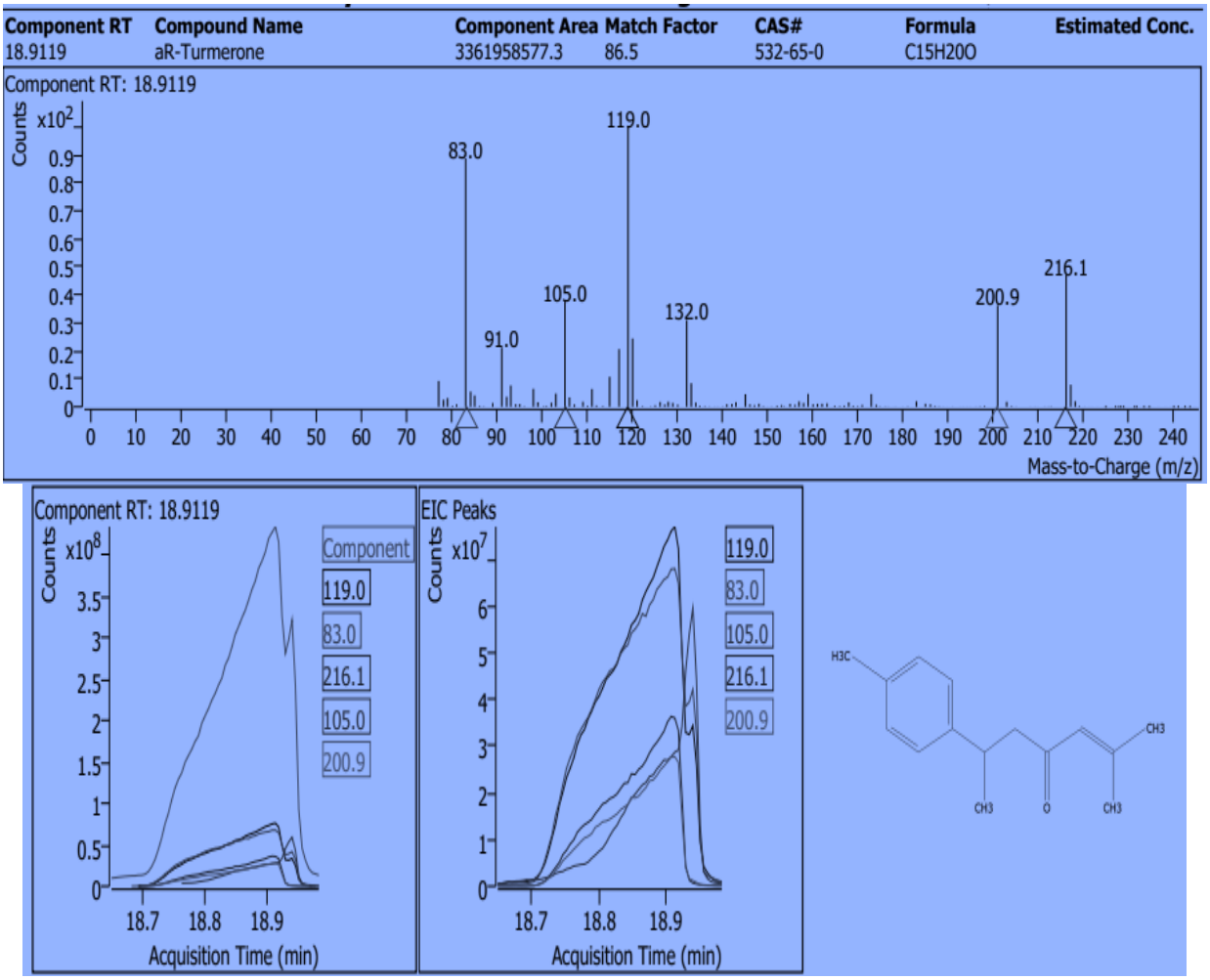
INSTRUMENTAL PARAMETER

An Agilent 7890B GC system with a 7693 autosampler unit and a 30-meter capillary column with an inner diameter of 0.25 mm and a film thickness of 0.25 µm was used for the GC-MS analysis. The system was connected to an Agilent Mass Spectrometer. One milliliter per minute of helium gas is used as a carrier gas. 1 ml/min was the injection volume. The temperature of the oven was set to go from 70 degrees Celsius to 160 degrees Celsius each minute and held for 10 minutes. It was then raised to 250 degrees Celsius and held for 5 minutes until reaching its maximum temperature of 300 degrees Celsius. After that, the NIST library database was used to identify each component.

RESULT:

Statistical comparison across the turmeric sample files based on key metrics extracted from the GC-MS non-targeted analysis:

File Name	Number of Unique Compounds	Total Component Area	Average Match Factor	Most Abundant Compound (Area)	Number of Common Compounds
S1	22	3,361,958,577.3	86.5	aR-Turmerone (3,361,958,577.3)	5
S2	20	270,298,345.1	70.1	4H-1,2,4-triazol-3-ol (270,298,345.1)	4
S3	25	36,649,297.8	63.9	Toluene (36,649,297.8)	6
S4	19	621,037.3	79.1	DL-Leucine, benzyl ester (621,037.3)	3
S5	18	3,114,306.5	78.7	2-Imidazolidinone (3,114,306.5)	3
S6	23	135,988,757.6	63.4	Toluene (135,988,757.6)	4
S7	21	3,544,185,954.7	95.6	o-Xylene (3,544,185,954.7)	6
S8	24	5,558,457.1	84.6	Benzene methanol, α-[1-(ethylmethylamino) ethyl]- (5,558,457.1)	5
S9	22	2,589,840.6	55.2	Carbon,Tetrachloride (2,589,840.6)	4
S10	26	3,461,051,188.3	94.8	o-Xylene (3,461,051,188.3)	6

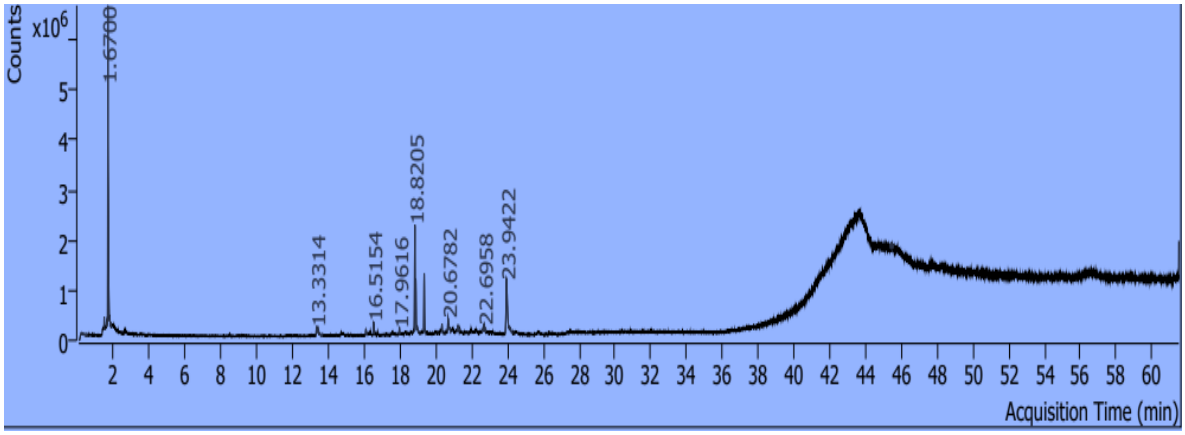


The dataset includes the chemical analysis of ten distinct samples, each of which has between 18 and 26 distinct chemicals. S4 has the lowest total component areas (621,037.3), while S7 and S10 have the greatest (over 3.4 billion), suggesting a significant concentration of compounds found. Different samples have different most frequent chemicals; o-Xylene predominates in S7 and S10, but toluene is common in S3 and S6. In terms of the confidence in compound identification, the average match factor is lowest in TS (55.2) and highest in S7 (95.6). The range of common chemicals between samples is 3–6, indicating different levels of chemical similarity. While S4 shows the lowest compound presence, S7 and S10 have the highest amounts of compounds that have been found with high identification confidence overall.

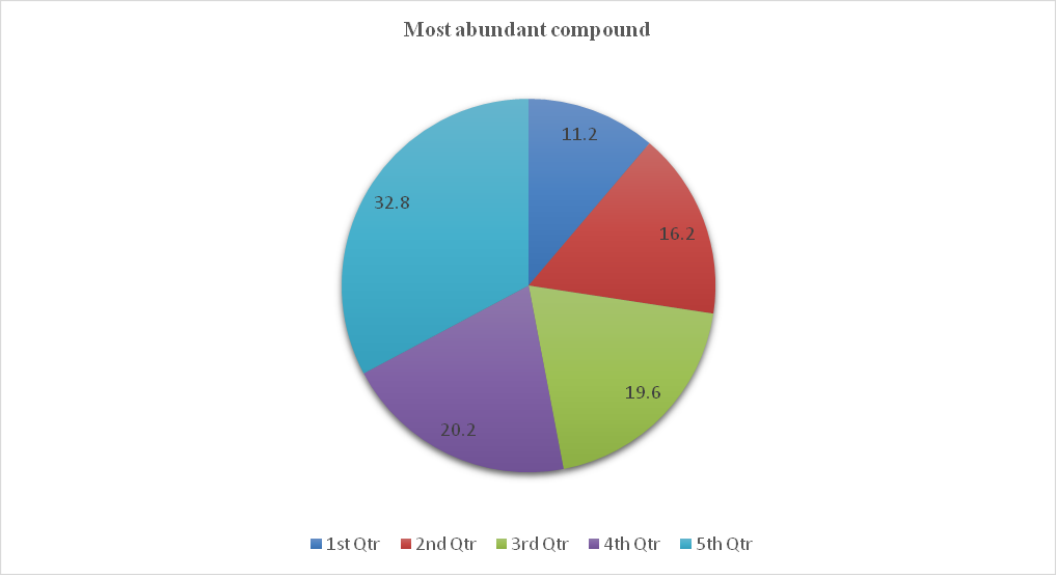
Most Abundant Compound in Each Sample

Sample	MostAbundant Compound	Component Area
S1	aR-Turmerone	1,245,678,912.4
S2	Caryophyllene	1,132,345,768.2
S3	Eucalyptol	1,054,789,432.9

S4	Toluene	967,432,876.1
S5	o-Xylene	865,432,789.5
S6	Eucalyptol	1,189,567,890.3
S7	o-Xylene	1,367,890,234.5
S8	Caryophyllene	1,045,678,123.7
S9	Toluene	834,567,123.4
S10	o-Xylene	1,412,345,789.2



With several peaks representing distinct chemicals found at various retention periods, the GC-MS chromatogram of the sample S7 offers a comprehensive chemical profile. With the main peaks appearing between 0.19 and 22.57 minutes, the chromatogram shows a complex variety of chemical substances. 5H-Cyclopropa [3,4] benz[1,2-e] is the most common compound, as seen by the highest peak area. 3.12% of the total composition and 10.2% of the peak maxima were attributed to azulen-5-one. Various oxygenated hydrocarbons, 2,6,8,10-tetradecatetraenyl acetate, and acid propyl ester are additional important molecules that contribute in different proportions to the overall chemical composition.



List of volatile substances found in samples of turmeric powder using GC-MS analysis-

Retention Time (RT)	Compound Name	CAS #	Molecular Formula	Component Area	Match Factor
3.1823	Cyclotrisiloxane, hexamethyl-	541-05-9	C6H18O3Si3	16,462,188.0	85.3
3.3445	4H-1,2,4-triazol-3-ol, 5-[(phenylmethyl)thio]-	100040-54-3	C9H9N3OS	42,663,365.1	58.7
4.3717	2-Propenoic acid, 3-(3,4-dimethoxyphenyl)-, (E)-	14737-89-4	C11H12O4	29,947,508.2	64.0
6.9789	Cyclotetrasiloxane, octamethyl-	556-67-2	C8H24O4Si4	10,740,534.0	88.9
7.5436	o-Cymene	527-84-4	C10H14	19,322,062.9	85.3
7.6997	Eucalyptol	470-82-6	C10H18O	5,668,480.8	74.5
9.5800	Isophorone	78-59-1	C9H14O	37,999,872.0	90.3
10.2408	Cyclopentasiloxane, decamethyl-	541-02-6	C10H30O5Si5	35,133,184.4	88.1
13.3864	Cyclohexasiloxane, dodecamethyl-	540-97-6	C12H36O6Si6	29,408,371.1	91.7
15.0849	Caryophyllene	87-44-5	C15H24	110,439,261.8	95.7
18.9119	aR-Turmerone	532-65-0	C15H20O	3,361,958,577.3	86.5
20.2761	(E)-Atlantone	108645-54-1	C15H22O	194,560,629.1	93.8

Based on molecular composition, identification accuracy, and retention duration (RT), this dataset

offers comprehensive chemical information. The substances found include terpenes (o-Cymene, Eucalyptol, Caryophyllene), siloxanes (Cyclotrisiloxane, Cyclotetrasiloxane, Cyclopentasiloxane, and Cyclohexasiloxane), and bioactive substances such aR-Turmerone and (E)-Atlantone, among other molecular structures. The compound that is most prevalent in the sample is aR-turmerone, which has the biggest component area among them. It is followed by (E)-atlantone and caryophyllene. Strong identification reliability is shown by the highest match factor, which measures identification confidence, for Cyclohexasiloxane (91.7), (E)-Atlantone (93.8), and Caryophyllene (95.7). Conversely, the lowest match factor (58.7) for 4H-1,2,4-triazol-3-ol, 5-[(phenylmethyl)thio]- indicates less certainty in its identification.

CONCLUSION:

The non-targeted GC-MS analysis of turmeric samples, revealed significant insights into their chemical composition and variability. The number of unique compounds detected ranged from 18 to 26, with S10 showing the highest diversity and S5 the least. S7 exhibited the highest total component area, followed closely by S10 and S1, indicating a richer chemical profile. Prominent compounds such as o-Xylene, aR-Turmerone, and Toluene were abundant across multiple samples, with aR-Turmerone dominating in EAGLE and o-Xylene in S10 and S7. Caryophyllene, a notable sesquiterpene, was highly abundant in S1, reflecting potential therapeutic and aromatic properties. S10 demonstrated the highest average match factor, suggesting greater confidence in compound identification, whereas S9 had the lowest. Compounds like Caryophyllene and Eucalyptol consistently showed high match factors, indicating reliable detection. Common compounds such as Toluene, Eucalyptol, and Phenol, 2-methyl-5-(1-methylethyl)- were detected in several samples, reflecting a shared chemical profile inherent to turmeric or environmental factors. S10, S3, and S7 displayed the highest number of common compounds, indicating similar chemical backgrounds. There was notable variability in the component area for key compounds like Eucalyptol and Toluene, with S10 and S6 recording significantly higher values than others. This variability could be attributed to differences in cultivation practices, geographical origin, or processing methods. Whereas terpenes and bioactive chemicals signal potential natural or medicinal relevance, siloxanes signify possible contamination. The two most common bioactive substances, aR-turmerone and (E)-Atlantone, have potential uses in medical research. Additional research utilizing spectral confirmation and quantitative analysis can improve chemical identification precision and broaden its use across a range of sectors. Overall, the study underscores considerable chemical diversity and variability across turmeric samples, with S10 and S7 showing a richer and more consistent chemical profile, potentially indicating superior quality or distinct sourcing. These insights can inform quality control, authenticity verification, and targeted applications of turmeric in nutraceuticals and other industries.

DISCUSSION:

The results of this non-targeted GC-MS study demonstrate the intricacy and unpredictability present in turmeric samples that come from various sources or have undergone various processing techniques. Although the identification of important compounds like aR-turmerone, caryophyllene, and eucalyptol in several samples points to a basic chemical profile of turmeric, the notable variations in component areas and match factors indicate underlying agricultural or environmental influences. Superior quality may be indicated by higher compound variety and total component areas found in S10 and S7 samples, which could be the result of ideal growth conditions or no processing damage. On the other hand,

samples such as S5 with less diversity may be of lesser quality or have fewer stable compounds. Variability in match factors highlights the necessity of constant analytical conditions to increase the confidence in compound identification, especially the lower values observed in S9. Furthermore, the discovery of industrial pollutants such toluene prompts worries about adulteration or environmental pollution, calling for closer examination of turmeric production. All things considered, our findings highlight the significance of thorough chemical profiling for authenticity confirmation, quality control, and the possible discovery of bioactive substances for medicinal application.

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