**Turmeric (Curcuma longa)**

Root and Rhizome, and Root and Rhizome Extracts

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**Keywords:** Curcuma longa, turmeric, adulteration, turmeric root, turmeric rhizome, turmeric powder, curry, turmeric oleoresin, curcuminoids, curcumin

**Goal:** The goal of this bulletin is to provide information on issues of adulteration of turmeric (Curcuma longa) root, turmeric extracts, and curcuminoids, in particular with zedoary (Curcuma zedoaria, syn. C. malabarica), yellow colorants, and synthetic curcumin†. Also discussed is the mislabeling of previously extracted (spent) underground parts of turmeric as genuine turmeric root and rhizome. The bulletin may serve as guidance for quality control personnel, the international herbal products industry, and extended natural products community in general. It is also intended to present a summary of the scientific data and methods on the occurrence of species substitution, adulteration, the market situation, and economic and safety consequences for the consumer and the industry.

1. General Information

**Common Names:** Turmeric, common turmeric, Indian saffron*, yellow ginger1-3

1.2 Other Common Names:

Arabic: Kurkum4  
Assamese: Lidar, halodhi1,4,5  
Bengali: Halud1,4,5  
Burmese: Tanum1  
English: Curcuma2,6  
Cambodian: Ro miet7

† Curcumin in this document is defined as the chemical compound diferuloylmethane, or \( (1^E,6^E)-1,7\)-bis(4-hydroxy-3-methoxyphenyl)hept-1,6-diene-3,5-dione. The term curcumin is also used by members of the dietary supplement industry to describe a turmeric extract enriched in curcuminoids at a ratio of curcumin:demethoxycurmin:bisdemethoxycurcumin of approximately 77:17:3. To avoid confusion, extracts enriched in curcuminoids will be indicated as turmeric extracts.

‡ The Chinese Pharmacopoeia lists the dry tuberous root of Curcuma longa, C. kwangsiensis, C. phaeocaulis, and C. wenyujin as yu jin. Curcuma longa is specified as huang si yu jin.

Chinese: Jiang huang (姜黄), [huang si] yu jin (郁金),4,8,9 jianghuang,10 yu chin4  
Danish: Gurkemeje10  
Dutch: Geelwortel4  
Filipino (Tagalog): dilau, luyang-dilau11  
French: Curcuma, safran des Indes10  
German: Kurkuma, Gelbwurzel10  
Gujarati: Haldar (હળદર)1,4,5  
Hindi: Haldi, haldee (हल्दी)12,13  
Italian: Curcuma, zafferano delle Indie, turmerico4  
Japanese: Ukon4  
Kannada: Arishina, arisina1,4,5  
Laotian: Khì min7  
Malay: Kooneit1  
Malayalam: Manjal1,4,5  
Marathi: Halad (हल्द)1,4,5  
Nepali: Besar (बेसार)1,4,5,14  
Norwegian: Gurkmeie  
Oriya: Haladi1,4,5  
Portuguese: Acafrao-da-India4  
Russian: Yellow ginger - zheltyj imbir’ (жёлтый имбирь), curcuma (куркума)4,14  
Spanish: Curcuma4  
Sanskrit: Gauti, varnavat, haridra, marmadri, nisha, shati4,10,13,14, haridra13  
Swedish: Gurkmeja1,4,5  
Tamil: Manjal1,4,5  
Telugu: Pasupu, haridra4  
Urdu: Haldi (ہالدی)5,12  
Vietnamese: Nghẽ, uât kim7,14

The term “Indian saffron” is also used for saffron (Crocus sativus, Iridaceae) cultivated in India; the two materials should not be confused.

The Chinese Pharmacopoeia lists the dry tuberous root of C. longa, C. kwangsiensis, C. phaeocaulis, and C. wenyujin as yu jin. Curcuma longa is specified as huang si yu jin.
1.3 Accepted Latin binomial: *Curcuma longa* L.

1.4 Synonyms: *Curcuma domestica*²,¹⁰,¹⁵,¹⁶

1.5 Botanical family: Zingiberaceae

1.6 Distribution: The plant is native to Southeast Asia, especially India.¹¹,¹³-¹⁵ It is available in all states of India, but particularly in Tamil Nadu, West Bengal, and Maharashtra.¹³ Turmeric is a tropical crop cultivated at sea level to 1,200 meters above sea level. It grows in light black clay loam soils and red soils under irrigated and rainfed conditions.⁴ Turmeric is extensively cultivated in India, Pakistan, China, Haiti, Jamaica, Peru, Taiwan, Nigeria, Bangladesh, and Thailand. Other important producers include Japan, Indonesia, Sri Lanka, Burma (Myanmar), Cambodia, Malaysia, and the Philippines.⁷,¹⁷-²⁰ It has a wide distribution as a non-native species in Madagascar, Oceania, and the Antilles.⁵,⁷

1.7 Plant part and form: *Curcuma longa* is an herbaceous perennial reaching 1.5 m (4.9 feet) in height. The part of the plant used is the rhizome, which is of stout, short, cylindrical, or ellipsoidal structure, lateral-growing, branching, and generally subterranean. It has a golden yellow color inside.⁴,⁷,¹³ The rhizome is used as a fresh root, powder, herbal tea, or after extraction, as oleoresin, dry extract, or tincture with 70% ethanol.²,¹⁷ The deep orange-yellow powder known as turmeric is prepared from peeled, boiled, and dried rhizomes of the plant.²¹

Depending on its origin and the soil conditions where it is grown, turmeric rhizome naturally contains between 2–9% curcuminoids.²²

1.8 General uses: The rhizome is used as a condiment, an ingredient in curry powder, and for coloring food, cotton, silk, and wool.¹³ The powder is most widely used as a spice to color and flavor food, such as mustard, cheese, and butter, and is consumed along with many foods.²³ Turmeric spice is incorporated into teas and is a base component in many culinary spice blends, specifically curry. It is a component in ethnic dishes like kedgeree and piccalilli (England), *sorfito* (Africa), and *la-kama* (Morocco).¹⁷ Turmeric is extensively used in the Indian systems of medicine (Ayurveda, Siddha, and Unani), as well as in Eastern Asian systems (traditional Chinese medicine [TCM], Japanese Kampo, Korean, and Malay medicine).¹⁷ Since the 1970s, *Curcuma longa* has been included in recognized pharmacopeial monographs and compendial works, including the German Commission E, *United States Pharmacopeia, British Pharmacopoeia, European Pharmacopoeia, Mexican Herbal Pharmacopoeia, Japanese Pharmacopoeia, Korean Herbal Pharmacopoeia, Pharmacopoeia of the People’s Republic of China, Ayurvedic Pharmacopoeia of India, Unani Pharmacopoeia of India*, and many others.¹¹,¹³,¹⁷,²¹,²⁵ Turmeric uses include: indigestion (dyspepsia) treatment and joint pain alleviation, as an antioxidant, and as a choleretic to increase bile excretion and stimulate gallbladder contraction (cholagogue).²⁶ Turmeric is also used topically in the treatment of skin conditions and as an insect repellent.²⁴,²⁵,²⁷ In Ayurvedic medicine, turmeric is primarily used as a treatment for inflammatory conditions²⁵ and in TCM, it is used mainly as stimulant, aspirant, carminative, cordial, emmenagogue, astringent, detergent, and diuretic.²¹,²⁸,²⁹ Additional indications based on recent pharmacological studies include the prevention of cardiovascular disease and cancer, improvement of liver function, metabolic syndrome, topical treatment of skin diseases, and as adjuvant to conventional cancer therapy.¹⁰,³⁰,³¹

1.9 Nomenclature considerations: Turmeric is the dried rhizome or bulbous root of *Curcuma longa*, distinguished by the presence of the orange pigment curcumin. Several other species of *Curcuma*, e.g., *C. aromatica* and *C. zedoaria*, are also known to contain curcumin, which has caused some confusion in the local vernacular names used in India.³²

Today, *C. domestica* is considered a synonym of *C. longa*,²,¹⁰,¹⁵ but in older reference books the two were not considered the same.³²,³³ Guenther, in Volume V of his book *The Essential Oils*, p. 123, categorically differentiated *C. domestica* as a distinct species.³²

Earlier references confused *C. caesia* and even *C. zedoaria* with *C. longa*.³² The Dictionary of the Economical Products of India suggested that the so-called forms of *C. longa* were tubers of different species. *The Wealth of India*, published in 1950 by the Indian Council of Scientific and Industrial Research, mentioned *C. longa* substitution with *C. aromatica*, as well as its close resemblance to *C. zedoaria*.³² Both of these species, particularly the latter (local name Kachura, Soti), are considered to be adulterants and have been reportedly mixed with *C. longa* in powdered form.³²

### Table 1: US Dollar sales data in the natural channel for turmeric dietary supplements from 2012–2016

<table>
<thead>
<tr>
<th>Year</th>
<th>Rank</th>
<th>Sales [US $]</th>
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<tbody>
<tr>
<td>2012</td>
<td>3</td>
<td>16,873,153</td>
</tr>
<tr>
<td>2013</td>
<td>1</td>
<td>20,082,843</td>
</tr>
<tr>
<td>2014</td>
<td>1</td>
<td>28,245,699</td>
</tr>
<tr>
<td>2015</td>
<td>1</td>
<td>37,334,821</td>
</tr>
<tr>
<td>2016</td>
<td>1</td>
<td>47,654,008</td>
</tr>
</tbody>
</table>

According to SPINS (SPINS does not track Whole Foods Market sales, which is a major natural products retailer in the US). Source: Smith et al., 2017,³⁵ Smith T (American Botanical Council) email communications, September 2-3 2015; K. Kawa (SPINS) email communication, July 11, 2016.

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2. Market

2.1 Importance in the trade: Turmeric-based dietary supplements (which also include standardized extracts with high concentrations of curcumin) have seen a steady increase in popularity in the United States and elsewhere (Tables 1 and 2). In the United States, the largest market for turmeric supplements, sales have almost tripled from 2013 to 2016, totaling over US $69 million (not including sales at stores like Walmart, Costco, and Whole Foods) in 2016, with ca. 70% being sold in the natural channel (Table 1).

2.2 Supply sources: India is by far the largest consumer, producer, and exporter of turmeric rhizome and turmeric essential oil, turmeric oleoresin, and turmeric preparations. Other important producers of turmeric are China and the countries of the West Indies.

Turmeric is grown all over India, but different sources contend as to which geographic region is more widely cultivated and produced. The Annual Report of the Spices Board India, Ministry of Commerce & Industry, Government of India, mentions 190,420 hectares of turmeric under cultivation, resulting in a yearly production equivalent to 843,530 metric tons in 2015-2016. This was an increase from the 178,470 hectares used for turmeric cultivation in 2014-2015. According to the Spices Board of India, turmeric is extensively cultivated in the Northeastern States, where agro-climatic conditions are more suitable for its cultivation. Yet, other sources indicate that production of turmeric is greater in South and Central India, with Andhra Pradesh state accounting for 60% of total turmeric production, followed by Tamil Nadu (13%), and Orissa (12%). In fact, the productivity of turmeric in Andhra Pradesh state is estimated at a 5,404 kg/ha, which is 33% higher than the national average (A. Benny [Arjuna Natural] email communication, May 5, 2017). The word “curcuminoid” is used to describe a mixture of diarylheptanoids, mainly consisting of curcumin, demethoxycurcumin, and bisdemethoxycurcumin. Turmeric oleoresin, curcuma oil, or oil of turmeric is referred to as the organic extract of turmeric containing the volatile oil, but also resin waxes and other secondary metabolites, obtained by non-aqueous solvent extraction, with curcumin being the major component. Turmeric oleoresin may contain up to 55% curcumin. Curcumin is sometimes also referred to as a purified extract containing a mixture of the three major curcuminoids but most often describes a specific diarylheptanoid, also known as diferuloylmethane.

Table 2: US Dollar sales data in the mass market channel for turmeric dietary supplements from 2012–2016

<table>
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<tr>
<td>22</td>
<td>9,752,445</td>
<td>30</td>
<td>4,428,543</td>
<td>29</td>
<td>7,227,447</td>
</tr>
<tr>
<td>10</td>
<td>22,057,946</td>
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</table>

According to SPINS/IRI (the Mainstream Multi-outlet channel was formerly known as food, drug, and mass market channel [FDM], exclusive of possible sales at Walmart from 2013-2015). Source: Smith et al., 2017.35 Smith T (American Botanical Council) email communications, September 2-3 2015; K. Kawa (SPINS) email communication, July 11, 2016.
2.4 Market dynamics: In the 2015-2016 period, a total volume of 88,500 metric tons of turmeric was exported from India, versus 86,000 tons in the preceding period of 2014-2015.\textsuperscript{4}

Besides India, many other Asian, Latin American, and Caribbean countries have entered turmeric production. Vietnam and Pakistan, as well as traditional-producing countries like Peru, have also increased their production level.

Since the late 1980s, the area, production, and productivity of turmeric have exhibited an increasing trend. India is the most important exporter of turmeric, and the United Arab Emirates are the major importer of turmeric from India, followed by the United States, Japan, the United Kingdom, Iran, Singapore, Sri Lanka, and South Africa. Turmeric export registered a growth rate of 7.56%, 17.19%, and 8.95% in terms of quantity, value, and unit value, respectively, during the period 1981-1982 to 2000-2001. The International Trade Centre, Geneva, has estimated an annual growth rate of 10% in the world demand for turmeric.\textsuperscript{36}

3. Adulteration

3.1 Known adulterants: The fact that this spice is frequently sold in powdered form (which renders identification to species by macroscopic visual inspection impossible) makes it more susceptible to mixing with extraneous, lower-cost botanical ingredients, starches, chalk powder, cassava, and synthetic dyes.\textsuperscript{32,37-40} A report has raised the issue regarding what appears to be the trade of turmeric roots that were pre-extracted and mixed with non-extracted roots. The spent roots were lighter, less dense, and of a red color different from the roots that did not appear to be pre-extracted. (R. Upton email communication to S. Gafner, April 16, 2018). Whole rhizomes of turmeric have also been found to be adulterated with species from the same genus containing curcumin, e.g., C. zedoaria.\textsuperscript{32,38,40,41}

The first report of adulteration of C. longa with C. zedoaria and C. aromatica was published in the 1970s.\textsuperscript{32} Curcuma zedoaria, a wild relative of turmeric, also sometimes known as white turmeric, is a plant easy to mix with turmeric powder due to its close resemblance and wide availability. The plant is indigenous to Bangladesh, Sri Lanka, and India, and is also widely cultivated in China, Japan, Brazil, Nepal, and Thailand.\textsuperscript{32,42} Adulteration has also been reported with C. zanthorrhiza.\textsuperscript{33}

Turmeric powder has been subject to adulteration with potentially toxic chemical compounds. Metanil yellow (sodium 3-[4-anilinophenylazo] benzenesulfonate) is a synthetic, non-permitted food color and additive, which has been used as a turmeric adulterant, since it mimics the color appearance of curcumin.\textsuperscript{37,44} Other dyes which have been cited as adulterants in turmeric are lead chromate,\textsuperscript{27,39,43} acid orange 7 (sodium 4-[[2(E)-2-(2-oxonaphthalen-1-ylidene) hydrazinyl]benzenesulfonate),\textsuperscript{45} and Sudan Red G.\textsuperscript{46} Turmeric is also diluted with yellow soapstone powder, a natural mineral.

Extracts standardized to curcuminoids are among the fastest-growing herbal ingredients presently in the United States (Tables 1 and 2). Prices for natural curcuminoids from C. longa are above $150/kg, about three times that of synthetic curcumin, which costs around $50/kg. This has given rise to unethical suppliers spiking natural turmeric extracts with synthetic curcumin (N. Kalyanam [Sabinsa] email communication, March 1, 2017).

3.2 Sources of information supporting confirmation of adulteration: Scientific papers from the 1970s and 1980s describe adulteration of turmeric with other Curcuma species, starches, and dyes, and provide methodologies for their detection, but no commercial samples were evaluated in these papers.\textsuperscript{32,46,47}

In 2004, three market samples of turmeric powder brands in the Indian market were analyzed based on genetic profiling (Random Amplified Polymorphic DNA [RAPD] analysis) and compared to genuine powders of C. longa and C. zedoaria. The analysis revealed the presence of more C. zedoaria (wild species) powder than C. longa (the common culinary turmeric) powder, even though the curcumin levels of the samples met the quality standards.\textsuperscript{42}

In 2011, six samples of turmeric powder procured from a local market at Calicut, Kerala, India were analyzed using two Sequence Characterized Amplified Region (SCAR) markers, a method to determine the identity of turmeric based on DNA markers. Both markers detected the presence of adulteration with C. zedoaria or C. malabarica in four market samples and in simulated mixtures, i.e., samples of turmeric powder and the adulterants made at different concentrations.\textsuperscript{48} In 2015, one out of 10 turmeric samples analyzed by DNA using single nucleotide polymorphisms (SNPs) that discriminate between C. longa and C. zedoaria was shown to be adulterated with C. zedoaria.\textsuperscript{49}

The Bureau of Indian Standards suggests a minimum of 3% curcumin for powdered turmeric, whereas the mandatory Prevention of Food Adulteration (PFA) Act of 1954 does not specify any minimum curcumin limit.\textsuperscript{44} Despite the regulations in place in India, the quality of turmeric products on the Indian market is highly variable.

In 2008, a report showed turmeric adulteration and detected the presence of organic dyes, such as metanil yellow (1.5–4.6 mg/g), Sudan I (4.8–12.1 mg/g), and Sudan IV (0.9–2 mg/g) in loose turmeric and chili samples from city markets across India. The curcumin content in turmeric and mixed curry powder samples ranged from 6.5 to 36.4 mg/g and from 0.3 to 1.9 mg/g, respectively.\textsuperscript{37}

In a 2013 report, four commercial samples of whole dried rhizome turmeric were collected randomly from four different areas of the spice market of Allahabad, India, and analyzed for possible adulteration using laser-induced breakdown spectroscopy (LIBS), an atomic absorption technique providing signatures of each element. The analysis demonstrated that one of the four samples had spectral signatures corresponding to lead (Pb) and chromium (Cr), suggesting they might contain lead chromate as an adulterant providing color to make them more attractive to consumers.\textsuperscript{27}

In another study, food samples from the unorganized sector in West Bengal, India were tested. The unorganized
sector is comprised of private enterprises owned by individuals or households that produce or sell goods and services, operate on a proprietary or partnership basis, and employ less than ten workers. Fifty-eight samples of a total of 253 collected (20.94%) contained metanil yellow, with 32.95% of the turmeric powder specimens and 31.32% of the laddoo (ball-shaped traditional Indian dessert made with flour, milk, sugar, and turmeric) samples containing metanil yellow. No significant contamination of metanil yellow was found in besan (a flour made from a variety of ground chickpea) samples.50

A recent review on ground turmeric as a source of lead exposure in the United States was conducted by researchers at the Department of Environmental Health, School of Public Health at Boston University. The review focused on the contamination of turmeric with lead (with high lead levels likely coming from the addition of lead chromate, although environmental contamination cannot be excluded) in products imported from India and Bangladesh to the United States. According to the authors, spices, food, and dietary supplements in the United States may be extensively adulterated with lead to enhance its weight, color, or both.39 In 2011 and 2012, the authors purchased 32 samples of turmeric from mainstream grocery stores, specialty stores, and ethnic markets throughout the greater Boston area and found detectable levels of lead in all of the samples, with a median concentration of 0.11 μg/g (range: 0.03-99.50 μg/g), using inductively coupled plasma-mass spectrometry. The authors cite several FDA enforcement reports from 2011 to 2014 showing 13 lead contaminated turmeric brands recalled (voluntarily) in several US states. In 2016, seven brands of turmeric were recalled because of elevated lead levels, as well as five brands of curry powder, amounting to 337,000 pounds.39

Most recently, 38,000 pounds of turmeric that were distributed to Florida and New York by Spices USA, Inc. were recalled because of elevated lead levels.51 The FDA issued an import alert of lead poisoning on September 26, 2016, which allows ports to detain future shipments from specific importers, targeting turmeric from Pran (Bangladesh), Visakarega Trading (India), and Indo Vedic Nutrients (India).51

In 2014, Harvard University researchers reported lead concentrations of up to 483 μg/g in turmeric samples collected from 18 households in rural Bangladesh, a country where the permissible level of lead in turmeric is 2.5 μg/g.39,52 A newspaper article (Times of India, published May 10, 2010) reported a raid by the Indian Food and Drug Authority in 2010, with inspectors discovering over 100 bags of raw turmeric contaminated with lead chromate at a spice manufacturing plant.53

The issue of adulteration of natural curcumin with synthetic curcumin was first reported in 2011, when EuroPharma (Green Bay, WI), a US manufacturer of natural turmeric extract supplements, considered the possibility of commercially available curcumin supplements made with a lower-cost synthetic version and began working with University of Georgia on tests using radiocarbon dating
techniques to analyze curcumin products on the market to determine the percentage that contained synthetic versus natural curcumin, or a combination of both.23,54

After the 2011 report by EuroPharma, other suppliers initiated strategies to identify products adulterated with synthetic ingredients23,54,55 and, in some instances, apparently prompted industry members to take legal action. On May 26, 2015, Sabinsa Corporation’s parent company Sami Labs Limited (Bangalore, India), filed a criminal complaint with the chief magistrate, Bangalore and the Peenya police department, Bangalore, against Bayir Extracts Private Limited, Bangalore, India for knowingly supplying adulterated turmeric oleoresin with a forged Certificate of Analysis.56,57

The 14C testing of five commercial samples of curcumin sold by Bayir for export to the U.S. showed that four of the materials contained curcumin that was 32–45% synthetic, while the fifth sample was 100% natural.57 Using the same testing approach, materials from another supplier (Biotikon®, Gorxheimertal, Germany) were also found to contain significant amounts of synthetic curcumin.58

3.3 Accidental or intentional adulteration: Turmeric is likely one of the spices most frequently adulterated because of its widespread use and high cost. In some situations, the use of C. zedoaria could be a case of mistaken identity and qualified to be an accidental adulteration due to human error. But the uses of cassava, talc powder, starches, yellow dyes, minerals and synthetic curcumin are clearly intentional and constitute economically-motivated adulteration.

3.4 Frequency of occurrence: Adulteration of turmeric powder commonly occurs with synthetic dyes, zedoary root, starch, and cassava in food ingredients, and also with synthetic curcumin on turmeric curcumin used as an ingredient in dietary supplements. The use of dyes in unbranded turmeric powders sold in bulk is prevalent in different regions in India. The frequency of adulteration of C. longa with C. zedoaria is not known. Morgan et al.59 suggest that adulteration with C. zedoaria is rare, but a large market sample analysis has yet to be performed.

The presence of C. zedoaria was detected in all three samples of popular turmeric powder products tested.52 In another study, one out of 10 branded samples from an Indian market showed the presence of zedoary and starches although the label claimed nothing other than turmeric powder.49

Thin-layer chromatography (TLC) analysis of market samples (of turmeric, chili, and curry purchased in Lucknow, India) showed the presence of the food dyes metanil yellow (1.5–4.6 mg/g), Sudan I (4.8–12.1 mg/g), and Sudan IV (0.9–2.0 mg/g) in loose turmeric and chili samples; the occurrence of the Sudan dyes was limited to the chili samples.57

In a more detailed study by the same group, 712 commercial samples in India were tested using a two-dimensional high-performance thin-layer chromatography (HPTLC) method. None of the branded samples (N =100) showed the presence of artificial color, but 105 (17.2%) of the non-branded samples (N =612) of turmeric powders were dyed with metanil yellow.44

Four samples of whole dried turmeric rhizome collected randomly from four different areas of the spice market of Allahabad (India) were analyzed directly by the LIBS technique for a complete profiling of elements present in the samples. Three samples were found to be authentic, while one sample had a bright yellow color. This latter sample was found to be adulterated with lead chromate dye.57

Analysis of 253 food samples, consisting of three different types of food items — turmeric powder, laddoo, and besan — were tested for the presence of metanil yellow. Fifty-eight out of the 253 samples collected, i.e., 20.9%, were found to contain metanil yellow with 36.2% of the positive samples below the maximum permissible limit and 63.8% above the maximum permissible limit of 100 mg/kg, as specified in the Prevention of Food Adulteration Act of India.50,60 No metanil yellow was found in any food samples prepared from the food items (turmeric powder, laddoo, and besan) produced by the organized sector, i.e., those companies that are registered with the Indian government and follow its rules and regulations.50

The practice of adulteration with dyes in India is regional, and turmeric from poorer sectors in the Indian state of West Bengal has been found to contain metanil yellow more often than turmeric from the more affluent regions of the state.50

The occurrence of adulteration of C. longa with other Curcuma species as lower-cost substitutes in the marketplace has been mentioned in many publications since the 1970s,32,38,49 but reports of the analysis of samples of branded commercial turmeric products are limited. In one report, one of the 10 samples analyzed by DNA barcoding showed the presence of C. zedoaria DNA. The 10 samples were from popular brands of turmeric powder procured locally from Kozhikode (Kerala state, India). Each of the 10 samples was produced by a different company.49

Another report using RAPD markers to distinguish among Curcuma species found all three samples analyzed were adulterated with C. zedoaria.42 Finally, an investigation from 2014 into the quality of 39 commercial turmeric samples for food, dietary supplement and cosmetic use sold in supermarkets and retail stores in the United Kingdom (27), India (8), the Netherlands (2), Iceland (1), and Greenland (1) labeled to contain C. longa (34), C. amada (1), C. aromatica (2), C. zanthorrhiza (1), and C. kwang-siensis (1) by HPTLC showed that three products did not contain any bands (suggesting spent or no turmeric in these products), one turmeric product was adulterated with C. aromatica, and one product from India contained merely curcumin, with little to no demethoxy- and bisde-methoxycurcumin.41

As noted above, a more recent practice is the use of synthetic curcumin to adulterate turmeric extracts claiming a specific curcuminoid content. Since synthetic curcumin is of much lower cost, companies that produce
all-natural ingredients have reported that fraudulent suppliers of turmeric extracts containing synthetic curcumin are able to offer materials at lower prices (N. Kalyanam [Sabinsa] email communication, April 2, 2017).

As stated in section 3.2 above, four out of five samples from one supplier were found to contain synthetic curcumin. To date, no report with test results of a larger set of commercial samples is available to confirm the frequency of adulteration with synthetic curcumin, and its geographic distribution.

3.5 Possible safety/therapeutic issues: Metanil yellow, a common adulterant of turmeric and curry powders, is not approved as a food colorant by the UN FAO/WHO Codex Alimentarius or the US FDA. Studies on rats show that long-term consumption of metanil yellow causes neurotoxicity, hepatocellular carcinoma, tumor development, deleterious effect on gastric mucin, and lymphocytic leukemia. This dye is potentially dangerous to human health and has been toxicologically classified under the category CII, a category of food colorants for which the available safety data are inadequate, by the joint FAO/WHO Expert Committee on Food Additives in 1965. When evaluating the risk of carcinogenicity, the International Agency for Research on Cancer (IARC) classified lead chromate, and Sudan dyes in group 3, which means that the available studies do not permit conclusions regarding the causality between exposure and cancer occurrence.

Some cases of lead poisoning may be attributed to the consumption of turmeric. In 2010, a report detailed the case of a 12-month-old baby with a blood level of 28 mg/dL, which exceeded the Centers for Disease Control and Prevention’s reference level of 5 mg/dL. After conducting a detailed investigation of the child’s home, the Massachusetts Department of Public Health determined that daily consumption of several lead contaminated spices, including turmeric, was the primary pathway of exposure.

Safety of Curcuma zedoaria

Despite several reports about the potential toxicity of C. zedoaria rhizome, information from authoritative sources suggest no risks for consumption at the low amounts used in cooking and as a stomachic; therefore, it should not be gener-
the reports have raised some cautions about the safety of turmeric adulterated with zedoary. The second edition of the American Herbal Products Association’s Botanical Safety Handbook lists zedoary as contraindicated during pregnancy but otherwise it is considered safe under normal conditions of use.

A new potential safety concern has risen with turmeric or curcumin ingredients partially adulterated or completely substituted with synthetic curcumin. This less expensive synthetic curcumin has not been studied to assess its safety.

In 2006, the Canadian safety assessment and regulatory affairs consulting company Cantox submitted a New Dietary Ingredient (NDI) Notification to the US FDA on behalf of Yung Zip Chemical’s Elite (synthetic) Curcumin. The safety data provided for synthetic curcumin came exclusively from animal toxicity studies using the natural diarylethepanoid extracted from turmeric. The argument by Cantox was that although Yung Zip’s Elite curcumin was synthetically prepared, it was chemically identical to the compound obtained through solvent extraction from a natural source. The FDA rejected the filing, stating that it was unable to determine the identity of the NDI and therefore could not assess that the NDI does not present a significant or unreasonable risk of illness or injury.

3.6 Analytical methods to detect adulteration:
Details on the microscopic features of turmeric root and other Curcuma species such as C. aromatica, C. longa, C. zanthorrhiza, and C. zeodaria have been published by several authors. Based on the published data, it is not clear if the microscopic features are distinct enough to determine the identity to the species level.

A number of simple physical and colorimetric tests using reagents have been used to test for the presence of chalk, yellow soapstone, starch, and dyes. These physical and colorimetric methods are suitable as screening tests to allow for a quick determination of adulteration with the above-mentioned coloring materials.

A rapid TLC technique was developed to identify C. longa and distinguish it from other Curcuma species. The method involves a three-step color sequence for the detection of camphor and camphene, chemicals found in these adulterants, which are absent in turmeric. More recently, the HPTLC Association published a method to distinguish C. longa and C. zanthorrhiza. The same method allowed detection of adulteration with C. aromatica.

A two-dimensional HPTLC was used to detect adulteration of turmeric by dyes and identify them. The method allows resolution of the three curcuminoids and the synthetic dye metanil yellow by the initial development. Resolution of Sudan I and Sudan IV was achieved by developing the plate in the second direction.

Since many commercial turmeric dietary supplements contain essential oil in addition to the curcuminoids, distinction among Curcuma species can also be achieved by analyzing the essential oil fraction using gas chromatography. There are substantial differences in the composition of the sesquiterpene fraction and lower amounts or absence of turmerones in some of the adulterating species.

A number of HPLC methods have been used for the detection and estimation of curcuminoids as a tool for the evaluation of the quality of commercial ingredients and products. The methods include a variety of detection systems (UV, diode array, mass spectrometric, and fluorescence) and chromatographic techniques (HPLC, GC, CE).

For turmeric extracts, HPLC chromatograms showing a characteristic fingerprint of the three curcuminoids in a consistent ratio (77% curcumin, 17% demethoxycurcumin and 3% bisdemethoxycurcumin) has been, for many years, the approach to determine the product identity and quality. However, identification of the correct Curcuma species solely based on the curcuminoid analysis may not be appropriate due to the presence of cultivars and hybrids that may represent variations from the curcuminoid ratio mentioned above.

In 2010, the NIH ODS Dietary Supplements Presidential Task Force identified turmeric as a high–priority supplement requiring a validated method for the determination of curcuminoids in raw materials and finished products. Turmeric methods were evaluated by an AOAC committee, and the selected HPLC method was subjected to a single-laboratory validation, according to the AOAC International guidelines using 12 raw materials and finished products containing turmeric roots.

Recently, laser-induced breakdown spectroscopy has been used to detect the presence of dyes in turmeric. The elements of the samples, carbon, sodium, potassium, magnesium, calcium, iron, and molecular bands of cyanide, are identified as well as the spectral signatures of the toxic elements like lead and chromium, which were found in one of the four commercial samples analyzed, demonstrating adulteration.

The presence of metanil yellow is easily detected by simple acid-base tests and can also be done by Fourier Transform-Raman (FT-Raman) and Fourier Transform-infrared (FT-IR) spectroscopy. (N. Kalyanam [Sabinsa] email communication, April 2, 2017) FT-IR can detect metanil yellow in concentrations of 5% and higher, while the FT-Raman method is more sensitive, detecting as little as 1% of metanil yellow in the sample. The use of HPLC-MS provides even lower sensitivity with a limit of detection of as little as 100 pg/mL. 1H NMR spectroscopy-metabolomics has been used to identify Curcuma species and authenticate turmeric samples.

1H NMR spectra of turmeric samples were examined visually for appropriate reference peaks for the
identification of curcuminooids. Using this method it was possible to differentiate *C. longa* from *C. aromatic* and *C. zanthorrhiza* based on principal component analysis (PCA). A contribution plot also allowed determination of the main metabolite differences among the *Curcuma* species (the absence of bisdemethoxycurcumin in *C. aromatic* and *C. zanthorrhiza* being one of the main distinguishing factors) and among *C. longa* extracts made with different solvents.41

Genetic methods have been used to detect adulteration with fresh or dried, whole or powdered material from other botanicals. Sasikumar et al. reported a genetic method to detect adulteration of turmeric with white turmeric in market samples. The authors used eight selected random decamer primers as molecular markers to be analyzed by the RAPD technique.42 DNA barcoding was used to detect plant-based adulterants in turmeric powder using a library of authentic rhizomes from *C. longa* and *C. zedoaria*. The genetic ITS region contained single nucleotide polymorphisms (SNPs) specific to *C. zedoaria* DNA. These SNPs proved useful in detecting adulteration.49

The method of choice to determine whether a chemical compound is plant-derived or of synthetic origin is via 14C measurement. There is a steady-state between incorporation of 14C (via photosynthesis using CO₂) into plant material and its decay (half-life of 5730 years). After a plant dies, there is no further incorporation of 14C; therefore, the concentration of 14C is highest in living plants, while fossil fuel-derived products have little or no 14C. The concentration of 14C can be measured using specific mass spectrometers. In case of the presence of synthetic curcumin, the 14C concentration will be very low or 14C will be absent altogether. Alternatively, in the manufacturing of synthetic curcumin, vanillin is used as the starting material,67 and traces of vanillin may be detected by HPLC-MS and thus determine the presence of synthetic curcumin in the sample.22

4. Conclusions

Powdered turmeric root and rhizome and turmeric extracts are valued both for their medicinal properties and for their popular culinary use, such as being a component in curry powder. Due to turmeric’s high demand in international trade, turmeric powder and extracts have been subject to deliberate, economically-motivated adulteration. The adulteration of this plant species is an extensive, complex, and multifactorial enterprise driven by economic incentive within the food ingredient category. The curcuminooids, which are some of the principal compounds of turmeric, are responsible for its yellow color; thus, color was a good indicator as a measure of turmeric quality in antiquity. However, many bright yellow turmeric powders may currently be adulterated with synthetic dyes, such as metanil yellow, or lead chromate, decreasing the usefulness of color as a measure of quality. Addition of these colorants may pose a safety risk, and these ingredients are not accepted food-coloring agents according to international regulatory authorities. Turmeric can also be adulterated with other *Curcuma* species, such as zedoary, containing curcumin or their curcumin/volatile oil-extracted matrices; foreign starches (cassava), t alc, and, more recently, synthetic curcumin, which is intended to serve as a lower-cost substitute. These latter adulterants dilute curcumin and turmeric quality and efficacy, but do not impact its safety. The replacement of natural curcumin with synthetic curcumin is a deliberate practice that eludes most spectroscopic and analytical tests. Carbon isotope measurement, requiring a sophisticated accelerator mass spectrometer to measure 14C in the sample, is the most effective method to determine if a curcumin material is plant-derived or of synthetic origin. With help of this analytical technology, industry laboratories can detect samples containing synthetic curcumin in the marketplace, a practice which is leading to legal battles and a re-definition of turmeric adulteration practices.

5. References


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