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Article

Turmeric spice: Authenticity, fraud detection, and traceability vis-a-vis consumers' health

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Abstract: Introduction: Turmeric, a golden yellow spice used mostly in South Asia but now used globally, is in high demand due to its varied medicinal and culinary uses. This has led to the deceptive practice of using adulterants to increase bulkiness and brightness for economic gains. Unfortunately, there is inadequate inspection of commercially available turmeric powder, and some adulterants, e.g., lead chromate, are dangerous to consumers' health. **Objective:** This review aimed to shed light on the complexities surrounding turmeric powder authenticity and fraud detection, highlighting the importance of traceability in maintaining the integrity of this cherished spice, thereby protecting consumers' health. **Methodology:** The scientific literature was searched, using key terms of "turmeric", "adulterants", "authenticity", "fraud detection", "traceability", "consumers' health", and "toxicity" to guide the selection of relevant research papers. **Results/Discussion:** The findings of this paper speculate challenges associated with turmeric powder authenticity and fraud detection, weakened by inadequate traceability systems to track and trace turmeric powder from the market to the source, with potential implications on consumers' health. However, by providing consumers with proper information to help them make informed decisions on the sources of turmeric powder, they would be more likely to gain health benefits from turmeric powder. **Conclusion:** It is critical to comprehend the misleading nature of adulterated turmeric spice and the possible health risks for a proper approach to handling this problem.

Keywords: turmeric; fraud detection; adulterants; consumers' health; authenticity; traceability

1. Introduction

Turmeric, a rhizome plant that is scientifically known as *Curcuma longa* L. originating from the ginger family of *Zingiberaceae*, has a vibrant yellow color and distinctive flavor and holds a revered status in both culinary traditions and medicinal properties worldwide, especially in India [1,2]. The increased interest in turmeric has been fueled by the revelation of its diverse medicinal uses for traditional Ayurvedic medicine. The plant is known for centuries to contain curcumin (diferuloylmethane), its active component, and it has potent properties, such as antiseptic, antioxidant, anti-cancer, and anti-inflammatory properties, etc. [3]. However, amidst its rising popularity, which has made this golden spice vulnerable to fraud/adulteration, concerns have emerged regarding the need for robust measures to tackle the problem of turmeric fraud, safeguard consumer health, and preserve the reputation of this valued spice [4,5].

Adulteration, a type of food fraud, underscores the authenticity and quality of turmeric products available in the market. Food fraud is the intentional addition of substances that are not part of the original product to increase the quantity or appearance for economic gains [6,7]. Reports have been brought up concerning the use of various harmful substances, such as aniline dye, lead chromate, and metanil dye, which are non-permitted coloring agents used to increase the quantity or appearance of turmeric being sold [8,9]. This review paper sought to shed light on the complexities surrounding turmeric powder authenticity and fraud detection, highlighting the importance of traceability in maintaining the integrity of this cherished spice, thereby protecting consumers' health.

2. Methodology

This paper reviewed and summarized relevant information from the existing literature on turmeric powder from farm-to-market and health safety perspectives: authentication, fraud detection, health effects, and the need for traceability. The quality of each existing study of interest was not rigorously assessed. The keywords of "turmeric powder", "cultivation", "processing", "culinary values", "medicinal benefits", "authenticity", "toxicity", "adulterant", "fraud detection", "exposure", "health implication", "control measures", and "traceability" were used to search for relevant datasets on various search engines, which were Yahoo, Google, and Bing. The review was conducted using data obtained from online publications, which were the Web of Science, Google Scholar, and Scopus. Only articles published in the English Language were retained for this study. To include potentially uncaptured but relevant to this study, a manual search of the reference lists of identified articles from the literature was carried out. Tables and figures were added to the narrative presentation of the results when necessary.

3. Results and discussion

3.1. Cultivation and processing of turmeric

Turmeric can be grown under rain-fed and irrigated conditions, where mother rhizome is used as the seed for planting [10]. Planting typically occurs during the monsoon season (June–July). The crop is harvested 7–9 months after planting. Turmeric can be produced in tropical climates with temperatures between 20 °C and 30 °C and an annual rainfall of at least 1500 mm at the sea level up to an elevation of 1500 m [11]. **Table 1** presents aspects of turmeric from cultivation to the powder across different geographic areas, while **Figure 1** shows turmeric at various processing stages.

Table 1. Some aspects of turmeric cultivation in India and Africa.

Aspect	India	Africa	References
▪ Climate (warm, humid, 21 °C–30 °C)	√	√	[11]
▪ Soil (well-drained, fertile)	√	√	[10,11]
▪ Planting season (June–July)	√	√	[12]
▪ Harvesting season (7–10 months after planting)	√	√	[10]
▪ Curing: boiling/steaming	√	×	[13]
▪ Drying method: Sun drying as primary method	√	√	[13]
▪ Area of cultivation	82%	3% (Nigeria)	[11]
Usage: ▪ Medicinal ▪ Culinary ▪ Traditional ceremonies	 √ √ √	 √ √ ×	[1,3,14]

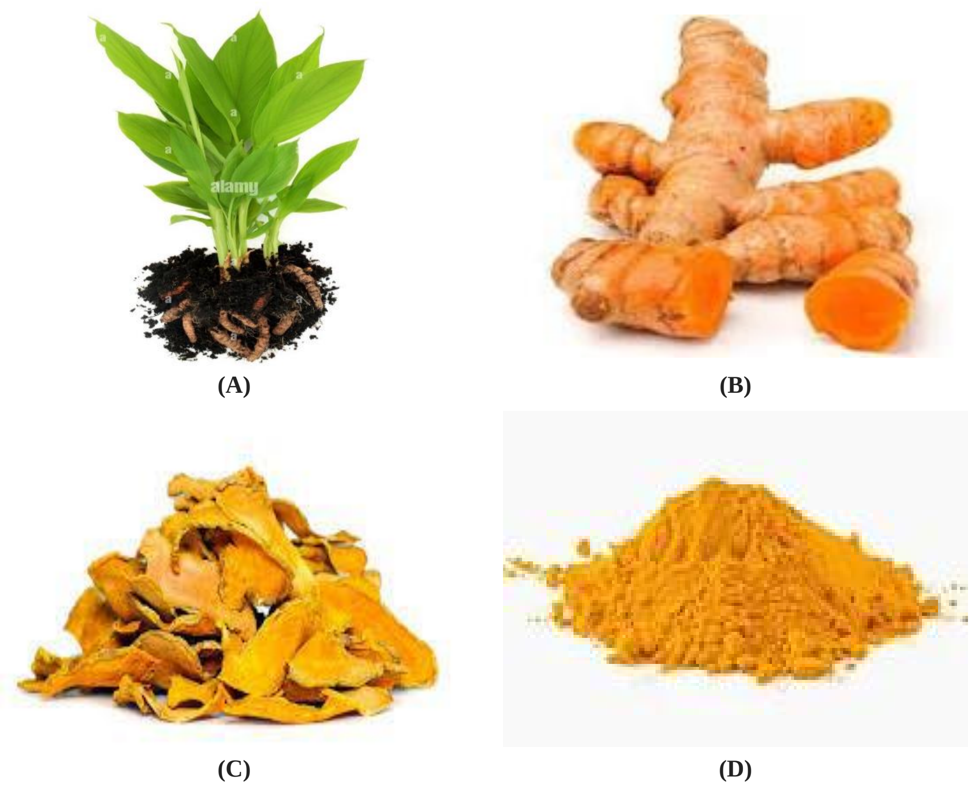

Figure 1. Different developmental forms of turmeric: **(A)** turmeric plant, **(B)** fresh turmeric, **(C)** dry turmeric, and **(D)** turmeric powder.

3.2. Consumption of turmeric as spices and medication

Turmeric, with its rich golden color and earthy flavor, does not serve only as a staple spice in culinary delights but also as a potent medicinal remedy with a history spanning millennia [15].

In culinary applications, turmeric adds depth and vibrancy to dishes, imparting a distinctive aroma and flavor profile to cuisines across the globe. Turmeric is used as a spice in cooking and has been used in the food industry to enhance the sensory properties of food products [16]. Turmeric has been studied for its potential as a natural food preservative due to its antioxidant and antibacterial properties [17]. Furthermore, turmeric is used worldwide as a food dye, and a major ingredient in processed foodstuffs, such as curry powder and tea [18]. In India, turmeric is a cornerstone of culinary traditions, primarily used as a spice in nearly every region. Turmeric powder is an essential component of curry powders and masalas, lending not just flavor but also the characteristic yellow color to dishes [19]. In Southern India, turmeric is sometimes used in *Rasam* soup [20]. In Northern India, dried turmeric powder is common in lentils (*dal*), vegetables, meat dishes, and even drinks, such as *haldi doodh* (turmeric milk) [21]. However, turmeric does not have such a high culinary value elsewhere as in India. For example, in China, mainly the Yunnan and Sichuan provinces, turmeric occasionally features in meat stews and herbal broths [22]. Likewise, in Africa, particularly in East Africa (Kenya, Tanzania, etc.) and parts of West Africa, turmeric is used increasingly in cooking but does not hold the central position it does in Indian cuisine. Its adoption in African kitchens is often influenced by Indian and Middle Eastern migration and trade [23], especially in coastal regions, such as Zanzibar, where Indian spices have long been integrated into local dishes. In East Africa, turmeric is used in pilau rice, curries, and stews, offering color and a mild flavor [23].

Turmeric has multiple biological and pharmacological properties and its main active bio-component is curcumin (diferuloylmethane). Curcumin exerts a myriad of health-promoting effects within the body. Turmeric (mainly due to its curcumin contents) possesses antioxidants, anti-bacterial, anti-cancer, antiparasitic, antiviral, and anti-inflammatory properties [24,25]. Curcumin's ability to inhibit inflammatory mediators, such as NF-κB and COX-2, contributes to its anti-inflammatory effects, which may alleviate symptoms of chronic inflammatory diseases, such as arthritis, inflammatory bowel disease, and liver disease [26]. Furthermore, the anti-inflammatory properties of curcumin make it a valuable ally in combating chronic inflammatory conditions, such as rheumatoid arthritis, and studies on its therapeutic effect in treating tuberculosis and AIDS are still ongoing [27]. Calebin A, a polyphenolic component, is another important curcuminoid analog derivative also known to have anti-inflammatory, as well as anti-tumor, properties for preventing and treating neurodegenerative diseases, metabolic disorders, and diseases of the musculoskeletal system [28]. Furthermore, its antioxidant property helps neutralize free radicals, thereby protecting cells from oxidative damage and reducing the risk of chronic diseases, such as cardiovascular disorders and cancer [26,29–31]. Turmeric's antimicrobial properties may help in combating bacterial and viral infections, while its potential anticancer effects warrant further investigation into its role in cancer prevention and treatment [29]. Additionally, turmeric's potential as a medicinal remedy extends to other health conditions, including digestive disorders, skin ailments, and even neurological diseases [32]. Its ability to modulate neurotransmitter levels and enhance cognitive function suggests promising applications in supporting brain health [32] and potentially mitigating neurodegenerative conditions, such as Alzheimer's and Parkinson's diseases [33]. **Table 2** shows the different compounds of turmeric and their medicinal properties.

Table 2. Compounds/metabolites of turmeric and their medicinal properties.

Compound and Metabolites	Medicinal Properties	Reference
Turmeric powder	Anti-protozoan, anti-inflammatory, anti-tumor, and wound healing	[3,28]
Methylcurcumin	Anti-protozoan	[3,34]
Demethoxycurcumin	Anti-oxidant	[3,35]
Bisdemethoxycurcumin	Anti-oxidant	[3,36]
Volatile oils (tumerone, flavonoids)	Anti-bacterial, anti-fungal, anti-inflammatory, anti-cancer, anti-oxidant, and anti-inflammatory	[3,37]
Curcumin	Stimulate gallbladder to produce bile	[3,36,38]
Phenolic	Anti-oxidant, skin protective effect, and anti-inflammatory	[3]
Tetrahydro curcumin	Pro-oxidant and antioxidant	[39]
Hexahydro curcumin	Antitumor and cardiovascular Protective	[40]

3.3. Authenticity of turmeric

Food authenticity refers to the assurance that food products being consumed are genuine, of the stated quality, and free from adulteration or misrepresentation [41,42]. Authenticity encompasses various aspects, including but not limited to products' origin, species, composition, and production methods, which ensure that food labels accurately reflect the true nature of the products [7,41,43]. Ensuring the authenticity of turmeric is paramount for consumers seeking its health benefits and culinary delights alike. Thus, turmeric authenticity may refer to the genuineness and originality, i.e., the state of turmeric being pure and free from added substances. Authentic turmeric powder originates from the *Curcuma longa* L. plant that has not been tampered with during cultivation and possesses distinct characteristics, such as vibrant color, aromatic fragrance, and a rich flavor profile [44]. **Table 3** presents some factors that can be used to assess the authenticity of turmeric powder.

Table 3. Factors used to evaluate authenticity.

Factor	Description	References
Origin	The source, plant origin, and supply chain from which consumers buy turmeric.	[45]
Method of processing	Authenticity is preserved by using conventional techniques, such as proper harvesting methods, sun-drying, and grinding without the use of chemicals or additions for preservatives.	[46]
Color	Authentic turmeric typically has a vibrant yellow-orange color, indicating the presence of natural compounds.	[20,47]
Aroma	A fresh, earthy, and slightly pungent aroma is characteristic of authentic turmeric.	[48,49]
Taste	Authentic turmeric has a slightly bitter, peppery flavor with hints of citrus and ginger.	[20]
Certification	Certifications, such as organic or Fair Trade, can indicate authenticity and ethical sourcing.	[50]
Reputation	Turmeric products from reliable vendors or brands that are renowned for their dedication to authenticity and quality.	[45]

The advantage of ensuring turmeric powder is authentic using one or more authentication methods (**Table 3**) is significant to enhance the value and benefit of turmeric powder to consumers and the turmeric industry. The intake of authentic turmeric powder would elucidate therapeutic value (e.g., antioxidant and anti-inflammatory qualities) to consumers' health [3,36]. Genuine turmeric helps people stay connected to their roots by preserving these cultural customs and behaviors. Furthermore, fair labor procedures, sustainable farming practices, and support for local communities are frequently ensured by ethically buying authentic turmeric from reliable producers or certified organic farms [45]. This aligns with ethical consumer preferences and values. Also, the trust and reputation of brands or producers prioritizing authenticity and quality are established. This can lead to customer loyalty and positive word-of-mouth recommendations [45].

Spectroscopic techniques, such as infrared spectroscopy and nuclear magnetic resonance spectroscopy, can analyze the chemical composition of turmeric samples, enabling the differentiation between genuine turmeric and adulterated counterparts [51]. Additionally, DNA barcoding has emerged as a powerful tool for verifying the botanical origin of turmeric and detecting any substitution or contamination along the supply chain [52]. Spectroscopy, chromatography, and DNA barcoding are major tools employed to distinguish genuine turmeric from adulterated counterparts [4].

3.4. Turmeric fraud and fraud detection

Food fraud is the deliberate deception of consumers by intentionally altering, misrepresenting, substitution, or tampering with food products [6]. It is estimated to cost the global food industry $40 billion per year according to PwC and the Safe Supply of Affordable Food Everywhere and between $10 billion to $15 billion per year according to the Grocery Manufacturers Association [53], which is about 10% of commercially sold food products. Also, the spice industry is worth $4 billion presently and turmeric is a well-known and recognized spice used regularly. The demand for the species industry is expected to grow to $6.5 billion, making the demand for popular ingredients continue to rise [53], and thus the possibility of fraud might increase**.** Turmeric fraud may be regarded as the addition of inferior substances or harmful colorants to increase the bulkiness or brighten its color, respectively. Turmeric fraud presents a significant challenge as its demand exceeds supply.

Adulteration is the major challenge threatening turmeric authenticity and the global spice market. Adulteration of turmeric involves the addition of cheaper substitutes or contaminants to enhance color or bulk for a higher profit margin. Common adulterants include lead chromate [54], metanil yellow [55], and other synthetic dyes or fillers, which not only compromise the quality and authenticity of turmeric but also pose significant health risks to consumers [4]. Furthermore, variability in the quality of turmeric powder can be due to various factors, such as weather conditions, soil quality, and cultivation practices [10,56]. Ensuring consistent quality across batches can be challenging, especially for small-scale producers. **Table 4** summarizes the various adulterants used in turmeric and their intended purposes.

Table 4. Adulterants and purpose of use for economic benefits.

Adulterants	Purpose	References
Maize (corn flour), cassava flour	Increase bulkiness	[57]
Chalk	Increase bulkiness	[57]
Metanil dye	Intense yellow coloring	[58]
Aniline dye	Intensify yellow color	[8,9]
Lead chromate	Increase yellow color brightness	[59]
Sudan dye	Intensify the yellow color	[60]
Spent turmeric	Increase bulkiness	[61]
Other spices	Increase bulkiness	[62]

Turmeric fraud detection is a practice of investigating and exposing attempts to mislead or cheat for unlawful gain. The detection of various adulterants in turmeric may require sophisticated equipment. Additionally, a lack of transparency in the turmeric supply chain can make it challenging to trace the origin of the turmeric and verify its authenticity. Complex supply chains with multiple intermediaries increase the risk of adulteration. Also, the cost of authentic turmeric is more expensive compared to adulterated or lower-quality turmeric [63]. This cost difference can pose challenges for consumers looking for high-quality turmeric products within their budget.

Detecting fraud requires advanced analytical techniques capable of identifying adulterants such as lead chromate and metanil yellow, commonly used to mimic the color and appearance of authentic turmeric. Various methods have been developed to detect turmeric fraud. Some of these methods include chromatography [64], and Chemical [65]. **Table 5** shows methods for detecting turmeric adulterants. The prevention of turmeric adulteration requires robust quality control measures and advanced analytical techniques capable of identifying adulterants at various stages of the turmeric powder supply chain.

Table 5. Some physicochemical methods for detecting various adulterants in turmeric powder.

Adulterant	Method for detection	Description	References
Maize flour or starch	Microscopic test	• Observe turmeric powder under microscope and look for granular particles with smooth texture, spherical shape, and consistent size, which differ from natural turmeric particles	[65]
Chalk	Concentrated hydrochloric acid test	• Mix turmeric powder with hydrochloric acid; effervescence (bubbling) indicates chalk powder due to carbon dioxide release	[65,66]
Metanil yellow	Hydrochloric acid test	• Mix turmeric powder with hydrochloric acid; pink/violet color that persists after dilution indicates metanil yellow	[65,67]
Aniline dye	Rectified spirit test	• Add rectified spirit to turmeric suspension; the disappearance of yellow color in rectified spirit layer suggests aniline dye's presence	[65,66]
Lead chromate	Sulfuric acid test or hydrochloric acid test	• Mix turmeric powder with sulfuric acid; a color change from yellow to pink signifies lead chromate adulteration • Mix sample with hydrochloric acid. If pink color appears, this suggests lead salts are present; if pink color disappears when further diluted with water, then metanil yellow is the more likely culprit.	[65,68]

3.5. Traceability in turmeric supply chain

The traceability of turmeric is the ability to follow the path of turmeric from the farm where it is grown to the finished product or when it reaches consumers [69]. By tracking the movement of turmeric, stakeholders can implement corrective actions to mitigate adulteration-associated risks, uphold the integrity of turmeric powder/products, and uphold the reputation of this valuable spice. Creating public awareness and understanding of simple methods in identifying inauthentic turmeric may help consumers identify adulterated turmeric during purchase. Moreover, regulatory bodies play a vital role in enforcing quality standards and implementing severe penalties for those found guilty of adulterating turmeric products, thus ensuring consumer confidence in the authenticity and safety of turmeric. Implementing robust fraud detection measures and traceability is crucial for safeguarding consumer health and maintaining transparency and integrity of the turmeric market. Furthermore, initiatives leveraging blockchain technology aim to enhance transparency and traceability, empowering consumers to make informed choices and hold suppliers accountable for the authenticity and integrity of turmeric products. Establishing strong traceability measures enhances consumers' safety and fosters accountability in the turmeric industry. Additionally, traceability initiatives can help build trust among consumers by assuring that turmeric products meet stringent quality standards and are free from adulterants. Furthermore, the use of food safety tools, such as the EU Rapid Alert System for Food and Feed (RASFF), is relevant and may be useful to have sub-regional or continental RASFF, as recently proposed for Africa [70].

3.6. Toxicity and health implications of potential adulterants in turmeric and associated legislations

The presence of adulterants in turmeric poses health risks to consumers, depending on consumers' age and health condition, the type of adulterant, and the duration of exposure. Adulterants such as lead chromate, aniline dye, and metanil yellow, commonly used to enhance the color and appearance of turmeric [71], have been linked to various adverse health effects. According to regulations set by the Bangladesh Standards and Testing Institution (BSTI), the Bureau of Indian Standards (BIS), and the Indian Agricultural Produce Grading and Marking Act, turmeric must not contain lead chromate. The permissible lead content in turmeric powder varies among these agencies, with the BSTI allowing 2.5 ppm [72], the BIS allowing 10 ppm [73], the Food and Agriculture Organization of the United Nations allowing 2.5 ppm [74,75] and the European Commission allowing 1.5 mg/kg in fresh roots and turmeric rhizomes [76].

Lead chromate is a known neurotoxin that can accumulate in the body over time, leading to neurological impairments, developmental disorders, and even cognitive deficits, especially in vulnerable populations, such as children and pregnant women [77,78]. Similarly, metanil yellow, which has a maximum limit of 100 mg/kg set by India's Prevention of Food Adulteration Act [79], has been associated with gastrointestinal discomfort and allergic reactions [55,80]. Moreover, the EU in 2006, considering the widespread report of Sudan dyes in foodstuffs, set the maximum permissible limits of all Sudan dyes to be 0.5 mg/kg [81]. Sudan dye, which is also used to enhance the color of turmeric, is classified under Group 3 human carcinogens [60,82] and it also causes tumors in the liver [83]. Chronic exposure to aniline causes hyperpigmentation, hyperplasia, fibrosis, erythropoietic activity, and splenomegaly [84]. Furthermore, chalk is known to cause digestive and stomach disorders [85]. On the other hand, corn flour, which might also be allergic to some people, has been used as an adulterant to increase the bulkiness of turmeric powder [86]. **Table 6** below presents some common adulterants and their negative impacts on health.

Table 6. Adulterants and their toxic effects.

Adulterant	Toxic effects	References
Maize flour	Allergic reactions (corn allergies)	[87]
Chalk	Digestive issues (in high amounts), constipation, and bloating	[85]
Metanil dye	Gastrointestinal discomfort and allergic reactions	[55,80]
Lead chromate	Lead poisoning (abdominal pain, nausea, vomiting, headaches, nerve damage, and developmental problems in children)	[78,88]
Aniline dye	Methemoglobinemia (reduced oxygen delivery to tissues), dizziness, headaches, and blue-colored skin (cyanosis)	[89]
Sudan dye	Carcinogen (potential cancer) and organ damage (liver, and kidneys)	[60]

Legislations surrounding potential turmeric adulterants vary across regions, with some countries enacting firm regulations to safeguard public health and ensure the integrity of turmeric products. Regulatory frameworks aim to prohibit and/or regulate the use of harmful substances as adulterants in turmeric and other spices and establish quality standards to govern their production, processing, and distribution. For instance, the Codex Committee on Spices and Culinary Herbs, one of the committees of the Codex Alimentarius Commission, is the worldwide regulatory body that deals with spices and aromatic herbs. It conducts inspections and enforces compliance with good manufacturing practices to prevent the adulteration of turmeric and other spices with substances deemed unsafe for human consumption [90]. The European Spice Association and the European Commission are just two of the numerous organizations that create restrictions, guidelines, and standards for the spices and aromatic herb business sector [91]. Industries that deal with spices and aromatic herbs are quite concerned about potential threats to public health [91].

Similarly, some countries have implemented legislation and quality standards specific to turmeric and its adulterants. In India, the Spices Board, a government regulatory body, oversees the quality and export of spices, including turmeric, be it whole or ground, through the Spices Board Act and various regulations [92] and has set a maximum limit at 10 ppm for lead [75]. Furthermore, the government of Nepal has established food safety policies to protect its population and ensure the quality of food products [93]. Despite these legislative efforts, there is still a need for legislation against the presence of adulterants in some countries. Challenges persist in enforcing regulations and combating turmeric fraud globally. Limited resources, inadequate testing capabilities, and the complexity of global supply chains contribute to gaps in oversight and opportunities for fraud. Moreover, the emergence of new adulteration techniques and substances necessitates ongoing regulatory vigilance and adaptation of laws to address evolving threats to turmeric authenticity and consumer safety. Collaborative efforts between governments, industry stakeholders, and international organizations are essential to strengthen legislation, enhance enforcement mechanisms, and ensure the integrity of turmeric products in the global marketplace.

4. Conclusion

Turmeric's journey from farm to table is fraught with challenges related to authenticity, fraud, and traceability. Empowering consumers with knowledge on adulteration and how to detect that turmeric powder has been adulterated, i.e., not authentic, may help them make informed decisions about their food purchases. Additionally, by implementing rigid quality control measures, regulatory inspections/enforcement of food laws, and consumer education initiatives, stakeholders can work together to combat turmeric fraud and ensure the integrity of turmeric products. By prioritizing transparency, accountability, traceability systems, and consumer safety, the turmeric industry can continue to thrive, offering consumers access to authentic, high-quality products that promote health and well-being.

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