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Laboratory of Pharmacology and Toxicology
Laboratoire de Pharmacologie et Toxicologie

**Assessment of Authenticity, and Detection of Fraud
of Turmeric Powder Sold in Yaoundé and Douala,
Cameroon**

Dissertation presented to the Faculty of Science, University of Yaoundé 1 in partial fulfillment of the requirements for the award of a Master of Science Degree in Biochemistry.

Specialty: Public Health Biotechnology

Presented by

TATY BRANDY PERKWANG
Bachelor's Degree in Biochemistry
Matricule: 19C2607



Supervised by

Wilfred Angie ABIA, PhD

Senior Lecturer
University of Yaoundé 1

Paul Willians, PhD

Senior Lecturer
Queens University Belfast, UK

Academic Year: 2023-2024

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DEDICATION

I dedicate this work to God for giving me the strength to have gone through it successfully. To my family, especially my grandma (Tasinda Magdalene), and my mother for their love and support and who always told me that my education is very important. Finally, to myself for having taken up the challenge to complete it.

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I am profoundly grateful to the Almighty God for bestowing upon me the knowledge, strength, and guidance necessary to successfully complete this research endeavor.

I would like to extend my sincere thanks to everyone who, directly or indirectly, contributed to the successful completion of this project.

Firstly, I am indebted to my supervisors, Dr. Wilfred Abia (Senior Lecturer, University of Yaoundé 1) and Dr. Paul Williams (Senior Lecturer, Queens University Belfast, UK), for initiating this project and guiding me through its completion. Their invaluable mentorship, insights, and guidance have been instrumental in shaping the direction and outcome of this work.

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My biggest appreciation goes to my mom (Forlah Mirabel Tansinda) for supporting me both financially and mentally and to my aunts and uncles with whom I stayed in their homes during my study and research period. I am really grateful.

I would like to thank the Director of Research at the Institute of Medical Research and Studies of Medicinal Plants (IMPM) for granting me the opportunity to conduct my research at the institute. I am deeply appreciative of the support provided by my internship supervisor, Dr. Mouafo Hippolyte, for his daily guidance and assistance in the laboratory throughout my research at IMPM. I am grateful to all the researchers at IMPM, especially Achigui Nestor (Papa Nestor) and Metsatedem Tongwa Quentin for their invaluable research knowledge and experiences, which contributed significantly to the success of this work.

Finally, I would like to acknowledge the significant contributions of my classmates, and friends, Dama, Benjamin, Forkwen Kelly-bright, and all the sellers from whom I purchased samples from, together with the customers who provided responses, their essential assistance, guidance, encouragement, and their support were crucial to the success of this project.

ABSTRACT

Introduction: Turmeric (*Curcuma longa*) is a popular spice and medicinal herb that is widely used globally and in Cameroon. However, there is growing concern about the authenticity of turmeric sold worldwide and Cameroon is not left out. This popularity has made turmeric powder vulnerable to fraud. **Aim:** The aim of this study was to assess the authenticity and detect fraud in turmeric powder sold in Yaoundé and Douala. **Methodology:** Different questionnaires for turmeric powder sellers (administered face to face) and consumers (administered online) were used to gather general information about turmeric practices. Additionally, turmeric powder samples (N=103) were purchased from sellers in Yaounde (n=62) and Douala (n=41), while one turmeric powder was processed in the laboratory and used as control. The samples were assessed for authenticity and screened to detect fraud using a variety of microscopic and physicochemical techniques. All 104 turmeric powder samples were further screened for lead chromate (using x-ray fluorescence analyzer) and metanil yellow (using near infra-red spectroscopy). **Results:** A total of 79 sellers and 119 consumers provided responses to the questionnaires. The findings from the survey revealed that turmeric powder is generally being processed in Cameroon through a series of steps. Northwest is the main producer followed by West Region, South West and Littoral Region. Generally, turmeric powder sold in Yaounde and Douala revealed 3 typical colorations; whitish yellow (1.9%), orange yellow to golden yellow (92%) and dark brown (5.8%). 74.6 % of consumers and 69.6 % of the sellers agreed that turmeric powder sold is being adulterated for economic gains. Microscopic examination revealed that; turmeric powder starch granules in 96/103 samples, compliance and 7/103 samples non-turmeric powder starch granules, non-compliant samples. High starch was detected in 6.796% (7/103 samples). Different samples from Yaounde, had chalk powder and metanil yellow were each detected in 1/103 while lead chromate and aniline were not detected in any sample. However, using advanced instruments, lead was detected in 22% of the turmeric powder samples and no metanil yellow detected. **Conclusion:** Many of the studied turmeric powder samples were authentic, while a few were suspicious of adulteration with starch. It is less likely that chalk, metanil yellow, aniline dye, and lead chromate were present in the turmeric samples. Considering the observed lead levels may be due to natural contamination

Keywords: Authenticity, fraud/adulterant detection, Turmeric powder, Sellers, Consumers, Yaounde and Douala.

RÉSUMÉ

Introduction : Le curcuma (*Curcuma longa*) est une épice populaire et une plante médicinale largement utilisée dans le monde et au Cameroun. Cependant, l'authenticité du curcuma vendu dans le monde entier suscite de plus en plus d'inquiétudes et le Cameroun n'est pas en reste. Cette popularité a rendu la poudre de curcuma vulnérable à la fraude. **But :** Le but de cette étude était d'évaluer l'authenticité et détecter la fraude dans la poudre de curcuma vendue à Yaoundé et Douala. **Méthodologie :** Des questionnaires différenciés pour les vendeurs de poudre de curcuma (administrés en face à face) et les consommateurs (administrés en ligne) ont été utilisés pour recueillir des informations générales sur les pratiques du curcuma. De plus, des échantillons de poudre de curcuma (N = 103) ont été achetés auprès de vendeurs à Yaoundé (n = 62) et à Douala (n = 41), tandis qu'une poudre de curcuma a été traitée en laboratoire et utilisée comme témoin. Les échantillons ont été évalués pour leur authenticité et examinés pour détecter la fraude à l'aide de diverses techniques microscopiques et physicochimiques. Les 104 échantillons de poudre de curcuma ont été en outre examinés pour le chromate de plomb (en utilisant un analyseur de fluorescence X) et le jaune métanile (en utilisant une spectroscopie proche infrarouge). **Résultats :** Au total, 79 vendeurs et 119 consommateurs ont fourni des réponses aux questionnaires. Les résultats de l'enquête ont révélé que la poudre de curcuma est généralement transformée au Cameroun par une série d'étapes. Le Nord-Ouest est le principal producteur, suivi de la région de l'Ouest, du Sud-Ouest et de la région du Littoral. En général, la poudre de curcuma vendue à Yaoundé et Douala a révélé 3 colorations typiques ; jaune blanchâtre (1,9 %), jaune orangé à jaune doré (92 %) et brun foncé (5,8 %). 74,6 % des consommateurs et 69,6 % des vendeurs ont convenu que la poudre de curcuma vendue est falsifiée à des fins économiques. L'examen microscopique a révélé que les granules d'amidon de poudre de curcuma dans 96/103 échantillons, étaient conformes et 7/103 échantillons, les granules d'amidon de poudre de curcuma non conformes. Une teneur élevée en amidon a été détectée dans 6,796 % (7/103 échantillons). Différents échantillons de Yaoundé contenaient de la poudre de craie et du jaune de métanil, chacun détecté dans 1/103, tandis que le chromate de plomb et l'aniline n'ont été détectés dans aucun échantillon. Cependant, à l'aide d'instruments avancés, du plomb a été détecté dans 22 % des échantillons de poudre de curcuma et aucun jaune de métanil n'a été détecté. **Conclusion :** De nombreux échantillons de poudre de curcuma étudiés étaient authentiques, tandis que quelques-uns étaient suspects d'adultération avec de l'amidon. Il est moins probable que de la craie, du jaune de métanil, du colorant à l'aniline et du chromate de plomb soient présents dans les échantillons de curcuma étant donné que les niveaux de plomb observés peuvent être dus à une contamination naturelle.

Mots clés: Authenticité, détection de fraude/adultération, poudre de curcuma, vendeurs, consommateurs, Yaoundé et Douala.

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LIST OF ABBREVIATIONS AND ACRONYMS

BSTI	:	Bangladesh Standards and Testing Institution
DNA	:	Deoxyribonucleic Acid
EU	:	European Union
GMP	:	Good Manufacturing Practices
HACC	:	Hazard Analysis and Critical Control Points
IMPM	:	Institute of Medical Research and Studies of Medicinal Plant
ISO	:	International Organization for Standardization
Kg	:	Kilogram
ND	:	Not Detected
Ppm	:	Parts per million
SPSS	:	Statistical Package for Social Sciences
BIS	:	Bureau of Indian Standards
FSSAI	:	Food Safety and Standard Authority of India
WHO	:	World Health Organization
FDA	:	Food and Drug Administration
TCM	:	Traditional Chinese Medicine

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GENERAL INTRODUCTION

INTRODUCTION

Background and scope

In recent years, the global demand for turmeric (*Curcuma longa*) has increased due to the discovery/ massive use of it for its benefits and its derivatives, such as curcumin (Chemical formula; $C_{21}H_{20}O_6$) which have surged due to the increasing recognition of its potential health benefits (Sontsa *et al.*, 2022). Turmeric cultivation has expanded beyond its traditional regions in Asia, with African countries, including Cameroon, emerging as a market for turmeric in the global turmeric market (Ministry of Foreign Affairs, 2022). In Africa, turmeric production has experienced a trajectory of growth driven by factors such as climate suitability, market demand, and the crop's adaptability to various agro-climatic conditions. Despite the climatic favorability of this spice, turmeric production has been traditionally centered in these 2 parts of Africa (West and East Africa), with countries Ethiopia and Djibouti, Madagascar, and Nigeria being the main producers and exporters (Ministry of Foreign Affairs, 2022; Nair and Kodoth, 2019). Nevertheless, Cameroon with its diverse agro-ecological zones has made cultivation and production of turmeric worthy, and local farmers have embraced turmeric as a cash crop. However, this growing demand in local and international markets due to its various health benefits and culinary uses and inadequate supply of turmeric has created opportunities for fraudulent practices in the turmeric supply chain, including adulteration which is the deliberate addition of substances that are not the substance to increase its quantity for profit motive (Scally, 2013). These fraudulent activities not only deceive consumers but also pose potential health risks such as stomach problems, liver damage, and skin allergies and people not getting the desired result they ought to have from using turmeric (Li *et al.*, 2022; Velázquez *et al.*, 2023). Understanding the extent and evolution of these fraudulent activities is essential for devising effective countermeasures and methods to mitigate and combat the practice of turmeric fraud and food fraud in general.

Problem statement

The authenticity of turmeric powder sold in Cameroon is a pressing concern due to reports of adulteration which is the deliberate addition of substances into food for profit motive (Scally, 2013) and substandard quality for consumers. These adulterants include corn flour, lead chromate, metanil yellow, aniline dyes, or chalk powder (FSSAI, 2017). These fraudulent practices not only jeopardize consumer health as some of these adulterants can cause cancer and other diseases but also undermine the economic integrity of the turmeric industry. The lack of systematic assessment and fraud detection mechanisms poses a substantial risk to consumers

and people doing turmeric businesses. Addressing this problem is crucial to ensure consumer safety, promote fair trade, and uphold the reputation and sustainability of the turmeric sector in Cameroon.

Rationale/ Justification

The assessment of the authenticity of turmeric sold in Cameroon and the detection of associated fraud are imperative for multiple reasons. Firstly, ensuring the authenticity of turmeric products is paramount for consumer health and safety, as fraudulent practices can introduce harmful substances or diminish turmeric's efficacy, posing significant risks to public well-being. Secondly, these practices jeopardize the economic viability of the burgeoning turmeric industry in Cameroon, impacting local farmers and businesses. Moreover, turmeric holds deep cultural and culinary significance, and maintaining its authenticity preserves cultural heritage and traditional practices. For example, turmeric is used in the production of different products such as species, medicine, tea, and skincare products. Leveraging recent scientific and technological advancements, this research not only addresses a pressing issue in Cameroon but also contributes to the development of tailored fraud detection methods applicable beyond the region. Lastly, it provides valuable insights for strengthening regulatory frameworks, enhancing consumer protection, and ensuring the integrity of food products in the market.

Research questions

The main research question of this study was *'Is the turmeric powder sold in major markets in Yaounde and Douala authentic? and if not, what are the adulterants used and potential implications on consumers' health?'* From this main research question, specific research questions will be developed to help facilitate the research process.

The specific research questions were as follows:

1. How much is known about turmeric powder (e.g. cultivation, processing, consumption, commercialization, authenticity, adulteration etc) in Cameroon?
2. Could the turmeric powder sold in popular markets in the two cosmopolitan cities in Cameroon: Yaounde and Douala, be inauthentic?
3. If (all or some) turmeric powder sold in popular markets in Yaounde and Douala, Cameroon are inauthentic, what are the main adulterants?

Objectives

General Objectives:

The overall objective of this research study was to assess the authenticity, and detect fraud, in turmeric powder sold in popular markets in Yaoundé and Douala, Cameroon.

Specific Objectives:

The specific objectives of this work were:

1. To assess the origin, color/presentation, cost/economic value/affordability, processing, uses, and consumption patterns of turmeric powder sold in popular markets in Yaounde and Douala, Cameroon, as well as assess the awareness of malpractices for economic purposes, perception, and knowledge of the turmeric powder sellers and consumer populations.
2. To screen turmeric powder sold in popular markets in Yaounde and Douala, Cameroon for authenticity (compliance) e.g. starch granule, moisture content etc.
3. To detect fraud (i.e. the presence of potential adulterants, e.g. lead chromate, metanil yellow, aniline, chalk powder etc) in turmeric powder sold in popular markets in Yaounde and Douala, Cameroon.

Extension (Product):

To develop a series of standard operating procedures (SOPs) for detecting fraud and or confirming the authenticity of turmeric powder for ease of protecting consumers' health via guaranteeing safe and authentic turmeric along the turmeric supply chain.

Hypothesis

Turmeric powder sold in popular markets in Yaounde and Douala, Cameroon, are not authentic and contain illegally added adulterants, manipulated for the economic gains.

Significance of the study

This research dissertation is significant as it addresses a critical food safety – public health issue in Cameroon's major cities. By assessing the authenticity and detecting fraud in turmeric powder sold in popular markets, the study shall contribute toward protecting public health, enhancing consumer trust, and providing valuable data for regulatory authorities. For example, the findings could lead to improved quality control measures, stricter regulations, and contribute to the broader fight against food fraud in Cameroon, potentially uncovering economic impacts of fraudulent practices in the local spice trade.

CHAPTER ONE: LITERATURE REVIEW

I. Food and spices Authenticity and fraud

I.1. Food authenticity and fraud

Food refers to any substance consumed by living organisms to provide nutritional support and sustain life. It includes a wide range of items, such as fruits, vegetables, grains, meat, fish, and dairy products, which supply essential nutrients like carbohydrates, proteins, fats, vitamins, and minerals (Onyeike, 2012). Food serves as the primary source of energy, enabling growth, repair of body tissues, and maintaining overall bodily functions. For humans, food also holds cultural significance and is central to social interactions, rituals, and traditions (Anderson, 2014).

Authentic or genuine food is defined by its adherence to the original state and the accuracy of the information on the label (Danezis *et al.*, 2016, Abia, 2023). Authentic products are free from any form of adulteration, particularly in terms of composition, nature, varietal purity, geographical origin, and manufacturing process (Danezis *et al.*, 2016, Abia, 2023). Various methods are employed to ascertain the authenticity of food, such as isotopic analysis, which examines isotopic ratios to determine the food's origin (Drivelos and Constantinos, 2012), chromatographic technique that separate similar compounds, molecular techniques that differentiate authentic from non-authentic food products (Bayen *et al.*, 2024), proteomics which analyzes proteins and peptides to characterize food products, and metabolomics that provides insights into the overall composition of food products (Ferri *et al.*, 2015). Metabolomics offers insights into the comprehensive composition of food products. Fluorescence spectroscopy is a quick, sensitive, and non-invasive method that can capture the unique characteristics of food products (Hassoun *et al.*, 2019).

In recent years, the issue of food fraud has gained significant attention worldwide due to its adverse effects on consumer health, economic losses, and damage to market integrity (Abia, 2023). Food fraud encompasses various deceptive practices, including adulteration, counterfeiting, smuggling, mislabeling, or substitution of food products with cheaper or inferior alternatives (Johnson 2014; Robson *et al.*, 2021; Gwenzi and Marumure 2023; Abia, 2023). Within the broader scope of food fraud, spices, such as turmeric powder, drinks such as wine, food such as palm oil and even baby food such as milk have emerged as particularly vulnerable commodities (Johnson 2014).

Food fraud involves the deliberate/ illegal addition of substances into food for profit motive which may be harmful to health and/or the intentional misrepresentation of food products for economic gain, often at the expense of consumer trust and safety (Johnson, 2014; Visciano and

Schirone 2021; Abia, 2023). This fraudulent activity can manifest in numerous ways, ranging from dilution with fillers such as water (for example red palm oil) to the addition of harmful substances (e.g. milk powder) or undisclosed ingredients (pasta with alternative wheat varieties). According to Johnson (2014), food fraud accounts for approximately 10% of all commercially sold food products worldwide.

Table 1 provides a summary of the various types of food fraud and descriptions. The motivations behind food fraud may vary, but commonly include maximizing profits, circumventing regulatory standards, and exploiting market demand (Rees, 2020).

The recognition and concern for food fraud, particularly economically motivated adulteration as a distinct subcategory, are on the rise. Regardless of the origin of the food risk, the responsibility for preventing food adulteration falls on both the industry and the government (Spink and Moyer 2011), as well as consumers (Abia, 2023).

Table 1: Types of food fraud and definitions (Source: Zambonin, 2021; Abia, 2023)

Types of food fraud		Definitions
Adulteration	Substitution	Replacing a nutrient, an ingredient, a food or part of a food with another one with a lower value.
	Dilution	Mixing an ingredient with a high value with an ingredient with a lower value.
	Unapproved enhancement	Adding unknown and undeclared compounds to food products in order to enhance their quality attributes.
	Concealment	Hiding the low quality of food ingredients or products.
Counterfeiting		Refer to intellectual property rights infringement.
Mislabeling		Process of putting false claims on packaging for economic gain
Grey market		Refer to all unauthorized sales channels for products.

I.1.1 Spices Authenticity and Fraud

Spices are aromatic plant substances used to flavor, color, or preserve food (Embuscado, 2015; De *et al.*, 2017). Derived from seeds, bark, roots, fruits, or flowers, spices are usually used in small quantities but have a significant impact on the taste and aroma of dishes (Sachan *et al.*, 2018). Common examples include cinnamon, pepper, turmeric, and garlic. While they enhance the sensory appeal of food, many spices also offer health benefits due to their antioxidant, anti-inflammatory, or antimicrobial properties (Embuscado, 2015). Throughout history, spices have played important roles in trade and cultural exchanges, influencing global cuisine and medicine. Spices authenticity refers to the accurate identification and verification of spices, ensuring they are pure, unadulterated, and truthfully labeled in terms of origin and composition. Given the high value of many spices, authenticity is critical in preventing fraud, which can occur through adulteration, substitution, or misrepresentation (Velázquez *et al.*, 2023). For instance, high-priced spices like saffron, vanilla, or turmeric are often targeted for dilution with cheaper materials or synthetic adulterants. Methods to verify spices' authenticity include DNA barcoding to confirm species identity, chromatography to detect additives or contaminants, and spectroscopy to analyze chemical composition (Osman *et al.*, 2019; Velázquez *et al.*, 2023). These techniques help ensure that spices meet quality standards, safeguarding consumer health and promoting fair trade.

Spices, prized for their flavor, aroma, and medicinal properties, are susceptible to adulteration and misrepresentation. Spice fraud encompasses deceptive practices aimed at altering the quality, quantity, or origin of spice products to deceive consumers or gain unfair economic advantages (Velázquez *et al.*, 2023). Turmeric, a widely used spice with diverse culinary and medicinal applications, has faced increasing scrutiny due to reports of adulteration and fraudulent practices within its supply chain, affecting spice markets worldwide. Numerous previous studies have shed light on the alarming prevalence of turmeric fraud, revealing a disconcerting pattern of adulteration and mislabeling that transcends geographical boundaries (Jahanbakhshi *et al.*, 2021; Shannon *et al.*, 2022). Globally, spices, including turmeric, consistently rank among the most frequently adulterated food products (Forsyth *et al.*, 2019). Furthermore, a study carried out by the European Union (EU) in 2021 in 21 EU states revealed that 11% of turmeric samples were adulterated (Alex, 2021). This unsettling trend is exacerbated by a multitude of factors, including the increasing global demand for turmeric and its associated products. The consequences of this rampant fraud are severe, encompassing significant health

risks to consumers, economic losses across the supply chain, and erosion of trust in the spice industry on a global scale.

Within the African continent, the issue of turmeric fraud manifests within a unique context. Limited research exists on the specific extent of turmeric fraud in Africa, but emerging reports and anecdotal evidence suggest that fraudulent practices involving turmeric are not uncommon (Gwenzi *et al.*, 2023). The reasons behind such fraud in Africa are multifaceted and for-profit motives. Looking at the case turmeric market in Cameroon, it has been expanding greatly. In 2019 Cameroon exported 4 tons of turmeric and the price of exportation was shown to be 1.67\$ per kilogram and has to increase to 2.00\$/kg in 2023 when compared to the price in 2013 which was 0.33\$/kg (Selina, 2023). However, there is limited information available on the authenticity of turmeric products sold in the country. Reports of adulteration, and substandard quality are concerning and warrant thorough investigation.

I.1.2 Turmeric:

I.1.2.1 Agriculture of Turmeric and Production/Yields in the World and Africa

Turmeric cultivation, also known as turmeric farming, is primarily concentrated in tropical and subtropical regions of the world with adequate rainfall and well-drained soil. The plant thrives in warm, humid climates and is propagated through rhizome divisions and is grown under rain-fed and irrigated conditions (Prasath and Leela 2018; Ravi *et al.*, 2021). Turmeric usually takes seven to nine months to be fully mature and suitable for harvesting (Prasath and Leela 2018). When turmeric is fully mature, it has a characteristic yellow leaf color, and the leaves start falling off.

In terms of global production, countries such as India (80%), China (8%), and Myanmar (4%) are among the leading producers of turmeric (Choudhary and Shakuntla, 2018). For example, India produced approximately 0.94 million metric tons of turmeric in 2015 and 1.22 million tons in 2023 which makes India the largest turmeric farming country in the world contributing to 80% of the global turmeric production (Sandhya, 2023). This same statistic aligns with Spices Board GOI; comply by Bhuwan Bhaskar in Figure 1. Within Africa, regions like Nigeria contributes 3% to the global turmeric production (Choudhary and Shakuntla, 2018), while turmeric production in Ethiopia has expanded significantly from 2,000 tons in 2008 to 12,000 tons in 2014 (Shimelis, 2021) and Cameroon has contributed to the cultivation and production of turmeric albeit to a lesser extent compared to Asian countries. Figure 2 below show the different forms of turmeric from the plant to the powder turmeric.

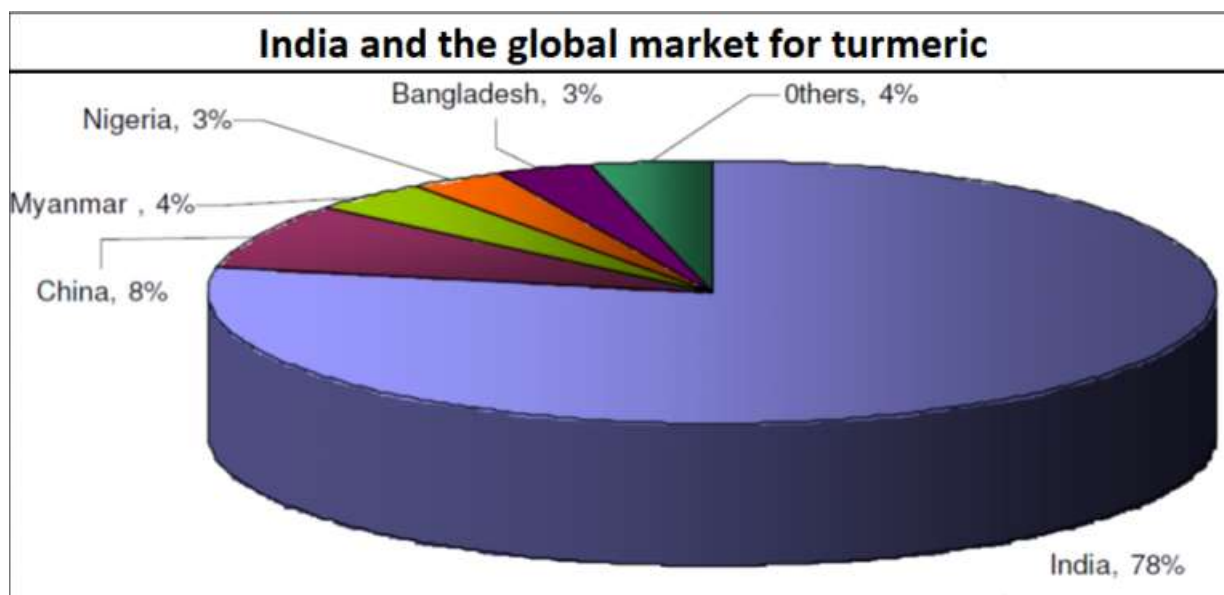


Figure 1: Turmeric Production and the Global Market (Source: Spices Board, GOI; Report compiled by Bhuwan Bhaskar of NCDEX and cited by Neutriherbs: Reported Chani Chen February 2024)

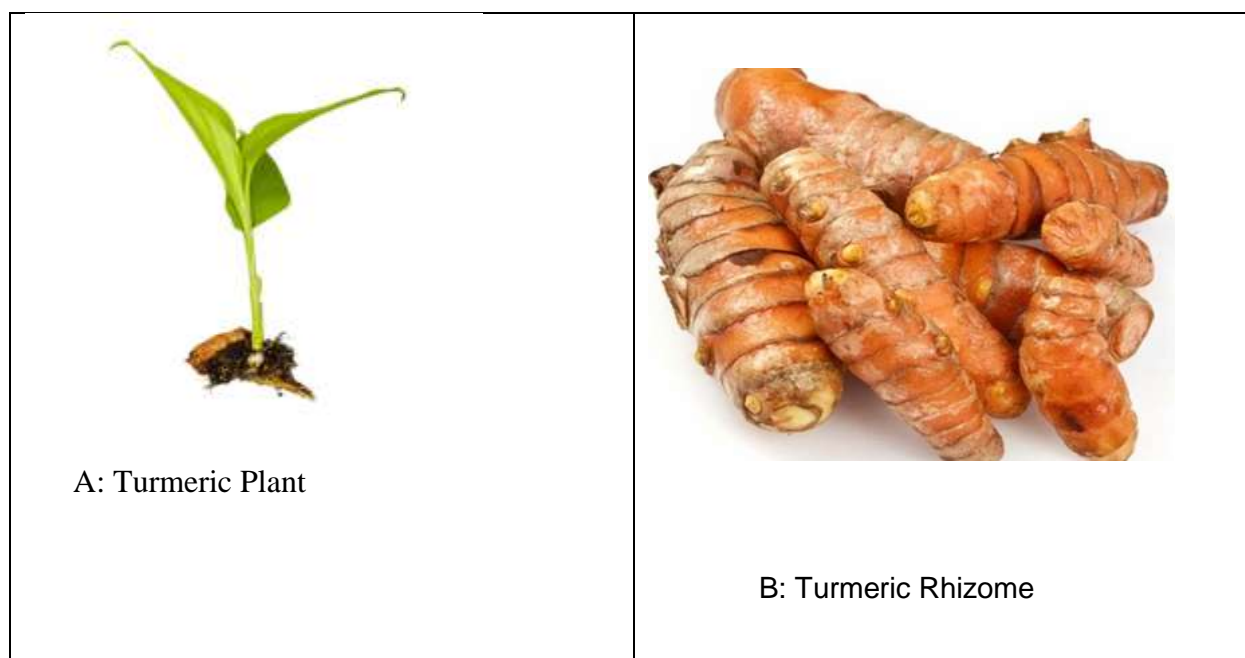




Figure 2 : The different developmental stages of Turmeric (A. turmeric plant, B. turmeric rhizome, C. dried slices of turmeric rhizome, D. turmeric powder)

(Source: Modified from Yadav and Gaur, 2017)

I.1.2.2 Nutritional Values and Characteristic/ Composition of Turmeric

Turmeric is known to have a warm bitter flavor like black pepper and an earthy, mustard-like aroma (Kumar *et al.*, 2021). It is used as a colorant due to its strong orange to yellow color. Figure 4 below gives the chemical composition of turmeric. Turmeric is made up of several key components, including 5-10% curcuminoids (such as curcumin) that give it its yellow color and medicinal properties, and 3-5% turmerones, which are part of its essential oil contributing to its aroma and anti-inflammatory effects. It also contains 60-70% carbohydrates (primarily starches) for energy, 6-13% proteins, 4-7% essential minerals like potassium, iron, and manganese, and 10-15% fats. Additionally, turmeric contains small amounts of vitamins such as vitamin C and B6, along with 3-7% essential oils that play a significant role in its therapeutic properties and moisture content of about 11 -17%.

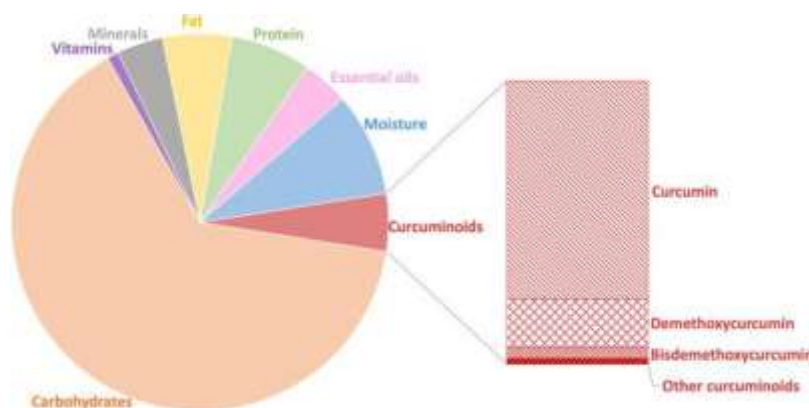


Figure 3: Chemical Composition of turmeric (Source: Zhang and Kitts, 2021)

I.1.2.3. Turmeric processing

The processing of turmeric rhizomes is known to vary from one region to another. This variation might have an effect on the quality of the powder turmeric that is obtained, as it is known that the method of cooking has an effect on the physical, chemical, and nutritional composition (Emelike, 2020). Some of the processing methods of turmeric after slicing into small pieces are; boiling, steam cooking, sun drying, blanching and oven drying (Jayashree and John, 2016; Emelike, 2020). In India which is known to be the highest producer and consumer of turmeric worldwide (Prasath *et al.*, 2018), 2 most common methods of processing turmeric into powder form exist; boiling (curing) in alkaline water to give it a characteristic bright color and remove the raw scent and give it a good aroma of the turmeric and non-boiling method (drying). The effect of heat or pressure on turmeric is known to decrease its active principles. Lahari *et al.* (2020) showed that the oleoresin content of the powder turmeric obtained in non-boiled turmeric is higher than in boiled turmeric. Also, it is known that powder turmeric obtained through the boiled method has a higher moisture content than those from the drying method. For example, an experiment carried out by Lahari *et al.*, 2020 showed that turmeric powder obtained from the boiled method was 14.60 percent while powder turmeric obtained from the drying method was 14.48 percent. Figure 4 gives the flowchart of Turmeric processing.

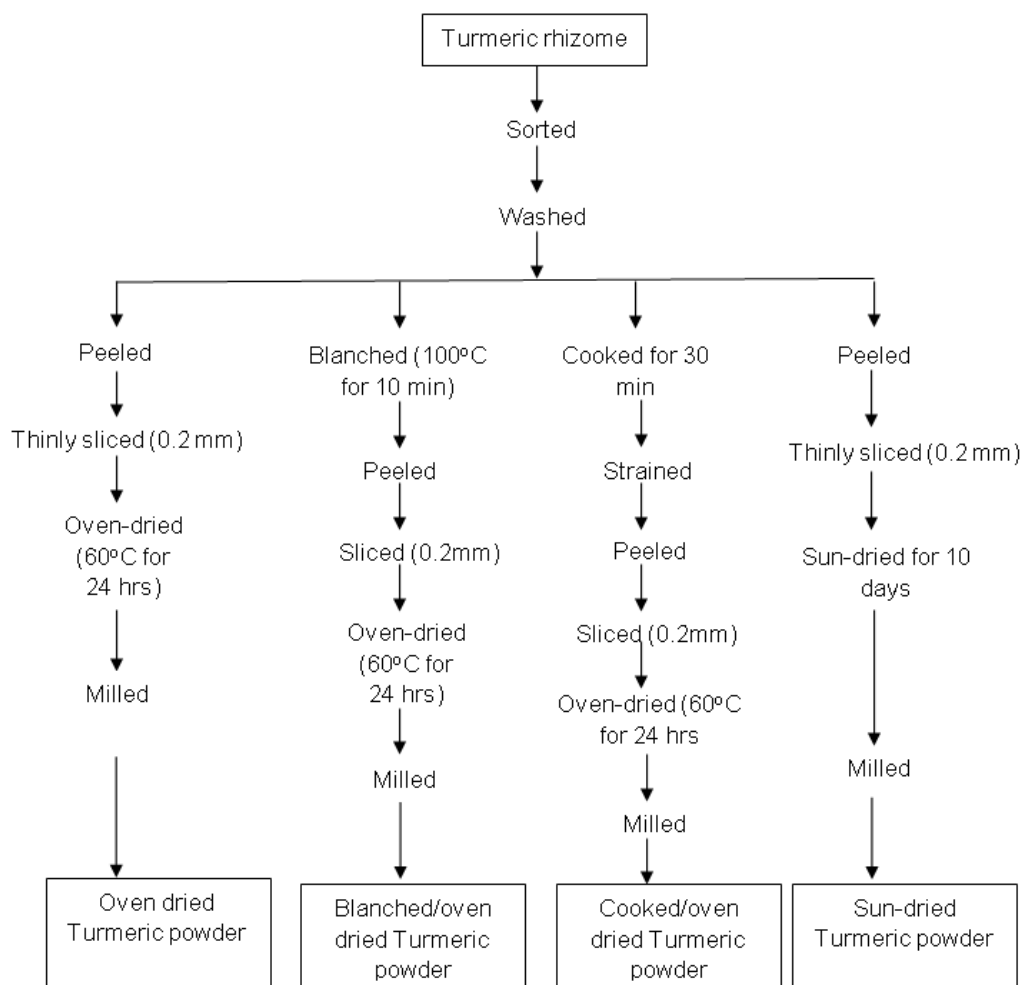


Figure 4: Turmeric processing flowchart (Source: Emelike, 2020)

I.1.2.4 Turmeric uses as Spice and as Medicine

Turmeric (*Curcuma longa*) is known to be a perennial herbaceous plant belonging to the ginger family, *Zingiberaceae* (Prasath and Leela, 2018). Renowned for its vibrant yellow color and distinct flavor, turmeric has been an integral part of culinary traditions and use as a natural food coloring agent. For example, turmeric is used as the main element in curry (Prasath and Leela, 2018) which is generally used to cook varieties of food globally. Due to its distinctive color, flavor and health benefits, it is used in savory dishes such as rice, stew and side dishes to beverages, sauces, marinades, and baked goods. Turmeric has been studied for its potential as a natural food preservative due to its antioxidant and antibacterial properties (Gul and Jehan, 2015) thereby enabling it to be use by many food processing industries.

Turmeric has a range of medicinal properties such as anti-inflammatory, anti-cancer, antioxidant (Antioxidants help neutralize harmful free radicals in the body, thereby reducing oxidative stress and lowering the risk of chronic diseases), anti-diabetic, anti-microbial, gastroprotective, neuroprotective, hypoglycemic and cardioprotective (Jyotirmayee and Mahalik, 2022). Additionally, turmeric powder is a good source of dietary fiber, vitamins (such as vitamin C and vitamin E), and minerals (such as iron and potassium), contributing to overall health and well-being. This has provoked the usage of turmeric in the formulation of skin care products such as body scrubs and soap which is reputed for its ability to cleanse, soothe, and rejuvenate the skin, offering benefits for conditions like acne, eczema, and uneven skin tone (Rathaur *et al.*, 2012). It is also used in medicinal products such as tea, oil and even drugs (e.g. curcumin or diferuloylmethane with drug bank accession number DB11672, which helps to fight cancer and might be use as an alternative chemotherapy or chemoprevention in hepatocellular carcinoma (Zhao, et al., 2020)). It also holds a significant place in traditional medicine systems globally, including Ayurveda, Traditional Chinese Medicine (TCM), and African traditional medicine (Kaur, 2019). These medicinal properties and products made from turmeric are used to treat arthritis, help prevent cancer/ treat cancer, depression, diabetes, etc. (Jyotirmayee and Mahalik, 2022). Moreover, turmeric-infused beverages are believed to support digestion, promote detoxification, and boost immune function (Prasad and Bharat, 2011). Furthermore, the medicinal properties of turmeric are primarily attributed to its phytochemical constituents, notably curcuminoids, volatile oils, and other bioactive compounds. These phytochemicals exert diverse pharmacological effects, ranging from anti-inflammatory and antioxidant to antimicrobial and anticancer activities.

In traditional medicine systems worldwide, turmeric has been employed to address various health conditions, including arthritis, digestive disorders, skin ailments, respiratory issues, and more. Its anti-inflammatory properties make it particularly valuable for managing inflammatory conditions like arthritis and inflammatory bowel diseases. Table 2 below gives the major bioactivities, the bioactive components of turmeric with its relation to specific health problems.

Table 2 : Major bioactivities of turmeric and its bioactive constituents that relate to specific health disorders (Zhang and Kitts, 2021)

Health Disorder	Reported bioactivity
Oxidative stress	Anti-oxidant
Inflammation and Inflammatory diseases	-Anti-Inflammatory -Immunomodulatory
Allergic	Anti-allergic
Cardiovascular Diseases	-Hypolipidemic -Atheroprotective - Cardioprotective
Diabetes	-Hypoglycemic - Antiglycation - Antidiabetic
Cancer	- Antitumor - Pro-apoptotic -Antimetastatic
Neurodegenerative diseases	Neuroprotective
Depression	Antidepressant
Liver Disease	Hepatoprotective

I.1.2.5 Potential Turmeric adulterants their toxic effects

The integrity of turmeric powder can be compromised by the presence of adulterants. These adulterants can be natural contaminants, or intentional adulterants, posing risks to consumer health and safety.

Intentional adulterants may include substances such as cornstarch and ginger which might not pose a significant risk to consumers' health except for people who are allergic to the substance. Also, contaminants may arise from environmental pollution such as dust, mixtures with other nearby spices, agricultural practices, or processing methods.

Intentional adulteration of turmeric powder is a significant concern, driven by economic motives and market pressures. Common adulterants may include cheaper botanical materials, synthetic dyes (such as aniline dye, lead chromate, metanile dye), or toxic substances added to enhance color or weight. Table 3 below gives the various turmeric adulterants and their health effects on man.

Table 3 : Adulterants and their toxic effects

Adulterants	Toxic effects	Citations
Maize flour	Allergic reactions (corn allergies)	Guillen <i>et al.</i> (2014)
Chalk	Digestive issues (high amounts), constipation, bloating	Zabin (2017)
Metanile dye	Gastrointestinal discomfort and allergic reactions	Mishra (2020); Bhowmik <i>et al.</i> (2022)
Aniline dye	Methemoglobinemia (reduced oxygen delivery to tissues), dizziness, headaches, blue-colored skin (cyanosis)	Thomas <i>et al.</i> (2019)
Lead chromate	Lead poisoning (abdominal pain, nausea, vomiting, headaches, nerve damage, developmental problems in children)	Sarkar (2018); Lopez <i>et al.</i> (2022)
Sudan dye	Carcinogen (potential cancer), organ damage (liver, kidneys)	Sadef <i>et al.</i> (2023)

Adulterants such as lead chromate, aniline dye, metanil yellow, and Sudan dye are often added to turmeric to enhance its color and appearance, but they pose significant health risks (Soliman *et al.*, 2022). Lead chromate, a neurotoxin that can accumulate in the body, is linked to neurological impairments and developmental disorders, especially in vulnerable populations like children and pregnant women (Hartwig *et al.*, 2023; Lopez *et al.*, 2022). Regulations from the Bangladesh Standards and Testing Institution (BSTI), the Bureau of Indian Standards (BIS), and the Indian Agricultural Produce Grading and Marking Act prohibit its presence in turmeric, with permissible lead content varying from 2.5 ppm to 10 ppm (Cowell *et al.*, 2017). Metanil yellow, allowed up to 100 mg/kg under India's Prevention of Food Adulteration Act, can cause gastrointestinal discomfort and allergic reactions (Mishra, 2020; Bhowmik *et al.*, 2022; Verma *et al.*, 2022). Sudan dye, classified as a Group 3 human carcinogen, is associated with liver tumors and has a maximum limit of 0.1 mg/kg (Sadef *et al.*, 2023). Aniline dye has toxic effects such as hyperpigmentation, hyperplasia, and splenomegaly with chronic exposure (Khan *et al.*,

2014). Additionally, chalk, used to adulterate turmeric, can cause digestive issues (Zabin, 2017), while corn flour, another common adulterant, may trigger allergies in some individuals.

I.1.2.7 Reasons for Adulterating Turmeric Powder

The adulteration of turmeric powder may occur for various reasons, including economic gain, market demand, and supply chain vulnerabilities (Galvin-King *et al.*, 2018). Economic motivations drive unscrupulous actors to dilute or adulterate turmeric with cheaper fillers or substitutes to maximize profits (Galvin-King *et al.*, 2018). Market pressures and competition may also incentivize the use of additives to enhance color, texture, or perceived quality. Additionally, supply chain complexities and inadequate regulatory oversight create opportunities for fraudulent practices to go undetected.

I.1.3 Food and Turmeric Authenticity Control Measures

In response to the pervasive threat of spices and turmeric fraud, regulatory agencies, industry stakeholders, and international organizations have implemented various control measures to detect, prevent, and mitigate fraudulent activities throughout the supply chain. These control measures encompass regulatory frameworks, quality assurance protocols, analytical techniques, and technological innovations aimed at ensuring the authenticity, safety, and integrity of food and spices.

I.1.3.1 Food Authenticity Control Measure

Food authenticity is about ensuring that food offered for sale or sold is of natural, substance, and quality expected by the purchaser (Johnson, 2014).

Food authenticity control measures are essential to prevent fraud and ensure that consumers receive genuine, high-quality products. One of the primary measures is the implementation of strict regulatory standards and labeling requirements, which mandate that spices are accurately labeled with details on origin, composition, and processing methods (Popping *et al.*, 2022). Regular inspection and certification processes by government bodies and independent organizations help verify that these standards are met. In addition, traceability systems are used to monitor the entire supply chain, from the spice farm to the market shelf, ensuring transparency and accountability. Advanced analytical techniques such as DNA barcoding, chromatography, and spectroscopy play a vital role in detecting adulteration and verifying the authenticity of spices (Negi *et al.*, 2021; Kotsanopoulos and Athanasios, 2022). Certification schemes like Geographical Indications (GI) also protect regional spices by confirming their origin and

quality, such as Kampot pepper from Cambodia or Saffron from Iran (Barth, 2019). These control measures, combined with increased industry collaboration and consumer awareness, are crucial for maintaining the integrity of the global spice trade and protecting traditional spice producers.

I.1.3.2 Turmeric authenticity Control Measure

Turmeric authenticity control measures are essential for ensuring the purity, quality, and accurate labeling of this valuable spice. By utilizing advanced techniques like DNA barcoding and chromatography, combined with traceability systems that monitor the supply chain from cultivation to sale, these measures help prevent adulteration and maintain consumer trust.

I.1.3.2a Turmeric Traceability

Turmeric traceability (Figure 5) is essential to ensure product quality and safety. By tracking the journey of turmeric from the farm to the consumers, consumers can gain confidence in its origin, production methods, and potential health benefits. Traceability systems involve labeling individual batches, recording harvest dates, and maintaining accurate records of processing and transportation (Qian *et al.*, 2022). This information helps identify issues in the supply chain, such as contamination or unethical labor practices and allows for swift corrective actions

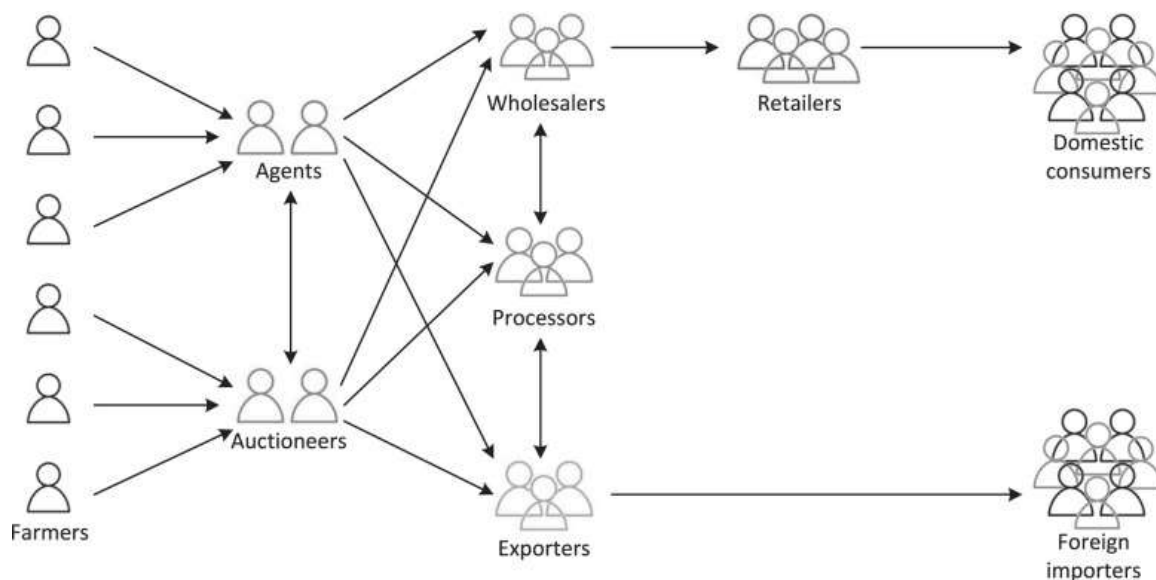


Figure 5: Schematic representation of a typical supply chain of Turmeric powder. (Source: Rukundo *et al.*, 2020)

I.1.3.2b Methods Applied to Study Authenticity of Turmeric Powder

Authenticity assessment of turmeric powder involves applying specific analytical methods tailored to detect adulterants, and other forms of fraud. Some techniques commonly used to study the authenticity of turmeric powder include;

Microscopic Analysis: This is a physical method use to observe features such as structure of the starch granules and colour for genuinity. It shows if foreign structures or colour are included which may indicate the presence of adulterants (Sasikumar, 2019)

Curcumin Content Analysis: Quantifying the curcumin content of turmeric powder using spectrophotometric methods or chromatographic techniques, such as HPLC, to verify the presence and concentration of curcuminoids (Kotra *et al.*, 2019), the bioactive compounds responsible for turmeric's characteristic color and medicinal properties.

DNA-based Authentication: Employing DNA barcoding and molecular genetic techniques to identify species-specific DNA markers and authenticate the botanical origin of turmeric powder, distinguishing it from adulterants or substitutes (Nehal *et al.*, 2021).

Chemical Profiling: Conducting chemical profiling of turmeric powder samples using chromatographic and spectroscopic methods to characterize their chemical composition, volatile profile, and phytochemical profile, enabling differentiation between authentic turmeric and adulterated products (Li *et al.*, 2011).

Furthermore, organoleptic components can also be used to study the authenticity of Turmeric powder as shown on Table 4 below:

Table 4: Factors used to evaluate Turmeric Authenticity

Factors	Description	Citations
Color	Authentic turmeric typically has a vibrant yellow-orange color, indicating the presence of natural compounds.	Acharya (2014); Mahato and Harishankar, (2023)
Aroma	A fresh, earthy, and slightly pungent aroma is characteristic of authentic turmeric.	Sharma and Happy (2022)
Taste	Authentic turmeric has a slightly bitter, peppery flavor with hints of citrus and ginger.	Acharya (2014)

I.1.4. Food and Turmeric Fraud Control/ Detection Measures

I.1.4.1 Food Fraud Control/Detection Measures

Food fraud control measures encompass a range of strategies and interventions to address the diverse forms of fraudulent practices observed in the food industry. Key initiatives include:

Regulatory Compliance: Enforcing strict regulatory standards and labeling requirements to detect fraudulent activities and promote transparency and accountability in food production and distribution (Hellberg *et al.*, 2020).

Supply Chain Traceability: Implementing traceability systems and documentation protocols to track the movement of food products from farm to consumers, enabling rapid identification and mitigation of fraudulent activities (Qian *et al.*, 2022).

Quality Assurance Programs: Establishing quality assurance programs, such as Good Manufacturing Practices (GMP) and Hazard Analysis and Critical Control Points (HACCP), to uphold product quality, safety, and integrity throughout the production process (De *et al.*, 2016).

Laboratory Testing and Authentication: Employing advanced analytical techniques, including DNA analysis, spectroscopy, and chromatography, to authenticate food products, detect adulterants, and verify product claims (Nehal *et al.*, 2021).

Table 5: Food fraud detection techniques

Category of methods	Specific methods	References
Spectrometry	High-resolution mass spectrometry	Sciuto <i>et al.</i> (2017)
Chromatography	High performance Liquid chromatography (HPLC)	Amoako-Mensah (2016)
Spectroscopy and Machine learnings	Raman spectroscopy	Andoh <i>et al.</i> (2019); Abia (2023)
	NIR spectroscopy coupled with chemometrics	Teye <i>et al.</i> (2019); Abia (2023)
Optical and photonic methods	Optical screening	Andoh <i>et al.</i> (2020)
Chemical	Chemical test with petroleum ether and hydrochloric acid	Ibukun <i>et al.</i> (2021)
		Nwachoko <i>et al.</i> (2019)

I.1.4.2 Turmeric Fraud Control Measures

Turmeric fraud control measures target the unique challenges associated with the production, processing, and trade of turmeric and other spices. These measures include:

Regulatory Oversight: Enforcing regulatory standards and specifications for turmeric, including purity, quality, and labeling requirements, to safeguard consumer interests and uphold market integrity (Núñez, 2021).

Quality Assurance and Certification: Implementing quality assurance programs and certification schemes, such as ISO standards and Global Good Agricultural Practices (GAP), to ensure the authenticity, safety, and traceability of turmeric throughout the supply chain. **Figure 5** which shows the supply chain of turmeric.

Adulterant Detection: Utilizing analytical techniques, such as chromatography, mass spectrometry, and chemical techniques, to detect common adulterants and contaminants in spices, including colorants, fillers, and pesticide residues (Nehal *et al.*, 2021).

International Collaboration: Fostering collaboration among governments, industry associations, and international organizations to harmonize regulatory approaches, share best practices, and strengthen enforcement mechanisms for combating spice fraud on a global scale.

Table 6: Turmeric Fraud Detection Techniques

Adulterants	Method of Detection	References
Lead Chromate	Sulfuric Acid test or - Hydrochloric acid	FASSI (2017); BhanuKumar, and Ghadevaru (2022)
Aniline Dye	Test Rectified Spirit test	Niharika et al. (2022); FASSI (2017)
Metanile yellow	Hydrochloric acid test	FSSAI (2017); Dhakal <i>et al.</i> (2016)
Chalk	Hydrochloric acid test	Niharika <i>et al.</i> (2022); FSSAI (2017)

I.1.5 Legislature of potential turmeric adulterants

The legislature surrounding turmeric adulterants is essential to protect consumer health, ensure product integrity, and maintain accurate labeling standards. Due to turmeric's high value and demand, it is sometimes adulterated with harmful or unauthorized substances, including lead chromate, Sudan dye, metanil yellow, aniline dye, chalk, and corn starch. These adulterants enhance color, weight, or appearance but pose serious health risks and dilute product quality. Regulatory bodies worldwide, such as the U.S. Food and Drug Administration (FDA), European Food Safety Authority (EFSA), Codex Alimentarius, and India's Food Safety and Standards Authority of India (FSSAI), have set maximum permissible limits and standards to control these adulterants.

For instance, lead is a neurotoxin which damages the brain and permanently lowers IQ (Forsyth et al., 2019), has different acceptable limits by various organization; for example, the European Union (EU) which fixed lead limit at 1.5 milligrams per kilogram (mg/kg) (EC, 2021), BIS and the Indian Agricultural Produce Grading with permissible lead content varying from 2.5 ppm to 10 ppm (Cowell *et al.*, 2017), while the Joint Food and Agriculture Organization of the United Nations/WHO Expert Committee on Food Additives (WHO, 2013) indicated that, for lead (Pb), there is no safe exposure level, the FDA (FDA, 2019). Sudan dyes (Sudan I, II, III, IV and Para Red) are not permitted dyes to be use in food due to their carcinogenic effects (Pan *et al.*, 2012) are strictly banned in food products by the European Food Safety Authority (EFSA, 2005), enforcing a zero-tolerance policy. Similarly, metanil yellow and aniline dyes are cancerous and are entirely prohibited in foods (Pardeshi, 2019). Each measure serves to uphold the purity and authenticity of turmeric in the global market, though regulatory limits and enforcement methods may vary by region.

CHAPTER TWO: MATERIALS AND METHODS

II. MATERIALS AND METHODS

II.1 Overview of Methodology

This research was carried out using qualitative and quantitative methods. The qualitative method focused on the opinions, assessed the hidden social actions of turmeric fraud practices, as well as measure and analyze the primary datasets. while the quantitative method involves collecting and analysing numerical data.

II.2 Study site

The study was conducted in major markets in two cosmopolitan cities in Cameroon: the administrative capital city, Yaounde (Central Market, Essos market, Mokolo market, Nsam Market, Odza market, Mendong market, Mvog-beti market, Mvog-Mbi Market, Acacia Market, Soa market, Mfoundi market) and the economic capital city, Douala (Central market, Nkouloulou Market, Bonamoussadi Market, Logpom Market, Sandaga Market, Cite sec market, Deido Market, Carrefour Market, PK 14 Market), Cameroon. These cities were selected partly because they are cosmopolitan and may constitute the major markets for turmeric powder in Cameroon. In addition, online survey was done in Cameroon.



II.3 Target Population

Figure 6: Cameroon Map showing turmeric powder collection sites: Yaounde and Douala

The target population for this study were turmeric sellers in different major markets in Yaounde and Douala, Cameroon, and turmeric consumers in Cameroon. Additionally, spices (including turmeric) consumers, all around the nation, who could voluntarily provide frank responses to the questionnaires were involved.

II.4 Sample size calculation

In order to gather primary data for this study, the sample size was calculated using the sample size determination formula for a proportion/percentage (Bartlett, Kotrlik and Higgins, 2001) as follows:

$$n = (Z^2 * p * q) / E^2$$

Where:

n = Sample size

p = Percentage of market women selling spices and had turmeric amongst their spices (50%), in this case, based on a field survey

E = Percentage maximum error (margin of error), 0.103

q = Percentage of market people without/ who do not sell turmeric = $1 - p = 50\%$

Z = 1.96, Confidence level = 95%,

Therefore, the sample size for this study was considered to be

$$n = (1.96^2 * 0.5 * 0.5) / 0.103^2$$

$$n = 92.99$$

$$n \approx 93$$

Therefore, considering possibilities of loss of samples, a total of $93 + 10$ ($n=103$) samples was the target sample size.

II.5 Sample collection

Samples were collected following a stratified random sampling technique and each turmeric powder sample was purchased from one in every stratum of 3-5 different turmeric sellers. A total of 103 samples were purchased (62 samples from in Yaounde (which was purchased from wholesalers and retailers in Yaounde) and 41 samples purchased from local producers in Douala), and 1 control sample was prepared in the laboratory. An estimated 50-100 g of

turmeric powder samples were purchased ranging from 500frs to 1000frs per sample. The samples were labeled and transferred in an airtight container to the IMPM laboratory and kept in a dark cupboard at ambient temperature until analysis.

The Control sample was prepared from fresh turmeric rhizome which was purchase for 1000frs CFA from Mvog-beti market in Yaounde, Cameroon. Once returned to the laboratory, the turmeric rhizome was washed properly to ensure no dirt or sand was left on it. It was sliced into smaller pieces and placed in a hot air oven at 40 °C for 2days (Lim *et al.*, 2011). The dried rhizome was milled and 115g of turmeric powder was obtained and stored in an airtight container and kept away from light and humidity.

II.6: Laboratory Analysis

Two categories of analysis were performed in the laboratory. One was to confirm the authenticity, and the other was to detect fraud (or presence of adulterants) in the studied turmeric powder samples. These two categories of analysis included visual inspection, microscopic analysis, physiochemical tests and advance analytical tests.

II.6.1 Authenticity Analysis

Physical tests in the context of quality control and analysis refer to the set of procedures that were used to assess the physical characteristics and properties of turmeric powder. Some common physical tests conducted were: visual impaction, microscopic analysis, and moisture content.

a. Visual inspection

Principle:

Visual inspection test is based on assessing the various colour and uniformity of turmeric powder. Authentic Turmeric has a deep yellow-orange to golden yellow colour while inauthentic turmeric powder shows irregularities in color due to the presence of fillers or dye (TOI, 2024).

Materials:

The materials used for the visualization were:

- Naked eyes and
- White Paper

Procedure:

The colour, of each turmeric sample and control was placed on a white paper and visually observed (using naked eyes) for any irregularities or inconsistency.

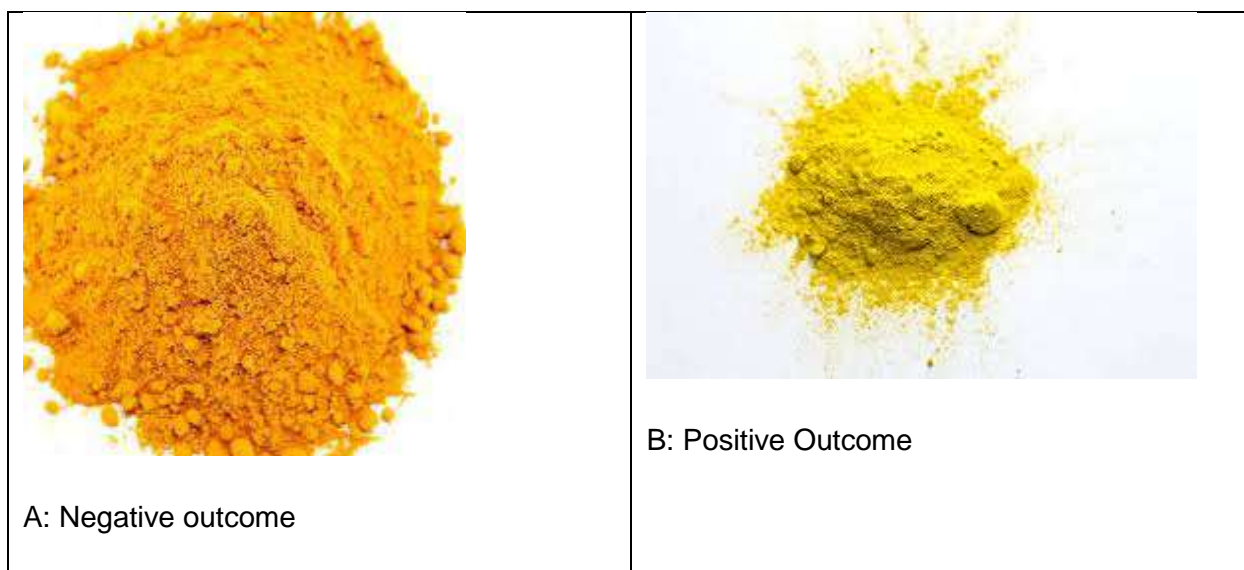


Figure 7: Outcomes of Visual Observation

b. Microscopic Examination for the presence of added starch to Turmeric powder

Principle:

The microscopic analysis of turmeric powder is based on the different structures of starch granules (diagnostic features including yellow clumps of starch, starch granules, vessels, cork and fibers) and particles characteristics (Osman *et al.*, 2019)

The materials used included:

- Microscope
- Slides
- Spatula
- Gloves
- Distill water

Procedure:

The samples of the turmeric powder were examined under a light microscope (leica DM 2000) to assess its physical characteristics, such as particle shape/ structures, and colour. A very small quantity of turmeric was placed on a slide and mixed (using a spatula) with 3 drops of distilled water (using a dropper). The slide was later placed under the microscope using a magnification power of 40x for viewing.

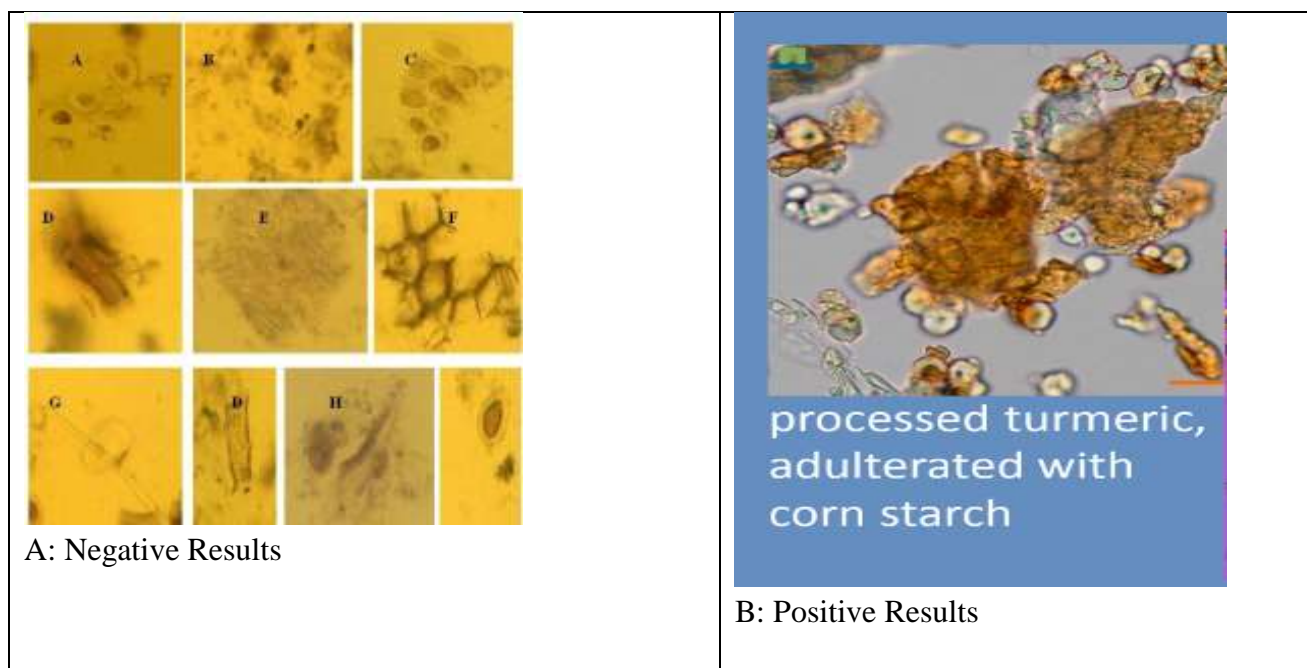


Figure 8 : Outcomes of Microscopic analysis

c. Moisture content analysis

Principle:

The moisture content of turmeric powder is based on assessing the dryness or moisture level of turmeric powder.

The materials used included:

- Crucibles
- Oven
- Electronic Balance

Procedure:

Three grams (3g) of turmeric powder from each sample was measured and put in an aluminum crucible. It was later placed inside a drying oven at 105 °C for 24 hours. Accurate moisture measurement can help improve shelf life, reduces microbial growth and spoilage.

Calculation was done as follows (Nielsen, 2010).

$$\text{Moisture Content (\%)} = \frac{\text{Initial Weight} - \text{Final Weight}}{\text{Initial Weight}} \times 100$$

II.6.2 Fraud Detection Methods

For fraud detection, chemical analysis that involved the use of chemicals to determine the presence of an adulterant in turmeric powder were employed.

a. Test for the presence of additional starch using iodine Lugol's solution:

Principle:

The detection of starch in turmeric powder was based on the reaction of starch with iodine solution. Iodine forms a blue-black complex with starch molecules. The principle relies on the colour change from the initial yellow colour of turmeric powder to a blue-black colour when starch reacts with iodine (FSSAI, 2017(equation 1)) .

Starch + Iodine → Blue-Black Complex equation 1

$(C_6H_{10}O_5)_n + I_2 \rightarrow (C_6H_{10}O_5)_n \cdot I_2$ equation 1 substituted with formulae

In this reaction, starch $(C_6H_{10}O_5)_n$ reacts with iodine (I_2) to form a blue-black complex, where iodine molecules are trapped within the starch structure. The blue-black coloration indicates the presence of starch in the turmeric sample.

Procedure:

0.25g of turmeric powder was mixed with 2 mL of hot water at 100 °C inside a beaker. 3 drops of Lugol's iodine solution were dropped in the same spot in the beaker. The intensity of the colour change was observed immediately from yellow to blue-black which indicates the presence of starch.

b. Test for Aniline dye

Principle:

The detection of aniline dyes in turmeric powder involves the reaction of aniline dye with rectified spirit (C_2H_6O). Aniline dyes are synthetic colourants that can be used to adulterate turmeric. The principle is based on the disappearance of the yellow colour of aniline dye which reacts with C_2H_6O . The yellow color disappearance can be visually observed and used to indicate the presence of aniline dyes in the turmeric sample (FSSAI, 2017).

Procedure

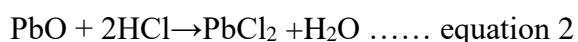
0.25-gram turmeric powder was put inside a test tube and 2 ml water was added to it make a suspension. 1ml of rectified spirit was later added to it. The Immediate separation/

disappearance of the yellow color in the rectified spirit layer indicates the presence of Aniline dye.

c. Test for the presence of Lead salt

Principle:

The detection of lead salt in turmeric powder is based on the reaction between lead salt for example lead oxide (a metallic oxide) which reacts with HCl to give Lead chloride and water. This reaction results in a change of color (Magenta color) which indicates the presence of yellow lead oxide (FSSAI, 2017(equation 2)).



Procedure

0.25g of turmeric powder was placed in a tube and 0.5ml of water was added to it. 0.25ml of Conc HCL was later added to it and the colour change was observed. The appearance of magenta color shows the presence of yellow oxides of lead in turmeric Powder.

d. Test of Metanil Yellow dye

Principle:

Detection of Metanil Yellow in turmeric powder is based on the reaction between Metanil yellow and Hydrochloric acid to give a red color which disappears slowly with the addition of distilled water into pink/violet color. (FSSAI, 2017; Verma *et al.*, 2022)

In principle, metanil Yellow in turmeric reacts with concentrated hydrochloric acid to produce a pink/violet color.

Procedure

0.25-gram turmeric powder was placed in a test tube and 1.25 ml of water was added to it to make a suspension. 5 drops of concentrated HCl were then added to it. The Appearance of pink/violet color which disappears on dilution with water shows the presence of unadulterated turmeric. Persistent colour indicates the presence of metanil yellow.

e. Test of the presence of Chalk in Turmeric powder

Principle:

The detection of chalk powder in turmeric powder was based on the reaction of calcium carbonate (present in chalk) with hydrochloric acid. The principle relies on the effervescence or bubbling that occurs when chalk powder reacts with hydrochloric acid, resulting in the release of carbon dioxide gas (FSSAI, 2017).

Calcium Carbonate + Hydrochloric acid → Calcium Chloride + Water + Carbon Dioxide... equation 3

$\text{CaCO}_3 (\text{s}) + 2\text{HCl} (\text{aq}) \rightarrow \text{CaCl}_2 (\text{aq}) + \text{H}_2\text{O} (\text{l}) + \text{CO}_2 (\text{g})$ equation 3 in formulae

In this reaction, calcium carbonate (CaCO_3) reacts with HCl to produce calcium Chloride (CaCl_2), water (H_2O), and carbon dioxide (CO_2). The release of carbon dioxide gas leads to effervescence or bubbling, which can be observed as evidence of the presence of chalk powder in the turmeric sample.

Procedure

0.25g of turmeric powder was in a test tube containing 1.25 ml of water. 15 drops of concentrated Hydrochloric acid were added to it. The occurrence effervescence indicates the presence of chalk powder.

II.6.3: Advanced analysis of the turmeric samples

A portion of the turmeric samples were taken to Queen's University Belfast (QUB) for screening on advanced techniques to confirm physicochemical analysis done in Cameroon. The analysis carried out was mainly spectroscopy techniques. Spectroscopy is based on the interaction between light and matter. When the matter absorbs the light, it undergoes excitation and de-excitation, resulting in the production of a spectrum. When matter absorbs ultraviolet radiation, the electrons present in it undergo excitation.

a. Measurement of lead chromate in the samples using the XRF Spectroscopy (Ghidotti et al., 2021)

The measurement was done using the X-ray fluorescence (XRF) analyzer. The XRF is a non-destructive analytical technique used to determine the elemental composition of materials. XRF analyzers determine the chemistry of a sample by measuring the fluorescent (or secondary) X-ray emitted from a sample when it is excited by a primary X-ray source. Each of the element's present in a sample produces a set of characteristic fluorescent X-rays ("a fingerprint") that is unique for that specific element, which is why XRF spectroscopy is an excellent technology for qualitative and quantitative analysis of material composition.

The Principles of XRF Spectroscopy

It relies on the principle that when a material is irradiated with high-energy X-rays, the atoms within the material are excited, leading to the emission of characteristic X-ray fluorescence radiation. By detecting and analysing these emitted X-rays, the elemental composition of the sample can be determined.

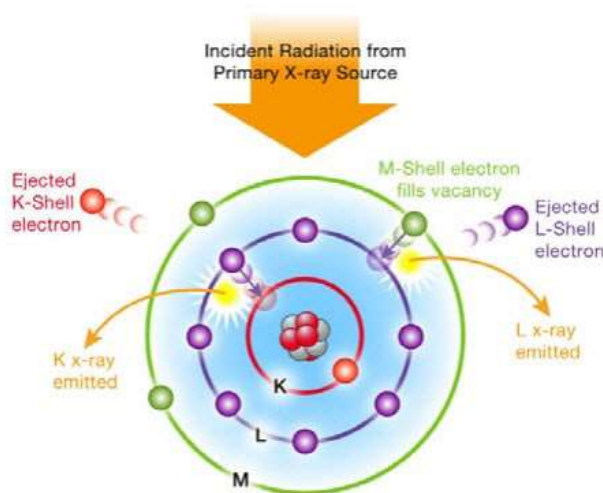


Figure 9: The XRF process

Analysis

Turmeric powder sample (approximately 3 g each) was placed into an XRF cup, pressed under soft press pressure, and cocked, and the sample height in the cup and the exact weight noted. Each XRF cup containing the sample was then placed into the Rigaku XRF machine and the elemental composition was read using the Rigaku software.

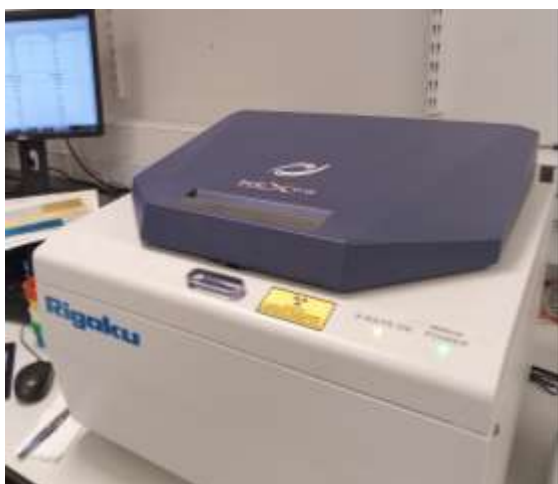


Figure 10: The XRF analyzer (Rigaku)

b. Measurement of metanil yellow in the samples using the NIR Spectroscopy (Teye et al., 2019, Abia, 2023)

Near-infrared (NIR) spectroscopy or near-infrared spectrophotometry (NIRS) is an absorption spectroscopy method that helps determine the chemical composition of a compound or solution by measuring how much near-infrared radiation the compound or solution absorbs.

NIR spectroscopy is a method that makes use of the near-infrared region of the electromagnetic spectrum (from about 700 to 2500 nanometers). By measuring light scattered off of and through a sample, NIR reflectance spectra can be used to quickly determine a material's properties without altering the sample.

The Principles of NIR Spectroscopy

The main principle behind the different methods of spectrophotometry, including NIR spectroscopy, is the Beer-Lambert Law. According to this law, the concentration of a certain chemical compound in a solution determines how much light, whether visible or infrared, this solution will absorb. The higher the concentration, the more radiation of a specific wavelength will be absorbed.

Analysis of metanil yellow in the samples

The procedure for analyzing the turmeric powder samples using near-infrared (NIR) spectroscopy involved a spiking experiment followed by analysis of the turmeric powder samples.

Into four separate 50 mL tubes, 5 g of the controlled turmeric powder sample (self-prepared, certain about its authenticity) was placed, while an additional empty tube was included. Into each of the tubes, different concentrations of metanil yellow standard (1%, 5%, 15%, 25%, or 100%) were placed. The tube was mixed thoroughly, contents were poured into the NIR-cups

and then read on the NIR spectroscopy instrument. The results were used to calculate the recovery level and to establish a calibration for the method suitable for the studied matrix. Later, each turmeric sample was then poured into the NIR-cup and read on the NIR spectroscopy instrument. The spectra were then compared with those of the spiked samples.



Figure 11: The iS50 NIR Integrating sphere sampling area and features

CHAPTER THREE: RESULTS

III- RESULTS

This results section unveils the extensive examination conducted to assess the authenticity, and the detect potential fraud in turmeric powder sold in popular markets in Yaoundé and Douala.

III.1. Survey Findings

III.1.1. Turmeric Production Area in Cameroon

The physical survey conducted using interviews with 79 sellers (50 from Yaounde and 29 from Douala) in the various markets showed that some sellers bought fresh and dry turmeric rhizomes from whole sellers, mainly from the North West and West regions of Cameroon (Figure 12) and processed the rhizomes into turmeric powder by themselves while others buy turmeric powder from bulk sellers. This speculates that North West and West regions are the highest-producing regions in the country even though turmeric can be grown in all areas but in very little quantity. Other areas revealed to be cultivating turmeric rhizome were Littoral and South West.



Figure 12: Percentage of turmeric rhizome production in Cameroon by Region

III.1.2 Processing of Turmeric powder

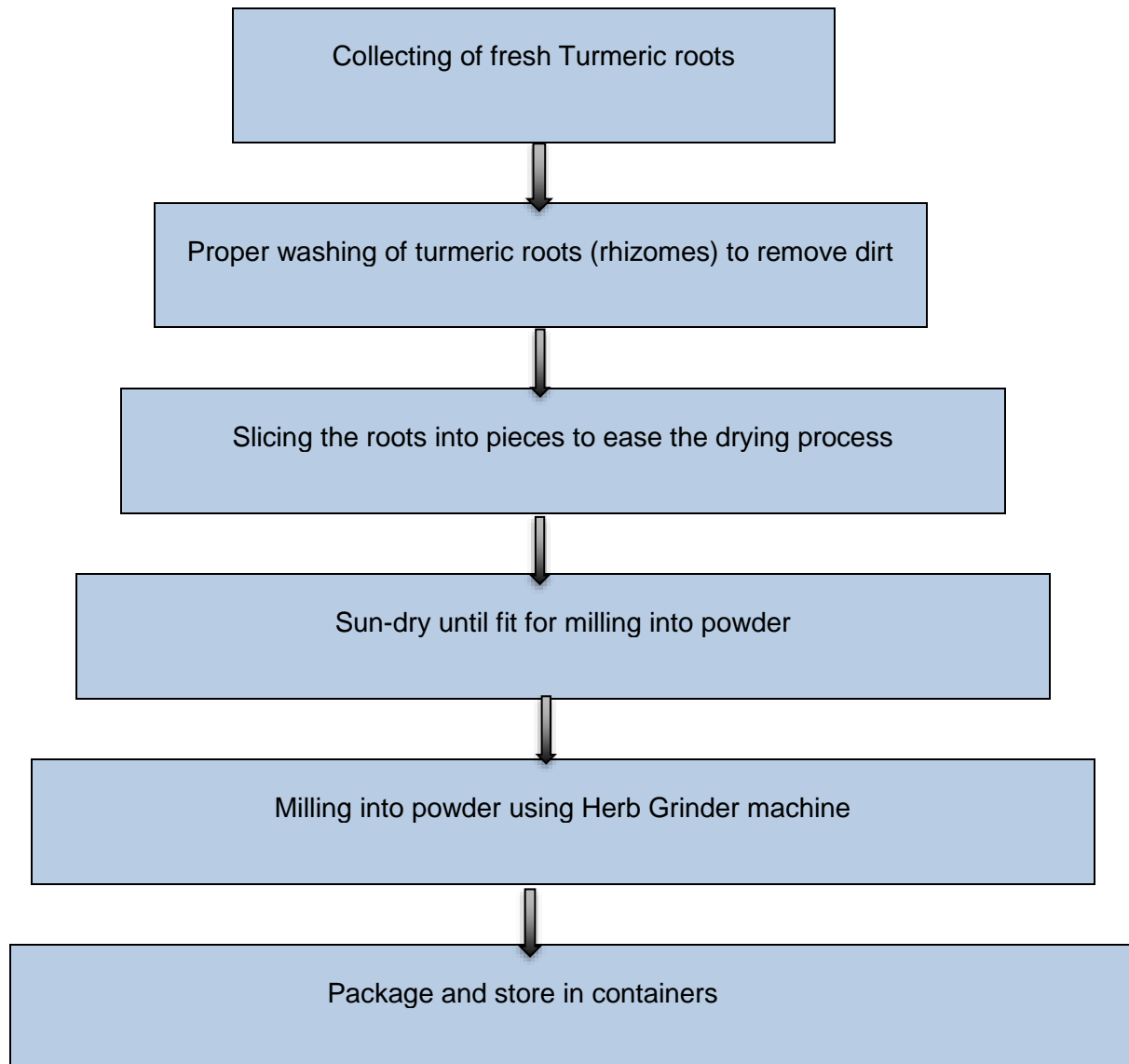


Figure 13: Turmeric Processing in Cameroon

Out of 79 Respondents, 38% (30 people) process turmeric from the fresh rhizome to the powder while 62 % (49 individuals) buy dry rhizomes and grind before selling/ buy turmeric powder and sell. Amongst those who process it, the steps include washing of turmeric roots, slicing the roots into small sizes for easy and fast drying using sun light, grinding of the dried rhizomes into powder and packaging to avoid moisture and sunlight exposure.

III.1.3 Opinions on Speculation, Authenticity and Adulteration of Turmeric powder

The high demand for turmeric, driven by its medicinal and culinary benefits stated by the consumers has create room for sellers wanting more gains and hence employing mal practices. As on table 7, 74.6 % of consumers and 69.6 % of the sellers acknowledged that turmeric powder sold is being adulterated by unknown sellers for economic gains. Table 7 below gives the reasons why turmeric powder is being adulterated with the main reason being to increase profit as stated by 77.2% of the sellers and 80.7% of the consumers. Other reasons given were to attract customers, increase quantity and quality. However, the Table 8 below gives the adulterants use to fraud turmeric powder with the main adulterant being corn flour which is use to increase the bulkiness of the turmeric being sold. Moreover, consumers stated some authenticity methods which can be used to identify genuine turmeric powder (Table 9).

Table 7 : The main reasons for adulterating turmeric powder as stated by the seller and consumers

Parameters	Sellers		Consumers	
	Frequency	Percentage	Frequency	Percentage
Confirmation of turmeric powder being adulterated	55	69.6	89	74.6
To increase profit	61	77.2	96	80.7
To attract Customers	23	29.1	32	26.9
To increase quality	1	1.3	20	16.8
To add colour	-	-	18	15.1
To increase shelf life	-	-	15	12.6
To increase quantity	-	-	1	0.8

Table 8: Common adulterants used in Cameroon

Parameters	Sellers		Consumers	
	Frequency	Percentage	Frequency	Percentage
Chemicals	7	8.9	32	26.9
Corn flour	49	62.0	43	36.1
Rice	2	2.5	0	0
Cassava	7	8.9	0	0
Mixed with other spices	1	1.3	20	16.8

Table 9: Checks for authenticity of turmeric powder done by sellers and Consumers

Parameters	Sellers		Consumers	
	Frequency	Percentage	Frequency	Percentage
Visual Inspection	48	60.8	76	63.9
Smell	19	24.1	52	43.7
Taste	0	0	39	032.8
Rely on suppliers' quality	9	11.4	33	27.7

Uses and Consumption Pattern of Turmeric

Consumers typically buy turmeric for a couple of uses both medicinal and culinary uses. Some of the reasons are for skincare, treating malaria, cough, treating nerve problems, fifth disease or irritation infection locally known as (‘children's red buttocks’), and easing the blood circulation. Figure 14 illustrates the primary reasons for turmeric consumption, with cooking and skincare being the most common applications. Furthermore, turmeric consumers reported using it in various forms, such as tea, juice, and as a spice.

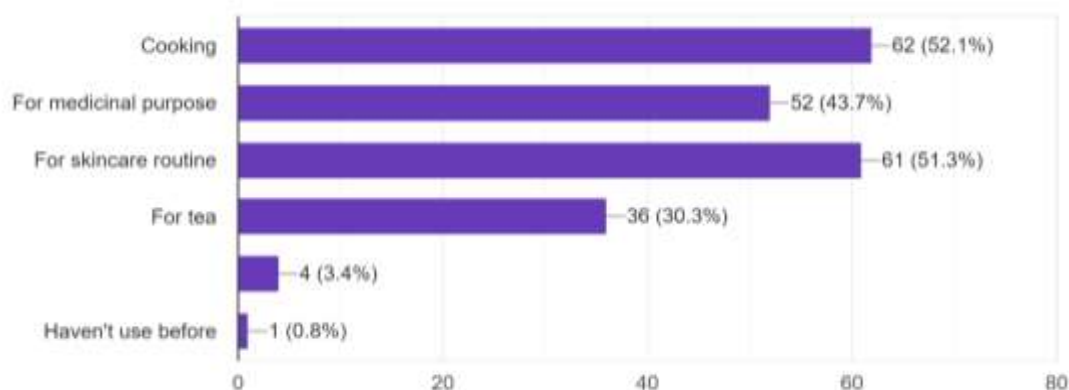


Figure 14 : Uses of Turmeric

The regular intake of turmeric in various forms is likely due to consumers' familiarity with its medicinal benefits, as illustrated in figure 14. Responses to the question about turmeric consumption frequency were diverse. Some individuals consume turmeric daily, often in the form of a teaspoon per meal or as a tea. Others consume it less frequently, such as once a week or even once a month. A few people reported never having used turmeric before, despite being aware of its health benefits. Additionally, 104 (89.7 %) of the consumers prefer purchasing the turmeric powder for regular use, 14 (12.1%) prefer the fresh and 5 (4.3%) consumers prefer the dry turmeric as well as where the purchase the turmeric they use as shown on figure15 below.

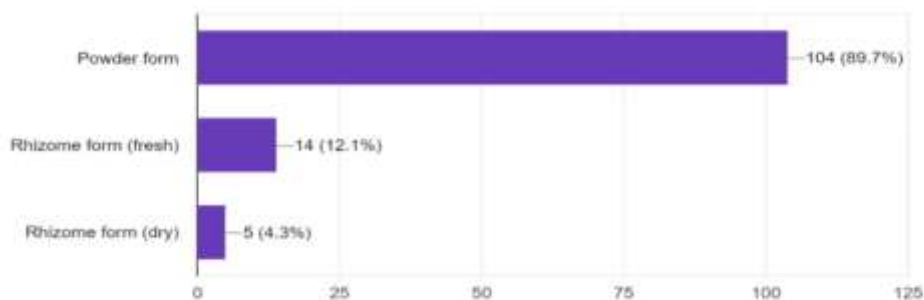


Figure 15 : Preferred forms of turmeric purchase

Despite consumers emphasizing quality criteria (Table 9) when purchasing turmeric powder, many may fail to verify the authenticity of their product, while various turmeric powder storage methods is shown on Table 10. A significant portion of consumers noticed quality deterioration, 40.7% observed a change in colour, 31.4% experienced mold, and 33.1% noted a loss of aroma. Only a small percentage reported insect infestation or no noticeable changes (Table 10).

Table 10: Ways in which turmeric powder is being stored and the Changes observed over time by the consumer

Ways of Storage		
Parameter	Frequency	Percentage
Airtight container	54	45.4
Cool Dry place	61	51.3
In Refrigerator	10	8.4
Don't pay attention to storage	16	13.4
Changes Observed		
Parameter	Frequency	Percentage
Colour Change	48	40.7
Mold	37	31.4
Loss of aroma	39	33.1
Presence of insects	11	9.3

III.2 Authenticity assessment results

III.2.1 Physical Observation with Naked Eyes

The characteristic colour of the turmeric samples ranges from whitish yellow to dark brown. When compared to the confirmed colour of turmeric powder from the control sample in figure 16A to be golden yellow. 1.9% (2 Samples) of the 103 samples were whitish yellow, 92.3% (95 samples) had an orange yellow to golden orange yellow while 5.8% (6 samples) had dark brown colour.



A and B 92% of the samples had this colour



1.9% of the sample had this whitish colour

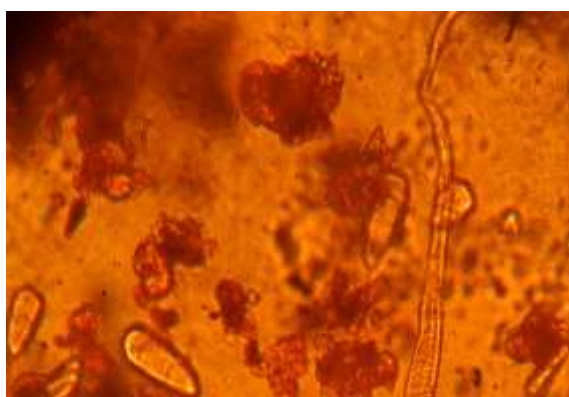


5.8% of the sample had this colour (dark brown)

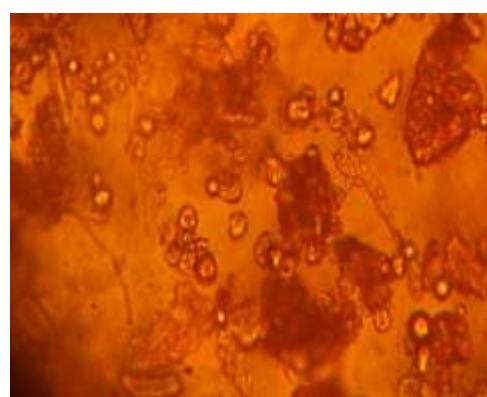
Figure 16 : The different colours of the turmeric powder samples

III.2.2 Microscopic Analysis

104 samples (including the self-prepare control) were observed microscopically, 96 (93.2%) samples had no evidence of adulteration with cornflower addition while 7 (6.79%) samples showed structures of corn flour as shown on Figure 17 below.



Unadulterated (96/103, 93.2%)



Adulterated (7/103, 6.79%)

Figure 17: Authentic and Inauthentic microscopic Visualization of Turmeric powder

III.2.3 Moisture Content

Appendix 5 contains data on the fresh weight, dry weight, and calculated moisture content for all the samples. The mean moisture content 16.145. The standard deviation varies among the samples but is less than 1 for all the samples.

Table 11: Summary of the Moisture Content Analysis

Source of samples	Mean Fresh weight (g)	Mean Dry Weight (g)	% Dry weight	Mean moisture content (g)	Standard Deviation
Laboratory prepared (Control)	1.043	0.853	81.725	18.275	0.183
Yaoundé	1.063	0.895	84.816	15.449	0.395
Douala	1.058	0.894	85.257	14.709	0.417
Mean	1.054	0.881	83.933	16.145	0.332

III.3 Fraud detection outcome

III.3.1 Lugol Iodine Test

The samples were classified base on the intensity of the colour change upon addition of the Lugol Iodine solution from +1 to +5. All samples with a positive microscopic test exhibited a colour change beyond +3, indicating the presence of additional starch.

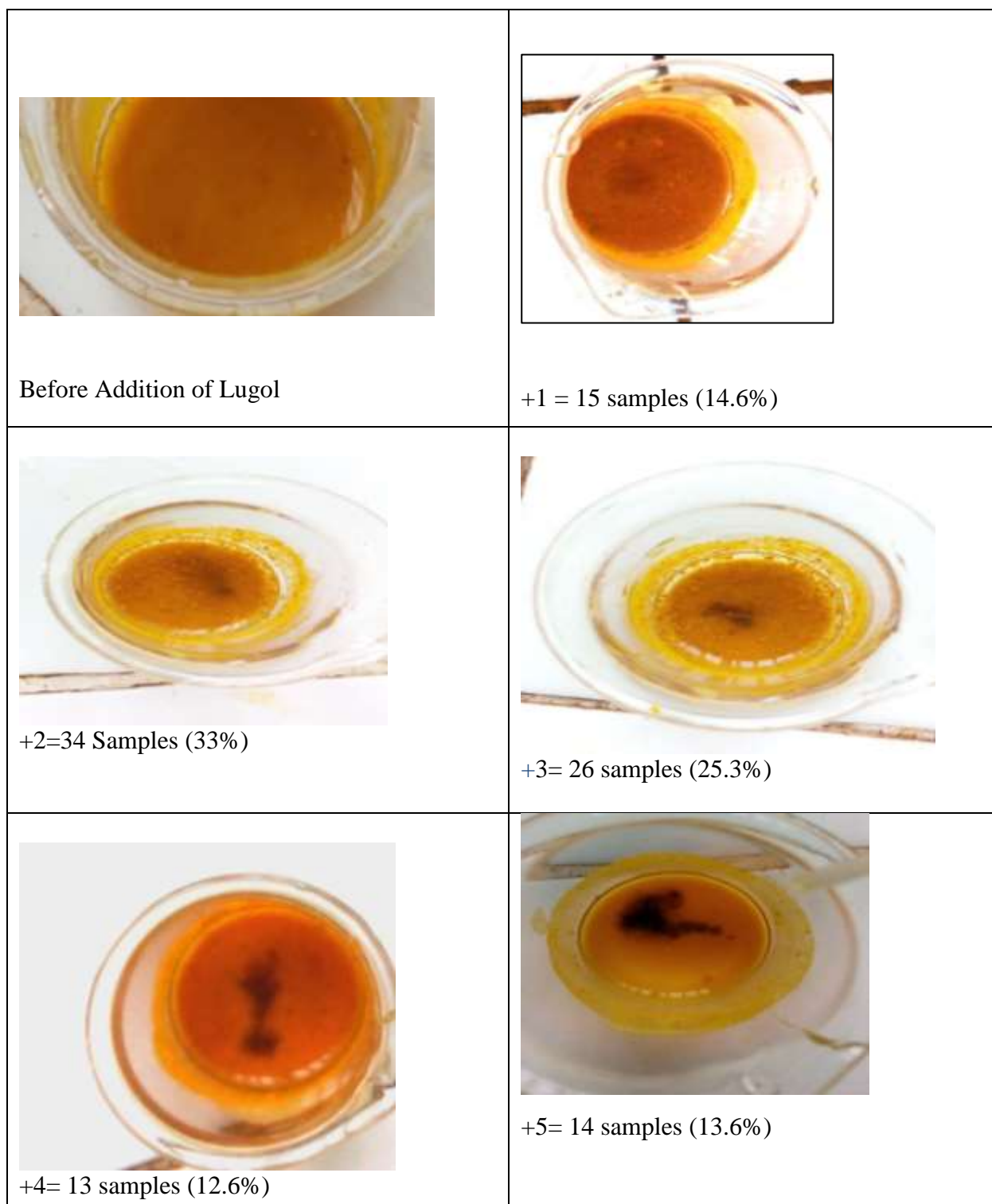


Figure 18: Different color intensity of turmeric in the presence of lugol solution

III.3.2 Aniline dye

None of the 103 turmeric powder samples exhibited a two-layer separation on the supernatant, indicating that aniline dye adulteration is less likely to be suspected. The positive control, containing a known amount of aniline dye, produced a distinct two-layer separation,

confirming the effectiveness of the test procedure. The negative control, consisting of pure turmeric powder, showed no two-layer separation.

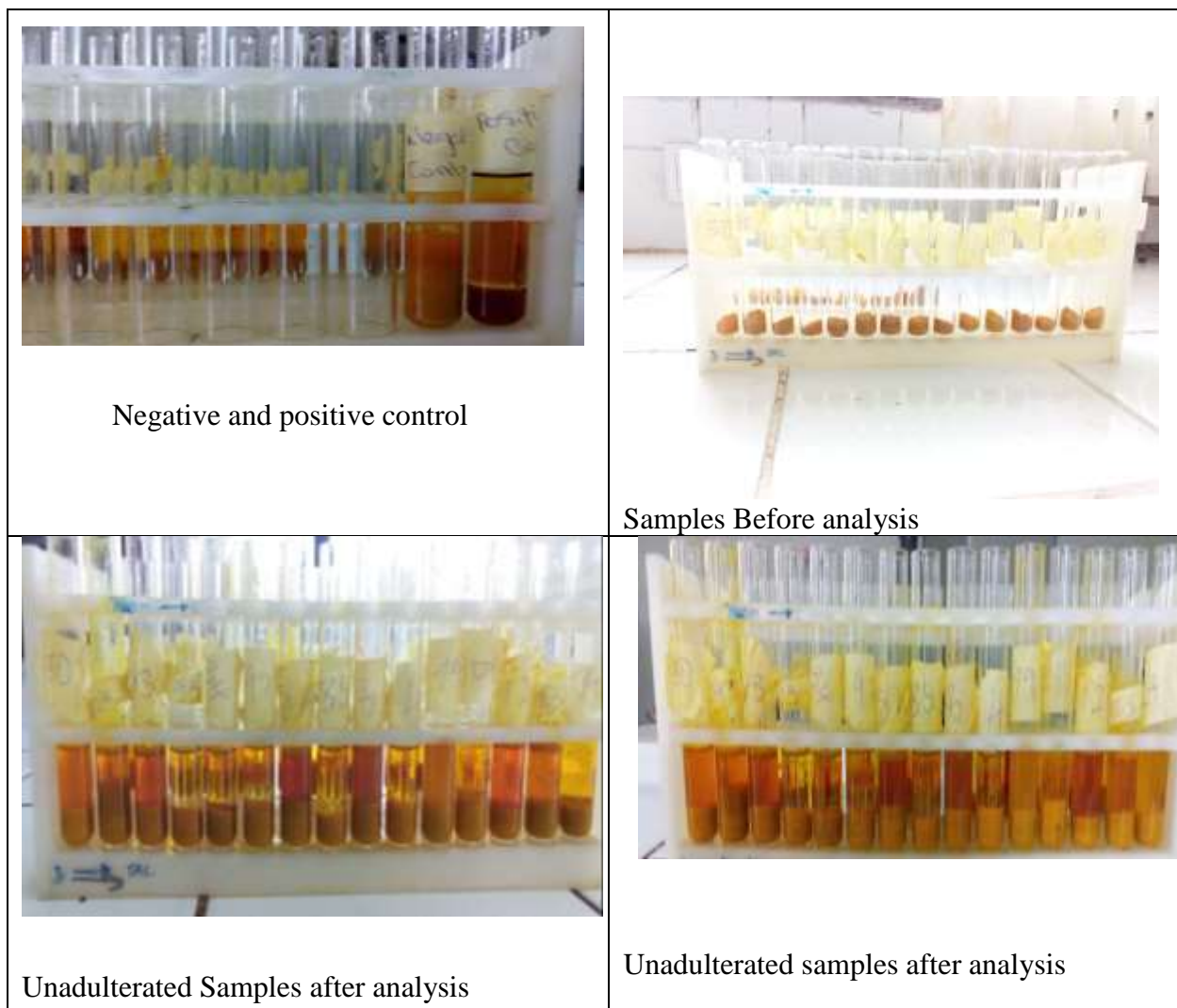


Figure 19 : Turmeric samples after Aniline test

III.3.3 Lead Salt

A total of 104 samples including the control sample turmeric powder samples were analyzed. All sample were tested negative for the presence of lead chromate

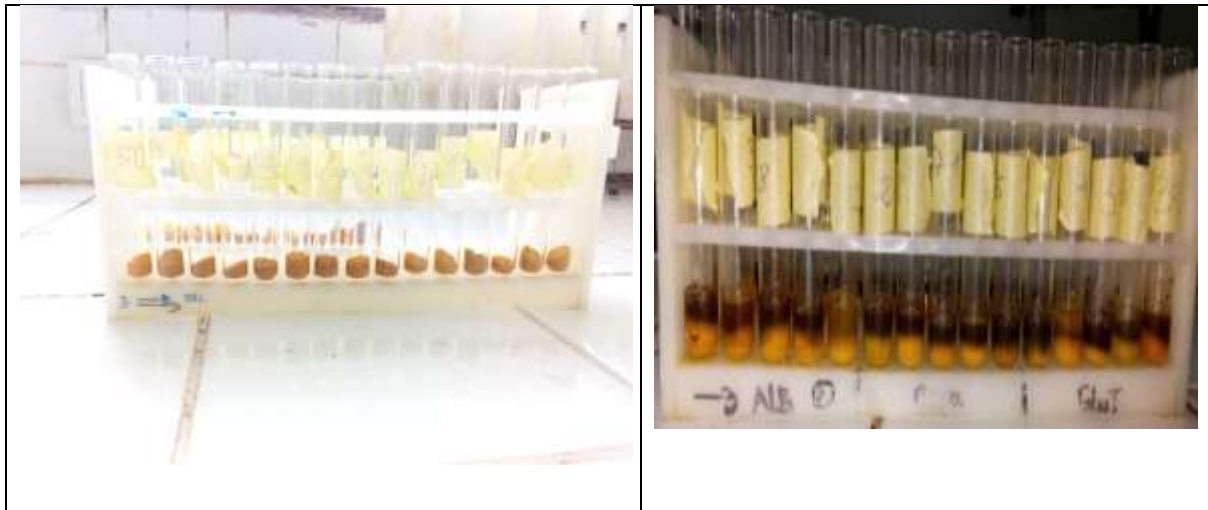


Figure 20: Lead Salt Images before and after Analysis

III.3.4 METANIL DYE

A total of 104 turmeric powder samples were analyzed including the control sample. One sample (sample #30) exhibited a distinct pink color change upon addition of HCl, indicating the presence of metanil dye adulteration.

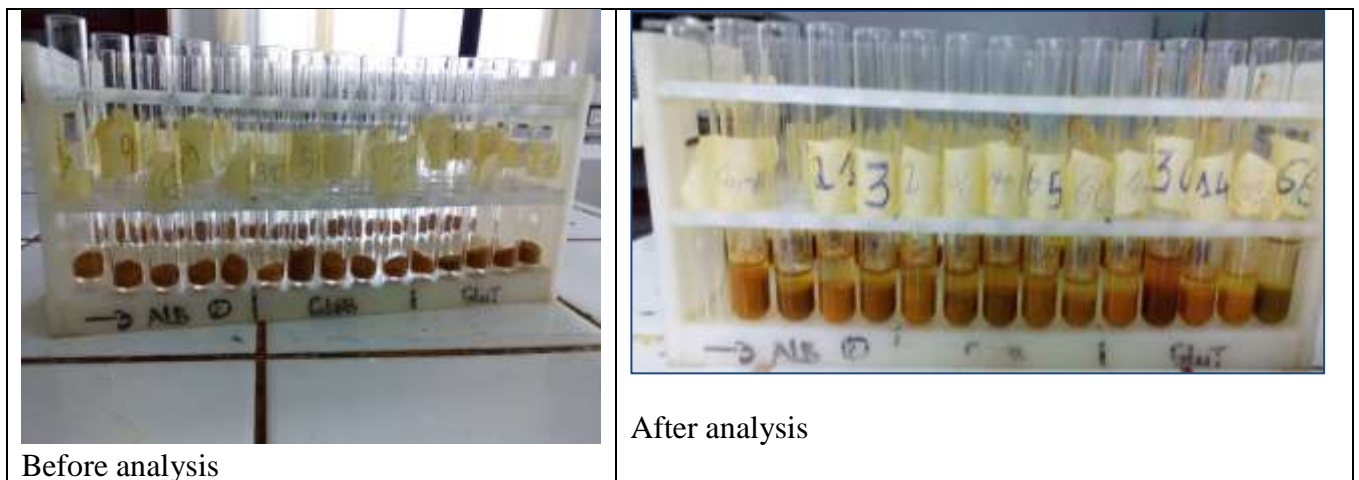


Figure 21: Sample before and after Metanil Dye Test Analysis

III.3.5 Turmeric powder adulteration with Chalk powder

A total of 104 turmeric powder samples were analyzed (Including the self -prepared control sample).

One sample (sample #18) exhibited a distinct white precipitate upon addition of HCl, indicating the presence of chalk adulteration.

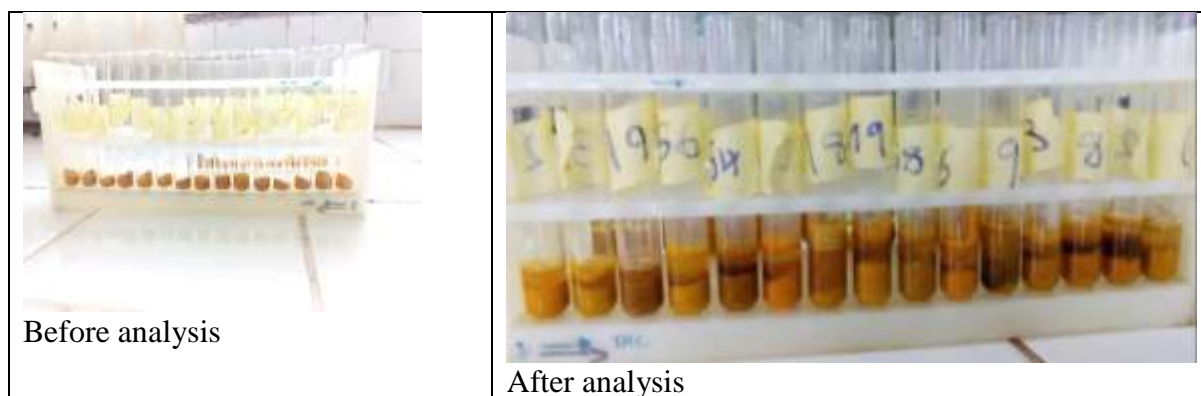


Figure 22: Samples before and after Chalk test analysis

III.4 Advanced analysis of the turmeric samples Results

In view of the need to confirm the results from the physicochemical test for lead chromate and metanil yellow using more advanced techniques, Table 12 shows the levels of lead detected in the studied turmeric samples using XRF analyzer. Overall, lead (mean: 2.58 mg/kg) was detected in 20.2% (21/104) turmeric powder samples at levels higher than the maximum limit (ML) for lead in root and rhizome spices in the European Union (EU) fixed at 1.5 milligrams per kilogram (mg/kg) (EC, 2021).

Table 12: Concentration of lead detected in the studied turmeric powder samples

	Mean (mg/kg)	STDE V	Min. (mg/kg)	Max. (mg/kg)	# Positive	% Positive	# Positive >ML (%)
Turmeric Samples (N=104)	2.58	0.72	1.11	3.76	22	21.15	21 (20.2)

STDEV: Standard deviation; Min.: Minimum; Max.: Maximum; ML: Maximum Limit

Likewise, following NIR spectroscopy analysis, metanil yellow was not detected in any of the 104 turmeric samples.

CHAPTER FOUR: DISCUSSION AND LIMITATIONS

IV. DISCUSSION AND LIMITATIONS

IV.1 Discussion

This study provides a thorough assessment of the authenticity and fraud detection of turmeric powder sold in popular markets in Yaoundé and Douala, Cameroon. The study towns Yaoundé and Douala were partly selected due to their massive population size characterized by influx from the restive regions and refugees, making jobs relatively scarce in these cities, and thus provokes these additional people and existing dwellers/inhabitants to do anything to have money, resulting to fraud of food items such as turmeric. Furthermore, increasing population in an uncontrolled manner may imply increase disease prevalence, thus a potential increase in turmeric consumption in the target cities.

IV.1.1. Survey Findings on Adulteration in the Turmeric Market

This study reveals a significant perception of adulteration among both sellers and consumers of turmeric powder in Yaoundé and Douala, Cameroon. A substantial **69.9%** of sellers and **74.6%** of consumers acknowledged the likelihood of turmeric adulteration. This aligns with a global trend, as seen in studies from India, where similar adulteration practices occur, primarily to enhance product appearance and weight for economic benefit (Shannon *et al.*, 2022). This local awareness suggests that adulteration might be a common and accepted practice within the marketplace, potentially due to a lack of strict regulatory oversight or enforcement mechanisms. Despite this general awareness, only **8.9%** of sellers and **26.9%** of consumers identified specific adulterants like aniline dye or lead chromate, suggesting limited knowledge of chemical adulterants beyond more visible, cheaper fillers such as corn-flour. This lack of knowledge highlights a need for better educational outreach programs aimed at sellers, emphasizing the risks and health impacts of turmeric adulteration on consumers.

In as much as producers of turmeric are likely to be involved in the fraud chain, preliminary survey and hearsay revealed that turmeric distributors and/or sellers mainly purchase the rhizome from the farms and or an agreed meeting point with farmers, and then process it into powder and sell directly to customers and or supply to retailers. Therefore, a potential turmeric fraud chain may begin from the turmeric powder producers, many of whom are the market sellers, and may have rich feedback from their consumers including any information about potential manipulation of turmeric e.g. adulterating with corn-flour, chemicals, etc, reason to consider them in this study and purchasing samples from them. Consumers of turmeric on the

other hand, just like sellers, have rich experiences with the color, taste, and even efficacy of turmeric powder they have bought and used in the past, were better placed to confirm based on their experiences if turmeric sold in the markets are efficacious or varies from seller to seller, if they have experienced any form of manipulations of turmeric they buy and use, if there is a need to monitor fraud and valorize turmeric powder sold in the markets for increase health benefits to consumers, amongst others.

IV.1.2 Authenticity Assessment

The authenticity analysis in this study involved a thorough examination of the physical and microscopic characteristics of turmeric powder. Observations revealed noticeable inconsistencies in color and texture, with some samples showing color ranging from whitish orange-yellow to dark brown. These variations may be due to differences in the processing, storage, or preservation of turmeric or could indicate adulteration. Microscopic analysis provided a closer look at these inconsistencies, revealing cornstarch granules in a subset of samples, supporting the idea that cornstarch is used locally to bulk up turmeric powder in Cameroon. This finding aligns with other studies, such as Van Raamsdonk (2015), which identified cornstarch as a common adulterant used to increase product volume at a lower cost. Additionally, moisture content measurements showed low variability with mean being 16.145 with a standard deviation under 1, suggesting that turmeric powder samples are generally well-preserved but possibly compromised by adulterants that do not significantly affect moisture content.

IV.1.3 Fraud Detection Analysis of Chemical Adulterants

The study's fraud detection tests found no evidence of more harmful chemical adulterants such as aniline dye or lead chromate in the turmeric powder samples, which stands in contrast to reports from other regions like Europe and India. In **2021**, a survey in **21 EU states** found that **11%** of turmeric samples were adulterated with potentially toxic additives like lead chromate (Alex, 2021), highlighting a global concern over chemical contaminants in spices. However, one sample from Yaounde in this study tested positive for metanil yellow, a synthetic dye associated with adverse health effects, and another sample still from Yaounde exhibited chalk adulteration, a non-toxic yet deceptive additive that can lower the quality of the spice. The relatively low frequency of these adulterants in this study with less than 1% for both metanil yellow and chalk—may suggest limited use of these chemical additives in Cameroon's

turmeric powder market. Nevertheless, these findings indicate a need for comprehensive surveillance and regulatory measures to monitor and prevent potential toxic adulterants. Developing standardized testing procedures and strengthening enforcement can help protect consumers and uphold product integrity in Cameroon's turmeric market.

However, using advanced techniques/instrument, lead was detected in 21.15% of the turmeric powder sample using x-ray fluorescence analyzer, while no metanil yellow was detected using the Near infra-red spectroscopy Technique.

By focusing on the evaluation of authenticity and potential fraud from a public health standpoint, this work provides information which can be used to produce a food fraud mitigation plan on turmeric supply chain.

IV.2 Limitation of the study

Conducting this research in Cameroon presented unique challenges, as there were inadequate studies on turmeric authenticity and fraud detection specific to Cameroon making it necessary to rely on studies from other countries, predominantly India, where similar research has been conducted. Furthermore, there were complications and reluctance of some sellers to participate in the survey portion of the study. The lack of sophisticated equipment, which was not readily available locally but relied on less sensitive methods.

CONCLUSION, RECOMMENDATION AND PERSPECTIVES

CONCLUSION

On the basis of the findings from this study, and aforementioned discussion, the hypothesis of this study that “Turmeric powder sold in popular markets in Yaounde and Douala, Cameroon, are not authentic and contain illegally added adulterants, manipulated for the economic gains” was confirmed. Therefore, it can be concluded that:

1. Turmeric powder is produced in Cameroon as follows: washing, slicing, sun-drying and milling. Also, North-West, West, Littoral and South-West regions are major producers of turmeric in that order. Additionally, the sellers (69.6%) and consumers (74.8%) population in this study revealed that it is likely that turmeric powder sold in Yaounde and Douala were adulterated with adulterants, such as red corn flour/starch (major adulterant), chalk, and other chemicals aimed at enhancing weight or appearance for economic gain.
2. The studied turmeric powder samples revealed visually observable colour variation ranging from whitish yellow to golden orange yellow to dark brown, indicating possibility of inauthenticity. Furthermore, microscopic examination of the 103 samples revealed that 93.2% had the expected turmeric starch granules (otherwise considered authentic or compliant), while 6.7% displayed alternative starch granules (considered non-turmeric powder starch granules, thus considered inauthentic/non-compliance).
3. The studied turmeric powder samples were adulterated with starch (51.45%) considering all the suspected samples showed significant colour change beyond +3 dark colour intensity upon addition of Lugol's iodine solution. Also, chalk and metanil yellow were speculated but need confirmation on sophisticated instrument. Although lead was detected on advanced instruments, it's potentially from natural contamination than from lead chromate. Metanil yellow was confirmed to be absent using advanced instrument.

RECOMMENDATION

1. Government:

Implement strict regulations such as fines and enforcement measures as well as weekly control on Turmeric powder sellers to prevent turmeric powder fraud and ensure authenticity and safety of turmeric powder in the markets.

2. Sellers:

Turmeric powder is light sensible; it should be stored in opaque containers to avoid the fading of its orange yellow color.

Turmeric powder should not be sold open alongside other powdered spices as wind may blow the powder into each other and introduce a false adulteration (cross contamination of spices).

3. Consumers:

Stick to specific turmeric powder sellers once you've confirmed their turmeric powder is serving you satisfactorily whether for culinary and or medicinal values.

Grow your own turmeric garden and produce your own turmeric powder (the SOPs can guide you).

4. Civil Society Organizations:

Raise awareness and build capacities of communities on the need for authentic turmeric powder and detection of fraud in the market using proper information, education and communications skills.

PERPECTIVES

1. Conduct a massive survey and laboratory analysis of turmeric powder sold in all 10 regions of Cameroon to have a proper picture of authenticity/adulteration and establish a turmeric powder food chain.
2. Use more sophisticated methods such as spectroscopic technics (e.g. near infra-red, and fourier-transfer infra-red spectroscopy) coupled with chemometrics to predict authenticity and or fraud in turmeric powder.
3. In view of the low fraud detection levels, encourage turmeric farming and exportation to high turmeric powder consuming nations.

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APPENDIX

Appendix 1: Survey (Seller's Questionnaire)

Dear Madam/Sir

I am Professional Master Student offering Public Health Biotechnology in The Department of Biochemistry, Faculty of Science of the University of Yaoundé I. I am carrying out a study on the the awareness and practices related to turmeric among sellers in Cameroon.

The questionnaire should take only fifteen (5) minutes of your time. It is anonymous so your name and contact details are not required.

Should you have any further queries please contact Dr Wilfred Abia (abiawilfred@yahoo.com)

Section 1 Socio-demographic parameters

1. What gender do you belong to ?*

Male

Female

2. What age group do you fall under ?*

18-29

30-49

50 and above

3. What is your highest education level ?*

No formal education

Primary

Secondary

University

Beginners Islamic school

Intermediate Islamic school

Advance Islamic school

4. What is your marital status ?*

Single

Married

Divorced

Widow/widower

Concubined

5. In which sector of activity your profession belong to ?*

Public (working for the government)

Private (working for a registered private company or organization)

Informal

Unemployed

6. In which City/Town do you reside ?*

Réponse courte

Section 2: Knowledge and Good Practice in Turmeric Business

1. Where is the tumeric you sell being cultivated or grown?

2. Do you own a production structure/farm?

Yes

No

3. If yes, what is your farm size

4. How long have you been selling tumeric?

Less than 1 year

1 to 2 years

3 to 5 years

More than 5 years

5. How many types of tumeric do you sell?

One type

Two types

Three types

6. What is your primary source of turmeric and or tumeric products

Local suppliers (such as farmers, specify)

from own farm

Wholesale market (specify)

Imported products (specify)

Others (Specify):

7. How frequently do you change your turmeric supplier?

Very often

Occasionally

Rarely

Stick to one supplier

Others:

8. Which form of tumeric do you prefer?

Rhizome (fresh)

Rhizome (dry)

Powder (Processed and package)

Powder (Processed and not package)

9. What is your monthly turn over from selling Turmeric? in CFA

Less than 10,000

11, 000 to 20,0000

21, 000 to 30,000

31,000 to 40,0000

41,000 and 50,000

More than 50,000, Specify

10. Have you received any training regarding tumeric business

Yes (Specify)

No

11. What type of business do you operate ?

Grocery store

Market stall

Food processing unit

Others:

12. What is your Market location?

Section 3: Attitude towards turmeric (Authenticity and fraud)

Section 3.1 Tumeric originality or authenticity

1. How do you store turmeric to ensure its quality?

Airtight container

Away from sunlight

In cool dry place

Others:

2. Do you conduct any form of quality check before selling turmeric?

Yes

No

I don't know

3. If yes, which type of check?

Visual inspection (observation with eye)

Laboratory test

By Smelling it (smell test)

Taste

I rely on suppliers's quality

Others:

4. Are you aware of any efforts your suppliers make to ensure the authenticity of the turmeric they provide?

Yes (Specify)

No

I don't know

5. How do you handle turmeric products to minimize the risk of contamination or adulteration?

Use gloves

Use clean utensils

Avoid contact with other chemicals

Others:

6. Have you received any formal training or information about food safety practices?

Yes

No

I don't know

7. Do you follow any food safety regulations or guidelines in handling and selling turmeric?

Yes

No

I don't know

8. It is important for me to ensure the originality or authenticity of the turmeric I sell.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

9. I am willing to invest time and effort to educate myself about detecting adulterated turmeric

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

10. Tumeric business people and Consumer awareness about turmeric fraud should be increased through educational campaigns.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

Section 3.2 Tumeric fraud

1. Do you think that tumeric powder may be adulterated with other substances?

Yes

No

I don't know

2. What are the reasons for adding or subtracting or tampering with tumeric

To make more profit

To attract customers (make it more attractive to customers)

To inceased shelflife

To increase quality

3. Can you name any common substances that might be used to do any of the following to tumeric or tumeric powder?

To attract customers (make it more attractive to customers)

To inceased shelflife

To increase quality

4. Which of the following is generally added to tumeric powder?

Chalk

Chemicals

Dye

Spices

Lead Chromate

Metanil yellow

Aniline dye

Others:

5. Have you ever heard about food fraud?

Yes

No

6. Which of the following best describe food fraud?

When the food is contaminated naturally

When something is added to the food deliberately to make look better

When something is added to the food deliberately to make look to increase profit.

7. Do you think that consuming tumeric that has been adulterated with a harmful chemical (i.e., tumeric to which a harmful chemical has been added to it) can cause health problems to consumer?

Yes

No

I don't know

8. Have you ever encountered any information or campaigns about the risks of consuming adulterated turmeric powder in your local community or the media?

Yes

No

I don't know

9. Are you interested in participating in any originality (authenticity) of food fraud?

Yes

No

Appendix 2: Survey (Consumer's questionnaire)

Dear Madam/Sir

I am Professional Master Student offering Public Health Biotechnology in The Department of Biochemistry, Faculty of Science of the University of Yaoundé I. I am carrying out a study on the the awareness and practices related to turmeric among sellers in Cameroon.

The questionnaire should take only five (5) minutes of your time. It is anonymous so your name and contact details are not required.

1. Socio demographic Information

1. What gender do you belong to?*

Female

Male

2. What is your highest level of education?*

No formal education

Primary
Secondary
University
Cosamic
Other...

3. What is your marital status ?*

Single
Married
Divorced
Widow/ Widower
Concubine

4. In which sector of activity your profession belong to?

Education (Student)
Researcher
Public (working for the government)
Private (working for a registered private company or organization)
Informal
Unemployed

5. In which City/Town do you reside? *

Section 2. Awareness on Turmeric

1. Have you heard of the spices called "turmeric" or "curcuma"?

Yes
No
Maybe

2. Do you use turmeric?

Yes
No
Maybe

3. What do you (or others) generally use turmeric for?

Cooking
For medicinal purpose
For skincare routine
For tea
Other...

4. What is the color of Turmeric powder?

Yellow
Orange
White
Red
I don't know

5. Are you able to distinguish between Turmeric and Ginger?

Yes
No
Maybe

6. In what manner/ways do you (or others) often consume turmeric?

Tisane (tea)
Juice
spice
Other...

7. Are you familiar with the potential health benefits of consuming turmeric?

Yes
No
Maybe

8. What's your consumption frequency of turmeric (e.g what quantity per meal or usage such as a tea spoon per day)?

9. What form of turmeric do you use (or prefer to use) regularly?

Powder form
Rhizome form (fresh)
Rhizome form (dry)

10. Where do you buy your turmeric form?

Local market
Supermarkets
Street vendors
From farm

11. Do you have a farm turmeric?

Yes
No
Maybe

12. Where is Turmeric cultivated in Cameroon? List them

Section 3. Practice on Turmeric

1. How often do you buy turmeric powder?

Daily
Weekly
Monthly
Rarely

2. What factors do you consider when purchasing turmeric powder?

Colour
Price/cost
Quantity
Package
Label
Source/origin
Seller
Other...

3. Quality criteria at purchasing

Color
odor
absence of visual contaminant
cost
Other...

4. Have you ever taken any actions to verify the authenticity of the turmeric powder you purchased?

Yes
No

Maybe

5. Which methods have you used to check the authenticity of turmeric powder? (Check all that apply)

Visual inspection (eye)

Taste

Smell

Laboratory testing

Asking the seller

Feeling it with hands

Water test

Others :

6. How do you usually store turmeric powder to ensure its quality over time?

In airtight container

In cool dry place

In the refrigerator

I don't pay attention to storage

Other...

7. What quality changes do you see in your stored turmeric?

Colour change

mould

Disappearance of turmeric odor

Presence of insects

Other...

8. Have you ever heard about adulteration?

Yes

No

Maybe

9. Do you think that turmeric powder can be adulterated?

Yes

No

Maybe

10. What will be your feelings if you find a seller adulterating (ie adding something to) Turmeric powder to increase quantity and make more profit?

Happy

Very Happy

Angry

Very Angry

It's not strange, I will feel normal

11. If you realize you have just paid money for an adulterated Turmeric powder, what will you do?

Ask for refund or replacement

Stop using it

Report to local authorities

Do nothing

Section 4.1 Turmeric powder originality or authenticity

1. How confident are you in your ability to recognize genuine turmeric powder from adulterated or fake ones?

Not confident at all

1

2

3
4
5

Very confident

2. Are you aware of any efforts your suppliers make to ensure the authenticity of the turmeric powder they provide?

Yes

No

Maybe

3. How do you handle turmeric powder to minimize the risk of contamination or adulteration?

Use gloves

Use clean utensils

Avoid contact with other chemicals

Others:

4. Have you received any formal training or information about food safety practices?

Yes

No

Maybe

5. Do you follow any food safety regulations or guidelines in handling turmeric powder?

Yes

No

Maybe

6. It is important for me to ensure the originality or authenticity of the turmeric I sell or buy

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

7. I am willing to invest time and effort to educate myself about detecting adulterated turmeric

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

8. Turmeric business people and Consumer awareness about turmeric fraud should be increased through educational campaigns.

Strongly disagree

Disagree

Neutral

Agree

Strongly agree

Section 4.2 Turmeric fraud

1. Do you think that turmeric powder may be adulterated with other substances?

Yes

No

Maybe

2. What do you think are some of the reasons for adding or subtracting or tampering with turmeric powder ?

To make more profit

To attract customers (make it more attractive to customers)

To increase shelflife

To increase quality

To add colour

I don't know

Other...

3. What do you think can be of the following is generally added to turmeric powder?

Chalk

Spices

Corn flour (especially red corn flour)

Chemicals

Colour dyes

Colour dyes, name some :

Lead Chromate

Metanil yellow

Aniline dye

Others:

4. Name an adulterant you know is use in turmeric powder?

Short answer text

Section 5. Altitude towards turmeric fraud

1. How concerned are you about the authenticity and quality of turmeric powder available in the market?

Not concern at all

1

2

3

4

5

Very concern

2. Would you be willing to pay for original good quality turmeric/ authentic turmeric powder for your satisfaction?

Yes

No

Maybe

3. Do you think that turmeric fraud is a significant issue in Cameroon?

Yes

No

Maybe

4. Share any opinion about turmeric which has not been talk of above

Short answer text

Appendix 3: Laboratory Results

Sample Number	Sample code	Source	Sample appearance	Microscopic test	Lugol test	Aniline test	Lead Chromate	Metanil dye	Chalk
Control	C1	Yaounde	Orange yellow	-	-	-	-	-	-
1	Y1	Yaounde	Dark yellow	-	-	-	-	-	-
2	Y2	Yaounde	Orange yellow	-	-	-	-	-	-
3	Y3	Yaounde	Orange yellow (White traces)	-	-	-	-	-	-
4	Y4	Yaounde	Orange yellow	-	-	-	-	-	-
5	Y5	Yaounde	Orange yellow	-	-	-	-	-	-
6	Y6	Yaounde	Orange yellow	-	-	-	-	-	-
7	Y7	Yaounde	Orange yellow	-	-	-	-	-	-
8	Y8	Yaounde	Orange Yellow	-	-	-	-	-	-
9	Y9	Yaounde	Thick orange yellow	-	-	-	-	-	-
10	Y10	Yaounde	Orange yellow	-	-	-	-	-	-
11	Y11	Yaounde	Light orange yellow	-	-	-	-	-	-
12	Y12	Yaounde	Thick orange yellow	-	-	-	-	-	-
13	Y13	Yaounde	Orange yellow	-	-	-	-	-	-
14	Y14	Yaounde	Orange yellow (Dark traces)	-	-	-	-	-	-
15	Y15	Yaounde	Thick orange yellow	-	-	-	-	-	-
16	Y16	Yaounde	Orange yellow	-	Positive	-	-	-	-
17	Y17	Yaounde	Orange yellow	-	-	-	-	-	-
18	Y18	Yaounde	Orange yellow	Positive	positive	-	-	-	Positive
19	Y19	Yaounde	Light orange yellow	-	-	-	-	-	-
20	Y20	Yaounde	Orange yellow	-	-	-	-	-	-
21	Y21	Yaounde	Thick orange yellow	-	-	-	-	-	-
22	Y22	Yaounde	Orange yellow	-	Positive	-	-	-	-
23	Y23	Yaounde	Orange yellow	-	-	-	-	-	-
24	Y24	Yaounde	Light orange yellow	-	Positive	-	-	-	-
25	Y25	Yaounde	Dark yellow	-	-	-	-	-	-
26	Y26	Yaounde	Orange yellow	-	-	-	-	-	-
27	Y27	Yaounde	Orange yellow	-	-	-	-	-	-
28	Y28	Yaounde	Orange yellow	-	-	-	-	-	-
29	Y29	Yaounde	Orange yellow	-	-	-	-	-	-

30	Y30	Yaounde	Light orange yellow	Positive	Positive	-	-	Positive	-
31	Y31	Yaounde	Orange yellow	-	Positive	-	-	-	-
32	Y32	Yaounde	Orange yellow	-	Positive	-	-	-	-
33	Y33	Yaounde	Light orange yellow	Positive	Positive	-	-	-	-
34	Y34	Yaounde	Orange yellow	-	-	-	-	-	-
35	Y35	Yaounde	Orange yellow	-	-	-	-	-	-
36	Y36	Yaounde	Orange yellow (with white traces)	-	-	-	-	-	-
37	Y37	Yaounde	Orange yellow	-	-	-	-	-	-
38	Y38	Yaounde	Orange yellow	-	-	-	-	-	-
39	Y39	Yaounde	Orange yellow	-	-	-	-	-	-
40	Y40	Yaounde	Thick orange yellow	-	-	-	-	-	-
41	Y41	Yaounde	Thick orange yellow	-	-	-	-	-	-
42	Y42	Yaounde	Orange yellow	-	-	-	-	-	-
43	Y43	Yaounde	Light orange yellow	Positive	Positive	-	-	-	-
44	Y44	Yaounde	Light orange yellow	-	Positive	-	-	-	-
45	Y45	Yaounde	Light orange yellow	-	-	-	-	-	-
46	Y46	Yaounde	Orange Yellow	-	-	-	-	-	-
47	Y47	Yaounde	Orange Yellow	-	-	-	-	-	-
48	Y48	Yaounde	Thick orange yellow	-	-	-	-	-	-
49	Y49	Yaounde	Light orange yellow	-	-	-	-	-	-
50	Y50	Yaounde	Orange yellow	-	-	-	-	-	-
51	Y51	Yaounde	Redish orange yellow	-	-	-	-	-	-
52	Y52	Yaounde	Thick orange yellow	-	-	-	-	-	-
53	Y53	Yaounde	Orange yellow	-	Positive	-	-	-	-
54	Y54	Yaounde	Dark yellow	-	-	-	-	-	-
55	Y55	Yaounde	Light orange yellow	-	Positive	-	-	-	-
56	Y56	Yaounde	Orange yellow	-	-	-	-	-	-
57	Y57	Yaounde	Orange yellow	-	Positive	-	-	-	-
58	Y58	Yaounde	Orange yellow (with dark traces)	-	Positive	-	-	-	-
59	Y59	Yaounde	Orange yellow	-	-	-	-	-	-
60	Y60	Yaounde	Dark yellow	-	-	-	-	-	-
61	Y61	Yaounde	Orange yellow	-	-	-	-	-	-
62	Y62	Yaounde	Orange yellow	-	-	-	-	-	-

63	D1	Douala	Orange yellow	-	-	-	-	-	-
64	D2	Douala	Orange yellow	-	-	-	-	-	-
65	D3	Douala	Dark yellow	-	-	-	-	-	-
66	D4	Douala	Orange yellow	-	-	-	-	-	-
67	D5	Douala	Orange yellow	-	-	-	-	-	-
68	D6	Douala	Orange yellow	-	-	-	-	-	-
69	D7	Douala	Orange yellow	-	-	-	-	-	-
70	D8	Douala	Orange yellow	-	Positive	-	-	-	-
71	D9	Douala	Orange yellow (White traces)	-	-	-	-	-	-
72	D10	Douala	Orange yellow	-	-	-	-	-	-
73	D11	Douala	Whitish yellow	-	-	-	-	-	-
74	D12	Douala	Orange yellow	-	Positive	-	-	-	-
75	D13	Douala	Orange yellow	-	-	-	-	-	-
76	D14	Douala	Dark brown	-	-	-	-	-	-
77	D15	Douala	Orange yellow	-	-	-	-	-	-
78	D16	Douala	Orange yellow (White traces)	-	-	-	-	-	-
79	D17	Douala	Dark brown	-	-	-	-	-	-
80	D18	Douala	Dark brown	Positive	Positive	-	-	-	-
81	D19	Douala	Dark brown (yellow patches)	-	-	-	-	-	-
82	D20	Douala	Whitish yellow	-	-	-	-	-	-
83	D21	Douala	Orange yellow	-	-	-	-	-	-
84	D22	Douala	Brown yellow	-	-	-	-	-	-
85	D23	Douala	Orange yellow	-	-	-	-	-	-
86	D24	Douala	Orange yellow	-	-	-	-	-	-
87	D25	Douala	Orange yellow	-	Positive	-	-	-	-
88	D26	Douala	Brown yellow	-	-	-	-	-	-
89	D27	Douala	Dark yellow	-	-	-	-	-	-
90	D28	Douala	Brown yellow	-	-	-	-	-	-
91	D29	Douala	Orange yellow	-	-	-	-	-	-
92	D30	Douala	Orange yellow	-	-	-	-	-	-
93	D31	Douala	Thick orange yellow	-	Positive	-	-	-	-
94	D32	Douala	Dark yellow	-	-	-	-	-	-
95	D33	Douala	Orange yellow	-	Positive	-	-	-	-

96	D34	Douala	Dark yellow	Positive	Positive	-	-	-	-
97	D35	Douala	Orange yellow	-	-	-	-	-	-
98	D36	Douala	Orange yellow	Positive	Positive	-	-	-	-
99	D37	Douala	Brown yellow	-	-	-	-	-	-
100	D38	Douala	Orange yellow	-	-	-	-	-	-
101	D39	Douala	Orange yellow	-	-	-	-	-	-
102	D40	Douala	Orange yellow	-	-	-	-	-	-
103	B1	Douala	Orange yellow	-	Positive	-	-	-	-

Appendix 4. Lead concentrations in the studied samples based on the XRF analysis.

SNo.	Sample ID	Pb conc (mg/kg)
1	C36	3.36
2	C87	ND
3	C71	1.7
4	C89	ND
5	C63	2.51
6	C92	ND
7	C91	2.94
8	C49	ND
9	C88	3.62
10	C76	3.22
11	C18	2.06
12	C60	ND
13	C27	ND
14	C30	ND
15	C95	ND
16	C74	ND
17	C64	ND
18	C81	ND
19	C82	ND
20	C80	ND
21	C94	ND
22	C51	1.6
23	C3	ND
24	C8	ND
25	C32	ND
26	C45	ND
27	C x	ND
28	C97	ND
29	C91	ND
30	C37	ND
31	C61	ND
32	C102	ND
33	C56	ND
34	C9	ND
35	C77	ND
36	C65	ND
37	C98	ND
38	C25	1.97
39	C84	ND
40	C38	ND
41	C96	ND

42	C21	2.86
43	C58	ND
44	C59	ND
45	C83	ND
46	C79	ND
47	C72	ND
48	C99	ND
49	C68	2.44
50	C85	2.78
51	C90	ND
52	C48	3.76
53	C53	ND
54	C16	ND
55	C101	1.79
56	C28	ND
57	C93	ND
58	C14	ND
59	C45	ND
60	C67	ND
61	C11	ND
62	C75	ND
63	C40	ND
64	C6	ND
65	C22	ND
66	C62	ND
67	C41	1.11
68	C2	ND
69	C43	ND
70	C7	ND
71	C102	1.98
72	C10	ND
73	C19	ND
74	C50	ND
75	C104	ND
76	C24	ND
77	C73	ND
78	C12	ND
79	C57	ND
80	C1	2.26
81	C39	ND
82	C103	ND
83	C29	ND
84	C44	ND
85	C66	ND

86	C31	ND
87	C64	ND
88	C54	3.25
89	C23	2.46
90	C78	ND
91	C42	ND
92	C26	ND
93	C11	ND
94	C34	3.45
95	C55	ND
96	C5	ND
97	C4	3.15
98	C86	ND
99	C33	2.48
100	C20	ND
101	C64	ND
102	C35	ND
103	C70	ND
104	C15	ND
Cameroon (N=104)	Average (mg/kg):	2.6
	STDEV:	0.7
	Minimum (mg/kg):	1.1
	Maximum (mg/kg):	3.8
	# Positive	22
	% Positive	21.2
	Maximum Limit (ML)	1.5*
	# Pos>ML (%)	21 (20.2)

Appendix 5: Moisture content

SAMPL E	Fresh weight	Dry Weight	PERCENTAGE Dry weight	Mean moisture content	Standard Deviation
Control-1	1.04	0.85	81.73076923	18.27533578	0.1832264798
Control-2	1.05	0.86	81.9047619		
Control-3	1.04	0.848	81.53846154		
1-1	1.204	1.036	86.04651163	13.33438562	0.5403396453
1-2	1.077	0.936	86.90807799		
1-3	1.065	0.927	87.04225352		
2-1	1.1	0.92	83.63636364	16.93668831	0.6166844349
2-2	1.12	0.923	82.41071429		
2-3	1.05	0.873	83.14285714		
3-1	1.02	0.874	85.68627451	14.27016288	0.3083901652
3-2	1.04	0.895	86.05769231		
3-3	1.01	0.863	85.44554455		
4-1	1.02	0.843	82.64705882	16.69627257	0.9286696515
4-2	1.01	0.848	83.96039604		
5-1	1.06	0.876	82.64150943	16.98113208	0.5336654952
5-3	1.06	0.884	83.39622642		
6-1	1.157	0.996	86.08470182	14.04941701	0.1274481905
6-2	1.101	0.945	85.83106267		
6-3	1.031	0.886	85.93598448		

7-1	1.05	0.876	83.42857143	16.39729063	0.4161764972
7-2	1.03	0.866	84.0776699		
7-3	1.06	0.883	83.30188679		
8-1	1.058	0.901	85.16068053	14.85776781	0.03466922894
8-2	1.027	0.874	85.10223953		
8-3	1.038	0.884	85.16377649		
9-1	1.04	0.889	85.48076923	14.57988265	0.246927852
9-2	1.03	0.882	85.63106796		
9-3	1.01	0.86	85.14851485		
10-1	1.19	0.988	83.02521008	16.75869066	0.1878323424
10-2	1.11	0.925	83.33333333		
10-3	1.04	0.867	83.36538462		
11-1	0.788	0.081	81.73076923	18.365384615	0.081
11-2	0.764	0.081	81.53846154		
12-1	1.065	0.912	85.63380282	14.24701869	0.1252423717
12-2	1.013	0.87	85.88351431		
12-3	1.045	0.896	85.74162679		
13-1	1.044	0.866	82.95019157	17.05254638	0.119632291
13-2	1.37	1.138	83.06569343		
13-3	1.118	0.926	82.82647585		
14-1	1	0.863	86.3	13.68860597	0.09121126822
14-2	1.06	0.914	86.22641509		
14-3	1.03	0.89	86.40776699		

15-1	1.021	0.887	86.87561214	13.10981298	0.02061199283
15-2	1.008	0.876	86.9047619		
16-1	1.01	0.801	79.30693069	20.4950495	0.198019802
16-2	1.01	0.803	79.5049505		
16-3	1.01	0.805	79.7029703		
17-1	1.01	0.845	83.66336634	16.55207187	0.3289348862
17-2	1.08	0.903	83.61111111		
17-3	1.01	0.839	83.06930693		
18-1	1.129	0.996	88.21966342	11.62486969	0.2790794628
18-2	1.094	0.965	88.20840951		
18-3	1.044	0.926	88.69731801		
19-1	1.024	0.882	86.1328125	13.79217313	0.1233142642
19-2	1.011	0.873	86.35014837		
19-3	1.039	0.895	86.14051973		
20-1	1.08	0.907	83.98148148	16.23268748	0.5093570489
20-2	1.13	0.94	83.18584071		
20-3	1.04	0.875	84.13461538		
21-1	1.11	0.938	84.5045045	15.63404343	0.304247308
21-2	1.18	0.998	84.57627119		
21-3	1.17	0.983	84.01709402		
22-1	1.02	0.869	85.19607843	15.18021448	0.6085926778
22-2	1.02	0.858	84.11764706		
22-3	1.03	0.877	85.14563107		

23-1	1.1	0.907	82.45454545	17.38038063	0.2108503534
23-2	1.05	0.87	82.85714286		
23-3	1.06	0.875	82.54716981		
24-1	1.07	0.915	85.51401869	14.28312183	0.2041680474
24-2	1.03	0.885	85.9223301		
24-3	1.05	0.9	85.71428571		
25-1	1.003	0.862	85.94217348	13.90274479	0.1442920546
25-2	1.016	0.875	86.12204724		
25-3	1.002	0.864	86.22754491		
26-1	1.04	0.877	84.32692308	15.75364857	0.1990862613
26-2	1.02	0.857	84.01960784		
26-3	1.07	0.903	84.39252336		
27-1	1.01	0.85	84.15841584	15.45546215	0.3560252398
27-2	1.07	0.908	84.85981308		
27-3	1.04	0.88	84.61538462		
28-1	1.1	0.964	87.63636364	12.95751912	0.8398770434
28-3	1.07	0.925	86.44859813		
29-1	1.014	0.869	85.70019724	14.5923118	0.5435807997
29-2	1.025	0.869	84.7804878		
29-3	1.017	0.872	85.74237955		
30-1	1.02	0.905	88.7254902	11.4299194	0.4744811832
30-2	1.07	0.942	88.03738318		
30-3	1.14	1.014	88.94736842		

31-1	1.17	1.001	85.55555556	14.96523072	0.5255896303
31-2	1.13	0.961	85.04424779		
31-3	1.11	0.938	84.5045045		
32-1	1.03	0.864	83.88349515	16.85473709	0.6397726966
32-2	1.09	0.902	82.75229358		
32-3	1	0.828	82.8		
33-1	1.06	0.936	88.30188679	12.0990566	0.5670195887
33-3	1.08	0.945	87.5		
34-2	1.01	0.868	85.94059406	14.41288054	0.499888573
34-3	1.07	0.912	85.23364486		
35-1	1.04	0.891	85.67307692	14.59981685	0.2654524822
35-2	1.05	0.894	85.14285714		
35-3	1.04	0.888	85.38461538		
36-1	1.277	1.076	84.25998434	15.64035947	0.3057616243
36-2	1.144	0.969	84.7027972		
36-3	1.171	0.985	84.11614005		
37-1	1.08	0.889	82.31481481	17.31638418	0.368018831
37-2	1.18	0.98	83.05084746		
37-3	1.08	0.893	82.68518519		
38-2	1.05	0.896	85.33333333	14.37216828	0.4164836057
38-3	1.03	0.885	85.9223301		
39-1	1.01	0.847	83.86138614	15.81549763	0.4603012298

39-2	1.04	0.881	84.71153846		
39-3	1.03	0.865	83.98058252		
40-1	1.06	0.896	84.52830189	15.32224921	0.3240028956
40-2	1.01	0.859	85.04950495		
40-3	1.01	0.853	84.45544554		
41-1	1.05	0.908	86.47619048	13.63636364	0.7895895038
41-2	1.1	0.958	87.09090909		
41-3	1.05	0.898	85.52380952		
42-1	1.16	0.983	84.74137931	14.82890043	0.3798748499
42-2	1.19	1.017	85.46218487		
42-3	1.13	0.964	85.30973451		
				15.11376	0.362907
43-1	1.08	0.914	84.62962963		
43-2	1.05	0.894	85.14285714		
44-1	1.03	0.874	84.85436893	15.64198039	0.45448001
44-2	1.06	0.89	83.96226415		
44-3	1.01	0.851	84.25742574		
45-1	0.4	1.01	82.47524752	17.52475248	0.4681099056
45-2	0.38	1.02	83.1372549		
				15.67968	0.009332
46-1	0.37	1.02	84.31372549		
46-2	0.39	1.04	84.32692308		
				19.02722	0.821122
47-1	1.02	0.82	80.392156862745		

47-2	1.03	0.84	81.5533988058252		
48-1	1.137	0.962	84.60861917	15.60147103	0.2298643117
48-2	1.098	0.924	84.15300546		
48-3	1.06	0.895	84.43396226		
49-1	1.07	0.893	83.45794393	16.2150746	0.4607901104
49-2	1.09	0.919	84.31192661		
49-3	1.06	0.886	83.58490566		
50-1	1.01	0.845	83.66336634	16.12948188	0.2929568612
50-2	1.03	0.866	84.0776699		
51-1	1.05	0.892	84.95238095	14.97663971	0.1003799384
51-2	1.06	0.902	85.09433962		
51-3	1.02	0.87	85.29411765		
52-1	1.07	0.883	82.52336449	17.55907247	0.1165834668
52-2	1.06	0.873	82.35849057		
52-3	1.01	0.839	83.06930693		
53-1	1.05	0.905	86.19047619	13.63553114	0.2460627993
53-2	1.04	0.9	86.53846154		
53-3	1.04	0.896	86.15384615		
54-1	1.228	1.057	86.07491857	13.70857246	0.3061899226
54-2	1.008	0.872	86.50793651		
54-3	1.04	0.9	86.53846154		
55-1	1.03	0.875	84.95145631	15.56165502	0.725649006
55-3	1.07	0.898	83.92523364		

56-1	1.048	0.892	85.11450382	14.60039325	0.261990002
56-2	1.155	0.987	85.45454545		
56-3	1.048	0.8974	85.62977099		
58-1	1.033	0.869	84.12391094	15.9078359	0.04820307378
58-2	1.09	0.916	84.03669725		
58-3	1.001	0.842	84.11588412		
59-1	1.208	1.024	84.76821192	15.21499095	0.2071038911
59-2	1	0.85	85		
59-3	1.077	0.911	84.58681523		
60-1	1.04	0.876	84.23076923	15.55535206	0.2518419233
60-2	1.05	0.886	84.38095238		
60-3	1.08	0.915	84.72222222		
61-1	1.09	0.904	82.93577982	16.98692059	0.1093181372
61-3	1.029	0.855	83.09037901		
62-1	1.462	1.276	87.27770178	12.49208675	0.3266524748
62-2	1.013	0.885	87.36426456		
62-3	1.015	0.892	87.8817734		
63-1	1.08	0.937	86.75925926	14.25781701	0.9243606353
63-2	1.07	0.915	85.51401869		
63-3	1.07	0.909	84.95327103		
64-1	1.04	0.862	82.88461538	17.34609527	0.4494764875
64-2	1.02	0.846	82.94117647		
64-3	1.03	0.846	82.13592233		

65-1	1.07	0.871	81.40186916	18.69158879	0.1321694918
65-3	1.07	0.869	81.21495327		
66-1	1.05	0.869	82.76190476	16.65678857	0.514148333
66-2	1.02	0.852	83.52941176		
66-3	1.07	0.896	83.73831776		
67-1	1.02	0.86	84.31372549	15.59874821	0.1403257883
67-2	1.04	0.877	84.32692308		
67-3	1.03	0.871	84.5631068		
68-1	1.08	0.93	86.11111111	14.41969197	0.7506689151
68-2	1.01	0.859	85.04950495		
69-2	1.03	0.869	84.36893204	15.80618819	0.2476573973
69-3	1.07	0.899	84.01869159		
70-1	1.05	0.883	84.0952381	16.18767507	0.4000996353
70-3	1.02	0.852	83.52941176		
71-1	1.04	0.877	84.32692308	12.01923077	5.167318786
71-3	1.04	0.953	91.63461538		
73-2	1.03	0.857	83.2038835	17.25520111	0.6492436743
73-3	1.05	0.864	82.28571429		
76-2	1.01	0.88	87.12871287	12.5414128	0.4665127564
76-3	1.04	0.913	87.78846154		
79-1	1.124	0.97	86.29893238	13.54269442	0.2239735217

79-2	1.046	0.906	86.61567878		
80-1	1.026	0.92	89.66861598	10.54627509	0.4179131784
80-2	1.109	0.995	89.72046889		
80-3	1.469	1.307	88.97208986		
81-1	1.08	0.911	84.35185185	15.56445869	0.1183547675
81-3	1.04	0.879	84.51923077		
83-1	1.03	0.866	84.0776699	15.27508091	0.568880124
83-2	1.03	0.875	84.95145631		
83-3	1.03	0.877	85.14563107		
84-1	1.07	0.895	83.64485981	16.04395658	0.2750543346
84-2	1.08	0.909	84.16666667	15.88836478	
84-3	1.06	0.891	84.05660377	14.31429071	
85-1	1.08	0.943	87.31481481	12.29890788	0.3508486087
85-2	1.04	0.913	87.78846154		
85-3	1.1	0.968	88		
86-1	1.061	0.924	87.08765316	12.85819606	0.1581197618
86-2	1.063	0.925	87.01787394		
86-3	1.041	0.909	87.31988473		
87-1	1.006	0.885	87.972167	12.388623	0.3328774187
87-2	1.088	0.95	87.31617647		
87-3	1.092	0.956	87.54578755		
88-1	1.1	0.937	85.18181818	15.02591334	0.2937767341
88-2	1.07	0.907	84.76635514		

89-1	1.01	0.863	85.44554455	14.4049505	0.3918128408
89-2	1.01	0.869	86.03960396		
90-1	1.044	0.881	84.38697318	15.43967588	0.8125342848
90-2	1.01	0.863	85.44554455		
90-3	1.003	0.841	83.84845464		
91-1	1.174	0.999	85.09369676	14.72612569	0.1582286878
91-2	1.214	1.036	85.33772652		
91-3	1.102	0.941	85.39019964		
92-1	1.008	0.833	82.63888889	17.46171632	0.1170275398
92-3	1.137	0.937	82.40985048		
92-3	1.021	0.843	82.56611166		
93-1	1.19	1.004	84.3697479	15.33107169	0.3825748476
93-2	1.08	0.913	84.53703704		
93-3	1	0.851	85.1		
94-1	1.05	0.903	86	13.69943207	0.2868702592
94-2	1.05	0.909	86.57142857		
94-3	1.09	0.941	86.33027523		
95-2	1.124	0.964	85.76512456	13.59877913	0.3219795778
95-3	1.016	0.876	86.22047244		
96-1	1.06	0.912	86.03773585	13.98797114	0.765854164
96-2	1.02	0.885	86.76470588		
96-3	1.07	0.912	85.23364486		

97-1	1.03	0.857	83.2038835	16.55752269	0.2636250698
97-2	1.02	0.854	83.7254902		
97-3	1.03	0.859	83.39805825		
98-1	1.03	0.885	85.9223301	14.37828449	0.42513323
98-2	1.09	0.93	85.32110092		
99-1	1.04	0.893	85.86538462	13.80063914	0.29454062
99-2	1.03	0.889	86.31067961		
99-3	1.09	0.942	86.42201835		
100-1	1.126	0.968	85.96802842	14.10542253	0.06743857692
100-2	1.179	1.012	85.83545377		
100-3	1.119	0.961	85.88025022		
		0			
101-1	1.04	0.864	83.07692308	16.65221946	0.4380914365
101-2	1.09	0.914	83.85321101		
101-3	1.06	0.88	83.11320755		
102-1	1.08	0.929	86.01851852	14.27645503	0.4171555878
102-2	1.05	0.897	85.42857143		
103-1	1.09	0.943	86.51376147	13.51138961	0.02245212814
103-2	1.08	0.934	86.48148148		
103-3	1.02	0.882	86.47058824		

Appendix 6: Forms in which turmeric was sold in Public Markets in Yaoundé and Douala.



(Photo taken by Taty Brandy, 2024)

Appendix 7: Accepted review paper for publication to the Journal of Food Nutrition Chemistry

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 sheds 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 including "turmeric", "adulterants", "authenticity", "fraud detection", "traceability" "consumers' health" and "toxicity" guided 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 their sources of turmeric powder, they would be more likely to have 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 doom.

Keywords: Turmeric, fraud detection, adulterants, consumers' health, authenticity, traceability