Differentiating True and False Cinnamon

Subjects: Others

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Given the intricate compositions of essential oils (EOs), various discrimination approaches were explored to ensure quality, safety, and authenticity, thereby establishing consumer confidence.

discrimination | physical–chemical analysis | instrumental analysis | food industry

1. Introduction

Essential oils (EOs) are natural products obtained from different parts of plants (roots, bark, leaves, and flowers). They are hydrophobic liquids containing complex mixtures of aromatic compounds derived from the biosynthesis of secondary metabolites, serving as a defense against external agents. The components of EOs belong to different classes of compounds, such as monoterpenes and sesquiterpenes, alcohols, esters, aldehydes, ketones, and phenols, all of which possess various biological properties [1]. Currently, EOs have been widely used in the food, cosmetics, pharmaceutical, and chemical industries, as well as in perfumery [2].

One of the highly valued essential oils (EOs) by the food industry is cinnamon essential oil (CEO) from the *Cinnamomum* genus, which can be extracted from the root, bark, or leaves, each presenting distinct chemical compositions. Notably, cinnamon bark essential oil (EO) is rich in cinnamaldehyde, leaf EO contains eugenol, and root EO contains camphor [3]. CEO has been shown to possess antimicrobial [4][5], antifungal [6][7][8], anti-inflammatory [9][10], and antioxidant [11][12] activities. Consequently, CEO finds applications in culinary preparations due to its sweet and spicy aroma and flavor. It is commonly used in meat seasoning, baked goods, and pastries as an alternative preservative [13], and in chewing gum as a flavoring agent [14].

Cinnamon can be found on the market in two main species: *Cinnamomum verum* (true cinnamon or *Ceylon cinnamon*) and *Cinnamomum cassia* (syn. *Cinnamomum aromaticum*, false cinnamon). Due to its high market value, sweeter and milder flavor, and higher amounts of phenolic and aromatic compounds such as eugenol and cinnamaldehyde, true cinnamon is more challenging to obtain compared to false cinnamon. False cinnamon has a more astringent taste and contains a higher concentration of coumarin in its composition. Consuming large amounts of coumarin can lead to adverse health effects, thus justifying its lower cost in the market. As a result, true cinnamon is susceptible to fraud due to its quality and high value, and false cinnamon is often used as a substitute and/or adulterant, both in powdered form and as a CEO.

In detail, in just over the last thirteen years, cinnamon has received significant attention by the scientific community. The search employed specific terms, including “true and false cinnamon”, “*Cinnamomum verum* and *Cinnamomum* *cassia*", "authenticity of cinnamon essential oil", or "cinnamon adulteration", and focused on articles where these terms appeared in the field title, abstract, and keywords. The intention was to exclude publications unrelated to the subject matter. The search encompassed the entire period from the inception of the Scopus database up to 2010, with the final retrieval conducted in September 2023. **Figure 1** illustrates the upward trajectory of scientific publications related to cinnamon over time. This is evidenced by a total of 120 scientific papers published in recent years.

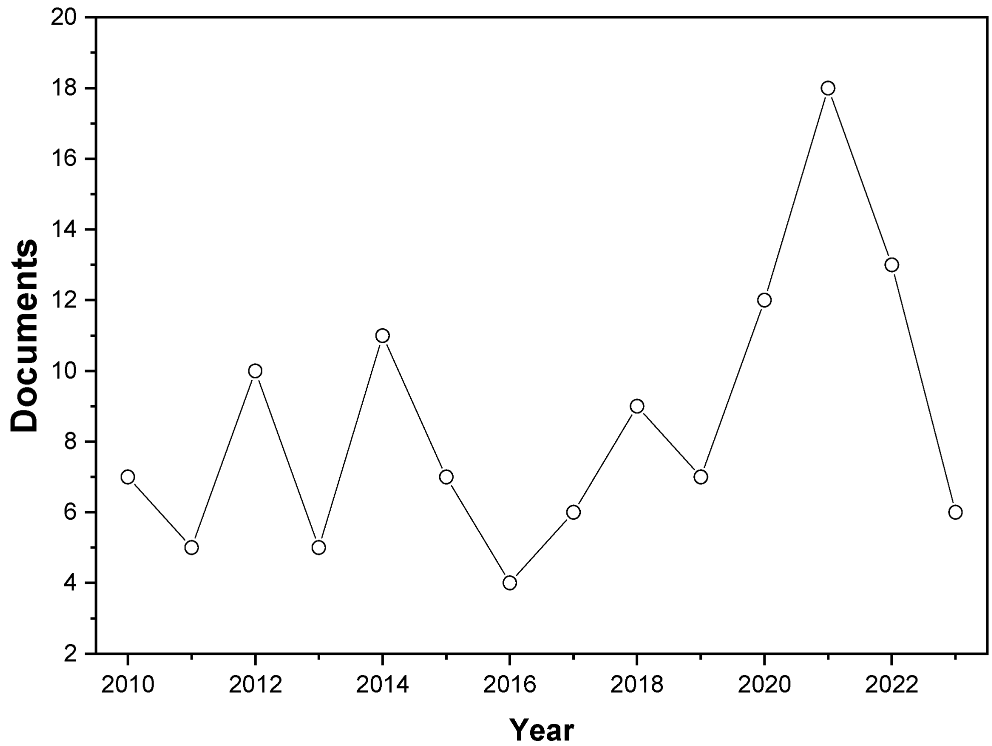

Figure 1. Number of annual peer-reviewed publications related to cinnamon.

The assurance of quality, safety, and authenticity of EOs is a paramount concern due to their intricate compositions. EOs, derived from various plant parts, encompass a diverse array of aromatic compounds, each contributing to their distinct aromas and potential therapeutic properties. As these oils find their way into numerous products in industries ranging from food and cosmetics to pharmaceuticals, ensuring their purity and legitimacy becomes imperative to safeguard consumer well-being.

A plethora of techniques have been detailed in the scientific literature to address the multifaceted nature of EOs. These methodologies span a spectrum from traditional organoleptic assessments, which involve human sensory evaluations, to more advanced and precise analytical methods. Physical, chemical, and instrumental approaches play pivotal roles in verifying the genuineness of CEOs.

Spectroscopic techniques, such as infrared and nuclear magnetic resonance spectroscopy, provide insights into the molecular structure of EOs, aiding in their identification and authentication. Chromatographic methods, such as gas chromatography-mass spectrometry (GC-MS) and high-performance liquid chromatography (HPLC), enable the separation and quantification of individual compounds within the complex EO matrices. These techniques serve as valuable tools for pinpointing specific markers that can distinguish authentic CEOs from adulterated or counterfeit versions.

Nevertheless, the successful application of these techniques demands skilled personnel, extensive equipment, and a considerable time investment. Moreover, some approaches may inadvertently alter the CEO sample or are resource-intensive, posing challenges to their widespread use.

2. *Cinnamomum* sp.

Cinnamon is a spice belonging to the genus *Cinnamomum* in the Lauraceae family, and it is widely used across various cultures around the world [15]. The name "cinnamon" is derived from the Greek word, meaning "sweet wood" [16]. It is a perennial tree that can grow to heights of 7 to 10 m, although it can also be cultivated as a shrub, reaching less than 3 m in height. Cinnamon thrives in tropical, warm, and humid climates, and it becomes ready for harvest after about three years of growth. It features dark green leaves, small white-yellowish flowers, and purple fruits that contain a single seed [3].

Around 250 to 350 species of cinnamon have been identified and distributed across North America, Central America, South America, Southeast Asia, and Australia. Among these species, four are considered of greater importance and are commonly used for obtaining the spice: *Cinnamomum zeylanicum* Blume (also known as *C. verum*), *Cinnamomum aromaticum* (or *C. cassia*), native to China, *Cinnamomum burmannii*, native to Indonesia, and *Cinnamomum loureiroi*, native to Vietnam [17][18].

Its consumption is associated with health benefits such as antimicrobial activity [19], antioxidant properties [20], anticancer effects [21], and glucose control in diabetes [22]. Cinnamon is utilized in foods, seasonings, cosmetics, and medications, and is available in various forms, such as whole material, ground, extracts, or essential oils obtained from the leaves and bark. However, the consumption of cinnamon may also lead to adverse health effects. *Trans*-cinnamaldehyde, also known as cinnamaldehyde, the main component of cinnamon bark, can result in skin sensitization and cause contact dermatitis [23]. Cinnamic acid is also known to induce hypersensitivity upon contact [24].

True cinnamon native to Sri Lanka, also known as *Ceylon cinnamon*, includes the species *C. verum* and *C. zeylanicum*, and false cinnamon, which have diverse origins such as China, South America, and Indonesia, and include the species *C. cassia*, *C. aromaticum*, *C. burmannii*, and *C. loureiroi* [25] (**Table 1**).

The aroma and taste of true cinnamon are soft and sweet, and its color is light brown, whereas fake cinnamon is darker, in addition to having a stronger, astringent, and spicy flavor [26]. In addition, they have distinct characteristics regarding the composition of phenolic compounds, with true cinnamon being rich in aromatic and phenolic compounds, such as cinnamaldehyde and eugenol, while false cinnamon has higher amounts of coumarin

(2000 to 5000 mg/kg), approximately a thousand times higher than those found in true cinnamon (2 to 5 mg/kg), and tannins in the bark, which explains the astringent taste [25][27][28][29].

Table 1. Differences between *Cinnamomum verum,* and *Cinnamomum cassia* species.

	C. verum	***C. cassia***	***C. burmannii***	***C. loureiroi***
Country where it originates	Sri Lanka	China	Indonesia	Vietnam
Flavor	Mild Sweet	Bitter Spicy	Spicy	Sweet spicy
Color	Light reddish brown	Dark reddish brown	Dark reddish brown	Dark reddish brown
Coumarin content (g/kg)	0.017	0.31	2.15	6.97

Coumarin is an anticoagulant agent that can pose serious health risks due to its hepatotoxic and carcinogenic effects in animals. For this reason, health agencies have established restrictions regarding the tolerable daily intake of coumarin, thus determining the daily intake at 0.1 mg/kg/day, and consequently the consumption of *C. cassia*, guaranteeing its safe use [30][31].

The European Regulation (EC) No 1334/2008 [32] established specific coumarin maximum limits as follows: 50 mg/kg for traditional and/or seasonal bakery products with cinnamon mentioned in their labeling, 20 mg/kg for breakfast cereals, including muesli, 15 mg/kg for fine bakery products (excluding traditional and/or seasonal bakery products with cinnamon in the labeling), and 5 mg/kg for desserts.

In general, *C. loureiroi* contains high levels of coumarin, which can cause adverse side effects for the consumer, including liver damage. True cinnamon, on the other hand, is highly vulnerable to fraud due to its added value and higher quality compared to false cinnamon [33].

C. verum is a highly prized spice and is considered superior to false cinnamon, which is commonly found and cheaper. Visually, the bark cinnamon appears in the form of rolled cylinders. However, the true cinnamon has a light reddish-brown color rolled in several layers, while the others are in dark reddish-brown tones, hard, and rolled in only one layer [34].

The different parts of cinnamon bark, leaf, or powder, have differences in composition (**Figure 2**), which can be used for quality control. The bark, for example, contains natural antioxidants, while the branches are used to treat inflammatory diseases. Cinnamon bark powder, when added with other medications, can slow down the deterioration process of some heart conditions [35][36][37].

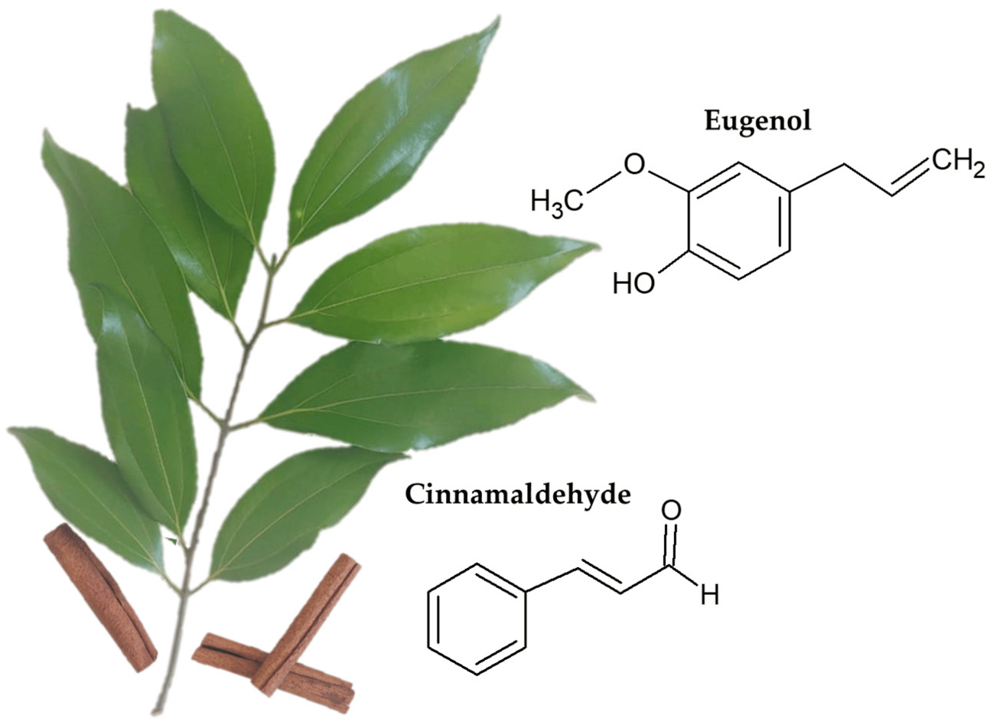

Figure 2. Parts of cinnamon and its main constituents.

2.1. Cinnamon Essential Oil

CEOs are complex mixtures of aromatic products from the secondary metabolism of plants, normally produced by secretory cells or groups of cells from different parts of the plant, such as stems, roots, leaves, flowers, and fruits [38][39]. The essential oil content may vary according to the species, physical form of the sample, part of the plant used (**Table 2**), geographical origin, and stage of development of the plant [3].

The constituents of CEOs can belong to several classes of compounds, with emphasis on terpenes and phenylpropenes, which are the classes of compounds commonly found. Monoterpenes and sesquiterpenes are the most frequently found terpenes in EOs, as well as diterpenes, and minor constituents [40].

Different parts of cinnamon, bark, leaves, branches, fruits, and roots can be used for the production of essential oils by distillation and oleoresins by solvent extraction [41]. The volatile components of the EO are present in all parts of the plant (**Table 2**) and can be classified into monoterpenes, sesquiterpenes, and phenylpropenes, with main constituents such as *trans*-cinnamaldehyde (bark), eugenol (leaves), and camphor (root) [3][42].

Table 2. Volatile compounds present in the bark and leaf of *C. verum* and *C. cassia* essential oils.

Compounds	Content (%)			
	Bark		Leaf	
	C. cassia	***C. verum***	***C. verum***	***C. cassia***
1,3-dimethyl-benzene	0.23	0.15	-	-

Compounds	Content (%)			
	Bark		Leaf	
	C. cassia	*C. verum*	*C. verum*	*C. cassia*
Styrene	0.19	0.14	-	-
Benzaldehyde	0.41	0.29	0.05	0.10
Camphene	0.35	0.21	-	-
Acetophenone	0.96	tr	-	-
β-Pinene	0.15	0.44	-	-
Linalool	0.68	-	-	-
Camphor	0.97	0.53	-	-
Benzene propanal	0.64	0.53	-	-
Borneol	0.19	0.12	-	-
Cis-cinnamaldehyde	1.95	2.29	-	-
Trans-cinnamaldehyde	77.21	74.49	16.25	30.65
Eugenol	0.21	7.29	79.75	-
Geranyl acetate	0.14	0.12	-	-
Benzene,1-(1,5-dimethyl-4-hexenyl)-4-methyl	0.37	0.15	-	-
Cinnamyl acetate	0.14	0.49	-	-
α-muuroleno	0.47	0.11	-	-
3-Methoxy-1,2-propanediol	-	-	-	29.30
Cinnamyl alcohol	-	-	0.07	0.65
Acetaldehyde	-	-	-	0.47
o-Methoxy cinnamaldehyde	-	-	-	25.39
Coumarin	-	-	0.05	6.36

[17] and the main constituent of EO. It is recognized as safe by the United States Food and Drug Administration and the Association of flavor and extract manufacturers, receiving status A, that is, it can be used in food [43]. Its commercial use is limited due to its low solubility in water and sensitivity when exposed to light and air for prolonged periods [44]. Friedman; Kozuke; Harden [45] evaluated the stability of *trans*-cinnamaldehyde present in EO at different temperatures and observed that around 60 °C the compound was decomposed. Das, Gitishree et al. [46] report that cinnamaldehyde has a biological effect and is quickly oxidized into cinnamic acid, and as a product of its degradation, benzoic acid is excreted by the urinary system.

Due to cinnamic acid and cinnamaldehyde, cinnamon has protective effects against cardiotoxicity produced by the compound isoproterenol [47]. In addition, cinnamon is associated with the inhibition of fatty acids such as arachidonic acid, which has an inflammatory effect. The compound eugenol, identified in cinnamon extracts, has an antioxidant effect, helping to inhibit lipid peroxidation and the generation of reactive oxygen species [48].

Eugenol is the main volatile compound of OECF [49]. It is an aromatic substance with a pleasant odor and taste, belonging to the class of phenylpropanoids [50]. It is usually found as a yellowish oily liquid [51]. Like cinnamaldehyde, eugenol is also recognized as a safe food by the Food and Drug Administration [52]. Eugenol has antimicrobial [4][5], antifungal [6][7], anti-inflammatory [9][10], and antioxidant [11][12] activities. Despite having good biological properties, eugenol has low solubility in water [53], and sensitivity to light [52].

CEO contains some vital bioactive components in the form of terpenes and aromatic compounds, giving it remarkable biological properties. Thus, CEO has been widely used as a raw material in the medicine industry, as natural additives, condiments, and flavorings in the food industry, and in perfumery [42][54].

The main responsibility for the biological activities is often attributed to the major compounds present in the oil, such as the volatile fraction and the phenolic compounds [55]. In addition, biological activities can also be related to the joint contribution of different compounds, with minor components producing a synergistic effect with the others [3][56]. **Table 3** provides an overview of the diverse biological activities associated with various species of Cinnamomum. The compounds found in cinnamon have demonstrated a wide range of biological effects, including antimicrobial, anti-inflammatory, antioxidant, insecticidal, and antidiabetic activities. This compilation highlights the multifaceted potential of Cinnamomum in various fields, from traditional medicine to modern pharmaceutical research, pest control, and diabetes management.

Table 3. Biological, insecticidal, and antidiabetic activity of cinnamomum.

Cinnamomum Species/Type	Sample	Biological Activity	Result	References
		Insecticidal activity		
C. verum	Essential oil	*Odontotermes assamensis*	2.5 mg/g	[57]
C. osmophloeum	Essential oil	*Aedes albopictus*	40.8 µg/mL	[58]
		Culex quinquefasciatus	31.6 µg/mL	
		A rmigeres subalbatus	22.1 µg/mL	
C. zeylanicum L.	Essential oil	*Acanthoscelides obtectus*	46.8 µL/kg	[59]
C. cassia	Bark extract	*Tribolium castaneum*	3.96 µg/adult	[60]
		Lasioderma serricorne	23.89 µg/adult	

Cinnamomum Species/Type	Sample	Biological Activity	Result	References
		Antioxidant activity		
-	Cinnamon powder (raw extract)	ABTS	1.52 mg/mL	[61]
	Cinnamon powder (in vitro digestion)		1.18 mg/mL	
C. cassia	Extract	DPPH	10 mg/mL	[62]
C. burmannii	Essential oil (leave)	DPPH	100 µg/mL	[63]
C. cassia	Cinnamon bark oil	DPPH O_2	10 mg/mL 1 mg/mL	[62]
C. zeylanicum	Essential oil (leave)	DPPH	4.78 µg/mL	[64]
		ABTS	5.21 µg/mL	
C. zeylanicum	Extract	ABTS	1119.9 µmol Trolox/g MS	[65]
		PCL	177.4 µmol Trolox/g MS	
		CV	39.8 µmol Trolox/g MS	
		Anti-inflammatory activity		
C. osmophloeum	Essential oil (leave)	NO production in RAW 264.7 cells	9.7 to 65.8 µg/mL	[66]
C. cassia	Extract	NO production in RAW 264.7 cells	9.3 to 43 µg/mL	
		Antidiabetic effect		
-	Gelatin capsule with cinnamon powder	Group A: placebo in capsule	17.4% reduction after 12 weeks	[67]
		Group B: 1000 mg/day of cinnamon powder in capsule form	10.12% reduction after 6 weeks	
-	Cinnamon extract	Rats divided into 5 groups (I—placebo only, II to V extract concentrations)	The highest dose of 200 mg/kg was more effective	[68]

Cinnamomum Species/Type	Sample	Biological Activity	Result	References
-	Cinnamon Polyphenols	Mice divided into 5 groups (diabetic model, dimethylbiguanide, low, moderate and high dose of polyphenols)	Treatments with different doses of polyphenols (0.3, 0.6 and 1.2 g/kg/d caused a marked reduction in glucose	[69]
C. osmophloeum	Essential oil (leave)	Mice were induced with diabetes and then divided into six groups receiving different concentrations of essential oil	All doses tested significantly reduced blood glucose	[70]
		Antimicrobial activity		
C. verum	Essential oil	*Staphylococcus hyicus*	minimal inhibitory concentration (MIC) and minimal bactericidal concentration (MBC) values ranging from 0.078 to 0.313%	[71]
C. verum	Essential oil	*Streptococcus suis* *Actinobacillus pleuropneumoniae*	MIC and MBC ranging from 0.01 to 0.156% (*v*/*v*)	[72]
C. verum	Essential oil	*Candida tropicalis*	MIC of 7.8 µL/mL	[73]
C. cassia	Essential oil	*Candida albicans*	65 µg/mL	[74]
C. cassia	Essential oil	*Staphylococcus aureus*	1.25% MIC	[75]
C. cassia [13]	Essential oil	*Escherichia coli*, *Pseudomonas aeruginosa*, [14] and *Streptococcus pyogenes*	0.25 to 0.50 mg/mL MIC	[76]
C. cassia	Essential oil	*Aspergillus flavus*, *Penicillium viridicatum*, and *Aspergillus carbonarius*.	1.67 to 5.0 µL/mL MIC [78]	[77]

2.2. Adulteration of Cinnamon Essential Oils (CEOs)

With the growth in demand in the food, perfumery, and cosmetics industries, the market for natural aromatic raw materials is expanding exponentially to meet your needs. To meet this search for aromatic products, research has focused on compounds from biotechnological processes used in the production of aromas and fragrances from other plant origins [78].

Intentionally altered products with hidden properties or quality and incomplete and unreliable information define adulteration. In general, counterfeiting involves actions that deteriorate the specific properties of the products while maintaining their characteristic indicators, such as appearance, color, consistency, and aroma [79].

Currently, the authenticity of food and food ingredients is a major challenge, as it is often related to fraud. Food adulterations have been occurring for a long time, with the difference that they have been improved over the years, accompanying or even advancing in the field of research into new methods. A greater number of adulterations among raw materials are found in spices, edible oils, honey, milk and its derivatives, fruits and fruit juice, coffee, flour, and meat products [26].

Among the raw materials, cinnamon is one of the spices commonly adulterated. These adulterations can include species (mixing different species of Cinnamomum), origin (incorrectly labeling the country of origin), additives and fillers (adding other substances such as starch, sawdust, or other spices), and oil (adulterating EOs derived from cinnamon with synthetic or cheaper oils).

Due to its high added value and high cost, true cinnamon is highly prone to adulteration with false cinnamon species, which are of lower quality and cheaper, causing potential health risks and making the product unsafe for the consumer. This practice is usually carried out in powder form, which makes it difficult to discriminate between cinnamons as their characteristics are lost during the process [29].

Furthermore, true cinnamon can be adulterated with other types of spices, such as clove and chili powder, and clove and cinnamon oil, as reported by Gopu et al. [80]. Cinnamon fraud triggered research for the development of new, more accurate, reliable, and sensitive analytical methods in order to identify and quantify potential adulterants in true cinnamon more quickly and efficiently, ensuring food safety. Among the methods developed, chromatography is based on the determination of the main active compounds of cinnamon or adulterants, called marker compounds, such as cinnamaldehyde, eugenol, linalool, and coumarin, among others [80].

Cinnamon adulterations do not only occur in the form of powder, frauds are also found in CEO by mixing other compounds or even false cinnamon species. Through physical–chemical and instrumental analyses, the CEOs purity can be proven through qualitative and quantitative analyses, that is, determining the constituents or identifying the compounds present in the oil, respectively [79].

To prevent the entrance of adulterated cinnamon products into local markets, the regulatory sector takes several steps: product testing and certification are performed by implementing regular product testing to verify the authenticity and quality of cinnamon products; certifying authentic products with recognized standards can help consumers identify genuine products; labeling regulations require accurate information about the species, country of origin, and any additives or fillers in the product; clear and transparent labeling helps consumers make informed choices; traceability systems that track the supply chain of cinnamon products from production to market, which can help identify and eliminate adulterated products at different stages; import controls and inspections to ensure that products entering the country meet regulatory standards, which includes checking for proper documentation and compliance with labeling regulations; public awareness and education about the different types of cinnamon and their characteristics—informed consumers are less likely to purchase adulterated products; penalties and enforcement for those found guilty of adulteration, and rigorous enforcement of these penalties, which can act as a deterrent to unethical practices; collaboration with industry and associations to establish self-regulation practices and codes of conduct that promote authenticity and quality; and international cooperation with international regulatory bodies and other countries to share information and best practices in combating cinnamon adulteration, especially when products are imported.

For the regulation of EOs, the molecules must come from the raw material of the reference plant to be considered and labeled as 100% pure and natural [78]. Adulteration of CEOs can be divided into four types [79]: essential oil diluted with a solvent that has similar physicochemical characteristics, such as vegetable oils or organic solvents; cheaper CEO, but similar in origin or chemical composition, mixed with authentic CEO; unique natural or synthetic compounds added to mimic aromatic characteristics or composition; and/or substituting with low-value or blending CEOs.

As they are complex matrices, the EOs need to be analyzed by different techniques to ensure quality, safety, and authenticity, in addition to ensuring safety for consumers. As a result, a wide range of techniques have been reported, including organoleptic, physical, and chemical methods. However, these techniques, for the most part, require specialized people, have a high investment cost, are time-consuming, and some degrade the samples [79][81].

Molecules produced from natural reagents, also known as semi-synthetic compounds, can be used to adulterate specific EOs [78]. Cinnamaldehyde molecules can be produced from the benzaldehyde found in bitter almonds and used as an adulterant [82]. There are several scams associated with bitter almond and CEO, and since the false origin is cheaper than the Ceylon origin, blends between these CEOs are common. Despite this, it is possible to detect this type of adulteration by analyzing differences in composition between EOs or by spectroscopic analysis [26][28][78].

Adulterations along the food chain present a health hazard, and continuous vigilance is fundamental in terms of food safety, regarding research and development of analytical methods to detect adulterations and contamination in food from the raw materials used [26].

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