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REVIEW ARTICLE

"Ceylon cinnamon": Much more than just a spice

Lalith Suriyagoda[1] | Anoma Janaki Mohotti[1] | Janak K. Vidanarachchi[2] | Suranga P. Kodithuwakku[2] | Madushani Chathurika[2] | Pradeepa C. G. Bandaranayake[3] | Alistair M. Hetherington[4] | Chalinda K. Beneragama[1]

[1]Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka

[2]Department of Animal Science, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka

[3]Agricultural Biotechnology Center, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka

[4]School of Biological Sciences, University of Bristol, Bristol, UK

Correspondence
Chalinda K. Beneragama, Department of Crop Science, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka.
Email: chalindab@agri.pdn.ac.lk

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Societal Impact Statement

Cinnamomum zeylanicum ("Ceylon cinnamon/true cinnamon") is native to Sri Lanka. In addition to generating significant foreign income, over 350,000 families are involved in the cinnamon industry, demonstrating its long-established role in the Sri Lankan society. The spice constitutes many bioactive compounds with antioxidant, antimicrobial, and insecticidal properties, in addition to therapeutic and preventive effects against many diseases and disorders. New uses of cinnamon continue to emerge, and in this review, we discuss the opportunities for crop and product improvement, which will likely impact positively on the lives and livelihood of the population in Sri Lanka.

Summary

Cinnamomum zeylanicum Blume, known as Ceylon cinnamon, is native to Sri Lanka, whereas *Cinnamomum cassia* J. Presl (Cassia cinnamon) and other types of *Cinnamomum* spp. are grown in China and many other parts of Asia. Ceylon cinnamon is relatively expensive due to its chemical composition, high quality, proven health benefits, and ultra-low levels of the toxic chemical compound, coumarin, which is reported in comparatively high concentrations in Cassia cinnamon. In Sri Lanka, more than 350,000 families are involved in the cinnamon industry. Among the total agricultural produce of Sri Lanka, cinnamon exports provide the second highest in terms of income (second only to tea). In addition to the use of cinnamon as a spice, leaf and bark extracts are used in the food industry to (a) improve the postharvest life of perishable foods through antimicrobial activity and (b) control pests in postharvest storage (insecticidal activity). The human health benefits include antioxidant activity and therapeutic and preventative properties against diseases and disorders. The potential uses of Ceylon cinnamon in the global food industry, health, and cosmetics sectors are abundant. However, to ensure maximum benefits to producers and consumers, accredited laboratory testing and legislative procedures need to be developed and strengthened to detect and reduce malpractice and product adulteration in the global marketplace. There are also considerable opportunities for crop improvement. The application of contemporary genomic and genetic approaches coupled to plant breeding will be needed to improve yields and disease resistance and to safeguard production in the face of the threats posed by global environmental change.

KEYWORDS
Cassia cinnamon, Ceylon cinnamon, *Cinnamomum cassia*, *Cinnamomum zeylanicum*, health benefits

1 | BACKGROUND

1.1 | History of cinnamon

Cinnamon is the peeled, dried bark of some *Cinnamomum* spp. belonging to the family Lauraceae. It has been used as a spice by human beings since ancient times (Anonymous, 2015; Barceloux, 2008; Leja & Czaczyk, 2016). In addition to its use as a spice, the bark and leaves of the plant are used for the production of volatile oils (Barceloux, 2008). Cinnamon has long been used as an ingredient in cooking and is an important ingredient in both the confectionary and cosmetics industries. It was also used in the embalming process in ancient Egypt and the Bible contains several references to cinnamon (Thomas & Duethi, 2001). The bioactive molecules in cinnamon have been exploited in the context of treatment of many ailments (Baker & Grant, 2018; Bandara et al., 2011; Barceloux, 2008; Ulbricht et al., 2011), in the perfume industry, and as a mosquito repellent (Baker & Grant, 2018; Thomas & Duethi, 2001).

Historically, the presence of cinnamon has attracted foreign invaders to Sri Lanka (previously known as Ceylon). Arabs were involved in the trading of cinnamon across the globe until the 10th–15th century and were careful to keep the origin of the product a closely guarded secret (Ravindran & Nirmal-Babu, 2005). Gaining access to cinnamon was a prime motivation for the Portuguese to invade Sri Lanka in the early 16th century (Chatoor, 2017; Thomas & Duethi, 2001). During the 16th–17th centuries, the Portuguese established a very successful business of exporting cinnamon to Europe (Barceloux, 2008). The Dutch commenced systematic cultivation of cinnamon in plantations after they captured the island in the mid-17th century and this was prompted when the Sri Lankan king obstructed the collection of cinnamon from the forests (Chatoor, 2017). After the British captured Sri Lanka in 1796, cinnamon exports to Europe continued, with the British East India Company being the main exporter (Barceloux, 2008). Because of high export duties imposed by the Dutch, there was a significant reduction in the export of Ceylon cinnamon, which was replaced by cheaper Cassia cinnamon. Sri Lanka still continues to be an important supplier of Ceylon cinnamon to customers throughout the world.

1.2 | Different species of cinnamon

There are over 250 known aromatic species of the genus *Cinnamomum*, which are primarily located in Asia and Australia. Many of these species are aromatic and used as flavoring agents (Thomas & Duethi, 2001). Of these species, *Cinnamomum zeylanicum* Blume (Ceylon cinnamon; syn—*Cinnamomum verum* J. Presl.) and *Cinnamomum cassia* J. Presl (Cassia cinnamon) are the economically most important species (Barceloux, 2008; Muhammed & Dewettinck, 2017). *Cinnamomum burmannii* Blume that grows in Indonesia, *Cinnamomum loureiroi* Nees in Vietnam (Chen et al., 2014), and *Cinnamomum tamala* in India and Nepal also have some economic importance (Anonymous, 2015; Barceloux, 2008). *Cinnamomum camphora* in southern China and Indonesia, *Cinnamomum sintok* in Java and Sumatra, *Cinnamomum ineris* in Japan and South India, *Cinnamomum obtusifolium* in Northeast India and Myanmar, *Cinnamomum olivera* in Australia, *Cinnamomum culilawan* and *Cinnamomum rubrum* in the Moluccas and Amboyna, and *Cinnamomum glaucascens* in Nepal are other species of significance (Thomas & Duethi, 2001). *C. zeylanicum*, widely known as the "true cinnamon," is naturally found in Sri Lanka, while *C. cassia*, *C. burmannii*, and *C. loureirii* are collectively called Cassia cinnamon (Ghodki & Goswami, 2016).

In a substantial amount of literature, "cinnamon" is misleadingly associated with *C. cassia* or used as a generalized term for both *C. cassia* and *C. zeylanicum* together. We felt that this "confusion" does Ceylon cinnamon a considerable disservice. Therefore, the objective of this review was to emphasize that there are significant differences in terms of properties between Ceylon cinnamon and other species, especially cassia. This is important because cassia is commonly traded as "cinnamon" in most supermarkets. Here, we compare the botanical characteristics (Table 1) and biochemical properties of the products derived from *C. zeylanicum* and *C. cassia* (Table 2). We will also discuss the present uses and benefits of cinnamon; however in this context, we focus only on Ceylon cinnamon. For comparison purposes, the articles reporting the characteristics of both Ceylon cinnamon and Cassia cinnamon were used. When compiling literature, the keywords "cinnamon," "Ceylon cinnamon," "true cinnamon," "*Cinnamomum zeylanicum*," "*Cinnamomum verm*," and "cassia cinnamon" either in the title, keywords, or abstract of an article using Google Scholar®, Science Direct®, PubMed, ResearchGate databases, and Google browser were used. For this review, the articles clearly specifying the different species were selected as much as possible.

1.3 | Comparison of major botanical and chemical features between *C. zeylanicum* and *C. cassia*

Both *C. zeylanicum* and *C. cassia* are evergreen, medium to large trees in their natural habitat (Figure 1a and h). The leaves are dark green and leathery with characteristics, three prominent veins, while young leaves are red/reddish in color. In both species, the bark is more valuable than the leaves. In the case of *C. zeylanicum*, this is the dried inner bark and in *C. cassia* it is both inner and outer bark (Table 1, Figure 2). Cinnamon is rich in phytochemically active and structurally diverse compounds with antimicrobial, antioxidant, and

TABLE 1 General comparison between *Cinnamomum zeylanicum* and *Cinnamomum cassia*

	C. zeylanicum Blume	*C. cassia* J. Presl	References
Synonyms	***Cinnamomum*** *verum* J.S. Presl *Laurus cinnamomum* L.	***Cinnamomum*** *aromaticum* Nees *C. cassia* Nees ex Blume	Barceloux (2008); Jayaprakasha & Rao (2011); Chen et al. (2014)
Common names	True cinnamon, Ceylon cinnamon, Sri Lankan cinnamon, Cortex Cinnamomi (bark)	Cassia cinnamon, Chinese cinnamon, Cassia bark, Cortex Cinnamomi (bark)	He et al. (2005); Barceloux (2008); Jayaprakasha & Rao (2011); Chen et al. (2014); Ghodki and Goswami (2016)
Occurrence/ Native habitat	Indigenous to Sri Lanka. At present, also grown in Seychelles, Madagascar, and northwestern India	Occurs wild in the mountains of southern China, now cultivated in the Guangxi (Kwangsi) and Guangdong (Kwangtung) provinces of China	Wijesekera and Chichester (1978); Barceloux (2008); Jayaprakasha & Rao (2011); Thomas and Kuruwilla (2012)
Plant Characteristics	Large, tropical, evergreen trees that grow to a height of about 10–14 m in their natural habitat. In plantations coppiced annually starting from 2.5 to 3 years for the harvesting of bark. Young branches are smooth and brown	Slender, evergreen trees that grow up to 20 m in height. Young branches are smooth and brown	Wijesekera and Chichester (1978); Pathirana (2007); Barceloux (2008); Anonymous (2015)
Leaf characteristics	Leaves are carried on short petioles, opposite, leathery, ovate to broadly ovate with three (and rarely five) prominent veins. Entire margin, obtuse, and brittle tips. Young leaves are bright vermillion red that turns light-yellow green with maturation. Fully mature leaves are dark green in color on the upper surface and pale green underneat.	Leaves are sub-opposite, slender, lanceolate, or oblanceolate with three prominent veins. Leaves are reddish when young and dark green when mature.	Wijesekera and Chichester (1978); Pathirana (2007); Barceloux (2008)
Flower and fruit characteristics	Small (about 3 mm in diameter), pale yellow flowers are borne in axillary or terminal panicles, at the end of twigs. Exhibit protogynous dichogamy with two flower types "Type A" and "Type B" Fruit is a fleshy, ovoid drupe that turns dark purple or black when ripe and contains one seed. Persistent calyx	Small, white flowers are borne in axillary or terminal panicles. Fruit is a green, fleshy, globose drupe that turns dark purple or black when ripe and contains one seed	Wijesekera and Chichester (1978); Barceloux (2008); Azad et al., 2018
Bark characteristics	Almost papery, brittle, easily crushed, or powdered. The color is pale yellowish-brown	Bark is thick and hard when dried. Dark brown in color	Barceloux (2008); Chen et al. (2014); Thomas and Duethi (2001)
Bark/Quills	Quills are made using the dried inner bark of the stems. Rolled into quills of less than 0.08 mm thick and usually debarked. Has a single spiral curl and is filled with single, short pieces of bark.	Rolled to the center resembling scrolls and possess an average thickness of 1.5 mm. Has a double curl when dries, a spiral of dried bark, a small bit of relatively straight bark, and then the other long edge spiral in the opposite direction. Ground cassia has a very reddish-brown color	Thomas and Duethi (2001); Jose et al. (2019)
Flavor characteristics	Considered to be the most delicate and complex of the major species of cinnamon. Its flavor is more subdued, less bitter, and has a decidedly sweet finish in the aftertaste. Its smell is sweet and aromatic	Has a strong, spicy-sweet flavor, and aroma. The flavor is extremely bitter and burning with somewhat of a bite in the aftertaste.	Chen et al. (2014); Thomas and Duethi (2001)
Flavor and aroma	Delicate and complex	Strong, spicy-sweet flavor, and aroma	Chen et al. (2014)
Volatile oils	Present in all parts including leaves, bark, roots, and fruits. Volatile oils are low molecular weight compounds (<300 Da), that vaporize readily at room temperature. Extracted by steam or solvent extraction	Present in all parts including leaves, bark, roots, and fruits	Gruenwald et al. (2010); Chen et al. (2014)

TABLE 2 Comparison of the biochemical properties of *Cinnamomum zeylanicum* and *Cinnamomum cassia*

	C. zeylanicum Blume	*C. cassia* J. Presl
Bark		
Bark powder		
Major volatile compounds	Cinnamaldehyde 1.99% (range 1.49%–3.20%), cinnamyl acetate, cinnamyl alcohol 0.043% (range *n.d.*–0.083%), eugenol (Archer, 1988)	Cinnamaldehyde (range 0.005%–9.383%), cinnamic acid (0.001%–0.191%, cinnamyl alcohol (0.001%–0.177%) cinnamyl acetate, cinnamyl alcohol (*n.d.*), eugenol (Archer, 1988; He et al., 2005)
Coumarin content	*n.d.* (Archer, 1988), 0.004% (Lungarini et al., 2008)	0.001%–1.218% (Archer, 1988; He et al., 2005; Jose et al., 2019), up to 5% (Lungarini et al., 2008)
Bark essential oil		
Essential oil yield	0.93%–3.06% (Jose et al., 2019; Liyanage et al., 2017; Singh et al., 2007; Unlu et al., 2010)	2%–4% (Jose et al., 2019)
Major volatile compounds in essential oil	*trans*-Cinnamaldehyde 49.9–97.7%, eugenol 2.77–16.03%, α-pinene 1.64–5.76%, linalool 1.38–3.78%, β-caryophyllene 3.66%, myrcene 1.38%, benzaldehyde 9.94%, (*E*)-cinnamyl acetate 7.44%–10%, limonene 4.42%, 1,8-cineole 1.55%, (*E*)-cinnamic acid 1.15%, δ-cadinene 0.9%, α-copaene 0.8%, α-amorphene 0.5% (Jayaprakasha & Rao, 2011; Jeyaratnam et al., 2016; Liyanage et al., 2017; Muhammed & Dewettinck, 2017; Singh et al., 2007; Unlu et al., 2010)	*trans*-Cinnamaldehyde 66.28%–97%, anethole 0.6%–2.2%, (+)-δ-cadinene 0.09%–3.07%, α-amorphine 0.3%–0.9%, caryophyllene oxide 0.4%, cinnamyl acetate 2.5%, coumarin/cinnamic acid 1.0%–1.1%, benzene propanol 0.6%–0.7%, o-methoxy cinnamaldehyde 0.44%–5.49%, *trans*-cinnamic acid 0.09%–16.1% (Jeyaratnam et al., 2016; Jose et al., 2019; Liyanage et al., 2017; Muhammed & Dewettinck, 2017)
Bark oleoresin		
Oleoresin yield	9.7%–12% (Shahidi & Hossain, 2018; Singh et al., 2007)	-
Major components of oleoresin	(*E*)-Cinnamaldehyde 50%, coumarin 16.6%,(check) δ-cadinene 7.8%, α-copaene 4.6%, (*Z*)-cinnamaldehyde 1.5%, ortho-methoxy cinnamaldehyde 1.5%, β-bisabolene 1.4% (Muhammed & Dewettinck, 2017; Singh et al., 2007)	-
Leaves		
Leaf Essential Oil		
Essential oil yield (%)	1.5–4.7% (Jayaprakasha & Rao, 2011; Jose et al., 2019; Liyanage et al., 2017; Singh et al., 2007; Wang et al., 2009)	0.27–1.54% (Jose et al., 2019; Liyanage et al., 2017; Singh et al., 2007; Wang et al., 2009)
Major volatile compounds in essential oil	Eugenol 74.9%–90%, *trans*-cinnamaldehyde 2.07%–16.25%, (3-ethoxy-hexa−1,5-dienyl)-benzene 1.14%, borneol 0.92%, acetyl eugenol 6.07%, β-caryophyllene 1.08%–1.9%, linalool 0.97%, bicyclogermacrene 3.6%, α-phellanderene 1.9%, aromadendrine 1.1%, *p*-cymene 0.7%–21.35%, 1,8-cineole 0.7%, benzaldehyde, safrol (Jayaprakasha & Rao, 2011; Jose et al., 2019; Liyanage et al., 2017; Muhammed & Dewettinck, 2017; Singh et al., 2007; Wang et al., 2009; Wijesekera & Chichester, 1978)	*trans* -Cinnamaldehyde 30.36%–67.86%, 3-methoxy−1,2-propanediol 29.3%, o-methoxy-cinnamaldehyde 11.29%–25.39%, coumarin 0.27%–6.36%, glycerin 3.01%, benzeneethanol 1.32%, δ-cadinene 0.33%–2.31%, o-Anisaldehyde 1.99%–4.39% (Jose et al., 2019; Wang et al., 2009)
Coumarin content	0.05% (Wang et al., 2009)	6.36% (Wang et al., 2009)
Leaf oleoresin		
Oleoresin yield	6.9% (Singh et al., 2007)	-
Major volatile compounds in oleoresin	Eugenol 87.2%, spathulenol 1.7%, bicyclogermacrene 1.7%, β-carryophyllene 1.4%, δ-elemene 1.0%, eugenol 87.2% (Muhammed & Dewettinck, 2017; Singh et al., 2007)	-

Note: n.d., Not detected.

Coumarin – 2*H*-1-benzopyran-2-one (Archer, 1988).

Cinnamaldehyde – 3-phenyl-2-propanol (Archer, 1988).

FIGURE 1 *Cinnamomum zeylanicum* (a) seedling nursery plants; (b) leaves of a mature tree; (c) a mature, trained tree; (d) harvested sticks with the outer bark cleaned; (e) preparation of quills; (f) drying; and (g) quills ready for sale. Photographs (a) to (g) depict *C. zeylanicum* and belong to the authors. Informed consent was obtained for photograph (e)

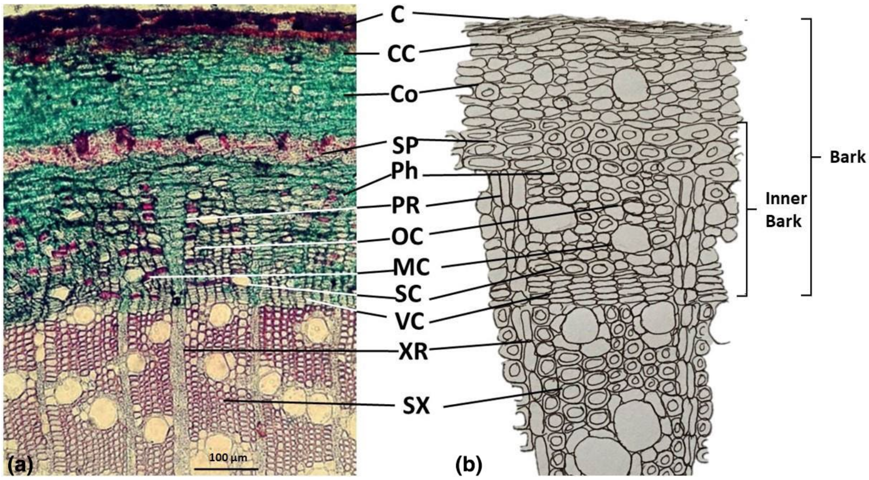

FIGURE 2 (a) A transverse section (×10) and (b) a line diagram showing different anatomical components of a cinnamon stem. C: Cork (Phellem), CC: Cork cambium (Phellogen), Co: Cortex, SP: Sclerenchymatous pericycle, Ph: Phloem, PR: Phloem rays, OC: Oil cells, MC: Mucilage cells, SC: Stone cells, VC: Vascular cambium, XR: Xylem rays, SX: Secondary xylem. Image and diagram courtesy of A J Mohotti (unpublished)

many other medicinal properties. The flavonoid concentration, antioxidant capacity, composition, and chemical properties of cinnamon oils vary with species, age of bark and leaves, harvesting dates, extracting methods, and type of solvent (Muhammad et al., 2017). Although little information is available, the bioaccessibility and bioavailability of the biomolecules present in cinnamon are considered to be high (Muhammed & Dewettinck, 2017).

The leaves, barks, wood, twigs, roots, and fruits of cinnamon are utilized for the production of essential (volatile) oils and oleoresins by distillation and solvent extraction, respectively (Muhammed & Dewettinck, 2017). The volatile oils obtained from different parts of the species *C. zeylanicum* and *C. cassia* vary substantially (Gruenwald et al., 2010; Muhammed & Dewettinck, 2017). In the bark oil of both species, the primary constituent is cinnamaldehyde, whereas in the leaf and root bark oil, the primary constituents are eugenol and camphor, respectively (Gruenwald et al., 2010).

The essential oil from the bark of *C. zeylanicum* consists of *trans*-cinnamaldehyde, eugenol, and linalool as the main components, representing more than 80% of the total composition (Table 2), and *trans*-cinnamaldehyde can account for up to 98% of the total. In contrast, the dried stem bark of *C. cassia* consists of cinnamaldehyde, cinnamic acid, cinnamyl alcohol, and coumarin as the major components (Gruenwald et al., 2010). The ultra-low level of coumarin reported in *C. zeylanicum* (Archer, 1988) is an advantage as coumarin is known to possess hepatotoxic (Ballin & Sørensen, 2014) and carcinogenic (Fotland et al., 2012) properties, and hence can cause ill effects in human beings.

2 | PRESENT STATUS OF THE CINNAMON INDUSTRY

2.1 | The world

In 2018, China was the biggest cinnamon producer in the world with a production of 60,124 metric tons, followed by Indonesia and Sri Lanka 41,380 and 17,450 metric tons of production, respectively. However, when export earnings are considered, Sri Lanka dominated with USD 205 million, followed by Indonesia (USD 141 million) and China (USD 135 million) (ITC, 2019). This is because "Pure Ceylon Cinnamon®" generally commands a price that is more than 10 times the price of the Cassia cinnamon (EDB, 2020).

2.2 | Sri Lanka

Cinnamon cultivation is mainly in the hands of smallholders, providing livelihoods for approximately 350,000 families in Sri Lanka (Samarawickrama, 2015). The extent of cinnamon cultivation has increased by 14% over the past 10 years, with a 52% increase in the annual production (Figure 3) during the same period (DEA, 2019). Cinnamon is the most important export commodity of Sri Lanka accounting for *ca*. 1.7% of the total export earnings in 2017. Among all agricultural commodities that Sri Lanka produces for the export market, cinnamon is the second only to tea contributing ca. 11% (ITC, 2019) of exports. Mexico buys almost 44% of Sri Lankan cinnamon exports, with the United States being the second most important customer (ca. 13%) (ITC, 2019).

2.3 | Commercial cultivation of *C. zeylanicum*

C. zeylanicum can be propagated from either seeds or stem cuttings (Anonymous, 2015; Wijesekera & Chichester, 1978). Vegetative propagation is achieved using single-leaved semi-hardwood pieces of stem approximately 2.5 cm long (Azad et al., 2019). Seeds or stems are raised in nurseries for 4–6 months before field planting (Anonymous, 2015) (Figure 1a). These are field planted in commercial plantations with a spacing of 120 × 90 cm, and 60 × 120 cm in slopes (Anonymous, 2015; Wijesekera & Chichester, 1978) (Figure 1c). Soil conservation, weed control, manuring, pest and disease management, and training of the plant are important aftercare operations.

The commercial production of *C. zeylanicum* begins about 3–4 years after field planting and the plants have an economic lifespan of around 35–40 years (Wijesekera & Chichester, 1978). Initial plant training is important in order to produce a long-lasting and spreading plant base which produces continuous, vigorous, and straight shoots (Anonymous, 2015) (Figure 1c). The actual yield (average 445 kg/ha) is known to be much lower than the potential yield (1,000 kg/ha). This is known to be related to aging and poor maintenance of the crop and the incidence of pests and diseases. The wood-boring moth (*Ichneumoniptera cinnamomumi*) can be considered as the major pest and rough bark disease (*Phomopsis* spp.) as the disease of significance, causing major yield losses (Jayasinghe et al., 2016).

2.4 | Harvesting and processing of Ceylon cinnamon

The stems are ready for the first harvest in about 2.5–3 years, when the bark turns a brown color. The subsequent shoots are ready to be harvested in about 1.5 years. Traditionally, harvesting takes place when the new leaves turn a light green color because, at this stage, the bark is easier to peel. Peeling is difficult at times when plants bear red-colored immature leaves, flowers or fruits, and during dry periods (Anonymous, 2015). Peelability and its basis are still inadequately researched, but are suggested to be related to water relations of the plant (Gallage et al., 2019).

When harvesting, the stems are coppiced, leaving one to two immature stems per bush to grow, at a 45° angle toward the middle of the base, which promotes spreading of the base. During processing (making of "quills"), the tops of the branches are lopped-off for leaf oil distillation. The corky tissues of sticks are scraped off (Figure 1d) and then the sticks are rubbed using a brass rod to loosen the bark from the hardwood. Two longitudinal slits are drawn from an end of stick to the end on the two opposite sides, and the knife is worked between the bark and stem to detach the bark into two halves. These barks are connected one inside the other until 106.7-cm (42-inches) long, cigar-shaped quills are made by joining the overlaps, and the hollow is filled with smaller pieces of the same peel (Figure 1e) and the edges were trimmed as necessary. The quills are then dried on coir rope strands indoors for 4–7 days (Anonymous, 2015; Barceloux, 2008; Wijesekera & Chichester, 1978) (Figure 1f). Quills are graded based on the diameter, thickness of the quill, uniformity, and color, and "foxing." Foxing is a defect that appears as reddish-brown patches on the surface of the quills. These patches may turn dark brown in color with time.

Quill making is a traditional, highly skilled, and time-consuming task (Figure 1d–g), which is unique to the cinnamon produced in Sri Lanka (Wijesekera & Chichester, 1978) and is associated with the lives of its people culturally, socially, and economically (Ravindran & Nirmal-Babu, 2005). A skilled worker can produce 4–5 kg of dried, processed cinnamon per day, for which they are required to peel about 50 sticks, taking approximately 10–15 hr. The method

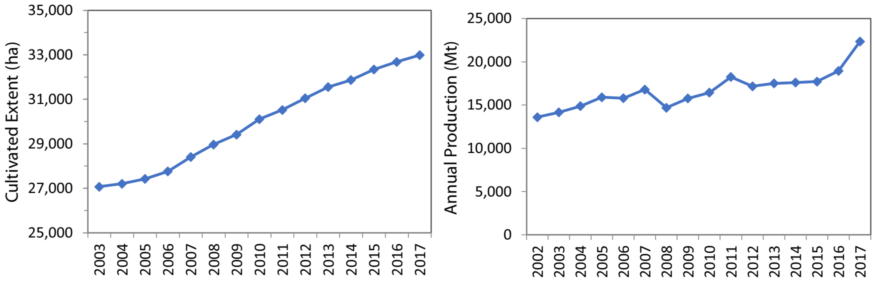

FIGURE 3 Cultivated extent (left) and annual production (right) of Ceylon cinnamon in Sri Lanka (Data Source: Department of Export Agriculture, Sri Lanka)

of quill making is known to be low in efficiency and high in cost due to the labor charges, which can account up to 50% of the income (Ranaweera, 2016).

3 | USES OF CINNAMON

The processed bark and the extracts of cinnamon are valued for their insecticidal properties, medicinal bioactive properties, health benefits against common diseases and disorders, preservative activity on food commodities, and as a raw material in cosmetics and an ingredient for incorporation into foods as discussed subsequently.

3.1 | Incorporation into foods

Because of its fragrance, cinnamon has been traditionally used as a spice and a flavoring agent in cooking for centuries (Barceloux, 2008; Rao & Gan, 2014). Cinnamon is a common ingredient in seasonings, sauces, baked goods, and drinks throughout the world. The presence of cinnamaldehyde in cinnamon brings about the sweet taste of it, and when cinnamon is used along with sweet food, the sweet sensation is enhanced due to the synergetic effect between the sweet taste of sugar and the sweet aroma of cinnamon. The deodorizing/masking property of cinnamon bark is due to the presence of trimethylamine (Thomas & Duethi, 2001). The increase in shelf life (postharvest life) of cinnamon-treated food commodities is because of the presence of phenolic compounds in cinnamon oil. However, it has been reported that phenolic compounds can degrade and develop unpleasant odors and color changes, thus limiting the applications of cinnamon oil (Cadena et al., 2018; Ghaderi-Ghahfarokhi et al., 2017; Lu et al., 2010; Ostroschi et al., 2018; de Souza et al., 2018). Moreover, researchers have found that cinnamon oil can make complexes with numerous food ingredients (i.e., enrichment) protecting its biochemical properties, and enhancing its applicability in a wide range of food commodities (Ahmed et al., 2018; Chuesiang et al., 2019; Hu et al., 2015; Lin et al., 2017; Meghani et al., 2018; Premkumar et al., 2018; Zhang, Zhang, et al., 2017; Zhang, Li, et al., 2017).

Enrichment of cinnamon oil has widely been practiced through encapsulation into different food materials, such as gelatin and polysaccharides (Ghani et al., 2018; Kim et al., 2018), Tween 80 (Zhang, Zhang, et al., 2017; Zhang, Li, et al., 2017), β-cyclodextrin (Munhuweyi et al., 2018; Ponce-Cevallos et al., 2010), maltodextrin (Santiago-Adame et al., 2015), vitamin D (Meghani et al., 2018), chitosan (Ghaderi-Ghahfarokhi et al., 2017; Hu et al., 2015), polylactic acid (Wen, Zhu, Feng, et al., 2016; Wen, Zhu, Wu, et al., 2016), polyvinyl alcohol (Jo et al., 2015; Wen, Zhu, Feng, et al., 2016; Wen, Zhu, Wu, et al., 2016), polypropylene films (Manso et al., 2014), mesoporous silica (Cadena et al., 2018), and sodium alginate (Han et al., 2018; Kapetanakou et al., 2019). These compounds can either be incorporated into food commodities or used as protective films to act against pathogens and increase the shelf life (Kapetanakou et al., 2019; Van Haute et al., 2017) (Table 3).

3.2 | Antimicrobial activity of cinnamon on food commodities

Microbial infections of food commodities have become a major health care challenge owing to the rise in drug-resistant microorganisms. Natural antimicrobials, such as essential oils, contain compounds that can act against many micro- and macro-organisms in food commodities. Eugenol and cinnamaldehyde are responsible for the antimicrobial properties of cinnamon (Table 3), whereas coumarin, cinnamyl acetate, and benzaldehyde have low or no antibacterial effect. Cinnamaldehyde and cinnamic acid may damage cell membranes, alter lipid profiles, and inhibit enzymatic activities, reproduction, and biofilm formation of various microorganisms (Vasconcelos et al., 2018). Cinnamon oil has shown promise in controlling bacterial and fungal infections in numerous food commodities, ranging from fresh vegetables, fruits, meat, fish, dairy, and various other processed food products (Table 3). These antimicrobial properties were gained by incorporating cinnamon oil into food commodities (Ghaderi-Ghahfarokhi et al., 2017; Lianou et al., 2018), by coating or immersing in a solution containing cinnamon oil (Cadena et al., 2018; Park et al., 2018), or by incorporating as a constituent in packing materials (Black-Solis et al., 2019; Kapetanakou et al., 2019). Cinnamon oil also shows synergistic effects when combined with other plant-derived oils, such as thyme oil, in controlling both "Gram-positive" and "Gram-negative" bacteria (Lu et al., 2011). The application method of cinnamon oil to increase the postharvest quality of food commodities varies depending on the quality parameters of the product. Cinnamon oil has been identified as a "Generally Recognized As Safe" (GRAS) product by the "United States Food and Drug Administration" (FDA). Findings from the aforementioned research and GRAS recognition from the US FDA have increased the potential use of cinnamon in the food industry for purposes such as increasing the postharvest life of perishables.

3.3 | Antioxidant activity of cinnamon

Antioxidants can be used to retard the development of undesirable characteristics in food products and animal feeds, such as off-flavors, odors, and toxic compounds due to the oxidation of lipids (Decker et al., 2005; Vidanarachchi et al., 2014). The oleoresins of cinnamon have shown inhibition of lipid oxidation activity (Singh et al., 2007). In human beings, antioxidants can protect cells against the damage caused by reactive oxygen species and free transition metal ions, which damage structural and functional compounds/molecules in cells causing various health problems (Ngo et al., 2011; Vidanarachchi et al., 2014).

Due to the negative health implications of many synthetic antioxidants widely used in the food industry, in recent years, increasing attention has been given to plant-based natural antioxidants (Mathew & Abraham, 2004). When compared to synthetic antioxidants, plant-based natural antioxidants have been identified and are widely accepted in terms of disease prevention, health promotion, improved safety, and consumer acceptability (Muhammed

TABLE 3 Antimicrobial activities of Cinnamon

Food commodity	Types of microorganisms controlled	Mode of cinnamon incorporation	Reference
Almond	*Salmonella enteritidis*, *Salmonella tennessee*	Immersion in coating solution	Tsai et al. (2017)
Apple	*Aspergillus carbonarius*	Immersion in coating solution	Kapetanakou et al. (2019)
Banana	*Escherichia coli*, *Staphylococcus aureus*	Immersion in coating solution	Han et al. (2018)
Beef patties	-	Embedded into patties	Ghaderi-Ghahfarokhi et al. (2017)
Beef	*S. aureus*, *Streptococcus pyogenes*	-	Ghani et al. (2018)
Bread	*Penicillium commune*, *Eurotium amstelodami*	Films	Souza et al. (2013)
Cantaloupe	*Salmonella enterica*, *E. coli*, *Listeria monocytogenes* Yeast and mold	Coating	Zhang et al. (2015)
Cantaloupe	*E. coli*, *L. monocytogenes*, *S. enterica*	Immersion in coating solution	Ma et al. (2016)
Chicken	*L. monocytogenes*, *Salmonella typhimurium*	Films	Ahmed et al. (2016)
	Yeats and molds	Incorporated in marinade solution	Van Haute et al. (2016)
	L. monocytogenes, *S. typhimurium*	-	Ahmed et al. (2017)
	L. monocytogenes, *S. typhimurium*, *Campylobacter jejuni*	-	Ahmed et al. (2018)
Common carp fillets	*Aeromonas*, *Lactococcus*	Immersion in cinnamon solution	Zhang, Zhang, et al. (2017), Zhang, Li, et al. (2017)
Fish skin gelatin	*E. coli*, *S. aureus*, *Aspergillus niger*, *Rhizopus oryzae*, *Paecilomyces varioti*	Mixing with fish skin gelatin oil	Wu et al. (2017)
Grass carp fillets	*Aeromonas veronii*, *Shewanella putrefaciens*, *Psuedomonas jessenii*	Immersion in coating emulsion	Huang et al. (2017)
Guava	*Colletotrichum gloesporiodies*	Immersed in coating gels	Botelho et al. (2016)
Kale leaves	*L. monocytogenes*, *E. coli*	Added into washing solution	Kang et al. (2019)
Kiwi fruit	*Colletotrichum acutatum*		He et al. (2018)
Milk chocolate, caramel soft candy, cookies	*Plodia interpunctella* (larve)	Films	Jo et al. (2015)
Mushroom sauce	*E. coli*, *Bacillus subtilis*, *S. typhimurium*, *S. aureus*	Incorporated as a nanoemulsion	Zhang, Zhang, et al. (2017), Zhang, Li, et al. (2017)
Orange pomegranate juices	*Saccharomyces cerevisiae*	Added to pomegranate juice	Sánchez-Rubio et al. (2016)
Pea	*Pseudomonas syringae* pv. pisi,	Coating	Cadena et al. (2018)
Pear	*A. carbonarius*	Immersion in coating solution	Kapetanakou et al. (2019)
Pork	*E. coli*, *S. aureus*	Nanofilm packaging	Wen, Zhu, Feng, et al. (2016); Wen, Zhu, Wu, et al. (2016)
	Yeats and molds	Incorporated in marinade solution	Van Haute et al. (2016)
Rainbow trout	-	Immersion in cinnamon solution	Ojagh et al. (2010)
Red chard	*L. monocytogenes*, *S. typhimurium*	Washing in cinnamon solution	Park et al. (2018)
Salmon	Yeats and molds	Incorporated in marinade solution	Van Haute et al. (2016)
Snakehead fish fillets	Bacteria	Immersion in coating solution	Lu et al. (2010)
Strawberry	*E. coli*, *S. aureus*	Nanofilm packaging	Wen, Zhu, Feng, et al. (2016); Wen, Zhu, Wu, et al. (2016)
Strawberry jam	*Aspergillus flavus*, *Penicillium expansum*, *Zygosaccharomyces rouxii*, *Zygosaccharomyces bailii*	Mixing with strawberry jam	Ribes et al. (2017)
Tomato	*Alternaria alternata*	Incorporated into nets	Black-Solis et al. (2019)
Treviso leaves	*L. monocytogenes*	Added into the washing solution	Kang and Song (2018)
Vanilla cream pudding	*L. monocytogenes*	Added to vanilla cream pudding	Lianou et al. (2018)

& Dewettinck, 2017; Schmidt et al., 2006; Singh et al., 2007). Polyphenolic compounds found in cinnamon oil carry antioxidant properties. Morgan et al. (2014) tested the possibility of using cinnamon aqueous extracts against oxidative disorders caused by bisphenol A (BPA) and octylphenol (OP) in male albino rats. They found a significant reduction of reduced glutathione (GSH) content and catalase (CAT) and superoxide dismutase (SOD) activity in tissues when compared to the control vehicle group.

Nanoparticles of cinnamon can remain in the bloodstream for a long period, facilitating bioavailability (Borzoei, Rafraf, Niromanesh, et al., 2018). It has been found that the growth, antioxidant and digestive enzyme activities, and the innate immunity of Nile tilapia (*Orechromis niloticus*) could be enhanced by providing a diet rich in cinnamon nanoparticles (El-Gawad et al., 2016). Moreover, some recent work found that cinnamon bark powder supplementation could improve the antioxidant status and serum lipid profile in women with polycystic ovary syndrome (PCOS) and could be used for reducing PCOS risk factors as well (Borzoei, Rafraf, Niromanesh, et al., 2018; Hajimonfarednejad et al., 2018; Kort & Lobo, 2014).

3.4 | Health benefits of cinnamon against common diseases and disorders

Ceylon cinnamon has received an increased level of interest recently in the field of medicine due to the discovery of its many therapeutic and preventive properties against common diseases and disorders. There have been many benefits claimed in the literature and a few extended into phase I and II clinical trials. The list includes (1) lowering of blood glucose (Akilen et al., 2010, 2013; Crawford et al., 2016; Davis & Yokoyama, 2011; Ranasinghe et al., 2017; Zhu et al., 2017); (2) blood pressure control (Akilen et al., 2010, 2013; Azimi et al., 2016); (3) lowering of serum cholesterol (Chatterji & Fogel, 2018; Gupta et al., 2017; Maierean et al., 2017); (4) antimicrobial activity (Condo et al., 2018; Husain et al., 2018; Mamajiwala et al., 2018; Rangel et al., 2018; Raybaudi-Massilia et al., 2006; Sethi et al., 2019; Shahina et al., 2018); (5) antiparasitic activity (Yang et al., 2014); (6) antioxidative properties and related free radical scavenging action (Dhuley, 1999; Khaki et al., 2014; Panickar et al., 2009; Ranasinghe et al., 2013; Shahid et al., 2018; Sharma et al., 2017); (7) prevention of aggregates and filament formation in Alzheimer's disease (AD) (Kang et al., 2016; Madhavadas & Subramanian, 2017; Malik et al., 2015; Momtaz et al., 2018); (8) gastritis and antigastric ulcer effects (Muhammad et al., 2015; Nir et al., 2000); (9) inhibition of osteoclastogenesis (Mendi et al., 2017; Tsuji-Naito, 2008); (10) anti-inflammatory (Fayaz et al., 2019; Ose et al., 2019; Schink et al., 2018); (11) wound healing and dressings (Ahmed et al., 2019; Ferro et al., 2019; Seyed Ahmadi et al., 2019), and more recently, promise for use in wound care practices (Ahmed et al., 2020); (12) hepatoprotective effects (Askari et al., 2014; Bellassoued et al., 2019; Hussain et al., 2019; Lopes et al., 2015); (13) anticancer effects (Kwon et al., 2010; Kwon et al., 2009; Parvazi et al., 2016; Perng, Tsai, Cherng, Kuo, et al., 2016; Perng, Tsai, Cherng, Wang, et al., 2016; Sadeghi et al., 2019; Schoene et al., 2005; Schoene et al., 2009; Yang et al., 2015); and (14) therapeutic effects against PCOS (Borzoei, Rafraf, Asghari-Jafarabadi, 2018; Borzoei, Rafraf, Niromanesh, et al., 2018; Hajimonfarednejad et al., 2018; Kort & Lobo, 2014; Wiweko & Susanto, 2017).

Due to the many health benefits and the presence of a relatively very low level of coumarin in Ceylon cinnamon in comparison to Cassia cinnamon (Ranasinghe et al., 2013), there is considerable potential to promote Ceylon cinnamon (products and extracts) as pharmaceutical or nutraceutical supplements, in addition to its well-known and historical role as a spice. Even though Ceylon cinnamon has such promising therapeutic and preventive properties against many disorders, more in-depth research with advanced analysis, high-throughput bioassays combined with proteomics, genomics, and metabolomics, and robust preclinical and clinical trials are needed to bring it up to bedside therapeutic or prophylactic use for clinical disorders and diseases. Of all the benefits of Ceylon cinnamon against human disorders and diseases, the effects of cinnamon on neurological diseases and diabetes are perhaps the most investigated and these will be described in more detail.

3.5 | Effect of cinnamon on neurological diseases

Alzheimer's disease is the most common form of dementia, with patients showing symptoms of memory loss and cognitive degeneration. β-Amyloid peptide (βA) is mainly responsible for AD and it is the main toxic compound produced by the sequential proteolytic cleavage of amyloid precursor protein by β-secretase and ɾ-secretase enzymes. Neuronal cell death can be induced by the overproduction of βA, which forms oligomers and fibrils (O'Brien & Wong, 2011). Therefore, the inhibition of the production of βA can be considered as a therapeutic means to prevent AD. It has been reported that cinnamon bark is effective against the development of AD (Kang et al., 2016). The beneficial effects against AD are due to the presence of phenylpropanoids, such as medioresinol and crytamygin, in cinnamon oil.

Parkinson's disease (PD) is another common neurodegenerative disorder, with a prevalence rate nearly 1–2% in aging population (Massano & Bhatiya, 2012). It has been shown that cinnamon and its metabolite sodium benzoate could upregulate brain-derived neurotropic factors as well as neurotrophin-3 in the mouse central nervous system. Parkinson's disease protein-7 (DJ-1) is recognized as a key neuroprotective protein and could be effective as a compound in therapeutic drugs to prevent PD. It has been indicated that oral feeding of cinnamon powder could induce the production of sodium benzoate in blood and brain in mice and thereby suppressing astrogliosis and the upregulation and/or protection of Parkin/DJ-1 (Khasnavis & Pahan, 2014). Furthermore, cinnamon has been shown to reverse the biochemical and anatomical changes observed in PD-affected brains of mice (Khasnavis & Pahan, 2014; Patel et al., 2019). Therefore, cinnamon shows great potential to halt the development of PD.

Multiple sclerosis (MS) is a neurodegenerative disorder that affects the central nervous system causing numbness in the limbs, paralysis, and loss of vision. It has been observed that sodium benzoate, a metabolite of cinnamon, can inhibit the expression of various proinflammatory molecules in brain cells and block the disease process of MS in mice (Pahan, 2011). Mondal and Pahan (2015) explained that administration of cinnamon powder could upregulate anti-autoimmune Treg/Th2 cells and downregulate autoimmune Th17/Th1 cells, and concluded that it has the potential to control the occurrence of MS.

3.6 | Antidiabetic activity of cinnamon

Diabetes mellitus is the most significant chronic metabolic disease and a growing health problem in the world. Effective blood glucose control is key for preventing and reversing diabetic complications. Oral hypoglycemic medications such as sulfonylureas, metformin, thiazolidinediones, and α-glucosidase inhibitors are available for the treatment of type 2 diabetes. However, these synthetic compounds are expensive and lead to adverse side effects in long-term use. It has been found that cinnamon has bioactive components that can lower cholesterol and glucose levels. Proanthocyanidins, phenolic compounds belonging to the class flavonoids, are used in the prevention of damage caused by diabetes. Ping et al. (2010) showed that cinnamon has a regulatory role in blood glucose and improved the function of pancreatic cells. These researchers also revealed that cinnamon proanthocyanidins were able to inhibit the in vitro formation of advanced glycation end products, which are involved in the pathogenic process of diabetes complications. Therefore, it is advisable to use cinnamon proanthocyanidins in foods, especially for consumption by people with type 2 diabetes.

3.7 | Cinnamon as an insecticide

Controlling pests in agriculture largely involves the use of conventional insecticides. The use of such insecticides may cause the development of pest resistance, health risks to human beings, and environmental pollution (Özkara et al., 2016). However, cinnamon oil has been shown to have insecticidal properties in storage and postharvest conditions (Baker & Grant, 2018; Correa et al., 2015; Plata-Rueda et al., 2018). Cinnamon oil is known to act against granary weevil (*Sitophilus granarius* L.), flour beetle (*Tribolium castaneum*), maize weevil (*Sitophilus zeamais* Motschulsky) lesser grain borer (*Rhyzopertha dominica*), and bean weevil (*Acanthos celidesobtectus* Say). Depending on their level of resistance to conventional insecticides, cinnamon is understood to act on these insects by reducing their rate of metabolic activity, minimizing their mobility on cinnamon oil-treated food surfaces, and reducing their population growth rates (Baker & Grant, 2018; Correa et al., 2015; Plata-Rueda et al., 2018). Furthermore, no non-target effects have been recorded with the use of cinnamon oil (Baker & Grant, 2018). Moreover, cinnamon oil has been tested to control parasites in poultry and is promising as a potential acaricide for *Dermanyssus gallinae* (Na et al., 2011).

Cinnamon oil (at 10.5% concentration) in combination with eugenol, geranium oil, peppermint, and lemongrass oil repelled mosquito species *Aedes albopictus* and *Culex pipiens* in equal efficacy to metafluthrin as the active ingredient. Cinnamon oil also proved effective against cecidomyiid gall midge (*Camptomyia corticalis*), but a formulation containing cinnamon oil was ineffective against western flower thrip (*Frankliniella occidentalis*), sweet potato whitefly (*Bemisia tabaci*), and green peach aphid (*Myzus persicae*) (Baker & Grant, 2018).

Cinnamaldehyde and eugenol are identified as the main biologically active substances in cinnamon, in addition to many other compounds with significant activity. The main mode of action of cinnamon as a pesticide appears to be as a repellent, and it has biocidal action at higher doses (Baker & Grant, 2018). Although investigations on cinnamon oil as an insecticide are at the early stages, the results so far are promising and suggest that this might be a fruitful area for future research, especially in the context of reducing losses of stored agricultural products.

4 | CURRENT LIMITATIONS OF USING CINNAMON IN THE FOOD AND HEALTH SECTORS

4.1 | Ensuring quality in the value chain

Due to the presence of numerous chemical compounds (both favorable and unfavorable) in different cinnamon species and plant parts, it will be very important to deploy the most recent analytical techniques that will allow the identification and quantification of these compounds. Currently, most of the cinnamon raw materials are exported from Sri Lanka as oils and/or quills (Thanthirige, 2011), and these are used in the preparation of a wide range of products as discussed above. Despite the recognized importance of separating cinnamon raw materials based on their quality (i.e., chemical composition), cinnamon is currently exported from Sri Lanka with limited product diversification and portfolio. Due to these reasons, malpractice and adulteration take place in the value chain of cinnamon and the authenticity of the original product cannot be traced at the end of the value chain. Currently, Sri Lanka is taking measures to obtain the Geographical Indication (GI) for Ceylon Cinnamon, and thereby the origin of a Ceylon cinnamon sample can be traced back in the value chain. Therefore, market or product-based standards need to be identified and introduced as an urgent need.

Molecular biological approaches such as polymerase chain reaction (PCR)-based random amplified polymorphic DNA (RAPD) techniques, and biochemical approaches such as mass spectrometry (MS), nuclear magnetic resonance (NMR), high-performance liquid chromatography (HPLC), fingerprinting technologies have immensely contributed to differentiate the composition of cinnamon oil from different plant parts and species (Abeysinghe et al., 2014; Chen et al., 2014; Ding et al., 2011; Farag et al., 2018). However, further improvements are needed to make testing cost-effective and efficient.

4.2 | Negative health effects

Adverse effects related to short- or long-term consumption of cinnamon have been reported (Fotland et al., 2012; Hajimonfarednejad et al., 2018). These are mostly connected to the presence of coumarin, which is a hepatotoxic natural compound found in cassia cinnamon. However, Ceylon cinnamon is reported to contain ultra-low levels of coumarin (Archer, 1988; Ballin & Sørensen, 2014; Lungarini et al., 2008) in contrast to Cassia, which contains relatively high amounts of coumarin (Ballin & Sørensen, 2014) (Table 2). Coumarin is known to be hepatotoxic for several species, and be a non-genotoxic carcinogen in rodents (Ballin & Sørensen, 2014; Fotland et al., 2012). The most common ill effects are allergic reactions and gastrointestinal disorders (Hajimonfarednejad et al., 2018).

Fotland et al. (2012) have assessed the toxicity of coumarin and established a new tolerable daily intake (TDI) of 0.07 mg coumarin/kg bw/day. Coumarin intake estimates have shown that in young children, consuming oatmeal porridge sprinkled with cinnamon several times a week could have an intake of coumarin of 1.63 mg/kg bw/day, which exceeds the TDI by several folds. In addition, adults consuming cinnamon-based tea or cinnamon supplements could likely exceed the recommended TDI of coumarin. Ballin and Sørensen (2014) found that fine bakery products in Danish markets exceeded the EU limit for coumarin in almost 50% of cases and that cinnamon was of the *C. cassia* origin. Daily exceedances of such large TDI of coumarin, even for a short duration of 1–2 weeks, may result in negative effects on human health (Fotland et al., 2012). Moreover, the authenticity of Ceylon cinnamon with low coumarin levels used by European food manufacturers is not guaranteed due to the loose value chain of cinnamon from the farmer to end user. Thus, a practical guide to the food industry, including farmers, processors, and international food administrators, is needed to ensure the safe use of cinnamon in food.

Although there are many positive effects of bioactive substances that are present in *Cinnamomum*, various in vivo and in vitro studies concluded that certain constituents in various *Cinnamomum* spp. could impart either negative effects or have no beneficial effect on human health. For instance, cinnamaldehyde, cinnamyl alcohol, and cinnamic acid have been identified as predisposition compounds toward allergic reactions. Furthermore, it has been reported that certain compounds from *Cinnamomum* could negatively interact with medications, and may have mutagenic, tumorigenic, or carcinogenic effects in animals and human beings when used in high doses (Ulbricht et al., 2011). The dose of *Cinnamomum* bark powder, or specific bioactive substances that are present in bark or leaves, is based on the most commonly used doses in accessible clinical trials, research studies, or on traditional practice; however, the optimum or safe recommended daily intake is not well documented. Moreover, there is immense variation among various batches and even manufacturers when preparing *Cinnamomum*-based products. In certain preparations, it is not clear what the active substance/s of the product are, and standardization procedures have not been practiced when preparing such products (Ulbricht et al., 2011). Interestingly, a recent phase I clinical study from Sri Lanka reported that up to 3 g of Ceylon cinnamon per day has no side effects while imparting beneficial effects (Ranasinghe et al., 2017).

4.3 | Crop improvement

A significant amount of genetic diversity is generated among *C. zeylanicum* progeny that results from a single cross-pollination event and this is also reflected in morphological and biochemical diversity (Liyanage et al., 2020). However, only limited published literature is available on genetic diversity assessment of *C. zeylanicum*. Kojoma et al. utilized chloroplast intergenic spacer regions between the *trnL* 3'exon and *trnF* exon (*trnL -trnF* IGS) and the *trnL* intron region for identification of *C. zeylanicum* and three other species, *C. cassia*, *C. burmannii*, and *Cinnamomum sieboldii* (Kojoma et al., 2002). Accordingly, one variable nucleotide site in the *trnL-trnF* IGS and three sites in the *trnL* intron could identify the four species correctly. Furthermore, they could observe different banding patterns in single-strand conformation polymorphism from the *trnL-trnF* IGS and the *trnL* intron for *C. cassia*, *C. zeylanicum*, and *C. burmannii*.

Abeysinghe et al. utilized the chloroplast regions, the *trnL* intron, the *trn*T-*trn*L, *trn*L-*trn*F, and *trn*H-*psb*A intergenic spacers, as well as the internal transcribed spacer (ITS) of nuclear ribosomal DNA (rDNA) for identification of *C. zeylanicum* and several wild *Cinnamomum* species found in Sri Lanka (Abeysinghe et al., 2014). Interestingly, the chloroplast regions alone could not completely resolve the phylogenetic relationships among *C. zeylanicum*, *Cinnamomum citriodorum*, *Cinnamomum capparu-coronde*, *Cinnamomum dubium*, *Cinnamomum litseifolium*, *Cinnamomum rivulorum*, *Cinnamomum sinharajaense*, and *Cinnamomum ovalifolium*. The sequences of the ITS region turned out to be more useful for the identification of the above species (Abeysinghe et al., 2009).

Later, a small number of *C. zeylanicum* accessions were studied using RAPD, sequence-related amplified polymorphism (Abeysinghe et al., 2014). Work comprising all the *Cinnamomum* species present in Sri Lanka has assessed both intraspecies and interspecies diversity using universal barcoding regions, *rbc*L, *mat*K, and a widely used identifier, *trn*H-*psb*A. The assessed regions had identical nucleotide sequences in all three *C. zeylanicum* accessions, while considerable intraspecies diversity was observed in wild species (Chandrasekera et al unpublished).

The Department of Export Agriculture (DEA), Sri Lanka, on the other hand, holds the largest *C. zeylanicum* germplasm in the world, which consists of over 600 superior accessions collected island wide. Nevertheless, *C. zeylanicum* breeding and crop improvement efforts in Sri Lanka are limited, except for two varieties, *Sri Wijaya* and *Sri Gemunu* released based on selections from the DEA germplasm. The recently assembled draft of the *C. zeylanicum* (variety *Sri Gemunu*) genome and identification of gene-specific markers (Narampanawa et al., unpublished) would facilitate future crop improvement efforts, including pest and disease resistance. Furthermore, the recent transcriptomics and metabolomics work on the effect of plant growth environment and maturity stage on the quality of *C. zeylanicum* leaf and bark yield (Liyanage et al., unpublished) would assist the decision-making process of the government and commercial growers on the establishment of new plantations for diversified products and markets.

5 | CONCLUSION AND WAY FORWARD

Cinnamomum zeylanicum, also known as Ceylon cinnamon, is a spice produced from the bark of the plant. Due to its high fragrance, it has been globally used as a spice and flavoring agent since ancient times and has always been highly valued. It is a crop indigenous to Sri Lanka, which is of unique and high social significance. Furthermore, it is a crop of major economic importance to the country and the source of livelihood for a substantial number of people, including a considerable number of smallholders and primary processors.

The processed bark and the essential oils that are extracted from the bark, leaves, and roots of *C. zeylanicum* have long been used by human beings for various purposes. Cinnamon is increasingly used as an antimicrobial agent, an insect repellent, and as a flavoring agent in the food industry. Moreover, it has shown promising beneficial bioactivities against a wide range of diseases and disorders in human beings.

Despite its importance, there are many issues associated with the crop. Cinnamon is known to have a wide yield gap, which is thought mainly to be due to the management, and pest and disease issues. Furthermore, the processed product of cinnamon, that is, quills, which are individually hand-made after peeling off the bark of the stems, is unique to Sri Lanka. The production of quills requires a substantial amount of skills and time, making the process quite expensive. The process also makes mechanization very difficult. Furthermore, cinnamon can only be peeled during certain seasons, the underlying reasons of which are yet unclear. Limited progress has been made with respect to the improvement of the crop using molecular breeding approaches, including next-generation sequencing (NGS) data.

The global market also consists of cinnamon products from other *Cinnamomum* species (collectively called "Cassia cinnamon"), which are much cheaper alternatives and traded under the name "cinnamon." These can be considered "inferior" to Ceylon cinnamon in several aspects, including their biochemical composition. The major concern is the presence of relatively high concentrations of "coumarin," a hepatotoxic, carcinogenic compound, in other *Cinnamomum* species sold as cinnamon, but it is found only in trace amounts in Ceylon cinnamon. Currently, Sri Lanka exports cinnamon mainly as a raw material (i.e., the bark, essential oils, and oleoresins), and lacks technology for product diversification, value addition and branding, experiences long value chains, thereby increasing the risk of adulteration and contamination of cinnamon. As a result, Sri Lankan farmers and processors do not receive the maximum revenue for their exported products. Therefore, institutional, scientific, and legislative procedures have to be developed and strengthened to ensure the flow of high-quality Ceylon cinnamon from the farmer to the end user, under the brand name "Ceylon cinnamon."

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AUTHOR CONTRIBUTIONS

LS, AJM, AMH, and CKB developed the concept and the structure. LS, AJM, AMH, CKB, JKV, SPK, MC, and PCGB contributed equally in writing the manuscript.

ORCID

Chalinda K. Beneragama https://orcid.org/0000-0003-4305-0860

REFERENCES

Abeysinghe, P. D., Samarajeewa, N. G. C. D., Li, G., & Wijesinghe, K. G. G. (2014). Preliminary investigation for the identification of Sri Lankan *Cinnamomum* species using randomly amplified polymorphic DNA (RAPD) and sequence related amplified polymorphic (SRAP) markers. *Journal of National Science Foundation of Sri Lanka*, *42*(3), 201–208. https://doi.org/10.4038/jnsfsr.v42i3.7393

Abeysinghe, P. D., Wijesinghe, K. G. G., Tachida, H., Yoshda, T., & Thihagoda, M. (2009). Molecular characterization of Cinnamon (*Cinnamomum verum* Presl) accessions and evaluation of genetic relatedness of Cinnamon species in Sri Lanka based on trnL intron region, intergenic spacers between trnT-trnL, trnL-trnF, trnH-psbA and nuclear ITS. *Research Journal of Agriculture and Biological Sciences*, *5*(6), 1079–1088.

Ahmed, J., Altun, E., Aydogdu, M. O., Gunduz, O., Kerai, L., Ren, G., & Edirisinghe, M. (2019). Anti-fungal bandages containing cinnamon extract. *International Wound Journal*, *16*(3), 730–736. https://doi.org/10.1111/iwj.13090

Ahmed, J., Gultekinoglu, M., & Edirisinghe, M. (2020). Bacterial cellulose micro-nano fibres for wound healing applications. *Biotechnology Advances*, *41*, 107549. https://doi.org/10.1016/j.biotechadv.2020.107549

Ahmed, J., Mulla, M. Z., & Arfat, Y. A. (2016). Thermo-mechanical, structural characterization and antibacterial performance of solvent casted polylactide/cinnamon oil composite films. *Food Control*, *69*, 196–204. https://doi.org/10.1016/j.foodcont.2016.05.013

Ahmed, J., Mulla, M., & Arfat, Y. A. (2017). Application of high-pressure processing and polylactide/cinnamon oil packaging on chicken sample for inactivation and inhibition of Listeria monocytogenes and Salmonella Typhimurium, and post-processing film properties. *Food Control*, *78*, 160–168. https://doi.org/10.1016/j.foodcont.2017.02.023

Ahmed, J., Mulla, M., Arfat, Y. A., Bher, A., Jacob, H., & Auras, R. (2018). Compression molded LLDPE films loaded with bimetallic (Ag-Cu) nanoparticles and cinnamon essential oil for chicken meat packaging applications. *LWT - Food Science and Technology*, *93*, 329–338. https://doi.org/10.1016/j.lwt.2018.03.051

Akilen, R., Pimlott, Z., Tsiami, A., & Robinson, N. (2013). Effect of short-term administration of cinnamon on blood pressure in patients with prediabetes and type 2 diabetes. *Nutrition*, *29*(10), 1192–1196. https://doi.org/10.1016/j.nut.2013.03.007

Akilen, R., Tsiami, A., Devendra, D., & Robinson, N. (2010). Glycated haemoglobin and blood pressure-lowering effect of cinnamon in multi-ethnic Type 2 diabetic patients in the UK: A randomized, placebo-controlled, double-blind clinical trial. *Diabetic Medicine: A Journal of the British Diabetic Association*, *27*(10), 1159–1167. https://doi.org/10.1111/j.1464-5491.2010.03079.x

Anonymous. (2015). Cinnamon cultivation and processing. Technical Bulletin 5 (Published in Sinhala language), Department of Export Agriculture of Sri Lanka, 41 pp.

Archer, A. W. (1988). Determination of cinnamaldehyde, coumarin and cinnamyl alcohol in cinnamon and cassia by high performance liquid chromatography. *Journal of Chromatography*, *447*, 272–276. https://doi.org/10.1016/0021-9673(88)90035-0

Askari, F., Rashidkhani, B., & Hekmatdoost, A. (2014). Cinnamon may have therapeutic benefits on lipid profile, liver enzymes, insulin resistance, and high-sensitivity C-reactive protein in nonalcoholic fatty liver disease patients. *Nutrition Research*, *34*(2), 143–148. https://doi.org/10.1016/j.nutres.2013.11.005

Azad, R., Jayasekara, L., Ranawaka, R. A. A. K., Senanayake, G., Kumara, K. L., Pushpakumara, D. K. N. G., & Geekiyanage, S. (2019). Development of a core collection for Sri Lankan cinnamon germplasm based on morphological characterization using an eco-geographic survey. *Australian Journal of Crop Science*, *13*(9), 1473. https://doi.org/10.21475/ajcs.19.13.09.p1561

Azad, R., Kumara, W., Senanayake, G., Ranawaka, R. A. A. K., Pushpakumara, D. K. N. G., & Geekiyanage, S. (2018). Flower morphological diversity of cinnamon (*Cinnamomum verum* Presl) in Matara district, Sri Lanka. *Open Agriculture*, *3*, 236–244. https://doi.org/10.1515/opag-2018-0025

Azimi, P., Ghiasvand, R., Feizi, A., Hosseinzadeh, J., Bahreynian, M., Hariri, M., & Khosravi-Boroujeni, H. (2016). Effect of cinnamon, cardamom, saffron and ginger consumption on blood pressure and a marker of endothelial function in patients with type 2 diabetes mellitus: A randomized controlled clinical trial. *Blood Pressure*, *25*(3), 133–140. https://doi.org/10.3109/08037051.2015.1111020

Baker, B. P., & Grant, J. A. (2018). Cinnamon and cinnamon oil profile, Active ingredient eligible for minimum risk pesticide use. Publications (NYS Integrated Pest Management Program), Cornell Coorperative Extension. Retrieved from https://ecommons.cornell.edu/bitstream/handle/1813/56117/cinnamon-MRP-NYSIPM.pdf?sequence=1&isAllowed=y

Ballin, N. Z., & Sørensen, A. T. (2014). Coumarin content in cinnamon containing food products on the Danish market. *Food Control*, *38*, 198–203. https://doi.org/10.1016/j.foodcont.2013.10.014

Bandara, T., Uluwaduge, I., & Jansz, E. R. (2011). Bioactivity of cinnamon with special emphasis on diabetes mellitus: A review. *International Journal of Food Sciences and Nutrition*, *63*(3), 380–386. https://doi.org/10.3109/09637486.2011.627849

Barceloux, D. G. (2008). Cinnamon (*Cinnamomum* Species). *Medical toxicology of natural substances: Foods, fungi, medicinal herbs, toxic plants, and venomous animals* (pp. 39–43). John Wiley & Sons. https://doi.org/10.1016/j.disamonth.2009.03.003

Bellassoued, K., Ghrab, F., Hamed, H., Kallel, R., van Pelt, J., Lahyani, A., Ayadi, F. M., & El Feki, A. (2019). Protective effect of essential oil of *Cinnamomum verum* bark on hepatic and renal toxicity induced by carbon tetrachloride in rats. *Applied Physiology, Nutrition, and Metabolism*, *44*(6), 606–618. https://doi.org/10.1139/apnm-2018-0246

Black-Solis, J., Ventura-Aguilar, R. I., Correa-Pacheco, Z., Corona-Rangel, M. L., & Bautista-Baños, S. (2019). Preharvest use of biodegradable polyester nets added with cinnamon essential oil and the effect on the storage life of tomatoes and the development of *Alternaria alternata*. *Scientia Horticulturae*, *245*, 65–73. https://doi.org/10.1016/j.scienta.2018.10.004

Borzoei, A., Rafraf, M., & Asghari-Jafarabadi, M. (2018). Cinnamon improves metabolic factors without detectable effects on adiponectin in women with polycystic ovary syndrome. *Asia Pacific Journal of Clinical Nutrition*, *27*(3), 556–563. https://doi.org/10.6133/apjcn.062017.13

Borzoei, A., Rafraf, M., Niromanesh, S., Farzadi, L., Narimani, F., & Doostan, F. (2018). Effects of cinnamon supplementation on antioxidant status and serum lipids in women with polycystic ovary syndrome. *Journal of Traditional and Complementary Medicine*, *8*, 128–133. https://doi.org/10.1016/j.jtcme.2017.04.008

Botelho, L. N. S., Rocha, D. A., Braga, M. A., Silva, A., & de Abreu, C. M. P. (2016). Quality of guava cv. 'Pedro Sato' treated with cassava starch and cinnamon essential oil. *Scientia Horticulturae*, *209*, 214–220. https://doi.org/10.1016/j.scienta.2016.06.012

Cadena, B. M., Preston, G. M., Van der Hoorn, R. A. L., Flanagan, N. A., Townley, H. E., & Thompson, I. P. (2018). Enhancing cinnamon essential oil activity by nanoparticle encapsulation to control seed pathogens. *Industrial Crops and Products*, *124*, 755–764. https://doi.org/10.1016/j.indcrop.2018.08.043

Chatoor, G. S. (2017). *The Spic(e)y story* (p. 47). Saboor Chatoor (Pvt) Ltd.

Chatterji, S., & Fogel, D. (2018). Study of the effect of the herbal composition SR2004 on hemoglobin A1c, fasting blood glucose, and lipids in patients with type 2 diabetes mellitus. *Integrative Medicine Research*, *7*(3), 248–256. https://doi.org/10.1016/j.imr.2018.04.002

Chen, P., Sun, J., & Ford, P. (2014). Differentiation of the four major species of cinnamons (*C. burmannii*, *C. verum*, *C. cassia*, and *C. loureiroi*) using a flow injection mass spectrometric (FIMS) fingerprinting method. *Journal of Agricultural and Food Chemistry*, *62*, 2516–2521. https://doi.org/10.1021/jf405580c

Chuesiang, P., Siripatrawan, U., Sanguandeekul, R., McClements, D. J., & McLandsborough, L. (2019). Antimicrobial activity of PIT-fabricated cinnamon oil nanoemulsions: Effect of surfactant concentration on morphology of foodborne pathogens. *Food Control*, *98*, 405–411. https://doi.org/10.1016/j.foodcont.2018.11.024

Condo, C., Anacarso, I., Sabia, C., Iseppi, R., Anfelli, I., Forti, L., de Niederhausern, S., Bondi, M., & Messi, P. (2018). Antimicrobial activity of spices essential oils and its effectiveness on mature biofilms of human pathogens. *Natural Product Research*, *34*(4), 567–574. https://doi.org/10.1080/14786419.2018.1490904

Correa, Y. D. C. G., Faroni, L. R., Haddi, K., Oliveira, E. E., & Pereira, E. J. G. (2015). Locomotory and physiological responses induced by clove and cinnamon essential oils in the maize weevil *Sitophilus zeamais*. *Pesticide Biochemistry and Physiology*, *125*, 31–37. https://doi.org/10.1016/j.pestbp.2015.06.005

Crawford, P., Thai, C., Obholz, J., Schievenin, J., True, M., Shah, S. A., Hallgren, J., Clark, J., & Sharon, D. (2016). Assessment of the effect of lifestyle intervention plus water-soluble cinnamon extract on lowering blood glucose in pre-diabetics, a randomized, double-blind, multicenter, placebo controlled trial: Study protocol for a randomized controlled trial. *Trials*, *17*(1), 9. https://doi.org/10.1186/s13063-015-1138-7

Davis, P. A., & Yokoyama, W. (2011). Cinnamon intake lowers fasting blood glucose: Meta-analysis. *Journal of Medicinal Food*, *14*(9), 884–889. https://doi.org/10.1089/jmf.2010.0180

de Souza, V. B., Thomazini, M., Echalar Barrientos, M. A., Nalin, C. M., Ferro-Furtado, R., Genovese, M. I., & Favaro-Trindade, C. S. (2018). Functional properties and encapsulation of a proanthocyanidin-rich cinnamon extract (*Cinnamomum zeylanicum*) by complex coacervation using gelatin and different polysaccharides. *Food Hydrocolloids*, *77*, 297–306. https://doi.org/10.1016/j.foodhyd.2017.09.040

DEA. (2019). Estimated production of export agriculture crops. Department of Export Agriculture, Sri Lanka [online]. Retrieved from http://www.exportagridept.gov.lk/web/index.php?lang=en#

Decker, E. A., Warner, K., Richards, M. P., & Shahidi, F. (2005). Measuring antioxidant effectiveness in food. *Journal of Agricultural Food Chemistry*, *53*(10), 4303–4310.

Dhuley, J. N. (1999). Anti-oxidant effects of cinnamon (*Cinnamomum verum*) bark and greater cardamom (*Amomum subulatum*) seeds in rats fed high fat diet. *Indian Journal of Experimental Biology*, *37*(3), 238–242.

Ding, Y., Wu, E. Q., Liang, C., Chen, J., Tran, M. N., Hong, C. H., & Kang, J. S. (2011). Discrimination of cinnamon bark and cinnamon twig samples sourced from various countries using HPLC-based fingerprint analysis. *Food Chemistry*, *127*(2), 755–760. https://doi.org/10.1016/j.foodchem.2011.01.011

EDB. (2020). Sri Lanka Export Development Board. Ceylon cinnamon vs Cassia cinnamon. [online]. Retrieved from https://www.srilankabusiness.com/blog/ceylon-cinnamon-vs-cassia.html

El-Gawad, E. A. A., El-Latif, A. M. A., & Shourbela, R. M. (2016). Enhancement of antioxidant activity, non-specific immunity and growth performance of *Nile tilapia*, *Oreochromis niloticus* by dietary fructooligosaccharide. *Journal of Aquaculture Research and Development*, *7*(5). https://doi.org/10.4172/2155-9546.1000427

Farag, M. A., Labib, R. M., Noleto, C., Porzel, A., & Wessjohann, L. A. (2018). NMR approach for the authentication of 10 cinnamon spice accessions analyzed via chemometric tools. *LWT-Food Science and Technology*, *90*, 491–498. https://doi.org/10.1016/j.lwt.2017.12.069

Fayaz, E., Damirchi, A., Zebardast, N., & Babaei, P. (2019). Cinnamon extract combined with high-intensity endurance training alleviates metabolic syndrome via non-canonical WNT signaling. *Nutrition*, *65*, 173–178. https://doi.org/10.1016/j.nut.2019.03.009

Ferro, T. A. F., Souza, E. B., Suarez, M. A. M., Rodrigues, J. F. S., Pereira, D. M. S., Mendes, S. J. F., Gonzaga, L. F., Machado, M., Bomfim, M. R. Q., Calixto, J. B., Arbiser, J. L., Monteiro-Neto, V., Andre, E., & Fernandes, E. S. (2019). Topical application of cinnamaldehyde promotes faster healing of skin wounds infected with *Pseudomonas aeruginosa*. *Molecules*, *24*(8), 1627. https://doi.org/10.3390/molecules24081627

Fotland, T. Ø., Paulsen, J. E., Sanner, T., Alexander, J., & Husøy, T. (2012). Risk assessment of coumarin using the bench mark dose (BMD) approach: Children in Norway which regularly eat oatmeal porridge with cinnamon may exceed the TDI for coumarin with several folds. *Food and Chemical Toxicology*, *50*(3), 903–912. https://doi.org/10.1016/j.fct.2011.12.005

Gallage, R. P. R., Amarathunge, K. S. P., Beneragama, C. K., Suriyagoda, L. D. B., & Mohotti, A. J. (2019). Determination of the physiological basis of peelability of cinnamon. In: Proceedings of the Annual Sessions of the Institute of Biology of Sri Lanka, held on 27thSeptember 2019, Colombo, 51.

Ghaderi-Ghahfarokhi, M., Barzegar, M., Sahari, M. A., Ahmadi Gavlighi, H., & Gardini, F. (2017). Chitosan-cinnamon essential oil nano-formulation: Application as a novel additive for controlled release and shelf life extension of beef patties. *International Journal of Biological Macromolecules*, *102*, 19–28. https://doi.org/10.1016/j.ijbiomac.2017.04.002

Ghani, S., Barzegar, H., Noshad, M., & Hojjati, M. (2018). The preparation, characterization and in vitro application evaluation of soluble soybean polysaccharide films incorporated with cinnamon essential oil nanoemulsions. *International Journal of Biological Macromolecules*, *112*, 197–202. https://doi.org/10.1016/j.ijbiomac.2018.01.145

Ghodki, B. M., & Goswami, T. K. (2016). Optimization of cryogenic grinding process for cassia (*Cinnamomum loureiri* Nees L.). *Food Process Engineering*, *39*, 659–675. https://doi.org/10.1111/jfpe.12258

Gruenwald, J., Freder, J., & Armbruester, N. (2010). Cinnamon and health. *Critical Reviews in Food Science and Nutrition*, *50*, 822–834. https://doi.org/10.1080/10408390902773052

Gupta, J. S., Puri, S., Misra, A., Gulati, S., & Mani, K. (2017). Effect of oral cinnamon intervention on metabolic profile and body composition of Asian Indians with metabolic syndrome: A randomized double-blind control trial. *Lipids in Health and Disease*, *16*(1), 113. https://doi.org/10.1186/s12944-017-0504-8

Hajimonfarednejad, M., Nimrouzi, M., Heydari, M., Zarshenas, M. M., Raee, M. J., & Jahromi, B. N. (2018). Insulin resistance improvement by cinnamon powder in polycystic ovary syndrome: A randomized double-blind placebo controlled clinical trial. *Phytotherapy Research*, *32*(2), 276–283. https://doi.org/10.1002/ptr.5970

Han, Y., Yu, M., & Wang, L. (2018). Physical and antimicrobial properties of sodium alginate/carboxymethyl cellulose films incorporated with cinnamon essential oil. *Food Packaging and Shelf Life*, *15*, 35–42. https://doi.org/10.1016/j.fpsl.2017.11.001

He, J., Wu, D., Zhang, Q., Chen, H., Li, H., Han, Q., Lai, X., Wang, H., Wu, Y., Yuan, J., Dong, H., & Qin, W. (2018). Efficacy and mechanism of cinnamon essential oil on inhibition of *Colletotrichum acutatum* isolated from 'Hongyang' Kiwifruit. *Frontiers in Microbiology*, *9*, 1288. https://doi.org/10.3389/fmicb.2018.01288

He, Z. D., Qiao, C. F., Han, Q. B., Cheng, C. L., Xu, H. X., Jiang, R. W., But, P. P. H., & Shaw, P. C. (2005). Authentication and qualitative analysis on the chemical profile of cassia bark (Cortex Cinnamomi) by high-pressure liquid chromatography. *Journal of Agriculture and Food Chemistry*, *53*, 2424–2428. https://doi.org/10.1021/jf048116s

Hu, J., Wang, X., Xiao, Z., & Bi, W. (2015). Effect of chitosan nanoparticles loaded with cinnamon essential oil on the quality of chilled pork. *LWT - Food Science and Technology*, *63*(1), 519–526. https://doi.org/10.1016/j.lwt.2015.03.049

Huang, Z., Liu, X., Jia, S., & Luo, Y. (2017). Antimicrobial effects of cinnamon bark oil on microbial composition and quality of grass carp (*Ctenopharyngodon idellus*) fillets during chilled storage. *Food Control*, *82*, 316–324. https://doi.org/10.1016/j.foodcont.2017.07.017

Husain, I., Ahmad, R., Chandra, A., Raza, S. T., Shukla, Y., & Mahdi, F. (2018). Phytochemical characterization and biological activity evaluation of ethanolic extract of *Cinnamomum zeylanicum*. *Journal of Ethnopharmacology*, *219*, 110–116. https://doi.org/10.1016/j.jep.2018.02.001

Hussain, Z., Khan, J. A., Arshad, A., Asif, P., Rashid, H., & Arshad, M. I. (2019). Protective effects of *Cinnamomum zeylanicum* L. (Darchini) in acetaminophen-induced oxidative stress, hepatotoxicity and nephrotoxicity in mouse model. *Biomedicine & Pharmacotherapy*, *109*, 2285–2292. https://doi.org/10.1016/j.biopha.2018.11.123

ITC. (2019). *Trade Map – International Trade Center*. [online] Retrieved from http://www.trademap.org/

Jayaprakasha, G. K., & Rao, L. J. M. (2011). Chemistry, biogenesis, and biological activities of *Cinnamomum zeylanicum*. *Critical reviews in food science and nutrition*, *51*(6), 547–562. https://doi.org/10.1080/10408391003699550

Jayasinghe, G. G., Ketakumbura, K. H. M. P. K., Wijesinghe, K. G. G., Hemachandra, K. S., & Weligamage, S. (2016). Relationship between pest and disease incidences and agronomic operations implemented by farmers in cinnamon (*Cinnamomum zeylanicum* Blume) fields in southern Sri Lanka. *Sri Lanka Journal of Food and Agriculture*, *2*(1), 35–40. https://doi.org/10.13140/RG.2.1.4207.9843

Jeyaratnam, N., Nour, A. H., Kanthasamy, R., Nour, A. H., Yuvaraj, A. R., & Akindoyo, J. O. (2016). Essential oil from *Cinnamomum cassia* bark through hydro distillation and advanced microwave assisted hydro distillation. *Industrial Crops and Products*, *92*, 57–66. https://doi.org/10.1016/j.indcrop.2016.07.049

Jo, H.-J., Park, K.-M., Na, J. H., Min, S. C., Park, K. H., Chang, P.-S., & Han, J. (2015). Development of anti-insect food packaging film containing a polyvinyl alcohol and cinnamon oil emulsion at a pilot plant scale. *Journal of Stored Products Research*, *61*, 114–118. https://doi.org/10.1016/j.jspr.2015.01.005

Jose, A. J., Leela, N. K., Zachariah, T. J., & Rema, J. (2019). Evaluation of coumarin content and essential oil constituents in *Cinnamomum cassia* (Nees & T.Nees) J. Presl. *Journal of Spices and Aromatic Crops*, *28*(1), 43–51. https://doi.org/10.25081/josac.2019.v28.i1.5743

Kang, J. H., Park, S. J., Park, J. B., & Song, K. B. (2019). Surfactant type affects the washing effect of cinnamon leaf essential oil emulsion on kale leaves. *Food chemistry*, *271*, 122–128. https://doi.org/10.1016/j.foodchem.2018.07.203

Kang, J.-H., & Song, K. B. (2018). Combined effect of a positively charged cinnamon leaf oil emulsion and organic acid on the inactivation of *Listeria monocytogenes* inoculated on fresh-cut Treviso leaves. *Food Microbiology*, *76*, 146–153. https://doi.org/10.1016/j.fm.2018.05.004

Kang, Y. J., Seo, D. G., & Park, S. Y. (2016). Phenylpropanoids from cinnamon bark reduced beta-amyloid production by the inhibition of beta-secretase in Chinese hamster ovarian cells stably expressing amyloid precursor protein. *Nutrition Research*, *36*(11), 1277–1284. https://doi.org/10.1016/j.nutres.2016.10.002

Kapetanakou, A. E., Nestora, S., Evageliou, V., & Skandamis, P. N. (2019). Sodium alginate–cinnamon essential oil coated apples and pears: Variability of *Aspergillus carbonarius* growth and ochratoxin A production. *Food Research International*, *119*, 876–885. https://doi.org/10.1016/j.foodres.2018.10.072

Khaki, A., Khaki, A. A., Hajhosseini, L., Golzar, F. S., & Ainehchi, N. (2014). The anti-oxidant effects of ginger and cinnamon on spermatogenesis dysfunction of diabetes rats. *African Journal of Traditional, Complementary and Alternative Medicines*, *11*(4), 1–8. https://doi.org/10.4314/ajtcam.v11i4.1

Khasnavis, S., & Pahan, K. (2014). Cinnamon treatment upregulates neuroprotective proteins Parkin and DJ-1 and protects dopaminergic neurons in a mouse model of Parkinson's disease. *Journal of Neuroimmune Pharmacology*, *9*, 569–581. https://doi.org/10.1007/s11481-014-9552-2

Kim, H., Beak, S.-E., & Song, K. B. (2018). Development of a hagfish skin gelatin film containing cinnamon bark essential oil. *LWT- Food Science and Technology*, *96*, 583–588. https://doi.org/10.1016/j.lwt.2018.06.016

Kojoma, M., Kurihara, K., Yamada, K., Sekita, S., Satake, M., & Iida, O. (2002). Genetic identification of cinnamon (Cinnamomum spp.) based on the trnL-trnF chloroplast DNA. *Planta Medica*, *68*(01), 94–96.

Kort, D. H., & Lobo, R. A. (2014). Preliminary evidence that cinnamon improves menstrual cyclicity in women with polycystic ovary syndrome: A randomized controlled trial. *American Journal of Obstetrics and Gynecology*, *211*(5), 481–486. https://doi.org/10.1016/j.ajog.2014.05.009

Kwon, H. K., Hwang, J. S., So, J. S., Lee, C. G., Sahoo, A., Ryu, J. H., Jeon, W. K., Ko, B. S., Im, C. R., Lee, S. H., Park, Z. Y., & Im, S. H. (2010). Cinnamon extract induces tumor cell death through inhibition of NFkappaB and AP1. *BMC Cancer*, *10*, 392. https://doi.org/10.1186/1471-2407-10-392

Kwon, H. K., Jeon, W. K., Hwang, J. S., Lee, C. G., So, J. S., Park, J. A., Ko, B. S., & Im, S. H. (2009). Cinnamon extract suppresses tumor progression by modulating angiogenesis and the effector function of CD8+ T cells. *Cancer Letters*, *278*(2), 174–182. https://doi.org/10.1016/j.canlet.2009.01.015

Leja, K. B., & Czaczyk, K. (2016). The industrial potential of herbs and spices – A mini review. *Acta Scientiarum Polonorum. Technologia Alimentaria*, *15*(4), 353–365. https://doi.org/10.17306/J.AFS.2016.4.34

Lianou, A., Moschonas, G., Nychas, G.-J.-E., & Panagou, E. Z. (2018). Growth of *Listeria monocytogenes* in pasteurized vanilla cream pudding as affected by storage temperature and the presence of cinnamon extract. *Food Research International*, *106*, 1114–1122. https://doi.org/10.1016/j.foodres.2017.11.027

Lin, L., Dai, Y., & Cui, H. (2017). Antibacterial poly(ethylene oxide) electrospun nanofibers containing cinnamon essential oil/beta-cyclodextrin proteoliposomes. *Carbohydrate Polymers*, *178*, 131–140. https://doi.org/10.1016/j.carbpol.2017.09.043

Liyanage, N. N., Ranawake, A. L., & Bandaranayake, P. C. G. (2020). Cross-pollination effects on morphological, molecular, and biochemical diversity of a selected cinnamon (*Cinnamomum zeylanicum* Blume) seedling population. *Journal of Crop Improvement*, *35*, 21–37. https://doi.org/10.1080/15427528.2020.1795769

Liyanage, T., Madhujith, T., & Wijesinghe, K. G. G. (2017). Comparative study on major chemical constituents in volatile oil of true cinnamon (*Cinnamomum verum* Presl. Syn. *C. zeylanicum* Blum) and five wild cinnamon species grown in Sri Lanka. *Tropical Agricultural Research*, *28*(3), 270–280. https://doi.org/10.4038/tar.v28i3.8231

Lopes, B. P., Gaique, T. G., Souza, L. L., Paula, G. S., Kluck, G. E., Atella, G. C., Gomes, A. C., Simas, N. K., Kuster, R. M., Ortiga-Carvalho, T. M., Pazos-Moura, C. C., & Oliveira, K. J. (2015). Cinnamon extract improves the body composition and attenuates lipogenic processes in the liver and adipose tissue of rats. *Food & Function*, *6*(10), 3257–3265. https://doi.org/10.1039/C5FO00569H

Lu, F., Ding, Y.-C., Ye, X.-Q., & Ding, Y.-T. (2011). Antibacterial effect of cinnamon oil combined with thyme or clove oil. *Agricultural Sciences in China*, *10*(9), 1482–1487. https://doi.org/10.1016/S1671-2927(11)60142-9

Lu, F., Ding, Y., Ye, X., & Liu, D. (2010). Cinnamon and nisin in alginate–calcium coating maintain quality of fresh northern snakehead fish fillets. *LWT - Food Science and Technology*, *43*(9), 1331–1335. https://doi.org/10.1016/j.lwt.2010.05.003

Lungarini, S., Aureli, F., & Coni, E. (2008). Coumarin and cinnamaldehyde in cinnamon marketed in Italy: A natural chemical hazard? *Food Additives and Contaminants*, *25*(11), 1297–1305. https://doi.org/10.1080/02652030802105274

Ma, Q., Zhang, Y., Critzer, F., Davidson, P. M., Zivanovic, S., & Zhong, Q. (2016). Physical, mechanical, and antimicrobial properties of chitosan films with microemulsions of cinnamon bark oil and soybean oil. *Food Hydrocolloids*, *52*, 533–542. https://doi.org/10.1016/j.foodhyd.2015.07.036

Madhavadas, S., & Subramanian, S. (2017). Cognition enhancing effect of the aqueous extract of *Cinnamomum zeylanicum* on non-transgenic Alzheimer's disease rat model: Biochemical, histological, and behavioural studies. *Nutritional Neuroscience*, *20*(9), 526–537. https://doi.org/10.1080/1028415X.2016.1194593

Maierean, S. M., Serban, M. C., Sahebkar, A., Ursoniu, S., Serban, A., Penson, P., & Banach, M. (2017). The effects of cinnamon supplementation on blood lipid concentrations: A systematic review and meta-analysis. *Journal of Clinical Lipidology*, *11*(6), 1393–1406. https://doi.org/10.1016/j.jacl.2017.08.004

Malik, J., Munjal, K., & Deshmukh, R. (2015). Attenuating effect of standardized lyophilized *Cinnamomum zeylanicum* bark extract against streptozotocin-induced experimental dementia of Alzheimer's type. *Journal of Basic and Clinical Physiology and Pharmacology*, *26*(3), 275–285. https://doi.org/10.1515/jbcpp-2014-0012

Mamajiwala, A. S., Sethi, K. S., Raut, C. P., Karde, P. A., & Khedkar, S. U. (2018). Comparative evaluation of chlorhexidine and cinnamon extract used in dental unit waterlines to reduce bacterial load in aerosols during ultrasonic scaling. *Indian Journal of Dental Research*, *29*(6), 749–754. https://doi.org/10.4103/ijdr.IJDR_571_17

Manso, S., Pezo, D., Gómez-Lus, R., & Nerín, C. (2014). Diminution of aflatoxin B1 production caused by an active packaging containing cinnamon essential oil. *Food Control*, *45*, 101–108. https://doi.org/10.1016/j.foodcont.2014.04.031

Massano, J., & Bhatiya, K. P. (2012). Clinical approach to Parkinson's disease: Features, diagnosis, and principles of management. *Cold Spring Harbor Perspectives Medicine*, *2*(6), a008870. https://doi.org/10.1101/cshperspect.a008870

Mathew, S., & Abraham, T. E. (2004). Studies on the antioxidant activities of cinnamon bark extracts, through various *in vitro* models. *Journal of Food Chemistry*, *94*, 520–528. https://doi.org/10.1016/j.foodchem.2004.11.043

Meghani, N., Patel, P., Kansara, K., Ranjan, S., Dasgupta, N., Ramalingam, C., & Kumar, A. (2018). Formulation of vitamin D encapsulated cinnamon oil nanoemulsion: Its potential anti-cancerous activity in human alveolar carcinoma cells. *Colloids and Surfaces B: Biointerfaces*, *166*, 349–357. https://doi.org/10.1016/j.colsurfb.2018.03.041

Mendi, A., Yagci, B. G., Kiziloglu, M., Sarac, N., Yilmaz, D., Ugur, A., & Uckan, D. (2017). Effects of *Syzygium aromaticum*, *Cinnamomum zeylanicum*, and *Salvia triloba* extracts on proliferation and differentiation of dental pulp stem cells. *Journal of Applied Oral Science*, *25*(5), 515–522. https://doi.org/10.1590/1678-7757-2016-0522

Momtaz, S., Hassani, S., Khan, F., Ziaee, M., & Abdollahi, M. (2018). Cinnamon, a promising prospect towards Alzheimer's disease. *Pharmacological Research*, *130*, 241–258. https://doi.org/10.1016/j.phrs.2017.12.011

Mondal, S., & Pahan, K. (2015). Cinnamon ameliorates experimental allergic encephalomyelitis in mice via regulatory T cells: Implications for multiple sclerosis therapy. *PLoS One*, *10*(1), e0116566. https://doi.org/10.1371/journal.pone.0116566

Morgan, A. M., El-Ballal, S. S., El-Bialy, B. E., & El-Borai, N. B. (2014). Studies on the potential protective effect of cinnamon against bisphenol A and octylphenol induced oxidative stress in male albino rats. *Journal of Txicology Reports*, *1*, 92–101. https://doi.org/10.1016/j.toxrep.2014.04.003

Muhammad, D. R. A., Lemarcq, V., Alderweireldt, E., Vanoverberghe, P., & Dewettinck, K. (2017). Effect of cinnamon (*Cinnamomum burmanii* Blume) essential oils on the textural, rheological, thermal profile and antioxidant activity of white chocolate. Applied Biological Sciences, 22nd National symposium, Abstracts. Presented at the 22nd National symposium for Applied Biological Sciences.

Muhammad, J. S., Zaidi, S. F., Shaharyar, S., Refaat, A., Usmanghani, K., Saiki, I., & Sugiyama, T. (2015). Anti-inflammatory effect of cinnamaldehyde in *Helicobacter pylori* induced gastric inflammation. *Biological & Pharmaceutical Bulletin*, *38*(1), 109–115. https://doi.org/10.1248/bpb.b14-00609

Muhammed, D. R. A., & Dewettinck, K. (2017). Cinnamon and its derivatives as potential ingredient in functional food-A review. *International Journal of Food Properties*, *20*(2), 2237–2263. https://doi.org/10.1080/10942912.2017.1369102

Munhuweyi, K., Caleb, O. J., van Reenen, A. J., & Opara, U. L. (2018). Physical and antifungal properties of β-cyclodextrin microcapsules and nanofibre films containing cinnamon and oregano essential oils. *LWT-Food Science and Technology*, *87*, 413–422. https://doi.org/10.1016/j.lwt.2017.09.012

Na, Y. E., Kim, S.-I., Bang, H.-S., Kim, B.-S., & Ahn, Y.-J. (2011). Fumigant toxicity of cassia and cinnamon oils and cinnamaldehyde and structurally related compounds to *Dermanyssus gallinae* (Acari: Dermanyssidae). *Veterinary Parasitology*, *178*(3), 324–329. https://doi.org/10.1016/j.vetpar.2011.01.034

Ngo, D. H., Wijesekara, I., Vo, T. S., Van Ta, Q., & Kim, S. K. (2011). Marine food-derived functional ingredients as potential antioxidants in the food industry: An overview. *Food Research International*, *44*(2), 523–529. https://doi.org/10.1016/j.foodres.2010.12.030

Nir, Y., Potasman, I., Stermer, E., Tabak, M., & Neeman, I. (2000). Controlled trial of the effect of cinnamon extract on *Helicobacter pylori*. *Helicobacter*, *5*(2), 94–97. https://doi.org/10.1046/j.1523-5378.2000.00014.x

O'Brien, R. J., & Wong, P. C. (2011). Amyloid precursor protein processing and Alzheimer's disease. *Annual Review of Neuroscience*, *34*, 185–204. https://doi.org/10.1146/annurev-neuro-061010-113613

Ojagh, S. M., Rezaei, M., Razavi, S. H., & Hosseini, S. M. H. (2010). Effect of chitosan coatings enriched with cinnamon oil on the quality of refrigerated rainbow trout. *Food Chemistry*, *120*(1), 193–198. https://doi.org/10.1016/j.foodchem.2009.10.006

Ose, R., Tu, J., Schink, A., Maxeiner, J., Schuster, P., Lucas, K., Saloga, J., & Bellinghausen, I. (2019). Cinnamon extract inhibits allergen-specific immune responses in human and murine allergy models. *Clinical and Experimental Allergy*, *50*(1), 41–50. https://doi.org/10.1111/cea.13507

Ostroschi, L. C., Brito de Souza, V., Echalar-Barrientos, M. A., Tulini, F. L., Comunian, T. A., Thomazini, M., Baliero, J. C. C., Roudaut, G., Genovese, M. I., & Favaro-Trindade, C. S. (2018). Production of spray-dried proanthocyanidin-rich cinnamon (*Cinnamomum zeylanicum*) extract as a potential functional ingredient: Improvement of stability, sensory aspects and technological properties. *Food Hydrocolloids*, *79*, 343–351. https://doi.org/10.1016/j.foodhyd.2018.01.007

Özkara, A., Akyıl, D., & Konuk, M. (2016). Pesticides, environmental pollution, and health. In M. L. Larramendy & S. Soloneski (Eds.), *Environmental health risk – Hazardous factors to living species*. IntechOpen. https://doi.org/10.5772/63094

Pahan, K. (2011). Immunomodulation of experimental allergic encephalomyelitis by cinnamon metabolite sodium benzoate. *Immunopharmacology and immunotoxicology*, *33*(4), 586–593. https://doi.org/10.3109/08923973.2011.561861

Panickar, K. S., Polansky, M. M., & Anderson, R. A. (2009). Cinnamon polyphenols attenuate cell swelling and mitochondrial dysfunction following oxygen-glucose deprivation in glial cells. *Experimental Neurology*, *216*(2), 420–427. https://doi.org/10.1016/j.expneurol.2008.12.024

Park, J.-B., Kang, J.-H., & Song, K. B. (2018). Combined treatment of cinnamon bark oil emulsion washing and ultraviolet-C irradiation improves microbial safety of fresh-cut red chard. *LWT-Food Science and Technology*, *93*, 109–115. https://doi.org/10.1016/j.lwt.2018.03.035

Parvazi, S., Sadeghi, S., Azadi, M., Mohammadi, M., Arjmand, M., Vahabi, F., Sadeghzadeh, S., & Zamani, Z. (2016). The effect of aqueous extract of cinnamon on the metabolome of *Plasmodium falciparum* using (1)HNMR spectroscopy. *Journal of Tropical Medicine*, *2016*, 3174841. https://doi.org/10.1155/2016/3174841

Patel, D., Jana, A., Roy, A., & Pahan, K. (2019). Cinnamon and its metabolite protect the Nigrostriatum in a mouse model of Parkinson's disease via Astrocytic GDNF. *Journal of Neuroimmune Pharmacology.*, *14*, 503–518. https://doi.org/10.1007/s11481-019-09855-0

Pathirana, L. S. S. (2007). Factors affecting bark yield components of cinnamon. *Bulletin of the Rubber Research Institute of Sri Lanka*, *48*, 43–48.

Perng, D. S., Tsai, Y. H., Cherng, J., Kuo, C. W., Shiao, C. C., & Cherng, J. M. (2016). Discovery of a novel anti-cancer agent targeting both topoisomerase I and II in hepatocellular carcinoma Hep 3B cells in vitro and in vivo: *Cinnamomum verum* component 2-methoxycinnamaldehyde. *Journal of Drug Targeting*, *24*(7), 624–634. https://doi.org/10.3109/1061186X.2015.1132221

Perng, D. S., Tsai, Y. H., Cherng, J., Wang, J. S., Chou, K. S., Shih, C. W., & Cherng, J. M. (2016). Discovery of a novel anticancer agent with both anti-topoisomerase I and II activities in hepatocellular carcinoma SK-Hep-1 cells in vitro and in vivo: *Cinnamomum verum* component 2-methoxycinnamaldehyde. *Drug Design, Development and Therapy*, *10*, 141–153. https://doi.org/10.2147/DDDT.S93599

Ping, H., Zhang, G., & Ren, G. (2010). Antidiabetic effects of cinnamon oil in diabetic KK-A^y mice. *Journal of Food and Chemistry Toxicology*, *48*, 2344–2349. https://doi.org/10.1016/j.fct.2010.05.069

Plata-Rueda, A., Campos, J. M., da Silva Rolim, G., Martínez, L. C., Dos Santos, M. H., Fernandes, F. L., Serrão, J. E., & Zanuncio, J. C. (2018). Terpenoid constituents of cinnamon and clove essential oils cause toxic effects and behavior repellency response on granary weevil, *Sitophilus granarius*. *Ecotoxicology and Environmental Safety*, *156*, 263–270. https://doi.org/10.1016/j.ecoenv.2018.03.033

Ponce-Cevallos, P. A., Buera, M. P., & Elizalde, B. E. (2010). Encapsulation of cinnamon and thyme essential oils components (cinnamaldehyde and thymol) in β-cyclodextrin: Effect of interactions with water on complex stability. *Journal of Food Engineering*, *99*(1), 70–75. https://doi.org/10.1016/j.jfoodeng.2010.01.039

Premkumar, J., Sudhakar, T., Dhakal, A., Shrestha, J. B., Krishnakumar, S., & Balashanmugam, P. (2018). Synthesis of silver nanoparticles (AgNPs) from cinnamon against bacterial pathogens. *Biocatalysis and*

Agricultural Biotechnology, *15*, 311–316. https://doi.org/10.1016/j.bcab.2018.06.005

Ranasinghe, P., Jayawardena, R., Pigera, S., Wathurapatha, W. S., Weeratunga, H. D., Premakumara, G. A. S., Katulanda, P., Constantine, G. R., & Galappaththy, P. (2017). Evaluation of pharmacodynamic properties and safety of *Cinnamomum zeylanicum* (Ceylon cinnamon) in healthy adults: A phase I clinical trial. *BMC Complementary and Alternative Medicine*, *17*(1), 550. https://doi.org/10.1186/s12906-017-2067-7

Ranasinghe, P., Pigera, S., Premakumara, G. A., Galappaththy, P., Constantine, G. R., & Katulanda, P. (2013). Medicinal properties of 'true' cinnamon (*Cinnamomum zeylanicum*): A systematic review. *BMC Complementary and Alternative Medicine*, *13*, 275. https://doi.org/10.1186/1472-6882-13-275

Ranaweera, K. S. (2016). Development a cinnamon bark peeling equipment. Thesis, Development of a Cinnamon Bark Peeling Equipment, Department of Mechanical Engineering University of Moratuwa, Sri Lanka. Retrieved from http://dl.lib.mrt.ac.lk/bitstream/handle/123/13210/Full-thesis.pdf?sequence=1&isAllowed=y

Rangel, M. L., de Aquino, S. G., de Lima, J. M., Castellano, L. R., & de Castro, R. D. (2018). In vitro effect of *Cinnamomum zeylanicum* Blume essential oil on *Candida* spp. involved in oral infections. *Evidence-Based Complementary and Alternative Medicine*, *2018*, 4045013. https://doi.org/10.1155/2018/4045013

Rao, P. V., & Gan, S. H. (2014). Cinnamon: A multifaceted medicinal plant. *Evidence-Based Complementary and Alternative Medicine*, *2014*, 642942. https://doi.org/10.1155/2014/6429422014

Ravindran, P. N., & Nirmal-Babu, K. (2005). Introduction. In P. N. Ravindran, K. N. Babu, & M. Shylaja (Eds.), *Cinnamon and Cassia. The genus Cinnamomum* (p. 361). CRC Press.

Raybaudi-Massilia, R. M., Mosqueda-Melgar, J., & Martin-Belloso, O. (2006). Antimicrobial activity of essential oils on *Salmonella enteritidis*, *Escherichia coli*, and *Listeria innocua* in fruit juices. *Journal of Food Protection*, *69*(7), 1579–1586. https://doi.org/10.4315/0362-028x-69.7.1579

Ribes, S., Fuentes, A., Talens, P., & Barat, J. M. (2017). Application of cinnamon bark emulsions to protect strawberry jam from fungi. *LWT-Food Science and Technology*, *78*, 265–272. https://doi.org/10.1016/j.lwt.2016.12.047

Sadeghi, S., Davoodvandi, A., Pourhanifeh, M. H., Sharifi, N., ArefNezhad, R., Sahebnasagh, R., Moghadam, S. A., Sahebkar, A., & Mirzaei, H. (2019). Anti-cancer effects of cinnamon: Insights into its apoptosis effects. *European Journal of Medicinal Chemistry*, *178*, 131–140. https://doi.org/10.1016/j.ejmech.2019.05.067

Samarawickrama, S. (2015). Assessment of the kalli- and line system in the Sri Lankan cinnamon sector. A report. UNIDO and The Spce Council of Sri Lanka.

Sánchez-Rubio, M., Taboada-Rodríguez, A., Cava-Roda, R., López-Gómez, A., & Marín-Iniesta, F. (2016). Combined use of thermo-ultrasound and cinnamon leaf essential oil to inactivate Saccharomyces cerevisiae in natural orange and pomegranate juices. *LWT- Food Science and Technology*, *73*, 140–146. https://doi.org/10.1016/j.lwt.2016.06.005

Santiago-Adame, R., Medina-Torres, L., Gallegos-Infante, J. A., Calderas, F., González-Laredo, R. F., Rocha-Guzmán, N. E., Ochoa-Martínez, L. A., & Bernad-Bernad, M. J. (2015). Spray drying-microencapsulation of cinnamon infusions (*Cinnamomum zeylanicum*) with maltodextrin. *LWT - Food Science and Technology*, *64*(2), 571–577. https://doi.org/10.1016/j.lwt.2015.06.020

Schink, A., Naumoska, K., Kitanovski, Z., Kampf, C. J., Frohlich-Nowoisky, J., Thines, E., Poschl, U., Schuppan, D., & Lucas, K. (2018). Anti-inflammatory effects of cinnamon extract and identification of active compounds influencing the TLR2 and TLR4 signaling pathways. *Food & Function*, *9*(11), 5950–5964. https://doi.org/10.1039/c8fo01286e

Schmidt, E., Jirovetz, L., Buchbauer, G., Eller, G. A., Stoilova, I., Krastanov, A., Stoyanova, A., & Geissler, M. (2006). Composition and antioxidant activities of the essential oil of cinnamon (*Cinnamomum zeylanicum* Blume) leaves from Sri Lanka. *Journal of Essential Oil Bearing Plants*, *9*, 170–182. https://doi.org/10.1080/0972060X.2006.10643490

Schoene, N. W., Kelly, M. A., Polansky, M. M., & Anderson, R. A. (2005). Water-soluble polymeric polyphenols from cinnamon inhibit proliferation and alter cell cycle distribution patterns of hematologic tumor cell lines. *Cancer Letters*, *230*(1), 134–140. https://doi.org/10.1016/j.canlet.2004.12.039

Schoene, N. W., Kelly, M. A., Polansky, M. M., & Anderson, R. A. (2009). A polyphenol mixture from cinnamon targets p38 MAP kinase-regulated signaling pathways to produce G2/M arrest. *The Journal of Nutritional Biochemistry*, *20*(8), 614–620. https://doi.org/10.1016/j.jnutbio.2008.06.006

Sethi, K. S., Mamajiwala, A., Mahale, S., Raut, C. P., & Karde, P. (2019). Comparative evaluation of the chlorhexidine and cinnamon extract as ultrasonic coolant for reduction of bacterial load in dental aerosols. *Journal of Indian Society of Periodontology*, *23*(3), 226–233. https://doi.org/10.4103/jisp.jisp_517_18

Seyed Ahmadi, S. G., Farahpour, M. R., & Hamishehkar, H. (2019). Topical application of *Cinnamon verum* essential oil accelerates infected wound healing process by increasing tissue antioxidant capacity and keratin biosynthesis. *The Kaohsiung Journal of Medical Sciences*, *35*(11), 686–694. https://doi.org/10.1002/kjm2.12120

Shahid, M. Z., Saima, H., Yasmin, A., Nadeem, M. T., Imran, M., & Afzaal, M. (2018). Antioxidant capacity of cinnamon extract for palm oil stability. *Lipids in Health and Disease*, *17*(1), 116. https://doi.org/10.1186/s12944-018-0756-y

Shahidi, F., & Hossain, A. (2018). Bioactives in spices, and spice oleoresins: Phytochemicals and their beneficial effects in food preservation and health promotion. *Journal of Food Bioactives*, *3*, 8–75. https://doi.org/10.31665/JFB.2018.3149

Shahina, Z., El-Ganiny, A. M., Minion, J., Whiteway, M., Sultana, T., & Dahms, T. E. S. (2018). *Cinnamomum zeylanicum* bark essential oil induces cell wall remodelling and spindle defects in *Candida albicans*. *Fungal Biology and Biotechnology*, *5*, 3. https://doi.org/10.1186/s40694-018-0046-5

Sharma, U. K., Sharma, A. K., Gupta, A., Kumar, R., Pandey, A., & Pandey, A. K. (2017). Pharmacological activities of cinnamaldehyde and eugenol: Antioxidant, cytotoxic and anti-leishmanial studies. *Cellular and Molecular Biology*, *63*(6), 73–78. https://doi.org/10.14715/cmb/2017.63.6

Singh, G., Maurya, S., deLampasona, M. P., & Catalan, C. A. N. (2007). A comparison of chemical, antioxidant and antimicrobial studies of cinnamon leaf and bark volatile oils, oleoresins and their constituents. *Food and Chemical Toxicology*, *45*, 1650–1661. https://doi.org/10.1016/j.fct.2007.02.031

Souza, A. C., Goto, G. E. O., Mainardi, J. A., Coelho, A. C. V., & Tadini, C. C. (2013). Cassava starch composite films incorporated with cinnamon essential oil: Antimicrobial activity, microstructure, mechanical and barrier properties. *LWT-Food Science and Technology*, *54*(2), 346–352. https://doi.org/10.1016/j.lwt.2013.06.017

Thanthirige, J. B. (2011). Technological and marketing issues in Cinnamon industry in Sri Lanka. Thesis: Master of Business Administration. University of Moratuwa. [Online]. Retrieved from http://dl.lib.mrt.ac.lk/bitstream/handle/123/9972/Pre-text.pdf?sequence=1

Thomas, J., & Duethi, P. P. (2001). Cinnamon. In K. V. Peter (Ed.), *Handbook of herbs and spices*. Woodhead Publishing Limited.

Thomas, J., & Kuruwilla, K. M. (2012). Introduction. In *Handbook of herbs and spices* (Volume 1, 2nd ed.). [online]. Retrieved from sciencedirect.com/topics/food-science/cinnamon.pdf

Tsai, H.-C., Sheng, L., & Zhu, M.-J. (2017). Antimicrobial efficacy of cinnamon oil against *Salmonella* in almond based matrices. *Food Control*, *80*, 170–175. https://doi.org/10.1016/j.foodcont.2017.04.045

Tsuji-Naito, K. (2008). Aldehydic components of cinnamon bark extract suppresses RANKL-induced osteoclastogenesis through NFATc1 downregulation. *Bioorganic & Medicinal Chemistry*, *16*(20), 9176–9183. https://doi.org/10.1016/j.bmc.2008.09.036

Ulbricht, C., Seamon, E., Windsor, R. C., Armbruester, N., Bryan, J. K., Costa, D., Giese, N., Gruenwald, J., Iovin, R., Isaac, R., & Grimes Serrano, J. M. (2011). An evidence-based systematic review of cinnamon (*Cinnamomum* spp.) by the Natural Standard Research Collaboration. *Journal of Dietary Supplements*, *8*(4), 378–454.

Unlu, M., Ergene, E., Unlu, G. V., Zeytinoglu, H. S., & Vural, N. (2010). Composition, antimicrobial activity and *in vitro* cytotoxicity of essential oil from *Cinnamomum zeylanicum* Blume (Lauraceae). *Food and Chemical Toxicology*, *48*, 3274–3280. https://doi.org/10.1016/j.fct.2010.09.001

Van Haute, S., Raes, K., Devlieghere, F., & Sampers, I. (2017). Combined use of cinnamon essential oil and MAP/vacuum packaging to increase the microbial and sensorial shelf life of lean pork and salmon. *Food Packaging and Shelf Life*, *12*, 51–58. https://doi.org/10.1016/j.fpsl.2017.02.004

Van Haute, S., Raes, K., Van der Meeren, P., & Sampers, I. (2016). The effect of cinnamon, oregano and thyme essential oils in marinade on the microbial shelf life of fish and meat products. *Food Control*, *68*, 30–39. https://doi.org/10.1016/j.foodcont.2016.03.025

Vasconcelos, N. G., Croda, J., & Simionatto, S. (2018). Antibacterial mechanisms of cinnamon and its constituents: A review. *Microbial Pathogenesis*, *120*, 198–203. https://doi.org/10.1016/j.micpath.2018.04.036

Vidanarachchi, J. K., Ranadheera, C. S., Wijerathne, T., Udayangani, R. M. C., Himali, S. M. C., & Pickova, J. (2014). Applications of seafood by-products in the food industry and human nutrition. In S. K. Kim (Ed.), *Seafood processing by-products: Trends and applications* (pp. 463–528). Springer Science.

Wang, R., Wang, R., & Yang, B. (2009). Extraction of essential oils from five cinnamon leaves and identification of their volatile compound compositions. *Innovative Food Science and Emerging Technologies*, *10*, 289–292. https://doi.org/10.1016/j.ifset.2008.12.002

Wen, P., Zhu, D.-H., Feng, K., Liu, F.-J., Lou, W.-Y., Li, N., Zong, M.-H., & Wu, H. (2016). Fabrication of electrospun polylactic acid nanofilm incorporating cinnamon essential oil/β-cyclodextrin inclusion complex for antimicrobial packaging. *Food Chemistry*, *196*, 996–1004. https://doi.org/10.1016/j.foodchem.2015.10.043

Wen, P., Zhu, D.-H., Wu, H., Zong, M.-H., Jing, Y.-R., & Han, S.-Y. (2016). Encapsulation of cinnamon essential oil in electrospun nanofibrous film for active food packaging. *Food Control*, *59*, 366–376. https://doi.org/10.1016/j.foodcont.2015.06.005

Wijesekera, R. O. B., & Chichester, C. O. (1978). The chemistry and technology of cinnamon. *Critical Reviews in Food Science and Nutrition*, *10*(1), 1–30. https://doi.org/10.1080/10408397809527243

Wiweko, B., & Susanto, C. A. (2017). The effect of Metformin and cinnamon on serum anti-mullerian hormone in women having PCOS: A double-blind, randomized, controlled trial. *Journal of Human Reproductive Sciences*, *10*(1), 31–36. https://doi.org/10.4103/jhrs.JHRS_90_16

Wu, J., Sun, X., Guo, X., Ge, S., & Zhang, Q. (2017). Physicochemical properties, antimicrobial activity and oil release of fish gelatin films incorporated with cinnamon essential oil. *Aquaculture and Fisheries*, *2*(4), 185–192. https://doi.org/10.1016/j.aaf.2017.06.004

Yang, F., Long, E., Wen, J., Cao, L., Zhu, C., Hu, H., Ruan, Y., Okanurak, K., Hu, H., Wei, X., Yang, X., Wang, C., Zhang, L., Wang, X., Ji, P., Zheng, H., Wu, Z., & Lv, Z. (2014). Linalool, derived from *Cinnamomum camphora* (L.) Presl leaf extracts, possesses molluscicidal activity against *Oncomelania hupensis* and inhibits infection of *Schistosoma japonicum*. *Parasites & Vectors*, *7*, 407. https://doi.org/10.1186/1756-3305-7-407

Yang, X. Q., Zheng, H., Ye, Q., Li, R. Y., & Chen, Y. (2015). Essential oil of Cinnamon exerts anti-cancer activity against head and neck squamous cell carcinoma via attenuating epidermal growth factor receptor – Tyrosine kinase. *Journal of the Balkan Union of Oncology*, *20*(6), 1518–1525.

Zhang, S., Zhang, M., Fang, Z., & Liu, Y. (2017). Preparation and characterization of blended cloves/cinnamon essential oil nanoemulsions. *LWT- Food Science and Technology*, *75*, 316–322. https://doi.org/10.1016/j.lwt.2016.08.046

Zhang, Y., Li, D., Lv, J., Li, Q., Kong, C., & Luo, Y. (2017). Effect of cinnamon essential oil on bacterial diversity and shelf-life in vacuum-packaged common carp (*Cyprinus carpio*) during refrigerated storage. *International Journal of Food Microbiology*, *249*, 1–8. https://doi.org/10.1016/j.ijfoodmicro.2016.10.008

Zhang, Y., Ma, Q., Critzer, F., Davidson, P. M., & Zhong, Q. (2015). Effect of alginate coatings with cinnamon bark oil and soybean oil on quality and microbiological safety of cantaloupe. *International Journal of Food Microbiology*, *215*, 25–30. https://doi.org/10.1016/j.ijfoodmicro.2015.08.014

Zhu, R., Liu, H., Liu, C., Wang, L., Ma, R., Chen, B., Li, L., Niu, J., Fu, M., Zhang, D., & Gao, S. (2017). Cinnamaldehyde in diabetes: A review of pharmacology, pharmacokinetics and safety. *Pharmacological Research*, *122*, 78–89. https://doi.org/10.1016/j.phrs.2017.05.019

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