RESEARCH ARTICLE Indian Journal of Agricultural Research, Volume 59 Issue 7: 1060-1067 (July 2025)

Comparison of Chemical Profile and Antibacterial Activity of *Cinnamomum cassia* Bark Essential Oil from Three different Vietnamese Provinces

Son L. Hoang[1], Thanh N.K. Le[1], Han T.G. Nguyen[1]

10.18805/IJARe.AF-923

ABSTRACT

Background: This study aimed to investigate the variations in constituents, physicochemical properties and antibacterial activity of *Cinnamomum cassia* bark essential oils from three selected regions of Vietnam (Yen Bai, Quang Ngai and Kon Tum).

Methods: Gas chromatography- Mass spectroscopy was employed for the analysis of essential oils extracted by hydro-distillation. Physicochemical properties were analyzed per standard test methods (AOAC). The antibacterial activity of *Cinnamomum cassia* bark essential oils against ten different microbial strains was assayed by the determination of minimum inhibitory concentration and minimum bactericidal concentration values employing the broth macro-dilution and inoculation methods.

Result: The *Cinnamomum cassia* bark essential oil from Quang Ngai was recorded to be the highest yield (2.600±0.037%), followed by Kon Tum essential oil (1.505±0.045%) and Yen Bai essential oil (1.315±0.136%). GC-MS analysis revealed the extremely high content of trans-cinnamaldehyde present in *Cinnamomum cassia* bark essential oils from Kon Tum (96.07%), followed by Yen Bai essential oil (94.72%) and Quang Ngai essential oil (94.06%). There were generally no significant differences in physicochemical parameters among the three essential oils tested; however, variations in antibacterial activity against ten studied microbial strains have been documented in terms of MIC and MBC values. These findings confirmed the high quality of *Cinnamomum cassia* bark essential oils from three selected provinces but varying in MIC and MBC values against ten studied microbial strains.

Key words: Antibacterial activity, *Cinnamomum cassia* bark, Essential oil, GC-MS, Physicochemical, *Trans*-cinnamaldehyde.

INTRODUCTION

Cinnamomum cassia (*C. cassia*), commonly known as Chinese cinnamon or cassia, is a tropical aromatic evergreen plant belonging to the Lauraceae family. The species is natively cultivated for its barks in Southern China, India, Vietnam and other Southeast Asian countries. Dried cinnamon bark is commonly used as a flavor for a large variety of food and beverages. Cinnamon bark is highly rich in essential oil (EO) which is traditionally used as aromatherapy and is now widely incorporated into many healthcare products like medicated oils, soaps and transdermal patches. *C. cassia* has long been traditionally used as a medicinal herb for the treatment of various illnesses including fevers, coughs, digestive symptoms, arthritis, muscle pain and menstrual discomfort. Contemporary research data have shown that cinnamon has a wide range of significant pharmacological properties, including anti-carcinogenic, anti-inflammatory, anti-diabetic, antimicrobial, cardiovascular protective and neuroprotective effects. Phytochemical analysis of *C. cassia* essential oil revealed the presence of starch, glycosides, mucilage, tannins and essential oil. The predominant component in essential oil is cinnamaldehyde (65-85%), a bioactive aromatic aldehyde compound (Kosari *et al*., 2020), along with other components mainly belonging to classes of terpenoids and phenylpropanoids (Barceloux, 2009), has demonstrated notable antioxidant, anticancer, anti-inflammatory and antimicrobial properties.

[1]Department of Applied Biochemistry, Faculty of Biotechnology, Ho Chi Minh City International University- Vietnam National University, Ho Chi Minh City (700 000), Vietnam.

Corresponding Author: Thanh N.K. Le, Department of Applied Biochemistry, Faculty of Biotechnology, Ho Chi Minh City International University- Vietnam National University, Ho Chi Minh City (700 000), Vietnam. Email: lnkthanh1996@gmail.com

ORCIDs: 0000-0002-3385-6169, 0000-0003-4745-4600, 0009-0006-5481-1417

How to cite this article: Hoang, S.L., Le, T.N.K. and Nguyen, H.T.G. (2025). Comparison of Chemical Profile and Antibacterial Activity of *Cinnamomum cassia* Bark Essential Oil from Three different Vietnamese Provinces. *Indian Journal of Agricultural Research.* **59(7):** 1060-1067. doi: 10.18805/IJARe.AF-923.

Submitted: 21-11-2024 **Accepted:** 07-02-2025 **Online:** 03-03-2025

In general, the quality and quantity of essential oil and its molecules might be extremely variable depending on various factors including plant species, genotypes, geographical origin, climatic conditions, cultivation practices, harvesting time and experimental conditions. Vietnam is well known as one of the best sources of high-quality cinnamon, partly owing to the soil and climate considerably contributing to favorable conditions for growing premium quality organic cinnamon. The cinnamon growing area in Vietnam is approximately estimated to be 150,000 hectares, accounting for 17% of the global cinnamon growing area (Center for WTO and International

Trade Vietnam Chamber of Commerce and Industry, 2023). In the first half of 2023, Vietnam exported 43,186 tons of cinnamon to fastidious markets like the EU, USA, Japan, Bangladesh and India. In 2022, Vietnam was the largest supplier of cinnamon to India, accounting for 32,650 tons of cinnamon (85%) of India's total imported cinnamon output. Vietnamese cinnamon is commonly cultivated on large scales in several provinces ranging from the North to the Central of Vietnam; however, three provinces, namely Yen Bai, Quang Ngai and Kon Tum, are best known as the most cinnamon growing regions of Vietnam where cinnamon is cultivated commercially for domestic and international market (Fig 1).

In this regard, this present research aimed to investigate the variation of essential oil composition from the bark of cinnamon cultivated in three different provinces as mentioned above. The physicochemical properties and antibacterial activity of obtained essential oils were also subjected to the investigation.

MATERIALS AND METHODS

Selection and preparation of materials

Fresh cinnamon barks (Fig 2) were collected in March 2024 from various farms located in three selected provinces (Yen Bai- 21°41′35″N, 104°52′22″E, QN- 15°072′263″N, 108°482′423″E and KT- 14°212′423″N, 108°002′303″E) and then washed several times with running water to remove any impurities. The barks were immediately air-dried, cut into small pieces and then ground into smaller particles. The extraction of essential oil was carried out at the International University- Vietnam National University by hydro-distillation for 5-6 h using a Clevenger circulatory hydro-distillation apparatus (Bicchi and Maffei, 2012), (Naik *et al*., 2017). Once the distillation had been complete, the obtained essential oil was dehydrated using anhydrous sodium sulfate and then stored in sealed opaque brown bottles at 4°C for further analysis.

Gas chromatography - Mass spectroscopy analysis

Gas chromatography - Mass spectroscopy (GC-MS) was employed to analyze obtained EO (Son L.Hoang and Nhi H.M.Nguyen, 2023). GC-MS analyses were performed using Nexis GC-2030. Helium was used as carrier gas at a constant flow rate of 1 mL/min. The oven temperature was initially programmed at 50°C for 1 min and then increased to 80°C at 30°C/min. Shortly afterward, it was increased to 230°C at 5°C/min and finally to 280°C at 25°C/min where it was thermally held for 3 min. The injector temperature was set at 250°C and the split ratio was set at 1:30. Fragmentation was done by electron impact under a field of 70 eV. The mass spectra were recorded over the mass range of 50-500 amu with the full-scale mode at a rate of 1s/scan.

Physicochemical analysis

Determination of specific gravity (SG)

The specific gravity of EO was determined using a 50-mL density bottle (pycnometer) at 20°C according to the procedure described in the AOAC Official Method (AOAC 920.212, 1920). The density bottle must be clean and dry prior to the assay. The empty dry bottle with a stopper was initially weighed on the analytical balance and documented as W_0. The bottle was then filled with distilled water and the stopper was inserted, followed by gently tapping the sides of the bottle to remove the air bubbles. Once the bottle had been carefully wiped off, it was weighed and recorded as W_1. The same process was repeated but using EO instead of distilled water. The bottle was then weighed and noted as W_2.

$$\text{The specific gravity of the oil sample} = \frac{W_2 - W_0}{W_1 - W_0}$$

Determination of optical rotation

A 10-mL polarimeter tube containing oil was placed at 20°C in the trough of the instrument between the polarizer and analyzer. This test was done by a polarimeter of Kruss equipment (AOAC 920.142, 1920).

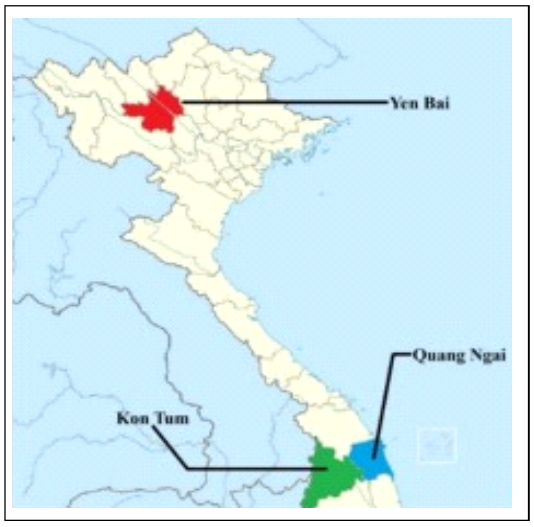


Fig 1: Geographic map of three selected provinces for sampling.



Fig 2: The cinnamon bark samples.

Determination of total acid number (TAN)

One gram of EO was accurately weighed into a conical flask containing 25 mL of ethanol mixed with 25 mL of diethyl ether. Two drops of phenolphthalein were added and then titrated with 0.1 N KOH solution until the color of the endpoint turned pale pink and must persist for at least 30 sec. The AV was then calculated using the following formula according to the standard procedure (AOAC 969.17, 1995).

$$\text{Acid number} = \frac{V \times N \times 56.1}{W}$$

V = Volume of potassium hydroxide used.
N = Normality of potassium hydroxide.
W = Weight in g of the sample.

Determination of saponification value (SV)

Two grams of EO were accurately weighed into a conical flask containing 30 mL of 0.2 N ethanolic KOH solution. The mixture was then refluxed with continuous agitation for 2 h, followed by the addition of two drops of phenolphthalein. Shortly thereafter, the mixture was titrated with 0.5 N HCl until the pink color disappeared completely. Titration was simultaneously conducted for blank determination (AOAC 920.160, 1920).

$$\text{Saponification value} = (T\text{-}B) \times N \times 56.1$$

B = mL of HCl required by blank.
T = mL of HCl required by the oil sample.
N = Normality of HCl.
W = Weight of oil in gram.

Determination of ester value (EV)

The ester value was determined based on the acid and saponification values (ISO 709:2001, 2001) using the following formula:

$$\text{Ester value} = \text{Saponification value} - \text{Acid value}$$

Determination of iodine value (IV)

0.2 g of respective oil was weighed into an Erlenmeyer flask containing a mixture of 10 mL of 0.1 N iodine in ethanol and the solution was kept in the dark for 30 min at room temperature. The resulting solution was titrated against 0.1 M sodium thiosulphate ($Na_2S_2O_3$) until the color was dark yellow. Starch was used as an indicator; if it was green, adjusted until a straw yellow color appeared. A blank sample was simultaneously prepared under the same condition. The iodine value (ISO 3961:2018, 2018) was then calculated by the following formula:

$$\text{Iodine value} = \frac{0.01269 \times 100 \times (V_1 - V_2)}{m}$$

V_1 = Volume of $Na_2S_2O_3$ in blank (mL).
V_2 = Volume of $Na_2S_2O_3$ in EO (mL).
M = Weight of used EO(g).

Determination of peroxide value (PV)

Two grams of EO were accurately weighed into the 250-mL glass-stoppered Erlenmeyer flask containing 30 mL of a mixture of three volumes of glacial acetic acid and two volumes of chloroform. The flask was promptly closed with the glass stopper and then swirled until completely dissolved. Shortly afterward, 1 mL of freshly prepared saturated KOH solution was added to the mixture. The flask was then closed and agitated for 60 sec in the dark and subsequently, 30 mL of distilled water was added and titrated against a standard solution of sodium thiosulfate (0.01 N) till the yellow color was almost gone. Thereafter, 0.5 mL of starch solution (1%) was added to the mixture with continuous agitation, followed by titration with sodium thiosulfate until the blue color disappeared. A blank titration was simultaneously carried out under the same condition (ISO 3960:2017, 2017). The volume of sodium thiosulfate was recorded. The peroxide value (milliequivalent peroxide/kg of sample) was calculated using the following formula:

$$\text{PV (meq/kg)} = \frac{S \times N \times 1000}{\text{Weight of essential oil}}$$

Where:
S = mL of sodium thiosulfate.
N = Normality of sodium thiosulfate.

Antibacterial activity

Microbial strains

The antibacterial effectiveness of EOs from *C. cassia* was tested against ten different microbial strains. Gram-positive species were *Staphylococcus aureus* ATCC 25923 (*S. aureus* 25923), *Streptococcus pneumoniae* ATCC 49619 (*S. pneumoniae* 49619), *Streptococcus pyogenes* ATCC 19615 (*S. pyogenes* 19615), *Enterococcus faecalis* ATCC 29212 (*E. faecalis* 29212) and *Bacillus subtilis* ATCC 15245 (*B. subtilis* 15245). Gram-negative strains included *Escherichia coli* ATCC 25922 (*E. coli* 25922), *Pseudomonas aeruginosa* ATCC 27853 (*P. aeruginosa* 27853), *Klebsiella pneumoniae* ATCC 700603 (*K. pneumoniae* 700603), *Acinetobacter baumanni* ATCC 19606 (*A. baumanni* 19606) and *Proteus mirabilis* ATCC 12453 (*P. mirabilis* 12453). The identity of the microorganisms assayed in this research was confirmed by morphological studies and standard biochemical tests Franco-Duarte *et al*., 2019; Gundappa *et al*., 2021.

Determination of minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC)

The MIC (Djahida and Houcine, 2021) and MBC were determined using the broth macro-dilution method (Ivan G. Ivanov *et al*., 2019). In this assay, 1.76 mL of the EO was diluted with 20.24 mL of Muller-Hinton broth (MHB) and DMSO (1%). Two-fold serial dilutions of EOs were then prepared to achieve a series of decreasing concentrations ranging from 8 to 0.0156% (8, 4, 2, 1, 0.5, 0.25, 0.125, 0.0625, 0.0313 and 0.0156%). Each concentration was divided into 11 tubes consisting of 100 µL each. 50 µL of the bacterial suspension (prepared in a saline solution) was added to each tube in a final concentration of McFarland 0.5. The EO was not

added to the positive control tube while microorganisms were not included in the negative control sample. All tubes were incubated at 37°C for 24 h.

After 24 h of incubation, the turbidity of each test tube was compared against the corresponding control, followed by the selection of two adjacent tubes having turbidity equal to and greater than the standard, respectively. Thereafter, 50 µL of each selected tube was taken and spread on a petri dish with TSA medium by sterile cotton swabs. After 24 h of incubation, the growth of microorganisms was evaluated by observing the appearance of colonies growing on plates. The MIC value was defined as the lowest EO concentration that did not show any growth of bacteria. The MBC value was determined as the lowest concentration of the EO showing negative subculture after incubation at 37°C for 24 h.

Statistical analysis

All experiments were conducted in triplicate and the results were expressed in terms of Mean ± Standard Error of Mean (SEM). Statistical analysis was performed by SPSS and analysis of variance (ANOVA) with a level of significance $p < 0.05$.

RESULTS AND DISCUSSION

Essential oil yield

The yield of the YBO, QNO and KTO were 1.315 ± 0.136, 2.600 ± 0.037 and 1.505 ± 0.045%, respectively. The yield of QNO (2.600 ± 0.037%) was approximately equal to that of *C. cassia* bark essential oil from Guangdong and Guangxi (2.55%) which was conducted by (Abdurahman Nour *et al*., 2016).

Chemical compositions of essential oils

Fig 3 and Table 1 show the identified components present in EOs of YB, QN and KT, respectively. The EO from *C. cassia* bark of YB consists of 19 compounds accounting for 99.91% of the total oil. Meanwhile, the EO from *C. cassia* bark of QN contains 19 constituents representing 99.98% of the total oil. EO from *C. cassia* bark of KT, on the other hand, includes 21 compounds accounting for 99.88% of the total oil. As expected, *trans*-cinnamaldehyde was the most abundant in three EOs which was accounted to compose more than 94% of the constituents of total oil. Noticeably, the KT *C, cassia* bark EO provided the highest *trans*-cinnamaldehyde concentration at 96.07% of 99.91% total, followed by YB (94.72%) and QN (94.69%). The amount of *trans*-cinnamaldehyde present in YBO, QNO and KTOwas extremely greater than that of the *C. cassia* bark EOs from the Guangdong and Guangxi provinces (66.28 - 71.22% and 73.56 - 77.21%, respectively) which was conducted by (Li *et al*., 2013). Notably, GC-MS analysis revealed the presence of nine other compounds in all three EOs (Fig 4 -A, B). However, four components were only detected in YBO (Fig 4 -C1), seven in QNO (Fig 4 -C2) and nine in KTO only (Fig 4 -C3).

Organoleptic and physicochemical properties

Table 2 details the physicochemical and organoleptic characteristics of the *C. cassia* bark essential oils from YB,

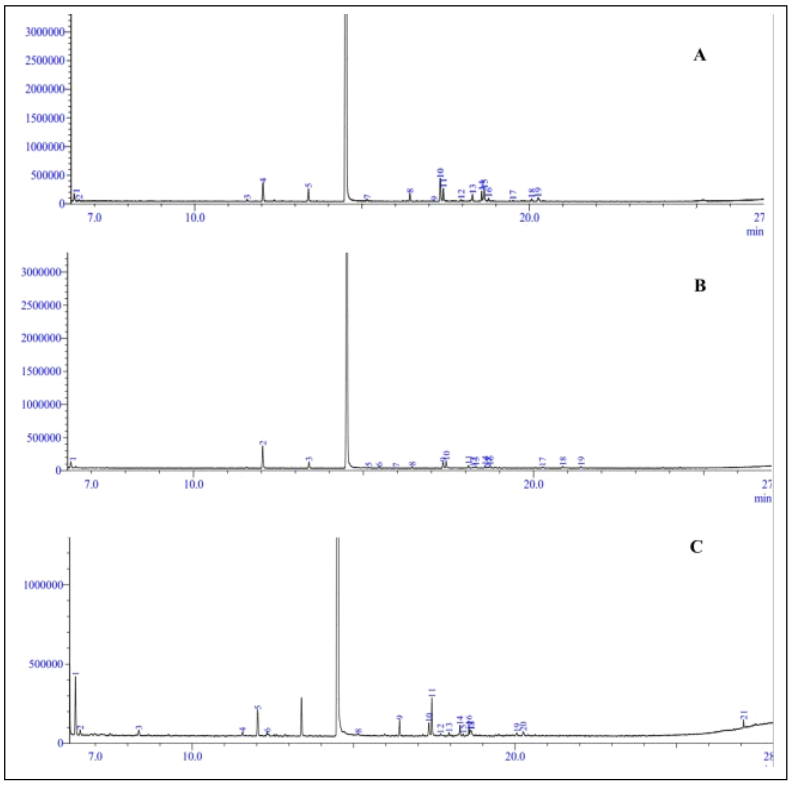


Fig 3: GC-MS Chromatogram of *Cinnamomum cassia* bark essential oil: (A) Yen Bai ; (B) Quang Ngai; and (C) Kon Tum.

QN and KT. All three essential oils had the same color (light yellow), odor (cinnamon-like note) and taste (hot and spicy). There were generally no significant differences in physicochemical parameters among three *C. cassia* bark essential oils, namely total acid number, saponification value, ester value and peroxide value, but specific gravity, optical rotation and iodine value.

Minimum inhibitory concentration and minimum bactericidal concentration

There were significant differences in the susceptibilities of *C. cassia* bark EOs against ten studied microbial strains (Table 3). Indeed, KTO generally exerted powerful effectiveness against ten selected microbial strains as both MIC and MBC were recorded as low as 0.0156-0.125% and 0.0313-0.250%, respectively. Differences in the susceptibility of tested microorganisms to KTO were quantitatively identified. Accordingly, KTO was able to powerfully inhibit the growth of *S. pyogenes* 19615 at the lowest dose of 0.0156% whereas five microbial strains, namely *S. aureus* 25923, *E. faecalis* 29212, *B. subtilis* 15245, *E. coli* 25922 and *A. baumanni* 19606, displayed the least sensitivity to KTO with the same highest MIC value

Table 1: Chemical composition of *Cinnamomum cassia* bark essential oil from three different provinces.

Retention time	Constituent	YB	QN	KT
6.394	Benzaldehyde	0.31	0.54	1.14
6.531	4-Penten-2-one, 4-methyl- (CAS)	-	-	0.11
6.541	7-Octen-2-one (CAS)	0.06	-	-
8.345	1,8-Cineole	-	-	0.12
11.566	2-Propenal, 3-phenyl-	0.08	-	0.08
12.038	Benzenepropanal (CAS)	0.8	1.98	0.52
12.32	endo-Borneol	-	-	0.06
13.397	(Z)-3-Phenylacrylaldehyde	0.54	0.52	-
14.528	*trans*-Cinnamaldehyde	94.72	94.69	96.07
15.149	(Z)-Cinnamyl alcohol	0.07	0.04	0.03
15.454	n-Tetradecane	-	0.08	-
15.957	3-Allyl-2-Methoxyphenol	-	0.03	-
16.431	α-Copaene	0.31	-	0.28
17.148	Caryophyllene	0.01	-	-
17.337	Coumarin	1.01	0.52	0.26
17.431	Cinnamyl acetate	0.48	0.53	0.66
17.69	Tetradecamethylcycloheptasiloxane	-	-	0.03
17.962	Naphthalene,1,2,4a,5,6,8a-hexahydro-4,7 -dimethyl-1-(1-methylethyl)-	0.06	0.15	0.05
18.087	n-Octadecane	-	0.16	-
18.226	2,6,10-Trimethyltetradecane	-	0.03	-
18.3	α-Muurolene	0.29	0.09	0.16
18.389	β-Bisabolene	-	-	0.04
18.575	(-)-δ-Cadinene	0.38	-	0.15
18.616	Naphthalene, 1,2,3,4-tetrahydro-1,6 -dimethyl-4-(1-methylethyl)-, (1S-cis)-	-	-	0.03
18.645	3-(2-methoxyphenyl)-2-propenal	-	-	0.02
18.653	Ortho methoxy cinnamic aldehyde	0.52	0.03	-
18.719	Eicosane	-	0.17	-
18.784	Naphthalene,1,2,3,4,4a,7-hexahydro-1,6 -dimethyl-4-(1-methylethyl)- (CAS)	0.03	-	-
19.509	Gleenol	0.02	-	-
20.055	Epi-cubenol	-	-	0.03
20.067	α-Cubebene	0.08	0.13	-
20.261	tau-Muurolol	0.14	0.03	0.04
20.857	Heneicosane	-	0.12	-
21.396	n-Docosane	-	0.14	-
27.079	Decanoic acid	-	-	0.1

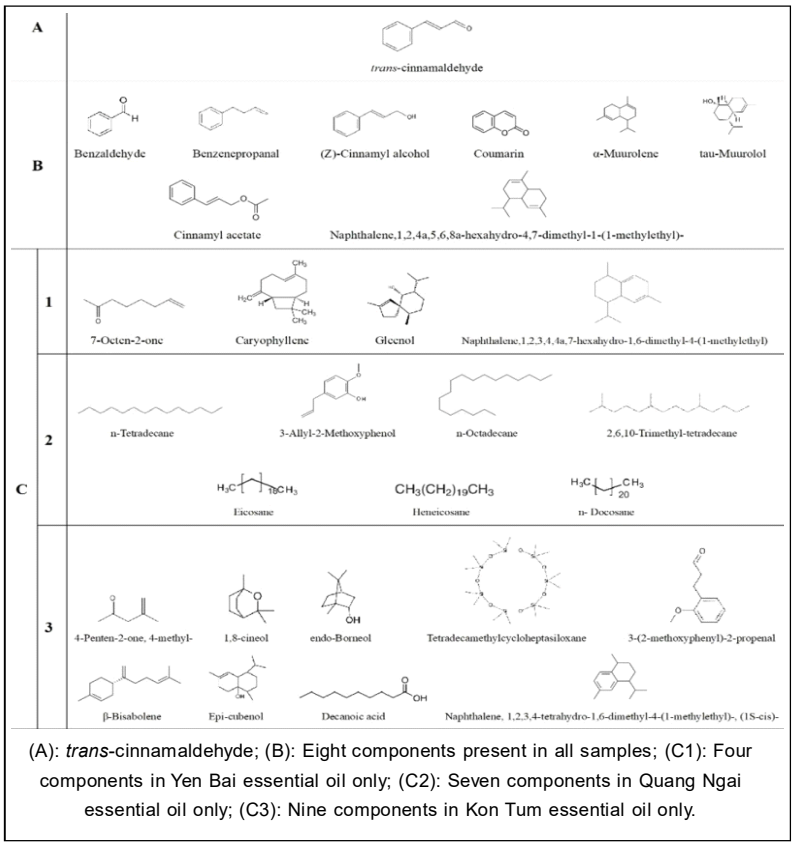
Note: "-" indicates the undetected compound.

of 0.125%. Notably, the same trend had been identified in MBC, but at different levels.

QNO also exhibited potent antibacterial capacity against ten selected microbial strains as MIC and MBC were documented to be 0.0313-0.250% and 0.0625-0.500%, respectively. *P. mirabilis* 12453, in contrast to KTO, was found the most susceptible to QNO as both MIC and MBC were recorded to the lowest dose of 0.0313% and 0.0625%, respectively. Three microbial strains, namely *P. aeruginosa* 27853, *K. pneumoniae* 700603 and *A. baumanni* 19606, displayed the same MIC and MBC values of 0.0625% and 0.125%, respectively. However, the differences in susceptibility of six other tested microbial strains to QNO could be noted as MIC of three microbial strains, namely *S. aureus 25923*, *S. pneumoniae* 49619 and *S. pyogenes* 19615, was valued at the same dose of 0.125%, whereas *E. faecalis* 29212, *B. subtilis* 15245 and *E. coli* 25922 had the same dose of 0.250%. The same pattern had been observed in MBC but at different levels.

On the other hand, YBO of the lowest concentration (MIC value of 0.0625% and MBC value of 0.125%) was able to inhibit six studied microbial strains (*S. aureus 25923*, *S. pneumoniae* 49619, *E. coli* 25922, *P. aeruginosa* 27853, *A. baumanni* 19606, *P. mirabilis* 12453). *B. subtilis* 15245, on the contrary, exerted the least sensitivity to YBO with MIC and MBC values of 0.250% and 0.500%, respectively.

Although *trans*-cinnamaldehyde was predominant in all three EOs, representing more than 94% of the total oil, significant differences in antibacterial activity against ten studied microbial strains were documented, reflecting the



(A): *trans*-cinnamaldehyde; (B): Eight components present in all samples; (C1): Four components in Yen Bai essential oil only; (C2): Seven components in Quang Ngai essential oil only; (C3): Nine components in Kon Tum essential oil only.

Fig 4: Major chemical compositions present in three *Cinnamomum cassia* bark essential oils.

Table 2: Organoleptic and physicochemical properties of *Cinnamomum cassia* bark essential oils from three selected provinces.

Characteristics	*Cinnamomum cassia* bark essential oils		
	YB	QN	KT
Specific gravity (20°) (ρ = 0.028)	0.918±0.004	0.903±0.019	0.947±0.016
Optical rotation 20° (°) (ρ = 0.00008)	-0.967±0.007	-0.997±0.004	-0.950±0.004
Total acid number (mg KOH/g) (ρ = 0.245)	2.057±0.187	1.870±0.187	2.244±0.324
Saponification value (mg KOH/g) (ρ = 0.248)	120.428±0.374	120.303±0.249	120.802±0.374
Ester value (mg/g) (ρ = 0.592)	118.371±0.324	118.932±0.857	118.553±0.671
Iodine value (g/g) (ρ = 0.0006)	36.380±0.210	37.650±0.210	38.070±0.360
Peroxide value (meq/kg) (ρ = 0.125)	0.027±0.001	0.026±0.001	0.025±0.001

Table 3: The minimum inhibitory concentration and the minimum bactericidal concentration of *Cinnamomum cassia* bark essential oils from three selected provinces.

Bacteria strains- ATCC	Minimum inhibitory concentration (%)			Minimum bactericidal concentration (%)		
	YB	QN	KT	YB	QN	KT
Staphylococcus aureus- 25923	0.0625	0.125	0.125	0.125	0.250	0.250
Streptococcus pneumoniae- 49619	0.0625	0.125	0.0625	0.125	0.250	0.125
Streptococcus pyogenes- 19615	0.125	0.125	0.0156	0.250	0.250	0.0313
Enterococcus faecalis- 29212	0.125	0.250	0.125	0.250	0.500	0.250
Bacillus subtilis- 15245	0.250	0.250	0.125	0.500	0.500	0.250
Escherichia coli- 25922	0.0625	0.250	0.125	0.125	0.500	0.250
Pseudomonas aeruginosa- 27853	0.0625	0.0625	0.0625	0.125	0.125	0.125
Klebsiella pneumoniae- 700603	0.125	0.0625	0.0313	0.250	0.125	0.0625
Acinetobacter baumanni- 19606	0.0625	0.0625	0.125	0.125	0.125	0.250
Proteus mirabilis- 12453	0.0625	0.0313	0.0313	0.125	0.0625	0.0625
Range	0.0625	0.0313	0.0156	0.125	0.0625	0.0313
	- 0.250	- 0.250	- 0.125	- 0.500	- 0.500	- 0.250

effects of other components in *C. cassia* bark essential oils. EO is a complex mixture of naturally occurring volatile compounds, primarily terpenoids, phenylpropanoids and phenolics. Certain components present in EO might interact with others, resulting in variations in binding affinity to different lipophilic molecular structures of lipids, protein, glycolipids, lipoprotein and glycoprotein present in the bacterial cell wall and cytoplasmic membrane. In addition to the diversified and complicated nature of phytocomponents present in EOs, the differences in susceptibility of Gram-negative and Gram-positive to a variety of EOs considerably attribute to the effects of antibacterial activity against microorganisms. Nevertheless, the present results would hopefully encourage more studies to elucidate the mechanisms behind which *C. cassia* bark essential oils exhibited antibacterial effects, for the purpose of exploiting the potential of this valuable EO to the fullest.

CONCLUSION

In conclusion, *trans*-cinnamaldehyde was found to be the major constituent in all three essential oils claiming more than 94% of the total composition of essential oils. There were generally no significant differences in essential oil compositions and physiochemical parameters but varying in antibacterial activities against ten studied microbial strains. This present research scientifically contributes to the herbal database system and promotes the significant potential of high-quality *C. cassia* bark essential oils from three selected regions of Vietnam that might be exploited to develop in the food and pharmaceutical industry, bringing huge benefits to human health, which encourages increased planting of crops for export and domestic industry. The extraction of *C. cassia* bark essential oils was conducted using an eco-friendly method, minimizing environmental impact and ensuring sustainability. Nevertheless, further studies are necessary to establish the international standard for essential oils from the cinnamon bark of *C. cassia* planted in three selected geographic regions of Vietnam, particularly the regulation of specific quantity ranges of major active components present in *C. cassia* bark essential oils. Perhaps, the design of sampling on certain geographic regions is the limitation of this study. Future research should expand more studies on geographical scope, investigating molecular mechanisms, assessing health benefits, developing novel pharmaceutical products and considering other varieties within this species based on geographical and environmental factors.

ACKNOWLEDGEMENT

The authors are grateful to the authorities at the Department of Applied Biochemistry, Ho Chi Minh City International University- Vietnam National University for providing the facilities to conduct this study.

Conflict of interest

The authors declare to have no conflict of interest.

REFERENCES

Abdurahman, N., Nitthiyah, J. and John, O.A. (2016). The potential of microwave assisted hydrodistillation in extraction of essential oil from *Cinnamomum cassia* (cinnamon). *ARPN Journal of Engineering and Applied Sciences*. **11(4):** 1819-6608.

AOAC 920.142. (1920). Official Methods of Analysis of AOAC International- Optical Rotation of Lemon and Orange Oils. Oxford University Press.

AOAC 920.160. (1920). Official Methods of Analysis of AOAC International- Saponification Number (Koettstorfer Number) of Oils and Fats. Oxford University Press.

AOAC 920.212. (1920). Official Methods of Analysis of AOAC International- Specific gravity (apparent) of oils. Pycnomet (Version 17th). Oxford University Press.

AOAC 969.17. (1995). Official Methods of Analysis of AOAC International- Acid value of butterfat. Titrimetric method (Version 16th). Oxford University Press.

Barceloux, D.G. (2009). Cinnamon (Cinnamomum Species). Disease-α-Month. **55(6):** 327-335. https://doi.org/10.1016/j.disamonth.2009.03.003.

Bicchi, C. and Maffei, M. (2012). The Plant Volatilome: Methods of Analysis. In: High-Throughput Phenotyping in Plants. J. Normanly (Ed.), Humana Press. 918: 289-310. https://doi.org/10.1007/978-1-61779-995-2_15.

Center for WTO and International Trade Vietnam Chamber of Commerce and Industry. (2023). India, US and Bangladesh remain largest Vietnamese cinnamon export markets. https://wtocenter.vn/chuyen-de/22511-india-us-and-bangladesh-remain-largest-vietnamese-cinnamon-export-markets.

Djahida, A. and Houcine, B. (2021). Phytochemical content, antioxidant and antimicrobial effects of *Thapsia garganica* L. leaves and roots grown wild in North-west Algeria. *Indian Journal of Agricultural Research.* **55(5):** 519-526. doi: 10.18805/IJARe.A-648.

Franco-Duarte, R., Èernáková, L., Kadam, S.S., Kaushik, K., Salehi, B., Bevilacqua, A., Corbo, M.R., Antolak, H., Dybka-Stêpieñ, K., Leszczewicz, M., Relison Tintino, S., Alexandrino De Souza, V.C., Sharifi-Rad, J., Melo Coutinho, H.D., Martins, N. and Rodrigues, C.F. (2019). Advances in Chemical and Biological Methods to Identify Microorganisms-From Past to Present. *Microorganisms.* **7(5):** 130. https://doi.org/10.3390/microorganisms7050130.

Gundappa, M., Prabhurajeshwar, C., Ahmed, S., Navya, H.M., Vijayasarathy, M. and Velayuthaprabhu, S. (2021). Microbiological evaluation and antibiotic susceptibility pattern of bacterial isolates associated with some contaminated edible fruits and vegetables. *Indian Journal of Agricultural Research.* **58(2):** 227-234. doi: 10.18805/IJARe.A-5681.

ISO 709:2001. (2001). Essential oils-Determination of ester value (ICS/ : 71.100.60; Version edition 2nd). International Organization for Standardization.

ISO 3960:2017. (2017). Animal and vegetable fats and oils-Determination of peroxide value-Iodometric (visual) endpoint determination (ICS/ : 67.200.10; Version edition 2nd). International Organization for Standardization.

ISO 3961:2018. (2018). Animal and vegetable fats and oils-Determination of iodine value (ICS/ : 67.200.10; Version edition 2nd). International Organization for Standardization.

Ivan, G.I., Radka, Z.V., Nadezhda, T.P., Ilian, K.B., Yulian, T. and Ivayla, N.D. (2019). Phytochemical compounds of anise hyssop (*Agastache foeniculum*) and antibacterial, antioxidant and acetylcholinesterase inhibitory properties of its essential oil. *Journal of Applied Pharmaceutical Science.* **9(2):** 72-78. https://doi.org/10.7324/JAPS.2019.90210.

Kosari, F., Taheri, M., Moradi, A., Hakimi Alni, R. and Alikhani, M. Y. (2020). Evaluation of cinnamon extract effects on clbB gene expression and biofilm formation in *Escherichia coli* strains isolated from colon cancer patients. *BMC Cancer.* **20(1):** 267. https://doi.org/10.1186/s12885-020-06736-1.

Li, Y., Kong, D. and Wu, H. (2013). Analysis and evaluation of essential oil components of cinnamon barks using GC-MS and FTIR spectroscopy. *Industrial Crops and Products.* **41:** 269-278. https://doi.org/10.1016/j.indcrop.2012.04.056

Naik*, G., Bhandari, U., Gwari, G. and Lohani, H. (2017). Evaluation of essential oil of *Cymbopogon distans* and *Cinnamomum tamala* against plant pathogenic fungi. *Indian Journal of Agricultural Research.* **51(2):** 191-193. doi: 10.18805/ijare.v0iOF.7641

Son L.Hoang and Nhi H.M.Nguyen. (2023). Antibacterial synergism of blended essential oils from *Piper betle* L. and *Melaleuca alternifolia*. *South Asian Research Journal of Natural Products.* **6(2):** 88-100.