

# A review of chemical constituents and pharmaceutical properties from essential oil of *Xylopi* species

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*Xylopi* L. is the second largest genus of the Annonaceae family, whose species have long been used as traditional medicine and spice. The chemical constituents obtained from the essential oils (EOs) of certain members of this genus were found to mainly contain relatively equal amounts of oxygenated monoterpenes, monoterpene hydrocarbons, sesquiterpene hydrocarbons and oxygenated sesquiterpenes etc. In addition, The EOs isolated from the *Xylopi* members have been reported to possess various biological properties. This review was thus aimed to provide an overview of information related to the phytochemical composition and pharmaceutical properties of the EOs isolated from various plant parts of *Xylopi* plants.

**Keywords:** Annonaceae, Chemical compositions, Essential oils, Pharmaceutical properties, *Xylopi*

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## Introduction

The Annonaceae is a flowering plant family of 129 genera and 2500 species, mainly distributed in pantropical regions<sup>1</sup>. Many species in this family have been reported to have economic values, including soursop (*Annona muricata*), sugar-apple (*Annona squamosa*), and ylang-ylang (*Cananga odorata*)<sup>2</sup>. In particular, they have been commonly used as folk medicine and products. Their essential oils (Eos) are considered important natural resources<sup>2,3</sup>. They were also documented to have many bioactive components, including terpenoids, steroids, alkaloids, polyphenols and flavonoids<sup>1</sup>.

*Xylopi* L., a genus of the Annonaceae family, includes over 150 species of shrubs and trees distributed worldwide<sup>2</sup>. Members in the genus include aromatic plants, which have been mainly used for medicine<sup>3</sup>. In traditional medicine, the *Xylopi* plants have been used as antimicrobial and anthelmintic agents. Various bioactive components from *Xylopi* plants, such as acetogenins, kauranes, labdanes, sesquiterpenes, flavonoids, diterpenes and alkaloids, have been recently documented<sup>1</sup>.

Owing to the aromatic shrubs, the different parts of *Xylopi* plants contain EOs, such as leaves, seeds, fruits,

roots, root barks, stem barks, flowers and twig parts<sup>4-8</sup>. The chemical composition obtained from *Xylopi* EOs was found to mainly contain relatively equal amounts of oxygenated monoterpenes and monoterpene hydrocarbons, followed by sesquiterpene hydrocarbons, oxygenated sesquiterpenes, etc.<sup>4-8</sup>. Furthermore, several pharmaceutical activities of *Xylopi* EOs have been reported by prior studies, including antibacterial<sup>9</sup>, antifungal<sup>10</sup>, trypanocidal, lavicidal<sup>11</sup>, anticholinesterase<sup>12</sup>, antioxidant, anti-inflammatory<sup>13</sup>, cytotoxic, antitumor<sup>14,15</sup>, molluscicidal<sup>16</sup> and insecticidal<sup>17</sup> activities. Recently, many studies have focused on the phytochemical components and biological properties of EOs obtained from *Xylopi* plants. Therefore, This review provides comprehensive information on the chemical profiles and pharmaceutical properties of the EOs from *Xylopi* species.

## Materials and Methods

This review used relevant literature from scientific databases, including Google Scholar, PubMed, Web of Science, and other related databases.

### Volatile compounds of *Xylopi* species

Major chemical components obtained in EOs from different species of the genus *Xylopi* is given in Table 1.

#### *Xylopi aethiopia* (Dunal) A.Rich.

Synonym: *Xylopi dekeyzeriana* De Wild., *X. eminii* Engl., *X. gillettii* De Wild.

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Table 1 — Major chemical components obtained from *Xylopi*a EOs

Scientific name	Locaion	Organ	Major components	References
<i>X. aethiopica</i>	Togo	Fruit	sabinene (9.8%), $\alpha$ -pinene (11.0%), $\beta$ -pinene (23.6%)	5
<i>X. aethiopica</i>	Mali	Fruit	<i>trans</i> -pinocarveol (8.6%), $\gamma$ -terpinene (14.7%), $\beta$ -pinene (19.1%)	24
<i>X. aethiopica</i>	Ibadan, Nigeria	Fruit	terpinen-4-ol (4.1%), sabinene (6.6%), 1,8-cineole (15.15%)	27
<i>X. aethiopica</i>	Ibadan, Nigeria	Fruit	benzyl benzoate (10.0%), $\alpha$ -cadinol (13.0%), $\beta$ -santalol (14.5%)	29
<i>X. aethiopica</i>	Kwara, Nigeria	Fruit	1,8-cineole (6.8%), acetyleugenol (7.0%), eugenol (12.2%)	9
<i>X. aethiopica</i>	Ogun State, Nigeria	Seed	cyclohexane methanol (4.79%), $\beta$ -terpineol (5.93%), terpinen-4-ol (11.88%)	12
<i>X. aethiopica</i>	Gore, La Nya Pendé	Fruit	$\beta$ -phellandrene (10.4%), sabinene (14.5%), $\beta$ -pinene (24.6%)	25
<i>X. aethiopica</i>	Kribi, Cameroon	Fruit	$\alpha$ -pinene (10.8%), terpinen-4-ol (15.1%), $\beta$ -pinene (28.2%)	25
<i>X. aethiopica</i>	Cameroon	Fruit	limonene (8.6%), $\alpha$ -pinene (18.4%), $\beta$ -pinene (37.8%)	9
<i>X. aethiopica</i>	Bafoussam, Cameroon	Fruit	Z- $\gamma$ -bisabolene (10.07%), $\beta$ -phellandrene (10.71%), $\beta$ -pinene (32.16%)	10
<i>X. aethiopica</i>	Congo	Fruit	sabinene (9.9%), $\beta$ -pinene (11.5%), 1,8-cineole (13.3%)	28
<i>X. aethiopica</i>	Ivory Coast	Fruit	1,8-cineole (7.44%), $\alpha$ -pinene (17.77%), $\beta$ -pinene (20.5%)	6
<i>X. aethiopica</i>	Ivory Coast	Leaf	$\alpha$ -pinene (10.39%), $\beta$ -eudesmol (12.66%), $\beta$ -pinene (16.1%)	6
<i>X. aethiopica</i>	Sudan	Fruit	$\alpha$ -terpineol (6.02%), $\beta$ -pinene (6.12%), 4-terpineol (11.30%)	30
<i>X. aethiopica</i>	Senegal	Fruit	$\alpha$ -pinene (10.0%), 1,8-cineole (14.7%), $\beta$ -pinene (29.9%)	26
<i>X. aethiopica</i>	Ghana	Leaf	<i>trans</i> -caryophyllene (5.2%), $\beta$ -pinene (17.3%), germacrene (24.5%),	4
<i>X. aethiopica</i>	Ghana	Root bark	bornyl acetate (5.3%), $\beta$ -copaene-1 $\alpha$ -ol (13.3%), <i>trans</i> -m-metha-1(7)8-diene (30.4%)	4
<i>X. aethiopica</i>	Ghana	Stem bark	$\alpha$ -pinene (7.3%), germacrene D (8.8%), <i>trans</i> -m-metha-1(7)8-diene (30.7%)	4
<i>X. aethiopica</i>	Ghana	Fresh fruit	$\beta$ -phellandrene (9.7%), germacrene D (19.1%), $\beta$ -pinene (25.5%)	4
<i>X. aethiopica</i>	Ghana	Dried fruit	1,8-cineole (7.1%), $\beta$ -pinene (21.6%), germacrene D (25.1%)	4
<i>X. aromatica</i>	Araguaia, Brazil	Leaf	limonene (4.6%), pathulenol (20.5%), bicyclogermacrene (36.5%)	31
<i>X. aromatica</i>	Araguaia, Brazil	Flower	$\beta$ -pinene (16.7%), $\alpha$ -pinene (24.8%), limonene (44.6%)	31
<i>X. aromatica</i>	Araguaia, Brazil	Fruit	$\beta$ -pinene (13.3%), $\alpha$ -pinene (19.2%), limonene (36.4%)	31
<i>X. aromatica</i>	Goiás, Brazil	Leave	$\beta$ -pinene (7.75%), $\alpha$ -pinene (8.23%), bicyclogermacrene (44.80%)	33
<i>X. aromatica</i>	Goiás, Brazil	Fruit	$\beta$ -pinene (22.51%), $\beta$ -phellandrene (31.05%), $\alpha$ -pinene (35.40%)	33
<i>X. aromatica</i>	Catalão, Brazil	Flower	7-epi- $\alpha$ -eudesmol (7.76%), bicyclogermacrene (9.74%), pentadecan-2-one (16.38%)	8
<i>X. aromatica</i>	Catalão, Brazil	Leaf	bicyclogermacrene (8.52%), khusinol (13.04%), Spathulenol (27.11%)	8
<i>X. aromatica</i>	Pará, Brazil	Leaf	limonene (4.6%), spathulenol (20.5%), bicyclogermacrene (36.5%)	32
<i>X. aromatica</i>	Cuba	Leaf	2-hexadecanone (1.0%), Spathulenol (64.4%)	34
<i>X. brasiliensis</i>	São Paulo, Brazil	Leaf	1,8-cineole (11.1%), verbenone (11.1%), spathulenol (40.8%)	50
<i>X. cayennensis</i>	Pará, Brazil	Leaf	caryophyllene oxide (14.5%), $\beta$ -pinene (16.5%), $\alpha$ -pinene (29.2%)	32
<i>X. elliptica</i>	Negeri Sembilan, Malaysia	Leaf	$\alpha$ -pinene (9.0%), sabinene (10.6%), bicyclogermacrene (11.5%)	42
<i>X. elliptica</i>	Negeri Sembilan, Malaysia	Twig part	$\alpha$ -cadinol (6.8%), $p$ -cymene (7.4%), terpinen-4-ol (11.9%)	7
<i>X. emarginata</i>	Mato Grosso do Sul, Brazil	Leaf	<i>trans</i> -pinocarveol (6.3%), caryophyllene oxide (25.0%), spathulenol (34.4%)	51
<i>X. emarginata</i>	Pará, Brazil	Leaf	humulene epoxide II (3.4%), spathulenol (73.0%)	32
<i>X. ferruginea</i>	Malaysia	Leaf	guaiol (13.4%), elemol (13.7%), Bicyclogermacrene (23.6%)	37
<i>X. frutescens</i>	Malaysia	Leaf	elemol (12.8%), germacrene D (14.2%), bicyclogermacrene (22.8%)	37

(Contd.)

Table 1 — Major chemical components obtained from *Xylopi*a Eos — (Contd.)

Scientific name	Locaion	Organ	Major components	References
<i>X. frutescens</i>	Paraíba, Brazil	Leaf	$\beta$ -ocimene (8.19%), $\gamma$ -cadinene (12.48%), caryophyllene (23.91%)	38
<i>X. frutescens</i>	Sergipe, Brazil	Leaf	germacrene D (9.66%), bicyclogermacrene (15.13%), ( <i>E</i> )-caryophyllene (31.48%)	39
<i>X. frutescens</i>	French Guyana	Stem bark	limonene (3.9%), $\delta$ -cadinol (27.4%), $\alpha$ -cubebene (25.2%)	40
<i>X. fusca</i>	Negeri Sembilan, Malaysia	Leaf	$\beta$ -elemene (11.5%), bicyclogermacrene (12.0%), germacrene D (17.0%)	42
<i>X. fusca</i>	Negeri Sembilan, Malaysia	Twig part	vulgarone B (4.8%), $\alpha$ -cadinol (8.2%), spathulenol (11.8%)	7
<i>X. hypolampra</i>	Africa	Stem bark	1,8-cineole (5.9%), borneol (7.8%), verbenone (20.2%)	53
<i>X. laevigata</i>	Sergipe, Brazil	Leaf	germacrene D (9.09%), $\delta$ -cadinene (13.45%), $\gamma$ -muurolene (17.99%)	11
<i>X. laevigata</i>	Sergipe, Brazil	Leaf	bicyclogermacrene (7.77%), $\delta$ -cadinene (12.23%), $\gamma$ -muurolene (17.78%)	13
<i>X. laevigata</i>	Brazil	Leaf	( <i>E</i> )-caryophyllene (7.98%),bicyclogermacrene (14.63%), germacrene D (43.62%)	15
<i>X. laevigata</i>	Itabaiana Mountain National Park, Brazil	Leaf	Germacrene D (9.09%), $\delta$ -cadinene (13.45%), $\gamma$ -muurolene (17.99%)	14
<i>X. laevigata</i>	Mata do Crasto, Brazil	Leaf	( <i>E</i> )-caryophyllene (6.37%), bicyclogermacrene (11.65%), germacrene D (60.44%)	14
<i>X. laevigata</i>	Municipality, Brazil	Leaf	Caryophyllene (7.98%), bicyclogermacrene (14.63%), ( <i>E</i> )-germacrene D (43.62%)	14
<i>X. langsdorffiana</i>	Paraíba, Brazil	Fruit	limonene (31.75%), $\alpha$ -pinene (34.57%)	46
<i>X. langsdorffiana</i>	Paraíba, Brazil	Leaf	$\beta$ -caryophyllene (15.7), <i>trans</i> - $\beta$ -guaiene (22.6), germacrene D (22.9),	16
<i>X. magna</i>	Malaysia	Leaf	spathulenol (11.1%), bicyclogermacrene (22.8), germacrene D (35.9%)	37
<i>X. malayana</i>	Negeri Sembilan, Malaysia	Leaf	elemol (11.6%), $\alpha$ -pinene (15.2%), $\beta$ -pinene (42.0%)	42
<i>X. malayana</i>	Negeri Sembilan, Malaysia	Twig part	$\alpha$ -eudesmol (5.9%), elemol (8.3%), Spathulenol (12.9%)	7
<i>X. nitida</i>	Pará, Brazil	Leaf	$\alpha$ -terpinene (12.6%), <i>p</i> -cymene (13.7%), $\gamma$ -terpinene (44.1%)	32
<i>X. parviflora</i>	Gore, La Nya Pendé	Fruit	myrtenol (6.5%), $\alpha$ -pinene (11.1%), $\beta$ -pinene (35.7%)	25
<i>X. parviflora</i>	Kribi, Cameroon	Fruit	$\beta$ -ocimene (8.0%), $\alpha$ -pinene (10.8%), $\beta$ -pinene (32.9%)	25
<i>X. pierrei</i>	Ben En National Park, Vietnam	Leaf	$\beta$ -caryophyllene (11.2%), bicycloelemene (13.9%), $\beta$ -elemene (23.4%)	52
<i>X. pynaertii</i>	Zaire	Stem bark	$\gamma$ -muurolene (10.1%), $\alpha$ -cadinene (10.3%), Cubenol (12.6%)	40
<i>X. pynaertii</i>	Zaire	Root	isoeugenol (7.2%), $\alpha$ -cubebene (8.6%), elemol (27.1%)	40
<i>X. quintasii</i>	Agboville, Ivory Coast	Leaf	$\beta$ -pinene (7.6%), $\alpha$ -Humulene (9.2%), ( <i>E</i> )- $\beta$ -caryophyllene (28.6%)	47
<i>X. quintasii</i>	Azaguie, Ivory Coast	Leaf	( <i>E</i> )- $\beta$ -caryophyllene (10.2%), $\alpha$ -pinene (14.0%), $\beta$ -pinene (18.3%)	47
<i>X. quintasii</i>	Adiopodoume, Ivory Coast	Leaf	( <i>E</i> )- $\beta$ -caryophyllene (9.8%), ( <i>Z</i> )- $\beta$ -Ocimene (28.5%)	47
<i>X. sericea</i>	Minas Gerais, Brazil	Fruit	germacrene D (8.11%), guaiol (13.93%), spathulenol (16.42%)	49
<i>X. sericea</i>	French Guyana	Root bark	$\alpha$ -muurolene-3-one (6.9%), $\alpha$ -gurjunene (13.8%), <i>p</i> -cymene (22.8%)	40
<i>X. vielana</i>	Ke Go Natural Reserve, Vietnam	Leaf	germacrene D (14.9%), bicyclogermacrene (15.0%), $\beta$ -elemene (19.7%)	52
<i>X. villosa</i>	Petit Yapo, Ivory Coast	Leaf	$\alpha$ -pinene (8.5%), ( <i>Z</i> )- $\beta$ -ocimene (17.4%), sabinene (39.5%)	48
<i>X. villosa</i>	Petit Yapo, Ivory Coast	Stem bark	$\beta$ -pinene (8.0%), terpinen-4-ol (14.5%), sabinene (33.6%),	48
<i>X. villosa</i>	Yapo Abbé, Ivory Coast	Leaf	camphene (7.2%), sabinene (25.2%), ( <i>Z</i> )- $\beta$ -ocimene (31.1%)	48

*Xylopi*a *aethiopic*a is commonly known as “Africa pepper”, “Guinea pepper”, “spice tree”, or “Ethiopian pepper”<sup>18,19</sup>. The plant is native to Africa and widely found in West, Central and Southern Africa<sup>20</sup>. Different plant parts of *X. aethiopic*a were widely used as a spice and traditional medicine in some African countries<sup>4,21</sup>. For instance, the dried fruit of this species was used to

treat several diseases, such as skin disease, cough, stomach ulcer, stomach ache, dysentery, bronchitis, hernia and cholera<sup>22</sup>. Furthermore, the plant has been reported to have various pharmacological properties such as antimicrobial and antioxidant, cytotoxic, anti-anaphylactic, anti-inflammatory, antiproliferative, hypolipidemic and antioxidant activities<sup>23</sup>.

The *X. aethiopica* fruits are the most important part by reason of their nutritive and pharmaceutical values<sup>20</sup>. Thus, a large number of studies reported the chemical constituents in the EOs obtained from this plant. Accordingly,  $\beta$ -pinene has been widely reported as the most abundant component in the EOs of *X. aethiopica* fruits from Togo<sup>5</sup>, Mali<sup>24</sup>, Gore, La Nya Pendé and Cameroon<sup>9,10,25</sup>, Ivory Coast<sup>6</sup>, Senegal<sup>26</sup> and Ghana<sup>4</sup>. Meanwhile, the fruit EOs of the species from Ibadan and Kwara, Nigeria, Congo and Sudan contained 1,8-cineole<sup>27,28</sup>,  $\beta$ -santalol<sup>29</sup>, eugenol<sup>9</sup>, and 4-terpineol<sup>30</sup>, respectively as the most major components. In addition, the EOs isolated from *X. aethiopica* root and stem barks grown in Ghana possessed *trans*-m-metha-1(7)8-diene as the most abundant constituent, while germacrene,  $\beta$ -pinene and *trans*-caryophyllene were the major compounds in the leaf oils of the same sample<sup>4</sup>. Also, the seed oil of *X. aethiopica* collected from Ogun State, Nigeria, was mainly composed of terpinen-4-ol,  $\beta$ -terpineol, cyclohexane methanol and  $\alpha$ -copaene<sup>9</sup>.

#### *Xylopi aromatic (Lam.) Mart.*

Synonym: *Xylopi grandiflora* A.St.-Hil., *X. longifolia* A.DC., *X. xylopioides* (Dunal) Standl.

*Xylopi aromatic* is commonly known as “pimenta-de-macaco”, “pimenta-de-negro”, “esfolia-bainha” and “pachinho” in Brazil. It is a small tree found widely in South and Central America, Africa, Asia, and Australia<sup>31</sup>. Several plant parts of *X. aromatic* were used in folk medicine as a stimulant, carminative or spice<sup>32</sup>. The chemical components of EO obtained from *X. aromatic* have been reported by previous studies. Accordingly, the leaf EO of *X. aromatic* collected from Araguaia, Brazil, possessed bicyclogermacrene, pathulenol and limonene as the major compounds, while the flower and fruit oils were found to be rich in limonene,  $\alpha$ -pinene and  $\beta$ -pinene<sup>31</sup>. The chemical composition of the leaf EO of *X. aromatic* from Goiás, Brazil, contained bicyclogermacrene,  $\alpha$ -pinene and  $\beta$ -pinene as the main constituents, whereas  $\alpha$ -pinene,  $\beta$ -phellandrene and  $\beta$ -pinene were the main components in the fruit oil<sup>33</sup>. The flower oil of these plants grown in Catalão, Brazil, was dominated by pentadecan-2-one, bicyclogermacrene, 7-epi- $\alpha$ -eudesmol, and khusinol, while the leaf oil was characterised by large quantities of spathulenol, khusinol and bicyclogermacrene<sup>8</sup>. The leaf oil from Pará, Brazil, was found to be rich in bicyclogermacrene, spathulenol and limonene<sup>32</sup>. Finally, the EO of the *X. aromatic* leaves from Cuba contained spathulenol as the most components<sup>34</sup>.

#### *Xylopi frutescens* Aubl.

Synonym: *Xylopi meridensis* Pittier, *X. setosa* Poir.

*Xylopi frutescens* popularly called “embira”, “embira-vermelha” and “pau carne” in Brazil. It is a medicinal plant distributed widely in South and Central America, Asia and Africa<sup>35</sup>. In traditional medicine, the plant was used to treat inflammation and rheumatism and as antidiarrheal<sup>35,36</sup>. Furthermore, pharmacological activities of *X. frutescens* have been reported by previous studies, including antimicrobial, anti-inflammatory, antiplasmodial and anti-viral activities<sup>36</sup>. A published work has revealed that the leaf EOs of *X. frutescens* collected from Malaysia have demonstrated bicyclogermacrene, germacrene D, elemol and guaiol as the main compounds<sup>37</sup>. However, the leaf oils of this species from Paraíba and Sergipe, Brazil were found caryophyllene as the most abundant compound, followed by  $\gamma$ -cadinene,  $\beta$ -ocimene (Paraíba)<sup>38</sup> and bicyclogermacrene, germacrene D,  $\delta$ -cadinene (Sergipe)<sup>39</sup>. Moreover, the stem bark EO of *X. frutescens* collected from French Guyana was found to be rich in  $\alpha$ -cubebene,  $\delta$ -cadinol and limonene<sup>40</sup>.

#### *Xylopi laevigata* (Mart.) R.E. Fr.

*Xylopi laevigata* is commonly known as “meiu” or “pindaiba” in Brazil. It is a small tree and native to Brazil. This plant is also found in the tropical American forest<sup>41</sup>. In folk medicine, *X. laevigata* was used to treat inflammation and pain<sup>13</sup>. The chemical constituents of EOs obtained from *X. laevigata* have been reported by prior studies. Accordingly, the leaf EOs of *X. laevigata* from Mata do Crasto and Municipality, Brazil, were characterised by the predominance of germacrene D, bicyclogermacrene, (E)-caryophyllene and germacrene B<sup>14,15</sup>. Meanwhile,  $\gamma$ -muurolene,  $\delta$ -cadinene, germacrene D and bicyclogermacrene were the main compounds in the leaf oils from Itabaiana Mountain National Park and Sergipe, Brazil<sup>11,13,14</sup>.

#### Other *Xylopi* species

*Xylopi elliptica* Maingay ex Hook.f. & Thomson, *Xylopi fusca* Maingay ex Hook.f. & Thomson and *Xylopi malayana* Hook.f. & Thomson are rare species and native to Peninsular Malaysia<sup>7</sup>. *X. elliptica* is popularly known as “Lilan” in Malaysia<sup>7</sup>. The leaf EO of *X. elliptica* collected from Negeri Sembilan, Malaysia, was mainly composed of bicyclogermacrene, sabinene,  $\alpha$ -pinene, elemol and  $\beta$ -pinene<sup>42</sup> while the twig part oil contained terpinen-4-ol,  $\rho$ -cymene,  $\alpha$ -cadinol and  $\beta$ -cedrene as the major compound<sup>7</sup>. In

addition, *X. fusca* is commonly called "Jangkang paya" in Malaysia. This species has been used as an antidote for insect bites and an abortifacient in folk medicine<sup>7</sup>. The leaf EO of *X. fusca* from Negeri Sembilan, Malaysia, was found to be rich in germacrene D, bicyclogermacrene,  $\beta$ -elemene and  $\beta$ -pinene<sup>42</sup> whereas spathulenol,  $\alpha$ -cadinol and vulgarone B were the major constituents in the twig part oil. Furthermore, *X. malayana* is also known as "Jangkang" in Malaysia. Malaysian traditional medicine uses *X. malayana* leaves for treatment after childbirth<sup>7</sup>. The leaf EO of *X. malayana* from Negeri Sembilan, Malaysia possessed  $\beta$ -pinene,  $\alpha$ -pinene, elemol and bicyclogermacrene as the main compounds<sup>42</sup> while the twig part oil was mainly composed of spathulenol, elemol,  $\alpha$ -eudesmol and cyperotundone<sup>7</sup>.

*Xylopiya langsdorffiana* St.-Hil. & Tul. is commonly known as 'pimenteira-da-terra' in Brazil. Studies demonstrated that several diterpenes from this species possessed cytotoxic activities against murinesarcoma 180 in vivo<sup>43</sup> and leukemic cells<sup>44,45</sup>. The fruit EO of *X. langsdorffiana* collected from Paraiba, Brazil, was found to be rich in  $\alpha$ -pinene and limonene<sup>46</sup> while the leaf oil contained germacrene D, *trans*- $\beta$ -guaiene and  $\beta$ -caryophyllene as the major compounds<sup>16</sup>. Another *Xylopiya* species, *Xylopiya quintasii* Engl. & Diels is widely distributed in tropical regions of western and central Africa. This plant has been used to treat stomach disorders and coughs<sup>47</sup>. The specimens of *X. quintasii* from three regions of the Ivory Coast had a diversity of chemical compositions in EOs. Accordingly, the leaf EO from Agboville mainly included (*E*)- $\beta$ -caryophyllene,  $\alpha$ -humulene and  $\beta$ -pinene. The leaf oil from Azaguie contained  $\beta$ -pinene,  $\alpha$ -pinene and (*E*)- $\beta$ -Caryophyllene as the major compounds, while the sample from Adiopodoume presented a characteristic composition with (*Z*)- $\beta$ -Ocimene, (*E*)- $\beta$ -caryophyllene and germacrene D<sup>47</sup>.

The leaf EO of *Xylopiya villosa* Chipp grown in Petit Yapo, Ivory Coast, was dominated by sabinene, (*Z*)- $\beta$ -ocimene,  $\alpha$ -pinene and  $\beta$ -pinene while (*Z*)- $\beta$ -ocimene, sabinene and camphene and  $\alpha$ -pinene were the major components in the leaf oil from Yapo Abbé, Ivory Coast. The stem bark EO of *X. villosa* was made up predominantly of sabinene, terpinen-4-ol and  $\beta$ -pinene<sup>48</sup>. In addition, the fruit EO of *Xylopiya parviflora* Spruce from Gore, La Nya Pendé and Kribi, Cameroon, possessed  $\beta$ -pinene and  $\alpha$ -pinene as the main constituents<sup>25</sup>. The stem bark EO of *Xylopiya*

*pynaertii* De Wild. Collected from Zaire contained mainly cubenol,  $\alpha$ -cadinene and  $\gamma$ -muurolene, while the major volatile components of the root oil included elemol,  $\alpha$ -cubebene and isoeugenol<sup>40</sup>.

The EO obtained from the *Xylopiya sericea* A. St.-Hil. fruits grown in Minas Gerais, Brazil, were found to be rich in spathulenol, guaiol and germacrene D<sup>49</sup>, while root bark oil contained *p*-cymene,  $\alpha$ -gurjunene and  $\alpha$ -muurolene-3-one as the major compounds<sup>40</sup>. Spathulenol was the most abundant constituent in the leaf EOs of *Xylopiya brasiliensis* Spreng. and *Xylopiya emarginata* Mart. from Brazil<sup>32,50,51</sup>. Furthermore, the leaf oil *Xylopiya ferruginea* (Hook.f. & Thomson) Baill. from Malaysia was characterised by the predominance of bicyclogermacrene, elemol, guaiol and germacrene D, whereas the leaf oil of *Xylopiya magna* Maingay ex Hook.f. collected from the same location had germacrene D, bicyclogermacrene and spathulenol as the main compounds<sup>37</sup>. The major volatile compounds of the leaf oil of *Xylopiya cayennensis* Maas from Pará, Brazil, included  $\alpha$ -pinene,  $\beta$ -pinene, caryophyllene oxide and bicyclogermacrene, while the leaf oil of *Xylopiya nitida* Dunal grown in the same location contained  $\gamma$ -terpinene, *p*-cymene,  $\alpha$ -terpinene and limonene as the major compounds<sup>32</sup>. In addition, the EO obtained from *Xylopiya pierrei* Hance from Ben En National Park, Vietnam, were dominated by  $\beta$ -elemene, bicycloelemene,  $\beta$ -caryophyllene, bicyclogermacrene, germacrene D while  $\beta$ -elemene, bicyclogermacrene, germacrene D, camphene were the main components in the leaf EO of *Xylopiya vielana* Pierre grown in Ke Go Natural Reserve, Vietnam<sup>52</sup>.

### Pharmaceutical properties of *Xylopiya* essential oils

Pharmaceutical properties of EOs of different *Xylopiya* species is given in Table 2.

#### Antimicrobial activity

The EO obtained from fruits of *X. aethiopica* from Kwara, Nigeria, possessed significant antimicrobial effects against four Gram-negative and three Gram-positive bacteria. Accordingly, the oil showed potent activities against *Treptococcus pyogenes*, *Bacillus subtilis*, *Staphylococcus aureus*, *Klebsiella pneumonia*, followed by *Serratia marcescens*, *Escherichia coli*, *Enterobacter aerogenes*<sup>9</sup>. Fleischer *et al.*<sup>54</sup> provided the antimicrobial effects of EOs isolated from various plant parts of *X. aethiopica* grown in Ghana. This result showed that the leaf, stem bark, root bark, fresh fruit and dried fruit oils

Table 2 — Pharmaceutical properties of *Xylopia* essential oils

Scientific name	Part	Pharmaceutical properties	References
<i>X. aethiopica</i>	Fruit	Antimicrobial, antioxidant and insecticidal activities	9,10,12,45,46,55,56
<i>X. aromatica</i>	Leaf	Antimicrobial, antioxidant and cytotoxic activities	2,45,46,58
<i>X. aethiopica</i>	Stem, bark	Antimicrobial and antioxidant activities	4,54
<i>X. aethiopica</i>	Root bark	Antimicrobial and antioxidant activities	4,54
<i>X. aromatica</i>	Flower	Antimicrobial activities	8
<i>X. aethiopica</i>	Seed	Anticholinesterase activities	12
<i>X. frutescens</i>	Stem bark	Antimicrobial activities	40
<i>X. frutescens</i>	Leaf	Cytotoxic activities	39
<i>X. hypolamptra</i>	Stem bark	Antibacterial activities	53
<i>X. laevigata</i>	Leaf	Antimicrobial, trypanocidal, larvicidal, antioxidant, anti-inflammatory, cytotoxic and antitumor activities	11,13-15
<i>X. langsdorffiana</i>	Fruit	Cytotoxic activities	46
<i>X. langsdorffiana</i>	Leaf	Spasmolytic and molluscicidal activities	16,61
<i>X. parviflora</i>	Leaves	Cytotoxic activities	25
<i>X. parviflora</i>	Root bark	Insecticidal activities	17
<i>X. pynaertii</i>	Stem bark	Antimicrobial activities	40
<i>X. pynaertii</i>	Root	Antimicrobial activities	40
<i>X. sericea</i>	Root bark	Antimicrobial activities	40
<i>X. sericea</i>	Fruit	Antibacterial and antioxidant activities	49

possessed strong antibacterial activities against *Bacillus subtilis*, *Pseudomonas aeruginosa* and *Staphylococcus aureus* while these samples presented moderate antifungal effects against *Candida albicans*<sup>54</sup>. In addition, the fruit EOs of *X. aethiopica* from Cameroon showed good inhibition of growth of *Aspergillus flavus*, *A. fumigatus*, *A. versicolor*, *A. niger* and *Fusarium oxysporium* with MIC values of ranged from 3000 to 4000 ppm<sup>10</sup>. Also, the EO of *X. aethiopica* fruits from Nigeria possessed antifungal effects against *Aspergillus flavus*, *A. ocheraceus*, *Stellocapella maydis* and *Fusarium oxysporium*<sup>55</sup>.

The flower and leaf EOs of *X. aromatica* from Brazil showed strong antibacterial effects against *Streptococcus pyogenes* with MIC values of 200 and 100 µg/mL, respectively, while these oils showed MIC values of 400 µg/mL towards *Burkholderia cepacia*, *Pseudomonas aeruginosa* ATCC 14502, *P. aeruginosa* ATCC 27853, *Staphylococcus aureus* ATCC 25923, *S. aureus* ATCC 43300, and *S. aureus* ATCC 29213<sup>8</sup>. Furthermore, the flower and leaf oils of this plants also presented antifungal effects against *Candida albicans*, *C. tropicalis* and *Propionibacterium acnes*, with MIC values ranging from 400 to 2000 µg/mL<sup>8</sup>. In addition, the *X. hypolamptra* Stem bark oils showed antibacterial activities against *Staphylococcus aureus*, *Escherichia coli* and *Streptococcus pyogenes* with MIC values of 500 µg/mL<sup>53</sup>. The leaf oils of *X. laevigata* collected from Brazil showed strong antimicrobial effects

against *Staphylococcus aureus*, *S. epidermidis* and *Candida tropicalis* with MIC values of 100 µg/mL, followed by *C. albicans* (MIC=5000 µg/mL)<sup>11</sup>. Also, the *X. sericea* fruit EO from Brazil possessed potent antibacterial activities against four bacterial strains, including *Staphylococcus aureus*, *Enterobacter cloacae* (MIC values of 7.8 µg/mL), *Bacillus cereus* (MIC value of 15.63 µg/mL), *Klebsiella pneumonia* (MIC value of 62.5 µg/mL)<sup>49</sup>.

Fournier *et al.*<sup>40</sup> demonstrated that the EOs and their major chemical constituents obtained from three *Xylopia* species, such as *X. frutescens*, *X. sericea*, and *X. pynaertii* possessed antimicrobial activities. As a result, the stem bark oil of *X. frutescens* collected from French Guyana showed potent antimicrobial effects against *Myobacterium smegmatis* (MIC= 2 mg/mL), followed by *Staphylococcus aureus* (MIC= 10 mg/mL), *Escherichia coli*, *Candida albicans* (MICs= 20 mg/mL) and *Pseudomonas aeruginosa* (MIC > 20 mg/mL)<sup>40</sup>. In addition, the root bark oil of *X. sericea* from French Guyana had a weak antibacterial effect against *S. aureus*, *E. coli* and *P. aeruginosa* with MIC values of more than 20 mg/mL, whereas this sample showed stronger antifungal activities against *M. smegmatis* and *C. albicans* with MIC values of 10 mg/mL<sup>40</sup>. Furthermore, the stem bark oil of *X. pynaertii* from Zaire possessed weak antimicrobial effects against five microorganisms with MIC values of 20 or more than 20 mg/mL<sup>40</sup> while the root oil of this species had

potent antimicrobial activities against *S. aureus* and *M. smegmatis* with MIC values of 2 mg/mL, followed by *C. albicans* (MIC = 20 mg/mL), *E. coli* and *P. aeruginosa* (MIC > 20 mg/mL)<sup>40</sup>.

Several major compounds obtained from EOs of *X. frutescens*, *X. sericea*, and *X. pynaertii* have been reported to possess antimicrobial activities<sup>40</sup>. Accordingly, carvacrol showed the strongest antimicrobial effects against *S. aureus*, *E. coli* and *C. albicans* with MIC values lower than 0.1 mg/mL, followed by *P. aeruginosa* and *M. smegmatis* (MICs = 1 mg/mL)<sup>40</sup>. Myrtenol also presented potent antimicrobial activities against *E. coli*, *M. smegmatis* (MICs = 0.1 mg/mL), *S. aureus* and *C. albicans* (MICs = 0.51 mg/mL), while caryophyllene and *p*-cymene showed weak antimicrobial effects against five oral microorganisms with MIC values of more than 20 mg/mL<sup>40</sup>.

#### Antioxidant activity

The antioxidant effects of the EO of *X. aethiopica* fruit collected from Bafoussam, Cameroon, were determined using 1,1-diphenyl-2-picrylhydrazol (DPPH) with SC<sub>50</sub> value of 594.58 µg/mL. This study found that *X. aethiopica* fruit oils had a low antioxidant effect compared to butylated hydroxytoluene (SC<sub>50</sub> = 65.03 µg/mL)<sup>10</sup>. The fruit and leaf EOs of *X. aethiopica* from Ivory Coast had strong antioxidant activities against DPPH radicals. Accordingly, the IC<sub>50</sub> value of fruit oil (4.1 mg/mL) was lower than that of vitamin E (IC<sub>50</sub> = 4.3 mg/mL), whereas the leaf oil possessed the IC<sub>50</sub> value (4.9 mg/mL) slightly more than that of Vitamin E<sup>6</sup>. In a published study done by Sulaimon *et al.*<sup>12</sup>, the free radicals scavenging effect of fruit EO of *X. aethiopica* from Nigeria against DPPH with IC<sub>50</sub> value of 2.19 mg/mL was reported to be higher than that of ascorbic acid, which used as positive control (IC<sub>50</sub> value of 0.013 mg/mL)<sup>12</sup>.

Moreover, the antioxidant potential of *X. aethiopica* oil was also presented by FRAP and TAC values of 10.03 and 10.92 mg AAE/g, respectively<sup>12</sup>. The antioxidant effects of EOs isolated from different organs of *X. aethiopica* collected from Ghana have been investigated according to the DPPH assay. Accordingly, the oil isolated from fresh fruit presented the greatest antioxidant effects with 85.6% interaction. The leaf oil produced approximately 43.8% interaction, followed by the root and stem barks (32.4 and 36.5% interaction), while the dried fruit EO had the lowest interaction (21.2%)<sup>4</sup>.

In addition, using the oxygen radical absorbance capacity (ORACFL) assay, Costa *et al.*<sup>11</sup> showed that the EO of *X. laevigata* leaf from Brazil had an antioxidant effect with an ORAC value of 1468.96 µmol of TE/g. The antioxidant activity of (*E*)-caryophyllene, a major constituent obtained from *X. laevigata* oil, was also investigated with an ORAC value of 1097.64 µmol of TE/g<sup>11</sup>. Similarly, the leaf EO obtained from *X. laevigata* grown in Brazil was investigated for antioxidant activities using a DPPH assay. As a result, the *X. laevigata* oil possessed a strong antioxidant effect with an IC<sub>50</sub> value of 11.98 µg/mL compared to butylated hydroxytoluene (IC<sub>50</sub> = 11.06 µg/mL)<sup>13</sup>. Furthermore, the antioxidant effects of fruit EO of *X. sericea* from Brazil were investigated by DPPH, β-Carotene/linoleic acid bleaching, thiobarbituric acid-reactive substance (TBARS) and total antioxidant capacity (TAC) methods<sup>49</sup>. Accordingly, *X. sericea* oil showed greater antioxidant effects in the TAC (78.2% RAA quercetin) and TBARS (80.0% inhibition) test as compared to that of ascorbic acid (34.2% RAA quercetin) and butylated hydroxytoluene (13.7% inhibition), respectively<sup>49</sup>. Meanwhile, the *X. sericea* oil possessed lower antioxidant effects in the DPPH assay with an IC<sub>50</sub> value of 49.16 µg/mL when compared to that of the reference compounds, including α-tocopherol (IC<sub>50</sub> = 0.72 µg/mL) and ascorbic acid (IC<sub>50</sub> = 0.41 µg/mL)<sup>49</sup>. Similarly, the *X. sericea* oil also showed lower antioxidant activity in β-carotene/linoleic acid bleaching with an IC<sub>50</sub> value of 6.92 µg/mL as compared to that of quercetin (IC<sub>50</sub> = 1.18 µg/mL)<sup>49</sup>.

#### Cytotoxic and antitumor activities

Bakarnga-Via *et al.*<sup>25</sup> reported a cytotoxic and antitumor study using MTT assay, in which the leaf EO obtained from *X. aethiopica* and *X. parviflora* grown in La Nya Pendé and Cameroon have been reported to possess cytotoxic effects against normal epithelial (ARPE-19) and human breast cancer (MCF-7) cell lines<sup>25</sup>. Specifically, the *X. aethiopica* oil from La Nya Pendé had cytotoxic activities against MCF-7 cell (IC<sub>50</sub>=0.325 µg/mL) and ARPE-19 cell (IC<sub>50</sub>=1.233 µg/mL) while IC<sub>50</sub> values of 0.6 and 0.825 µg/mL respectively were showed by the oil from Cameroon towards the same cell lines<sup>25</sup>. Meanwhile, the EO of *X. parviflora* leaves possessed cytotoxic effects slightly higher than *X. aethiopica* oil. Consequently, *X. parviflora* oil from La Nya Pendé highly cytotoxic to MCF-7 and ARPE-19 cells with IC<sub>50</sub> values of 0.155

and 0.91  $\mu\text{g/mL}$ , respectively while this sample from Cameroon had  $\text{IC}_{50}$  values of 0.166 and 0.92  $\mu\text{g/mL}$ , respectively<sup>25</sup>. In addition, the leaf EO of *X. frutescens* collected from Brazil showed cytotoxic activities against NCI-H358M (bronchoalveolar lung carcinoma), OVCAR-8 (ovarian adenocarcinoma) and PC-3M (metastatic prostate carcinoma) human tumour cell lines. As a result, the *X. frutescens* oil possessed the highest cytotoxic effect against H358M cells with  $\text{IC}_{50}$  values of 24.6  $\mu\text{g/mL}$ , followed by OVCAR-8 cell ( $\text{IC}_{50}$ =33.9  $\mu\text{g/mL}$ ) and PC-3M cell ( $\text{IC}_{50}$ = 40.0  $\mu\text{g/mL}$ )<sup>39</sup>.

Quintans *et al.*<sup>14</sup> provided that the leaf EO of *X. laevigata* from different regions, such as Itabaiana Mountain National Park, Mata do Crasto and Municipality, Brazil, possessed cytotoxic and antitumor activities. Accordingly, the sample oil from Itabaiana Mountain National Park had potent cytotoxic effects against HL-60 and SF-295 cell lines with  $\text{IC}_{50}$  values of 17.5 and 14.4  $\mu\text{g/mL}$ , followed by HCT-116, OVCAR-8 and PBMC cells with  $\text{IC}_{50}$  values of 22.2, 31.6, and 63.7  $\mu\text{g/mL}$ , respectively<sup>14</sup>. The sample from Mata do Crasto showed the strongest effects against SF-295 cells ( $\text{IC}_{50}$ =17.9  $\mu\text{g/mL}$ ), moderate activities against HL-60, HCT-116, OVCAR-8 and PBMC cells with  $\text{IC}_{50}$  values of 25.0, 25.5, 27.1, and 35.3  $\mu\text{g/mL}$ , respectively<sup>14</sup>. The oil from Municipality displayed cytotoxic activities against OVCAR-8, SF-295, HL-60, HCT-116, and PBMC cell lines with  $\text{IC}_{50}$  values of 18.5, 20.5, 20.6, 27.6, and 56.9  $\mu\text{g/mL}$ , respectively<sup>14</sup>. Furthermore, Quintans *et al.*<sup>14</sup> provided that the leaf EO of *X. laevigata* collected from Mata do Crasto also possessed antitumor activities. After 7 days of treatment, the effect of the EO on mice transplanted with sarcoma 180 tumour was significant. At doses of 50 and 100 mg/kg/day, tumour growth inhibition rates of the EOs were 37.3 and 42.5%, respectively. These rates were slightly lower than the control's (5-FU with 67.8% inhibition)<sup>14</sup>.

Pereira *et al.*<sup>15</sup> have reported the cytostatic and mutagenic activities of the leaf EO of *X. laevigata* collected from Brazil using MTT and mitotic index methods in cultured human lymphocytes. At 89, 178, 267, and 356  $\mu\text{g/mL}$  doses, the oil showed 17.3, 21.27, 32.72, and 39.67% cytotoxicity, respectively<sup>15</sup>. In addition, the leaf EO of *X. laevigata* from Brazil showed high toxicity against UACC-62, NCI-ADR/RES and NCI-H460 with TGI values of 4.03, 4.26, and 8.37  $\mu\text{g/mL}$ , respectively, followed by VERO, MCF-7, U251, 786.0, OVCAR-3, PC-3, HT-29, and K562 cell lines

with TGI values of 15.94, 19.44, 20.29, 21.66, 31.48, 35.57, 36.71, and 250  $\mu\text{g/mL}$ <sup>11</sup>.

Moura *et al.*<sup>46</sup>, in a study, have found cytotoxic and antitumor activities of the EO of *X. langsdorffiana* fruit collected from Paraiba State, Brazil, using haemolysis, acute toxicity and micronucleus assays. The result in the study concluded that the oil exhibited cytotoxic activities against several cell lines, including glioma (U251), kidney (786-O), ovary multidrug resistance phenotype (NCI-ADR/RES), lung (NCI-H460), breast (MCF-7), prostate (PC-3), colon (HT-29), ovary (OVCAR), leukaemia (K562), skin (line of non-tumour cells) (HaCat). Accordingly, the oil showed the strongest cytotoxic effect against K562 with TGI value of 1.8  $\mu\text{g/mL}$ , followed by NCI-ADR/RES, HaCat, PC-3, MCF-7, 786-O, U251, HT-29, NCI-H460 and OVCAR with TGI values of 45.4, 74.5, 78.4, 102.1, 107.3, 118.2, 118.8, 191.9, and 250  $\mu\text{g/mL}$ <sup>46</sup>.

#### Insecticidal and larvicidal activities

The EO of *X. aethiopica* fruit grown in Nigeria possessed insecticidal effects against rice weevil (*Sitophilus oryzae*), a pest of stored grains and processed grain products<sup>56</sup>. At a dose of 0.5 mg/cm<sup>2</sup>, the *X. aethiopica* oil showed 21.67% mortality of *Sitophilus oryzae* adults while 84.17% and 98.33% were showed by the oil towards the same rice weevil at doses of 1.0 and 1.5 mg/cm<sup>2</sup>, respectively. Finally, at a dose of 2.0%, the *X. aethiopica* oil showed the strongest insecticidal activity against rice weevil with 100% mortality of *Sitophilus oryzae* adults<sup>56</sup>. In addition, the root bark EO of *X. parviflora* collected from Nigeria showed insecticidal activities against the bruchid beetle (*Callosobruchus maculatus*), a pest of stored seeds<sup>17</sup>. Once *C. maculatus* was exposed to *X. parviflora* EO at a dose of 6.25 mL/mL air, the  $\text{LT}_{50}$  value (lethal time for 50% of assayed adults) was 2.71 hours. This value was significantly lower than  $\text{LT}_{50}$  obtained from exposure of *C. maculatus* to other lower doses, ranging from 0.78 to 3.15 mL/mL air<sup>17</sup>. Furthermore, the leaf EO of *X. laevigata* from Brazil showed larvicidal activities against the yellow fever mosquito (*Aedes aegypti*) with an  $\text{LC}_{50}$  value of 632.36  $\mu\text{g/mL}$ <sup>17</sup>.

#### Other activities

The leaf EO of *X. laevigata* from Brazil has been reported to possess strong anti-trypanosomal activities against *Trypanosoma cruzi* with an  $\text{IC}_{50}$  value of 93.9  $\mu\text{g/mL}$ . The potent trypanocidal effect of the *X. laevigata* EO could be associated with the

predominance of  $\delta$ -cadinene, (*E*)-caryophyllene, germacrene D,  $\gamma$ -cadinene, bicyclogermacrene and  $\alpha$ -copaene<sup>11,57-60</sup>.

In another research, the leaf EO isolated from *X. laevigata* grown in Brazil was investigated for anti-inflammatory activities using carrageenan-induced hindpaw oedema and carrageenan-induced leukocyte migration tests in mice. In brief, the *X. laevigata* oil at doses of 12.5, 25, and 50 mg/kg presented 33.5, 36.4, and 42.4% inhibition for carrageenan-induced leukocyte migration and 34.4, 41.0, and 44.3% inhibition respectively for carrageenan-induced hindpaw oedema<sup>13</sup>. Those percentages of inhibition were significantly lower than that of indomethacin (standard drug), with 59.2 and 65.6% inhibition at a dose of 10 mg/kg in carrageenan-induced leukocyte migration and carrageenan-induced hindpaw oedema tests, respectively<sup>13</sup>.

Correia *et al.*<sup>61</sup> have used smooth muscle models of different body systems to investigate the spasmolytic effects of the *X. langsdorfiana* leaf EO from Brazil<sup>61</sup>. As a result, on guinea pig trachea and rat aorta and uterus, the *X. langsdorfiana* oil showed low spasmolytic activities at a dose of 243 mg/mL while the sample had significant effects on these organs at a dose of 729 mg/mL<sup>61</sup>. In guinea pig ileum, the *X. langsdorfiana* oil significantly inhibited carbachol and histamine-induced phasic contractions with IC<sub>50</sub> values of 83.3 and 81.8 mg/mL, respectively<sup>61</sup>. In ileal myocytes stimulated by histamine, the *X. langsdorfiana* oil reduced fluorescence intensity at the dose of 81 mg/mL<sup>61</sup>. In addition, leaf EO of *X. frutescens* collected from Brazil also possessed spasmolytic activities<sup>38</sup>.

*Biomphalaria glabrata* is the main intermediate host for transmission of the worm *Schistosoma mansoni*<sup>62</sup>. Tavares *et al.*<sup>16</sup> showed molluscicidal activity of the leaf EO of *X. langsdorfiana* from Brazil. Accordingly, the *X. langsdorfiana* oil had a potent molluscicidal effect against *B. glabrata* with LC<sub>10</sub>, LC<sub>50</sub> and LC<sub>90</sub> values of 5.61, 3.72, and 1.83  $\mu$ g/mL, respectively. The strong molluscicidal activities of *X. langsdorfiana* EO could be attributed in part to  $\beta$ -pinene and  $\alpha$ -pinene as the major components. Lahlou<sup>63</sup> demonstrated that  $\beta$ -pinene and  $\alpha$ -pinene possessed strong molluscicidal activity against *B. glabrata* with LC<sub>90</sub> values of 0.54 and 0.49 ppm, respectively.

The EOs obtained from *X. aethiopica* grown in Ogun and Ondo, Nigeria, showed strong

anticholinesterase activities. As a result, IC<sub>50</sub> values for the concentration-dependent inhibition of acetylcholine esterase and butyrylcholine esterase inhibition of the oil from Ogun, Nigeria, were 1.21 and 1.41 mg/mL, respectively<sup>12</sup>, while 18.7 and 26.4  $\mu$ g/mL, respectively were shown by the sample from Ondo, Nigeria towards the same enzymes<sup>55</sup>. Notably, the EO of *X. aethiopica* collected from the Ogun and Ondo regions of Nigeria possessed an acetylcholine esterase inhibition stronger than the butyrylcholine esterase inhibition. The *X. aethiopica* EOs, thus, show extensive therapeutic potentials for improving cognitive effects or nerve cell communication<sup>12</sup>.

### Conclusion

In this review, many relevant scientific reports were gathered and reviewed to provide information on the chemical components and pharmaceutical properties in the EOs obtained from *Xylopi*a species. Consequently, the chemical profiles of the EOs isolated from *Xylopi*a plants greatly varied with the different regions where the specimens were collected. As mentioned earlier, the bioactive compounds and pharmaceutical properties of the *Xylopi*a EOs obtained from the studies would partially contribute to the herbal medicine development technology. However, most of the studies on the biological activities of *Xylopi*a species were limited to the whole EO extract rather than each constituent. Further research in the future should be oriented towards the isolation of each constituent. Aside from that, each constituent and the combination of some constituents should be investigated for their biological activities.

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### Conflict of interest

There is no conflict of interest.

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