Phytometabolites, Pharmacological Effects, Ethnomedicinal Properties, and Bioeconomic Potential of Velvet Apple (*Diospyros discolor* Willd.): A Review

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Abstract

Diospyros discolor Willd., commonly known as Velvet apple or Mabolo, is an underutilized fruit. Traditionally, various parts of *D. discolor* have been used in medicine for treating dysentery, diarrhoea, and respiratory issues. Pharmacologically, the plant has exhibited diverse effects including anti-acetylcholinesterase, anti-asthmatic, anti-aging, antimicrobial, antioxidant, cytotoxic, and thrombolytic activities. These findings substantiate its traditional uses, particularly its potential as an antidiabetic, antidiarrheal, analgesic, anti-inflammatory, and vasorelaxant agent. This plant is notable for its rich aromatic profile, containing 39 volatile compounds in the fruit and peel, with esters and α-farnesene being the predominant compounds. Volatile esters such as methyl butyrate and ethyl dominate the aroma. Nutritionally, the fruit contains dietary fibre, malic acid, vitamins, essential fatty acids, flavonoids, and triterpenes. Additionally, bioactive compounds including flavonoids, triterpenes, and dimeric naphthoquinones (e.g., diospyrin) have been isolated from the plant. The essential oil derived from its flowers further enhances its bioeconomic and health benefits. Moreover, *D. discolor* holds bioeconomic potential as a biosorbent, a source of timber and edible fruits, and a material for synthesizing silver nanoparticles. This review consolidates current knowledge on the traditional uses, phytometabolites, pharmacological properties, and bioeconomic potential of *D. discolor*. The potential toxicity of this plant and its components has also been reviewed.

Keywords: *Diospyros discolor*; *Diospyros blancoi*; *Diospyros mabolo;* Phytometabolites; Pharmacological properties; Ethnomedicine; Bioeconomy; Velvet apple

Introduction

Diospyros discolor Willd. (Synonym: *D. blancoi* A. DC.) from the family Ebenaceae is commonly known as Velvet apple, Velvet persimmon, Kamagong, Bisbul, or Mabolo tree, which comprises over 500 species. It is a dioecious tropical species indigenous to the Philippines.[1] The *D. discolor* tree thrives in regions with a monsoon climate and adapts well to various soil types. The plant produces edible fruits with a velvety, reddish-brown skin (Figure 1). In Bangladesh, this tree is locally referred to as "Bilati gab" and remains an underutilized fruit. Velvet apple has been used in traditional medicine.[2] and holds various potential benefits that are of increasing interest in scientific research.

Figure 1. Leaf and Fruit of *Diospyros discolor* Willd.

The name *Diospyros* originates from Greek, interpreted as "divine wheat," akin to "fruit of the gods".[3] The genus *Diospyros* holds significant economic, nutritional, and pharmacological value, with a long history of use in folk medicine.[1,4] Over 200 bioactive compounds have been identified in this genus, highlighting its potential for drug development and clinical applications.[5] For instance, the Naoxinqing tablet, derived from Japanese Persimmon (*Diospyros kaki* L.) leaf extract, is a patented Traditional Chinese Medicine included in the Chinese Pharmacopoeia and authorized for the treatment of cerebral arteriosclerosis.[6]

The *Diospyros* genus contains various phytochemicals, including naphthoquinones, naphthalene derivatives, phenolic compounds, and terpenoids.[1,4-5] These species exhibit diverse pharmacological effects, such as antioxidant, neuroprotective, antibacterial, anti-inflammatory, antiviral, antiprotozoal, antihypertensive, antifungal, analgesic, antipyretic, anthelmintic, enzyme-

inhibitory, and cosmeceutical properties, as demonstrated through *in vitro* and *in vivo* assays.[1] Within this genus, *D. kaki* and *D. lotus* have been extensively researched regarding their chemical composition and pharmacological properties.[5] However, there is no comprehensive review available to date on *Diospyros discolor*. Therefore, a systematic literature search was conducted on *D. discolor* using several databases e.g., Web of Science, PubMed and Google Scholar, and employing the search term '*Diospyros discolor'.* This review appraises the ethnomedicinal uses, phytochemicals, and pharmacological features of the plant from existing literature. In addition, the review explores the potential bioeconomic benefits of the Velvet apple tree.

Reported Ethnomedicinal Properties of *Diospyros discolor*

Diospyros discolor has been traditionally used for medicinal purposes in Bangladesh, Guyana, Indonesia and the Philippines.[1] In the Philippines, the leaves are used to treat kidney problems, fever, headache, sore throat, stomach ache, diarrhea, rashes, abdominal pain, and cough.[2] Additionally, it is believed to manage hypertension, heart disease, diabetes, eczema, and spider bites. In Bangladesh, ripe fruits are consumed for diabetes management, and unripe fruit juice is used for skin diseases and wound healing.[2] The seeds of are considered an aphrodisiac (**Table 1**).

Table 1. Reported ethnomedicinal uses of *Diospyros discolor* Willd.

Ailment	**Part(s) used and formulation**	**Country/region**	**References**
Kidney problem	Not recorded	Philippines	[7]
Fever and headache	Not recorded	Philippines	[8]
Sore throat, stomachache, diarrhea, and fever	Leaf; boiling	Philippines	[9]
Rashes	Leaf; Poultice	Philippines	[10]
Abdominal pain	Not recorded	Philippines	[11]
Cough	Leaf; boiling	Philippines	[12]
Colds, diarrhea, hypertension, heart disease, diabetes, stomachache, eczema, and spider bites	Leaf	Philippines	[13]
Hypertension, diabetes, hypertension, fever	Leaf	Philippines	[14]
Diabetes	Fruit. Ripe fruits are taken	Bangladesh	[15]
Dysentery	Fruit, bark; Ripe fruits and powdered bark of	Bangladesh	[16]

	young tree are taken orally		
Skin disease	Fresh juice is extracted by squeezing the unripe fruits of the plants. The juice is taken twice a day (200 mL each time) for 3 days	Bangladesh	[17]
Wounds	The fruit juice of unripe fruit is used as a wash	Bangladesh	[18]
Aphrodisiac	Seed	Bangladesh	[19]
Type 2 Diabetes Mellitus	Leaf	Guyana	[20]
Reduce cholesterol, risk of heart	Leaf	Indonesia	[21]

In Bangladesh, ripe fruits and powdered bark of young trees are taken orally to treat dysentery.[16] In Indonesia, it is believed that this plant may help reduce cholesterol and the risk of heart diseases.[21] In Guyana, the leaves are associated with managing Type 2 Diabetes Mellitus.[20]

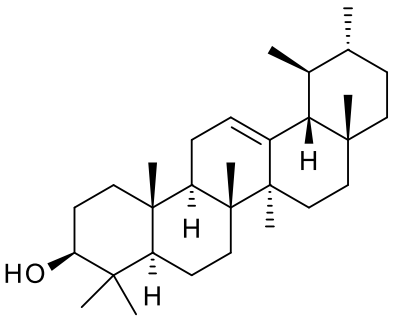
Reported Phytometabolites of *Diospyros discolor*

Velvet apple contains biologically active compounds of the chemical classes of anthraquinones, naphthoquinones, triterpenes, and various essential oil components that contribute to its health benefits. A comprehensive analysis of Velvet apple, focusing on both its aroma compounds and nutrient contents was conducted.[22] In total, 39 different volatile compounds were isolated from various parts of the fruit. Both the intact fruit and the peel contribute to the aromatic profile, with 24 compounds found in each. Additionally, the pulp contains 28 compounds.[22] Among these compounds, butyric acid esters and α-farnesene play crucial roles in shaping Mabolo's distinctive aroma. Mabolo boasts a dietary fibre content of 3.2%. Other nutrients include malic acid, vitamin B2, vitamin B3, folic acid, pantothenic acid, choline chloride, calcium, and zinc.[22] The fruit contains essential fatty acids such as 9,12-octadecadienoic acid, 9-octadecenoic acid, hexadecanoic acid, and octadecanoic acid, identified by gas chromatography-time of flight-mass spectrometry.[23]

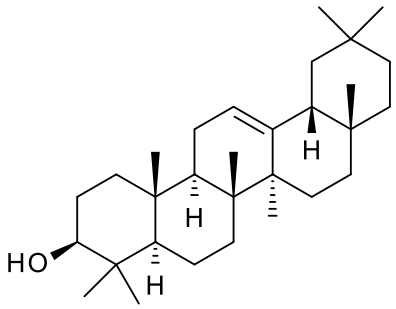
The fruit also contains volatile compounds identified as esters, making up 88.6% of the total volatiles.[24] These include methyl butyrate, ethyl butyrate, butyl butyrate, and benzyl butyrate. Another study identified 96 volatile compounds in the fruit, including benzyl butyrate, butyl butyrate, and (*E*)-cinnamyl butyrate. Lanostane-type triterpenes were isolated from Mabolo twigs,

along with three known triterpenes: betulinaldehyde, betulinic acid methyl ester, and ursaldehyde.[25-27]

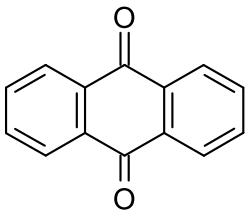
The total flavonoid content of the seeds was reported to be high.[28] 7,4'-Dihydroxy-5,3',5'-trimethoxyflavonol or 3,7,4'-trihydroxy-5,3',5'-trimethoxyflavone, along with other flavonoids and their glycosides and six triterpenes were isolated.[2] *Diospyros discolor* is a good source of bioactive triterpenes, such as cylindrin and fatty esters of α- and β-amyrin.[29] Three dimeric naphthoquinones, i.e., habibone, diospyrin, and 8'-hydroxyisodiospyrin, were isolated from the roots of *D. discolor*. Anthraquinone, ellagic acid glycosides, and the ubiquitous triterpenes lupeol, betulin, and betulinic acid were reported from the stem bark.[30] The chemical structures of a few bioactive compounds of *D. discolor* are shown in **Figure 2**.



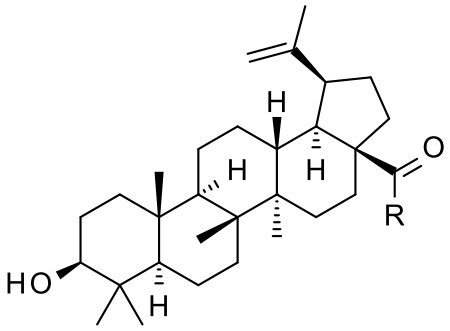
α-Amyrin



β-Amyrin



Anthraquinone



Betulinaldehyde R = H
Betulinic acid R = OH
Betulinic acid methyl ester R = OMe

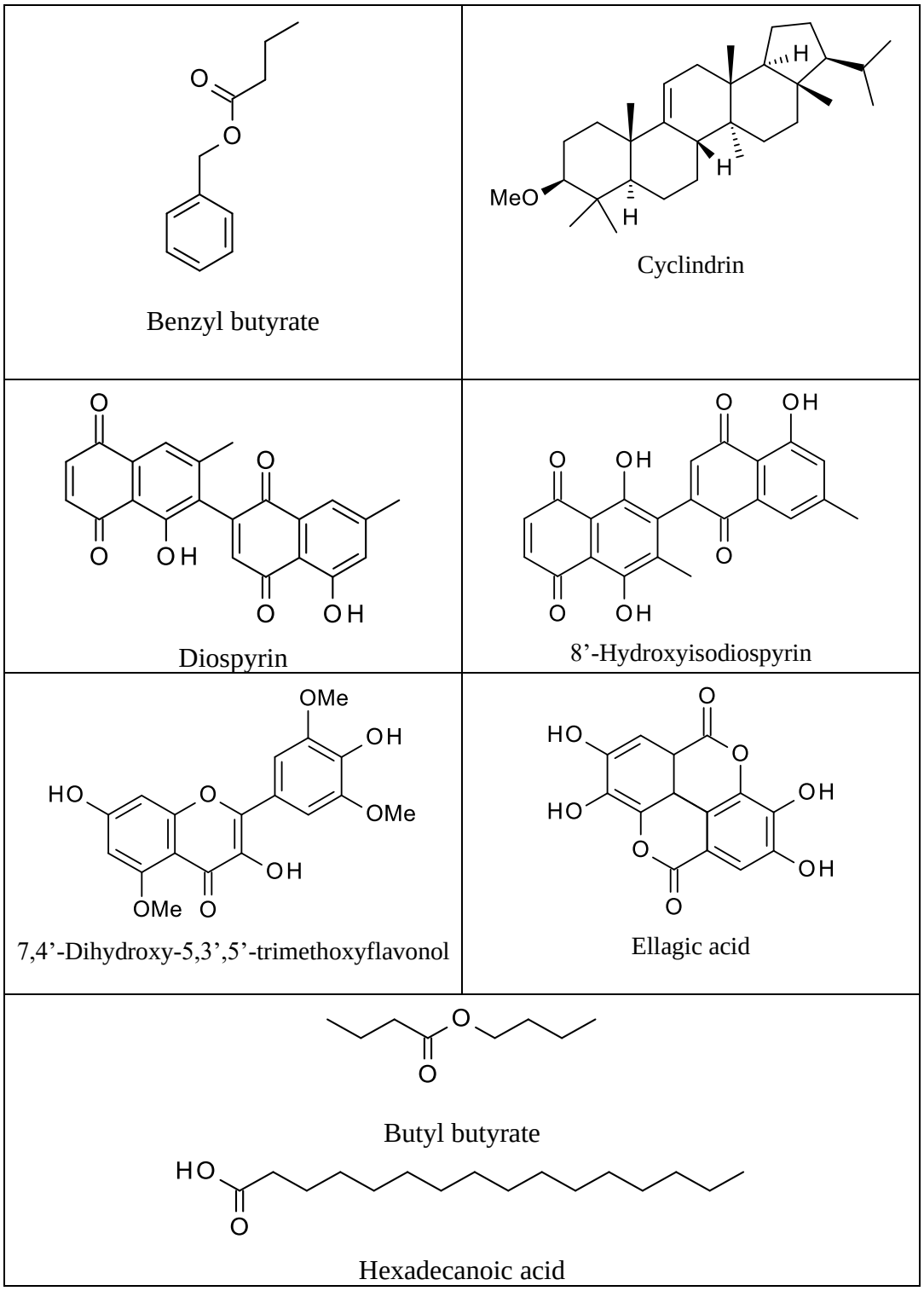


Figure 2. Structures of a few bioactive components of *D. discolor*

Pharmacologically active Components

Several bioactive phytochemicals found in *D. discolor* exhibit diverse pharmacological properties. Ellagic acid glycosides, for instance, show a hepatoprotective effect.[31] Additionally, diospyrin

has demonstrated anticancer, antibacterial, and antiparasitic activities; betulinaldehyde has antitumor and antibacterial effects; and betulinic acid possesses anti-inflammatory, antidiabetic, and antibacterial properties (**Table 2**).

Table 2. Reported pharmacological bioactive components of *Diospyros discolor*

Phytochemical (molecular formula)	**Bioactivity**	**References**
Betulinaldehyde ($C_{30}H_{48}O_2$)	Anti-tumor (betulinaldehyde exhibits substantial *in-vitro* anti-tumor properties by impeding several pro-cancers signaling pathways in tumor cells. Its anti-tumor impact is linked to its ability to regulate autophagy levels in A549 cells)	[32]
	Antibacterial (betulinaldehyde combined with α-amyrin and betulinic acid are pentacyclic triterpenoids known for their ability to display anti-staphylococcal effects. When used alongside vancomycin, the minimum inhibitory concentration (MIC) of betulinaldehyde is lowered against MRSA and MSSA3 reference strains)	[33]
Betulinic acid ($C_{30}H_{48}O_3$)	Antitumor (exhibits cytotoxicity against various cancer cell lines, making it a potential antitumor agent)	[34-35]
	Antiviral (demonstrated activity against HIV, inhibiting viral replication)	
	Antidiabetic (shows promise in managing diabetes by improving insulin sensitivity)	
	Antimalarial (impacts various stages of the malarial parasite life cycle. including both the liver and blood stages of the parasite)	
	Antihyperlipidemic (may help regulate lipid levels, benefiting individuals with hypercholesterolemia)	

	Parasiticidal and anti-infectious (shown activity against various parasites, such as *Leishmania* spp., *Plasmodium falciparum*; against bacteria, *Staphylococcus aureus, Mycobacterium tuberculosis*)	
Betulinic acid methyl ester ($C_{31}H_{50}O_{3)}$	Antiprotozoal (betulinic acid methyl ester (BA-ME) is a compound derived from betulinic acid and is isolated from *Pentalinon andrieuxii* leaves. Research indicates that altering the C-3 position of betulinic acid enhances its effectiveness against leishmaniasis, while changing both the C-3 and C-28 positions reduces its efficacy against trypanosomiasis)	[36]
Diospyrin ($C_{22}H_{14}O_6$)	Anticancer (diospyrin and its analogs have attracted interest for their potential anticancer properties. They can produce free radicals, leading to oxidative stress within cancer cells. These reactive oxygen species (ROS) can disrupt cellular processes and trigger apoptosis. These compounds likely interfere with the molecular signal pathways that control cell growth, survival, and apoptosis in cancer cells)	[37]
	Antibacterial (diospyrin derivatives were created and tested against *Mycobacterium tuberculosis* to assess their antimycobacterial activity. An aminoacetate derivative demonstrated higher activity than the original compound, diospyrin. Its minimum inhibitory concentration (MIC) was 50 mg/L against a drug-susceptible strain (H37Rv) of *M. tuberculosis* and it also showed an MIC of 50 mg/L against some multidrug-resistant strains of *M. tuberculosis*. However, two other derivatives and a structural analog did not exhibit significant	[38]

	antimycobacterial activity at the highest tested concentration of 100 mg/L. These results suggest that specific diospyrin derivatives hold promise as potential candidates for further research aimed at combating tuberculosis)	
	The compounds diospyrin and isodiospyrin were extracted from the root of *Diospyros piscatoria*. Diospyrin exhibited minimum inhibitory concentrations (MICs) ranging from 1.56 to 50 µg/mL against *Streptococcus pyogenes* ATCC 12344 and *Streptococcus pneumoniae* ATCC 33400. The MICs against *Salmonella choleraesuis* serotype *typhi* (*S. typhi*), ATCC 6539, and *Mycobacterium chelonae* ATCC 19977 ranged from 25 to 100 µg/mL. Isodiospyrin was found to be more effective than diospyrin. It displayed MICs against Gram-positive bacteria ranging from 0.78 to 50 µg/mL and MICs against *Pseudomonas aeruginosa* ATCC 15443 and *S. typhi* ranging from 50 to 100 µg/mL. The MIC for *M. chelonae* was between 6.25 and 25 µg/mL.	[39]
	Anti-parasitic (diospyrin, which is derived from the bark of *Diospyros montana* Roxb, was found to have antileishmanial properties. A specific derivative called D17 was tested against *Leishmania donovani* both *in-vitro* and *in-vivo*. D17 showed promising results with an IC_{50} of 0.18 µM against the intracellular amastigotes of the *L.*	[40]

	donovani clinical strain, leading to a significant 38% reduction in parasite load. The compound was also found to target ornithine decarboxylase, making it a potential candidate for antileishmanial treatment)	
Anthraquinone ($C_{14}H_8O_2$)	Antibacterial (Anthraquinones and their analogs have various antibacterial effects, such as preventing biofilm formation, destroying cell walls, inhibiting endotoxins, blocking nucleic acid and protein synthesis, and disrupting energy metabolism and other cellular functions).	[41]
	Purgative, anti-inflammation, immunoregulation, purgation, anti-hyperlipidemia, and anticancer	[42]
Hexadecanoic acid ($C_{16}H_{32}O_2$)	Anti-inflammatory (*n*-hexadecanoic acid functions as an anti-inflammatory agent by blocking the activity of Phospholipase A2 (PLA2). Based on structural evidence, it is found that *n*-hexadecanoic acid attaches to the active site of PLA2, competitively inhibiting its function. The binding of *n*-hexadecanoic acid to PLA2 is confirmed through Isothermal Titration Calorimetry. Compared in silico, its binding energy is demonstrated relative to other known inhibitors such as fatty acid tricarbonyl derivatives, thielocin B3, and compounds containing an indole moiety)	[43]

Understanding the mechanisms of action and safety profiles of bioactive principles from |*D. bicolor* is essential for harnessing their bioeconomic potential. Benzyl butyrate ($C_{11}H_{14}O_2$) is a fragrance ingredient,[44] and butyl butyrate ($C_8H_{16}O_2$) is used for flavor and fragrance purposes.[45] Notably, β-caryophyllene (**Figure 3**) is a natural flavoring agent approved by the Food and Drug Administration (FDA) and the European Food Safety Authority (EFSA). It enhances the taste of foods and beverages. [46]

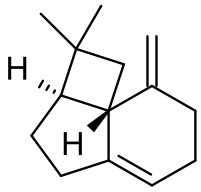


Figure 3. Structure of β-caryophyllene

Twenty-eight compounds were identified from flower essential oil, with the main components including (2*Z*,6*E*)-farnesol, α-cadinol, (*E*)-nerolidol, α-humulene, β-caryophyllene, and β-muurolol.[47] These essential oil components exhibit various pharmacological activities as shown in **Table 3**.

Table 3. Biological activities of flower essential components of *Diospyros discolor*

Compounds	**Biological activities**	**References**
α-Cadinol	Antifungal properties (α-cadinol has been identified in the leaf essential oil of *Neolitsea parvigemma*. Cadinol exhibits antifungal activity against wood-decay fungi, including *Trametes versicolor, Phaneochaete chrysosporium, Phaeolus schweintizii*, and *Lenzites sulphureu*)	[48]
	Hepatoprotective properties (α-cadinol, found in the leaf essential oils of *Cinnamomum osmophloeum*, exhibited hepatoprotective effects. In an LPS/D-GalN-induced acute hepatitis model, α-cadinol reduced AST, ALT, TNF-α, and IL-6 levels in serum. It also suppressed cleaved caspase-3 and cleaved PARP expressions in liver tissues and decreased liver lesion incidence)	[49]
	Potential antibacterial activity against drug-resistant tuberculosis (α-cadinol, a major compound in the essential oil of *Salvia aratocensis*, shows promise as an antimycobacterial agent. In a colorimetric macrodilution study, the essential oil was tested against 15 *Mycobacterium* species. α-cadinol exhibited significant activity against *M. tuberculosis* Beijing Genotype Strains	[50]

	(MIC values below 125 µg/mL) and Nontuberculous Mycobacterial Strains (MIC values ranging from 200 to 500 µg/mL).	
α-Humulene and β-caryophyllene	The β-caryophyllene was isolated in 1834 as a mixture of isocaryophyllene, trans-caryophyllene, and α-humulene from clove oil - *Eugenia caryophyllata* L., α-humulene and its isomers, β-caryophyllene had Anti-inflammatory, antitumor, anticancer, antimicrobial, anti-allergic, antispasmodic, and gastroprotective activities.	[51]
	β-Caryophyllene interacts with cannabinoid receptors (CB2), potentially influencing pain management and inflammation. Additionally, β-caryophyllene exhibits a dual role in cancer treatment. It induces apoptosis (programmed cell death) and suppresses cancer cell proliferation and reduces levels of tumor angiogenesis and metastasis markers. β-Caryophyllene increases cellular accumulation of chemotherapeutic drugs, enhancing their anticancer effectiveness.	[46]
(2*Z*,6*E*)-Farnesol	Anticancer and anti-inflammatory properties (Farnesol influences Ras protein and nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB) activation. As a result, it downregulates the expression of inflammatory mediators, including cyclooxygenase-2 (COX-2), inducible nitric oxide synthase (iNOS), tumor necrosis factor alpha (TNF-α), and interleukin-6 (IL-6).	[52]
	Antimicrobial potential (The essential oil from *D. discolor* exhibited growth suppression against both bacteria (including *Bacillus cereus, Staphylococcus aureus, S. epidermidis,* and *Escherichia coli*) and fungi (specifically *Enterobacter aerogenes* and *Candida albicans*). Inhibition zones ranged from 40 to 52 mm, and the minimum inhibitory concentration (MIC) values were 31.25-62.5 µg/mL. The active compounds responsible for	[47]

	this antimicrobial activity were identified as α-cadinol, τ-cadinol, τ-muurolol, and (2Z,6E)-farnesol).	
	Cytotoxic activity against human colon, liver, and lung cancer cells.	
(*E*)-Nerolidol	Anti-inflammatory activity	[53]
	Antioxidant property	
	Antimicrobial and anti-biofilm activities	
	Antiparasitic activity	
	Antitumor activity	
	Anti-ulcer property	
	Effective in pain management	
	Enhances skin penetration of drugs	
	Insect repellent activity	

Reported Pharmacological Aspects of *D. discolor*

Various parts of the *D. discolor* demonstrate pharmacological activities such as antimicrobial, anti-asthmatic, anti-acetylcholinesterase, antidiabetic, antidiarrheal, anticancer, antiaging, and more, as summarized in **Table 4**.

Anti-aging Activity

Researchers investigated the antiaging properties of *D. discolor* leaf extract (LE) and stem bark extract (SBE), utilizing an ultrasound-assisted extraction with methanol as the solvent. Both extracts displayed potent anti-elastase properties, (IC_{50} = < 50 μg/mL). SBE demonstrated superior anti-elastase activity compared to LE, indicating its potential for anti-aging treatments.[54] Another study found that *D. discolor* extract inhibited matrix metalloproteinase-9 (MMP-9) activity following ultraviolet B (UVB) irradiation, suggesting its potential in anti-aging formulations.[55]

Anti-acetylcholinesterase Activity

The leaf extract *of D. discolor* showed significant inhibition of acetylcholinesterase (AChE) by 95.80 ± 1.57% at a concentration of 100 μg/mL. Specific compounds from the leaves and stem bark, such as stigmast-4-ene-3-one, demonstrated the lowest IC_{50} at 11.77 ± 2.11 μM. This AChE inhibitory activity highlights the potential for therapeutic uses.[2]

Cytotoxic Effect

The cytotoxicity and anticancer activities of *D. discolor* leaves, root bark, and stem bark were evaluated on brine shrimp nauplii and Ehrlich ascites carcinoma cells, showing moderate anticancer activity.[56] However, it should be noted that brine shrimp lethality assay is not really for assessing cytotoxicity but for general toxicity. The essential oil of the flower exhibited cytotoxic activity against human colon, liver, and lung cancer cells, with active compounds such as β-caryophyllene, α-humulene, (*Z*)-cadinol, (*Z*)-muurolol, α-cadinol, and (2*Z*,6*E*)-farnesol contributing to this effect.[47] In Zebrafish embryo studies, higher concentrations of *D. discolor* leaf extract led to increased mortality rates and various teratogenic effects, emphasizing the potential hazards during embryonic development.[57] The effectiveness against leukemia was assessed on HL-60 cells, showing a 37.3% survival rate at a concentration of 100 µg/mL, indicating potential for further investigation in cancer treatment.[58]

Antidiabetic Activity

The leaves of *D. discolor* offer natural antioxidants and compounds beneficial for managing diabetes. Ethanolic and water extracts of the leaves showed significant antidiabetic effects in mice with alloxan-induced diabetes, effectively reducing blood glucose levels, with the ethanolic extract demonstrating higher antioxidant activity.[59]

Table 4. Reported in-vivo, in-vitro, and in-silico pharmacological activities of *D. discolor*

Bioactivity	Used plant part(s)	Experimental method	References
Anti-aging	Leaf, stem bark; leaf	*In-vitro* anti-elastase and antioxidant activity; *in vitro* inhibitory effects of gelatinase (MMP-2 and -9) in human skin fibroblasts	[54-55]
Anti-acetylcholinesterase	Leaf, stem bark	*In-vitro* using Ellman's method	[2]
Anti-asthmatic	Leaf	*In-vivo* ovalbumin-induced mouse airway inflammation model	[60]
Antibacterial	Leaf	*In-vitro* anti-biofilm assay; *in-vitro* inhibitory activity against *B. cereus* and *E. coli*	[61-62]

Cytotoxic	Leaf; flower essential oil; seed and peel	*In-vivo* toxic and teratogenic effects; *in-vitro* cytotoxic effects against the human colon, liver, and lung cancer cells; *in-vitro* cytotoxic activity in brine shrimp (*Artemia salina*) lethality bioassay study	[47, 57, 63]
Antidiabetic	Leaf	*In-vivo* alloxan-induced diabetic mice models	[59]
Antidiarrheal	Leaf	*In-vivo* castor oil-induced mice models	[64]
Antimicrobial	Flower essential oil; seed	*In-vitro* growth inhibition tested against three Gram positive and five Gram-negative bacteria, and two fungi; in-vitro tested against 10 pathogenic Gram-positive and Gram-negative bacteria by using the disc diffusion method	[47, 65]
Antioxidant	Seed; leaf	*In-vitro* using the radical scavenging activity method	[28,64,66-67]
Anti-inflammatory, analgesic and thrombolytic	Seed	*In-vivo* analgesic and anti-inflammatory in mice, *in-vitro* clot lysis using male blood sample	[68]
Biopesticide	Fruit	*In-silico* binding of essential oil with *Drosophila melanogaster* octopamine receptor in mushroom bodies	[69]
Neuropharmacological	Leaf	*In-vivo* hole cross, force swimming and tail suspension tests	[70]
Vasorelaxant	Leaf	*In-vitro* carried out on isolated rat aortic rings	[71]

Antidiarrheal Activity

The ethanolic leaf extract significantly reduced defecation by 33.19% and 45.28% at doses of 250 and 500 mg/kg, respectively.[72] Another study using castor oil-induced mice models found substantial reductions in fecal output at these doses, validating traditional uses for treating diarrhea.[64]

Antimicrobial Properties

The flower essential oil demonstrated moderate to strong antimicrobial activity, with inhibition zones ranging from 40 to 52 mm and MIC values between 31.25–62.5 μg/mL. Active compounds such as (*Z*)-cadinol, (*Z*)-muurolol, and (2*Z*,6*E*)-farnesol contributed to this effect.[47] Additionally, the seed extract exhibited significant antimicrobial activity with a minimum inhibition concentration of between 1.6-6.3 mg/ml.[65] Leaf extracts also showed potent antibacterial activity against *S. aureus* and *S. mutans* with a maximum inhibition zone of 20 mm in ethyl acetate extract.[61] On the other hand, methanol leaf extract showed maximum inhibitory activity against *B. cereus* and *E. coli* at 1000μg/100μl concentration, compared to ethyl acetate extract.[62] The antimicrobial activity of the leaf of *D. discolor* is due to the presence of bioactive triterpenes, cylindrin (also called isoarborinol methyl ether) and fatty esters of α- and β-amyrin.[29]

Antioxidant Activity

Maceration extract from *D. disolor* seeds demonstrated strong antioxidant capacity, with an IC_{50} value of 18.9 μg/mL, comparable to quercetin (IC_{50} value of 6.38 μg/mL).[28] Leaf extract exhibited substantial antioxidant activity, with an IC_{50} value of 15.06 ± 0.49 μg/mL, compared to the standard ascorbic acid, with an IC_{50} value of 8.11±0.21 μg/mL.[64] The bark exhibited the highest antioxidant activity, with an IC_{50} value of 45.78 μg/mL among leaf (IC_{50} = 72.50 μg/mL) and fruit (IC_{50} = 69.13 μg/mL), compared to the standard (ascorbic acid, with an IC_{50} value of 43.04 μg/mL.[73]

Anti-asthmatic Effect

The methanolic extract of *D. discolor* significantly decreased inflammatory cells and cytokine levels in a mouse model of airway inflammation, suggesting potential for treating allergic bronchial asthma. The possible inhibitory mechanisms of allergen-induced inflammation in a murine model of asthma include the reduction of the Th2 immune response, suppression of matrix metalloprotenase (MMP-9) activity, and induction of heme oxygenase (HO) expression.[60] A

pharmaceutical composition using *D. disolor* extract has been developed for inflammatory diseases, allergies, and asthma.[74]

Analgesic Effect

Various parts of the *D. discolor* showed analgesic activity, supporting its use for pain management in folk medicine. The leaves exhibited writhing inhibition at doses of 250 and 500 mg/kg body weight, respectively. In comparison, the standard drug diclofenac sodium (25 mg/kg body weight) showed 75.76% writhing inhibition.[68] The seeds demonstrated inhibition at a dose of 200 mg/kg body weight, with a rate of 43.12% at the early stage and 400 mg/kg body weight at both late and early stages.[75]

Thrombolytic Activity

Cold methanolic extract of *D. discolor* seeds showed 38.17% clot lysis at 10 mg/mL, indicating potential as a thrombolytic agent.[68]

Vasorelaxant Effect

Leaf extracts demonstrated potential for relaxing blood vessels through endothelium-dependent mechanisms mediated by nitric oxide,[71] supporting traditional uses for hypertension and heart disease.

Biopesticide Potential

Recent studies have indicated that essential oils derived from *D. discolor* could influence insect behavior. The interaction between these plant extracts and the octopamine receptor in fruit flies was evaluated. Using gas chromatography-mass spectroscopy (GC-MS), specific aromatic esters with a higher binding affinity to the octopamine receptor were identified, surpassing the receptor's natural agonist, octopamine. This increased affinity is attributed to a unique interaction between the aromatic components of the plant compounds and the receptor. These findings propose that the aromatic esters of *D. discolor* may have future applications in pest management.[69]

Bioeconomic Potential of *Diospyros discolor*

The bioeconomy, as outlined by the Global Bioeconomy Summit, encompasses the sustainable utilization of biological resources, including renewable natural resources like plants, animals, and microorganisms. It leverages innovative biological methods and principles to provide goods and services across different economic sectors, such as agriculture, biotechnology, and renewable

energy, to build a stronger and eco-friendly future.[76] Beyond health benefits, *D. discolor* can be a valuable resource for bioeconomic potential.

Biosorbent

Biosorbents are biowaste that can offer eco-friendly solutions for pollution control and waste management. The use of biosorbents contributes to a circular bioeconomy. A study on the potential use of velvet apple fruit seeds as a biosorbent for removing Cr (III) from waste was conducted, and the results showed that the velvet apple fruit seeds had a maximum adsorption capacity of 5.592 mg/g and were able to remove 81.78% of Cr (III) ions, indicating that they could be a cost-effective alternative to remove heavy metals from solutions.[77]

Edible Fruit

The velvet apple tree is underutilized but has significant bioeconomic potential. The fruit is an ideal source of vitamins, micro- and macro-nutrients, as shown in **Table 5**. Scientists have created new Mabolo-based products such as cakes, tarts, fritters, and pancakes, which may help increase the economic value of the fruit and promote efforts to conserve this endangered species.[78] Moreover, researchers have investigated the possibility of producing seedless velvet apple fruits on a commercial scale by selecting larger fruits and utilizing methods to induce seedlessness.

Table 5. Reported nutritional contents of the *Diospyros discolor* fruit

Composition	**Content**		
	Based on the Philippine Food Composition Tables Online Database[79]	Based on the Food and Drug Administration, Ministry of Health and Welfare, Taiwan[22]	Based on biochemical study in Bangladesh[80-81]
Moisture (g/100g)	-	84.4	82.17
Ash (g/100g)	0.6	0.8	0.56
Calorie (Kcal/100g)	88	62	70.85
Carbohydrate (g/100g)	20.8	13.8	16.52
Dietary fiber (g/100g)	4.1	3.2	3.64
Protein	0.6	0.4	0.74
Calories from fat (Kcal/100g)	-	5.4	-

Crude fat (g/100g)	0.3	0.6	-
Total sugar (g/100g)	14.2	-	4.04
Glucose (g/100g)	-	1.9	-
Fructose (g/100g)	-	2.4	-
Beta-carotene (µg)	20	-	-
Vitamin C (mg/100g)	16	2.2	-
Vitamin E (mg/100g)	-	0.59	-
Vitamin B1 (mg/100g)	0.02	-	-
Vitamin B2 (mg/100g)	0.12	0.075	-
Vitamin B3 (mg/100g)	0.3	0.157	-
Folic acid (mg/100g)	-	0.623	-
Pantothenic acid (mg/100g)	-	0.19	-
Choline chloride (mg/100g)	-	62.52	-
Malic acid (mg/100g)	-	227.1	-
Fumaric acid (mg/100g)	-	4.5	-
Sodium (mg/100g)	3	2	22.50 ± 2.29
Calcium (mg/100g)	46	42.8	38.84 ± 6.34
Potassium (mg/100g)	-	19.6	238.51 ± 24.94
Magnesium (mg/100g)	-	7.7	32.45 ± 3.15
Phosphorus (mg/100g)	18	17	100.15 ± 34.06
Zinc (mg/100g)	-	3.6	0.54 ± 0.23
Iron (mg/100g)	0.6	-	1.81 ± 0.62

Successful results were achieved with a specific variety named SYD, which exhibited the best characteristics of large fruits. Thus, there are opportunities for value-added products (e.g., jams,

juices) from seedless Mabolo.[82] Akamine and Goo conducted a study on the ripening process of *D. discolor* fruit, examining two stages of maturity: mature green and 5% red-colored. They found that mature green Mabolo fruits took nine days to reach the climacteric peak stage, while slightly ripe fruits achieved this in five days. The ethylene production was linked to the onset of ripening, and the respiratory pattern during ripening confirmed the climacteric nature of *D. discolor*. These discoveries provide valuable insights into fruit ripening processes, with potential implications for postharvest handling and storage strategies.[83]

Silver Nanoparticles Biosynthesis

The production of silver nanoparticles (AgNPs) using natural sources aligns with the principles of the bioeconomy, emphasizing sustainability, resource efficiency, and diverse applications such as antimicrobial agents, biomedical device coatings, drug-delivery carriers, imaging probes, and optoelectronic platforms.[84] Silver nanoparticles were produced using the aqueous extract of *D. discolor* leaves and fruit flesh or seeds.[85,86] *D. discolor* extract contains phenolic and flavonoid compounds that act as effective reducing agents for synthesizing AgNPs, making this process environmentally friendly. Different concentrations of the extract were used to synthesize AgNPs, and the formation of silver nanoparticles was confirmed by analyzing absorption spectra between 350-450 nm using a UV-Vis spectrophotometer. The research demonstrates the potential of this plant as a sustainable source for AgNP synthesis.[87] Furthermore, CuO-Ag (copper oxide-silver) nanoparticles were created by researchers using an extract from *D. discolor* These nanoparticles displayed favorable structural and optical characteristics and showed wide-ranging antibacterial effects,[88] indicating their potential suitability for various biomedical applications,[89] and eco-friendly dye removal.[90]

Timber and Trade

The timber obtained from the velvet apple tree is highly prized for its applications in sculptures, furniture, and musical equipment. It is recognized as one of the Hongmu (redwood) woods, honoring customs of the Ming and Qing periods, and is celebrated for its suitability in crafting top-notch Chinese furniture.[91] Due to its density and acoustic characteristics, the wood is well-suited for making musical instruments like guitars and drums, delivering desirable resonant tones favored by musicians globally.[92] In the Philippines, the wood of *D. discolor* finds extensive use in crafting handicrafts, including carvings, hair combs, and musical instruments. It is also used for veneer, specialized furniture, and exterior applications.[26]

Essential Oil

Non-water-soluble liquids called essential oils are derived from plants and contain volatile aroma compounds. These compounds have applications across industries such as cosmeceutical and health. The global essential oils market has experienced substantial growth, with a value of USD 11.41 billion in 2023 and a projected value of USD 27.82 billion by 2032.[93] Research has identified compounds in *D. discolor* flower essential oil,[46] and fruit and peel also contribute to the aromatic profile,[22] indicating potential for sustainable bioeconomic practices in functional foods and pharmaceutical industries, as shown in **Table 3**. For example, α-farnesene (**Figure 4**), identified in the velvet apple pulp, is an acyclic volatile sesquiterpene that significantly functions in aircraft fuel, food flavoring, agriculture, pharmaceuticals, and chemical industries.[94]

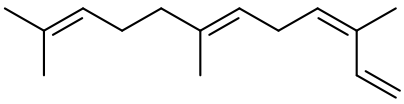


Figure 4. Structure of α-farnesene ($C_{15}H_{24}$)

Toxicological aspects

Although *D. discolor* possesses several pharmacological properties and produces bioactive compounds, certain parts of this plant, not necessarily fruits, have some toxicities as documented in the published literature.[57] Toxicity and teratogenicity of the water extract of the leaves of *D. discolor* were evaluated in the Zebrafish model.[57] In this study, 100% mortality of embryos was observed with %5 and 10% concentration of the leave extract. A significant increase in mortality at lower concentrations was noted with prolonged exposure. The extract also caused decreased heart rate, hatchability and malformation of the tail in Zebrafish. While the general toxicity of *D. discolor* was reported using the brine shrimp lethality assay,[56] the *in vitro* cytotoxicity of the flower essential oil of this plant was also assessed.[95]

Future perspectives

Several bioactivities of this plant have been reported as outlined in the previous sections, but most of those studies were in vitro. Further *in vivo* and *in silico* studies are necessary to understand the mechanisms of actions, bioavailability, pharmacokinetics, potential toxicity and their true therapeutic potential. Formulation aspects of the extracts and bioactive compounds of *D. discolor* as well as targeted delivery must be explored.

Conclusion

Diospyros discolor holds immense potential in various domains, from its rich phytometabolites and pharmacological benefits to its ethnomedicinal uses and bio-economy potential. Further research and development could unlock new applications and enhance the utilization of this valuable plant, contributing to health, economic, and environmental benefits. This article documents reported studies on *D. discolor* focusing on its phytochemicals, pharmacological properties, and ethnomedicinal uses. *D. discolor* has a history of traditional medicinal use in the folk medicine of Bangladesh, Guyana, Indonesia, and the Philippines, for various purposes. Additionally, the plant contains several phytocompounds, and the fruit is rich in nutrients. Both *in vitro* and *in vivo* pharmacological investigations have confirmed the health benefits of the plant and validated some of its traditional uses. Further research is necessary to explore its potential health benefits, understand the specific mechanisms of action, and establish rigorous clinical applications. Furthermore, the tree and its delicious fruit have the potential to contribute to the development of a circular bioeconomy, benefiting both society and the environment. Overall, *D. discolor*, or Velvet apple tree, is a valuable resource with diverse applications. Further research is essential to explore further pharmacological efficacy and develop the bioeconomic viability of *Diospyros Discolor* Willd.

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Conflict of Interest

The authors have no conflicts of interest to declare.

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References

[1] A. Rauf, G. Uddin, S. Patel, A. Khan, S. A. Halim, S. Bawazeer, K. Ahmad, N. Muhammad, M. S. Mubarak, *Biomed Pharmacother.* **2017**, *91*, 714–730. https://doi.org/10.1016/j.biopha.2017.05.012

[2] N. Somat, Z. Yusoff, C. Osman, C. Osman, *Pharmacogn. J.* **2020**, *12*, 1547–1551. https://doi.org/10.5530/pj.2020.12.212

[3] D. Gledhill. The Names of Plants, 4th Edition. Cambridge University Press, 2008.

[4] A. Ribeiro, R. Serrano, I. B. M. da Silva, E. T. Gomes, J. F. Pinto, O. Silva, *Plants* **2023,** *12*, 2833. https://doi.org/10.3390/plants12152833

[5] N. Fareed, D. M. El-Kersh, F. S. Youssef, R. M. Labib, *J Food Biochem.* **2022**, *46*, e14413. https://doi.org/10.1111/jfbc.14413

[6] C. Xie, Z. Xie, X. Xu, D. Yang, *J. Ethnopharmacol.* **2015**, *163*, 229–240. DOI: 10.1016/j.jep.2015.01.007

[7] J. C. Domingo, *The Vector: IJSTM*. **2022**, *31*. https://vector.unp.edu.ph/index.php/1/issue/view/9

[8] R. G. Tantiado, *Int J Bio-Sci Bio-Technol.* **2012**, *4*, 11–26.

[9] https://gvpress.com/journals/IJBSBT/vol4_no4/2.pdf

[10] D. J. C. Tindowen, J. C. Bangi, M. J. N. Mendezabal, *J Biodivers Environ Sci.* **2017**, *11*, 296–303.

[11] E. S. Caunca, L. O. Balinado, *IJTK.* **2021**, *20*. DOI: 10.56042/ijtk.v20i2.26862

[12] E. S. Caunca, L. O. Balinado, *AJBLS.* **2021**, *10*, 443–453. DOI:10.5530/ajbls.2021.10.59

[13] A. J. C. Abad, J. M. Guerrero, G. B. Pataray, J. C. Bangi, *Bannag: J Local Knowledge* **2015**, *2*, 6–19. http://urdc.usl.edu.ph/papers/bannag/bannag_vol2_no1_s2015_p5.pdf

[14] L. M. Clemen-Pascual, R. A. S. Macahig, N. R. L. Rojas, *Toxicol Rep.* **2022**, *9*, 22–35. https://doi.org/10.1016/j.toxrep.2021.12.002

[15] M. Z. Aumeeruddy, M. F. Mahomoodally, *S Afr J Bot.* **2020**, *135*, 451–464. DOI: 10.1016/j.sajb.2020.09.008

[16] M. Rahmatullah, D. Ferdausi, Md. A. H. Mollik, Md. N. K. Azam, M. Taufiq-Ur-Rahman, R. Jahan, *Am Eurasian J Sustain Agric.* **2009**, *3*, 534–541. https://www.aensiweb.net/AENSIWEB/aejsa/aejsa/2009/534-541.pdf

[17] S. Das, S. R. Bhadra, M. S. M. Khan, M. M. Hasan, M. R. Anwar, M. Shahriar, *J Pharm Sci.* **2022**, *21*, 127–146. https://doi.org/10.3329/dujps.v21i2.63114

[18] S. Rahman Brishty, N. Islam Setu, Md. R. Anwar, R. Jahan, M. M. K. Mia, M. Fahim Kadir, Md. Rabiul Islam, *Pharm Biomed Res.* ***2020***. https://doi.org/10.18502/pbr.v6i1.3429

[19] A. R. Islam, S. Das, M. Alam, A. Rahman, *J Biosci.* **2019**, *27*, 69–81. DOI: 10.3329/jbs.v27i0.44672

[20] M. Rahmatullah, Md. M. Hasan, M. Ahmed, M. W. Khan, Md. S. Hossan, Md. M. Rahman, D. Nasrin, Z. U. M. E. U. Miajee, M. S. Hossain, R. Jahan, Mst. A. Khatun, *Am Eurasian J Sustain. Agric.* **2010**, *4*, 111–116.

[21] C. Boston, J. Rosales, J. Singh, R. Kurup, *J Complement Alternat Med Res* **2019**, 1–12. DOI: 10.9734/JOCAMR/2019/v7i330100

[22] A. Susilowati, I. M. Ginting, H. H. Rachmat, F. G. Dwiyanti, A. H. Iswanto, T. Sucipto, IOP conference series. *Earth and Environmental Science Environ Sci.* **2022**, 977, 012016. DOI: 10.1088/1755-1315/977/1/012016

[23] S.-F. Hung, S.-F. Roan, T.-L. Chang, H.-B. King, I.-Z. Chen, *J Food Drug Anal.* **2016**, *24*, 83–89. https://doi.org/10.1016/j.jfda.2015.08.004

[24] A. O. Matemu, D. Adeyemi, H. Nyoni, L. Mdee, P. Tshabalala, B. Mamba, T. A. M. Msagati, *Int. J. Environ. Res. Public Health* **2017**, *14*, 1401. https://doi.org/10.3390/ijerph14111401

[25] R. M. Smith, L. Oliveros-Belardo, *J Essent Oil Res.* **2011**, 4, 28. https://doi.org/10.1080/10412905.1992.9698063

[26] C.-R. Chen, C.-W. Cheng, M.-H. Pan, Y.-W. Liao, C.-Y. Tzeng, C.-I. Chang, *Chem Pharm Bull.* **2007**, *55*, 908–911. https://doi.org/10.1248/cpb.55.908

[27] T. K. Lim, in *Edible Medicinal and Non-Medicinal Plants*, Springer Netherlands, Dordrecht, **2012**, pp. 421–424. https://link.springer.com/book/10.1007/978-90-481-8661-7

[28] J. A. Pino, L. Cuevas-Glory, V. Fuentes, *J Essent Oil Res.* **2011**, *20*, 506–508. https://doi.org/10.1080/10412905.2008.9700072

[29] R. R. Kusumah, D. Arrisujaya, D. Susanty, N. Yuliani, *J Mater Environ Sci.* **2020**, *11*, 609–614.

[30] C. Y. Ragasa, M. R. A. Puno, J. M. A. P. Sengson, C.-C. Shen, J. A. Rideout, D. D. Raga, *Nat Prod Res.* **2009**, *23*, 1252–1258. https://doi.org/10.1080/14786410902951054

[31] S. Ganapaty, P. S. Thomas, B. N. Mallika, S. Balaji, G. Karagianis, P. G. Waterman, *Biochem Syst Ecol.* **2005**, *33*, 313–315. https://doi.org/10.1016/j.bse.2004.07.002

[32] T. Morikawa, K. Imura, Y. Akagi, O. Muraoka, K. Ninomiya, *J Nat Med.* **2018**, *72*, 317–325. https://doi.org/10.1007/s11418-017-1137-y

[33] P. Huang, X. Duan, Z. Tang, Z. Zou, W. Song, G. Gao, D. Li, F. Nie, X. Yan, Y. Fu, R. Guo, Y. Xu, *Sci Rep.***2023**, *13*, 743. https://doi.org/10.1038/s41598-023-27580-w

[34] P. Y. Chung, *Phytomed.* **2020**, *73*, 152933. https://doi.org/10.1016/j.phymed.2019.152933

[35] H. Lou, H. Li, S. Zhang, H. Lu, Q. Chen, *Molecules* **2021**, *26*, 5583. https://doi.org/10.3390/molecules26185583

[35] J. Ríos, S. Máñez, *Planta Medica* **2018**, *84*, 8–19. https://doi.org/10.1055/s-0043-123472

[36] D. B. Domínguez-Carmona, F. Escalante-Erosa, K. García-Sosa, G. Ruiz-Pinell, D. Gutierrez-Yapu, M. J. Chan-Bacab, A. Giménez-Turba, L. M. Peña-Rodríguez, *Phytomed.* **2010**, *17*, 379–382. https://doi.org/10.1016/j.phymed.2009.08.002

[37] A. Rauf, Z. Akram, N. Hafeez, A. A. Khalil, A. Khalid, H. A. Hemeg, A. S. M. Aljohani, W. Al Abdulmonem, M. M. Quradha, A. M. F. Qahtan, *Food Sci Nutr.***2024**, fsn3.4237. https://doi.org/10.1002/fsn3.4237

[38] N. Lall, *J Antimicrob Chemother.* **2003**, *51*, 435–438. https://doi.org/10.1093/jac/dkg068

[39] B. A. Adeniyi, H. H. S. Fong, J. M. Pezzuto, L. Luyengi, H. A. Odelola, *Phytother Res.* **2000**, *14*, 112–117. https://doi.org/10.1002/(SICI)1099-1573(200003)14:2<112::AID-PTR488>3.0.CO;2-T

[40] S. Hazra, S. Ghosh, M. D. Sarma, S. Sharma, M. Das, P. Saudagar, V. K. Prajapati, V. K. Dubey, S. Sundar, B. Hazra, *Exp Parasitol.* **2013**, *135*, 407–413. https://doi.org/10.1016/j.exppara.2013.07.021

[41] T. Qun, T. Zhou, J. Hao, C. Wang, K. Zhang, J. Xu, X. Wang, W. Zhou, *RSC Med Chem.* **2023**, *14*, 1446–1471. https://doi.org/10.1039/d3md00116d

[42] D. Wang, X.-H. Wang, X. Yu, F. Cao, X. Cai, P. Chen, M. Li, Y. Feng, H. Li, X. Wang, *Front Pharmacol.* **2021**, *12*https://doi.org/10.3389/fphar.2021.638993

[43] V. Aparna, K. V. Dileep, P. K. Mandal, P. Karthe, C. Sadasivan, M. Haridas, *Chem Biol Drug Des.* **2012**, *80*, 434–439. https://doi.org/10.1111/j.1747-0285.2012.01418.x

[44] D. McGinty, C. S. Letizia, A. M. Api, *Food Chem Toxicol.* **2012**, *50*, S407–S411. https://doi.org/10.1016/j.fct.2012.02.063

[45] H. J. Noh, S. Y. Lee, Y.-S. Jang, *Appl Microbiol Biotechnol.* **2019**, *103*, 2079–2086. https://doi.org/10.1007/s00253-018-09603-z

[46] K. Fidyt, A. Fiedorowicz, L. Strządała, A. Szumny, *Cancer Med.* **2016**, *5*, 3007–3017. https://doi.org/10.1002/cam4.816

[47] Y.-C. Su, K.-P. Hsu, E. I.-C. Wang, C.-L. Ho, *Nat Prod Commun.* **2015**, *10*, 1311–1314.

https://pubmed.ncbi.nlm.nih.gov/26411038/

[48] C.-L. Ho, P.-C. Liao, E. I.-C. Wang, Y.-C. Su, *Nat Prod Commun.* **2011**, *6*, 1357–1360. https://pubmed.ncbi.nlm.nih.gov/21941915/

[49] Y.-T. Tung, C.-C. Huang, S.-T. Ho, Y.-H. Kuo, C.-C. Lin, C.-T. Lin, J.-H. Wu, *J Agric Food Chem.* **2011**, *59*, 8117–8123. https://doi.org/10.1021/jf2018935

[50] J. Bueno, P. Escobar, J. R. Martínez, S. M. Leal, E. E. Stashenko, *Nat Prod Comm.* **2011**, *6*, 1934578X1100601. https://doi.org/10.1177/1934578X11006011

[51] G. Mendes De Lacerda Leite, M. De Oliveira Barbosa, M. J. Pereira Lopes, G. De Araújo Delmondes, D. S. Bezerra, I. M. Araújo, C. D. Carvalho De Alencar, H. D. Melo Coutinho, L. R. Peixoto, J. M. Barbosa-Filho, C. F. Bezerra Felipe, R. Barbosa, I. R. Alencar De Menezes, M. R. Kerntof, *Trends Food Sci.* **2021**, *115*, 255–274. https://doi.org/10.1016/j.tifs.2021.06.049

[52] Y. Y. Jung, S. T. Hwang, G. Sethi, L. Fan, F. Arfuso, K. S. Ahn, *Molecules* **2018**, *23*, 2827. https://doi.org/10.3390/molecules23112827

[53] W.-K. Chan, L. T.-H. Tan, K.-G. Chan, L.-H. Lee, B.-H. Goh, *Molecules* **2016**, *21*, 529. https://doi.org/10.3390/molecules21050529

[54] E. Suwandy, B. Elya, N. Artanti, M. Hanafi, *Int J Agric Biol.* **2023**, 30, 113-118. https://doi.org/10.17957/IJAB/15.2065

[55] Y.-L. Lee, M.-H. Lee, H.-J. Chang, P.-Y. Huang, I.-J. Huang, K.-T. Cheng, S.-J. Leu, *Molecules* **2009**, *14*, 1062–1071. https://doi.org/10.3390/molecules14031062

[56] M. A. Khan, Md. M. Rahman, Md. N. Sardar, Md. S. I. Arman, Md. B. Islam, Md. J. A. Khandakar, M. Rashid, G. Sadik, A. K. Alam, *Asian Pac J Trop Biomed.* **2016**, *6*, 410–417. https://doi.org/10.1016/j.apjtb.2016.03.004

[57] J. F. Flaviano, M. A. A. Kenniker, F. J. C. Ganda, J. Sacedor, M. Y. S. Lee, K. S. P. Cabuhat, *Egypt. Acad. J. Biolog. Sci. B. (B. Zoology)* **2018**, *10*, 53-60. https://doi.org/10.21608/eajbsz.2018.22733

[58] Pardede, R. A. A. K. Wardhani, E. Frasisca, *EduChemia* **2020**, *5*, 111-118. http://dx.doi.org/10.30870/educhemia.v5i2.8320

[59] M. T. Demetillo, O. M. Nuñeza, M. M. Uy, W. T. P. S. K. Senarath, *Int J Pharm Sci Res.* **2019**, *10*, 3951–56. http://dx.doi.org/10.13040/IJPSR.0975-8232.10(8).3951-56

[60] K.-Y. Lee, J.-Y. Jung, M.-Y. Lee, D. Jung, E.-S. Cho, H.-Y. Son, *Inflamm.* **2012**, *35*, 623–632. https://doi.org/10.1007/s10753-011-9354-0

[61] L. Tahir, A. Aslam, S. Ahmed, *Pak J Pharm Sci.* **2017**, *30*, 163–169. DOI: 10.3923/pjbs.2017.70.81

[62] G. S. Vijayan, J. H. Chandra, *J Chem Pharm Sci.* **2015**, *8*, 389–392. https://core.ac.uk/download/pdf/362645556.pdf

[63] J. R. Setu, A. Akhter, R. Rahman, M. Islam, M. N. Koly, Md. S. Amran, T. Foyzun, *Ann Res Rev Biol*.**2017**, 21, 1-9. https://doi.org/10.9734/ARRB/2017/38478

[64] Md. S. I. Howlader, Md. M. Rahman, A. B. Ripon Khal, F. Ahmed, Md. M. Rahman, *Int J Pharmacol.* **2012**, *8*, 403–409. https://doi.org/10.3923/ijp.2012.403.409

[65] S. Akter, A. Sarker, *Int J Adv Pharm, Biol Chem.* **2015**, *4*, 789–793. http://www.ijapbc.com/files/21-10-15/10-4402.pdf

[66] D. Arrisujaya, D. Susanty, L. T. Hastuti, *Int J Fruit Sci.* **2020**, *20*, S1192–S1200. https://doi.org/10.1080/15538362.2020.1782803

[67] M.-H. Lee, C.-B. Jiang, S.-H. Juan, R.-D. Lin, W.-C Hou, *Fitoterapia*, **2006**, 77, 109-115. https://doi.org/10.1016/j.fitote.2005.11.012

[68] Md. Ibrahim, Md. S. Hussain, F. Sultana, N. Abhi, T. Ahmed, S. M. N. Uddin, A. Rahaman, M. Azmerin, T. D. Aka, S. Mosharraf, A. H. M. M. Uddin, *Asian J Biol Sci.* **2018**, *12*, 36–41.

[69] F. Dacanay, Ma. Ladra, H. Junio, R. Nellas, *Molecules* **2017**, *22*, 1677. https://doi.org/10.3390/molecules22101677

[70] Md. R. Rahman, T. Mony, S. Akter, K. Ahamed, A. Afrose, *J Pharmacogn Phytochem*, **2020**, *9*, 2121-2126 https://www.phytojournal.com/archives/2020/vol9issue3/PartAI/9-3-256-473.pdf

[71] R. K. G. Cadiang, M. O. Osi, J. G. Apostol, M. C. Ysrael, *Planta Med.* **2012**, *78*, PL31. DOI: 10.1055/s-0032-1325173

[72] H. Hossain, S. K. Dey, A. Hira, Md. S. I. Howlader, A. Ahmed, S. Sultana, *Int J Pharm Phytopharmacol Res.* **2012**, *1*, 371–374. https://eijppr.com/cg5L4mr

[73] S. C. Das, K. Hamid, I. J. Bulbul, Shapna Sultana, Md. S. Islam, *Res J Agric Biol Sci*.**2010**, *6*, 472–475. http://www.insipub.com/rjabs/2010/472-475.pdf

[74] K. S. Ahn, O.-K. Kwon, S. R. Oh, J. H. Kim, H. K. Lee, M.-Y. Lee, H.-Y. Son, K.-Y. Lee, S. Y. Kim, G. Tomayo-Castillo, K. Rosales-Ovares, R. Gamez-Lobo, *Pharmaceutical Composition for Preventing or Treating Inflammatory Diseases, Allergic Diseases or Asthma, Containing Diospyros Blancoi a. Dc. Extract as Active Ingredient*, **2013**, CN103140230A. https://patents.google.com/patent/CN103140230A/en

[75] S. Saha, M. L. Hossain, A. S. M. Monjur-Al-Hossain, S. K. Sadhu, *ASJP.* **2018**, *6*, 599–608. https://doi.org/10.5281/zenodo.1466112

[76] D. Nagarajan, D.-J. Lee, C.-Y. Chen, J.-S. Chang, *Biores Technol.* **2020**, *302*, 122817. https://doi.org/10.1016/j.biortech.2020.122817

[77] N. Ariesta, R. Rifansyah, D. Arrisujaya, M. Maslahat, *Sains Nat.* **2018**, *8*, 70. https://doi.org/10.31938/jsn.v8i2.157

[78] R. A. Pobar, *Int J Environ Rur Develop.* **2013**, *4*, 100-105 https://doi.org/10.32115/ijerd.4.1_100

[79] C. D. Oraye, H. De Chavez, C. H. M. Aguilar, F. C. Makiling, V. A. Ladia Jr., E. E. Enicola. M. L. D. Guevarra, L. S. Gueco, R. G. Maghirang, Ma. S. Anunciado, E. Monville-Oro, J. Gonsalves, D. Hunter, T. Borelli, S. Mendonce, *CGIAR*. **2023**, 90. https://hdl.handle.net/10568/135738

[80] M. N. Haque, B. K. Saha, M. R. Karim, M. N. H. Bhuiyan, *Bangladesh J Sci Ind Res.* **2010**, *44*, 353–358. https://doi.org/10.3329/bjsir.v44i3.4410

[81] M. M. Hossain, M. A. Rahim, M. R. Haque, *J Agric Food Res.* **2021**, *5*, 100148. https://doi.org/10.1016/j.jafr.2021.100148

[82] S.-F. Hung, I.-Z. Chen, S.-F. Roan, *Genet Resour Crop Evol*. **2015**, *62*, 1127–1134. https://doi.org/10.1007/s10722-015-0316-5

[83] E. K. Akamine, T. Goo, *Hort Sci.* **1981**, *16*, 519. https://doi.org/10.21273/HORTSCI.16.4.519

[84] S. H. Lee, B.-H. Jun, *Int J Mol Sci*.**2019**, *20*, 865. https://doi.org/10.3390/ijms20040865

[85] H. K. Ardani, C. Imawan, W. Handayani, D. Djuhana, A. Harmoko, V. Fauzia, *IOP Conf Ser. Mater Sci Eng.* **2017**, *188*, 012056. https://doi.org/10.1088/1757-899X/188/1/012056

[86] I. Nolia, W. Handayani, K. Secario, D. Djuhana, C. Imawan, *IOP Conference Series: Earth Environ Sci*.**2020**, *481*, 012038. https://doi.org/10.1088/1755-1315/481/1/012038

[87] H. Zukhrufa, W. Handayani, Y. Yasman, C. Imawan, Depok, *AIP Conf Proc.* **2020**, *2242*, 050001. https://doi.org/10.1063/5.0013037

[88] W. Handayani, H. Zukhrufa, Y. Yasman, C. Imawan, Surabaya, *AIP Conf Proc***. 2020**, *2314*, 020007. https://doi.org/10.1063/5.0034464

[89] W. Handayani, C. Imawan, A. Umar, Yasman, R. Yunilawati, D. Djuhana, *Adv Nat Sci: Nanosci Nanotechnol.* **2021**, *12*, 045007. https://doi.org/10.1088/2043-6262/ac458a

[90] Saruchi, V. Kumar, *Polymer Bulletin* **2020**, *77*, 3349–3365. https://doi.org/10.1007/s00289-019-02920-x

[91] M. Chudnoff, *Tropical Timbers of the World*. Agriculture Handbook 607. Forest Service, U.S. Department of Agriculture, **1984**. http://www.tropicaltimber.info/wp-

content/uploads/2015/06/USDA.TropicalTimbersoftheWorld-Chudnoff.Total1980version.pdf

[92] S. Yoshikawa, C. Waltham. *International Symposium on Musical Acoustics.* **2014.** https://doi.org/10.13140/2.1.5067.1369

[93] Fortune Business Insights, **2023**, Retrieved July 4, 2024, from https://www.fortunebusinessinsights.com/industry-reports/essential-oils-market-101063

[94] S.-L. Chen, T.-S. Liu, W.-G. Zhang, J.-Z. Xu, *Int J Mol Sci.* **2023**, *24*, 1767. https://doi.org/10.3390/ijms24021767

[95] Y-C. Su, K-P. Hsu, E. I-C. Wang, C-L. Ho, *Nat. Prod. Comm.* **2015**, *10*, 1311-1314. https//doi.org/10.1177/1934578X1501000744