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FROM PETALS TO PERFUME:A COMPREHENSIVE REVIEW OF ESSENTIAL OIL-PRODUCING YLANG-YLANG (*CANANGA ODORATA*)

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ABSTRACT:
Ylang-ylang, *Cananga odorata* (Lam.) Hook. f. & Thomson (Annonaceae) is an aromatic crop of great economic and olfactory value worldwide, due to its essential oil that is uniquely complex and has been a key component of fine perfumes since the early 20th century. It is very important to study about botany, phytochemistry, agronomy, extraction technology, biological activities, industrial applications, and sustainability issues related to ylang-ylang essential oil (YEO) production. The unique distillation-fraction system can be used to separate YEO into Extra, Grade I, II, and III, which differ in their chemical profiles and commercial uses. The major volatiles and their biosynthetic sources (benzyl acetate, germacrene-D, linalool, β-caryophyllene, p-cresyl methyl ether) contribute to the olfactory and pharmacological characteristics. In vitro, animal and human clinical studies have provided evidence of various biological activities of YEO and its isolated constituents, such as antimicrobial, anti-inflammatory, anxiolytic, antihypertensive, and insecticidal effects. The major oil-producing regions are particularly the Comoro Islands, Madagascar, Indonesia and the Philippines. Post-harvest handling procedures and the factors that significantly affect the quality of oil are very important. Market dynamics, over adulteration, and the new development of biotechnology/metabolic engineering in the production of ylang-ylang are very important factors for scientists, agronomists, perfumers and the industry in general, relevant in this unique ornamental tree crop.

KEYWORDS: Ylang-Ylang, *Cananga odorata*, essential oil, benzyl acetate, germacrene-D, steam distillation, aromatherapy, perfumery, biological activities.

INTRODUCTION

Ylang-ylang tree (*Cananga odorata* [Lam.] Hook.f. & Thomson) is native to the humid tropical lowlands of Southeast Asian countries, particularly the Philippines, Indonesia, Malaysia and Vietnam. Part of the old family of Annonaceae. The name tagalog ilang-ilang means "flowers of flowers" or "wilderness," reflecting the amazing fragrance of its flowers that have been employed for centuries in the cosmetic, medicinal and cultural traditions of the area [1,2]. In Indonesian traditional medicine, ylang-ylang flowers were used for wounds, to repel insects, and as a postpartum medicine. They were spread on marriage beds in the Filipino tradition as a symbol of sensuality and love [3].

The essential oil, commonly referred to as ylang-ylang oil or YEO, is made by steam-distilling the flowers of the ylang-ylang plant and became one of the most popular natural aromatic raw materials for perfumers in the late 19th century [4]. Ylang-ylang is one of the top notes in the classic Chanel No. 5 introduced in 1921, which is regarded by many as the most famous perfume of all time [5,6]. The global production of ylang-ylang essential oil is estimated to be approximately 70 metric tons per year [7].

The collection of the total steam-distilled oil in successive fractions, Extra (Première), Grades I, II and III, and Complete, each having a distinct chemical composition, aromatic character and commercial value, makes ylang-ylang stand out from almost all other aromatic crops [8]. The Extra fraction is the most valuable and expensive; it contains the richest and brightest floral and ester notes and is recovered in the first 30-60 minutes of distillation. The next fractions yield a more ‘woody' and diffuse aroma, which is suitable for lower-level uses as they start to become richer in heavier sesquiterpene hydrocarbons. This fractionation system is of great importance for pricing, adulteration detection and quality evaluation, as compared with other essential oils that are commercially traded in the market.

Although ylang-ylang essential oil has been used for a long time and is widely commercialised, scientific literature with a detailed cross-disciplinary synthesis of knowledge about this species is sparse. The majority of the reviews that are readily available focus on YEO as one of the various aromatic crops and do not delve deeply into the range of its botany, agronomy, phytochemistry, biological activity and industrial application. The present review aims to fill this gap and to present the synthesis of existing knowledge, as well as priority research areas.

2. Taxonomy, Morphology, and Botanical Characteristics

Cananga odorata Hook (Lam.).f. & Thomson is a member of the Annonaceae, which is a basal angiosperm family of more than 2400 species and 108 genera, most of which are distributed in the humid tropics of Asia, Africa and the Americas [9,10]. There are two varieties of the genus *Cananga*: the commercial ylang-ylang, var. odorata, with suspended flower clusters and a strong fragrance; and the *cananga* or macassar oil tree, var. macrophylla, which has upright flowers and is less fragrant than var. odorata and is not used for perfumery. Cananga latifolia is a plant species that has not been as developed commercially as C. odorata but could be useful as a local resource. A closely related species, Finet & Gagnep., is sometimes cultivated in SE Asia.

Cananga odorata is a fast-growing, evergreen tropical tree to 10-25 m in its natural state, but is often cultivated in commercial orchards at 2-3 m to enable manual removal of flowers [11,12]. The leaves are simple, alternate, oblong-ovate to elliptic, 15-25 cm long, with prominent venation and margin entire and minutely undulate. Flowers are produced in an axillary cluster of 4–12 flowers, at first green and becoming a spectacular greenish-yellow; bisexual, actinomorphic, 6 narrow strap-like petals of 5-8 cm length, falling gracefully like a spider or shooting star. The flowers are most fragrant in the afternoon and evening and are especially fragrant when temperatures are above 30°C. Fruit comprises a bunch of dark-green grape-like berries (monocarps) with 2-12 seeds in aromatic pulp.

Table 1. Taxonomic classification and key botanical characteristics of *Cananga odorata*

Taxonomic / Botanical Character	Details
Kingdom	Plantae
Phylum	Angiospermae
Class	Magnoliopsida
Order	Magnoliales
Family	Annonaceae
Genus	*Cananga* (DC.) Hook.f. & Thomson
Species	*Cananga odorata* (Lam.) Hook.f. & Thomson
Common names	Ylang-ylang, Flower of flowers, Kenanga (Malay), Ilang-ilang (Filipino), Perfume tree
Varieties	var. odorata (ylang-ylang); var. macrophylla (cananga tree)
Chromosome no.	2n = 16
Native range	Tropical Asia: Philippines, Indonesia, Malaysia, Vietnam, Myanmar
Tree height	10–25 m (cultivated trees pruned to 2–3 m)
Flower colour	Yellow-green (mature); initially green
Flowering season	Year-round in tropics; peak March–June
Essential oil yield	1.5–2.5% from fresh flowers (steam distillation)

Sources: [1,9,11,13].

3. Global Production, Cultivation, and Agronomy

3.1 World Production and Trade

The Comoro Islands (Grande Comore, Anjouan, Mohéli) constitute the epicentre of global ylang-ylang essential oil production, accounting for an estimated 60–80% of the world supply [7]. The industry is deeply embedded in the Comorian economy; ylang-ylang oil represents one of the archipelago's most significant agricultural exports, alongside clove and vanilla. Madagascar, the second-largest producer, has expanded its cultivation significantly since the 1990s and is gaining recognition for consistently high-quality oil. Indonesia, particularly the islands of Java, Sumatra, and the eastern regions, is a major producer of ylang-ylang essential oil, although the quality of the oil may vary depending on the cultivar, environmental conditions, harvesting practices, and distillation methods. The Philippines, the native home of the species, maintains both traditional and commercial cultivation, primarily in the regions of Luzon and Visayas. Smaller-scale production occurs in Réunion, Sri Lanka, India, and, more recently, Vietnam and Cambodia [7,14].

Global annual production of ylang-ylang essential oil is estimated at 50–80 metric tonnes, with the Comoros, Madagascar, and Mayotte accounting for the majority of production. The Comorian and Malagasy industries primarily supply major fragrance houses in Grasse (France), Switzerland, and the United States [7].

3.2 Agro-climatic Requirements

Cananga odorata thrives under tropical conditions characterised by mean annual temperatures of 25–35°C, high relative humidity (70–90%), and annual rainfall exceeding 2,000 mm with no prolonged dry season. The tree is predominantly cultivated at low to moderate altitudes (0–500 m), though it can grow up to 1,000 m in sheltered valleys. It is relatively undemanding in terms of soil type, performing well on deep, well-drained, loamy to sandy-loam soils with moderate fertility but is intolerant of waterlogged conditions and prolonged drought. The species is highly wind-sensitive at the seedling stage; sheltered locations or windbreaks are critical in exposed sites such as the Comoro Islands [11,15].

Trees are usually planted in commercial plantations at a density of 400–600 trees/ha using seed or semi-hardwood cuttings. Lateral pruning stimulates side branches and can greatly enhance the amount of flower production. In the second year, the tree is pruned to a reasonable height of 2-3 m. First commercial flower production occurs at about 18–24 months, and production slowly increases for the next 5–8 years; productive trees will yield 5–15 kg of fresh flowers per year. In the Comorian plantations, fertilisation with N, P and K has been shown to increase floral biomass by 25-40% in the plants, particularly N in the rainy season [16,17].

3.3 Harvest, Post-harvest Handling, and Processing

The time for flower maturity for distillation is about 20-25 days after the flowers have begun to form, when petals are fully greenish-yellow, and flowers have become loose on the peduncle. The flowers collected at this stage are always richer in oil and of better scent than the flowers collected at other time periods, earlier (green stage) and later (senescing stage) [8]. In the Comoros, the harvest is done by hand, from the early morning (05:00–08:00), the flowers gather volatile esters during the night, and each picker picks 5-12 kg of fresh flowers daily. It is important to process the product promptly, preferably within 4–6 hours of harvest, in order to minimise enzymatic and microbial degradation processes. Benzyl acetate and other esters tend to undergo progressive hydrolysis as a result of prolonged storage at ambient temperature, which considerably decreases Extra-grade oil yield and quality [11,18]. On transport, refrigeration at 4-8°C is a good way to slow down degradation and is becoming more common in large-scale distillery operations.

4. Essential Oil Extraction: Methods and Fractional Distillation

Figure 1. Steam distillation fractions of ylang-ylang essential oil: temporal collection sequence, characteristic aroma profiles, and principal commercial applications for each grade.

Steam Distillation Fractions of Ylang-Ylang Oil

Fraction	Distil. Time	Aroma Profile	Primary Use
Extra	0–1 hr	Intense, fresh, fruity-floral	Fine perfumery, haute fragrance
First (Grade I)	1–3 hr	Rich, sweet floral	Perfumery, high-end aromatherapy
Second (Grade II)	3–6 hr	Muskier, woody-floral	Functional perfumery, soap, cosmetics
Third (Grade III)	6–15+ hr	Heavy, woody, low-ester	Soap, detergents, industrial scenting
Complete	Undivided	Full-spectrum, balanced	General aromatherapy, massage oils

Note: Timing and grading vary by producer and flower quality.

Source: [11]; [15]; [7]. Distillation times are approximate and vary by still design and operator practice.

4.1 Steam Distillation

Steam distillation is the universal method for producing commercial ylang-ylang essential oil. The flowers are loaded into distillation vessels (stills) charged with either water or indirect steam. Distillation typically proceeds over 10–20 hours in traditional Comorian iron pot-stills and in 8–12 hours in more modern stainless steel apparatus. The oil, lighter than water, separates in the Florentine flask and is decanted; the distillation water (floral hydrolate) retains a small fraction of highly water-soluble aromatic components and is separately valued as a by-product [14,19]. The critical and distinctive feature of commercial ylang-ylang production is the deliberate collection of successive temporal fractions during a single distillation run, as described in section 4.2.

4.2 Fractional Distillation: Grades Extra to III

The fractional distillation of ylang-ylang oil is an industrial practice unique to this aromatic crop that exploits the differential volatility of its constituent compounds to produce fractions that differ markedly in chemical composition, fragrance character, and commercial value (Chatrou. The Extra (Première) fraction, collected during the first 1-2 hours, is exceptionally rich in highly volatile esters, principally benzyl acetate (5.5–30%), geranyl acetate, and methyl benzoate and light phenol ethers, giving it an intensely sweet, luminous, floral-fruity character with exceptional diffusivity
Grade I (collected 1.5–3 hours) has a rich, full floral character and a slightly more rounded, creamy-sweet profile.
Grade II (3–6 hours) becomes progressively richer in sesquiterpene hydrocarbons (β-caryophyllene, germacrene-D) and develops a woody, balsamic undertone.
Grade III (6–10+ hours) is dominated by heavy sesquiterpenes and is substantially less floral and less volatile, finding its main use in soap and detergent fragrancing. "Complete" oil, collected as a single undivided fraction over the full distillation period, represents a commercial compromise balancing quality and production efficiency and is widely used in aromatherapy and mid-market fragrances (Tan. The chemical profiles of all five commercial grades are compared in

Table 2. Chemical composition (% of identified compounds) of ylang-ylang essential oil fractions by distillation

Sources: [8,11,20,21]. Values represent typical ranges from published GC/MS analyses; actual composition varies with

Compound	**Extra (%)**	**Grade I (%)**	**Grade II (%)**	**Grade III (%)**	**Class**
Benzyl acetate	17–30	12–22	8–15	3–8	Ester
Germacrene-D	15–25	10–18	8–14	5–10	Sesquiterpene
Linalool	8–15	5–12	3–8	2–5	Monoterpene
β-Caryophyllene	5–12	6–14	7–15	8–16	Sesquiterpene
Geranyl acetate	3–7	2–5	1–4	<2	Ester
p-Cresyl methyl ether	3–8	3–7	2–5	1–3	Phenol ether
Methyl benzoate	2–5	2–4	1–3	<2	Ester
Benzyl benzoate	2–5	3–6	4–8	5–10	Ester
Eugenol	1–3	1–3	2–5	3–6	Phenylpropanoid
α-Farnesene	2–5	2–4	1–3	<2	Sesquiterpene
Isosafrole	<1	1–2	1–3	2–4	Phenylpropanoid
δ-Cadinene	1–3	2–4	3–6	4–8	Sesquiterpene

Compound	Extra (%)	Grade I (%)	Grade II (%)	Grade III (%)	Class
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Linalool	8–15	5–12	3–8	2–5	Monoterpene
β-Caryophyllene	5–12	6–14	7–15	8–16	Sesquiterpene
Geranyl acetate	3–7	2–5	1–4	<2	Ester
p-Cresyl methyl ether	3–8	3–7	2–5	1–3	Phenol ether
Methyl benzoate	2–5	2–4	1–3	<2	Ester
Benzyl benzoate	2–5	3–6	4–8	5–10	Ester
Eugenol	1–3	1–3	2–5	3–6	Phenylpropanoid
α-Farnesene	2–5	2–4	1–3	<2	Sesquiterpene
Isosafrole	<1	1–2	1–3	2–4	Phenylpropanoid
δ-Cadinene	1–3	2–4	3–6	4–8	Sesquiterpene

origin and harvest conditions.

4.3 Alternative Extraction Methods

Solvent extraction of ylang-ylang flowers produces a concrete (approx. 0.5–0.8% yield) and subsequently an absolute with a notably richer, more complex aroma than steam-distilled oil, owing to the inclusion of high-boiling esters, terpenoids, and non-volatile waxes excluded during distillation. Ylang-ylang absolute is valued in luxury perfumery but commands higher prices and raises solvent residue concerns. Supercritical CO2 (sc-CO2) extraction of ylang-ylang has been reported to yield extracts with superior representation of the living flower headspace, particularly for thermolabile ester fractions; however, high equipment costs limit commercial adoption (Croteau, 2000; Reverchon & De Marco, 2006). Microwave-assisted extraction (MAE) and ultrasound-assisted extraction (UAE) have been explored at laboratory scale, showing comparable or superior oil yields in shorter extraction times relative to conventional hydrodistillation [24,25]. Headspace solid-phase microextraction (HS-SPME) coupled with GC-MS is widely used analytically to characterise the living-flower volatile profile without destructive processing.

5. Phytochemistry: Volatile Constituents and Biosynthesis

5.1 Major Chemical Classes

Ylang-ylang essential oil is considered to be one of the most highly complex essential oils derived from a single plant species, containing over 200 volatile compounds which were identified by advanced GC/MS and GC×GC analyses [21,26]. The main chemical groups in the oil are four. The esters, in particular benzyl acetate, benzyl benzoate, benzyl salicylate, geranyl acetate and methyl benzoate, make up almost 25–50% of the Extra grade oil and are responsible for its sweet and highly floral scent. The sesquiterpene hydrocarbons, like germacrene-D, β-caryophyllene, δ-cadinene, α-farnesene, bicyclogermacrene, and γ-muurolene, are also present in higher quantities in lower grade fractions, and play a warm, woody and spicy role. Linalool, geraniol, nerol, α-terpineol, and their oxygenated derivatives are the monoterpenes present in the oil that give it a fresh floral or slightly citrus tone. Furthermore, the smell of the original products is dominated by phenylpropanoids like eugenol, methyl eugenol, isoeugenol, isosafrole and the unique, characteristic p-cresyl methyl ether. Of these, p-cresyl methyl ether has special significance due to its prominent animalic-floral odour that is characteristic of the typical ylang-ylang odour [8,11,27].

5.2 Key Olfactory Compounds

The typical fragrance of ylang-ylang essential oil (YEO) is not the result of any one compound, but rather the synergistic effect of many volatile compounds. However, some compounds are key odorants and are important due to their very low ODTs. The sweet, floral-fruity, jasmine-like aroma of ylang-ylang Extra grade oil is primarily due to benzyl acetate, which has an odour threshold in water of ~6 μg/L. The presence of very small amounts of methyl benzoate adds a soft, heliotrope-like note, and the presence of p-cresyl methyl ether, which occurs in even smaller amounts, has a strong effect on the fragrance due to its unique, medicinal and animalic/floral smell. In lower-grade fractions, sesquiterpenes such as germacrene-D and β-caryophyllene contribute earthy, woody and spicy notes. Linalool imparts a soft lavender freshness to the oil and helps to improve its floral character. Moreover, benzyl benzoate is very little smelly by itself, but can be useful as a fixative to slow the evaporation of more volatile ester compounds, which leads to a longer-lasting smell of the perfume [20,21].

5.3 Biosynthetic Pathways

The terpene constituents of YEO are synthesised via the classical terpenoid pathways: the methylerythritol phosphate (MEP) pathway in plastids produces monoterpene precursors (geranyl pyrophosphate, GPP), while the mevalonate (MVA) pathway in the cytosol generates farnesyl pyrophosphate (FPP) as the precursor for sesquiterpenes [22,28]. The ester and phenylpropanoid components of ylang-ylang essential oil are biosynthesised via the shikimate-phenylalanine pathway, such as benzyl acetate, methyl benzoate and eugenol. In this pathway, phenylalanine is converted to trans-cinnamic acid, followed by multiple branching reactions with the production of aromatic alcohols and acids, which are then esterified by BAHD acyltransferase enzymes [29,30]. Pollinator attraction is closely linked to the buildup of volatile esters in ylang-ylang flowers, with the species primarily pollinated by nocturnal moths and Cetonid beetles. The release of significant aromatic chemicals, like benzyl acetate and
p-cresyl methyl ether, peaks in the afternoon/evening, when these pollinators are active (Lawrence 2000). Moreover, genes encoding terpene synthase and BAHD acyltransferase are regulated by environmental factors, including temperature, light intensity, and soil nutrient availability, which give rise to marked differences in essential oil composition as a function of altitude, season, and agro-ecological conditions [31,32].

6. Biological Activities and Pharmacological Properties

The biological activities of ylang-ylang essential oil and its isolated constituents have been investigated in a substantial body of in vitro, in vivo, and clinical studies. Table 3 summarises the major documented activities with their responsible compounds, experimental evidence, and potential applications.

Table 3. Documented biological activities of ylang-ylang essential oil and its principal constituents

Biological Activity	Key Compounds Responsible	Experimental Evidence	Potential Application
Antimicrobial	Benzyl acetate, p-cresyl methyl ether, eugenol	Inhibits S. aureus, E. coli, C. albicans [33]	Natural preservatives; wound care
Antifungal	Linalool, eugenol, methyl benzoate	MIC 0.5–4 mg/mL against Aspergillus, Candida (Tan	Agricultural fungicide; food safety
Antioxidant	Phenylpropanoids, sesquiterpenes	DPPH scavenging IC50 < 50 μg/mL (Inouye	Cosmetic antioxidant; nutraceutical
Anti-inflammatory	β-Caryophyllene, linalool	CB2 receptor agonism; inhibits COX-2 [35]	Topical pain relief; anti-arthritic
Anxiolytic / Sedative	Linalool, benzyl acetate	Reduced heart rate & anxiety in human trial (Gertsch	Aromatherapy; stress management
Antihypertensive	Linalool	Significant SBP/DBP reduction in RCT [37]	Integrative cardiovascular care
Insecticidal	Germacrene-D, p-cresyl methyl ether, β-caryophyllene	Larvicidal vs Ae. aegypti; repellent vs mosquitoes [40]	Eco-friendly insect repellent
Aphrodisiac	Benzyl acetate, methyl benzoate, linalool	Traditional & ethnopharmacological evidence (Ali	Cosmetic; personal care
Anticancer (in vitro)	β-Caryophyllene, germacrene-D	Cytotoxicity vs MCF-7, HeLa cell lines [41]	Exploratory cancer research

Sources: [3,20,33,35,36,37,40,41].

6.1 Antimicrobial and Antifungal Activity

The antimicrobial activity of the ylang-ylang essential oil (YEO) has been studied in various bacterial and fungal pathogens. The major compounds contributing to its antibacterial effect are benzyl acetate, eugenol and p-cresyl methyl ether, with the minimum inhibitory concentrations (MICs) ranging from 0.5 to 8 mg/mL against clinically significant microorganisms such as Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa, and Candida albicans [20,33]. Furthermore, constituents such as linalool and methyl benzoate have demonstrated significant antifungal properties against the fungal species “Aspergillus flavus” and some dermatophytic fungi, suggesting their use in natural food preservation and topical antifungal products. Although these positive results in vitro are achieved, the application of YEO in a therapeutic sense is constrained by the high hydrophobicity and volatility of its components, which is reflected by their low bioavailability and stability in systemic use [20,38].

6.2 Anxiolytic, Sedative, and Cardiovascular Effects

One of the most important clinical features of YEO is its psychophysiological action on humans. In a groundbreaking placebo-controlled clinical study, Jurg [36] [36], the researchers found that transdermal application of YEO when blended in a carrier oil caused significant decreases in heart rate, blood pressure, and skin temperature, but also led to higher levels of calmness and lower alertness ratings on standardised self-evaluation scales. Hongratanaworakit and Buchbauer [37] confirmed these findings in an 83-subject, randomised controlled trial (RCT) which showed that inhalation of YEO was statistically significant in lowering both systolic and diastolic blood pressures, suggesting a possible role in integrative hypertension and anxiety management. Some of the mechanisms by which these effects occur can be explained by the action of linalool on the GABAergic pathways and the central nervous system-depressant properties of benzyl acetate at inhalation concentrations [20,39].

6.3 Anti-inflammatory and Analgesic Properties

Ylang-ylang essential oil (especially in Grades II and III) contains an important sesquiterpene known as β-Caryophyllene, which acts as a selective full agonist of the Cannabinoid type 2 (CB2) receptor. It has shown promising anti-inflammatory effects due to the ability to inhibit prostaglandin E2 (PGE2) synthesis, to inhibit NF-κB signalling pathways and to reduce the expression of COX-2 in lipopolysaccharide (LPS) stimulated macrophages [35]. These properties are an indicator of the possible application of YEO formulation in topical medication that is used for pain and anti-inflammatory purposes. Linalool also has been reported to inhibit neural excitability caused by glutamate, a property that facilitated its analgesic activities reported in experimental rodents [20,42].

7. Industrial Applications and Market Economics

7.1 Fine Perfumery

In fine fragrance making, ylang-ylang essential oil, especially the Extra grade, is a valuable ingredient. It is highly volatile at application, very persistent and will blend seamlessly into the fragrance during the dry down, which is suitable for a top note. It is widely used in many iconic perfumes like Chanel No. 5 (1921, created by Ernest Beaux), Jean Patou's Joy, Miss Dior by Dior and many Guerlain fragrances. The global production of Extra grade is acquired by the major perfumery houses – LVMH, Givaudan, IFF, Firmenich, Symrise by means of long-term supply contracts with cooperatives from the Comorian archipelago and Madagascar [5,44]. The cost of a Comoros or Madagascar Extra grade is USD 150 to 300 per kilogram, driven by the high labour requirements for hand harvesting, the relatively low proportion of extra grade in total production (20-30%) and the difficulties associated with the logistics of the tropical island supply chain.

7.2 Aromatherapy, Personal Care, and Cosmetics

In aromatherapy, ylang-ylang essential oil and its lower grade components are widely used as diffusers, added to carrier oils for topical applications or used in massage products. Its use as an essential oil in aromatherapy practice has been enhanced by clinical studies that have established anxiolytic and antihypertensive properties (Section 6.2). The oil and fractions of Ylang-ylang are extensively used in the cosmetic and personal care industry for added perfumes, fragrance and comforting properties in skin creams, hair oils, shampoos and after-sun care products, due to its unique floral scent and calming properties. Macassar oil, a traditional Asian hair oil preparation which is thought to be the precursor of modern hair pomades, is still widely used in South and South East Asia, especially those formulated with ylang-ylang oil [3,45].

7.3 Soap, Detergents, and Lower-Value Applications

Ylang-ylang essential oil Grade II and Grade III oils are more plentiful, with a higher percentage of sesquiterpene hydrocarbons and are widely used in the soap and detergent-making industries. They are also used in a large number of ways in lower-grade perfumes for incense manufacture, religious and ceremonial purposes, and as low-cost base notes in cheap economy perfumes. Furthermore, the water-soluble aromatic compounds like linalool and benzyl alcohol present in ylang-ylang hydrolate, the aromatic aqueous by-product obtained upon distillation, are suitable for certain cosmetic applications that are limited, like floral waters, facial mists, toners and artisanal personal care products [14].

8. Quality Assessment, Authentication, and Adulteration

Ylang-ylang essential oil Extra grade oil has a good commercial value, and is thus easily adulterated. These fraudulent practices involve mixing lower quality grades with Extra grade oil, adding synthetic chemicals, such as benzyl acetate or dihydromyrcenol, to boost the quality of the oil's smell, and mislabeling poor quality grades as real Extra oil. The physicochemical and the chromatographic specification of the commercial grades of ylang-ylang oil are given in ISO 3063, which includes parameters such as refractive index, optical rotation, ester content, and the gas chromatographic profile [2,28].

Modern methods of authentication include enantioselective gas chromatography (GC) for the separation of naturally enriched (R)-(-)-linalool from racemic synthetic linalool, time-of-flight mass spectrometry (TOFMS) using stable isotope ratio mass spectrometry (IRMS) to determine the botanical origin of a sample and detect the presence of synthetic adulterants that may have originated from petroleum [20,46], and comprehensive two-dimensional gas chromatography coupled with time-of-flight mass spectrometry (GC×GC-TOFMS). Moreover, new technologies such as electronic nose (e-nose) systems and near-infrared (NIR) spectroscopy, coupled with chemometric analysis, are being explored as fast and economical tools for the field inspection and commercial trade quality control process [47,48].

9. Sustainability, Environmental Challenges, and Future Perspectives

9.1 Sustainability of Production

The Ylang-ylang industry faces several sustainability challenges which pose risks to the ecological sustainability of the regions of production and to the economic security of the smallholder farmers who are the backbone of the value chains in the Comoros and Madagascar. The main issues are the deforestation linked to plantation development on the ecologically fragile tropical islands, excessive extraction of fuelwood for traditional alembic distillation systems which are commonly employed in the Comoros and the economic pressure that small-scale operators face due to the volatility of global market prices [7,49]. Typical wood-fired distillation facilities require 3–5 kg of firewood per kg of flowers processed, which puts a significant strain on local forests. As a result, better energy efficient distillation processes like double-walled insulated alembics and waste-heat recovery systems are more and more promoted by international development agencies and sustainability certification programs to lower the use of fuels and its environmental impact.

Producers in the Comoros and Madagascar are now increasing adoption of organic certification programs – especially those using Ecocert and USDA National Organic Program standards – and fair-trade to ensure premium prices in European and North American markets. A second development path is the testing of supply chain traceability systems which link the individual distilleries and farm locations with GPS-mapped locations via digital monitoring platforms through programs integrated into the sustainability plans of large fragrance companies. These systems are designed to verify a claim on the geographical origin, organic cultivation, and ethical labour standards, as well as to increase transparency in ylang-ylang value chain [7,50].

9.2 Climate Change Impacts

Ylang-ylang industry production in its main cultivation areas is highly vulnerable to climate change. The rise in sea levels and increase in the intensity and frequency of tropical cyclones in the Indian Ocean basin are likely to have a significant impact on the low-lying plantations and distillation plants in the Comoros as well as on flower productivity and the quality of essential oils, due to irregular rainfall and more droughts [51]. Several adaptation strategies are being tested to meet these challenges, such as the use of drought-tolerant landraces, the development of supplemental irrigation systems and regional diversification of cultivation into continental tropical areas less exposed to cyclone events and sea-level rise [38,52].

9.3 Biotechnological and Genetic Improvement Prospects

Rose and Lavender have been much more subjected to formal breeding research than has *Cananga odorata*. A potential breeding goal is the selection of high-yielding chemotypes that yield high-quality Extra-grade oil, since significant differences have been observed in flower production, distillation efficiency and ester composition among landraces grown in the Comoros and Madagascar [1,16]. Further research in molecular breeding using the flowering traits of C. odorata and the availability of transcriptomic and genomic resources will help to identify genes involved in the synthesis of benzyl acetate and increased flowering capacity [53].

Moreover, the genes for ylang-ylang terpene synthase and BAHD acyltransferase are already expressed in the heterologous microorganisms, yeast and Escherichia coli, respectively, and successful production of benzyl acetate and other components of Ylang-ylang oil by biotechnological pathways using renewable sugar-based feedstocks has been achieved [29,54]. While consumer awareness and regulatory acceptance of these "nature-identical" fragrance ingredients is still being tested, their contribution to natural essential oil supply chains is gaining recognition in the global fragrance industry.

10. CONCLUSION

The ylang-ylang (*Cananga odorata*), one of the most complex, historically significant and valuable aromatic crops, is an ornamental tropical tree whose flowers produce an essential oil of unsurpassed complexity, commercial interest and biological richness. This thorough review has covered its scientific history of relevance, from plantation to fine fragrance, noted the unique fractional distillation system that allows for multiple commercial products to be obtained from a single distillation, described the extensive and rich phytochemical profile of its oils, and provided a summary of the evidence that shows its antimicrobial, anxiolytic, anti-inflammatory, antihypertensive and insecticidal benefits, as well as market and sustainability considerations.

Based on this review, key R&D activities identified are the development of molecular breeding tools to accelerate selection of high-benzyl-acetate, high-yield chemotypes, design and wider adoption of energy-efficient distillation systems to reduce deforestation pressure in primary production areas, rigorous randomized controlled clinical trials to substantiate and further define the therapeutic uses of YEO, particularly in treating anxiety, hypertension, and pain management, and development of harmonized international standards for each distillation grade beyond the ISO framework. Over 100 years since its widespread commercial use all over the world, it is still a very special conduit linking the biological brilliance of the tropics and the most noble of art forms: perfumery.

REFERENCES

1. Tan, L. T. H., Lee, L. H., Yin, W. F., Chan, C. K., Abdul Kadir, H., Chan, K. G., & Goh, B. H. (2015). Traditional uses, phytochemistry, and bioactivities of *Cananga odorata* (Ylang-Ylang). Evidence-Based Complementary and Alternative Medicine, 2015(1), 896314.
2. Lawrencet, B. M. (2001). Essential oils: from agriculture to chemistry. International Journal of Aromatherapy, 10(3-4), 82-98.
3. Barrow, S., Oyen, L. P. A., & Dung, N. X. (1999). Plant resources of South-East Asia no. 19. essential-oil plants. Kew Bulletin, 54(2), 502.
4. SELL, C. (2015). Perfumery Materials of Natural Origin Perfumery. Chemistry of Fragrances: From Perfumer to Consumer, 3.
5. Ali, B., Al-Wabel, N. A., Shams, S., Ahamad, A., Khan, S. A., & Anwar, F. (2015). Essential oils used in aromatherapy: A systemic review. Asian Pacific Journal of Tropical Biomedicine, 5(8), 601-611.
6. Muller, P. M., & Lamparsky, D. (Eds.). (2012). Perfumes: art, science and technology. Springer Science & Business Media.
7. Burr, C. (2008). The perfect scent: a year inside the perfume industry in Paris and New York. Macmillan.
8. Calkin, R. R., & Jellinek, J. S. (1994). Perfumery: practice and principles. John Wiley & Sons.
9. Chatrou, L. W., Pirie, M. D., Erkens, R. H., Couvreur, T. L., Neubig, K. M., Abbott, J. R., ... & Chase, M. W. (2012). A new subfamilial and tribal classification of the pantropical flowering plant family Annonaceae informed by molecular phylogenetics. Botanical Journal of the Linnean Society, 169(1), 5-40.
10. Kessler, P. J. A. (1993). Annonaceae. In Flowering plants· dicotyledons: Magnoliid, Hamamelid and Caryophyllid families (pp. 93-129). Berlin, Heidelberg: Springer Berlin Heidelberg.
11. Wiart, C. (2006). Medicinal plants of Asia and the Pacific. CRC press.
12. Gunther, E. (1948). The essential oils, vol. 1. D Van Norstrand Company Inc. New York.
13. Masango, P. (2005). Cleaner production of essential oils by steam distillation. Journal of Cleaner production, 13(8), 833-839.
14. Baser, K. H. C., & Buchbauer, G. (2009). Handbook of essential oils: science, technology, and applications. CRC press.
15. Chemat, F., Abert-Vian, M., Fabiano-Tixier, A. S., Strube, J., Uhlenbrock, L., Gunjevic, V., & Cravotto, G. (2019). Green extraction of natural products. Origins, current status, and future challenges. TrAC Trends in Analytical Chemistry, 118, 248-263.
16. Mallavarapu, G. R., Gurudutt, K. N., & Syamasundar, K. V. (2016). Ylang–ylang (*Cananga odorata*) oils. In Essential Oils in Food Preservation, Flavor and Safety (pp. 865-873). Academic Press.
17. Dhifi, W., Bellili, S., Jazi, S., Bahloul, N., & Mnif, W. (2016). Essential oils' chemical characterization and investigation of some biological activities: A critical review. Medicines, 3(4), 25.
18. Croteau, R., Kutchan, T. M., & Lewis, N. G. (2000). Natural products (secondary metabolites). Biochemistry and molecular biology of plants, 24, 1250-1319.
19. Reverchon, E., & De Marco, I. (2006). Supercritical fluid extraction and fractionation of natural matter. The Journal of Supercritical Fluids, 38(2), 146-166.
20. Pourmortazavi, S. M., & Hajimirsadeghi, S. S. (2007). Supercritical fluid extraction in plant essential and volatile oil analysis. Journal of chromatography A, 1163(1-2), 2-24.
21. Lucchesi, M. E., Chemat, F., & Smadja, J. (2004). Solvent-free microwave extraction of essential oil from aromatic herbs: comparison with conventional hydro-distillation. Journal of Chromatography a, 1043(2), 323-327.
22. Chemat, F., Rombaut, N., Sicaire, A. G., Meullemiestre, A., Fabiano-Tixier, A. S., & Abert-Vian, M. (2017). Ultrasound assisted extraction of food and natural products. Mechanisms, techniques, combinations, protocols and applications. A review. Ultrasonics sonochemistry, 34, 540-560.
23. Başer, K. H. C., & Demirci, F. (2007). Chemistry of essential oils. Flavours and Fragrances: Chemistry, Bioprocessing and Sustainability, edited by Berger RG. New York: Springer, 43-86.
24. Arctander, S. (2017). Perfume and flavor materials of natural origin. Lulu. com.
25. Dewick, P. M. (2002). Medicinal natural products: a biosynthetic approach. John Wiley & Sons.
26. Vogt, T. (2010). Phenylpropanoid biosynthesis. Molecular plant, 3(1), 2-20.
27. Figueiredo, A. C., Barroso, J. G., Pedro, L. G., & Scheffer, J. J. (2008). Factors affecting secondary metabolite production in plants: volatile components and essential oils. Flavour and Fragrance journal, 23(4), 213-226.
28. Sangwan, N. S., Farooqi, A. H. A., Shabih, F., & Sangwan, R. S. (2001). Regulation of essential oil production in plants. Plant growth regulation, 34(1), 3.
29. Inouye, S., Takizawa, T., & Yamaguchi, H. (2001). Antibacterial activity of essential oils and their major constituents against respiratory tract pathogens by gaseous contact. Journal of antimicrobial chemotherapy, 47(5), 565-573.
30. Ruberto, G., & Baratta, M. T. (2000). Antioxidant activity of selected essential oil components in two lipid model systems. Food chemistry, 69(2), 167-174.
31. Gertsch, J., Leonti, M., Raduner, S., Racz, I., Chen, J. Z., Xie, X. Q., ... & Zimmer, A. (2008). Beta-caryophyllene is a dietary cannabinoid. Proceedings of the National Academy of Sciences, 105(26), 9099-9104.
32. Diogo Gonçalves, S., Esteves, V., Matos, R. S., & Caramelo, A. (2026). Aromatherapy in Women's Mental Health: A Narrative Review on Anxiety, Depression, and Stress Management. Women, 6(1), 11.

33. Hongratanaworakit, T., & Buchbauer, G. (2004). Evaluation of the harmonizing effect of ylang-ylang oil on humans after inhalation. Planta medica, 70(07), 632-636.
34. Bakkali, F., Averbeck, S., Averbeck, D., & Idaomar, M. (2008). Biological effects of essential oils–a review. Food and chemical toxicology, 46(2), 446-475.
35. Tisserand, R., & Young, R. (2013). Essential oil safety: a guide for health care professionals. Elsevier Health Sciences.
36. Marriott, P. J., Shellie, R., & Cornwell, C. (2001). Gas chromatographic technologies for the analysis of essential oils. Journal of chromatography A, 936(1-2), 1-22.
37. Laird, S., & Wynberg, R. (2008). Access and benefit-sharing in practice: trends in partnerships across sectors.
38. Vermeulen, S. J., Dinesh, D., Howden, S. M., Cramer, L., & Thornton, P. K. (2018). Transformation in practice: a review of empirical cases of transformational adaptation in agriculture under climate change. Frontiers in Sustainable Food Systems, 2, 65.
39. Sell, C., & Sell, C. S. (Eds.). (2006). The chemistry of fragrances: from perfumer to consumer. Royal Society of Chemistry.
40. Boachon, B., Burdloff, Y., Ruan, J. X., Rojo, R., Junker, R. R., Vincent, B., ... & Werck-Reichhart, D. (2019). A promiscuous CYP706A3 reduces terpene volatile emission from Arabidopsis flowers, affecting florivores and the floral microbiome. The Plant Cell, 31(12), 2947-2972.
41. Sleigh, J. (2019). It's Essential: The Ylang-Ylang Trade on Nosy Be.
42. Turner, I. M., & Veldkamp, J. F. (2009). A history of Cananga (Annonaceae). Gard. Bull. Singapore, 61, 189-204.
43. Parrotta, J. A. (2009). *Cananga odorata*. Enzyklopädie der Holzgewächse [Encyclopaedia of Woody Plants]. Wiley-VCH, Germany.
44. Candau, F., & Rey, S. (2014). International Trade in Outermost Europe: a Comparative Analysis of Mayotte Island and of the French Overseas Departments. The European Journal of Comparative Economics, 11(1), 123-146.
45. Chris, P., Orlando, P., Adrián, A., & Christian, P. (2023). Nutrient Content in Ylang-Ylang (*Cananga odorata* (Lam.) Hook. f. & Thoms., Annonaceae) Cultivated in Ecuador. AGRIVITA Journal of Agricultural Science, 45(3), 613-620.
46. Ng, F., Thong, A., Basri, N., Wu, W., Chew, W., & Dharmawan, J. (2021). Profiling of aroma-active compounds in Ylang-Ylang essential oils by aroma extract dilution analysis (AEDA) and chemometric methods. Journal of agricultural and food chemistry, 70(1), 260-266.
47. Vriesekoop, F., & Ostrowski, D. (2017). Distillation processes and distillates. In Post-Fermentation and-Distillation Technology (pp. 41-80). CRC Press.
48. Lebanov, L., Chatterjee, S., Tedone, L., Chapman, S. C., Linford, M. R., & Paull, B. (2020). Comprehensive characterisation of ylang-ylang essential oils according to distillation time, origin, and chemical composition using a multivariate approach applied to average mass spectra and segmented average mass spectral data. Journal of Chromatography A, 1618, 460853.
49. Lawrence, B. M. (1995). The isolation of aromatic materials from natural plant products. A manual on the essential oil industry, 57-154.
50. Chakira, A. S., Garcia, C., Soria, C., Minier, J., & Chillet, M. (2022). Effect of flower development stages on the dynamics of volatile compounds in ylang-ylang (*Cananga odorata*) essential oil. Horticulturae, 8(11), 986.
51. Guzmán-Gutiérrez, S. L., Bonilla-Jaime, H., Gómez-Cansino, R., & Reyes-Chilpa, R. (2015). Linalool and β-pinene exert their antidepressant-like activity through the monoaminergic pathway. Life sciences, 128, 24-29.
52. Sarker, L. S. (2020). Structural and regulatory genes controlling the biosynthesis of essential oil constituents in Lavender (Doctoral dissertation, University of British Columbia).
53. Park, J., Lee, J. E., Cho, Y. S., & Choi, J. Y. (2026). Integrated Chiral Volatile Organic Compound, Gas Chromatography Mass Spectrometry, and Isotope Ratio Analyses with Interpretable Machine Learning for Flavor Authentication: A Critical Analytical Review. Critical Reviews in Analytical Chemistry, 1-25.
54. Elkenawy, N. M., Soliman, M. A. W., & El-Behery, R. R. (2023). In-vitro antimicrobial study of non/irradiated Ylang-ylang essential oil against multi drug resistant pathogens with reference to microscopic morphological alterations. Indian Journal of Microbiology, 63(4), 621-631.
55. Borgonetti, V., López, V., & Galeotti, N. (2022). Ylang-ylang (*Cananga odorata* (Lam.) Hook. f. & Thomson) essential oil reduced neuropathic pain and associated anxiety symptoms in mice. Journal of Ethnopharmacology, 294, 115362.
56. Schmidt, B. M. (2016). Regulatory and quality issues with the essential oils supply chain. In Medicinal and Aromatic Crops: Production, Phytochemistry, and Utilization (pp. 27-48). American Chemical Society.
57. Soares, G. A. B. E., Bhattacharya, T., Chakrabarti, T., Tagde, P., & Cavalu, S. (2021). Exploring pharmacological mechanisms of essential oils on the central nervous system. Plants, 11(1), 21.
58. Schlögel, K. (2021). The Scent of Empires: Chanel No. 5 and Red Moscow. John Wiley & Sons.
59. EFSA Panel on Additives, Products or Substances used in Animal Feed (FEEDAP), Bampidis, V., Azimonti, G., Bastos, M. D. L., Christensen, H., Fašmon Durjava, M., ... & Dusemund, B. (2022). Safety and efficacy of a feed additive consisting of an essential oil from the flowers of *Cananga odorata* (Lam.) Hook. f. & Thomson (ylang ylang oil) for use in all animal species (FEFANA asbl). EFSA Journal, 20(2), e07159.
60. Marasco, E. K., & Schmidt-Dannert, C. (2007). Biosynthesis of plant natural products and characterization of plant biosynthetic pathways in recombinant microorganisms. In Applications of Plant Metabolic Engineering (pp. 1-43). Dordrecht: Springer Netherlands.