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Summary of Chemical Constituents and Pharmacological Effects of Essential Oil of Sweet Orange from Southern Jiangxi Province

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Abstract: Gannan sweet orange essential oil has garnered significant attention due to its diverse chemical composition and pharmacological activities. The main active ingredients include sabinene, limonene, and linalool, which exhibit antioxidant, anti-inflammatory, antibacterial, and analgesic properties. This essential oil has potential applications in the development of medicinal products. This paper reviews the primary chemical composition and pharmacological effects of Jiangxi orange flower essential oil, highlighting the need for future research to focus on its biological activity and clinical application potential. Additionally, it emphasizes the importance of optimizing extraction and detection technologies to enhance its application value in medicine and other industries, thereby promoting the development of Gannan's sweet orange industry.

Keywords: Gannan sweet orange; Sweet orange essential oil; Chemical composition; Pharmacological activity

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1. Introduction

Sweet oranges (*Citrus sinensis* (L.) Osbeck) belong to the *Citrus* genus within the *Rutaceae* family. In China, the principal varieties of sweet oranges include navel orange, summer orange, blood orange, and golden orange, with their planting area and yield ranking first globally. Gannan City in Jiangxi Province dedicates approximately 1.8 million mu to sweet orange cultivation, where 70 to 80 percent of the sweet orange flowers are male-degraded, asexual, or deformed flowers, which can be utilized for essential oil extraction.

Sweet orange essential oil is recognized for its ability to regulate qi, refresh the mind, and alleviate fatigue. It is widely employed in the preparation of food seasonings, daily chemical products, and cosmetics. Despite its extensive applications, the specific pharmacological action mechanisms of orange flower oil have not been fully elucidated. This paper reviews the main chemical compositions associated with pharmacological activities, offering a reference for further research while enhancing the comprehensive utilization value of Gannan sweet orange flowers.

2. Main chemical constituents and their pharmacological effects

Studies conducted by Xie [1] and Lin [2] have revealed that the chemical composition of essential oil extracted from Gannan sweet orange flowers varies depending on the region and extraction method, leading to differences in relative content. However, the primary constituents of Gannan sweet orange essential oil generally include monoterpenes, monoterpene alcohols, sesquiterpenes, and sesquiterpene alcohols, while minor components consist of monoterpene aldehydes and oxides. Among the monoterpenes, sabinene, limonene, ocimene, terpinene, and myrcene are predominant. The main monoterpene alcohols include linalool and terpinen-4-ol, while β-elemene is the most abundant sesquiterpene, and trans-nerolidol is the primary sesquiterpene alcohol. **Figure 1** illustrates the chemical structures of the main components found in Gannan sweet orange essential oil.

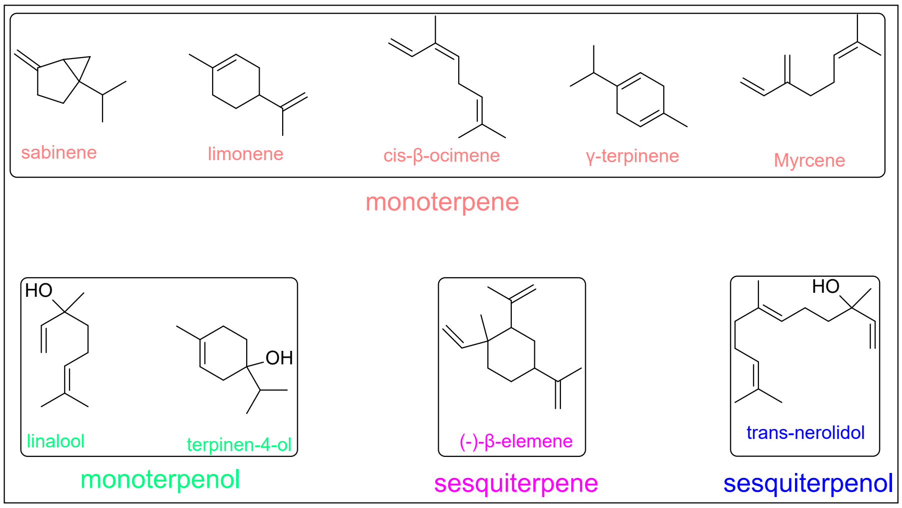

Figure 1. Representative compound structures

2.1. Monoterpenes

2.1.1. Sabinene

Sabinene, a natural bicyclic monoterpene, is present in the volatile extracts of various plants and is widely used in fragrances, perfume additives, fine chemicals, and advanced biofuels. It also demonstrates diverse biological activities:

(1) Antioxidant activity: Sabinene neutralizes free radicals and mitigates oxidative stress in human cells, contributing to its anti-aging and health-promoting properties.

(2) Anti-inflammatory activity: By inhibiting the production of inflammatory factors, sabinene regulates immune responses and alleviates inflammation, displaying anti-inflammatory and analgesic properties.

(3) Additional activities: Beyond antioxidant and anti-inflammatory effects, sabinene has been associated with other pharmacological benefits.

Qiu *et al.* [3] evaluated the in vitro anti-*Toxoplasma* activity of juniper (containing sabinene) by screening 26 terpenoids. The study demonstrated that juniper significantly inhibited *Toxoplasma* proliferation, with an IC_{50} of 90.76 μg/mL for the RH-2F strain. Giemsa staining and cellular immune fluorescence analysis revealed that juniper olefinic effectively suppressed cellular proliferation and invasion by *Toxoplasma* ($P < 0.001$).

Park *et al.* [4] investigated the effects of sabinene on dental caries in mice, focusing on mechanisms against *Streptococcus mutans* (SM), a cariogenic bacterium. Various concentrations of sabinene inhibited bacterial growth, acid production, and biofilm formation. Real-time PCR analysis confirmed that sabinene effectively suppressed the growth and adhesion of S. mutans, suggesting its potential for oral healthcare applications.

2.1.2. Limonene

Limonene, a cyclic monoterpene, is the primary component of citrus essential oils and exists as two isomers (left-handed and right-handed) due to its chiral center. Commonly used in perfumes and aromatherapy, limonene is valued for its ability to uplift the spirit, enhance pleasure, and regulate mood. Its physiological activities include antibacterial, anti-inflammatory, anticancer, antifungal, and antiseptic properties.

(1) Antibacterial activity: Wang *et al.* [5] used the minimum inhibitory concentration method and agar diffusion to assess limonene's antibacterial properties. Results showed that its minimum inhibitory concentration against brewer's and baker's yeast was 320 mg/L, and its bacteriostatic effects on baker's yeast and *Aspergillus niger* were superior to those of potassium sorbate and sodium benzoate.

(2) Anti-inflammatory activity: Guo *et al.* [6] conducted experiments using xylene-induced inflammation in mice. Limonene demonstrated significant anti-inflammatory effects within the dose range of 50 mg/kg to 150 mg/kg, with increasing efficacy at higher doses.

(3) Anticancer activity: Limonene inhibits various cancer types, primarily by disrupting the cell cycle and inducing apoptosis. While the exact mechanisms remain unclear, synergistic effects are likely. Regular intake of limonene may assist in cancer prevention, and its low toxicity and minimal resistance potential make it a promising anticancer agent. Furthermore, limonene enhances the efficacy of other anticancer drugs while mitigating their side effects.

2.1.3. Ocimene

Ocimene is a chain monoterpene initially isolated from basil oil and is also found in various essential oils, including those of Gannan sweet orange, lavender, and tarragon. It primarily comprises three structural types: α, cis-β, and trans-β. Naturally occurring ocimene exhibits a range of biological activities, such as anticonvulsant, antifungal, antineoplastic, and insect resistance properties.

Geng *et al.* [7] evaluated the protective effects of ocimene against photoaging in epidermal HaCaT cells by measuring the expression of oxidative stress markers and matrix metalloproteinases (MMPs). Their research demonstrated that after UVB exposure, basil-derived compounds effectively reduced reactive oxygen species (ROS) and malondialdehyde accumulation while enhancing superoxide dismutase (SOD) activity. This mechanism mitigates oxidative stress-induced photoaging. Furthermore, studies on UVB-exposed Hs68 cells revealed that ocimene inhibited MMP-1 expression and promoted the secretion of collagen and hyaluronic acid, thereby safeguarding the extracellular matrix. These findings indicate that ocimene holds the potential for preventing and alleviating skin photoaging.

2.1.4. Terpinene

Terpinene refers to a group of cyclic monoterpenes characterized by isomerism and typically existing as a colorless liquid with a distinctive pine-like fragrance. Terpinene is classified into four structural types (α, β, γ, and δ) based on the position of the double bond. Among these, γ-terpinene has drawn significant attention for its antioxidant, analgesic, and antinociceptive properties.

Passos *et al.* [8] examined the role of γ-terpinene in pain relief using formalin, capsaicin, and glutamic acid tests. Their findings indicated that γ-terpinene did not exhibit acute toxicity but demonstrated antinociceptive effects in the glutamate test, suggesting its potential role in modulating chemical nociception through interactions with cholinergic and opioid systems.

Li *et al.* [9] further explored the antioxidant properties of γ-terpinene against 2,2'-azobis(2-amidinopropane) (2AAPH)-induced oxidation of methyl linoleate (LH), DNA, and erythrocytes. The study found that γ-terpinene scavenged approximately 0.4 free radicals while protecting DNA and about 1.2 free radicals when safeguarding red blood cells and methyl linoleate. These results underscore the strong free radical scavenging ability and significant antioxidant activity of γ-terpinene.

2.1.5. Myrcene

Myrcene, also known as geranyl, is a chain monoterpene compound. While α-myrcene is rare in nature, β-myrcene is widely used in the fragrance industry. β-myrcene is a colorless or pale yellow liquid with a light balsamic aroma and is present in various essential oils, including those of Gannan sweet orange, cinnamon, cypress, and lemon. This compound demonstrates extensive pharmacological activities, including anti-anxiety, antioxidant, anti-aging, anti-inflammatory, and analgesic effects.

Surendran *et al.* [10] reviewed the biological and toxicological characteristics of β-myrcene, detailing its primary biological properties and active mechanisms. While animal studies have indicated that β-myrcene may provide notable health benefits, research involving human subjects remains limited, highlighting the need for further investigation.

2.2. Monoterpene alcohols

2.2.1. Linalool

Linalool, an acyclic monoterpene alcohol, is a volatile compound with diverse pharmacological activities, including analgesic, anxiolytic, sedative, and hypnotic effects.

Batista *et al.* [11] demonstrated that linalool inhibits glutamate-induced acute pain responses in a dose-dependent manner, with its analgesic effects mediated through interactions with ionic glutamate receptors. Further studies examining the analgesic effects of L-linalool in chronic inflammatory and neuroallergic mouse models revealed significant efficacy in alleviating pain in both conditions. Its mechanism of action in chronic pain management may involve the inhibition of pro-inflammatory factors and the regulation of NMDA-glutamate receptors.

Linck *et al.* [12] explored the anxiolytic activity of linalool in mice following inhalation. In the light-dark test, mice exposed to linalool exhibited improved social behavior and reduced aggression. Additionally, inhalation of 1% and 3% linalool concentrations resulted in extended sleep durations, reduced body temperatures, and slower motor activity, without impairing motor coordination.

2.2.2. Terpinen-4-ol

Terpinen-4-ol, the primary active component of tea tree essential oil, exhibits a variety of pharmacological effects. These include antibacterial activity, particularly against *Staphylococcus aureus*, and anticancer properties, such as inducing apoptosis in cancer cells.

Cordeiro *et al.* [13] demonstrated that terpinen-4-ol effectively inhibits the activity of the *Staphylococcus aureus* PBP2a protein by binding to it. Since PBP2a is a key factor in extensive drug resistance to beta-lactam antibiotics, this finding highlights its potential in combating resistant strains. Additionally, Calcabrini *et al.* [14] revealed that terpinen-4-ol induces apoptosis in melanoma cells through caspase-dependent mechanisms, with pronounced effects in drug-resistant mutant cells.

2.3. Sesquiterpenes

2.3.1. β-elemene

β-elemene is a macrocyclic alkene terpene compound characterized by its distinctive aroma and its ability to interact directly with the DNA of tumor cells, inhibiting and destroying these cells.

Numerous studies have shown that β-elemene induces apoptosis in a wide range of cancer cells. Guan *et al.* [15] discovered that β-elemene triggers both protective autophagy and apoptosis in human breast cancer cells, presenting a novel therapeutic approach for breast cancer treatment.

2.4. Sesquiterpene alcohols

2.4.1. Trans-nerolidol

Trans-nerolidol, a natural sesquiterpene alcohol, is found in various essential oils, including those of Gannan sweet orange, tea tree, and jasmine. It has demonstrated a range of biological activities, including anti-inflammatory, analgesic, and antioxidant effects.

Javed *et al.* [16] investigated the antioxidant and anti-inflammatory properties of trans-nerolidol. Their research revealed its efficacy in inhibiting the release of pro-inflammatory cytokines and inflammatory mediators. Furthermore, the trans-nerolidol treatment prevented rotenone-induced activation of glial cells and the subsequent loss of dopaminergic neurons and nerve fibers, thereby mitigating dopaminergic neurodegeneration caused by rotenone exposure.

3. Summary and prospect for research

The primary chemical components of Gannan sweet neroli essential oil, including monoterpenes, monoterpene alcohols, and sesquiterpenes, have been extensively studied. These compounds demonstrate significant pharmacological activities, such as antioxidant, anti-inflammatory, antibacterial, and analgesic effects. However, existing research primarily focuses on *in vitro* experiments, leaving the synergistic interactions among components and their specific mechanisms *in vivo* largely unexplored. Additionally, the chemical composition of Gannan sweet orange blossoms is significantly affected by factors such as geographic region, growth conditions, and extraction methods. As a result, standardizing the extraction process and improving the consistency of components remain critical challenges.

Future research should emphasize the *in vivo* pharmacological mechanisms of sweet orange essential oil, with particular attention to the metabolic pathways of its primary active components and their potential applications in disease treatment. Furthermore, advancing scientific extraction and detection methods, while integrating the pharmacological activity of Gannan sweet orange essential oil with its clinical applications, is anticipated to enhance its overall utilization value in medicine and health products.

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Disclosure statement

The authors declare no conflict of interest.

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