A review on the traditional uses, phytochemistry, and pharmacological activities of clove basil (*Ocimum gratissimum* L.)

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1. Introduction

The use of medicinal plants in traditional and complementary medicine for the treatment, management, or prevention of various diseases is as old as the origin of mankind (Yuan et al., 2016; Ekwogu et al., 2019). It has been estimated that approximately 80% of the world's population depends mainly on ethnomedicine or herbal medicine for the treatment, management, or prevention of various diseases (Joshi, 2013; Pant, 2014). Interestingly, the increasing preference for the use of herbal medicines over conventional medicines may be attributed to the efficacies of the active ingredients present in herbal medicine to serve as natural healing agents as well as their availability, accessibility, affordability, and acclaimed less or non-toxic effects (Ikpeazu et al., 2018; Ijioma et al., 2021).

Furthermore, over the last decade, medicinal plants and their bioactive compounds have attracted the attention of several researchers because of their usefulness in the management and prevention of life-threatening and chronic diseases (Sofowora et al., 2013; WHO, 2019) such as cancer, diabetes, stroke, and arthritis (Bernell and Howard, 2016), as an alternative therapy for the treatment of psychiatric disorders (Venuprasad et al., 2014), and in meeting the health requirements of the elderly (WHO, 2019). Currently, these medicinal plants have not only been employed in the treatment of numerous ailments, but also serve as a source of novel drugs for use in traditional or orthodox medicine. Drugs such as quinine, digoxin, aspirin, and morphine were produced from medicinal plants such as *Cinchona officinalis*, *Digitalis purpurea*, *Saix alba*, and *Papaver somniferum*, respectively (Mbanaso et al., 2020).
Ocimum gratissimum L., popularly known as scent leaf, is one of the discovered medicinal plants with the potential to serve as an alternative therapy for the treatment of various ailments or as a source of a new drug. It is a widespread and commercially viable perennial herbaceous plant with a very strong aromatic smell. It belongs to the family of Lamiaceae and is found in Africa, Asia, and South America (Tanko et al., 2008; Akara et al., 2021). It is used as a natural flavouring agent, condiment, or vegetable in the preparation of fish, meat, soup, and stew. It is also used in traditional medicine for the treatment of several ailments such as cough, pneumonia, fever, inflammation, anaemia, diarrhoea, pains, and fungal and bacterial infections (Akara et al., 2021).

Scientific reports have shown that O. gratissimum has a wide range of bioactive compounds such as flavonoids and polyphenols (Venuprasad et al., 2014; Iondji et al., 2016) and essential oils with several beneficial effects (Benitez et al., 2009; Melo et al., 2019), as shown in Tables 1 and 2.

Furthermore, several studies have shown this plant possesses numerous pharmacological properties such as anti-hyperglycaemic (Aguyi et al., 2009; Casanova et al., 2014), hypoglycaemic (Shiitu et al., 2019), anti-inflammatory (Ajayi et al., 2019), anti-diarrhoeal (Offiah and Chikwendu, 1999), anti-anaemic, hepatoprotective (Akara et al., 2021), anti-hypertensive (Shaw et al., 2017), antibacterial (Melo et al., 2019), antifungal (Mohr et al., 2017), and anti-oxidative properties (Joshi, 2013; Mahapatra and Roy, 2014) as well as exhibits many other pharmacological activities.

This study aims to provide comprehensive and up-to-date information on the medicinal uses, bioactive phytocompounds or essential oils, and the pharmacological activities of O. gratissimum. This paper also provides useful information on the beneficial effects of O. gratissimum and identifies gaps in current knowledge that can encourage further investigation into the effectiveness and commercialization of O. gratissimum in the treatment of various human diseases.

2. Methods used to obtain the materials for the review

In this study, only peer-reviewed journals and papers published in English were used. All the relevant materials were collected from only four online databases, namely PubMed (https://pubmed.ncbi.nlm.nih.gov/), Springer (https://www.springer.com/), Wiley (https://www.wiley.com/en-us), and Scienctific (https://www.sciencedirect.com/). The key search terms or words were Ocimum gratissimum or scent leaf alone or in combination with botanical description, taxonomy, ethnopharmacological uses, phytochemistry, essential oil, pharmacological activities, antioxidant activity, anxiolytic activity, antinociceptive activity, neuroprotective activity, anti-bacterial activity, anti-fungal activity, anti-viral activity, anti-protozoal activity, anti-anaemic activity, wound healing properties, and analgesic activity.

3. Botanical description, distribution, and taxonomy

3.1. Botanical description

Ocimum gratissimum is an aromatic herbaceous plant also known as basil, basil-clove, or alfawaca. It belongs to the Lamiaceae family (genus Ocimum and species gratissimum) (Nweze and Eze, 2009). It is about 1–3 cm tall, has an erect stem, and is branched, round-quadrangular, and woody at the base, with opposite, slender, and marginalized leaves.

3.2. Geographic location

Ocimum gratissimum is a perennial and odoriferous shrub found in tropical regions such as Brazil, India, Vietnam, Rwanda, Nigeria (Lahblou et al., 2004; Nweze and Eze, 2009), Cameroon, Togo, In Côte d’Ivoire, Kenya, Benin (Kpoviessi et al., 2014), and South Africa (Venuprasad et al., 2014).

3.3. Taxonomy

Plants of the Lamiaceae family are mostly classified as spices, herbs, and other aromatic variations. The Lamiaceae family comprises 236 genera and 7200 species of vines, shrubs, and trees found all over the globe. The genus Ocimum comprises about 60 species, most of which are found in Africa (Tanko et al., 2008). Ocimum gratissimum can be found in many forms and oftentimes classified into different species and subspecies.

3.4. Traditional uses

Ocimum gratissimum has been described as a plant easily available to communities and commonly utilized for the treatment of a plethora of diseases in numerous ethnopharmacological surveys (Ajayi et al., 2017a, b,c). This perennial and odoriferous plant is now found in all continents and possesses generally acknowledged medicinal properties. Its medicinal potential in Africa is incredibly vast and varies by country (Kpoviessi et al., 2014). Its infusions are regarded as tonic and pectoral in Cameroon, and the juice of its sheets is used to treat giddiness, headaches, cold, and cough. In Côte d’Ivoire, several formulations of this plant are used to treat ear infections, dermatoses, and ophthalmias (Kpoviessi et al., 2014). In Nigeria, it is recommended for diarrhoea therapy (Kpoviessi et al., 2014), while Sofowora (1970) recommended it for respiratory ailments and for use as an anthelmintic. It was also used to treat headaches, fevers, and ophthalmic and skin problems, as well as pneumonitis. In Togo, the plant’s infusion is used to relieve cough (antitussive). The fresh juice from its leaves has anti-diarrheic and antisyndetic properties; and its aqueous maceration is used to treat haematuria and purulent urethritis (Kpoviessi et al., 2014). In Benin Republic, the aqueous maceration of its pulp or aerial portions is used to treat dyspias, pelvic aches, colic, candidoses, digestive dysmennorhrea, emesis, haemorrhoids (pile), and diarrhoea. Its stem decoction is used to treat hepatitis, cough, asthma, and wound infections (Chah et al., 2006; Kpoviessi et al., 2014). The juice from its leaves is used to treat angina, cephalgias, headaches, fever, and malnutrition. Its inflorescences are utilized as aromatizers in a variety of meals.

Previous studies have shown that this type of basil has anaesthetic, anti-stress, anti-inflammatory, anthelmintic, antidiarrhoeal (Offiah and Chikwendu, 1999), antipyretic, anti-mutagenic, anti-ulcerative, gastro-protective, hepatoprotective, sedative, and fungicidal properties, validating its widespread medical use (Priyanka et al., 2018; Martins et al., 2021). O. gratissimum is antiseptic and has found widespread applications in the preparation of toothpaste and mouthwash and in topical therapies (Pessoa et al., 2002). It is an excellent wash for sore throat and tonsillitis. It is also used as an expectorant and as a cough suppressant. The plant extract is used to treat gastrointestinal helminths in both animals and humans (Chitwood, 2002). Reports on O. gratissimum revealed that the plant extract may be used as a medicinal resource for people living with the human immunodeficiency virus (HIV) and acquired immunodeficiency syndrome (AIDS) (Priyanka et al., 2018). It is used as a febrifuge and as a component in several malarial treatments in West Africa (Chah et al., 2006). Crushed leaves of the plant are used to cure conjunctivitis, while the oil extracted from the leaves is considered highly antimicrobial and has been used in wound dressing, the preparation of mouthwash, and the prevent postnatal sepsis (Chah et al., 2006). Furthermore, fresh aerial portions are consumed directly as vegetables in traditional soups, while dried and powdered aerial parts are utilized in a variety of traditional dishes (Kpoviessi et al., 2014).

4. Phytochemistry

4.1. Polyphenols and flavonoids found in Ocimum gratissimum

The phenolic compounds found in Ocimum gratissimum include rosmarinic acid, sinapic acid, salvigenin, gallic acid, catechins, methyl
Table 1. Chemical structures and biological activities of compounds isolated from *O. gratissimum*.

| Name of Compound | Structure of compound | Method of identification | Biological activities/beneficial effects | References |
|------------------|-----------------------|--------------------------|------------------------------------------|------------|
| Sinapic acid     | ![Sinapic acid structure](image1) | LC-ESI-MS/MS of 70% ethanolic fraction of *O. gratissimum* Venuprasad et al. (2014) | Exhibits antioxidant, anti-inflammatory, anticancer, antimutagenic, antiglycemic, neuroprotective, and antibacterial activities. | Chen (2016) |
| Rosmarinic acid  | ![Rosmarinic acid structure](image2) | LC-ESI-MS/MS of 70% ethanolic fraction of *O. gratissimum* Venuprasad et al. (2014) | Anti-microbial, immunomodulatory, anti-diabetic, anti-allergic, anti-inflammatory, hepato- and renal-protectant agent | Alagawany et al. (2017) |
| Luteolin         | ![Luteolin structure](image3) | LC-ESI-MS/MS of 70% ethanolic fraction of *O. gratissimum* Venuprasad et al. (2014), High Performance Liquid Chromatography Coupled with Diode Array Detection (HPLC-DAD) using *O. gratissimum* leaf extract (Irondi et al., 2016) | Anti-inflammatory, antioxidant, antibacterial and antiviral activities and blood pressure reduction | Lin et al. (2008) |
| Apigenin         | ![Apigenin structure](image4) | LC-ESI-MS/MS of 70% ethanolic fraction of *O. gratissimum* Venuprasad et al. (2014) | Anti-inflammatory, antioxidant, antibacterial and antiviral activities and blood pressure reduction | Yan et al. (2017) |
| Nepetolidin      | ![Nepetolidin structure](image5) | LC-ESI-MS/MS of 70% ethanolic fraction of *O. gratissimum* Venuprasad et al. (2014) | Anti-oxidant, anti-viral, anti-fungal and antitumor and antiviral effects, xanthine oxidase, nitric oxide inhibitor | Grayer et al. (2003), Tsai and Lee (2014), Abbaszadeh et al. (2014), Panahi et al. (2018), Ghazizadeh et al. (2020) |
| Xanthomicrol     | ![Xanthomicrol structure](image6) | LC-ESI-MS/MS of 70% ethanolic fraction of *O. gratissimum* Venuprasad et al. (2014) | Antiangiogenic and anticancer agent | Abbaszadeh et al. (2014), Panahi et al. (2018), Ghazizadeh et al. (2020) |
| Nevadensin       | ![Nevadensin structure](image7) | LC-ESI-MS/MS of 70% ethanolic fraction of *O. gratissimum* Venuprasad et al. (2014) | Antioxidant activities, Selective activities, Selective inhibitor of human carboxylesterase 1 (hCE1). | Tsai and Yin (2008), Wang et al. (2018) |
| Salvigenin       | ![Salvigenin structure](image8) | LC-ESI-MS/MS of 70% ethanolic fraction of *O. gratissimum* Venuprasad et al. (2014) | Antitumor, Potent neuroprotective | Noori et al. (2013), Rafatian et al. (2012) |
| Oleanolic acid   | ![Oleanolic acid structure](image9) | LC-ESI-MS/MS of 70% ethanolic fraction of *O. gratissimum* Venuprasad et al. (2014) | Antioxidant, anti-inflammatory, antiviral, and anti-diabetic effects | Sen (2020) |

(continued on next page)
| Name of Compound | Structure of compound | Method of identification | Biological activities/beneficial effects | References |
|------------------|-----------------------|--------------------------|------------------------------------------|------------|
| Gallic acid      | ![Gallic acid structure](image) | High Performance Liquid Chromatography Coupled with Diode Array Detection (HPLC-DAD) using *O. gratissimum* leaf extract (Irondi et al., 2016) | Antioxidant, anti-inflammatory, and antineoplastic, hepatoprotective and antihyperglycaemic properties | Kahkenhani et al. (2019), Huang et al. (2016), Hassani et al. (2020) |
| Catechin         | ![Catechin structure](image) | High Performance Liquid Chromatography Coupled with Diode Array Detection (HPLC-DAD) using *O. gratissimum* leaf extract (Irondi et al., 2016) | Anti-inflammatory and anticancer, Antibacterial, anti-hypertensive, and antioxidative activities | Musial et al. (2020), Fan et al. (2017) |
| Chlorogenic acid | ![Chlorogenic acid structure](image) | High Performance Liquid Chromatography Coupled with Diode Array Detection (HPLC-DAD) using *O. gratissimum* leaf extract (Irondi et al., 2016) | Antioxidant activity, antibacterial, hepatoprotective, cardioprotective, anti-inflammatory, antipyretic, neuroprotective, anti-obesity, antiviral, anti-microbial, anti-hypertension | Naveed et al. (2018) |
| Caffeic acid     | ![Caffeic acid structure](image) | High Performance Liquid Chromatography Coupled with Diode Array Detection (HPLC-DAD) using *O. gratissimum* leaf extract (Irondi et al., 2016) | Antioxidant, anti-inflammatory and anticarcinogenic activity. | Ye et al. (2010), Espíndola et al. (2019) |
| Ellagic acid     | ![Ellagic acid structure](image) | High Performance Liquid Chromatography Coupled with Diode Array Detection (HPLC-DAD) using *O. gratissimum* leaf extract (Irondi et al., 2016) | Anti-atherogenic, anti-inflammatory, and neuroprotective effects. | Ríos et al. (2018) |
| Epicatechin      | ![Epicatechin structure](image) | High Performance Liquid Chromatography Coupled with Diode Array Detection (HPLC-DAD) using *O. gratissimum* leaf extract (Irondi et al., 2016) | Antiangiogenic, anti-diabetic, antioxidant and anticancer effects | Abdulkhaleq et al. (2017) |
| Quercetin        | ![Quercetin structure](image) | High Performance Liquid Chromatography Coupled with Diode Array Detection (HPLC-DAD) using *O. gratissimum* leaf extract (Irondi et al., 2016) | Antidiabetic, anti-inflammatory, antioxidant, antimicrobial, anti-Alzheimer’s, antiarthritic, cardiovascular, and wound-healing effects | Salehi et al. (2020) |
| Rutin            | ![Rutin structure](image) | High Performance Liquid Chromatography Coupled with Diode Array Detection (HPLC-DAD) using *O. gratissimum* leaf extract (Irondi et al., 2016) | Antioxidant, cytoprotective, vasoprotective, anticarcinogenic, neuroprotective and cardioprotective activities | Javed et al. (2012), Richetti et al. (2011), Ganeshpurkar and Sahuja (2017) |
| Kaempferol       | ![Kaempferol structure](image) | High Performance Liquid Chromatography Coupled with Diode Array Detection (HPLC-DAD) using *O. gratissimum* leaf extract (Irondi et al., 2016) | Antioxidant, anti-inflammatory, antimicrobial, anticancer, cardioprotective, neuroprotective, anti-diabetic, anti-osteoprotic, estrogenic/antiestrogenic, anxiolytic, analgesic and anti-allergic activities. | Calderón-Montano et al. (2011) |
| Name of Compound | Structure of compound | Method of identification | Biological activities/beneficial effects | References |
|------------------|-----------------------|--------------------------|------------------------------------------|-------------|
| Camphene         | ![Camphene Structure](image) | GC-MS of microwave-assisted hydrodistillation extracted essential oils from *O. gratissimum* (Benitez et al., 2009), GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014) | Antioxidant activity and superoxide radical inhibition, hypolipidemic action | Quintans-Junior et al. (2013), Vallianou et al. (2011) |
| α- & β- Pinene    | ![α- & β- Pinene Structure](image) | GC-MS of microwave-assisted hydrodistillation extracted essential oils from *O. gratissimum* (Benitez et al., 2009), GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014), GC-MS and GC/FID of *O. gratissimum* leaf (Melo et al., 2019) | Antiviral, inhibitory, anticoagulant, antitumor, antimicrobial, antimalarial, antioxidant, anti-inflammatory, anti-inflammatory, anti-inflammatory and analgesic effects | da Silva et al. (2012), Zhou et al. (2004), Salehi et al. (2019) |
| Sabinene         | ![Sabinene Structure](image) | GC-MS of microwave-assisted hydrodistillation extracted essential oils from *O. gratissimum* (Benitez et al., 2009), GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014), GC-MS and GC/FID of *O. gratissimum* leaf (Melo et al., 2019) | Anti-inflammatory activity, management of dermatophytosis | Valente et al. (2013) |
| β-Myrcene        | ![β-Myrcene Structure](image) | GC-MS of microwave-assisted hydrodistillation extracted essential oils from *O. gratissimum* (Benitez et al., 2009), GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014), GC-MS and GC/FID of *O. gratissimum* leaf (Melo et al., 2019) | Anti-inflammatory and anti-catabolic effects | Rufino et al. (2015) |
| Limonene         | ![Limonene Structure](image) | GC-MS of microwave-assisted hydrodistillation extracted essential oils from *O. gratissimum* (Benitez et al., 2009), GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014), GC-MS and GC/FID of *O. gratissimum* leaf (Melo et al., 2019) | Anti-inflammatory, antioxidant, antinociceptive, anticancer, antidiabetic, antihyperalgesic, antiviral, and gastroprotective effects, relief of heartburn and gastroesophageal reflux | Vieira et al. (2018), Sun (2007) |
| 1,8-Cineole      | ![1,8-Cineole Structure](image) | GC-MS of microwave-assisted hydrodistillation extracted essential oils from *O. gratissimum* (Benitez et al., 2009), GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014), GC-MS and GC/FID of *O. gratissimum* leaf (Melo et al., 2019) | Mucolytic and spasmylic action on the respiratory tract, anti-inflammatory and antioxidant, antinociceptive activity | Juergens (2014), Liapi et al. (2007), Santos and Rao (2000) |
| trans-β-Ocimene  | ![trans-β-Ocimene Structure](image) | GC-MS of microwave-assisted hydrodistillation extracted essential oils from *O. gratissimum* (Benitez et al., 2009), GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014), GC-MS and GC/FID of *O. gratissimum* leaf (Melo et al., 2019) | Anticonvulsant activity, antifungal activity, antitumor activity | Bomfin et al. (2016), Sayyah et al. (2004) |
| Linalool         | ![Linalool Structure](image) | GC-MS of microwave-assisted hydrodistillation extracted essential oils from *O. gratissimum* (Benitez et al., 2009), GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014), GC-MS and GC/FID of *O. gratissimum* leaf (Melo et al., 2019) | Antimicrobial and insect-repellent properties, anti-inflammatory activity, antihyperlipidemia, antidepressant, neuroprotective and anticancer properties | Beier et al. (2014), Peana et al. (2002), Pereira et al. (2018) |
| α- & β-Terpineol | ![α- & β-Terpineol Structure](image) | GC-MS of microwave-assisted hydrodistillation extracted essential oils from *O. gratissimum* (Benitez et al., 2009), GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014), GC-MS and GC/FID of *O. gratissimum* leaf (Melo et al., 2019) | Inhibits the growth of tumour cells Antibacterial activity | Hassan et al. (2010), Li et al. (2015) |

(continued on next page)
### Table 2 (continued)

| Name of Compound | Structure of compound | Method of identification | Biological activities/beneficial effects | References |
|------------------|-----------------------|--------------------------|------------------------------------------|------------|
| Eugenol          | ![Eugenol Structure](image) | GC-MS of microwave-assisted hydrodistillation extracted essential oils from *O. gratissimum* (Benitez et al., 2009), GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014), GC-MS and GC/FID of *O. gratissimum* leaf (Melo et al., 2019) | Antimicrobial, anti-inflammatory, analgesic and antioxidant. | Mohammadi Nejad et al. (2017), Barbosa et al. (2018); Fujisawa and Morakami (2016). |
| α-Copaene        | ![α-Copaene Structure](image) | GC-MS of microwave-assisted hydrodistillation extracted essential oils from *O. gratissimum* (Benitez et al., 2009), GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014) | Antioxidant and antigenotoxic features, Potential anticancer agent | Turkz et al. (2014) |
| β-Elemene        | ![β-Elemene Structure](image) | GC-MS of microwave-assisted hydrodistillation extracted essential oils from *O. gratissimum* (Benitez et al., 2009), GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014) | Anti-inflammatory and antitumor effects | Xie et al. (2020), Li et al. (2010) |
| p-Cymene         | ![p-Cymene Structure](image) | GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014) | Analgesic and anti-inflammatory properties | Santana et al. (2011) |
| Thymol           | ![Thymol Structure](image) | GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014) | Antiseptic, antibacterial, antifungal, antimicrobial, antiviral, antioxidant, expectorant, antispasmodic, carminative, diaphoretic, sedative, anti-rheumatic, and even anti-cancer, anti-hyperlipidemic and anti-hyperglycemic action | Tohid et al. (2020), Saleghi et al. (2018), Li et al. (2017), Codduta et al. (2020), Tariq et al. (2019), Schnitzler (2019) |
| Carvacrol        | ![Carvacrol Structure](image) | GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014) | Antimicrobial, antioxidant, and anticancer, analgesic, antispasmodic, anti-inflammatory, angiogetic, antioxidants, antiplatelets, AChE inhibitory, insecticidal, antiheliotropic and hepatoprotective activities | Sharifi-Rad et al. (2018), Basri (2008) |
| β-Caryophyllene  | ![β-Caryophyllene Structure](image) | GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014) | Antioxidant, anti-inflammatory, anticancer, cardioprotective, hepatoprotective, gastroprotective, nephroprotective, antimicrobial, and immune-modulatory activity. | Machado et al. (2018), Fidy et al. (2016) |
| α-Humulene       | ![α-Humulene Structure](image) | GC/FID and GC/MS of extraction from fresh aerial parts of *O. gratissimum* (Kpoviessi et al., 2014), GC-MS and GC/FID of *O. gratissimum* leaf (Melo et al., 2019) | Anti-inflammatory properties | Rogerio et al. (2009) |

### 4.2. Chemical constituents of essential oil present in *O. gratissimum*

Compounds present in the essential oil of *O. gratissimum* include hydrocarbonated monoterpenes such as camphene, α-thujene, α-pinen, sabinene, β-pinene, β-myrcene, α and β-phellandrene, δ-3-carene, limonene, α-terpinene, p-cymene, trans-β-ocimene, γ-terpinene, terpinolene, p-cymene, and p-menthane-1,3,8-triene; oxygenated monoterpenes such as 1,8-cineole, cis-sabinene hydrate, linalool, trans-sabinene hydrate, trans-thujone, citronellal, umbellulone, borneol, terpinen-4-ol, p-cymen-8-ol, α-terpinene, thymol methyl ether, estragol, p-cymen-7-ol, thymol, and carvacrol; hydrocarbonated sesquiterpenes such as α-copaene, β-elemene, γ-elemene, β-caryophyllene, α-trans-bergamotene,
α-humulene, β-bourbunene, α-guaiene, δ-cadinene, germacrene D, γ-selinene, β-selinene, α-selinene, (Z,E)-farnesene, and 7-epi-α-selinene; and oxygenated sesquiterpenes such as caryophyllene oxide, 1,2-epoxydehydrohumulene, and 3,7-(11)-eudesmadiene, spathulenol (Vieira et al., 2001; Pessoa et al., 2002; Lahlou et al., 2004; Tchoumboungang et al., 2005; Lemos et al., 2005; Benitez et al., 2009; Kpoviesi et al. 2012, 2014; Nguemetchouin et al., 2013; Aguiar et al., 2015; Mohr et al., 2017; Chimnoi et al., 2018; Melo et al., 2019; Onyebuchi and Kavaz, 2020; Essoung et al., 2020). The bioactive compounds identified from the essential oil of O. gratissimum as well as their structures and various biological activities are shown in Table 2.

5. Pharmacological activities

5.1. Antioxidant activity

The antioxidant and anti-inflammatory properties of Ocimum gratissimum have been ascribed to its therapeutic benefits (Olamilosoye et al., 2019; Oyem et al., 2021). Its leaf extracts have been shown to contain antioxidant vitamins such as alpha-tocopherol and ascorbic acid (Olamilosoye et al., 2019). Previous research has shown that flavonoids and phenols protect against oxidative stress-induced cellular damage. Flavonoids and phenols exert anti-inflammatory and anti-oxidative effects through a variety of mechanisms, such as scavenging or quenching free radicals, chelating metal ions, or blocking enzyme systems that generate free radicals Olamilosoye et al., (2019). The presence of saponins, terpenoids, glycosides, and alkaloids in the aqueous extract of O. gratissimum may further contribute to its anti-inflammatory and anti-oxidative activities (Olamilosoye et al., 2019; Oyem et al., 2021). Joshi (2013) investigated the antioxidant activities of O. gratissimum and eugenol essential oils utilizing 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) test models. The DPPH and ABTS models had substantial IC50 values of 23.66 and 23.91, respectively, indicating that the essential oils of O. gratissimum may have antioxidant properties. The authors also revealed that the oils of O. gratissimum had higher antioxidant properties than pure eugenol (Joshi, 2013). Venuprasad et al. (2014) investigated the antioxidant activity of the leaf extract using a variety of in vitro free radical scavenging tests. The DPPH, iron chelating, ABTS, NO, and hydroxyl radical scavenging capabilities were tested, and the IC50 values were 470, 17.4, 133, 83, and 260 g/mL, respectively. The analytical results revealed that O. gratissimum may have free radical scavenging properties. Shittu et al. (2016) investigated the effects of the aqueous leaf extract of O. gratissimum on haematological and oxidative stress markers in alloxan-induced diabetic rats. The results showed that diabetic rats fed with the aqueous extract of O. gratissimum had a considerable decline in fasting blood glucose levels compared with untreated diabetic rats. There was a reversal of weight loss found in the rats tested. The authors also reported a decreased level in malondialdehyde (MDA) concentration and this marker increases during lipid peroxidation (Shittu et al., 2016) (Table 3).

5.2. Anxiolytic activity

Anxiety is a mental disorder marked by a person’s unpleasant conduct and inner turmoil that affects people of all ages, from children to the elderly. Benzodiazepines and other allopathic medicines that non-selectively target gamma-aminobutyric acid (GABA) receptors are commonly used to treat anxiety (Rudolph and Knollach, 2011). Okoli et al. (2010) reported that 200 and 400 mg/kg of methanol or petroleum ether extract increased the latency of tonic and tonic-clonic seizures and death. They also offered 50% protection in treated mice against seizure-induced mortality. Several studies have shown a link between antioxidant activity and anti-anxiety action (Hovatta et al., 2010). Several gene products play an important role in anxiety, with glyoxalase-1 and glutathione-1 being the major proteins whose activities affect anxiety (Hovatta et al., 2005). Venuprasad et al. (2014) emphasized O. gratissimum’s protective effect against DNA, protein, and lipid peroxidation. Pre-treatment with the leaf extract of the plant resulted in 44.8% protection from H2O2-induced DNA damage in SH-SYSY human neuronal cells, 80% protection from AAPH-induced BSA oxidation, and lipid peroxidation inhibition at an IC50 value of 735 g/mL. As observed from the open field and elevated plus maze tests, the plant had a substantial anxiolytic effect on the test mice at a dosage of 400 mg/kg body weight (Venuprasad et al., 2014).

5.3. Antinociceptive activity

In traditional medicine, O. gratissimum is used to treat painful conditions. In classic pain models, the antinociceptive effects of O. gratissimum essential oil and two of its active components (eugenol and myrcene) were investigated (hot plate test and formalin test) on neurogenic and inflammatory pain in murine pain models (Paula-Freire et al., 2013). In the first and second stages of the formalin test, the essential oil of O. gratissimum at a dose of 40 mg/kg, as well as its active components, eugenol and myrcene, at a dose of 10 mg/kg, successfully reduced pain in animals. These findings support the work of other authors on the antinociceptive action of the essential oil of O. gratissimum (Paula-Freire et al., 2013). Rabelo et al. (2003) showed that 30, 100 and 300 mg/kg of O. gratissimum essential oil inhibited writhing and inflammation in male Swiss mice. The report of Tanko et al. (2008) showed a significant antinociceptive effect of O. gratissimum at 1264.9 mg/kg body weight in the acetic-acid-induced abdominal constriction test and hot plate technique in rats, and this supports its traditional use in pain management.

5.4. Neuroprotective activity

Supplements of O. gratissimum leaf extract promote brain performance. Ajayi et al. (2018) reported the use of O. gratissimum at body weights of 25, 50, and 100 mg/kg in the treatment of behavioural impairment and depressive-like behaviour in mice using the open field test (OFT) and the forced swim test (FST). Bora et al. (2011) revealed that the neuroprotective ability of the extract of O. gratissimum in cerebral ischaemia is mediated by its antioxidant properties as observed during pre-treatment in Wistar rats with middle cerebral artery occlusion for 24 h followed by 24-hour reperfusion, as shown in Table 3.

5.5. Antimicrobial activity

A couple of studies have confirmed the antimicrobial activities of Ocimum gratissimum (Ibori et al., 1996; Nweze and Eze, 2009; Prakash et al., 2013; Melo et al., 2019). Prakash et al. (2011) described Ocimum gratissimum essential oil as a plant-based preservative and suggests its use as a nontoxic antibacterial and anti-aflatoxigenic agent against fungal and aflatoxin contamination of spices and as a shelf-life enhancer due to its antioxidant activity. Chimnoi et al. (2018) showed that 0.015–8.00 mg/ml essential oil extract of O. gratissimum leaf caused rapid inhibition of Escherichia coli and S. typhimurium. As reported by Talabi and Makanjuola et al. (2017), the aqueous extract of O. gratissimum strongly inhibited Pseudomonas aeruginosa and moderately inhibited Staphylococcus aureus, but the aqueous ethanolic leaf powder extract demonstrated a broader range of antimicrobial activities with significant inhibitory properties against E. coli, Bacillus cereus, P. aeruginosa, and S. aureus (Talabi and Makanjuola, 2017). Joshi (2013) used the tube-dilution method to test the antibacterial activity of O. gratissimum essential oils and its primary ingredient, eugenol, revealed strong antibacterial activity against Klebsiella pneumoniae, Serratia marcescens, and E. coli. Matias et al. (2011) reported that 2.5–0.0012 mg/ml aminoglycosides and 8–512 μg/ml methanol or hexane extracts of O. gratissimum synergistically inhibited E. coli and S. aureus.

Many studies have reported the antifungal activities of O. gratissimum (Lemos et al., 2005; Mohr et al., 2017). Lemos et al. (2005) showed that chlorofomric fraction inhibited 23 isolates (92%) of C. neoformans at a
### Table 3. Summary of the effects of Ocimum gratissimum on different experimental models.

| Doses | Experimental models | Observation | Effects | References |
|-------|---------------------|-------------|---------|------------|
| 0.015–8.00 mg/ml essential oil extract of *O. gratissimum* leaf | Bacteria | Demonstrated rapid killing of *E. coli* and *S. Typhimurium* | Antimicrobial activity | Chimnisi et al. (2018) |
| 16 μL essential oil extract of *O. gratissimum* leaf | Bacteria | Reduced the growth level of *S. aureus* and *E. coli* | Antimicrobial activity | Melo et al. (2019) |
| 0.5ml of 80% ethanolic *O. gratissimum* leaf extract | Bacteria | The extract was active against *E. coli, P. aeruginosa, S. aureus*, and *E. coli* | Antimicrobial activity | Talabi and Makanjuola et al. (2017) |
| 1 ml of 0.009–5.0 mg/ml of *O. gratissimum* essential oil in prepared with 10% DMSO | Bacteria | The essential oil was highly active against *E. coli, S. marcescens*, and *K. pneumoniae* | Antimicrobial activity | Joshi (2013) |
| 50 mg/ml,25 mg/ml,12.5 mg/ml and 6.25 mg/ml ethanolic extract of *O. gratissimum* leaf | Bacteria | In vitro activities against *E. coli, P. mirabilis, S. aureus* and *P. aeruginosa* | Antimicrobial activity | Nweze and Eze (2009) |
| 2.5–0.0012 mg/ml aminoglycosides + 8–512 μg/ml methanol or hexane extract of *O. gratissimum* | Bacteria | Synergistically inhibited *E. coli* and *S. aureus* | Antimicrobial activity | Matias et al. (2011) |
| 0.0–6.50 mg/ml aqueous extract of *O. gratissimum* | Bacteria | Active against *A. sobria, E. coli, P. shigelloides, S. typhi*, and *S. dysenteriae* | Antimicrobial and antidiarrhoeal activities | Ilori et al. (1996) |
| 0.312–40 mg/ml of *O. gratissimum* essential oil | Fungi | Inhibited *F. oxysporum f. sp lycopersici* and *Rhizoctonia solani* | Antifungi | Mohr et al. (2017) |
| 1.0–1000 μg/ml ethanolic crude extract, ethyl acetate, hexane, and chloroformic fractions, essential oil, and eugenol of *O. gratissimum* | Fungi | Chloroformic fraction inhibited 23 isolates (92%) of *C. neoformans* at a concentration of 62.5 μg/ml and eugenol inhibited 4 isolates (16%) at a concentration of 0.9 μg/ml | Antifungi | Lemos et al. (2005) |
| 31.2–1000 μg/ml of hexane, chloroformic fractions, the essential oil of *O. gratissimum* extract | Dermatophyte isolates: *M. canis, M. gypseum, T. rubrum* and *T. mentagrophytes* | Hexane and eugenol fractions inhibited the growth of 100% and 80% of dermatophytes respectively, at a concentration of 125 μg/ml | Antifungal activity | Silva et al. (2005) |
| 0.5, 1, 2, 4, and 8 μg/ml of essential oil of *O. gratissimum* extract | *Candida albicans, Candida krusei, Candida parapsilosis*, and *Candida tropicalis* | Fungicidal activity against all of the tested Candida species | Antifungal activity | Nakamura et al. (2004) |
| 100–1000 μg/ml of eugenol-rich essential oil of *O. gratissimum* extract | Leishmania amazonensis | Inhibited *Leishmania amazonensis* | Anti-leishmanicidal activity | Ueda-Nakamura et al. (2006) |
| 0–200 μg/ml *O. gratissimum* extract | In vitro antioxidant assays | The extract showed potent free radical scavenging activity, and protective effect against lipid, DNA and protein damage | Exhibits antioxidant activity | Venugopala et al. (2014) |
| 200 and 400 mg/kg of *O. gratissimum* leaf extract | Rats induced intraperitoneally with 50 mg/kg of phenylhydrazine (PHZ) for 2 consecutive days | The extract significantly improved PCV, Hb, and RBC in rats | Anti-anaemic property | Akara et al. (2021) |
| 200 and 400 mg/kg of *O. gratissimum* leaf extract | Rats induced intraperitoneally with 50 mg/kg of phenylhydrazine (PHZ) for 2 consecutive days | The extract reduced the levels of aspartate aminotransferase, alanine aminotransferase, and alkaline phosphatase. | Hepatoprotective effect | Akara et al. (2021) |
| 50 μL concentrations of 20–120 μg/ml of *O. gratissimum* leaf extract | In vitro | The extract inhibits ACE and scavenges DPPH in a dose-dependent manner | Management of obesity and obesity-related hypertension | Irodi et al. (2016) |
| 400 mg/kg of aqueous leaf extract of *O. gratissimum* | Diabetic rats (diabetes mellitus was induced using 100 mg/kg of alloxan monohydrate) | Fructosamine and FBG were reduced | Hypoglycaemic effect | Shittu et al. (2019) |
| 208 mg/kg of aqueous leaf extract of *O. gratissimum* | Type 1 diabetic rat model induced with intraperitoneal with a single dose of 65 mg/kg body weight of streptozotocin. | The extract reduced the blood glucose concentration | Hypoglycaemic effect | Olon and Umoren (2017) |
| 400 mg/kg methanolic extract of *O. gratissimum* leaf | Alloxan-induced diabetic rats | Reduced blood sugar level in both normal and diabetic rats by 56 and 69%, respectively. | Hypoglycaemic activity | Aguiyi et al. (2000) |
| 500–1500 mg/kg of aqueous leaf extract of *O. gratissimum* | Streptozotocin induced diabetic rats. | Reduced plasma glucose levels | Hypoglycaemic activity | Egwies et al. (2006) |
| 400 mg/kg extract of *O. gratissimum* | Alloxan monohydrate-induced diabetic rats | Reduced malondialdehyde (MDA) and increased superoxide dismutase (SOD) activities, decreased fasting blood glucose and | Antioxidant activity, improves hematological parameters antidiabetic activity | Shittu et al. (2016) |

(continued on next page)
| Doses | Experimental models | Observation | Effects | References |
|-------|---------------------|-------------|---------|------------|
| 3 mg/kg cholic acid from O. gratissimum | Streptozotocin-induced diabetic mice | Reduced glycemic levels in diabetic mice | Hypoglycemic activity | Casanova et al. (2014) |
| 250 and 500 mg/kg of methanol and oil extracts of O. gratissimum | Male albino rats | No inhibitory effect on the reproductive function and fertility | No detrimental effect reproductive function and fertility | Joseph et al. (2019) |
| 400 mg/kg of aqueous leaf extract of O. gratissimum | Diabetic rats (diabetes mellitus was induced using 100 mg/kg of alloxa monohydrate) | Arrested sperm maturation with empty spermatozoa in lumen, and decreased sperm count | Impairs sperm production in diabetic- induced rats | Shittu et al. (2019) |
| 1:10 w/v of O. gratissimum leaves | Rats | The extracts had inhibitory effect on phosphodiesterase-5 (PDE-5), angiotensin I – converting enzyme (ACE), acetylcholinesterase (AChE), and arginase | Management of erectile dysfunction | Ojo et al. (2019) |
| 400 and 800 μg/mL leaf extract of O. gratissimum | Hepatocellular carcinoma cells | The extract decreased the cell viability of HCC SK-Hep 1 and HAZ2T cells. It also decreased caspase 3 and FARP expressions, and CDW4 and p-ERK1/2 expressions. | Inhibits cell viability and tumor growth | Huang et al. (2020) |
| 50, 100 and 200 mg/kg of O. gratissimum leaf extract | Rodents | The extract exhibited antinociceptive and anti-inflammatory effects | Management of painful and inflammatory conditions | Tanko et al. (2008) |
| 0.0125–100 mg/kg of O. gratissimum | Rats | The extract inhibited free radicals and suppressed inflammation in carrageenan-induced inflammation | Management inflammation and oxidative stress in chronic diseases | Ajayi et al. (2017a) |
| 25–100 mg/kg of flavonoid-rich fraction of O. gratissimum leaves | Lipopolysaccharide-induced mice | The extract attenuates inflammatory and Oxidative Stress in lipopolysaccharide-induced mice | Anti-inflammatory and anti-oxidative stress | Ajayi et al. (2019) |
| 10, 20, or 40 mg/kg of O. gratissimum essential oil | Mice | Promoted anti-hypernociception and reduced the levels of interleukin-1β in the sciatic nerve | Anti-hypernociceptive activity | Paula-Freire et al. (2013) |
| 0.005–200 mg/kg of flavonoid-rich fraction of O. gratissimum | Peritonitis induced-rats | Reduced neutrophils, monocytes, NO, IL-1β, and TNF-α | Anti-inflammatory activity | Ajayi et al. (2017b) |
| 200, 400 and 800 mg/kg of polyphenol rich extract of O. gratissimum | Dextran sodium sulfate (DSS)- induced rat colitis models | Attenuated inflammation, and decreased disease activity index scores in rats with colitis. Decreased Interleukin-(IL)-6 and tumor necrosis factor (TNF)-α, myeloperoxidase, nitric oxide, cyclooxygenase-2 and malondialdehyde in the colon | Repairs colonic mucosa injury via anti-inflamatory and anti-oxidant activity | Alabi et al. (2018) |
| 50 and 100 mg/kg of phenolic-enriched ethylacetate fraction of O. gratissimum leaf extract | Rats | Reduced exudate volume, leucocyte count, nitrite, TNF-α, and myeloperoxidase activity. Protected against carrageenan-induced lipid peroxidation and glutathione depletion | Anti-inflammatory and anti-oxidant activity | Ajayi et al. (2017c) |
| 1–100 μg/mL of aqueous and methanol extract of fresh aerial part of O. gratissimum | In vitro | Inhibited DPPH, hydroxyl and nitric oxide radicals, antioxidant activity | Free radical scavenging activity and antioxidant activity | Mahapatra and Roy (2014) |
| 10.2 mg/mL and 23.2 mg/mL of O. gratissimum leaf extract | Rodents | Inhibitory action on pain | Analgesic activity | Aziha et al. (1999) |
| 1–25 μg methanol extract of O. gratissimum/ml | In vitro | Reduced the levels super oxide anion generation, nicotinamide adenine dinucleotide phosphate (NADPH) oxidase activity, myeloperoxidase (MPO) activity, lipid peroxidation, protein carbonyls, oxidized glutathione levels | Anti-oxidant activity, Decreases free radical generation, lipid and protein damage | Mahapatra et al. (2009) |
| Chloroform extracts of O. gratissimum at 100 mg/kg and 200 mg/kg | Cobalt chloride-induced cardio-renal dysfunction Rats | Reduced the levels of H2O2 and MDA, expression of caspase 8 and restored GSH levels, GPx, SOD and CAT activities | Antioxidant and pro-apoptotic caspase 8 activities | Akimrinde et al. (2016) |
| 30, 100 and 300 mg/kg of O. gratissimum essential oil | Male Swiss mice | Inhibited writhing and inflammation | Antinociceptive activity | Rabelo et al. (2003) |
Table 3 (continued)

| Doses | Experimental models | Observation | Effects | References |
|-------|---------------------|-------------|---------|------------|
| 200 and 400 mg/kg of methanol or petroleum ether extract | Adult male Swiss albino mice. Anticonvulsant activity was evaluated using pentyleneetrazol-induced seizure in mice | Increased the latency of tonic and tonic-clonic seizures and death. They also offered 50% protection of treated mice against seizure-induced mortality. The extracts and fraction decreased the frequency of line crossing, center square entries, rearing against a wall and grooming, whereas grooming duration and freezing frequency and duration were increased | Anticonvulsant and anxiolytic-like properties | Okoli et al. (2010) |

| Concentration | Species | Kind of extract | Effect of extract on cell morphology | Reference |
|---------------|---------|-----------------|------------------------------------|-----------|
| 0.0625, 0.12, 0.25, 0.5 and 1.0% of O. gratissimum leaf essential oil and eugenol | Haemonchus contortus | Efficiently inhibited ecdlodibility of H. contortus eggs | Anthelmintic activity | Pessoa et al. (2002) |
| 100, 200, and 400 mg/kg/day of O. gratissimum leaf | Gentamicin-induced kidney injury in rats | Increased GSH, urine, and plasma creatinine and decreased TBARS, and urine total protein | Management of gentamicin-induced kidney injury | Ogundipe et al. (2017) |
| 150 or 300 mg/kg of ethanol extract of O. gratissimum | Focal ischemia and reperfusion (I/R) insult in rat brain. | Attenuated brain oxidative stress, damage and neurological deficits | Neuroprotective effect on cerebral ischemia | Bora et al. (2011) |
| 20–80 mg/mL aqueous O. gratissimum extract | Hydrogen peroxide-induced toxicity in human HepG2 cells | Reduced thiobarbituric acid reactive substance (TBARS) formation. | Protective effect on oxidative stress in HepG2 cells | Chiu et al. (2012) |
| 0–40 mg/kg O. gratissimum extracts | COX-2 induced rats | Reduced liver damage, steatosis and fibrosis. Increased catalase and anti-oxidative enzymes | Anti-hepatic fibrosis properties | Chiu et al. (2014) |
| 12.5–300 μg/mL aqueous extract of O. gratissimum, hydrophobic and hydrophilic fractions | Human breast comedo-ductal carcinoma in situ | Decreased basement membrane disintegration, angiogenesis and matrix metalloproteinases (MMP-2 and MMP-9) activities | Inhibition of tumor growth and breast cancer cell | Nangia-Makker et al. (2013) |
| 6, 50, 100, 150, and 200 μg/mL of aqueous extract of O. gratissimum | Schwann RSC96 Cells | Inhibited H₂O₂-induced apoptotic protein caspase-3 activation and PARP cleavage, and reversed Bax up-regulation and Bcl-2 down-regulation. | Ameliorates cell stress and stress-induced apoptosis | Chao et al. (2017) |
| 125 and 250 mg/kg/bw ethanol extract O. gratissimum | Lead acetate induced Wistar rats | Reduced MDA, increased GSH, SOD, and CAT. Attenuated anemia, thrombocytopenia, and leucocytosis | Anti-oxidant and anti-anemia activities | Oyem et al. (2021) |
| 200 and 400 mg/kg/day of aqueous leaf extract of O. gratissimum | Acetic acid-induced colitis in male Wistar rats | Decreased the activities of MPO, SOD, NO and increased GSH levels in colitis rats Decreased diarrhea score and ulcer score to normal | Anti-inflammatory and anti-oxidative properties. Ameliorated colitis | Olamilosoye et al. (2019) |
| 100 or 500 mg/kg BW of O. gratissimum (whole plant) | Rats | Reduced systolic blood pressure, ACE levels in plasma and lung, and plasma endothelin-1 at 500 mg/kg dose | Antihypertensive effects | Shaw et al. (2017) |
| 500 mg/kg of 95%iso ethanol extract of O. gratissimum | Collagen-induced arthritis in rats | Reduced arthritic score and paw volume | Antiarthritis activity | Madhu and Harindran (2014) |
| 10–20 mL/kg aqueous extract of O. gratissimum | Castor oil-induced diarrhoea rats | Inhibited castor oil-induced diarrhoea | Anti diarrheal effects | Offiah and Chikwendu (1999) |
| 0.2 mg/kg body weight of O. gratissimum | carbon tetrachloride (CCl₄)-induced rats | Decreased stress proteins- (HSP70 and iNOS), MMP-9/MMP-2 ratio, phosphorylated ERK (p-ERK) and NF-κB (p-P65) | Hepatoprotective effect | Chiu et al. (2012) |

concentration of 62.5 μg/mL and eugenol inhibited 4 isolates (16 %) at a concentration of 0.9 μg/mL Mohr et al. (2017) revealed that 0.312–40 μg/mL of O. gratissimum essential oil inhibited P. oxysporum f. sp lycopersici and Rhizoctonia solani. Nakamura et al. (2004) investigated the in vivo antifungal activity of O. gratissimum essential oil against several Candida species. They were able to demonstrate that the plant extract had fungicidal activity against four distinct species of Candida examined, namely Candida albicans, Candida Krusei, Candida parapsilosis, and Candida tropicalis, by measuring their minimum inhibitory concentrations and time curves. The bud development of fungal cells treated with the extract was impaired. Significant alterations occurred in the cell wall and the structure of the subcellular organelles. These findings indicate that O. gratissimum essential oil might possibly be used as a phytotherapeutic agent in the treatment of various fungal disorders, and as a fungicidal agent in the management of fungi in the environment (Nakamura et al., 2004). According to Silva et al. (2005), the leaf extract of the plant contains bioactive components that are effective in vitro against dermatophytes. These findings further support O. gratissimum’s antifungal activity.

Nakamura et al. (1999) conducted an experimental examination of the antibacterial activity of O. gratissimum essential oil on various bacterial species. The essential oil of O. gratissimum extract suppressed the growth of S. aureus at 0.75 μg/mL concentration. Minimal inhibitory concentrations (MICs) ranged from 3 to 12 μg/mL for Shigella flexineri, Salmonella enteritidis, E. coli, Klebsiella species, and Proteus mirabilis. Eugenol was discovered as the primary component responsible for the
antibacterial action of *Ocimum gratissimum* essential oil. As a result, the plant has the potential to be used therapeutically in the prevention and treatment of bacterial infections (Nakamura et al., 1999).

Melo et al. (2019) investigated the antibacterial activity of *Ocimum gratissimum* essential oil extract against multidrug-resistant bacteria in planktonic and biofilm forms, such as isolates of *S. aureus* and *E. coli*. The antibacterial activity of the essential oil extract was determined by disk diffusion, while the checkerboard assay was used to assess the microdilution (MIC/MBC), growth curve under sub-MIC exposure, and combinatorial activity with ciprofloxacin and oxacillin. *S. aureus* and *E. coli* had much lower biofilm biomass and cell viability. These findings support the use of *Ocimum gratissimum* essential oil extract as a natural option for treating infections caused by multidrug-resistant bacterial strains (Melo et al., 2019). Aneke et al. (2019) reported that except for *Penicillium* species, two primary dermatomycotic agents isolated from animals exhibited considerable activity at 128 μg/mL concentration of ethanolic leaf extract of *Ocimum gratissimum*, namely *Microsporum* species and *Trichophyton* species. They showed a considerable degree of susceptibility at 128 μg/mL concentration. These findings imply that ethanolic extracts of *Ocimum gratissimum* contain active components with antifungal action against these fungal pathogens. As a result, it has the potential to be employed therapeutically in the treatment of dermatomycoses (Aneke et al., 2019) (Table 3).

5.6. Anti-protozoal activity

The essential oils and ethanolic crude extract of *Ocimum gratissimum* leaves and stems were evaluated in vitro against *Trypanosoma brucei* and *Plasmodium falciparum* in pre- and full flowering phases. The best growth inhibition of *Trypanosoma brucei* was observed, suggesting its anti-protozoal activities (Kpoviessi et al., 2014). In an in vitro and in vivo study reported by Adamu et al. (2009), the survival time of the parasite (*Trypanosoma brucei*) was dependent on the concentration of the extract, with lower (25 and 12.5 mg/mL) concentrations lasting longer than higher (100, 75, and 50 mg/mL) concentrations.

Tchoumbougnang et al. (2005) conducted a study on the suppressive impact of *Ocimum gratissimum* essential oil extract on *Plasmodium berghei* development in vivo in an animal model. According to the findings of their investigation, the extracted essential oil of *Ocimum gratissimum* shows considerable antimalarial activity in test mice after a four-day suppressive in vivo assessment. The plant's essential oil extract showed highest effectiveness at dosages of 200, 300, and 500 mg/kg, with parasitaemia suppression percentages of 62.1%, 81.7%, and 86.6%, respectively. Based on the findings of this investigation, the essential oil extract of *Ocimum gratissimum* might be therapeutically effective in the treatment and control of malaria (Tchoumbougnang et al., 2005) (Table 3).

5.7. Anti-anemic activity

Several studies have suggested that *Ocimum gratissimum* leaf extract has the ability to abate toxicities induced on haematological indices of Wistar rats. For example, Akara et al. (2021) reported that *Ocimum gratissimum* leaf extract at the dose of 400 mg/kg body weight ameliorates phenylhydrazine-induced anaemia in rats. Extracts of *Ocimum gratissimum* were identified to have haematological effects on the body as they led to an increase in the red blood cells, packed cell volume, haemoglobin, and platelet and neutrophil counts. A decrease in the platelet count was observed when 500 mg/kg of the extract alongside feed pellets were used (Olem et al., 2012). Akara et al. (2021) contended that the iron and vitamins present in the aqueous extract of *Ocimum gratissimum* may be responsible for the haematopoietic characteristics found in their investigation (Table 3).

5.8. Bio-pesticide

Essential oils from *Ocimum gratissimum* at a concentration of 1 μL/mL showed repellence and a toxic fumigation effect when used on *Tuta absoluta* (Essoung et al., 2020). The adult form of *Tribolium castaneum* is susceptible to the cinnamic acid esters isolated from *Ocimum gratissimum* at 26.92 mg/mL concentration (Buxton et al., 2020). Nguemtchouin et al. (2013) revealed that a mortality rate of 100–95% was observed with the combination of modified montmorillonite clay and *O. gratissimum* essential oil, which declined after 30 days as it had lost its insecticidal function by 60% and persisted for around 7–80 days.

5.9. Wound healing properties

Chang et al. (2021) reported that 100 μg/mL *Ocimum gratissimum* restored cell activity and protected against ultraviolet C-induced inhibition of cell proliferation and migration of skin cells, and therefore can serve as a potent natural wound care agent. Orafidiya et al. (2006) stated that the formulation containing 2% *Ocimum gratissimum* and honey as a surfactant had an antibacterial effect on *S. aureus*. It indicated that the net electrical charge on the surfactant with which it is produced influences the antibacterial activity of ocimum oil. The remarkable antibacterial action of the 2% ocimum oil in honey formulation, together with the documented wound healing characteristic of honey, suggests that the 2% ocimum oil in honey formulation might be useful as a topical antiseptic agent for wounds (Orafidiya et al., 2006).

5.10. Enzyme-inhibitory activity

The leaf extract of *Ocimum gratissimum* inhibited pancreatic lipase and angiotensin I-converting enzyme significantly, with IC₅₀ values of 20.69 g/mL and 29.44 g/mL, respectively. As a result, the leafy parts of *Ocimum gratissimum* can be used as functional foods in a therapeutic approach for the control of obesity and obesity-related hypertension (Irondi et al., 2016). Ojo et al. (2019) investigated the inhibitory effect of an aqueous extract (1:10 w/v) of *Ocimum gratissimum* leaves on some vital enzymes associated with erectile dysfunction, such as phosphodiesterase-5 (PDE-5), arginine, angiotensin 1-converting enzyme (ACE), and acetylcholinesterase (AChE), in penile and testicular tissues of study rats. The results of the study revealed that the extract has inhibitory effects on enzyme activities linked with erectile function, as well as free radical scavenging capacities, and these activities are linked with the plant's phenolic and flavonoid components (Ojo et al., 2019) (Table 3).

5.11. Analgesic activity

Aziba et al. (1999) studied the pharmacological activity of *Ocimum gratissimum* aqueous extracts in isolated rabbit jejenum, as well as their analgesic qualities in mice. Following administration of the extract, the spontaneous pendular movement of the rabbit jejenum was inhibited in a dose-dependent manner. The analgesic investigation also indicated an extended reaction time of 85% throughout a 20-minute observation period with no evident signs of toxicity. Their findings suggested that the aqueous extract of *Ocimum gratissimum* has analgesic and spasmylic properties (Aziba et al., 1999). Ajayi et al. (2017b) reported that *Ocimum gratissimum* exhibited the potential to reduce pain perception in analgesic experiments, as observed when all the constituents of *Ocimum gratissimum* were administered to mice.

5.12. Larvicidal activity

*Ocimum gratissimum* substantially reduced the mortality of *Anopheles gambiae* larvae at all doses of the extract tested on the organisms in an
experiment conducted by Ileke and Adesina (2019). It had a remarkable effectiveness against the pre-adult stages and adults of Anopheles gambiae, leading to 90% pupae death at a concentration of 0.5% (Ileke and Adesina, 2019). Following exposure of newly emerging adult beetles (Callosobruchus maculatus) at a dose of 25 mL/vial during a fumigation operation, essential oils produced by steam distillation from Ocimum gratissimum caused 80% death. It also had a substantial influence on the egg hatch rate, lowering it to roughly 15% at a concentration of 30 mL for the extract. Thus, the essential oil of Ocimum gratissimum may have anti-parasitic characteristics that might be useful in pest management (Keita et al., 2001). Harikampakdee and Chuchote (2018) reported that Ocimum gratissimum has the potential to enhance the control of dengue fever. They investigated the oviposition deterrent activity of the essential oil of Ocimum gratissimum and Ocimum gratissimum alginate beads against Aedes aegypti (Ae. aegypti) mosquitoes. The study’s findings revealed that the beads offered substantially longer oviposition deterrent efficacy against gravid Aedes aegypti, but free Ocimum gratissimum oil only did so for a shorter amount of time. The results suggest a less expensive method of managing dengue disease (Harikampakdee and Chuchote, 2018).

5.13. Leishmanicidal activity

Ueda-Nakamura et al. (2006) found that the eugenol-rich essential oil of Ocimum gratissimum had increasing inhibitory actions against Leishmania amazonensis growth at extract concentrations ranging from 100 to 1000 Ag/mL. At inhibitory concentrations (IC50) of 135 and 100 Ag/ml for promastigotes and amastigotes, respectively, there were significant mitochondrial alterations in essential oil-treated promastigotes and amastigotes. Both promastigotes and amastigotes have a minimum inhibitory concentration of 150 Ag/ml. Their research revealed that the essential oil had no cytotoxic effects on mammalian cells. This underlines the potential effectiveness of the essential oil of Ocimum gratissimum against protozoas and as a novel therapeutic source of antileishmanial drugs (Ueda-Nakamura et al., 2006).

5.14. Ovicidal activity

Pessoa et al. (2002) conducted a research to assess the ovicidal efficacy of Ocimum gratissimum essential oil and its major component, eugenol, against Haemonchus contortus, a gastrointestinal parasite found in small ruminants. During the egg hatch test, H. contortus eggs were also retrieved from the faeces of goats that had been experimentally infected with the test organism. The essential oil and eugenol, on the other hand, revealed a maximum eclosionability suppression of the organism’s growth at 0.5% concentration. These findings suggest that the use of the essential oil of Ocimum gratissimum might be a useful method to manage gastrointestinal helminthosis in small ruminants (Pessoa et al., 2002).

5.15. Cytotoxic activity

The cytotoxic impact of methanolic extract Ocimum gratissimum (ME-Og) was studied in murine peritoneal macrophages at doses ranging from 0.1 to 100 g/mL using the 3-(4,5-dimethylthiazol-2-yl)-2,5 diphenyltetrazolium bromide (MTT) technique. The findings indicated that Ocimum gratissimum plant extracts have a considerable modulatory influence on nicotine-induced free radical production, lipid-protein damage, and antioxidant status in peritoneal macrophages. Following a 12-hour treatment of murine peritoneal macrophages in culture medium with hazardous 10 mM nicotine, it was observed that ME-Og exerted a protective effect against nicotine toxicity. In rats treated with the extract, the impact of the poisonous substance was significantly decreased and the negative effects were significantly reduced. Therefore, the results confirm the modulatory effect of Ocimum gratissimum on hazardous chemicals such as nicotine (Mahapatra et al., 2009).

Chiu et al. (2012) found that Ocimum gratissimum aqueous extract (OGAE) protected the liver against CCl4-induced damage in rats utilized as a model of chronic hepatic damage. An increase in the blood catalase activity of CCl4-administered rats treated with the aqueous plant extract was observed, which was much higher than that of the control rats treated with saline solution. In a study comparing those given OGAE to those given saline or CCl4, it was observed that the livers of the CCl4-administered rats given the plant extract showed a significant decrease in stress proteins such as heat shock protein (HSP70) and inducible nitric oxide synthase (iNOS). A significant reduction in the ratio of MMP-9/MMP-2, phosphorylated ERK (p-ERK), and NF-κB (p-p65) was observed, suggesting the possible protective effect of OGAE against CCl4-induced toxicity in rats (Chiu et al., 2012).

The aqueous extract of Ocimum gratissimum exhibited ameliorative activities, which enabled it to provide protective benefits against acetic acid-induced colitis in male rats when administered at doses ranging from 200 to 400 mg/kg/day for 20 consecutive days (Olamilosoye et al., 2019). Similarly, it ameliorated the haematological parameters and significantly reduced the activities of MPO, SOD, and NO and increased the GSH levels in colitis rats (Olamilosoye et al., 2019). Ocimum gratissimum ameliorated the cytotoxic effects of H2O2-induced apoptosis by modulating the apoptotic pathway at concentrations ranging from 150 to 200 μg/mL (Ghao et al., 2017) (Table 3).

5.16. Anti-infertility effect

When administered, Ocimum gratissimum was observed to have an effect on penile and testicular tissues present in rats in the treatment of erectile dysfunction (Ojo et al., 2019). Joseph et al. (2019) reported that methanolic and oil extracts of Ocimum gratissimum leaves, when administered at two dosages of 250 and 500 mg for 14 and 28 days, had no negative effect on the reproductive capabilities of the male rats.

5.17. Hepatoprotective activity

Ajayi et al. (2011) discovered that Ocimum gratissimum given to mice at different concentrations might protect the liver by controlling the increase in catalase enzyme levels induced by CCl4 damage in liver cells. Chiu et al. (2014) opined that 0–40 mg/kg Ocimum gratissimum extracts reduced liver damage, steatosis, and fibrosis and increased catalase and anti-oxidative enzymes. Huang et al. (2020) revealed that in hepatocarcinoma cell (HCC) following treatment with Ocimum gratissimum at concentrations more than 20 mg/mL, an increase in p/ERK1/2 levels was observed, indicating that it has an effect on the survival signalling of the liver cancer cells. The flavonoid-rich ethyl acetate fraction of Ocimum gratissimum was discovered to exhibit hepatoprotective properties, indicating that it may be useful in slowing down the LPS-mediated sickness process in mice with LPS-induced sickness behaviour (Ajayi et al., 2019). Pandoh et al. (2008) reported that the administration of Ocimum gratissimum oil at the dose of 1000 mg/kg did not produce any hepatotoxic effects on the rat’s liver, as shown in Table 3.

5.18. Nephroprotective activity

Ogundipe et al. (2017) showed that 100, 200, and 400 mg/kg/day of Ocimum gratissimum leaf could be employed in the management of gentamicin-induced kidney injury. Treatment with Ocimum gratissimum aqueous leaf extract, on the other hand, induced a reduction in creatinine, urea, HCO₃, K⁺, Cl⁻, and Na⁺ suggesting that Ocimum gratissimum leaf extract may have renoprotective properties (Akara et al., 2021).

5.19. Anti-diarrhoeal activity

Offiah and Chikwendu (1999) investigated the anti-diarrhoeal effects of an aqueous extract of Ocimum gratissimum leaves. They were able to demonstrate the anti-diarrhoeal efficacy of the extract on castor oil-induced diarrhoea in rats, as evidenced by a substantial decrease in the amount of wet faeces in rats treated with the extract. The aqueous leaf
extract of the plant reduced diarrhoea and the propulsive movement of intestinal contents. It also had no direct effect on guinea pig harvested ileum, but it greatly reduced the ileum’s responsiveness to acetylcholine, nicotine, and histamine, resulting in lower contractile activity induced by these drugs. Further phytochemical assessments revealed that the plant’s principal constituents include tannins, steroids, triterpenoid, and carbohydrates. These findings suggest that the aqueous extract of O. gratissimum leaves may include pharmacologically active ingredients with antidiarrhoeal effects defined primarily by inhibitory activity on intestinal motility, perhaps via muscarinic receptor inhibition (Offiah and Chikwenda, 1999), as shown in Table 3.

5.20. Anti-diabetic activity

Studies on the hypoglycaemic activities of O. gratissimum have been reported by various researchers using animal models (Egesie et al., 2006; Shiitu et al., 2019). In mice, co-administration of the O. gratissimum leaf extract after oral administration of starch and glucose demonstrated that the extract inhibited the increase in postprandial blood glucose levels (Shimada et al., 2019). Their findings suggested that the inhibitory effect on sodium-dependent glucose transporter (SGLT1) could be one of the underlying mechanisms of the anti-hyperglycaemic effect of the leaf extract of O. gratissimum (Shimada et al., 2019). Aguiyi et al. (2000) observed a significant reduction in plasma glucose levels when O. gratissimum was administered at 400 mg/kg body weight. The research carried out by Casanova et al. (2014) showed the hypoglycaemic activity of O. gratissimum against streptozotocin-induced diabetes in rats. They contended that the cholic acid, a major phenolic constituent, may be responsible for this activity. However, further characterization of the plant’s bioactive components is recommended to determine other bioactive components that may exhibit these pharmacological activities. Other studies reported by Antora and Salleh (2017) showed that extracts of O. gratissimum when used on streptozotocin-induced diabetic rats at 500 mg/kg was found to be 81% effective. Okon and Umorenn (2017) contended that the hypoglycaemic efficacy of O. gratissimum was higher than that of insulin in streptozotocin-induced diabetic rats at 208 mg/kg (Table 3).

5.21. Anti-inflammatory activity

The plant has been reported to exhibit anti-inflammatory activities (Ajayi et al., 2017a,b,c; Alabi et al., 2018). For example, Ajayi et al. (2017a) suggested that O. gratissimum extract when used to treat rats induced with carrageenan was able to reduce inflammations at 50,100, and 200 mg/kg body weight. The extract at 100 mg/kg body weight had a significant effect on rats by inhibiting carrageenan-induced paw oedema, suggesting its therapeutic use in the treatment of inflammations (Ajayi et al., 2019). In the study conducted by Alabi et al. (2018), O. gratissimum was found to have anti-inflammatory effects on dextran sodium sulphate (DSS) induced colitis in rats at doses of 100–800 mg/kg where signs of repair were evident. The extract was found to be useful in the treatment of eosiinophilic airway inflammation in male AJ mice induced by Blomia tropicalis. In a murine model, doses of 25, 50, and 100 mg/kg of methanolic extract of the plant were found to be effective in alleviating respiratory allergy (Costa et al., 2012) (Table 3).

5.22. Anti-hypertensive activity

O. gratissimum at 100 and 200 mg/kg improved blood pressure and toxic processes in cobalt chloride-induced cardioenal dysfunction in rats (Akinrinde et al., 2016). Shaw et al. (2017) investigated the inhibitory effect of O. gratissimum (8 weeks at 100 or 500 mg/kg) on angiotensin-converting enzyme (ACE) in hypertensive rats (Table 3).

5.23. Anticancer activity

Anticancer activities from plant bioactive components have been documented (Sun et al., 2002; Surh, 2003; Ohigu et al., 2021). Lin et al. (2014) investigated the anticancer efficacy of an aqueous extract of O. gratissimum due to its antioxidant capabilities after treating human osteosarcoma cells with the extract, adding to the expanding body of research on the plant and its involvement in cancer treatments. Cell viability experiments demonstrated that the activity of the aqueous extract of O. gratissimum affected the viability of U-2 OS and HOS cells considerably and dose dependently. It is characterized by an increase in cell shrinkage, sub-G1 fragmentation, and caspase 3 activations (Lin et al., 2014). Treatment with O. gratissimum at 200 mg/kg caused tumour growth decrease through modulation of the ERK signalling pathway and aerobic glycolysis, and increasing cell apoptosis in mice induced with melanoma cells (Huang et al., 2020). Nangia-Makker et al. (2013) showed that 12.5–300 μg/mL extract of O. gratissimum decreased basement membrane disintegration, angiogenesis, and matrix metalloproteinases (MMP-2 and MMP-9) activities. This subsequently resulted in the inhibition of tumour growth and breast cancer cells. When human breast cancer cells were treated with both O. basilium and O. gratissimum, it was observed that O. gratissimum had a lower cytostatic and apoptotic impact on the MCF-7 human breast cancer cell line through activation of the mitogen-activated protein (MAPK) pathway (Torres et al., 2018). Eknwe and his co-researchers reported that partially purified O. gratissimum fractions (Eknwe et al., 2010) or aqueous or organic solvent-soluble extracts of O. gratissimum (Eknwe et al., 2013) inhibited the proliferation of several cancer cell lines, especially prostate adenocarcinoma (PC-3) cells (Table 3).

5.24. Immunomodulatory activity

Mahapatra et al. (2011) investigated the immunological functions and immunological responses in nicotine-induced (10 mM) macrophages as well as the immunomodulatory activity of O. gratissimum extract. Nicotine-induced NO production and iNOS II expression were considerably reduced after the administration of a 10 μg/mL aqueous extract of the plant. The aqueous extract of the plant had protective effects on murine peritoneal macrophages by downregulating Th1 cytokines in nicotine-treated macrophages while simultaneously activating Th2 responses (Mahapatra et al., 2011).

6. Conclusion and future perspectives

In conclusion, O. gratissimum has remarkable dietary and pharmaceutical applications, which make it an excellent functional ingredient for use in the treatment of a plethora of health abnormalities. Currently, various researchers are conducting in-depth studies on the useful components of this health-promoting plant. Because O. gratissimum is an excellent source of vital phytochemicals, nutrients, and essential oils, bioactive isolates with a higher biological value of this plant could be a better replacement for traditional medicine in the treatment of microbial infections, cough, cancer, diarrhoea, anaemia, and inflammatory diseases. Apart from its bioactive potential, O. gratissimum is an excellent source of micronutrients. The reported pharmacological/clinical activities exhibited by O. gratissimum are not limited to its antioxidant properties and ability to suppress inflammatory biomarkers. The presence of bioactive substances demonstrates the variations in this plant’s components. These differences arise as a result of variations in topography, meteorological conditions, yield, preparation process, and many other factors. Therefore, there is a need to investigate the phytochemical properties of O. gratissimum, which may be utilized to enhance the health benefits (animal and human nutrition), as well as the environment, by using its isolated chemicals in natural weed and pest control management. Therefore, further research in human clinical trials is recommended to effectively confirm the safe concentration of the extract.
required to manage health deviations. Apart from these benefits, *Ocimum gratissimum* has been effective against diabetes, anemia, infertility, diarrhoea, and inflammatory disorders. Hence, further studies are required to determine the specific mechanism by which *O. gratissimum* protects against various diseases, which can be used to design and create effective therapies for these disorders in the future. The studies included in this review collectively suggest that this plant has several healing properties. Owing to its multidirectional activities, *Ocimum gratissimum* has been regarded as an important medicine for a variety of diseases.

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