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Boswellia sacra in South Arabian Peninsula: A Review

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Abstract

Boswellia sacra, belonging to the genus *Boswellia* (family: Burseraceae), is a natural source of fragrant resin known as frankincense (*Luban*), which has held significant economic, medicinal, and religious importance since ancient Yemeni civilization. Predominantly distributed in the South Arabian Peninsula, frankincense resin contains diverse chemical compounds, including terpenoids, essential oils, gum acids, sesquiterpenes, phenolic compounds, and aldehydes, each contributing to its medicinal, therapeutic, and aromatic properties. The aromatic oleo-gum-resin from *B. sacra* is renowned for its use in traditional medicine to treat gastric disorders, hepatic ailments, and more. Additionally, frankincense finds applications in the cosmetic, perfume, beverage, and food industries due to its rich bioactive compounds, particularly boswellic acids and their derivatives. Although several studies have explored the constituents and pharmacological activities of frankincense, comprehensive research consolidating the valuable information on *B. sacra* is scarce. This review highlights the phytochemistry, traditional uses, and pharmacological activities of *B. sacra*, with a focus on its description, distribution, biochemical composition, and biological activities within the Arabian Peninsula. The aim is to provide a holistic understanding of *B. sacra*'s potential therapeutic applications and pharmacological properties.

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1. INTRODUCTION

The increasing prevalence of antibiotic resistance, high medication costs, and limited access to healthcare systems, especially in less developed countries, emphasize the importance of researching traditional medicines for sustainable and economical therapeutic solutions [1, 2]. Frankincense, a fragrant resin derived from the *Boswellia* genus, has been integral to the ancient Yemeni civilization, playing a pivotal role in economic, commercial, and religious contexts [3]. Yemen was historically a major producer of frankincense, which is used extensively in traditional medicine [4].

The term "frankincense" originates from the Old French phrase "franc incense," meaning "pure incense," while its Arabic counterpart, Luban, derives from the Semitic root indicating whiteness and purity [5]. Frankincense is obtained as a gum-like or solidified resin secreted by the *Boswellia* tree, particularly through wounds on the trunk. The genus *Boswellia* consists of approximately 30 species found mainly in the arid regions of the Arabian Peninsula, South Asia, and tropical Africa [6]. Among these, *Boswellia sacra* from southern Arabia is the primary species yielding high-quality frankincense resin [7].

For millennia, the oleo-gum-resin from *Boswellia* species has been treasured for its aromatic and therapeutic properties, being extensively used in religious rituals, perfume manufacturing, and as a phytomedicine [8]. The resin serves as a natural defense mechanism for the plant against pests and diseases and is secreted as a milky-white liquid upon wounding [7]. Recently, frankincense-derived essential oils have gained global recognition for their applications in aromatherapy and perfumery [9]. This review aims to explore the multifaceted significance of *B. sacra*, focusing on its phytochemistry, therapeutic applications, and pharmacological activities, particularly within the South Arabian Peninsula.

2. A BRIEFLY HISTORICAL ACCOUNT

Boswellia was particularly influential because of its cultural significance in addition to its naturalistic and taxonomic significance, given the historical-religious and symbolic importance of the frankincense tree in ancient cultures [10]. *Boswellia sacra* was first described by Carter in 1844 and 1846 in Oman and Yemen, respectively, and identified as a new species by Fliickiger in 1867.[11, 12]. Frankincense was a valuable commodity in international trade. Yemeni traders carried frankincense to various parts of the ancient world, especially to Ancient Egypt, the Arabian Peninsula, Mesopotamia, and India. It was one of the major sources of wealth in Southern Arabia, with trading caravans linking Yemen to the Mediterranean and Asia. The kingdoms of Saba and Himyar played key roles in this trade, making frankincense an important part of Yemen's economy. Humans have used the priceless gum resin that frankincense trees produce since ancient times. Frankincense was used in religious rituals in temples and shrines, where it was burned as incense to get closer to the gods. In the Sabean religion, it was believed to be a tool for connecting with the spiritual world, and its sweet scent was thought to enhance spirituality [3].

Frankincense is mentioned in Punt's Land and the Egyptians where burning incense was a common practice for all important rituals. Incense was burned to establish a connection with the gods and to ward off evil spirits. Frankincense was also mentioned in the Bible [13]. The fact that the Arabs gave the Persian emperor Darius an annual payment of one thousand Babylonian talents (24.5 tons) of frankincense demonstrated the significance of the frankincense trade during the period [13].

Frankincense was utilized for medical and hygienic purposes to be offered as a sacrifice to the gods by the Greeks and Romans. Massive amounts were consumed [13]. A large portion of the frankincense was moved by land from southern Arabia to the Mediterranean, aside from maritime transportation [13]. Attempted to rebuild this caravan route.

Portrayed the trade route as an early example of a global supply chain, monopolized for five centuries by the Nabatheans, an Arabian tribe that lived from approximately 300 BC to approximately AD 200 [14].

Figure 1. *Boswellia sacra* Flueck Tree [14]

Figure 2. Thin, Paper-Like Bark [13]

3. PLANT DESCRIPTION AND TAXONOMY

The genus *Boswellia* consists of medium-sized, deciduous flowering trees and shrubs (Figure 1). The dry parts of the Arabian Peninsula East Africa, and India are the native habitats of *Boswellia*. The trees are robust, although they have scraggly appearances and paper-like bark that ranges from whitish to pale brown (Figure 2). *Boswellia* produces co-sexual single flowers that are Yellowish-white (Figure 3) and start to bloom in the winter but may last until April. *Boswellia* fruit is a capsule (Figure 4) it often starts to ripen in March. Most well-known for its aromatic oleo-gum resin is the *Boswellia* tree. Sometimes referred to as olibanum, frankincense is the name of the oleo-gum resin made by *Boswellia* trees. After being planted, frankincense trees start producing resin in about eight to ten years [15].

The gum resin has a pleasant spicy, citrus, and even woodsy, earthy smell, according to descriptions of its fragrance. Frankincense is acquired by cutting into the trunk or branches and scraping the bark away (Figure 4). This action is referred to as pressing. When the tree is cut, priceless white resin seeps from the wound,

Figure 3. Yellowish-White Frankincense Flower with Honeybee [15]

Figure 4. *Boswellia* Fruit [15]

Figure 5. Incision and Puncture with Hardening Frankincense Resin [15]

releasing a strong scent right away [16].

Taxonomy of *Boswellia sacra*

The genus *Boswellia* is a member of the Burseraceae-flowering plant family, which includes approximately 700 species from 20 genera [17, 18]. *Boswellia sacra* is a species of tree in the family Burseraceae. Here is the taxonomy for *Boswellia sacra*:

Kingdom: Plantae

Division: Angiosperms

Class: Eudicots

Order: Sapindales

Family: Burseraceae

Genus: *Boswellia*

Species: *Boswellia sacra*

The species was first described by Flueck. and later revised by Harvey. *Boswellia sacra*, a species within this genus, is a tree known for its aromatic resin, frankincense, which has significant historical, religious, and cultural importance [19]

The taxonomy of *Boswellia sacra* is as follows: it belongs to the Kingdom Plantae, encompassing all plants; the Division Angiosperms, which includes flowering plants; the Class Eudicots, a group of dicotyledonous plants; and the Order Sapindales, which consists of various flowering plant families. It is classified under the Family Burseraceae, known for its resin-producing species. The tree falls under the genus *Boswellia*, with *sacra* being its specific species name. This species is primarily found in the Arabian Peninsula, particularly in Yemen, Oman, and Somalia [19].

4. DISTRIBUTION AND HABITAT

Boswellia sacra is found in Hadramaut and Mahra including the Socotra Island, which are the most famous habtats in Yemen. While in Oman distrbuted in Hoojr, Najdi and Shathri. In addition all the known *Boswellia* species are found throughout the World in the tropics of Africa, Somalia, Iran, Pakistan, and India. *Boswellia* Yemeni regions for frankincense cultivation and resin extraction. Also, known for Shabwa areas containing frankincense trees. Some mountainous regions in Al Hudaydah governorate have frankincense trees Figure 6 [3].

It grows on rocky slopes and gullies, frequently on limestone boulders and less frequently on rock faces, at elevations ranging from a little above sea level to roughly 1340 m above sea level. The upper limit in Arabia appears to be at the same elevation [16].

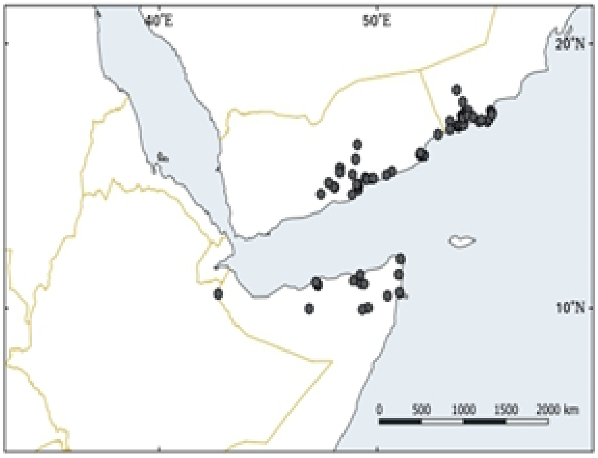

Figure 6. Map Showing the Distribution of *B. sacra*.

5. ENVIRONMENT AND ECOLOGY

Worldwide recognition exists forboth the ecological and socioeconomic relevance of *Boswellia* species. It has been found that distinct tropical climatic conditions support the growth of different species of *Boswellia*. For instance, *B. sacra* grow in dry tropical locations whereas *B. serrata* grows in wet ones. Both species have adapted to the extremely short winter season in the Sonoran Desert. Nevertheless, *B. socotrana* did not adapt to this area because, even in a greenhouse, it is a winter species. Making a basic choice and

assumption about an appropriate environment for its growth is difficult [6].

As each species has a unique ideal habitat, it is vital to do research before deciding and establishing guidelines for growing *Boswellia*. According to, practically all *Boswellia* species require heat and humidity; otherwise, there is little genetic overlap among them; instead, each species has a unique genetic makeup that allows for culture and adaption [6].

Harvesting Frankincense in Yemen

The process of harvesting frankincense begins with selecting the right tree, which is a crucial step for ensuring high-quality resin. Frankincense trees are typically found in the dry, mountainous regions of Yemen, such as Hadhramaut, Shabwa, and Al Hudaydah, where the climate and soil conditions are ideal for their growth. Harvesters carefully choose mature, healthy trees with strong, defect-free trunks, as these are the best candidates for producing high-quality resin [3], however, Oman annulaly produce of frankincence ranges from 80to 100 tons, requauiring nearly 500,000 trees [20]. Once the right tree is selected, the next step is making incisions on the tree's trunk or lower branches. Sharp knives or sickles are used to create shallow cuts in the bark, stimulating the tree to release resin. These cuts are done carefully to avoid harming the tree, as the resin flows from the cuts and solidifies quickly when exposed to air. After the resin hardens, it is manually collected by scraping or picking it from the tree [3].

Harvesting is an ongoing process, as the tree continues to produce resin after each collection. New incisions are made after every harvest to ensure that resin production continues. This process can extend over several months or even throughout the year, depending on the tree's health and the local climate. The repeated harvesting cycle is an essential part of the process, allowing the tree to yield resin over an extended period [13]

After the resin is collected, it goes through a sorting and purification process. The collected resin is carefully examined to remove impurities such as dirt, leaves, or small branches. The frankincense is then graded based on its purity, fragrance, and overall quality, with higher-quality resin being more valuable. The final product, once purified and graded, is highly sought after for use in perfumes, incense, and traditional medicines, playing a significant role in the local economy of regions where the trees grow. This traditional method of harvesting frankincense has remained largely unchanged for centuries, underscoring its cultural and economic importance [21].

6. PREVIOUS WORKS

Frankincense is a crucial scientific research topic in alternative medicine and pharmaceutical industries. Previous studies on *Boswellia sacra* highlight its benefits and uses, aiding in understanding and identifying research gaps for future studies. The table 1 presents previous studies on *Boswellia sacra*, outlining the key findings and research methods utilized.

7. BOSWELLIA SACRA CHEMISTRY

Frankincense resin contains a variety of chemical compounds that contribute to its distinct medicinal and aromatic properties. One of the key classes of compounds is triterpenoids, which are hydrocarbons with a structure of 30 carbon atoms. Important triterpenoids in frankincense include Alpha-boswellic acid (α-boswellic acid), Beta-boswellic acid (β-boswellic acid), and Acetyl-alpha-boswellic acid (Acetyl-α-boswellic acid). These compounds are primarily responsible for many of frankincense's medicinal effects, including its well-known anti-inflammatory and antibacterial properties [3].

Another important component of frankincense is its essential oils, which contain a variety of aromatic compounds that give the resin its distinctive fragrance. Major compounds in frankincense essential oil include Alpha-pinene (α-pinene), Beta-pinene (β-pinene), Limonene, Sabinene, Terpinene, and Myrcene. These compounds not only contribute to the fragrance but also play a role in its medicinal effects, such as improving breathing and helping to calm the nervous system.

In addition, frankincense resin contains gum acids, which act as sticky substances that help maintain the natural structure of the resin. These acids interact with other compounds, enhancing the resin's overall medicinal properties. Sesquiterpenes, another important group of hydrocarbons found in frankincense, contain 15 carbon atoms. Examples include Farnesene and Alpha-hydroxy-caryophyllene (α-hydroxycaryophyllene). These sesquiterpenes are known to contribute to frankincense's anti-inflammatory and antibacterial effects [3].

Frankincense also contains phenolic compounds, such as tannins and phenols, which act as antioxidants, protecting the body from damage caused by free radicals. Additionally, compounds like Octanal and Dodecanal, which are aldehydes, contribute to the resin's fragrance and also have antibacterial properties, supporting respiratory health.

One of the most prominent active compounds in frankincense is Acetyl-Boswellic Acid, which is renowned for its anti-inflammatory and antibacterial properties, making it an important component of frankincense's therapeutic effects. These various compounds work together to give frankincense its unique healing properties, making it highly valued in traditional medicine and modern therapeutic practices [3].

The frankincense gum resin is composed of three fractions: 25–30% water, 60–70% alcohol-soluble, and 5-9% oil. Terpenoids are abundant in the lipophilic portion, particularly the medicinally significant class of Boswellic acids (BAs) [52, 53]. Lipid-soluble blends of volatile and nonvolatile terpenoids make up plant resins [54].

Table 1. Some previous studies regarding to *Boswellia* species, region, extract, result and reference.

Species *Boswellia*	Region	Method extract and Plant part use	Result	Reference
B. Sacra	Oman	*B. sacra* oleo-gum resin	For the first time to our knowledge, research revealed that the ethanol extract of *B. sacra* oleo-gum resin, has antihyperglycemic, anti-inflammatory, and antioxidant qualities. Furthermore, it shields the pancreas from oxidative damage and repairs hepatic cells in rats with STZ-induced diabetes.	[22]
B. Sacra	Oman	Essential oils extract	It was determined that the oils and smoke of Hojari and Sha'bi frankincense had strong antibacterial properties that might be used to manage harmful bacteria in plants, animals, and humans.	[23]
B. Sacra	Iran	*B. sacra* resin	According to the study, a herbal formulation based on *B. sacra* dramatically improved cognitive and behavioral symptoms in patients with mild-to-moderate AD and MCI when compared to a placebo.	[24]
B. Sacra	Iraq	Frankincense chewing gum	According to the study's findings, chewing gum had antiproliferative and pro-apoptotic effects on cancer-damaged cells.	[25]
B. Sacra	Oman	Luban water extract	Treatment and prevention of experimentally produced kidney stones have been improved with Luban, especially when used at a dose of 150 mg/kg.	[26]
B. Sacra	Saudi Arabia	methanolic extract of *B. sacra*	The study's findings demonstrated that the male reproductive system is protected by *Boswellia sacra* extract.	[27]
B. Sacra	Saudi Arabia	Frankincense oil extract	The study's findings showed that frankincense oil did not interact with imipenem or gentamicin and had a mild inhibitory impact against MRSA and MDR-P. aeruginosa.	[28]
B. Sacra	Germany	*B. sacra* resin, ethanol extract	*Boswellia sacra*-loaded MBGNs demonstrated superior cell viability in human osteoblastic-like cells, demonstrating the potential of combining therapeutic benefits with MBGNs for tissue regeneration and repair	[29]
B. Sacra	Iran	*Boswellia sacra* resin, essential oil extract	BS-CNPs up-regulate P53, Cas-3, and 9, causing apoptosis, increasing free radical scavenging, inhibiting cell migration, and reducing angiogenic factors, making them suitable therapeutic targets in cancer research.	[30]
B. Sacra	Oman	Gum resin, ethanol extract.	The outcomes demonstrated that both *Bs* treatments markedly increased phagocyte activity. In contrast to the NBS treatment, both *Bs* treatments enhanced the overall antioxidant capacity while dramatically lowering the amounts of blood plasma urea, non-esterified fatty acids, hydroxybutyric acid, and interleukin-1.	[31]
B. Sacra	Switzerland	*Boswellia sacra* resin, methanol extract	The study found that natural extracts showed high sensitivity against various cancer cell lines, unlike those that required higher concentrations to induce cell death.	[32]
B. Sacra	China	Gum resin of *B. sacra,* ethanol extract	Compounds exhibited inhibitory activities on nitric oxide (NO) production induced by lipopolysaccharide in RAW264.7.	[33]
B. Sacra	Saudi Arabia	*Boswellia sacra* resin methanol extract	Three different extract dosages were tested on rats' blood cell effects, behavior, food intake, and water consumption. Different concentrations of boswellic acids were found, but none affected their diet or behavior.	[34]
B. Sacra	Oman	*B. sacra* Oleoresins	The ALA and HDF cell viability tests showed that none of the *B. sacra* extracts were harmful. The methanolic extracts' nonbiased GC-MS headspace analysis purportedly revealed a great diversity of monoterpenoids, with α-pinene abundances being especially high.	[35]
B. Sacra	China	Gum resin of *Boswellia sacra*, ethanol extract	Although there was no nitric oxide inhibition in primary mouse macrophages, the compounds demonstrated considerable cytotoxicity against the U87-MG human malignant glioma cell line, outperforming the control 5-fluorouracil.	[36]
B. Sacra	Tennessee State University	methanol extract	All live cells showed dose-dependent antitumor activity from the methanolic extract. The lung cancer cell line showed an indeterminate vi pattern, primarily due to a loss of cell viability at higher dosages, but the breast and prostate cancer cell lines showed a clear pattern.	[37]

B. Sacra	Egypt	Ethanol extract	Treatment of *Bs* resulted in linear increases in milk yield, energy-corrected milk, net energy for lactation, and feed efficiency.	[38]
B. Sacra	Saudi Arabia	Essential oil extract	Whether lipopolysaccharide (LPS) is present or not, crude *Bs*EO has been shown to impede the maturation and differentiation of DCs from progenitor cells. Compared to DCs co-cultured with LPS-stimulated DCs alone, *Bs*EO-treated DCs cultured in the presence of LPS decreased the ability of allogeneic T cells to proliferate.	[39]
B. Sacra	Oman	oleo gum resin, ethanol and chloroform extract by cold maceration method	A moderate antioxidant activity was shown by the resin extracts however their cytotoxic activity was observed to be quite remarkable at 1000 µg/l which could be attributed to their high boswellic acid content. The study confirmed that frankincense is rich in bioactive metabolites which are of significant economic and therapeutic importance.	[40]
B. Sacra	Oman	essential oils extract by hydro distillation method using Clevenger-type apparatus	All essential oils exhibited a strong antifungal effect against Candida albicans and Malassezia furfur, according to data from in vitro investigations.	[41]
B. Sacra	Saudi Arabia	oleo gum resin, methanol extract in a Soxhlet	The study proved that the doses tested of the methanol extract (250, 500, 1000 mg/kg) on blood cells in mice had no effect on the animals' behavior, food consumption, or weight gain.	[42]
B. Sacra	Sudan	Oleo gum resin, Oil extract	*Boswellia sacra*, a Sudanese Luban plant, is rich in alkaloids, flavonoids, triterpenes, sterols, tannins, and phenolic compounds, with twenty-five components identified through phytochemical screening.	[43]
B. Sacra	Oman	Oleo gum resin, methanol extract	*B. sacra* possess higher levels of amyrin and BAs in *Boswellia* resins, with varying distributions in arid mountains and coastal trees, and high α-amyrin concentration in roots.	[44]
B. Sacra	Saudi Arabia	water extract of *B. sacra* oleo gum resin	When given to healthy rats, the extract did not cause any ulcers. Compared to 5 ml/kg, the dose of 2 ml/kg was less PR ulcerogenic.	[45]
B. Sacra	Oman	Frankincense chewing gum	Demonstrate that frankincense chewing gum is a low-cost, safe herbal product that may be used to promote mouth hygiene in people of all ages by reducing the causes of microbial infections in the buccal and oral cavities. It has also been suggested to have extensive industrial and medicinal potential.	[46]
B. Sacra	Oman	oleo gum resin, methanol and oil extract	The study validates the analgesic properties of essential oils, extracts, and sub-fractions from *B. sacra* resin, supporting its use in traditional folk medicines and other products.	[47]
B. Sacra	Oman	green leaf, and oil extract from Frankincense resin	None of the *B. sacra* extracts detoxified pure aqueous aflatoxin B1. We have concluded that *B. sacra* resin and essential oil possess biological activity against biochemical synthesis and metabolic pathway of aflatoxin production of the two Aspergillus species.	[48]
B. Sacra	Oman	oleo gum resin, methanol extract	*Boswellia sacra* has a number of subfractions that have potent antioxidant and anti-glycemic effects.	[49]
B. Sacra	Oman	Essential Oils extracts	The study found that Hoojri and Shaabi, first and fourth grade lubans, had similar essential oil composition, yield, and physicochemical characteristics, while Najdi and Shathari had different compositions, yield, and specific rotation, but high limonene contents.	[50]
B. Sacra	Djibouti	oleo gum resin, Essential Oil and methanol extracts	*Boswellia*'s essential oil and methanol extract were more effective against bacterial species than yeast.	[51]

7.1. Volatile Terpenoids:

The chemical composition of the volatile oil of *B. sacra* resin has been investigated by GC-FID, GC/MS, and headspace SPME methods that revealed α-pinene (38%) (1), β-ocimene (32.3%; 2), camphene (29.4%; 3), 1-propanol, 2-(2-hydroxypropoxy) (14.4%; 4), limonene (13.36%; 5), and 2- propanol, 1, 1'-xybis (11.2%; 6) as the main compounds. Also, other compounds such as trans-pinocarveol (3.98%) (7), caryophyllene (3.03%; 8), cis-piperitol (2.53%; 9), β-selinene (2.49%; 10), myrcene (2.38%; 11), α-phellandren-8-ol (2.37%; 12), and delta-cadinene (2.21%; 13) have been reported in significant amounts in the essential oil from *B. sacra* (1–13) **(Figure 7)** [55, 56].

7.2. Terpene Derivatives:

Two oxygenated sesquiterpenes, rotundone (14) and mustakone (15**)** [56], were isolated and identified as a result of research on *B. sacra* **(Figure 7)**. These substances were extracted using sensory-guided fractionation from the gum resin's volatile oil [56]**.** Rotundone is a strong, unique sesquiterpene with woody, earthy, or peppery overtones, found in essential oils of plants like *Boswellia sacra*. It is crucial in flavor and fragrance industries and contributes significantly to the olfactory profile of spices like black

pepper. Rotundone, a compound with a bicyclic sesquiterpene skeleton, has strong olfactory properties due to its double bond at position 7, and its potential as a natural flavoring agent has been extensively researched [56].

Mustakone, a spicy, sweet, musky, and slightly floral sesquiterpene with a unique chemical formula, contributes to musky and woody scents in incense and perfumes, often found in *Boswellia sacra* essential oils. Mustakone, a warm, enduring odorant with a low sensory threshold, is a valuable ingredient in the flavor and fragrance industries for creating intricate musky, spicy accents [56].

7.3. Terpenoids

Four novel diterpenoids of the cembrane type, identified as boscartins (16–19), along with five known compounds (1S, 3R, 11S, 12R, and 7E), were isolated from the gum resin of *Boswellia sacra* by Wang et al.[57] Additionally, the researchers extracted 1,12-epoxy-4-methylenecembr-7-ene-3,11-diol (20), isoincensole oxide (21), incensole oxide (22), incensole acetate (23), and incensole oxide acetate (24).

The hepatoprotective activities of the isolated compounds were evaluated against paracetamol-induced damage in HepG2 cells, using bicyclol as a positive control. At a concentration of 10 μM, incensole acetate exhibited a strong hepatoprotective effect, whereas boscartin M, isoincensole oxide, incensole oxide, and incensole oxide acetate demonstrated moderate hepatoprotective effects under the same conditions [52].

The boscartins are a series of diterpenoids of the cembrane type isolated from the gum resin of *Boswellia sacra*. These compounds, specifically named Boscartins AL–AU, represent a novel subset of the cembranoid family with unique structural features, including various epoxy and hydroxyl groups that define their chemical diversity. [57]

The boscartins exhibit a broad range of bioactivities, including hepatoprotective and neuroprotective properties. Several compounds, such as Boscartins AL, AM, AN, and others, demonstrated noticeable hepatoprotective effects against paracetamol-induced HepG2 cell damage at a concentration of 10 μM. Their diverse biological activities and structural complexity make them promising candidates for further pharmacological investigations.[57]

In a separate study, Wang et al. isolated ten novel diterpenes of the cembrane type from *B. sacra*, including five known analogs (35–39) and boscartins AL–AU (25–34). Biological evaluations revealed that compounds 27, 29, 36, and 37 demonstrated hepatoprotective properties at a concentration of 10 μM against paracetamol-induced injury in HepG2 cells. Furthermore, several compounds showed modest neuroprotective effects in two different experimental models [53]. The structures of the diterpenoids isolated from *B. sacra* are illustrated in Figure 8.

7.4. Triterpenoids

Triterpenoid compounds play a critical role in the chemical identification of *Boswellia sacra*. These include lupeolic acid, α-boswellic acid, and β-boswellic acid (compounds 40, 41, and 42), along with their O-acetyl derivatives (43, 44, and 45) [28]. Additionally, two novel O-acetyl pentacyclic triterpenic acids, 3 α-acetoxyurs-5:12-dien-24-oic acid (46) and 3-acetoxylup-12:20-dien-24-oic acid (47), were isolated from Omani frankincense of *B. sacra.* These compounds were identified alongside four previously known substances: commic acid-D (48), 9, 11-dehydro-boswellic acid (49), 3-hydroxy-11-oxours-12-ene (50), and 11-hydroxy-3-oxours-12-ene (51) [54].

Al-Harrasi et al. also reported the isolation of a single ursane-type compound (52) and an oleanane-type compound (53) from *B. sacra* resin. The latter is identified as olean-11,13(18)-dien-3β,24-diol. Two additional lupane-type triterpenoids, lupeolic acid (54) and lupeol (55), were also characterized [54].

Pyrolysis of *B. sacra* frankincense resin, utilizing a self-developed assembly to trap the smoke in water, resulted in the extraction of two unique substances from the smoke-saturated water using an n-hexane solvent. These compounds identified as 1,2,4a,9-

tetramethyl-1,2,3,4,4a,5,6,14b-octahydropicene (56) and 2,9-dimethylpicene (57), demonstrated significant antiproliferative activity against MDA-MB-231 breast cancer cells, indicating their potential therapeutic applications [42].

Furthermore, a novel triterpene of the ursane class, nizwanone (58), was isolated from Omani frankincense *B. sacra* Flueck, along with two known triterpenoids: papyriogenin B (59) and rigidenol (60) [55]. Methanolic extracts of *B. sacra* resin yielded additional triterpenoid compounds, including 11-ketoursolic acid (61), 3-hydroxy-8,24-dien-tirucallic acid (76), 3-O-acetyl-oleanolic acid (62), and 3-O-acetyl-ursolic acid (64) [56]. In addition, ten more triterpenoids were identified, including one designated as compound 65 [57].

The diversity and structural complexity of these triterpenoids, as presented in Figure 9, underscore their significance not only as taxonomic markers for *B. sacra* but also as a source of bioactive compounds with therapeutic potential.

7.5. Boswellic Acid and Derivatives:

Boswellic acids are the main active ingredients in the *B. sacra* extract (BAs). BAs, which are classified into two types, other boswellic acid derivatives (compounds 67–71) were extracted from the resin of *B. sacra* [58]. These findings highlight the diversity and structural richness of BAs in this plant.

Furthermore, ten previously known boswellic acids (compounds 72–80) were isolated from the resin of *B. sacra*. Among these, compounds 73 and 75–77 exhibited significant inhibitory activity against α-glucosidase, with IC50 values ranging from 15.0 ± 0.84 to 80.3 ± 2.33 μM, while compound 78 displayed moderate inhibitory activity with an IC50 value of 799.9 ± 4.98 μM [59].

Several additional boswellic acid derivatives were identified from a methanolic extract of *B. sacra,* including β-BAs (ursane-type) and α-BAs (oleanane-type), are pentacyclic triterpenoids that are either oleanane or ursane and have carboxylic acid at C-4. (Figure 10) illustrates this. It is generally known that they are effective against hepatitis, ulcerative colitis, chronic colitis, inflammation, and arthritis. They have also demonstrated antiviral, antibacterial, antidiabetic, and antipruritic properties. The anti-inflammatory property of BAs is one of their major medical applications. Boswellic acids inhibit 5-lipoxygenase non-redox and non-competitively, which suppresses leukotriene production in neutrophilic granulocytes [60, 61, 62].

Anticancer and Bioactive Properties of Boswellic Acids Isolated from *Boswellia sacra.*

Boswellic acids (BAs) have demonstrated remarkable anticancer activity against a wide range of malignancies, including bladder, brain, cervical, colon, colorectal, liver, leukemia, lung, melanoma, meningioma, multiple myeloma, neuroblastoma, ovarian, pancreatic, and prostate cancers [63].

A novel boswellic acid derivative, 11 α-ethoxy-β-boswellic acid (EBA; compound 66), was isolated from Omani frankincense (*Boswellia sacra* Flueck) by Al-Harrasi et al [63]. Additionally, five 11-keto-β-boswellic acid (81), 3-O-acetyl-11-keto-β-boswellic acid (82), α-boswellic acid (83), β-boswellic acid (84), 3-O-acetyl-α-boswellic acid (85), and 3-O-acetyl-β-boswellic acid (86) [64].

The identification of these compounds highlights the pharmacological potential of boswellic acids and their derivatives, not only as promising anticancer agents but also as bioactive molecules with inhibitory effects on key enzymatic targets such as α-glucosidase. These findings further emphasize the importance of *Boswellia sacra* as a rich source of bioactive triterpenoids for therapeutic applications [55].

8. SELECTION OF OLEO GUM RESIN EXTRACTION METHOD

Oleo gum resin, which included polysaccharides, volatile oils, and resin containing boswellic acids, was separated using a variety of extraction techniques. Clogging and melting problems were caused by Soxhlet extraction and other heat-based techniques. Although it required several extractions with a different solvent each time to guarantee full extraction of boswellic acids, maceration was shown to be efficient [65].

9. TRADITIONAL AND MEDICINES USES

Frankincense is one of the primary materials used to prepare Yemeni incense, often used in religious rituals, celebrations, and for beautifying homes. In addition is used in folk medicine to treat respiratory diseases, as it is believed to have antibacterial and antiviral properties. Frankincense is used in the production of perfumes and is a key ingredient in many traditional Yemeni fragrances [29].

According to the 1500 BCE Ebers Papyrus, frankincense was utilized by the ancient Egyptians for a variety of medicinal purposes [66]. These included lowering phlegm, controlling vomiting, treating laryngeal and throat infections, preventing bleeding, and lessening asthma attacks. It has been established that the ancient Chinese utilized frankincense as early as the sixth century CE for a variety of purposes, including as improving blood circulation, relieving indigestion, and healing wounds and injuries. The Ayurvedic medical system in India prescribed frankincense gum for arthritic and inflammatory cases, pulmonary diseases, and gastric conditions [67]. Ibn Sina (Avicenna) prescribed frankincense for dysentery, ulcers, fevers, vomiting, and tumors. This traditional medical use continues with frankincense

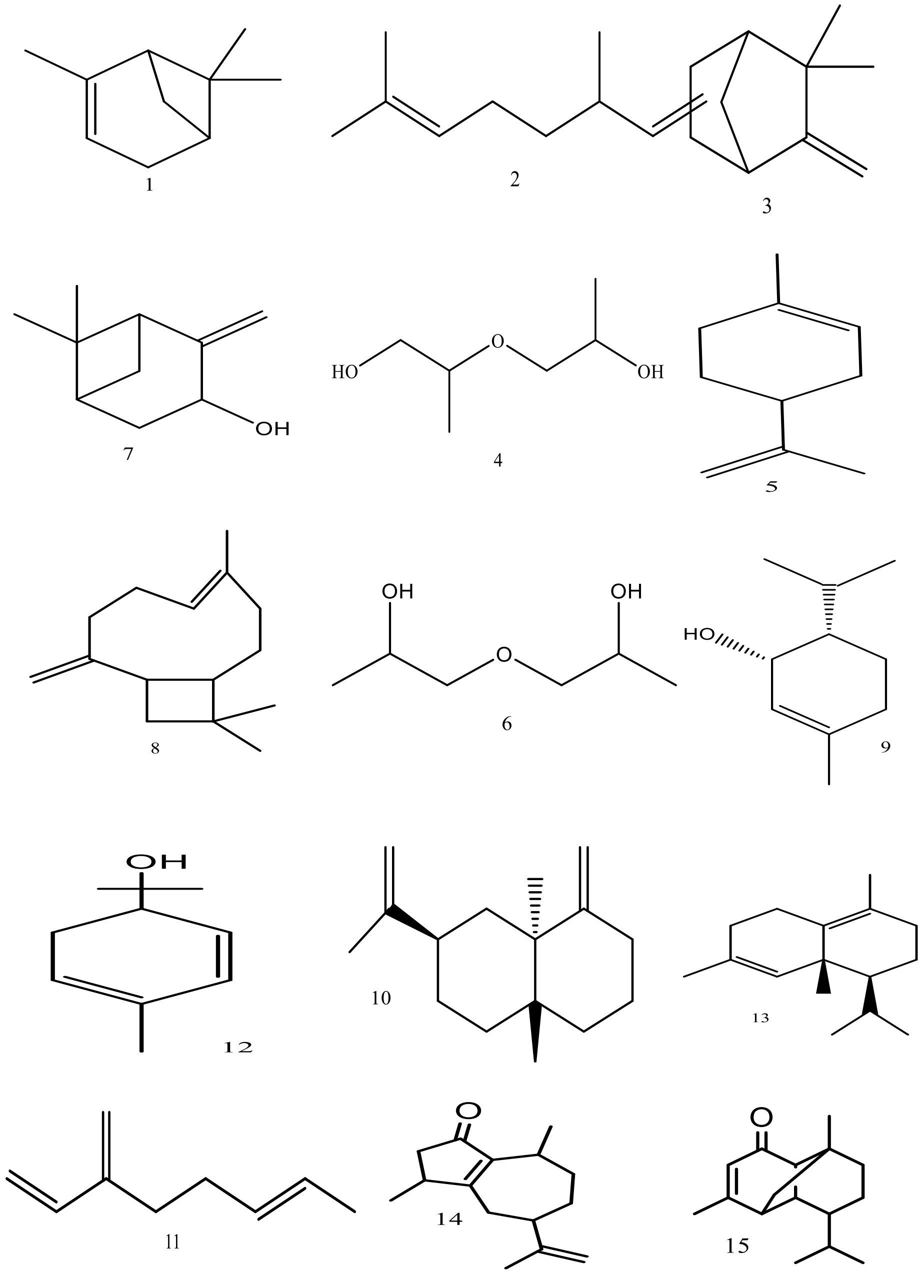

Figure 7. The Chemical Composition of the Volatile Oil of B. Sacra Resin according [55]

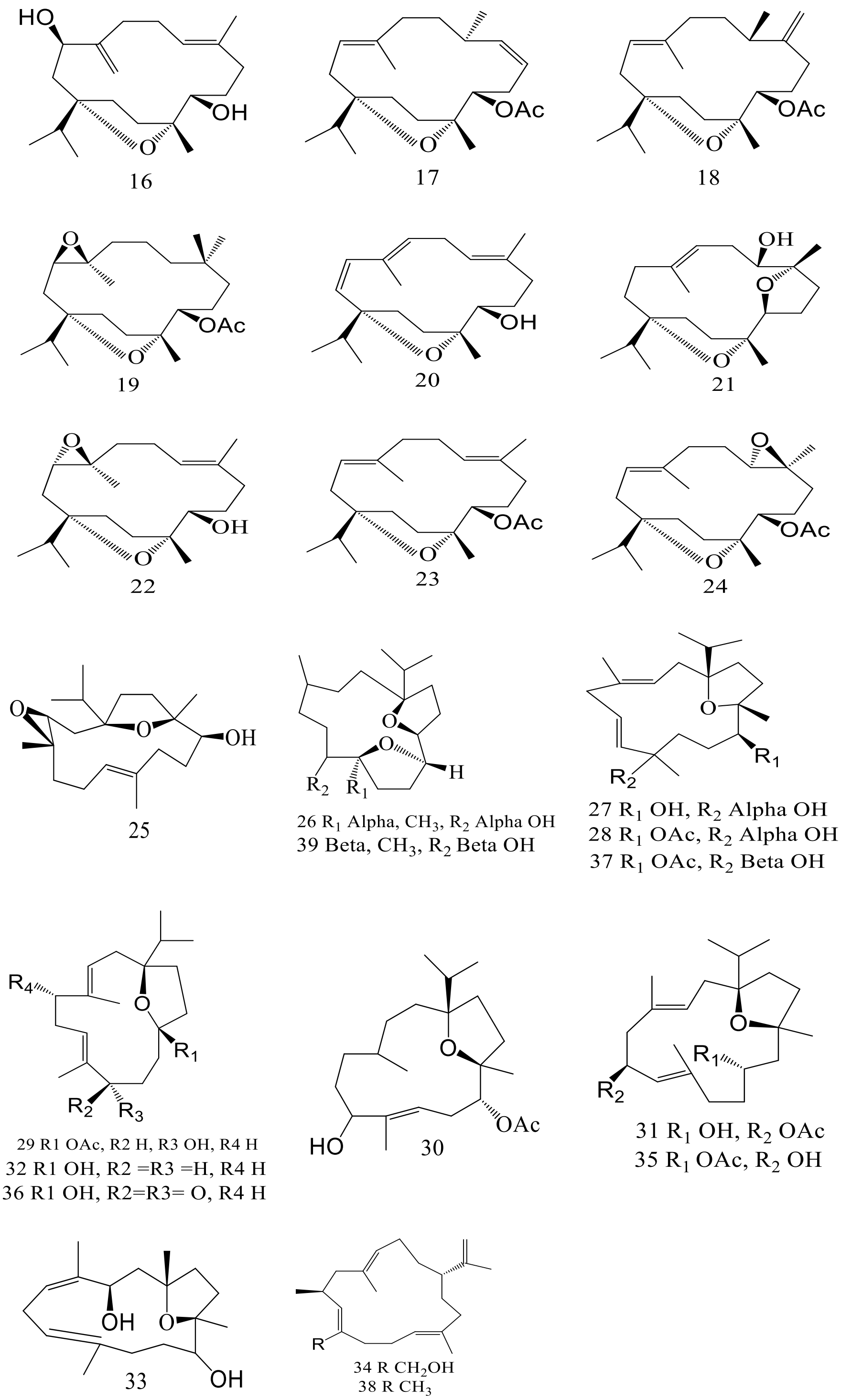

Figure 8. The structures of isolated diterpenoids from B. sacra according [55]

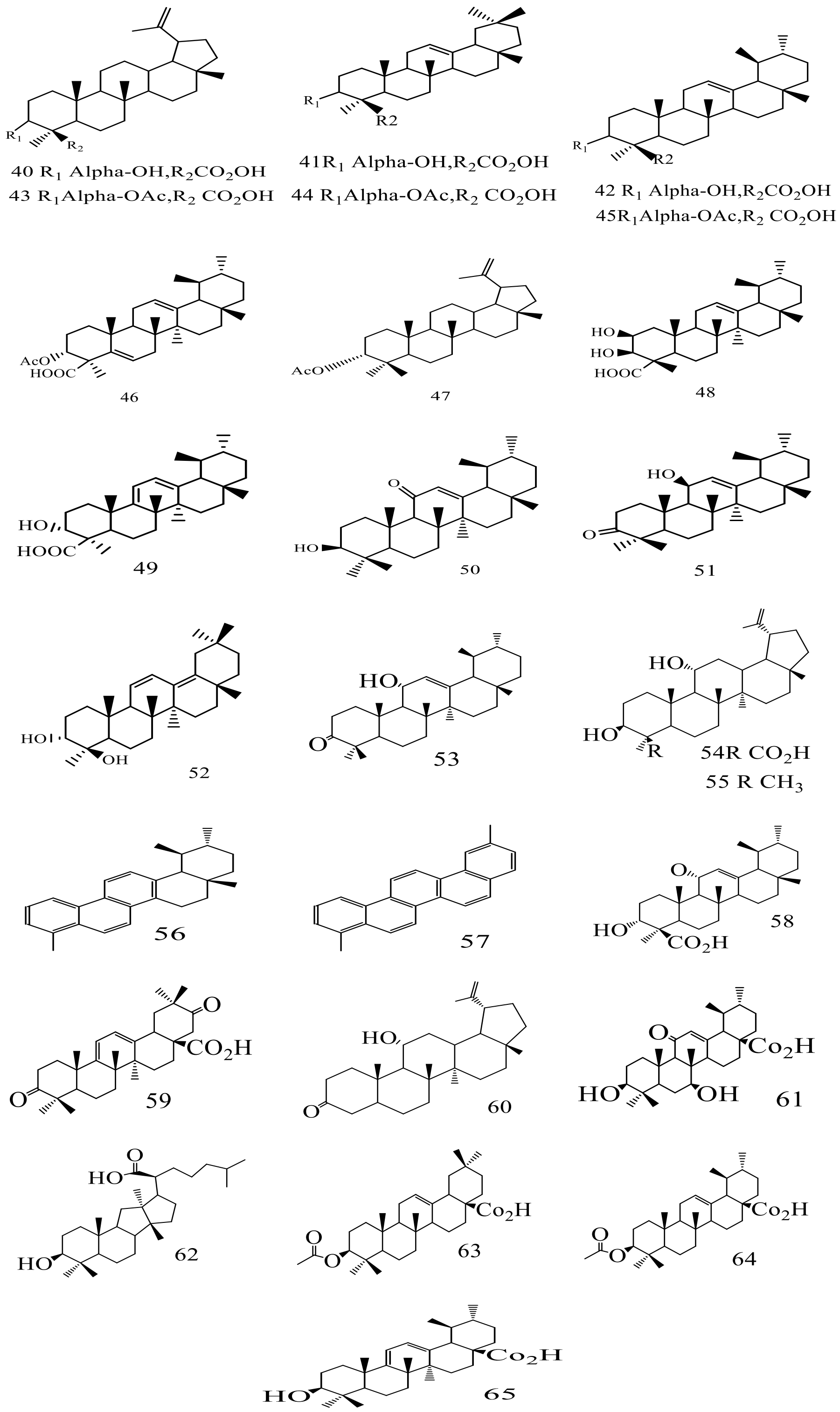

Figure 9. The structures of isolated triterpenoids from B. sacra according [55]

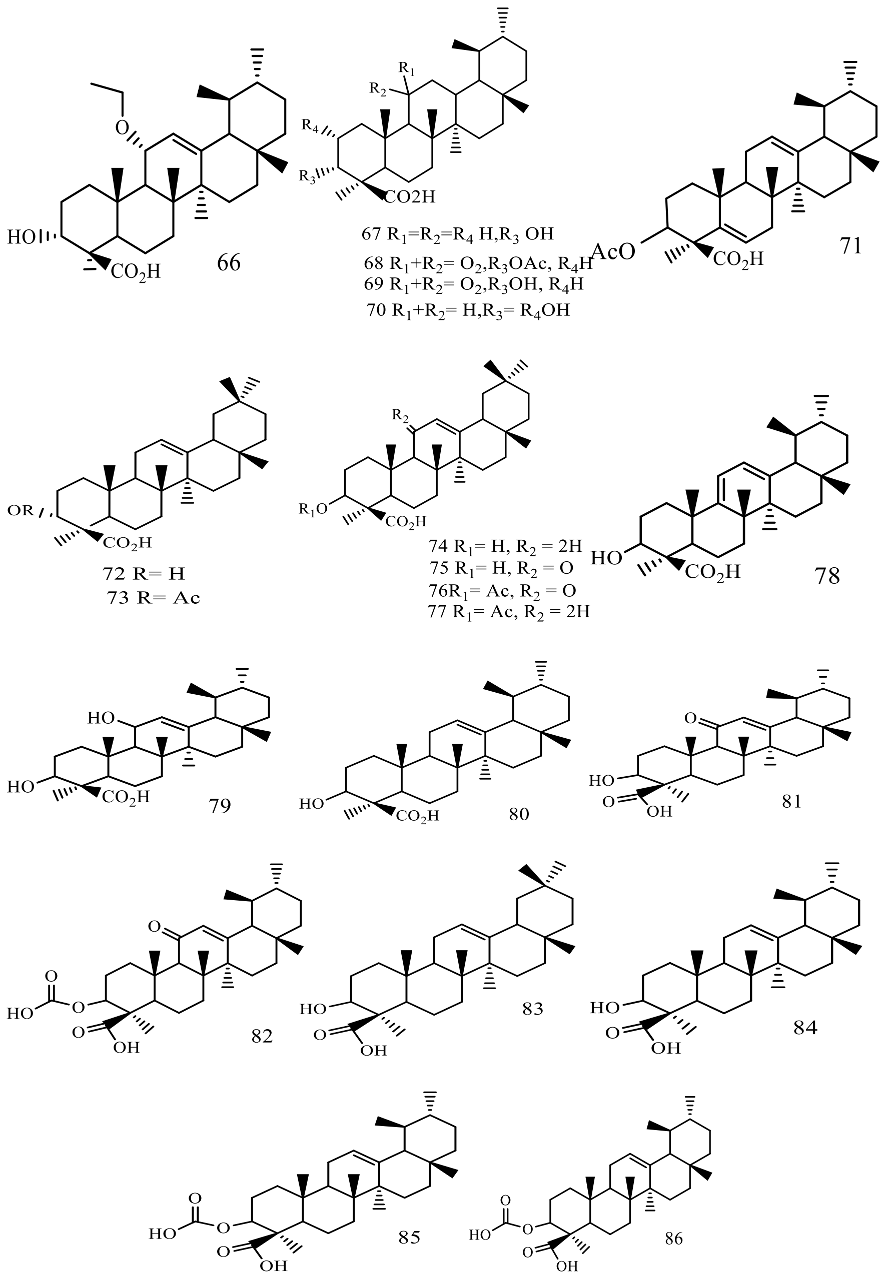

Figure 10. The Structures of Isolated Boswellic Acid and Derivatives from B. *sacra* [55].

used as a household natural or herbal treatment against coughs, throat swelling, dental problems, and wounds [68].

According to [66], certain commercially available frankincense-based ointments are beneficial in treating wounds, while others were designed to lessen arthritic symptoms. Since 1997, numerous patent applications based on frankincense or one or more of its derivatives have been filed in the USA and Europe. Anti-inflammatory qualities, the management of acute respiratory distress syndrome, neoplasia, and the prevention or treatment of cerebral ischemia, cerebral lesions, Alzheimer's disease, brain tumors, and other cancers are among the medical treatment potentials of these products [69].

Recent research on frankincense extracts or pure chemical derivatives has demonstrated its potential as a treatment for several illnesses and conditions in vitro, in vivo, and through a small number of clinical trials [70]. These include its anti-inflammatory properties in the treatment of rheumatoid arthritis; the anti-inflammatory properties of boswellic acids, particularly acetyl-11-keto-β-boswellic acid (AKBA), against intestinal inflammation; its antimicrobial properties against human pathogens such as *Candida albicans*, *Staphylococcus epidermidis*, and *S. aureus*; its inhibitory effects on tumor growth; and the direct effects of incensole acetate, one of its biomarker derivatives, on the central nervous system due to its antidepressant and "warmth"-inducing properties [70].

Urinary and bronchial infections are frequently treated with frankincense resin. In certain Asian nations, it is used as a restorative medication to treat menstrual discomfort, oral issues, wounds, sores, ulcers, carbuncles, hemorrhoids, inflammation, and throat issues. Additionally, frankincense oil is known to have diuretic, digestive, and carminative effects. The water extract from this gum resin, called "Moh-Lubban," has long been used to heal stomach issues and coughs [42].

Extracts from *B. sacra* gum have long been used in Omani traditional medicine to cure colds, coughs, muscle aches, fever, asthma, and various cancers, as well as to strengthen and stimulate the digestive system and treat dental infections [71, 58]. The gum resin is said to enhance memory in Arabian traditional medicine [72].

10. PHARMACOLOGY AND BIOLOGICAL ACTIVITIES

10.1. Anticancer Activity

Several cembranoids' cytotoxicity was investigated Cytotoxic action was demonstrated by serratol against the L6 rat skeletal myoblast cell lines. Boscartins were tested against IEC-6 cells, but no action was seen. Boscartins were also evaluated against human cancer cell lines, such as human ovarian cancer cell line A 2780 and human hematoma cell line Bel 7402. These substances did not, however, exhibit any cytotoxicity against any of these cell lines. Using cisplatin as a positive control, boscartins' antiproliferative activity against the HCT-116 human colon cancer cell was assessed. Every chemical had a negligible antiproliferative effect. Nevertheless, boscartins did not exhibit any appreciable activity when tested against the human breast cancer cell MCF-7 [47, 71].

10.2. Analgesic Effects

Two animal models of pain were used to examine the analgesic effects of crude extracts and fractions of Omani frankincense derived from *B. sacra*. The application of *B. sacra* resin extract, essential oils, and subfractions in formalin and acetic acid-induced writhing assays proved the plant's antinociceptive qualities, confirming its use as a traditional medicinal [47, 71].

10.3. Antimicrobial Effects

B. sacra essential oils have long been used to treat fungal and microbial illnesses. Monoterpenoids from *B. sacra* essential oil was found to have antibacterial action against *Propionibacterium acnes, Pseudomonas aeruginosa*, and *Staphylococcus aureus* in an in vitro investigation. Additionally, essential oils of frankincense demonstrated a noteworthy antifungal action against *Malassezia furfur* and *Candida albicans* [71]. Different amounts of *B. sacra* resin, leaf extract, and essential oil have been tested for their ability to suppress *Aspergillus flavus* and *Aspergillus parasiticus* growth and *aflatoxins generation*. According to this study, *B. sacra's* resin powder and essential oil significantly lower the generation of aflatoxin. In light of their antibacterial and aflatoxin-inhibiting properties, *B. sacra* resin powder and essential oil might therefore be suggested as secure natural food preservatives to lengthen the shelf life of food and feed products [41].

B. sacra oleoresin extract was discovered to have potential antibacterial and antibiofilm action against *Porphyromonas gingivalis* in another investigation [48]. Additionally, the efficacy of *B. sacra* extract in conjunction with conventional antibiotics was assessed against a variety of bacterial pathogens that affect the human gastrointestinal system as well as germs that trigger autoimmune diseases. According to the data obtained, *B. sacra* extracts combined with conventional antibiotics had significantly more action than each of the components by themselves [73]. According to a recent study, *B. sacra* essential oil showed encouraging antifungal efficacy against various fungi species, including *Botrytis* cinerea, *Aspergillus niger*, and *Rhizopus stolonifera*, that cause strawberry rot [35].

10.4. Hepatoprotective Effects

Some of the cembrane-type diterpenes that were isolated from *B. sacra* demonstrated clear hepatoprotective properties against HepG2 cell damage induced by paracetamol, according to biological evaluations of these compounds [74]. When *B. sacra's* aqueous extract of oleo-gum-resin was given to rats, it was shown to have hepatoprotective effects against both acute and chronic liver damage caused by carbon tetrachloride [74].

10.5. Antioxidant Effects

Using the DPPH radical scavenging method, it has been demonstrated that the essential oil of *B. sacra* gum resin has a potent antioxidant activity. However, compared to ascorbic acid's antioxidant capability, its antioxidant activity is reduced [57]. Testicular toxicity in rats has been researched about the effect of *B. sacra* oleo gum resin extract. The heat shock protein-70 (HSP70), glutathione-s-transferase-Pi (GSTPi), and insulin-like growth factor binding protein-3 (IGFBP3) gene expression in the testes was reduced by the plant extract. According to the study's findings, *B. sacra's* antioxidant properties may shield the testes against a variety of toxins by preventing free radicals from forming [75]. Furthermore, new research suggested that adding *B. sacra* essential oil to nanoparticles improved their ability to exhibit some pharmacological characteristics, like antioxidant activity [60].

10.6. Anti-Alzheimer Effect

Boswellia genus has been proposed as a potential treatment or preventive measure for neurodegenerative illnesses due to its anti-inflammatory, antioxidative, anti-amyloidogenic, and antiapoptotic properties [42]. An analysis of the effects of essential oils derived from *B. sacra* resins revealed that the acetylcholinesterase (AChE) enzyme can be strongly inhibited by frankincense essential oil. Patients with Alzheimer's disease have improved memory when AchE is inhibited, which raises acetylcholine levels in the brain. As a result, *B. sacra* as a medicinal herb may guard against Alzheimer's disease-related memory loss [30].

10.7. Anti-Inflammatory Effect

Promising results have been shown in the gum resin of *Boswellia* species against inflammatory arthritis, bronchial asthma, and various other associated disorders. It has been demonstrated that incense and its derivatives greatly enhance frankincense's overall activity [76].

Incensole and incensole acetate were found to be potential inhibitors of NF-KB, preventing cytokine- and bipopolysaccharide-mediated activation. They did not affect IKK activity or reduce IKB phosphorylation in co-stimulated T-cells [77].

10.8. Antiseizure Effect

More recently, a thorough investigation of the antiseizure properties of *B. sacra* resin was published by Wolfender and colleagues. The findings of this investigation showed that, of all the extracted terpenoids, β-boswellic acid, which is a member of the triterpenoid derivative family, was the most potent and, at 100 μg/mL, reduced pentylenetetrazole (PTZ)-induced seizures by 90% [1].

11. CONCLUSION

*Boswellia sacra*is one of the most common species distributed in the Arabian Peninsula, including Yemen which was used in traditional medicine from ancient times. Frankincense contains a variety of effective chemical compounds, such as triterpenoids, essential oils, gum acids, phenolic compounds, and sesquiterpenes, which contribute to its significance in traditional medicine and natural therapy. These compounds help in inflammation reduction, antibacterial action, and respiratory improvement. This recommends further evidence-based research on the therapeutic compounds derived from this plant.

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