



## *Artemisia herba-alba*: Phytochemical Profile, Bioactive Compounds, Pharmacological and Anticancer Properties: A Systematic Review

Nuri M. Abduali<sup>1</sup>, Hajir S. Awadh<sup>1</sup>, Jameelah Abdullah Hasan<sup>1</sup> and Hamad M. Hasan<sup>2</sup>

<sup>1</sup>Department of Chemistry, Faculty of Science, Derna University, Al-Gubba, Libya

<sup>2</sup>Department of Chemistry, Faculty of Science, Omar Al-Mukhtar University, Al-Bayda, Libya

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White wormwood, known in Arabic as “shih,” scientifically referred to as *Artemisia herba-alba*, is a perennial shrub belonging to the Asteraceae family and widely distributed across arid and semi-arid regions of North Africa and the Middle East. The use of *Artemisia herba-alba* in traditional medicine has occurred over time owing to its phytochemical content of essential oils, sesquiterpenes, lactones, flavonoids, phenolic acids, coumarins and sterols. Environmental and geographical factors influence qualitative and quantitative variation in bioactive compounds; hence they subsequently affect the plant’s biological activity. A substantial number of pharmacological studies confirm *A. herba-alba*’s broad spectrum of antimicrobial, antiviral, antioxidant, anti-inflammatory, antidiabetic, and hepatoprotective effects. Furthermore, there is increasing evidence that *Artemisia sp.* has anticancer properties by inhibiting proliferative activity of cancer cells and inducing apoptosis through modulation of cellular signaling pathways. Due to differences in extraction methodologies between studies and varying experimental designs, direct comparison of results from different researchers is difficult. Therefore, in order to present a comprehensive overview of recent information on *Artemisia sp.*, this article reviews the plant’s botanical characteristics, its phytochemical constituents, and its pharmacological activities to evaluate its potential as a natural source of drugs and highlight the necessity for more well-designed studies with appropriate experimental methodology to confirm the effectiveness of *Artemisia herba-alba* for use as a therapeutic agent.

## 1 Introduction

For millennia, people have relied on medicinal herbs to help maintain their health, and the use of these same herbs continues today to be an important source of contemporary medications. Throughout history, many systems of traditional medicine (e.g., Traditional Chinese Medicine (TCM) and Ayurvedic Medicine) have utilized plant-derived substances as their primary

means of managing and remedying a variety of illnesses. Furthermore, the role of medicinal herbs in primary health care is still significant today and remains especially critical in developing countries where many individuals depend on herbal medicine for their medicinal needs (Moufid & Eddouks, 2012). There are a wide variety of metabolites, including alkaloids, flavonoids, terpenoids, phenolic compounds, and glycosides, which are produced by plants. Medicinal plants have been acknowledged for their capacity of providing an extensive array of biologically active

compounds, including a variety of secondary metabolites, with a substantial number of therapeutic properties, e.g., antioxidant, antimicrobial, anti-inflammatory and anticancer. Due to the diversity of chemical agents found in these compounds, the development of many of today's pharmaceuticals has been directly or indirectly derived from these plant-based products (Newman & Cragg, 2020). Over the past decade there has been an increase in scientific interest aimed at exploring the use of these compounds from plants as alternative or adjunctive strategies in treating cancer (Pan *et al.*, 2010). Cancer is a complex disease characterized by the uncontrolled and rapid division of cells with an ability to invade other tissues and spread to distant sites within the body, representing a major challenge facing health care providers worldwide even with the advancements in the traditional treatment modalities (chemotherapy, radiotherapy and surgery) that are presently available (Nobili *et al.*, 2009). Because of these limitations, researchers have been searching for natural products that could provide treatments for cancer that are safer and more effective anticancer agents (Gordaliza *et al.*, 2007). For example, many of the most widely used chemotherapeutic agents, including paclitaxel and the alkaloids vincristine and vinblastine, have their origins from plants thus establishing how critical natural products are in the cancer drug discovery process (Cragg & Newman, 2013). There has been an increasing interest in searching for potential antitumor substances in plant-derived bioactive compounds. These compounds possess various mechanisms of action, such as inducing apoptosis, reducing the proliferation of tumor cells, inhibiting angiogenesis, and altering/resetting critical signaling pathways involved in tumor progression (Atanasov *et al.*, 2021). Therefore, medicinal plants will continue to help provide new, safer, more efficacious anticancer agents. One noteworthy source of potential antitumor agents is the genus *Artemisia* due to their complex phytochemical profiles and the numerous pharmacological properties associated with specific *Artemisia* spp. *Artemisia herba-alba*, which is abundant throughout North Africa and the Middle East, has had a long history of use by various cultures to treat a variety of conditions, including gastrointestinal disorders, infectious diseases, and inflammatory diseases. More recent studies have found many bioactive components present in *A. herba-alba* that contribute to its antioxidant, antimicrobial, and potentially anticancer effects (Bora & Sharma, 2011).

This study aims to investigate the phytochemical profile of *Artemisia herba-alba* and evaluate its potential biological activities, with a particular focus on its antioxidant and anticancer properties. It also seeks to provide scientific evidence supporting the traditional medicinal use of this plant and to identify possible bioactive compounds that may contribute to its

pharmacological effects. Ultimately, this research contributes to the growing body of evidence supporting medicinal plants as promising sources for the development of novel therapeutic agents.

### 1.1. Morphology and Taxonomy

Taxonomically, *Artemisia herba-alba* Asso belongs to the genus *Artemisia* within the family Asteraceae, which includes more than 500 species distributed across temperate regions of Europe, Asia, North Africa, and North America (Thurya *et al.*, 2025). The plant is a small perennial shrub (chamaephyte) reaching 20–40 cm in height, with a woody base that supports dense branching and adaptation to arid environments (Ouyahya *et al.*, 1990). Its aerial parts are covered with fine hairs that give the plant a grayish-green appearance and help reduce water loss and protect against harsh climatic conditions (Abad *et al.*, 2012). Glandular trichomes are responsible for producing essential oils and other secondary metabolites linked to its pharmacological activity (Boudjelal *et al.*, 2013). The leaves are reduced in size and adapted to minimize transpiration, which enhances survival in dry habitats (Ben Meftah *et al.*, 2018). The plant flowers in autumn, producing small yellow disc-like flowers typical of the Asteraceae family, which develop into seeds (achenes) that facilitate dispersal in harsh environments (Abu-Darwish *et al.*, 2015). The taxonomic and morphological characteristics are summarized in Figure 1 and Table 1.



**Figure 1:** The natural habitat and morphological features of *Artemisia* sp. are shown. A) An example of a typical field view of where the plant is found in arid rangelands; B) Close-up views of flowering branches and foliage (top), and of harvested materials (both dry and fresh) from *Artemisia* sp.

**Table 1.** Taxonomic classification of *Artemisia herba - alba*

Taxonomic Rank	Classification
Kingdom	Plantae
Subkingdom	Tracheobionta (Vascular plants)
Superdivision	Spermatophyta (Seed plants)
Division	Magnoliophyta (Angiosperms)
Class	Magnoliopsida (Dicotyledons)
Order	Asterales
Family	Asteraceae
Genus	Artemisia
Species	<i>Artemisia herba-alba</i> Asso

## 1.2. Origin and Distribution

This vigorously growing xerophytic shrub has wide distribution in the Mediterranean and North African regions and has an excellent adaptation to semi-arid environments. Drought tolerance of the plant is attributed mainly to an array of morphological and physiological characteristics including small leaves that have a hairy surface, a long root system and a reduction in the amount of water that is lost; therefore, the plant can tolerate excessive heat and extended periods of time without water. This species can also adapt well to the severely extreme climatic conditions of semi-arid and desert ecosystems (e.g, the deserts of southern Algeria) (Bougoutaia *et al.*, 2021). It has been used for medicinal purposes by traditional societies throughout its geographic distribution (for example, Algeria, Morocco and Egypt) as an infusion or decoction of the above-ground part of the axillary flower of the plant to treat ailments such as gastrointestinal problems, fever and parasitic infections. Thus, this plant has substantial historical significance as a medicinal plant (Bougoutaia *et al.*, 2021).

## 1.3. Geographic Distribution

The geographic distribution of *Artemisia herba-alba* spans a broad swath of North Africa, the Middle East, and the Mediterranean region (Figure 2). The species occurs in Algeria, Tunisia, Morocco, Libya; Saudi Arabia; Jordan; Syria; Palestine; Spain; and Greece, colonizing dry, sandy and rocky soils that generally consist of steppe or semi-desert landscapes. The presence of *A. herba alba* in these regions can be attributed to its strong ecological and genetic adaptability, with some studies suggesting that its phylogeographical distribution patterns are quite complex, and reflect its long presence in this region (on both sides of the Mediterranean basin). Within the range of *A. herba alba*, significant morphological and chemical variation exists among populations, due to localized

environmental pressures such as altitude, grazing intensity, and climatic micro-differences. The plasticity shown by *A. herba alba* demonstrates its ecological success in extreme environments, and also supports the possibility of multiple chemical profiles for *A. herba alba* which may have implications for pharmacological activity. *A. herba alba* continues to be researched for its potential as an ethically important source of bioactive phytochemicals with medicinal properties because of its historical distribution and use (Chiboub *et al.*, 2022).

**Figure 2:** Natural distribution of *Artemisia herba-alba*

## 2. Phytochemical composition and activities

Investigation of the chemical diversity of *Artemisia sp*, a plant of increasing relevance to the medicinal classes, indicates that it is a complex mixture of bioactive compounds (metabolites), especially in its essential oil. In general, essential oil composition, based on GC-MS analysis, shows that the two most abundant classes of volatiles are found in the oxygenated monoterpene class; namely,  $\alpha$ -thujone,  $\beta$ -thujone, camphor and 1,8-cineole have been shown to be responsible for a large portion (i.e.,  $\geq 75\%$  - 85%) of the bioactivities associated with this medicinal plant; i.e., antimicrobial and antioxidant activity (Ouchelli *et al.*, 2022). In addition to the above-mentioned volatile compounds (although they comprise the largest percentage of volatile components in (*Artemisia sp*), *A. herba-alba* contains high levels of phenolic (e.g., flavonoid) compounds that exhibit free radical-scavenging, lipid peroxidation-inhibiting, and antioxidant-enhancing potential (Kadri *et al.*, 2023). additional finding is that the chromatographic analysis of *A. herba-alba* essential oil shows that there are many volatile A number of studies have shown that *A. herba-alba* essential oil has significant antimicrobial and antifungal activity against a number of different

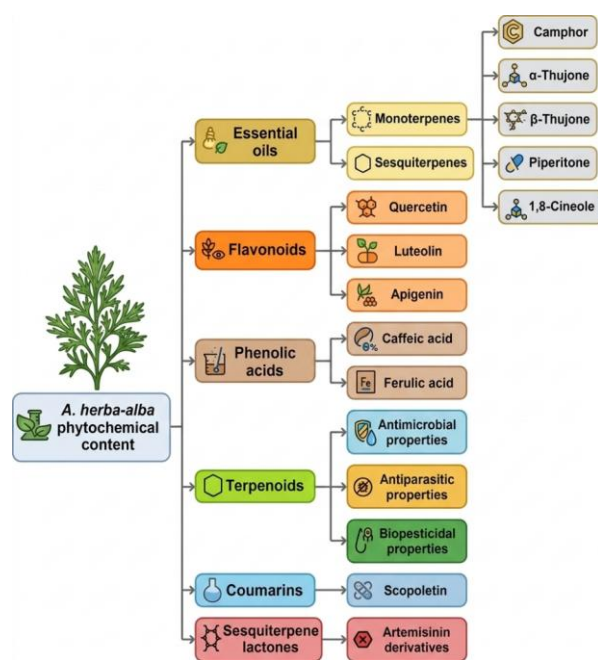
pathogenic microorganisms, which is likely due to the combined effects of the terpenoids and phenolic compounds (Mohammed *et al.*, 2021). A compound in this plant. This indicates that there are no 'individual' compounds that account for the biological properties of this essential oil; rather, they arise from interacting (synergistic) effects of the large number of components present in this essential oil (Abdallah *et al.*, 2025). It has been suggested that the chemical composition and biological activities of essential oils vary due to many environmental factors including geographic location, climate, soil type, and time of year the plant is harvested. Therefore, there is a need to establish a relationship between the phytochemical make-up and biological activities of *A. herba-alba* as a basis for developing standards for potential pharmaceutical use. Table 2 and Figure 3 present examples of miscellaneous research that presents the phytochemical and biological properties of *A. herba-alba*. Additionally, the phytochemical constituents and their ways to affect biological activities are related.

The action of the major phytochemical constituents of *A. herba-alba* include the interaction of terpenoids with the microbial cell membrane and the resulting damaging of the cells through the process of disrupting their cellular membrane and thus leading to the death of the cell. Also, because flavonoids and phenolic acids act as antioxidants, through the action of free radical scavenging, donating hydrogen atoms, and chelating metals, they help to reduce oxidative stress. Further, there are reports of these phytochemicals working together in the body to potentially induce apoptosis and inhibit cell division, therefore their cytotoxicity. The synergistic matrix of these terpenoids, flavonoids and phenolic acids is thought to combine and significantly increase the overall biological activity of *A. herba-alba*. Thus, the pharmacological effects of *A. herba-alba* are a result of the cumulative impact of all the phytochemical compounds in *A. herba-alba* and cannot be assigned to only one of these compounds (Alfazi *et al.*, 2025).

**Table 2.** Phytochemical Composition and Associated Biological Activities of Different Parts of *Artemisia herba-alba*

Plant Part	Major Phytochemical	Representative Compounds	Biological Activities	Analytical Techniques	References
Roots	Sesquiterpene lactones, sterols, phenolic derivatives	Lactone-type terpenoids, $\beta$ -sitosterol, phenolic compounds	Antimicrobial, anti-inflammatory, moderate cytotoxic activity (in vitro)	GC-MS, HPLC	(Baranová <i>et al.</i> , 2025; Mohammed <i>et al.</i> , 2021)
Seeds	Fixed oils, unsaturated fatty acids, phytosterols, tocopherols	Linoleic acid, oleic acid, stigmaterol, $\alpha$ -tocopherol	Antioxidant activity, potential cardioprotective effects	GC-MS	(Mohammed, 2022)
Leaves	Flavonoids, phenolic compounds, coumarins	Luteolin, apigenin derivatives, chlorogenic acid	Strong antioxidant, enzyme inhibition	HPLC, LC-ESI-MS/MS	(Souhila <i>et al.</i> , 2019)
Aerial Parts	Essential oils (monoterpenes), flavonoids, phenolic acids	$\alpha$ -Thujone, $\beta$ -thujone, camphor, 1,8-cineole, quercetin, kaempferol	Antimicrobial, antioxidant, antidiabetic, anti-inflammatory activities (in vitro & in vivo)	GC-MS, LC-MS, HPLC	(Lazreg <i>et al.</i> , 2025; Bourgou <i>et al.</i> , 2017)
Whole plant extracts	Wide metabolite spectrum (phenolics, flavonoids, terpenoids)	86 metabolites including flavones, coumarins, quinic acid derivatives, sesquiterpenes	Anticancer, antioxidant, antimicrobial activities	LC-ESI-TOF-MS, GC-MS	(Bourgou <i>et al.</i> , 2017)

Based on previously published studies, Table 1 identifies and summarizes the phytochemical compositions and biological activities of the different plant parts of *Artemisia herba-alba*. Various analytical techniques (GC-MS, HPLC, LC-MS, and LC-ESI-TOF-MS) identified both volatile and non-volatile compounds from the plant material. It is known to contain a variety of bioactive metabolites (monoterpenes, sesquiterpenes, flavonoids, phenolic acids, sterols, and fatty acids) that provide it with antioxidant, antibacteriogenic, anti-inflammatory, antidiabetic, and cytotoxic properties (Bourgou *et al.*, 2017; Mohammed *et al.*, 2021; Lazreg *et al.*, 2025). These differences in both the phytochemical profiles and/or the biological activities among the plant parts can be attributed to several factors including the differing environmental conditions under which the plant has grown and/or the extraction or analytical method used (Mohammed, 2022). Our findings confirm the pharmacological potential of *A. herba-alba*, and support continued investigation into this plant as a source of bioactive compounds for drug development.

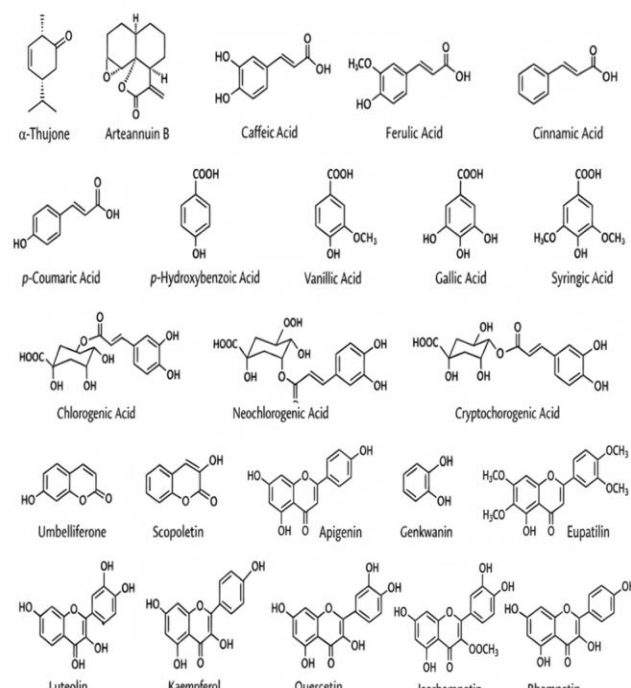


**Figure 3.** Schematic Representation of Major Phytochemical Classes and their associated biological activities in *Artemisia herba-alba*

### 3. Bioactive compounds and chemical constituents

After conducting a comprehensive chemical profile of the plant *Artemisia herba-alba* (White Wormwood), there are many secondary metabolites responsible for the biological activity of the plant. Essential oils obtained

from the plant contain mainly oxygenated monoterpenes, including  $\alpha$ -thujone,  $\beta$ -thujone, camphor, and 1,8-cineole, considered to be the main volatile components. In addition to the volatile components, solvent extracts of the plant also contain numerous non-volatile, bioactive compounds such as phenolic acids, flavonoids (e.g., quercetin and kaempferol), and sterols. The wide range of pharmacological effects attributed to these phytochemicals include, but are not limited to, antioxidant, antimicrobial, anti-inflammatory, antidiabetic, and cytotoxic properties. The different mechanisms through which the phytochemicals exert their pharmacological effects vary, and can include free radical scavenging, disruption of the microbial cell membrane, and modulation of various signal transduction pathways associated with cellular signaling events. Further research will be necessary to identify and characterize the major bioactive components of *Artemisia herba-alba* and their respective mechanisms of action. The qualitative and quantitative variation in chemical composition can be attributed to multiple environmental factors, geographic origins, and/or methods of extraction, which could explain inconsistencies in biological activity reported in the literature. Additionally, Figure 3 summarizes the major bioactive compounds derived from *Artemisia herba-alba* (Bsharat *et al.*, 2025).



**Figure 4:** Chemical Structures of Bioactive Compounds in *Artemisia herba-alba*

#### 4. Pharmaceutical and traditional medicinal uses

Recent discoveries in modern drugs have suggested strongly supportive evidence for many of the historical medicinal uses of *Artemisia herba-alba*. Throughout history, *Artemisia herba-alba* has been utilized to treat a variety of health conditions in various countries including Egypt and Arab nations of the Mediterranean region, including; (1) digestive disorders, (2) respiratory infections and conditions prescriptive of anti-inflammatory medicinal use, (3) antipyretic use (i.e.) treatment of fever. Many traditional cultures use herbal teas made from dried (aerial) portions of *Artemisia herba-alba* leaves or stems. The traditional medicinal uses of *Artemisia herba-alba* have provided substantiating evidence for increased research interest to scientifically validate the medicinal effects of *Artemisia herba-alba* (Boudjelal et al., 2013). One of the main reasons why the studies of *Artemisia* have been so extensive is due to the fact that it has many bioactive compounds. Some of these bioactive substances (not an exclusive list) in *Artemisia herba-alba* would include; (1) terpenes or terpenoids, (2) essential oils, (3) flavonoids, (4) phenolic acids, and (5) sesquiterpene lactones. The presence of these bioactive compounds has provided evidence that they exhibit a number of different pharmacological effects; hence, *Artemisia* would be an excellent candidate to be considered for the development of natural medicines (Oguirti et al., 2021). A significant amount of research has been conducted on the antimicrobial properties of *Artemisia herba-alba*. Numerous articles/evidence have provided information regarding the antimicrobial properties of *Artemisia herba-alba*. More specifically, strain-dependent antimicrobial properties (i.e., efficacy) have been documented for both Gram-positive and Gram-negative oral bacteria. As a traditional antiseptic and/or healing herb, it is expected that *Artemisia herba-alba* will have bacteriostatic properties in the healing of wounds (how the bacterium is eliminated through suppressive and/or without providing an opportunity for the bacteria to grow/reproduce). The chemical compounds responsible for these actions are mainly monoterpenes, including thujone, camphor, piperitone, and 1,8-cineole, which act by disrupting the membranes and metabolic processes of microorganisms (Mohsen & Ferchichi, 2009). *A. herba-alba* has considerable antifungal effects in addition to its antibacterial properties. Essential oils obtained from the plant have been shown to inhibit the growth of fungi, including species such as *Candida* and *Aspergillus*. Historically, *A. herba-alba* has been used to treat skin infections through topical administration. Through mechanisms such as disrupting fungal cell membrane structures and changing their permeability, *A. herba-alba* kills fungi by causing them to die (Houti et al., 2023). Another important pharmacological aspect of *A.*

*herba-alba* is its anti-inflammatory potentials. Tables 3 and 4 confirm the level of agreement between traditional use and validated pharmacological activity for *Artemisia herba-alba*.

**Table 3.** Ethnomedicinal Uses of *Artemisia herba-alba* in Different Regions

Region / Country	Plant Part Used	Preparation Method	Traditional Therapeutic Use
North Africa (Libya, Algeria, Morocco)	Leaves and aerial parts	Infusion or decoction	Treatment of digestive disorders such as stomach pain, diarrhea, and intestinal parasites
Middle East (Jordan, Syria)	Aerial parts	Herbal tea or decoction	Used for diabetes management and regulation of blood glucose levels
Morocco	Leaves	Decoction	Used to treat fever, cold, and respiratory infections
Algeria	Whole plant	Powder or infusion	Used as an antiseptic and for wound healing
Tunisia	Leaves and stems	Infusion	Used to relieve inflammation and pain
Saudi Arabia	Aerial parts	Decoction	Used to treat stomach disorders and digestive problems
Egypt	Leaves	Herbal tea	Used as an anthelmintic against intestinal worms
Mediterranean regions	Whole plant	Essential oil or infusion	Used for skin infections and fungal diseases
North African deserts	Leaves	Infusion	Used to reduce fever and treat colds
Greece (Mediterranean Europe)	Aerial parts and leaves	Infusion or decoction	Used traditionally for digestive disorders, fever, and as an antimicrobial and anti-inflammatory remedy

**Table 4:** Pharmacological Studies on *Artemisia herba-alba*

Authors / Year	Type of Study	Extract	Biological Activity	Main Results
(Mohsen & Ferchichi, 2009)	In vitro antimicrobial	Essential oil	Antibacterial	Strong antibacterial effects against Gram positive and Gram-negative bacteria.
(Abu-Darwish <i>et al.</i> , 2015)	In vitro antifungal	Essential oil	Antifungal	Inhibition of <i>Candida</i> and dermatophytes via membrane disruption.
(Amor <i>et al.</i> , 2010)	In vitro biological study	Plant extract	Antioxidant	Strong radical scavenging activity linked to phenolic compounds
(Khlifi <i>et al.</i> , 2013)	In vitro antioxidant	Methanolic extract	Antioxidant	High radical scavenging activity due to phenolic compounds.
(El Ouahdani <i>et al.</i> , 2021)	In vivo anti-inflammatory	Essential oil	Anti-inflammatory	Reduced carrageenan-induced edema in mice better than 1% diclofenac via modulation of inflammatory response.
(Hasan and Mousa, 2024)	Nanoparticle synthesis & characterization	Leaf and stem nanoparticles	Antibacterial	Showed strong antibacterial activity against both Gram-positive and Gram-negative bacteria.
(Sekiou <i>et al.</i> , 2020)	Experimental animal	Aqueous extract	Antidiabetic	Improved glucose tolerance and lipid profile in diabetic rats.
(Ouedrhiri <i>et al.</i> , 2019)	In vitro cytotoxicity & antifungal	Essential oil	Antifungal & low cytotoxicity	Antifungal activity with minimal toxicity toward normal cells.
(Hbika <i>et al.</i> , 2022)	In vitro enzyme inhibition	Plant extract	Antidiabetic mechanism	Inhibition of $\alpha$ glucosidase and $\alpha$ amylase enzymes.

Historically, *A. herba-alba* has been used for treating fever and relieving pain and reduces the level of inflammation through the inhibition of pro-inflammatory mediators and cytokines. The flavonoids and phenolic constituents of *A. herba-alba* play an important role in regulating inflammatory pathways and decreasing levels of oxidative stress (Khlifi *et al.*, 2013). Due to its flavonoid and phenolic content, *A. herba-alba* has strong antioxidant activity through its ability to scavenge free radicals and protect against oxidative damage. Oxidative stress has been linked to a number of chronic diseases, including various forms of cancer and heart disease; therefore, *A. herba-alba*'s antioxidant capacity suggests it may serve as an adjunct in preventive healthcare and disease management (Ben Nasr *et al.*, 2013).

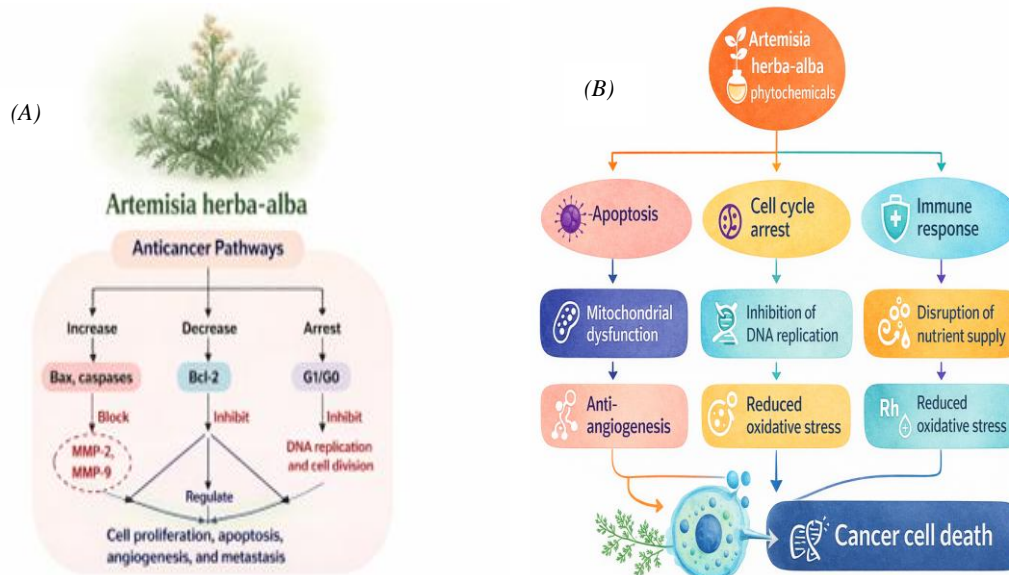
Table 4 shows the many medicinal properties documented in *Artemisia herba-alba* through research. Potentially due to its essential oil content, this plant has been found to be very effective at inhibiting bacteria and fungi. Research showed that the mechanism of action for these effects is through disruption of microbial membranes (Mohsen & Ferchichi, 2009; Abu-Darwish *et al.*, 2015). The methanolic and crude extracts of this plant consistently display strong antioxidant activity due to their high levels of phenolics and flavonoids (Amor *et al.*, 2010; Khlifi *et al.*, 2013). Furthermore, both in vivo and in vitro evidence supports the fact that this plant has currently demonstrated anti-inflammatory properties by inhibiting the production of pro-inflammatory indices and reducing oxidative stress factors (El Ouahdani *et al.*, 2021). In addition, there is a proven antidiabetic effect, supported by the results of enzyme inhibition studies and

results from animal model studies, in which extracts of *A. herba-Alba* exhibited inhibition of  $\alpha$ -amylase and  $\alpha$ -glucosidase activities and improved glucose control (Sekiou *et al.*, 2020; Hbika *et al.*, 2022). Recent studies have also demonstrated anticancer/antitumor activity in cytotoxicity studies in cell culture and animal tests with nanoparticles prepared from the various botanical parts of the *A. herba-alba* species (Hasan & Mousa, 2024; Ouedrhiri *et al.*, 2019). Taken together, scientific evidence demonstrates that *A. herba-alba* is a pharmacologically diverse medicinal plant with a large therapeutic potential based on a number of different experimental methodologies.

## 5. Anticancer effects and mechanisms

Through diverse chemical and biochemical processes, a wide variety of secondary metabolites are produced. Examples of this great number of secondary metabolites include flavonoids, monoterpenes and sesquiterpenes, as well as other phenolics. These many chemical compounds have all been shown to have high anticancer activity in many different *in vitro* studies (Bilia *et al.*, 2014; Pandey & Singh, 2017). In addition, many of these ingredients have been shown to have cytotoxic and/or antiproliferative effects on many different cancer cell lines, suggesting they may be suitable for the development of new anticancer agents (Efferth *et al.*, 2008).

Therefore, these studies support the pharmacological potentials of these plant extracts for the purposes of investigating new ways to treat cancer (Baranová *et al.*, 2025). Mechanistically, these phytochemicals act through multiple pathways, including induction of apoptosis, disruption of cellular signaling cascades, and modulation of oxidative stress within the tumor microenvironment, ultimately leading to inhibition of cancer cell growth (Amor *et al.*, 2010; Khlifi *et al.*, 2013). Additionally, cell cycle arrest and suppression of angiogenic processes have been reported as key mechanisms contributing to reduced tumor progression (Tilaoui *et al.*, 2015). The antioxidant capacity of these compounds also plays a crucial supportive role in anticancer defense by reducing reactive oxygen species (ROS)-induced DNA damage and maintaining genomic stability, thereby lowering the risk of carcinogenesis (Ben Salah *et al.*, 2012). Overall, the synergistic interaction of these phytochemicals highlights their significant potential in cancer prevention and therapeutic development. As illustrated in Figure 5, these interconnected mechanisms collectively contribute to tumor cell death, highlighting the potential of *A. herba-alba* as a promising natural source for anticancer drug development and therapeutic applications.



**Figure 5:** Detailed molecular pathways and multi-target anticancer mechanisms of *Artemisia herba-alba* bioactive compounds. The diagram illustrates two synergistic routes: (B) The Intrinsic Apoptotic Pathway, characterized by mitochondrial dysfunction, upregulation of pro-apoptotic proteins (Bax and Caspases), and downregulation of the anti-apoptotic protein Bcl-2; and (A) The Antiproliferative and Antimetastatic Pathway, which suppresses tumor invasion via MMP-2/9 inhibition and triggers G0/G1 phase cell cycle arrest to block DNA replication. These pathways are further reinforced by immune response modulation, nutrient supply disruption, and oxidative stress reduction, collectively leading to inhibited tumor progression and programmed cancer cell death.

Table (5) summarizes findings from the current literature as they pertain to anticancer actions of *Artemisia herba-alba* by various extraction methods using different models of cancer treatment. For example: most studies were performed using in vitro methods with either essential oil (EO), methanolic extract (ME), and/or aqueous extract (AE) compared to various types of cancer cells including breast, melanoma, carcinoma, and colorectal tumor cells. The data from each of these studies demonstrate considerable cytotoxic and antiproliferative characteristics of the extracts primarily due to the various bioactive components (i.e., monoterpenes, sesquiterpens, flavonoids, and phenolic compounds) found within the plant. Several mechanisms proposed within the literature include: induction of apoptosis, inhibition of cancer cell proliferation, antioxidant activity, anti-inflammatory properties, and inhibition of angiogenesis. Based on the data in the table, *Artemisia herba-alba* is likely to have substantial anticancer potential; however, most studies done on this plant were in vitro and additional studies (in vivo and/or clinical) are needed to evaluate its safety/efficacy for cancer treatment

A variety of studies provide evidence of the anticancer effects of the species *Artemisia herba-alba* through diverse extraction methods and experimental models. For example, (Tilaoui, *et al.*, 2015) demonstrated that the essential oil had a pronounced cytotoxic effect on the P815 mastocytoma and BSR cell lines, as evidenced by the IC<sub>50</sub> values for essential oil being between 15 and 50 µg/mL. Additionally, (Khlifi, *et al.*, 2013) indicated through their research that the methanolic extract displayed both antioxidant and anticancer effects through its high number of phenolic compounds. Likewise, (Abderrahman & Shbailat, 2014) showed that the ethanolic extract had effects that resulted in reduced cell viability and cytotoxic and genotoxic effects in mammalian cells at elevated concentrations. Moreover, (Abu-Darwish, *et al.*, 2015) confirmed that the essential oil exhibited numerous biological activities as well as potential therapeutic activities as a result of the terpenoid compounds found in it. Most recently, (Bou Malhab, *et al.*, 2024) also demonstrated that extracts from *A. herba-alba* could cause significant antiproliferative activity in eight different colorectal cancer cell lines with varying degrees of sensitivity to the extracts across the various cancer cell lines. Furthermore, (Mohammed & Alhusseini, 2025) showed that extracts from *A. herba-alba* exerted potent levels of cytotoxicity against the MCF-7 breast cancer cell line. According to the next line of research done by (Bsharat *et al.*, 2025), the oil had a significant anticancer effect on both MCF-7 and B16F10 cell-lines based on their relatively low IC<sub>50</sub> values. Based upon the findings of the previous paragraphs, Bsharat *et al.* concluded that *Artemisia herba-alba* has many bioactive compounds that all show potential as

anticancer agents, which act via different mechanisms including inhibition of cell proliferation, induction of apoptosis, generation of oxidative stress.

The genus *Artemisia* is famous for containing numerous biologically active compounds, including Artemisinin—an important sesquiterpene lactone initially isolated from *Artemisia annua* and is widely acknowledged to have strong anti-malarial properties and serve as a principal ingredient in artemisinin-based combination therapy (ACTs). The introduction of ACTs constitutes a significant advancement in the provision of malaria treatment. Artemisinin's unique structural characteristic of a cyclic peri-oxide bridge supports its unique biological functions. In total, artemisinin produces biological actions by first requiring iron-dependent activation in either parasitized or malignant cells with greater concentrations of available iron, hence producing reactive oxygen species (ROS). Additionally, ROS then create oxidative stress and resultant damage to cellular macromolecules, including DNA, protein and lipid components of cells, and ultimately cause the triggering of apoptosis. Other reported anti-cancer activities attributed to artemisinin include: inhibiting tumor cell proliferation, interrupting cellular cycle progression and modifying apoptosis-associated signalling pathways; potentially suppressing angiogenesis and reducing metastatic potential through mediation of vascular growth factor activity. In summary, given that artemisinin has dual historical significance as an exceptionally effective anti-malarial substance and is currently demonstrating significant clinically relevant selective cytotoxic behaviour against cancer cells, it is anticipated that artemisinin represents an auspicious natural agent in the future development of clinical anti-cancer therapeutic agents (Li *et al.*, 2021). Furthermore, interest in artemisinin has developed as it appears to be more selectively toxic toward cancer cells than normal cells. This apparent selectivity can be linked to the fact that malignant cells absorb significantly more iron than normal cells as well as the fact that malignant cells have altered metabolic activity compared to normal cells. Both of these characteristics contribute to increasing the activation of artemisinin and producing reactive oxygen species (ROS) preferentially in tumor tissue. Therefore, as a result of increased production of ROS, the likelihood of oxidative stress and apoptotic cell death are greater in cancer cells than normal cells. In addition, it has been shown in various studies that artemisinin in combination with traditional chemotherapy drugs has a synergistic effect, suggesting that artemisinin may serve as an adjunctive treatment to traditional cancer chemotherapy. Thus, artemisinin has not only been supported as a traditional antimalarial drug, but also has potential as a leading candidate for development into a modern anticancer pharmaceutical agent (Zhu *et al.*, 2021).

**Table 5.** Experimental Studies on the Anticancer Potential of *Artemisia herba-alba*

Authors / Year	Type of Study	Extract / Method	Cancer Model	Main Results
(Tilaoui <i>et al.</i> , 2015)	In vitro cytotoxic study	Essential oil (GC-MS characterized)	P815 mastocytoma, BSR cells	Demonstrated significant cytotoxicity with IC <sub>50</sub> values ranging ~15–50 µg/mL and selective toxicity toward tumor cells
(Khlifi <i>et al.</i> , 2013)	In vitro biological study	Methanolic extract	Cancer cell models	Demonstrated antioxidant and anticancer activity linked to phenolic compounds
(Abderrahman & Shbailat, 2014)	Cytotoxic/genotoxic study	Ethanollic extract	Mammalian cells	Reduced cell viability and induced cytotoxic effects at higher concentrations
(Abu-Darwish <i>et al.</i> , 2015)	Bioactivity study	Essential oil	Biological assays	Confirmed biological activity including potential therapeutic effects of essential oil
(Bou Malhab <i>et al.</i> , 2024)	In vitro anticancer study	Plant extract	Eight colorectal cancer cell lines	Demonstrated significant antiproliferative effects across multiple colorectal cancer cell lines, suggesting strong anticancer potential with variability in sensitivity between cell lines
(Mohammed & Alhusseini 2025)	In vitro cytotoxic study	Plant extracts	Breast cancer (MCF-7)	Demonstrated cytotoxic effects and anticancer potential of extracts
(Bsharat <i>et al.</i> , 2025)	In vitro anticancer study	Essential oil	MCF-7, B16F10	Showed significant anticancer activity with low IC <sub>50</sub> values

## Conclusion

*Artemisia herba-alba* has gathered much attention from the scientific community for being one of the most promising sources of herbal medicine with a vast array of pharmacological properties attributed to its high levels of secondary metabolites, such as flavonoids, phenolic compounds and essential oils, that exhibit various biological activities, including antimicrobial, antioxidant, anti-inflammatory, antidiabetic and cytotoxic activities. Furthermore, emerging data indicate that *artemisia* contains compounds that may be useful in treating cancer due to multiple mechanisms of action, including inducing apoptosis, reducing oxidative stress, altering the production of inflammatory mediators, inhibiting angiogenesis, and preventing cell proliferation in tumors. Despite the promising results from in vitro and early clinical trials of *artemisia*, there remains a lack of scientifically validated preclinical data to support its therapeutic value. As a result, additional studies are needed to investigate the effectiveness of *artemisia* in animal models as well as appropriate clinical studies.

Furthermore, multiple cultivars exist due, in part, to varying environmental conditions during growth and different methods of extraction, thereby resulting in differing phytochemical compositions that necessitate the establishment of quality control measures. Future studies should isolate and structurally characterize the active compounds present in *artemisia*, investigate their mechanism(s) of action, perform toxicology studies and investigate the pharmacokinetic properties of the active ingredients to assess their safety and efficacy. In conclusion, through continued integration of phytochemistry, pharmacology, and biomedical research as an area for interdisciplinary collaboration among researchers in these fields, *artemisia herba-alba* has great potential as an avenue for the development of novel therapeutic agents, especially in anticancer activity.

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