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Review Article

Exploring the Systematic Anticancer Mechanism in Selected Medicinal Plants: A Review

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Abstract

Cancer is thought to be the second most prevalent and leading cause of mortality worldwide, affecting both men and women among other chronic diseases. While there are several treatment options available, significant strains, side effects, and resistance have led researchers to focus on finding novel alternative medications for cancer treatment. Antioxidants and the immunomodulatory activities of medicinal plants are studied and considered to have anti-cancer effects. Medicinal plants contain diverse phytoconstituents as natural drugs, which possess numerous medicinal properties used for treating and preventing various illnesses. These phytoconstituents work through several mechanisms to target and kill cancer cells. Anticancer mechanisms include suppression and arrest of the G0/G1 phase, acting as anti-mitotic and anti-microtubule agents, enhancing the activity of macrophages, inhibiting cancer cells through various signaling cascades, anti-angiogenesis, and cytotoxicity. Investigating botanical sources and their metabolites can uncover new chemical entities for cancer treatment at the molecular target level and provide future interventions in cancer therapy. This article summarizes a few medicinal plants and their mechanisms of action for their anticancer potential. Furthermore, we discuss the future prospects and limitations of using medicinal plants in cancer treatment.

Introduction

Among the various causes of death due to diseases, approximately 74% are attributed to non-communicable diseases.[1] Despite the availability of advanced treatment strategies in the 21st century, cancer remains a major medical issue. In 2007, cancer was identified as the second most common cause of death worldwide, affecting both men and women. By 2015, there were about 17.5 million cancer cases and 8.7 million deaths reported. In 2020, the burden had drastically increased to 19.3 million new cases and 10.0 million deaths globally.[2] It is estimated that there would be 20 million new cases in 2022, with predictions suggesting that this number will reach 27.1 million in 2030 and 35 million by 2050. Approximately 53.5 million people were expected to be alive five years after receiving a cancer diagnosis. One in five people will develop cancer at some point in their lives; one in nine men and one in twelve women will die from the disease.[3–6]

Cancer cells possess complex ecosystems and exhibit remarkable variability in their composition, spatial distribution, and activation. These cells adopt various features for growth and survival, often evading therapies through epigenetic and genetic alterations, as well as changes in cellular processes, metabolism, and signaling pathways.[7–13]

Prostate, bronchus, lung, rectum, colon, and urinary bladder cancers affect the highest percentage of men, while breast, thyroid, and uterine corpus cancers are most prevalent among women. Children frequently suffer from cancers of the brain, blood, and lymph nodes.[14–18] Technological advancements and the accumulation of early-stage information may lead to more effective cancer treatments. Despite this, the belief persists that all cancers are preventable and treatable. Some adverse effects associated with modern medications can be anticipated and managed in cancer patients.[19,20] Consequently, the adverse effects of modern drug-based chemotherapy have been significantly reduced by using herbal combination chemotherapy regimens to achieve the desired therapeutic outcomes.[21–23]

Due to their convenience, safety, and minimal toxicity, the use of medicinal plants in treating a wide range of medical conditions has increased significantly. Phytoconstituents from medicinal plants target cancer cells through various mechanisms.[24–27] Plants produce a variety of phytoconstituents with a broad range of biological activities, from mild analgesics to anti-cancer prop-

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erties. These phytoconstituents play a significant role in drug delivery.[28–30] In this study, the authors attempted to investigate the phytoconstituents of medicinal plants and their roles in cancer treatment. Phytoconstituents such as oroxyline, banana lectin, colchicine, kaempferol, vincristine, vinblastine, and quercetin from various medicinal plants are well-researched for their anti-cancer potential. However, since there are very few research reports on these phytoconstituents and their anti-cancer effects, their mechanisms and other relevant phytoconstituents are yet to be explored. The medicinal plants and their anticancer mechanisms are reviewed in our current article. Medicinal plants and their anticancer mechanisms are summarized in Table 1.[31–53]

Anticancer mechanisms

Phytoconstituents exhibit their anticancer potential through several mechanisms, including:

1. Suppressing the G2/M and G0/G1 phases, inducing cell cycle arrest, and promoting apoptosis.
2. Acting as anti-mitotic and anti-microtubule agents, which reduce DNA synthesis.
3. Enhancing the activity of macrophages and inhibiting cancer cells.
4. Inhibiting cancer cells through various signaling cascades and pathways.
5. Exhibiting anti-angiogenesis effects and photocytotoxicity.
6. Regulating transcription.
7. Modulating autophagy.
8. Suppressing metabolic enzymes.
9. Causing membrane disruption.

Oroxylum indicum (O. indicum)

O. indicum (L.) Kurz has been traditionally utilized for generations in Asian ethnomedicinal practices to prevent and manage respiratory diseases, tumors, diabetes, and diarrhea. The genus Oroxylum belongs to the group of Angiosperms (flowering plants) and is a member of the Bignoniaceae family. Oroxylum is a genus with two species, one of which is widely recognized.

Earlier studies have highlighted that among the different species, *O. indicum* has been widely acknowledged for its diverse biological activities.[31] Several studies have demonstrated its anticancer, antioxidant, and immunomodulatory effects.[31] Flavonoids such as chrysin, baicalein, and oroxylin-A have been identified as its principal phytoconstituents. These flavonoids exhibit strong inhibitory action against proprotein convertases and endoprotease enzymes, both of which play important roles in the development of bacterial and viral infections as well as cancer.[31,32] One study investigated the anticancer potential of the ethyl acetate fraction of stem bark extract of *O. indicum* in an oral carcinogenesis model induced by 4-nitroquinoline-1-oxide. The extract exhibited anticancer activity by regulating the epidermal growth factor receptor/phosphatidylinositol 3-kinase (PI3K)/protein kinase B (AKT) signaling cascade in oral squamous cell carcinoma.[33] Another study by Sisin *et al.*[34] explored the anticancer effect of the methanol extract of *O. indicum* on SiHa cervical cancer cells. The anticancer effect was assessed by examining the expression of Bcl-2, Cas-3, and Cas-9 (apoptosis-related proteins), E6 and E7 (viral oncoproteins), and p53 and pRb (tumor suppressor proteins). The results demonstrated that the extract increased Cas-3 and -9 expression and reduced Bcl-2 expressions. Additionally, the extract inhibited viral oncoproteins (E6 and E7) and upregulated tumor suppressor proteins (p53 and pRb). The researchers also suggested that the flavonoid "gossypin," present in the extract, may be the active biomolecule responsible for preventing viral oncoprotein-dependent suppression of tumor suppressor proteins.[34]

The extract from the vent roots of *O. indicum* exhibited dose-dependent cytotoxicity against colon (HCT15), breast (MDA-MB-231), and endometrial cancer (HeLa) cell lines, with IC_{50} values of 92.43, 133.0, and 112.84 µg/mL, respectively. The study suggested that *O. indicum's* mode of action might involve mediation of cell cycle arrest during the G1/S phase. Additionally, the extract was found to pose less risk to non-cancerous cell lines at the assessed concentrations. Based on bioassay-guided purification and fractionation, the authors recommended further investigation into *O. indicum* to potentially identify a new chemical entity for future anticancer drug development.[35]

These findings underscore the need for further research on *O. indicum* (L.) Kurz to isolate its bioactive phytoconstituents, assess its pharmacological potential, and implement it as an effective treatment, which could enhance its commercial value in cancer therapy.

Musa paradisiaca (M. paradisiaca)

Plantain, also called *M. paradisiaca L.*, is a perennial herb that resembles a tree and is extensively found in tropical regions. The genus Musa belongs to the group of Angiosperms and is classified into the family *Musaceae.* In the genus Musa, 203 scientific plant names correspond to species rank, among which 66 species are recognized. An additional 181 species are classified at the intraspecific rank. Both traditional and scientific literature document that *M. paradisiaca* is widely accepted for its numerous biological activities among different species.[54] Among the different parts of the plant, the pulp possesses hepatoprotective, analgesic, wound-healing, antiulcer, and hair-growth-promoting activities.[54] The methanol extract of *M. paradisiaca* inflorescence was found to be cytotoxic to HT29 colon cancer cells. The extract reduced mitochondrial membrane potential and induced cell cycle arrest in the G2/M phase. It was suggested that the anticancer potential might be due to reduced adenosine triphosphate production, increased cytochrome C release, and induction of cell death in HT29 cells.[36]

Banana lectin (BanLec), extracted from the ripe pulp of *M. paradisiaca*, demonstrated strong cytotoxic effects on tumor-homing peripheral cells (THP-1). BanLec induced apoptosis by causing abnormalities in the morphology of cancerous cells, including fragmentation of nuclei, chromatin condensation, budding, and blebbing of the cell membrane. The percentage of cells in the G0/G1 phase increased, indicating that THP-1 cells were being induced to undergo apoptosis. In summary, BanLec appears to activate caspase-dependent apoptosis in THP-1 cells. These findings suggest that BanLec induces apoptosis and cytotoxicity in THP-1 cells and holds promise as a strong chemotherapeutic agent with potential benefits for cancer therapy.[37] It seems to be one of the most potent anticancer compounds with potential therapeutic activity against human leukemia.[38]

Colchicum autumnale (C. autumnale)

The genus *Colchicum* is a member of the primary group of *Angiosperms* and is included in the family *Colchicaceae*. In terms of species rank, there are 318 scientific plant names, with 103 recognized as species. Additionally, there are 127 scientific plant names of infraspecific rank within this genus. Among the different species, *C. autumnale* is commonly accepted. The most significant alkaloid of this plant is colchicine, which is traditionally used to treat gout, familial Mediterranean fever, and gout.

The alkaloid Colchicine, a bioactive phytoconstituent from *C. autumnale*, exhibits antiproliferative effects by suppressing

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Table 1. Mechanism of anticancer activity of medicinal plants

S.No.	Plant name	Family name	Phytoconstituents	Mechanism	Reference
1.	*Oroxylum indicum* (L.) Kurz	*Bignoniaceae*	Baicalein; Oroxyline Pinostrobin Stigmast-7-En-3-Ol	Act as a mediator for cell cycle arrest during ↓G0/G1 phase, G1/S phase ↑↓Regulating the signalling cascades	31–35
2.	*Musa paradisiaca L*.	*Musaceae*	Banana Lectin Leucocyanidin Quercetin	↑ Cell cycle arrest in G2/M Phase, Mitochondrial; ↓ membrane potential and induced cell cycle arrest in the G2/M phase, ↓ the ATP production, ↑ cytochrome C release, ↑ Apoptosis.	36–38
3.	*Colchicum autumnale*	*Colchicaceae*	Colchicine Demecolcine Anthocyanins Kaempferol Quercetin	Suppression of microtubule formation by interrupting the cell cycle at the G2/M phase and inducing apoptosis, ↑ Cell cycle arrest in G2/M Phase. ↓ instability or destabilization of microtubules; ↓ suppression of angiogenesis as well as the migration and propensity for metastasis	39–43
4.	*Catharanthus roseus*	Apocynaceae	Vincristine Anhydrovinblastine Vinblastine Vindesine Vinorelbine	↓ Cell division, ↓ cell cycle, ↓ Metaphase changes the dynamics of microtubules, causes regression in cell growth and apoptosis. ↓DNA and RNA synthesis, Vinblastine and vincristine have anticancer potential by binding with intracellular tubulin subsequently block the enzyme DNA-dependent RNA polymerase, Vinblastine often causes microtubular dynamic disruption	44–46
5.	*Psidium guajava* L.	*Myrtaceae*	Guaijavarin Quercetin; Resveratrol; Kaempferol; 3,5-dihydroxy-2,4-dimethyl1-O-(6′-O-galloyl-β-dglucopyranosyl)- benzophenone; 4,5-Diepipsidial A; Apigenin; Betulinic acid; Guajadial; Guajadial B, D & F ; Lycopene; Guavinoside C (Avicularin); Guavinoside B; Psiguadial D	↓ Inhibit constitutive AKT/mTOR/ribosomal p70 S6 kinase (S6K1) and MAPK activation pathway, apoptosis blocked the AKT/mTOR/S6K1 signaling pathway	47,48
6.	*Mangifera indica*	*Anacardiaceae*	Mangiferin; Kampferol; Quercetin	↑ Cell cycle arrest; ↑ AMPK signaling pathway Apoptosis; ↓ PI3K/AKT pathway; ↓ NF-κB signaling pathway	49–51
7.	*Lagerstroemia speciosa* (L.)	Lythraceae	Ellagitannins; P-Coumaric Acid Kaempferol Quercetin	↑ Cell cycle arrest in G1 Phase, ↑ in the number of apoptotic cells, cell cycle arrest at the subG0/G1 phase. Additionally, the expressions of p21, p27, p53 and FOXO1 were considerably upregulated by EEBL, ↓ expressions of MDM2, p-Akt, CDK4, cyclin D1 and E1	52
8.	*Moringa oleifera* L.	Moringaceae	Quercetin; Rhamnetin; Kaempferol; Apigenin; Myricetin, 4-[(A-L-Rhamnosyloxy) Benzyl]; Isothiocyanate	↑ Cell cycle arrest in G2/M phase, displayed a G2/M phase cell cycle arrest and significantly increased expressed of p53 and p21. ↓ Controls p53 and p21 arrest, inhibition of the MEK/ERK-mediated pathway	53

↑ implies Increased/enhanced/improved; ↓ implies decreased/reduced. AKT, protein kinase B; AMPK, AMP-activated protein kinase; ATP, adenosine triphosphate; CDK4, cyclin-dependent kinase 4; EEBL, ethanolic extract of banaba leaf; ERK, extracellular signal-regulated kinase; FOXO1, Forkhead box O1; MDM2, mouse double minute 2; MEK, mitogen-activated protein kinase; mTOR, mammalian target of rapamycin; NF-κB, nuclear factor-kappa B; p-Akt, phosphorylated-Akt; PI3K, phosphoinositide 3-kinase.

microtubule formation, interrupting the cell cycle at the G2/M phase, and inducing apoptosis. Despite its antiproliferative properties, Colchicine is not clinically utilized to treat cancer due to its toxicity. However, Colchicine remains a promising lead molecule for the development of new anticancer medications. Consequently, several colchicine analogues have been developed with the aim of creating innovative and practical medications with improved pharmacological characteristics.[39] Research is ongoing to produce less toxic colchicine semisynthetic compounds and potential drug-delivery systems that directly target various solid tumors. These developed analogues have proven to be less toxic than colchicine.[39]

Microtubules are essential for cell division and are considered a well-known target for cancer treatment. The formation of the mitotic spindle apparatus by microtubule dynamics is crucial for chromosome segregation during mitosis. Instability or destabilization of microtubules leads to mitotic arrest and disrupts microtubule dynamics.[40,41]

Purified colchicine and isolated colchicine from *C. autumnale* can control the expression levels of many genes involved in combating cancer cells, such as human (MCF-7) breast cancer cells. Moreover, the cytotoxicity and growth inhibitory effects increased significantly with higher doses of the extract and were nearly equivalent to doxorubicin in terms of cytotoxicity. These findings suggest that colchicine may be a viable option for both breast cancer prevention and therapy. Colchicine has also been associated with the suppression of angiogenesis, as well as the migration and metastasis of cancer cells.[42]

Foumani *et al.*[43] investigated the apoptotic effects of colchicine from *C. autumnale* in human breast (MCF-7) and mouse breast (4T1) cell lines, assessing the results based on apoptotic gene and protein expression. The study demonstrated that colchicine induces apoptosis in a dose-dependent manner by increasing the *Bax/Bcl-2* ratio through upregulation of *Cas-3*, *Cas-9*, *Bax*, and *P53* genes, and downregulation of the *Bcl-2* gene. They suggested that colchicine could be considered a potential molecule for breast cancer treatment.[43]

Catharanthus roseus (C. roseus)

The genus Catharanthus belongs to the group of Angiosperms and is classified in the Apocynaceae family. For the genus Catharanthus, there are 27 scientific plant names of species status, with eight officially recognized species names. Additionally, there are thirteen scientific plant names of infraspecific rank within the genus. Among the different species, *C. roseus* is particularly notable for its wide variety of applications. Investigational studies have identified numerous alkaloids in *C. roseus;* these alkaloids alter microtubule dynamics, leading to cell growth regression and apoptosis.[44]

Vinblastine inhibits cell division by binding to microtubules, resulting in mitotic block and apoptosis. It often causes microtubular dynamic disruption at low concentrations, especially at the extremities of the mitotic spindle and during metaphase arrest. Vinblastine and vincristine exhibit anticancer potential by binding to intracellular tubulin and subsequently blocking the enzyme DNA-dependent RNA polymerase, which prevents DNA and RNA synthesis.[44–46]

Phytoconstituents such as vinblastine, vincristine, and colchicine act on microtubules, as discussed in Sections 2.3 and 2.4. Colchine binds to the end of the microtubule to prevent its polymerization. However, vinblastine and vincristine hinder microtubule dynamics and inhibit DNA and RNA production.

Psidium guajava L

The plant *Psidium guajava*, commonly known as guava, has been utilized for centuries both as food and in traditional healing practices. The genus Psidium belongs to the primary group of Angiosperms, specifically the *Myrtaceae* family. In the Plant List, there are 488 scientific plant names of species rank within the genus Psidium, with 112 recognized as species. Additionally, the genus has 107 scientific plant names of infraspecific rank. The plant is widely distributed in both tropical and subtropical regions of the world. Its roots, bark, leaves, fruits, and seeds can be used as infusions or decoctions to treat various diseases. The fruit is rich in vitamins, fiber, and other nutrients. Numerous studies have documented that this plant possesses anti-inflammatory, antioxidant, antibacterial, antidiabetic, anticancer, and immunomodulatory activities.[55,56] Recent research highlights that the bioactive phytoconstituents from guavas can prevent cancer and its progression.[57]

Ryu *et al.*[47] performed an extraction of guava leaves with 80% methanol, further fractionating the extract with water, n-butanol, ethyl acetate, n-hexane, and chloroform. They assessed the anticancer potential of these fractions in human prostate cancer cells (PC-3) based on their inhibition of constitutive AKT/mammalian target of rapamycin (mTOR)/ribosomal p70 S6 kinase (S6K1) and mitogen-activated protein kinase activation pathways. The results showed that the n-hexane fraction (GHF) was the most effective in inducing apoptotic and cell death effects in PC-3 cells. Additionally, a correlation was established between the inhibition of the AKT/mTOR/S6K1 and mitogen-activated protein kinase signaling pathways and the apoptotic potential of GHF. The study concluded that GHF exhibited anticancer potential by interfering with multiple signaling cascades and suggested that isolating the bioactive phytocompound could be a promising therapeutic option for cancer treatment and prevention.[47]

Exposure of prostate cancer cells to guava leaf extracts and their fractions induced apoptosis and blocked the AKT/mTOR/S6K1 signaling pathway. The results imply that guava leaves can disrupt several signaling cascades connected to tumor development and offer a potential alternative source for medicinal plant products aimed at cancer prevention and management.[48]

Mangifera indica (M. indica)

M. indica, commonly known as Mango, is a member of the *Anacardiaceae* family of flowering plants. The genus Mangifera, which belongs to the group of Angiosperms, includes about 130 scientific plant names that correspond to species rank in the Plant List, with only eight recognized as species. The genus also has one scientific plant name of infraspecific rank. *M. indica* is widely grown across Southeast Asia, although it was originally believed to have originated in India. Different parts of the *M. indica* plant contain various phytoconstituents with immunomodulatory, anti-inflammatory, anti-cancer, antibacterial, and antioxidant properties.[49,58]

Research on the anti-tumor properties of polyphenolic phytochemicals from *M. indica* and its extracts from different parts of the plant has been evaluated in preclinical breast cancer models. The results revealed that the extract increased cell cycle arrest and apoptosis while decreasing cell viability, proliferation, growth, migration, and invasion. Several mechanisms have been suggested for its antitumor activity, including antioxidant activity, peroxisome proliferator-activated receptors modulation, suppression of the PI3K/AKT pathway, control of intracellular Ca^{2+} signaling, inhibition of the nuclear factor-kappa B (NF-κB) signaling pathway, activation of the AMP-activated protein kinase (AMPK) signal-

ing pathway, modulation of cell cycle regulators, modulation of endoplasmic reticulum activity, inhibition of the Ras-related C3 botulinum toxin substrate 1 (Rac 1)/WASP family Verprolin-homologous protein-2 (WAVE2) signaling pathway, inactivation of the β-catenin pathway, induction of miR-126 expression, inhibition of aromatase enzymatic activity and expression, inhibition of 3-Hydroxy-3-methylglutaryl-coenzyme A (HMG-CoA) reductase, and inhibition of proteasome and plasmin enzymatic activities.[50,51]

Lagerstroemia speciosa (L.) Pers

Lagerstroemia speciosa (L.), also known as Banaba Pers. (Lythraceae), is a plant frequently used in conventional medicine. Banaba leaf (Ethanolic Extract of Banaba Leaf) is utilized as herbal tea for treating diabetes and reducing weight. Research is being conducted on the cytotoxic potential of the ethanol extract of banaba leaf against the HepG2 cell line, a human model of hepatocellular carcinoma. Treatments with EEBL resulted in significant cytotoxicity in a concentration-dependent manner. The research revealed that EEBL caused chromatin condensation, an increase in the number of apoptotic cells, and cell cycle arrest at the sub-G0/G1 phase. Additionally, EEBL significantly upregulated the expressions of p21, p27, p53, and Forkhead box O1 (FOXO1), while downregulating the expressions of mouse double minute 2 (MDM2), phosphorylated-Akt (p-Akt), cyclin-dependent kinase 4 (CDK4), cyclin D1, and cyclin E1. These results suggest that EEBL may be effective in treating hepatocellular cancer.[52]

Moringa oleifera (M. oleifera)

M. oleifera L., commonly known as Moringa, is found throughout the Indian subcontinent. The genus Moringa is a member of the Angiosperm and belongs to the Moringaceae family. The genus includes 34 scientific plant names of species rank, with 13 accepted as species. For several decades, the antibacterial, anti-inflammatory, antioxidant, antiparasitic, and anticancer properties of crude leaf extract from *M. oleifera* have been recognized. The methanol extract of *M. oleifera* leaves (MEMO) contains a wide range of bioactive substances with potent anticancer activity against Dalton's lymphoma (DL) cells. Treatment with MEMO resulted in G2/M phase cell cycle arrest and a significant increase in the expression of p53 and p21 genes. Induction of apoptosis was indicated by increased levels of Bax, Cyt-c, and cas-3, along with decreased Bcl-2 protein expression. The inhibition of the mitogen-activated protein kinase/extracellular signal-regulated kinase (MEK/ERK)-mediated pathway in DL cells is believed to be responsible for MEMO's anticancer efficacy. Notably, in DL-bearing animals, MEMO suppressed DL development, associated with increased apoptosis and improved hematological parameters.[53]

Current development and future perspective of medicinal plants in cancer research

Extracts from herbs and medicinal plants have been used since ancient times by Chinese and Indian cultures to treat various illnesses. Due to their minimal toxicity and side effects, several phytoconstituents, as natural compounds, are derived and isolated from medicinal plants. These compounds have shown potential activity in cancer therapy and prevention, making them intriguing alternatives to current chemotherapy drugs. The identification, isolation, purification, and analysis of these bioactive phytoconstituents from extracts need to be performed in the near future.[59] Establishing the mechanisms of action between these active phytoconstituents and their biological effects will play a significant role in the prevention, treatment, and management of cancer.

Currently, phytoconstituents such as taxanes, vinca alkaloids, and podophyllotoxin are used to treat various types of cancer.[60,61] Phytoconstituents such as curcumin, berberine, sulforaphane, resveratrol, epigallocatechin, and gallate are considered to have anticancer activity; however, these phytoconstituents are still under clinical investigation. Medicinal plants used in cancer therapy hold great promise for targeted drug delivery and combination therapies in the near future. For the successful implementation of these natural products worldwide, it is important to overcome barriers and encourage collaboration between researchers, clinicians, herbalists, and communities for the benefit of cancer patients.[62]

Limitations

Worldwide, cancer remains a leading cause of death, but its impact can be mitigated through chemotherapy. This article highlights the importance of medicinal plants. Phytoconstituents are naturally occurring bioactive compounds present in medicinal plants and herbs that possess extensive medicinal properties. Recent awareness of the side effects caused by chemotherapeutic agents has led to numerous investigational studies on various medicinal plants for their therapeutic potential. The results have established that several plants exhibit anticancer, antiproliferative, anti-inflammatory, antiangiogenic, and immunomodulatory effects, leading to novel drug discovery for effective anticancer treatments with fewer side effects.[63] Additionally, herbal combination chemotherapy regimens have significantly reduced the adverse effects associated with modern drug-based chemotherapy. While medicinal plants and natural compounds have shown promising results in cancer research, there are some limitations. Despite combination therapies, some side effects may still persist.

Current research on cancer therapeutics is flourishing worldwide, promoting collaboration among various research professionals. In this context, therapies should focus on being target-specific, where the interaction between the drug and the target is minimized, thus reducing side effects and providing effective therapy.

Furthermore, the quantity and quality of natural bioactive compounds in plants vary due to different environmental factors. Increased environmental pollution—affecting water, soil, and air—can compromise the quality and safety of herbal drugs and products derived from medicinal plants. Additionally, several forensic investigations have indicated the presence of toxic heavy metals in medicinal products from various regions worldwide.[64] These factors must be considered significantly during the identification, isolation, and characterization of principal bioactive phytoconstituents from medicinal plants. Successful identification of new bioactive molecules from medicinal plants could pave the way for developing novel anticancer agents as lead molecules in drug discovery research, particularly in cancer therapy.

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Conflict of interest

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Author contributions

Conceptualization (AU, SLP), data curation, methodology (MV, SM, SKS), supervision (SLP), writing – review and editing (AU, SLP). All authors have approved the final version and publication of the manuscript.

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