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Review Article

Exploring Bioactive Compounds in Medicinal Plants for Cancer Therapeutics

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Abstract

One of the biggest causes of sickness and death in the globe is still cancer, prompting ongoing research into complementary and integrative therapeutic strategies. Medicinal plants have attracted a lot of interest due to their possible anticancer qualities, coupled with their ability to support nutritional health—an essential factor influencing patient outcomes. This review comprehensively examines the current literature on the role of medicinal plants in cancer treatment, with a particular focus on their contributions to enhancing nutritional status and overall health in cancer patients. We explore the bioactive compounds present in various plants, their mechanisms of action against cancer cells, and their impact on mitigating treatment-related side effects such as malnutrition, cachexia, and immune suppression. Additionally, the review discusses the synergistic effects of combining phytotherapy with nutritional interventions to improve therapeutic efficacy and quality of life. By integrating insights from phytochemistry, nutrition science, and oncology, this article underscores the potential of medicinal plants as valuable adjuncts in cancer care, advocating for further clinical research to standardize their use and optimize patient-centered outcomes.

Keywords: Medicinal Plants; Cancer Treatment; Nutritional Health; Phytotherapy

Introduction

Cancer remains one of the most significant public health challenges globally, typified by unchecked cell division and the capacity to infiltrate or disseminate to different bodily regions. Conventional cancer therapies, such as chemotherapy, radiation, and surgery, have shown considerable success in managing various cancer types. However, these treatments often come with limitations, including significant adverse effects, medication resistance, exorbitant expenses, and a decline in patients' quality of life. As a result, there has been increasing awareness of integrative and complementary methods that are both effective and supportive of overall health [1].

Medicinal plants been in use for years across cultures for the management of a number of illnesses, including cancer. They are rich sources of phytochemicals bioactive substances like phenolics, terpenoids, alkaloids, flavonoids, and saponins which exhibit a range of pharmacological activities, including antioxidant, anti-

inflammatory, immunomodulatory, and antitumor properties. Importantly, many of these phytochemicals also contribute to nutritional health, offering essential micronutrients and promoting metabolic balance, especially in cancer patients who often suffer from malnutrition or treatment-induced cachexia [2].

Recent research highlights the dual role of these nutritional phytochemicals: not only do they possess direct anticancer properties by modulating cell signaling pathways, inducing apoptosis, and inhibiting angiogenesis, but they also help support the body's nutritional needs and immune function. This integrative perspective provides a promising framework for developing novel, plant-based therapeutic strategies that enhance both the efficacy of conventional treatments and the nutritional well-being of patients [3,4].

This review aims to explore the current understanding of nutritional phytochemicals in medicinal plants, focusing on their role in cancer treatment. It examines the mechanisms of action, therapeutic potential, and nutritional relevance of selected phytochemicals, and discusses the prospects and challenges in integrating plant-based nutrition into oncology care.

Some medicinal plants having anticancer potential

Aloe vera

Aloe vera has shown significant anticancer potential due to its bioactive compounds such as aloe-emodin, aloin, and acemannan, which exhibit properties like inducing apoptosis, inhibiting proliferation, suppressing angiogenesis, and modulating the immune system. Aloe-emodin in particular has been reported to inhibit the growth of breast, lung, liver, and colon cancer cells by interfering with cell cycle progression and triggering programmed cell death. Acemannan enhances immune responses by stimulating macrophages and cytokine production, thereby supporting the body's defense against tumor growth. Studies also suggest that *Aloe vera* can act synergistically with chemotherapy drugs, improving their efficacy while reducing toxicity. Thus, its natural origin, multi-targeted action, and supportive immune effects make *Aloe vera* a promising complementary agent in cancer prevention and therapy [5].

Andrographis paniculata (Kalmegh)

Andrographis paniculata (Kalmegh) possesses strong anticancer potential mainly due to its active compound **andrographolide**, a diterpenoid lactone known for its anti-proliferative, pro-apoptotic, and immunomodulatory effects. Andrographolide has been shown to suppress tumor growth by inducing apoptosis, inhibiting angiogenesis, and blocking pathways like NF-κB, STAT3, and PI3K/Akt involved in cancer progression. Experimental studies report its effectiveness against breast, colon, prostate, and lung cancer cells, where it reduces cell viability and prevents metastasis. Its relatively low toxicity and synergistic effects with conventional chemotherapy highlight its promise as a complementary anticancer agent [6,7].

Annona muricata (Graviola/Soursop)

Annona muricata (Graviola or Soursop) is widely recognized for its anticancer potential, primarily due to its bioactive compounds called **acetogenins**, along with alkaloids and flavonoids. These compounds exhibit strong cytotoxic activity by inhibiting mitochondrial complex I, leading to depletion of cellular ATP and selective death of cancer cells while sparing normal cells. Studies have shown its effectiveness against breast, prostate, pancreatic, and liver cancer cells by inducing apoptosis, suppressing tumor growth, and blocking metastasis. Graviola extracts also modulate signaling pathways like EGFR and NF-κB, which are crucial in cancer progression, and enhance antioxidant defense to reduce oxidative stress. Experimental evidence suggests synergistic effects with chemotherapy drugs, making it a promising complementary therapy. But more clinical research is required to verify its safety and effectiveness in people [8,9].

Camellia sinensis (Green Tea)

Camellia sinensis (Green Tea) exhibits significant anticancer potential due to its rich content of **polyphenols**, particularly epigallocatechin-3-gallate (EGCG), the most active catechin. EGCG and other catechins act as powerful antioxidants that scavenge free radicals, reduce oxidative stress, and prevent DNA damage, thereby lowering cancer risk. Mechanistically, green tea polyphenols cause apoptosis, block angiogenesis, and reduce cancer cell proliferation by targeting pathways such as PI3K/Akt, MAPK, and NF-κB. Stud-

ies have reported protective and therapeutic effects against breast, prostate, colorectal, lung, and skin cancers, with evidence showing inhibition of tumor invasion and metastasis. Additionally, green tea enhances the body's detoxifying enzymes and modulates immune responses, contributing to its chemopreventive role. Its low toxicity and wide availability make it a promising natural adjunct in cancer prevention and therapy [10,11].

Catharanthus roseus (Madagascar Periwinkle)

Catharanthus roseus (Madagascar Periwinkle) is a well-known medicinal plant with strong anticancer potential, mainly due to its alkaloids vincristine and vinblastine, which are widely used as chemotherapeutic drugs. These alkaloids act by binding to tubulin, inhibiting microtubule formation, and arresting the cell cycle at metaphase, thereby preventing cancer cell division and promoting apoptosis. Clinical use of vincristine and vinblastine has shown significant efficacy in treating leukemias, lymphomas, breast cancer, Hodgkin's disease, and other malignancies [12,13].

Curcuma longa (Turmeric)

Curcuma longa (Turmeric) exhibits remarkable anticancer potential, primarily attributed to its active polyphenolic compound **curcumin**, which shows antioxidant, anti-inflammatory, and antiproliferative properties. Curcumin has anticancer properties by modifying many molecular targets and signaling pathways, including NF-κB, STAT3, PI3K/Akt, and Wnt/β-catenin, leading to inhibition of tumor initiation, promotion, and progression. It induces apoptosis, suppresses angiogenesis, and inhibits metastasis in various cancers such as breast, colon, lung, pancreatic, and prostate cancer. Furthermore, Curcumin increases the effectiveness of traditional chemotherapy medications. while reducing their side effects, highlighting its role as a synergistic agent in cancer therapy. Despite poor bioavailability, novel formulations like nanoparticles and liposomal curcumin have shown improved therapeutic potential. Overall, turmeric is regarded as one of the most promising natural chemopreventive agents [14,15].

Glycyrrhiza glabra (Licorice/Mulethi)

Glycyrrhiza glabra (Licorice or Mulethi) exhibits notable anticancer potential, primarily due to its bioactive compounds **glycyrrhizin, glabridin, and liquiritigenin**, which demonstrate antioxidant, anti-inflammatory, and cytotoxic activities. These substances alter important signaling pathways like NF-κB, PI3K/Akt, and MAPK, prevent the growth of cancer cells, and cause apoptosis, thereby suppressing tumor growth and metastasis. Studies have shown that licorice extracts are effective against breast, prostate, colon, and liver cancer cells, reducing oxidative stress and preventing DNA damage. Additionally, licorice compounds can enhance the efficacy of conventional chemotherapy while mitigating associated toxicity, making it a promising natural adjunct in cancer therapy. Its low toxicity, widespread availability, and multi-targeted action underscore its potential as a chemopreventive and therapeutic agent [16,17].

Nigella sativa (Black Seed/Kalonji)

Nigella sativa (Black Seed or Kalonji) demonstrates significant anticancer potential, primarily because of its bioactive component **thymoquinone**, along with nigellidine, α-hederin, and other phytochemicals. Thymoquinone exerts anticancer effects through triggering apoptosis, preventing cell division, reducing angiogenesis, and adjusting important signaling pathways like p53, PI3K/Akt, and NF-κB. Studies have shown its effectiveness against breast, colon, pancreatic, prostate, and liver cancer cells by promoting cell cycle arrest and reducing tumor growth. Furthermore, N. sativa has anti-inflammatory and antioxidant activities that shield healthy cells from oxidative stress and reduce the damage linked to chemotherapy. Its natural origin, low toxicity, and multi-targeted action make it a promising chemopreventive and adjunctive agent in cancer therapy [18,19].

Ocimum sanctum (Tulsi/Holy Basil)

Ocimum sanctum (Tulsi or Holy Basil) exhibits notable anticancer potential due to contains bioactive substances, including ursolic acid, rosmarinic acid, apigenin, and eugenol. By triggering apoptosis, preventing tumor cell division, reducing angiogenesis, and altering signaling pathways like NF-κB, PI3K/Akt, and MAPK, these phytochemicals have anticancer effects. Experimental studies have demonstrated its efficacy against breast, colon, lung, and pancreatic cancer cells by promoting cell cycle arrest and reducing metastasis. Additionally, Tulsi has strong antioxidant and immunomodulatory properties, enhancing the body's natural defense mechanisms while protecting normal cells from oxidative stress. Its low toxicity,

widespread availability, and multi-targeted action make *Ocimum sanctum* a promising natural chemopreventive and complementary agent in cancer therapy [20,21].

Panax ginseng

The key ingredients in Panax ginseng, known as ginsenosides, have anti-inflammatory, antioxidant, and immunomodulatory properties, which contribute to its strong anticancer potential. By triggering apoptosis, preventing tumor cell division, reducing angiogenesis, and altering important signaling pathways like NF-κB, PI3K/Akt, and MAPK, ginsenosides have anticancer effects. Research has demonstrated efficacy in preventing the growth, metastasis, and medication resistance of breast, lung, colon, liver, and prostate cancer. Additionally, *Panax ginseng* enhances immune responses by stimulating natural killer cells and cytotoxic T-cells, contributing to tumor suppression. Its low toxicity, synergistic effects with conventional chemotherapy, and multi-targeted action make it a promising natural adjunct in cancer prevention and therapy [22,23].

Phyllanthus amarus

Because of its abundance of lignans (including phyllanthin and hypophyllanthin), flavonoids, alkaloids, and polyphenols, Phyllanthus amarus has encouraging anticancer potential. By triggering apoptosis, preventing cell division, reducing angiogenesis, and altering signaling pathways such as NF-κB, PI3K/Akt, and MAPK, these bioactive substances have anticancer effects. Studies have demonstrated its efficacy against breast, liver, colon, and prostate cancer cells by promoting cell cycle arrest and reducing tumor growth and metastasis. Furthermore, P. amarus has potent anti-inflammatory and antioxidant qualities that strengthen the immune system and shield healthy cells from oxidative stress. Its multi-targeted action and low toxicity make it a promising natural chemopreventive and adjunctive agent in cancer therapy [24,25].

Podophyllum peltatum (Mayapple)

Podophyllum peltatum (Mayapple) exhibits significant anticancer potential due to its bioactive compounds **podophyllotoxin and its derivatives**, which are potent cytotoxic agents. Because podophyllotoxin prevents microtubule formation, cancer cells undergo apoptosis and cell cycle arrest during the metaphase stage. Semi-synthetic derivatives like **etoposide and teniposide** are widely used clinically in chemotherapy for treating lung, testicular, ovarian, and hematologic cancers. These compounds also interfere with topoisomerase II activity, preventing DNA replication and promoting cell death in rapidly dividing tumor cells. Additionally, *Extracts from P. peltatum exhibit anti-inflammatory and antioxidant qualities, which help to slow the growth of tumors overall.* Its multi-targeted mechanism and ability to serve as a source for clinically approved anticancer drugs underscore its importance in cancer therapy [26,27].

Taxus brevifolia (Pacific Yew – source of Paclitaxel)

Taxus brevifolia (Pacific Yew) is a well-known source of the anticancer compound **paclitaxel (Taxol)**, a diterpenoid that exhibits potent cytotoxic activity against various cancers. By stabilizing microtubules and preventing their depolymerization, paclitaxel stops the cell cycle at the G2/M phase and causes rapidly dividing tumor cells to undergo apoptosis. Clinically, it has been used extensively to treat Kaposi's sarcoma as well as lung, prostate, ovarian, and breast malignancies. Beyond its microtubule-stabilizing activity, paclitaxel also inhibits angiogenesis and modulates signaling pathways such as Bcl-2, NF-κB, and p53, enhancing its anticancer effects. Despite low natural abundance in the yew tree, semi-synthetic and biotechnological production methods have enabled large-scale availability. Its discovery and success underscore the importance of plant-derived compounds in modern chemotherapy [28,29].

Tinospora cordifolia (Guduchi/Giloy)

Tinospora cordifolia (Guduchi or Giloy) exhibits notable anticancer potential due to its bioactive compounds, including **tinosporaside, berberine, and alkaloids**, which possess antioxidant, immunomodulatory, and cytotoxic properties. By triggering apoptosis, preventing the growth of tumor cells, and altering important signaling pathways like NF-κB, PI3K/Akt, and MAPK, these substances have anticancer effects. Experimental studies have shown its efficacy against breast, colon, liver, and lung cancer cells, promoting cell cycle arrest and reducing tumor growth and metastasis. Additionally, *T. cordifolia* enhances immune responses by activating macrophages, natural killer cells, and T-lymphocytes, while its antioxidant properties protect normal cells from oxidative stress.

Its low toxicity, multi-targeted action, and potential synergistic effects with conventional chemotherapy make it a promising natural chemopreventive and adjunctive agent in cancer therapy [30,31].

Withania somnifera (Ashwagandha)

Withania somnifera (Ashwagandha) exhibits notable anticancer potential due to its bioactive compounds, primarily **withaferin A, withanolides, and sitoindosides**. These compounds exert anticancer effects by inducing apoptosis, inhibiting tumor cell proliferation, suppressing angiogenesis, and modulating multiple signaling pathways such as NF-κB, PI3K/Akt, MAPK, and p53. Studies have demonstrated its efficacy against breast, colon, lung, prostate, and pancreatic cancer cells by promoting cell cycle arrest and reducing metastasis. Additionally, Ashwagandha enhances immune responses, reduces oxidative stress, and protects normal cells during chemotherapy. Its multi-targeted mechanism, low toxicity, and potential synergistic effects with conventional anticancer drugs make *Withania somnifera* a promising natural chemopreventive and adjunctive agent in cancer therapy [32,33].

Millettia pinnata

This plant, referred to as karanja, has demonstrated encouraging anticancer properties, largely attributed to its key bioactive component, karanjin, a furanoflavonoid. Recent research has indicated that karanjin has notable cytotoxic effects against A549 non-small cell lung cancer cells, with an IC_{50} of about 4.85 μM, triggering apoptosis via the extrinsic pathway that involves Fas, FADD, and caspases 8, 3, and 9. Furthermore, it downregulates the expression of KRAS and lowers the levels of intracellular reactive oxygen species (ROS), illustrating its multifaceted anticancer action. Previous studies have also revealed karanjin's capacity to induce cell cycle arrest in various cancer cell lines, including HepG2 and HL-60. Supporting studies that utilize both seed and leaf extracts of *M. pinnata* reinforce its anticancer and antioxidant properties, indicating that both the isolated compounds and whole extracts could possess therapeutic potential [34-36].

Shorea roxburghii

This plant, which has been traditionally utilized in Southeast Asian medicine, has recently shown significant anticancer capabilities. Different extracts from its flowers on gastrointestinal cancer cell lines—namely KKU-213B (cholangiocarcinoma), HepG2 (liver cancer), and AGS (gastric cancer). The ethyl acetate extract demonstrated the highest cytotoxic effect, presenting IC_{50} values of 66.47 μg/mL (KKU-213B), 18.87 μg/mL (HepG2), and 16.05 μg/mL (AGS), while exhibiting low toxicity to normal fibroblast cells. Metabolomic analysis of the extract revealed various phenolic compounds, such as resveratrol, catechin, ferulic acid, and gallic acid, recognized for their antioxidant and antiproliferative effects. Mechanistic investigations revealed that the extract enhances apoptosis and decreases Bcl-2 expression, an essential anti-apoptotic protein. These results indicate that *Shorea roxburghii* may act as a potential natural resource for the treatments of gastrointestinal cancer [37].

Suaeda maritima

Suaeda maritima, a salt-tolerant plant located in saline and mangrove-related environments, has demonstrated encouraging anticancer properties in recent in vitro research. In a particular study, the acetone extract (SMAE) halted the growth of A549 lung cancer cells with an IC_{50} of approximately 78.19 μg/mL, demonstrating significantly reduced toxicity to non-cancerous HUVEC cells (IC_{50} around 300 μg/mL) [38].

Dolichos kilimandscharicus

This plant, which belongs to the Fabaceae family, has exhibited encouraging anticancer properties in in vitro research. For instance, leaf extracts (ethanol, ethyl acetate, methanol, etc.) from *D. kilimandscharicus* suppressed the growth of Jurkat T leukemia cells with IC_{50} values between ~21.6 and ~33.6 μg/mL, while exhibiting significantly less cytotoxicity toward normal RAW 264.7 cells (IC_{50} ~422-428 μg/mL), which suggests selectivity [39].

Medinilla beddomei

The leaf extracts of *Medinilla beddomei* have demonstrated considerable anticancer effects in breast cancer cell lines. The acetone leaf extract (utilizing ultrasound-assisted extraction) diminished the viability of MCF 7 and MDA MB 231 breast cancer cells, showing IC_{50} values of approximately 46.19 μg/mL and 68.27 μg/mL, respectively, while demonstrating considerably lower toxicity toward a normal cell line (L929) (IC_{50} ≈ 386.12 μg/mL) [40].

Vitex negundo

Commonly referred to as Nirgundi. The ethanol water (1:1) extract demonstrated notable cytotoxicity (IC_{50} = 44.31 ± 0.61 µg/mL). From this extract, four substances were obtained: 4 OH benzoic acid, negundoside, isoorientin, and agnuside. Isoorientin demonstrated the most potent anticancer activity with an IC_{50} of 18.50 ± 0.76 µM against A549 cells, while exhibiting minimal toxicity to normal human dermal fibroblasts [41].

Colchicum

Colchicum has been investigated for its potential against cancer, primarily because of its main alkaloid colchicine, which attaches to tubulin, interferes with microtubule polymerization, leads to cell-cycle arrest (especially at the G2/M phase), and promotes apoptosis in different cancer cell lines [42].

Excoecaria agallocha

The leaf extract of *Excoecaria agallocha*, a mangrove species, demonstrates strong anticancer activity against the human cervical cancer cell line SiHa through various mechanisms. The bioactive fraction (predominantly containing bergenin) induced G2/M phase cell cycle arrest, reduced levels of Cyclin B1, Cyclin D1, and Cdc2, while elevating p21 and p53. It concurrently triggered autophagy (formation of LC3 puncta), mitophagy, and apoptosis (through SMAC-induced cytochrome-c release and activation of caspase-3), causing minimal harm to normal peripheral blood mononuclear cells [43].

Couroupita guianensis

Couroupita guianensis (often referred to as cannonball tree) has demonstrated notable anticancer properties, especially concerning gastric adenocarcinoma. A recent study from 2022–2023 showed that the bark decoction and its bioactive component notably suppressed the growth of AGS gastric cancer cells by triggering cell cycle arrest, apoptosis, and autophagy. Mechanistically, the treatment increased levels of p53, p21, and pro-apoptotic protein Bak, triggered the activation of caspases (caspase-3 and -9), and altered signaling pathways related to p-AMPK and pAkt. Moreover, autophagic flux was validated by elevated levels of Beclin-1, LC3BII, and reduced p62 levels, indicating that C. guianensis induces both apoptotic and autophagic cell death. These results suggest its promise as a source of new anticancer compounds, although additional in vivo and clinical research is required to validate effectiveness and safety [44].

Pulicaria crispa

Pulicaria crispa (Asteraceae), commonly utilized in traditional medicine, is recognized for its cancer-fighting abilities. A study conducted in 2022 indicated that the hexane fraction of P. crispa demonstrated significant cytotoxic effects on human colorectal cancer cells (HCT116). The extract caused G_2/M phase cell cycle arrest, increased expression of tumor suppressor genes (p53, caspase-8, caspase-9), and decreased the anti-apoptotic gene Bcl-2, resulting in heightened activation of caspase-3 and caspase-7. It also induced oxidative stress by reducing antioxidant defenses (↓ GSH, ↓ SOD) and interfered with cancer cell energy metabolism by inhibiting glycolytic enzymes (pyruvate kinase, lactate dehydrogenase, aldolase). These synergistic effects indicate that P. crispa influences both survival signaling and metabolic routes, positioning it as a valuable natural option for colorectal cancer treatment [45].

Conclusion

Nutritious phytochemicals found in medicinal plants, such as polyphenols, flavonoids, alkaloids, terpenoids, and saponins, have strong anticancer effects through a variety of multi-targeted mechanisms, such as cell cycle arrest, apoptosis induction, and anti-angiogenesis. and immune modulation. Integration of these phytochemicals into cancer prevention and therapy offers a promising, low-toxicity complementary approach alongside conventional treatments. Continued research on their bioavailability, synergistic effects, and molecular mechanisms is crucial for translating these natural compounds into effective clinical interventions. Harnessing the therapeutic potential of medicinal plants may not only improve patient outcomes but also advance the development of safer, more holistic oncology care.

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