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Investigating The Role of Pharmacognosy in The Development of Novel Anticancer Agents

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ABSTRACT

Today Pharmacognosy functions as an essential scientific basis for discovering anticancer medications through research of natural medicating plants alongside additional natural resources. The article evaluates the vital role which pharmacognosy plays when developing compounds that act as cancer treatments. The article describes extraction techniques alongside screening and characterization protocols that help researchers find anticancer compounds among bioactive plant principles. The discovery of pharmacological agents' taxol and camptothecin and vinca alkaloids stands as one of the primary outcomes alongside their subsequent development into medicinal drugs. The scope includes modern screening procedures linked with molecular docking approaches along with biotechnological growth that enhances both efficiency and pharmaceutical research outcomes in pharmacognosy. The review addresses difficulties alongside existing trends and future guidance about employing natural products for developing oncological drugs.

Key Words:

Anticancer agents, natural products, bioactive compounds, medicinal plants

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1. INTRODUCTION

The global death rates from cancer continue to pose an urgent need to develop efficient therapies that safeguard patient safety [1]. Natural products offer promise as an alternative to traditional chemotherapeutic drugs because they possess diverse structures that work well with biological agents.

Pharmacognosy started as medicinal knowledge from ancient systems and now stands as a scientific field which identifies therapeutic compounds found in natural sources especially from plant material [2]. The importance of pharmacognosy emerges through the origin of present-day anticancer agents which stem from natural products.

1.1.Background Information and Context

The global health community identifies cancer as a significant public danger since this disease produces millions of new cancer cases and deaths yearly [3]. An increasing cancer incidence has launched a growing necessity to create novel treatment options that provide greater access with less adverse effects. Standard cancer treatments based on chemotherapy and radiotherapy have achieved improved survival outcomes yet they produce important negative effects [4]. These combined side effects from serious issues with systemic toxicity and drug resistance contribute to deteriorated patient life quality while limiting treatment effectiveness [5].

Natural products present a positive alternative for cancer treatments due to their diverse chemical structures and their ability to identify exact cancer development pathways [6]. Traditional medicine-based pharmacognosy as a scientific field maintains its focus on natural source plant research to identify bioactive compounds. Modern anticancer drugs starting from paclitaxel and vinblastine and calprotectin take their origin from natural products [7]. The utilization of pharmacognosy persists as a fundamental practice for creating modern anticancer medicines while addressing traditional medical deficiencies.

1.2.Objectives of the Review

- To discuss the role of pharmacognosy in anticancer drug discovery.
- To introduce major phytochemicals with established anticancer activity.
- To assess the methods employed in pharmacognostic research.
- To discuss the current limitations and future prospects in the field.

1.3.Importance of the Topic

The scientific value behind this subject is its ability to join medical knowledge from eras past with modern pharmacological research for finding new anticancer solutions. Natural products serve as sustainable drug sources which offer better toxicity levels than synthetic compounds thus providing potential solutions against traditional therapy side effects and drug resistance [8]. Pharmacognosy offers the potential to explore untouched biological wealth across Earth's untapped regions particularly where traditional herbal knowledge exists for discovering fresh compounds with advanced therapeutic abilities.

Pharmacognosy enables anticancer treatment development through the linkage of traditional knowledge with modern scientific equipment that includes bioinformatics and molecular docking and high-throughput screening [9]. Pharmacognosy benefits drug discovery operations while achieving sustainable medical practices and biodiversity conservation thus addressing human health threats of the current era.

2. PHARMACOGNOSY IN CANCER DRUG DISCOVERY: HISTORY, METHODS, AND KEY COMPOUNDS

2.1. Historical Context and Significance

Traditional medicine adopted natural products as part of its therapeutic practices for numerous centuries [10]. Through pharmacognosy science the traditional medicine methods received validation which led to new discoveries in drug development. Examples include:

- **Taxol (Paclitaxel)** – extracted from the bark of *Taxus brevifolia*, used in treating ovarian and breast cancer.

- **Vincristine and Vinblastine** – alkaloids from *Catharanthus roseus*, effective against leukemias and lymphomas.
- **Camptothecin** – derived from *Camptotheca acuminata*, led to the development of topotecan and irinotecan.

2.2. Methodologies in Pharmacognostic Research

Extraction and Isolation

The main components of pharmacogenetic research involve extracting bioactive compounds from natural substances including marine organisms and plants along with microbes. The common extraction method relies on solvent solutions including methanol ethanol and water to obtain specific phytochemicals [11]. Ethanol combined with methanol enables the recovery of alkaloids along with flavonoids and phenolic compounds but water serves well to obtain tannins and glycosides. Soxhlet extraction operates by continuous solvent reflux to extract compounds effectively and it normally operates automatically for consistent results [12]. Under thermolabile conditions the maceration technique needs plant material to be soaked in solvent solution at room temperature or slightly elevated temperatures [13]. SFE utilizes supercritical CO_2 under high pressure and temperature to perform environmentally sustainable extractions that are most suitable for the extraction of essential oils and terpenoids and other non-polar compounds [14]. The resulting material from extraction is separated into single bioactive compounds by using column chromatography after purification and fractionation processes.

Screening Techniques

The evaluation of anticancer properties occurs through specific testing methods after extraction procedures. The MTT assay functions as a standard colorimetric evaluation technique for confirming both cell survival rates and the susceptibility of cells to toxic substances [15]. Living cells in this test transform MTT into formazan which subsequently becomes measurable spectrophotometrically as a purple metabolite but decreased formazan values correlate with higher cytotoxicity effects [16]. Two methods to calculate viable cell percentages after test agent treatments are trypan blue exclusion and Alamar Blue assays and confirm the outcome of MTT results. Apoptosis assays remain critical because the primary mechanism cancer cells use for treatment includes apoptosis induction. Flow cytometry tools known as Annexin V binding assays plus propidium iodide staining tests determine the existence of apoptosis markers simultaneously with caspase activity measurements used to detect enzyme activation that drives apoptosis [17]. These tests help in identifying potential anticancer compounds.

Phytochemical Analysis

The identification process of bioactive compounds in pharmacogenetic studies requires phytochemical analysis because it provides important information about these molecules [18]. The analysis of compounds requires chromatographic procedures as an essential separation method. The separation process for compounds using both a mobile solvent and an immobilized phase of silica gel occurs rapidly during Thin Layer Chromatography (TLC) [19]. The HPLC system shows superior accuracy through its powerful detection system that allows compound identification and measurement.

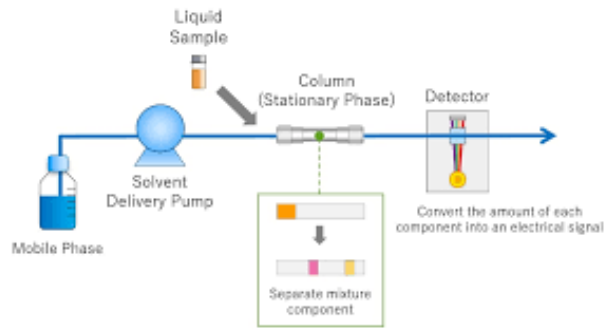

Figure 1: HPLC system

When operating on volatile and thermally stable compounds Gas Chromatography-Mass Spectrometry (GC-MS) produces detailed structural information [20]. Spectroscopic techniques supplement chromatographic methods. The evaluation of both Nuclear Magnetic Resonance (NMR) and Infrared Spectroscopy (IR) demonstrates that NMR determines molecular structures through atomic nucleus magnetic properties and IR identifies functional groups by their vibrational pattern frequencies [21].

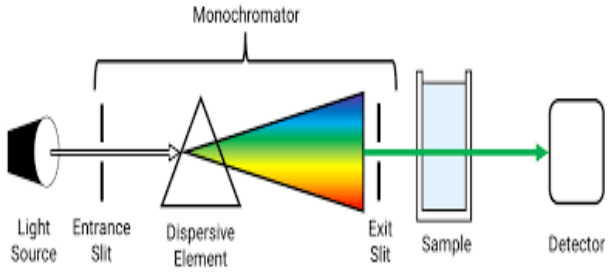

Figure 2: UV-Visible Spectroscopy (UV-VIS)

The identification of chromophores along with conjugated systems in bioactive molecules is made possible through UV-Visible Spectroscopy (UV-VIS). The correct identification of anticancer activity-inducing compounds emerges from using these technical approaches combined.

Mechanistic Studies

Understanding the mechanism through which bioactive compounds fight cancer requires scientific investigation of their effect [22]. A computer program known as molecular docking predicts how bioactive compounds interact with cancer process-related target proteins including enzymes receptors and DNA molecules [23]. The interaction between compounds and molecular targets as well as compound efficiency optimization occurs through molecular docking methods. Applications of quantitative PCR (qPCR) and RNA sequencing (RNA-seq) evaluate compound-controlled expression patterns of cancer-associated genes which include genes involved in apoptosis and cell division directions and metastasis events. Bioinformatics tool STRING helps discover cellular signaling pathway modifications that compounds affect across MAPK PI3K/Akt and p53 pathways [24]. Scientists can create new anticancer agents while understanding the precise therapeutic potential after they specify compound mechanisms of action.

Table 1: Promising Natural Compounds with Anticancer Activity

Compound	Source	Mechanism of Action	Cancer Type
Curcumin	*Curcuma longa*	Apoptosis induction, NF-κB inhibition	Multiple
Resveratrol	*Vitis vinifera*	Antioxidant, anti-inflammatory, p53 pathway	Colon, breast
Berberine	*Berberis aristata*	Mitochondrial dysfunction, cell cycle arrest	Lung, prostate

Epigallocatechin gallate (EGCG)	*Camellia sinensis*	Inhibition of angiogenesis, metastasis	Breast, liver

Multiple phytochemicals derived from plants display anticancer properties that target different mechanisms of cancer cell development according to this table. Curcuma longa (turmeric) produces curcumin which acts against cancer at various levels through two mechanisms which trigger programmed cell death and cut off NF-κB signaling that drives both cancer initiation and cancer progression [25]. The medicinal compound Resveratrol derived from grapes gives promise as a therapy for breast cancer and colon cancer treatment by means of its antioxidant properties and anti-inflammatory responses and p53 tumor suppressor pathway management [26]. The cancer-fighting properties of Berberine from Berberis aristata extract work primarily by causing cellular division arrest while disrupting mitochondrial function which helps stop tumor cell multiplication specifically in lung and prostate cancers. The predominant compound in green tea (Camellia sinensis) named epigallocatechin gallate (EGCG) demonstrates anticancer effects by blocking metastasis and angiogenesis which provides maximum benefit to breast and liver cancers [27]. These natural compounds show through their combined impact the drug potential of phytochemicals by using multiple biochemical methods thus paving the way for future studies of natural cancer treatments.

Table 2: Mechanisms of Action of Selected Phytochemicals in Cancer Therapy

Phytochemical	Plant Source	Primary Mechanism(s)	Targeted Cancer Pathway
Quercetin	*Allium cepa*, *Ocimum spp.*	Induces apoptosis, cell cycle arrest, ROS generation	PI3K/Akt/mTOR pathway
Betulinic acid	*Betula alba* (white birch)	Mitochondrial-mediated apoptosis, anti-angiogenesis	Intrinsic apoptotic pathway
Withaferin A	*Withania somnifera*	Modulation of cytoskeletal proteins, apoptosis	NF-κB, STAT3 pathways
Thymoquinone	*Nigella sativa*	Anti-inflammatory, DNA damage induction, ROS elevation	p53-dependent apoptosis pathway
Genistein	*Glycine max* (soybean)	Tyrosine kinase inhibition, angiogenesis suppression	Estrogen receptor signaling, VEGF
Emodin	*Rheum palmatum*	Cell cycle inhibition, inhibition of metastasis	Wnt/β-catenin, TGF-β pathways

Several plants containing major phytochemicals display therapeutic properties which the table demonstrates through their cancer-targeted pathways and mechanisms of action [28]. Allium cepa (onion) Quercetin along with Ocimum species (basil) Quercetin elicits cell death by apoptosis and stops cell cycles while generating ROS molecules to effectively disrupt the PI3K/Akt/mTOR survival pathway for cancer cells [29]. The apoptosis pathway independent of mitochondria triggers tumor suppression in Betula alba (white birch) derived betulinic acid while the drug also inhibits angiogenesis development. The compound Withaferin A extracted from Withania somnifera (ashwagandha) uses NF-κB and STAT3 signaling pathways to affect cytoskeletal proteins and induce apoptosis during inflammation and cancer cell growth. The anti-inflammatory thymoquinone in Nigella sativa black cumin causes DNA damage along with ROS production and activates the essential tumor suppressor mechanism known as p53-dependent apoptosis pathway. The soybean-derived genistein substance blocks tyrosine kinase pathways while preventing new blood vessel growth through its ability to influence VEGF pathways while altering estrogen receptor function. Emodin extracted from Rheum palmatum (rhubarb) functions to block the Wnt/β-catenin and TGF-β signaling pathways thus inhibiting cell cycle progression and metastasis during cancer cell invasion and migration. Studies have shown that these phytochemicals demonstrate different pathways of cancer prevention activity hence serving as a promising basis for developing targeted therapeutic strategies.

3. THEMATIC ADVANCES AND INTEGRATION WITH MODERN TECHNIQUES

3.1.Biotechnological Approaches

The expansion of pharmacognosy's focus is because biotechnology makes sustainable production of bioactive compounds achievable. The development of suspension cultures and hairy root cultures from plant cells provides new possibilities for secondary metabolite production through alternative methods to wild plant harvesting [30]. The technique of genetic engineering provides new abilities through pathway modification in plants or microbes which increases the yield of specific compounds. The production of anticancer drugs like taxol has been achieved through metabolic engineering that involves E. coli and Saccharomyces cerevisiae microorganisms. These modern pharmacognostic investigative techniques both solve supply problems and decrease environmental impact thus playing a critical role in current research.

3.2.Nano formulation

The process of nano formulation produces nanoparticles for enhancing the stability and bioavailability and targeted release of phytochemicals. Plant-derived agents such as curcumin along with quercetin face problems related to low solubility which leads to fast metabolism decreasing their therapeutic effectiveness [31]. The anti-metabolic protection of these agents happens through encapsulation with nanoparticles and liposomes and polymeric micelles which also enable precise delivery at their targeted sites. Curcumin nanoparticles show improved anticancer outcomes in preclinical trials because they extend the active drug time in body cells while improving its access to target areas. Through the use of nanoparticles

physicians can enable precise cancer cell targeting thus reducing unwanted side effects to obtain increased therapeutic value.

3.3.Synergistic Studies

The drug resistance problem can be solved through treatment enhancements achieved by mixing plant extracts with standard chemotherapy medications. Phytochemicals work in combination with synthetic medications to achieve enhanced anticancer results through effectuations that lower negative effects and traditional drug doses. Researchers have studied how resveratrol works with cisplatin to make it more successful against cancer cell lines that have developed resistance. This study examines how plant-based chemicals affect the biological processes of apoptotic pathways while examining their influence on cell cycle control and drug transport mechanisms in order to boost current cancer treatment standards. The natural substance variability helps scientists create enhanced cancer treatment strategies.

Table 3: Research Study

References	Title	Topic Covered	Research Study
Wu, K., Peng, X., Chen, M., Li, Y., Tang, G., Peng, J., ... & Cao, X. (2022) [32]	Recent progress of research on anti-tumor agents using benzimidazole as the structure unit	Benzimidazole-based anti-tumor agents	discussed the creation and use of benzimidazole derivatives in the treatment of cancer, emphasising how they work.
Kamran, S., Sinniah, A., Abdulghani, M. A., & Alshawsh, M. A. (2022) [33]	Therapeutic potential of certain terpenoids as anticancer agents: a scoping review	Terpenoids as anticancer agents	examined terpenoids' anticancer qualities, highlighting their capacity to target cancer pathways.
Zhang, J., Zhou, W., Chen, Y., Wang, Y., Guo, Z., Hu, W., ... & Si, S. (2023) [34]	Small molecules targeting Pin1 as potent anticancer drugs	Pin1-targeting small molecules	discussed how Pin1 contributes to the development of cancer and assessed small compounds as potential therapeutic treatments that target this protein.
Mahema, S., Roshni, J., Raman, J., Ahmad, S. F., Al-Mazroua, H. A., & Ahmed, S. S. (2024) [35]	Molecular Regulator Driving Endometriosis Towards Endometrial Cancer: A Multi-Scale Computational Investigation to	Endometriosis and endometrial cancer drug repurposing	examined the molecular processes that lead endometriosis to cancer and found anti-cancer medications that may be repurposed.

	Repurpose Anti-Cancer drugs		
Khazir, J., Mir, B. A., Pilcher, L., & Riley, D. L. (2014) [36]	Role of plants in anticancer drug discovery	Plants in anticancer drug development	emphasised the potential of phytochemicals and the role that plants play in the research and development of anticancer medications.
Chahar, M. K., Sharma, N., Dobhal, M. P., & Joshi, Y. C. (2011) [37]	Flavonoids: A versatile source of anticancer drugs	Flavonoids as anticancer agents	examined the various anticancer characteristics of flavonoids and how they work to combat various malignancies.
Isah, T. (2016) [38]	Anticancer alkaloids from trees: Development into drugs	Alkaloids as anticancer agents	examined the mechanisms and possibilities for drug development of anticancer alkaloids obtained from plants.
Pan, L., Chai, H. B., & Kinghorn, A. D. (2012) [39]	Discovery of new anticancer agents from higher plants	Anticancer agents from higher plants	Detailed information on the bioactivity of new anticancer chemicals from higher plants against cancer cells.
Prakash, O. M., Kumar, A., & Kumar, P. (2013) [40]	Anticancer potential of plants and natural products	Natural products in anticancer therapies	reviewed natural materials' anticancer potential and how they might be used to create new medicinal medicines.

4. DISCUSSION

4.1.Interpret and Analyze the Findings

The drug resistance problem can be solved through treatment enhancements achieved by mixing plant extracts with standard chemotherapy medications. Phytochemicals work in combination with synthetic medications to achieve enhanced anticancer results through effectuations that lower negative effects and traditional drug doses. Researchers have studied how resveratrol works with cisplatin to make it more successful against cancer cell lines that have developed resistance. This study examines

how plant-based chemicals affect the biological processes of apoptotic pathways while examining their influence on cell cycle control and drug transport mechanisms in order to boost current cancer treatment standards. The natural substance variability helps scientists create enhanced cancer treatment strategies.

4.2.Discuss Implications and Significance

Pharmacognosy creates numerous crucial impacts that improve cancer treatment procedures. Healthy ingredients outperform synthetic medicines because they combine well with biology and show less toxicity in addition to being highly structurally diverse. Natural substances show special cytotoxic behavior that destroys cancer cells while protecting non-malignant tissue which leads to decreased side effects compared to synthetic chemotherapeutic medication treatment. Research into previously unknown bioactive substances in fungal and plant and marine life diversity has developed a large potential for acquiring distinctive therapeutic compounds. The integration of cell culture and microbial fermentation with natural resources through biotechnology presents an invaluable possibility to build sustainable medicine production methods that remain friendly to the environment. The sustainable method of acquiring natural materials fits with global pharmaceutical industry attempts to decrease its environmental footprint.

4.3.Highlight Gaps and Suggest Future Research Directions

Pharmacognosy creates numerous crucial impacts that improve cancer treatment procedures. Healthy ingredients outperform synthetic medicines because they combine well with biology and show less toxicity in addition to being highly structurally diverse. Natural substances show special cytotoxic behavior that destroys cancer cells while protecting non-malignant tissue which leads to decreased side effects compared to synthetic chemotherapeutic medication treatment. Research into previously unknown bioactive substances in fungal and plant and marine life diversity has developed a large potential for acquiring distinctive therapeutic compounds. The integration of cell culture and microbial fermentation with natural resources through biotechnology presents an invaluable possibility to build sustainable medicine production methods that remain friendly to the environment. The sustainable method of acquiring natural materials fits with global pharmaceutical industry attempts to decrease its environmental footprint.

5. CONCLUSION

The search for new anticancer drugs still heavily relies on pharmacognosy. Its historical and modern contributions show how natural items can be used therapeutically. Through the integration of scientific innovation and conventional wisdom, researchers can open up new avenues for cancer treatment. Important first steps will be recognizing the potential of plant-derived chemicals, investing in sophisticated screening methods, and resolving formulation and regulatory issues. Therefore, pharmacognosy not only improves the drug development process but also opens the door to cancer treatments that are more efficient, reasonably priced, and long-lasting.

5.1.Recommendations

- Specific capital should go toward studying plant-derived chemicals extracted from biodiversity-wealthy zones with scarce utilization so

researchers can identify new anticancer drugs.

- Advanced drug delivery systems based on nanotechnology should be used for optimizing the therapeutic efficiency and stability as well as enhancing the bioavailability of chemicals found in plants.
- The clinical trial framework must be expanded to deliver safe and effective natural substances applicable for therapeutic uses by performing extensive in vivo and clinical research studies.
- Professional groups such as pharmacologists and biotechnologists and ethnobotanists should work together to match traditional practices with modern scientific approaches.
- A strong set of internationally recognized standards needs development for plant-based products throughout their drug development process to ensure safety and effectiveness and product uniformity.

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