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Therapeutic applications of Mushroom Bioactives in Oncology

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ABSTRACT
Cancer remains one of the leading causes of morbidity and mortality worldwide, prompting continuous exploration of safer and more effective therapeutic strategies. Natural products have historically contributed significantly to cancer drug discovery, and medicinal mushrooms have emerged as promising sources of bioactive compounds with anticancer potential. This review provides a comprehensive overview of the therapeutic applications of mushroom-derived bioactives in oncology. It critically examines the nutritional composition of edible and medicinal mushrooms and highlights key bioactive constituents, including polysaccharides, β-glucans, terpenoids, lectins, polyphenols, and phenolic compounds, that exhibit anticancer properties. Evidence from in vitro studies, animal models, and selected clinical trials is discussed to elucidate the mechanisms through which these compounds exert antiproliferative, pro-apoptotic, immunomodulatory, and anti-inflammatory effects. Particular emphasis is placed on the role of mushrooms in the management of breast, lung, colon, liver, and prostate cancers. This review also addresses emerging approaches such as mushroom-mediated nanoparticle synthesis and immune checkpoint modulation. While current findings demonstrate encouraging therapeutic potential and favorable safety profiles, limitations related to clinical validation are acknowledged. Overall, this review underscores the significance of mushroom bioactives as complementary agents in cancer therapy and highlights future research directions necessary for their translation into clinical oncology.

Key words: Mushroom, Cancer, Bioactives Compounds

Introduction

Mushrooms serve as the fruiting body for fungi which typically grow on land surfaces;

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they're most notable for their distinctive caps, stems, and often visible pores called gills beneath them. Despite numerous safe varieties of mushrooms being available, some types pose risks; precise recognition is crucial for safety. In common parlance, "mushrooms" typically refer to gilled mushrooms like the button mushroom; however, they can also encompass an array of other types including those without stems (such as puffballs) found in various ecosystems. In 2020. The edible fungi commonly referred to as mushrooms, specifically belonging to the genus Agaricus within the broader family of Agaricaceae, exhibit diverse appearances ranging from distinct forms, hues, and characteristics depending on their specific classification. In 2020, researchers Atila et al. published their findings. In 2017. As of now, there is information available. Five million fungal taxa exist; among these, approximately fourteen thousand mushroom-producing fungus species fall into two hundred categories recognized for their culinary value according to Grimm and Wösten in 2018. A substantial number of edible fungi belong to genera such as Agaricus, Auricularia, Hericium, Pleurotus, Cordyceps, Lactarius, and Pisolithus (as per Ramos et al.). In 2019. Mushrooms can be grown by cultivating them in various environments such as forests, fields, garden plots, or seedlings.

Mushrooms can be grown by planting them in soil, using tree roots as carriers for seedlings, employing vegetative propagation through cutting branches, or starting cultivation directly from spores. Mushroom growth varies by type; certain varieties such as morel mushrooms take longer to develop compared to quicker-growing types like oyster mushrooms. Mushroom cultivation thrives globally in numerous regions. Valverde et al. In 2015. A wide variety of mushrooms is commonly eaten around the globe for sustenance purposes. They are enjoyed due to their appealing taste and beneficial health properties. (Cheung et al.). In 2021; see also: Wong et al. In 2020. The mushrooms consist of approximately 85%-95% water content, while containing around 3%-5% proteins. A content of five percent in fats is present, along with six to ten grams per serving. Nine percent of materials exist in this composition. Mushrooms rich in proteins include abundant amounts of key amino acids such as leucine, glutamate, asparagine, isoleucine, and glycine. Moreover, the makeup of proteins found in edible fungi significantly contributes to overall well-being because these organisms possess non-necessary building blocks like GABA, crucial for brain function.

Over sixty percent of cancer therapies originate from naturally occurring substances; however, no such treatment has been derived entirely from mushrooms thus far (Demain & Vaishnav 2011). It's noteworthy given how widely known it was previously. Historically, fungi have been employed for their potential in treating malignancies. Over the past 300 years, studies on medicine and science in countries like Japan, China, South Korea, as well as more recent investigations in America, have shown how certain fungi extracts can help prevent and treat various cancers and other diseases. Figueiredo et al. In 2017. Polysaccharides extracted from mushrooms exhibit potent anti-cancer activity by targeting multiple types of cancerous cell lines. Additionally, their response was heightened in intensity upon being administer red alongside chemo therapy. Through its mechanism of action, this treatment enhances tumor-killing capabilities via an immune response facilitated by a thymus-based adaptive immunity requiring active participation of cytotoxic T cells.

Primarily, members within this carbohydrate family activate cytotoxic macrophages, NK cells, DCs, MΦs, NPs, as well as signaling molecules, thereby initiating coordinated immune reactions. Furthermore, these carbohydrates serve as multifunctional regulators, stimulating the synthesis of multiple immunomodulatory cytokines and their corresponding receptor proteins (Demain & Vaishnav, 2011; Figueiredo et al.). In 2017;

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Pandas et al. In 2021; see also: Twardowski et al. Terpenes belong to an additional class of molecules known for their biological activity. Numerous compounds derived from mushroom terpenoids exhibit promising anti-cancer properties. Terpenes may influence immune responses through gene activation of proteins involved similarly. Other groups of carbohydrates-attaching molecules found within mushroom cells exhibit anti-cancer effects via multiple mechanisms. Numerous lectins exhibit both anti-cancer and inhibitory effects on cell proliferation. Additional significant molecules include polyphenols; these recognized antioxidants function via multiple mechanisms. In cancer research trials, all aspects of the mushroom therapy appeared without risk and showed no negative outcomes. Alterations detected through biochemical signatures or diagnostic signs suggest an impact on bodily functions by fungi. Nevertheless, improvements in patient well-being exceeded outcomes such as prolonged survival free of disease or death rates (as reported by Panda et al.). In 2021.

This section's objective is to evaluate critically all available data on mushroom-based treatments potentially used in cancer therapy. Moreover, this evaluation highlights the most widely recognized types of mushrooms along with the specific chemical compounds they contain, as well as how these substances function within each mushroom's system. Moreover, this document includes research on certain types of fungi known for their cancer-fighting properties, which were tested both inside test tubes and animals but haven't yet undergone human trials.

Clinical Trials for a Variety of Cancers

Treatment of Breast Cancer

Mushrooms with antineoplastic exertion against bone cancer cells, fastening on the apparent bioactive composites and their mode of action Agaricus bisporus, Antrodia cinnamomea, Cordyceps sinensis, Cordyceps militaris, Coriolus versicolor, Ganoderma lucidum, Grifola frondosa, Lentinula edodes, and Pleurotus ostreatus. Novaković et al. 2019 described that a Wild A. auricula – judae showed antiproliferative exertion on MCF-7 mortal bone cancer cells with IC50 values of 333.3 µg/ ml and 285.7 µg/ ml for its water excerpt and ethanol excerpt, independently. Ethanol and ethyl acetate excerpts of C. comatus downregulated the expression of androgen receptor protein and glucocorticoid receptor reiterations in MDA- kb2 bone cancer cells (Zaidman et al., 2008). Coriolus versicolor excerpt increased the conflation of nucleosomes in the apoptotic bone cancer cell and had antiproliferative effect against MCF- 7, MDA- MB- 231, and T- 47D cells (Ho et al. 2005).

Lung cancer treatment

Calvatia gigantean (C. gigantea) belongs to the family Lycoperdaceae. It has been demonstrated that C. gigantea dropped cell growth of mortal lung cancer cells by downregulating the genes Akt, CDK4, CCND1, and CCND2, important controllers for cell cycle arrest in G1/ S. In addition, C. gigantea excerpt exerts apoptosis by downregulating the expression of antiapoptotic protein Bcl- 2 and enhances the apoptotic factors Bax, p53, caspase- 3, and caspase- 9. therefore, this excerpt of C. gigantea may act as an important agent for treating lung cancer singly. The excerpt of C. gigantea may be used as a promising treatment against lung cancer (Eroğlu et al., 2016).

In the study by Kaygusuz et al. (2017), methanol excerpts of Agaricus lanipes (A. lanipes) were estimated for antiproliferative exertion and apoptotic exertion on A549 lung cancer cells. A. lanipes excerpts were assessed for their antiproliferative exertion and apoptotic enthrallment. The outgrowth verified that mushroom excerpt reduced the growth of A549

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cells in a cure-dependent manner compared to the undressed control cells. Owing to the patterns reliant on both time and cure in the viability of A549 cells, the expression changes of genes, including Rel A (p65), Bax, Bcl- 2, caspase- 3, caspase- 9, p21, p53, and Cyclin D1(CCND1), were estimated at 24-, 48-, and 72- h following treatment of A549 cells with varying attention of the excerpt. Grounded on these findings, it was suggested that the A. lanipes excerpt can inhibit the cell cycle by downregulating CCND1 and converting A549 lung adenocarcinoma cells to suffer apoptosis via modifying the expression of Bax, Bcl-2, and caspases. Considering that the mushroom is taken as a diurnal supplement, its high antiproliferative capability and strongpro-apoptotic goods are profitable and may serve as a model for other exploration in the field as well as a source for new drug phrasings and treatments for cancer.

The methanol excerpt prepared from regenerating bodies of Amanita spissacea revealed significant in vitro cytotoxicity against mortal lung cancer cells in primary testing. The MeOH excerpt was tested in vitro for cytotoxicity in four different mortal lung cancer cell lines in relation to their p53 status "A549 cells with wild- type p53, H1264 cells with shifted p53, and H1299 and Calu- 6 cells lacking p53". Indeed, the MeOH excerpt dropped cell viability constantly in all cancer cell lines in a cure-dependent mode irrespective of its p53 status. In general, the cell morphological features indicated apoptosis after treatment with the MeOH excerpt, including cell rounding, cell loss, membrane blebbing, and detachment. farther separation and sanctification redounded in the identification of several composites from the MeOH excerpt, which included "(9E)-8-oxo-9-octadecenoic acid (1), (10E)-9-oxo-10-octadecenoic acid (2), (9E)-8-oxo-9-octadecenoate methyl ester (3), (9Z)-9-octadecenoate-(2 ′ S)- 2 ′, 3 ′- dihydroxypropyl ester (4),(9Z)-9-octadecenoic acid(5), and palmitic acid(6) ". Among them, composites 1 and 2 were the most cytotoxic. Induction of apoptosis by these composites was related to the activation of caspase- 3. These findings point toward A. spissacea as a implicit source for the development of new anticancer agents (So et al., 2019).

In the study by Konno et al., (2015), two bioactive excerpts of Phellinus linteus (PL) wielded their cytotoxic goods on mortal lung cancer cell (A549) in vitro. It's likely that oxidative stress intermediated this anticancer effect until its capstone into apoptosis. In the study by(Guo et al., 2006), PL has also been demonstrated to reduce excrescence proliferation against mortal lung cancer H5800 lung epithelial LA4 cells. It was set up that in lung cancer cells from mice and humans, PL intermediated the following two functions cell cycle arrest at a low attention of PL and apoptosis in response to a high cure of PL. After exposure to a low cure of PL, G1 growth arrest passed in the lung cancer cells. The decline in the exertion of cyclin-dependent kinases CDK2, 4, and 6 is reflective of the negative growth control intermediated by PL. still, PL caused cure-dependent apoptosis in lung cancer cells at high tablets. This was substantiated by DNA fragmentation, caspase activation, and loss of clonogenicity in the lung cancer cells, they were all absent from lung cancer cells treated with low boluses of PL. Also, the normal mouse lung epithelial cells were subordinated to low or high attention of PL. Complete repression of PL- convinced apoptosis was achieved by adding the caspase asset Z-VADfmk. likewise, the low lozenge of PL was suitable to round doxorubicin in causing the lung cancer cells to suffer apoptosis.

Treatment of colon cancer

In studies carried out for the structural characterization andanti-colon cancer exertion of Agaricus bisporus, five crude polysaccharides were attained by successional birth with room temperature water, hot water, high- pressure hot water, dilute alkaline result, and

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concentrated alkaline result; a homogeneous polysaccharide known as' WAAP- 1' was insulated from them using a DEAE Cellulose- 52 column. WAAP- 1 displayed veritably promising anticancer parcels against the proliferation of HT- 29 colon cancer cells(Zhang et al., 2023).

There was a significant reduction in the number of preneoplastic lesions(aberrant vault foci and microadenomas) in mice administered with either regenerating body or mycelia polysaccharide excerpts of Pleurotus pulmonarius. This inhibition of preneoplastic lesions redounded from reduced cell proliferation and increased cell death, as well as lower situations of thepro-inflammatory cytokine TNF- α(Lavi et al., 2012).

n- Hexane bit of the Pleurotus sajor- caju, PSC- hex, convinced cancer cell apoptosis through mitochondrial membrane eventuality breakdown in cancer cells, generation of ROS, adding the expression of the p53, BAX, and caspase- 3 proteins, and dwindling expression of the Bcl- 2(Finimundy et al., 2018).

Boletus edulis is a medicinal mushroom, enjoyinganti-colon cancer parcels, and its excerpt contains ellagic acid, rutin, and taxifolin at 532 µg/ g, 465 µg/ g, and 259 µg/ g, independently(Quero et al., 2024).

Treatment of Liver Cancer

Inonotus obliquus is a large fungus with high phenolic content that has demonstrated promising eventuality for the treatment of liver cancer. still, studies probing its medium of action in the treatment of liver cancer are scarce. To explore its medium of action, network pharmacology was used to collect phenolic composites from I. obliquus, identify implicit targets related to liver cancer, and examine their association with applicable signaling pathways. also, molecular docking was conducted to explore the list capacities between the phenolic composites of I. obliquus and core targets. Eventually, molecular dynamics simulations were performed to assess the list stability of protein- ligand complexes. A aggregate of 22 phenolic composites were linked in I. obliquus in the CNKI database. The 10 core targets in the PPI network included VEGFA, CTNNB1, KDR, VAV3, VAV2, CDC42, TP53, CBL, CCND1 and CDK2, all of which were primarily related to excrescence angiogenesis, irruption, migration and cell cycle. GO analysis yielded 1487 natural processes, 99 cellular factors, and 207 molecular functions. Meanwhile, KEGG enrichment analysis linked 103 signaling pathways, of which the MAPK pathway had the most annotated targets. also, the results of molecular docking indicated that phenolic composites in I. obliquus could effectively bind to the 10 core targets in the PPI network, with the smallest overall list energy observed for the target CDK2. Eventually, the results of molecular dynamics simulation demonstrated that over 100 ns, the phenolic composites in I. obliquus, videlicet hesperetin, quercetin, isorhamnetin-3-O-glucoside, and rutin, could stably bind to the target CDK2. Overall, these findings indicated that phenolic composites in I. obliquus regulate the proliferative, migrant and invasive capacities of liver cancer cells through multiple targets and signaling pathways. This study provides a scientific reference for the development of I. obliquus phenolic composites as remedial agents for liver cancer(Tan et al., 2025). Ganoderma mushrooms have a variety of pharmacological conditioning and may have antitumor goods. thus, the antitumor exertion of the methanolic fruiting body excerpts of three Ganoderma spp. will be estimated by estimating cell viability, cell cycle parameters and the mode of cellular death. Sulfo- rhodamine B staining and inflow cytometry were used in this regard. Hepatocellular melanoma(HepG2) and bone ductal melanoma(T- 47D) were the cancer cell lines. Mouse normal liver(BNL) and oral epithelial cell(OEC) lines served as separate controls. The results indicated that Ganoderma resinaceum excerpt

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showed dropped viability of BNL at an IC50> 100 µg/ mL but not that of HepG2, which was at an IC50 of 72.32 µg/ mL. also, Ganoderma australe and Ganoderma mbrekobenum dropped the viability of the OEC cell line at an IC50 of 328.29 and 271.56 µg/ mL, independently. On the negative, the IC50 of T- 47D were 221.95 and 236.45 µg/ mL, independently. Three excerpts arrested the life cycle of the cell at the G1 phase in each case. G. resinaceum excerpt stimulated total apoptosis(Q2 Q4) of 19.99 with low necrosis(Q1). In discrepancy to that, the chance of total cell necrosis in the T- 47D cell line treated with the other two excerpts was 31.10 and 18.28, independently, while that of total cell apoptosis was 6.83 and 1.78, independently. therefore, G. resinaceum significantly inhibited the viability of the HepG2 cell line, whereas both G. australe and G. mbrekobenum excerpts significantly reduced the viability of the T- 47D cell line. These results may be encouraging towards enterprises about their possible use for the remedial operation of hepatocellular melanoma and bone ductal melanoma after farther disquisition. Toson et al., 2025). Lepiota morganii-green- spored parasol, was employed by Akhtar et al. 2022, for green conflation of manganese oxide nanoparticles. Mycosynthesized nanoparticles(NPs) were characterized via XRD, UV spectroscopy, FTIR, and bitsy ways similar as SEM, and EDX ways showed their liquid structure, globular morphology, and a nanoscale size of 19.85 nm. The FTIR analysis linked some functional groups including flavonoids, phenolics, and proteins, suggesting participation in nanoparticle stabilization and natural exertion. Biocompatibility assays demonstrated minimal hemolysis, The cytotoxic goods of nanoparticles against HepG2 liver cancer cells were assessed by the MTT assay and demitasse violet staining assay, where a significant cure-dependent drop in the viability of cells passed, converting apoptosis with an IC50 of 50 µg/ mL. likewise, relative MTT assays verified the advanced efficacity of nanoparticles synthesized using Chlorophyllum molybdites. These studies verified the multifaceted biomedical efficacity of the mycosynthesized nanoparticles ranging from anticancer to antiparasitic, with a view toward sustainable nanoparticle conflation.

Treatment of Prostate Cancer

Still, studies by DeVere White et al., 2002; Sumiyoshi et al., 2010 with The global rise in cancer cases, especially prostate cancer, has come one of the major health burdens worldwide. Conventional treatment modalities include surgery, radiation remedy, hormone remedy, chemotherapy, and immunotherapy; all these options, though precious, come with their limitations and possible side goods. therefore, there's a trend towards exploring reciprocal curatives, including natural products like β- glucans, uprooted from incentive and mushrooms. In this review, we looked into the possible remedial part of medicinal mushrooms β- glucan in the treatment of prostate cancer. Pure β- glucans have shownanti-cancerous action in colorful preclinical trials, showing the inhibition of proliferation, induction of apoptosis, and modulation of vulnerable responses. In prostate cancer cell lines and beast models, the results are promising, showing that β- glucan could inhibit excrescence growth, induce DNA damage, and regulate excrescence labels similar as p53 and prostate-specific antigen. β- glucans act through colorful pathways similar as the stimulation of dendritic cells, modulation of cytokine stashing, repression of myeloid-deduced suppressor cells, and improvement of vulnerable responses. Besides this, β-glucans haveanti-androgenic and vulnerable- modulatory goods, so it has surfaced as a promising seeker for the treatment of prostate cancer. Further, in this study, we've concentrated on the medium of action of β- glucans through colorful pathways, including excrescence cell death due to oxidative stress created by ROS generation and autophagy. Although the preclinical data support the implicit remedial efficacity of medicinal

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mushrooms β- glucans, farther studies are needed to establish its clinical mileage and safety in mortal trials. Lentinus edodes excerpt failed to descry any significant effect on prostate cancer.(Trivedi et al., 2025).

Prostate cancer remains a significant global health challenge, challenging the development of new remedial approaches. This study delved the remedial eventuality of the Antrodia cinnamomea formula(XIANZHIFANG formula, XZF), comprising Antrodia cinnamomea, Sanghuangporus sanghuang, Ganoderma lucidum, Ganoderma sinense, and Inonotus obliquus, in prostate cancer treatment. HPLC analysis verified the presence of crucial triterpenoids, including Antcin A, B, C, K, and Zhankuic acid B, C, and 4,7- dimethoxy. Cytotoxicity assays demonstrated that XZF(50 – 200 μg/ mL) displayed picky exertion, maintaining viability innon-cancerous 293T- cells while enhancing the viability of actuated CD8 and CD4 T- cells in a cure-dependent manner. XZF significantly reduced PD- 1 expression in CD8 T- cells but not in CD4 T- cells and inhibited the PD- L1/ PD- 1 commerce, achieving 93 inhibition at 200 μg/ mL. likewise, when combined with atezolizumab(1 μg/ mL), XZF demonstrated complete leaguer of PD- L1/ PD- 1 commerce. In prostate cancer cells, XZF displayed discriminational antiproliferative goods. In PC- 3 cells, XZF significantly reduced viability across a attention range of 25 – 200 μg/ mL, whereas DU145 cells showed only partial inhibition at advanced attention(100 – 200 μg/ mL). LNCaP cells displayed a cure-dependent reduction in viability, mirroring the response pattern of PC- 3 cells. Conditioned medium from XZF- treated macrophages, particularly mortal THP- 1 cells, significantly suppressed the viability and migration of prostate cancer cells in a cure-dependent manner. specially, the conditioned medium from XZF- treated THP- 1 cells displayed a stronger inhibitory effect on prostate cancer cell viability and migration compared to murine RAW 264.7 macrophages. These findings indicate that XZF exerts its remedial eventuality through multiple mechanisms, including direct antiproliferative goods on cancer cells, improvement of T- cell responses, modulation of vulnerable checkpoint pathways, and macrophage- intermediated repression of prostate cancer cell survival and migration. The pronounced goods observed in mortal macrophage models suggest a promising avenue for farther disquisition in clinical settings, particularly in combination with being immunotherapies(Tsai et al., 2025).

To determine whether supplemental quantities of a polysaccharide/ oligosaccharide complex attained from a shiitake mushroom excerpt(SME) would lower the prostate-specific antigen(PSA) position in cases with prostate cancer. A aggregate of 62 men(mean age 73.2 times, range 53.6 to 85.5) with histologically proven prostate cancer who had two successive elevated PSA readings were accrued to the study during a 3- month period. This was an open- marker study in which the cases entered oral administration of capsules containing SME given three times daily for 6 months. The endpoint for the trial was the lowering of the PSA situations. Of the 62 men enrolled in the study, 61 were assessable. At 4 months, 1 case withdrew because of unconnected surgery and 7 withdrew because of complaint progression; none had responded with a drop of lesser than 50 in the PSA position. By 6 months, a aggregate of 23 cases had progression and none had responded. Thirty- eight cases had stable PSA situations after 6 months. Although not the primary endpoint of the study, in other studies these cases could have been included as askers. When the cases' rates of PSA rise before study entry were anatomized, 4(7) had stabilized complaint while taking SME. therefore, the final results for our study cases were 0 with a complete response, 0 with a partial response, 4(7) with stable complaint, and 23 of 61 with progression while taking SME. SME alone is ineffective in the treatment of clinical prostate cancer(White et al., 2002). The end of this study was to assess the

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efficacity and safety of two different types of medical mushrooms in cases with prostate cancer in Japan. Cases with biochemical failure after radical treatment fornon-metastasized prostate cancer were enrolled in this open- marker study. For 6 months they ingested one of the two following supplements Senseiro, containing excerpts from the Agaricus blazei Murill mushroom; and Rokkaku Reishi, containing the Ganoderma lucidum mushroom. situations of serum prostate-specific antigen(PSA) position and PSA doubling time were examined ahead and after study entry to assess the impact of these supplements on complaint progression. The primary end- point of this study was partial response rate(50 or further drop of serum PSA). Hormonal status, represented by serum testosterone situations, and toxin were also assessed. A aggregate of 51 cases were enrolled following radical prostatectomy. Forty- seven completed the protocol and could be assessed. Thirty-two cases entered Senseiro and the remaining 15 entered Rokkaku Reishi. No partial response in terms of PSA was observed. revision of PSA doubling time did n't relate with that of serum testosterone situations. Serious adverse goods were n't observed.No significant anticancer goods were observed with the input of these two medical mushrooms(Yoshimura et al., 2010).

Conclusion

Medicinal and edible mushrooms represent a rich and largely untapped reservoir of bioactive compounds with significant therapeutic potential in oncology. The evidence compiled in this chapter demonstrates that mushroom-derived polysaccharides, β-glucans, terpenoids, lectins, polyphenols, and phenolic compounds exert anticancer effects through multiple mechanisms, including inhibition of tumor cell proliferation, induction of apoptosis, modulation of immune responses, regulation of cell cycle progression, and suppression of inflammatory and oxidative pathways. Studies across various cancer types—such as breast, lung, colon, liver, and prostate cancers—highlight the versatility and broad-spectrum activity of mushroom bioactives.

Importantly, many mushroom-based interventions exhibit low toxicity and favorable safety profiles, making them attractive candidates as complementary or adjuvant therapies alongside conventional cancer treatments. Emerging strategies, including immune checkpoint regulation and mycosynthesized nanoparticles, further expand the therapeutic landscape of mushrooms in cancer management. However, despite strong preclinical evidence and limited clinical observations, the translation of mushroom bioactives into standardized anticancer therapeutics remains constrained by insufficient large-scale, well-controlled human trials.

Future research should focus on rigorous clinical validation, standardization of mushroom extracts, elucidation of molecular targets, and optimization of dosage and delivery systems. Integrating traditional knowledge with modern pharmacological and biotechnological approaches may accelerate the development of mushroom-based anticancer agents. In conclusion, medicinal mushrooms hold considerable promise as natural, multifunctional tools in oncology, warranting continued scientific investigation and clinical exploration.

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