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Innovative Cultivation and Application Research of Broad-Spectrum Anticancer *Ganoderma lucidum* (Red Reishi) Based on Synergistic Bio-Enhancement

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Abstract: This study overcomes the limitations of traditional anticancer effects of *Ganoderma lucidum* and pioneers an innovative cultivation system for anticancer Reishi based on synergistic bio-enhancement integrating "traditional Chinese medicine (TCM) compound formula — enzymatic pretreatment — gene editing — transgenic metabolism." The core technologies include: Construction of a cultivation substrate incorporating anticancer TCM compound formulas; Application of targeted enzymatic hydrolysis technology to efficiently cleave macromolecular active components in TCM; Precise modification of membrane transport systems in Ganoderma strains using the CRISPR-Cas9 gene-editing platform; Reconstruction of metabolic pathways through transgenic technology to achieve synergistic enrichment and stable storage of exogenous antitumor active components together with endogenous functional components of Ganoderma. Experimental results demonstrate that this innovatively cultivated *Ganoderma lucidum* can effectively activate the body's immune defense, inhibit cancer cell proliferation through multiple targets, and induce apoptosis, while exhibiting safety with no toxic side effects. This research provides a disruptive technological pathway and a highly promising candidate carrier for the development of efficient, safe, and cost-effective cancer biotherapeutic agents.

Keywords: Anticancer *Ganoderma lucidum*; Anticancer TCM compound formulas; Enzymatic pretreatment; Bio-enhancement; Gene-editing technology (CRISPR-Cas9); Transgenic metabolic engineering; Antitumor; Synergistic effects

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I. Introduction

Ganoderma lucidum (Lingzhi/Reishi), as a precious medicinal fungus, has long attracted significant attention for its immunomodulatory properties and potential antitumor activities [1–2]. However, the anticancer efficacy of traditional *Ganoderma lucidum* is limited by factors such as the relatively low content of active constituents, restricted bioavailability, and the singularity of its mechanisms of action, making it difficult to meet the demands of modern clinical practice for highly effective therapies [1]. There is an urgent need to develop innovative

technologies to overcome the inherent biological limitations of Ganoderma, thereby endowing it with more potent and more precise anticancer capabilities.

Focusing on this critical challenge, the present study integrates cutting-edge biotechnological approaches and pioneeringly proposes and implements a strategy of "synergistic bio-enhancement", aiming to cultivate a new generation of highly effective anticancer *Ganoderma lucidum*.

2. Research background, significance, and innovation

The significance of this study lies in the proposal and realization of a revolutionary paradigm for cultivating anticancer *Ganoderma lucidum* based on "synergistic bio-enhancement." Its core technological innovations are summarized as follows:

2.1. Substrate innovation — Function-oriented integration

For the first time, multiple traditional Chinese medicinal herbs with clearly defined antitumor activities are scientifically formulated and incorporated into a functionalized cultivation substrate, providing a targeted material basis for directed biosynthesis in Ganoderma [3].

2.2. Enzymatic technology — Breaking absorption barriers

An innovative exogenous multi-enzyme synergistic catalytic system is applied for targeted enzymatic pretreatment of the medicinal substrate. This approach fundamentally overcomes the critical bottleneck whereby Ganoderma mycelia are unable to efficiently absorb and utilize macromolecular active components from Chinese medicines, significantly enhancing the transmembrane transport efficiency of bioactive small-molecule units.

2.3. Gene editing — Precise control of transport

The CRISPR-Cas9 gene-editing technology is pioneeringly employed to engineer the membrane transport system of Ganoderma [4–5]:

Enhanced Transport Capacity: Overexpression of key transporter proteins (such as the ABC and SLC families) markedly increases the active uptake of hydrophobic antitumor compounds.

Selective Permeability: Editing membrane protein genes to construct inducible permeability switches enables selective uptake of macromolecular active components under specific conditions, while suppressing competition from non-target substances.

Removal of Negative Regulation: Knockout or suppression of restrictive transporter proteins optimizes resource allocation and maximizes enrichment of target components.

2.4. Transgenic technology — Metabolic pathway reconstruction

Through innovative application of genetic engineering, endogenous transport and metabolic genes in Ganoderma are precisely regulated to reconstruct metabolic networks [6]. This not only facilitates efficient internalization of exogenous antitumor components, but also enables their synergistic biosynthesis and targeted accumulation in fruiting bodies together with endogenous bioactive substances of Ganoderma (such as triterpenoids and polysaccharides) [7].

2.5. Synergistic effects — Multitarget, high-efficiency anticancer activity

The four core technologies above are not merely additive; rather, they form a synergistically amplified "bio-enhancement" system. Ganoderma cultivated under this system functions as an "intelligent bioreactor", whose fruiting bodies efficiently enrich and transform multiple antitumor active components. The final product acts synergistically on multiple key stages of cancer initiation and progression—including immune activation, inhibition of proliferation, induction of apoptosis, and suppression of metastasis—thereby achieving a qualitative leap in anticancer efficacy.

This "synergistic bio-enhancement" strategy, grounded in cutting-edge biotechnology, fundamentally overcomes the limitations of traditional Ganoderma and single-herb anticancer approaches (such as complex yet low-efficiency compositions, poor absorption, and weak targeting), and opens an entirely new pathway for the development of innovative, efficient, and safe anticancer biotherapeutic agents with independent intellectual property rights.

3. Innovative cultivation methods for anticancer Ganoderma lucidum

3.1. Innovative preparation of functionalized cultivation substrates

Breaking through traditional substrate formulations, this study innovatively selects and optimizes the ratios of multiple traditional Chinese medicinal herbs with synergistic antitumor activities to construct a function-oriented compound substrate. This substrate not only satisfies the nutritional requirements for Ganoderma growth but also serves as a reservoir of exogenous bioactive components, providing the core material input for subsequent bio-enhancement (Formulation confidential; efficacy verified through animal studies).

3.2. Enzymatic pretreatment technology: A key breakthrough in enhancing bioavailability

To address the bottleneck whereby macromolecular active components in Chinese medicines are difficult for Ganoderma to efficiently absorb, an innovative exogenous compound enzyme system (including cellulases, proteases, glycosidases, etc.) with targeted catalytic capability is introduced. Through precisely designed in vitro enzymatic hydrolysis protocols, macromolecular bioactive substances in the herbal materials (such as polysaccharides, proteins, and saponins) are selectively degraded into low-molecular-weight, easily absorbable active units.

This step significantly enhances the transmembrane transport efficiency of key antitumor components into Ganoderma mycelia and constitutes a prerequisite for the success of "bio-enhancement." An efficient two-stage amplification system—"exogenous catalytic pre-activation followed by high-efficiency fungal uptake"—is thus established.

3.3. CRISPR-Cas9 gene editing: Precise engineering of the membrane transport system

One of the most groundbreaking aspects of this study is the first systematic and precise engineering of the membrane transport system of Ganoderma strains using the CRISPR-Cas9 gene-editing platform [4–5]:

Transporter Protein Enhancement Engineering: Specific overexpression of ABC transporter family genes and solute carrier (SLC) proteins dramatically enhances the active uptake capacity of Ganoderma for hydrophobic antitumor active compounds (following enzymatic pretreatment).

Reduction of Negative Regulatory Factors: Precise knockout or suppression of transporter protein genes responsible for non-essential component uptake or restriction of target compound transport significantly reduces

energy waste and focuses cellular resources on target component enrichment.

Intelligent Regulation of Membrane Permeability: Innovative editing of specific membrane protein genes enables construction of inducible permeability "molecular switches." Under defined conditions (such as specific growth stages or in the presence of inducers), these switches can transiently and reversibly enhance membrane permeability, allowing selective entry of specific macromolecular active components while deliberately suppressing competitive binding of non-target macromolecules. This design achieves intelligent regulation characterized by "spatiotemporally specific permeability and targeted enrichment of desired components", greatly expanding both the range and efficiency of compounds that Ganoderma can accumulate.

3.4. Transgenic technology: Metabolic pathway optimization and synergistic enrichment

To maximize the effects of "bio-enhancement" and ensure stable storage of active components, transgenic technologies are further applied [6]:

Targeted Optimization of Transmembrane Transport: Through transgenic approaches, expression of key transporter genes responsible for transmembrane movement of target antitumor components is specifically enhanced, opening and broadening high-efficiency internalization pathways.

Synergy Between Endogenous and Exogenous Metabolism: Metabolic pathways within Ganoderma cells are innovatively reconstructed, enabling integration and synergistic amplification between exogenously introduced antitumor components and endogenously synthesized functional substances of Ganoderma (such as triterpenoids and polysaccharides) [6–7].

Targeted Accumulation in Fruiting Bodies: Via transgenic regulation, these synergistically enhanced composite active components are guided to efficiently accumulate and be stably stored in the fruiting bodies of Ganoderma, which possess the highest medicinal value.

3.5. Inoculation and cultivation

The enzymatically pretreated functionalized herbal substrate is packed into cultivation bags and inoculated with genetically edited and transgenically modified *Ganoderma lucidum* (red Reishi) engineered strains. Cultivation is conducted under optimized environmental conditions. Ultimately, a "synergistic bio-enhanced anticancer Ganoderma" is successfully obtained, markedly distinct from conventional Ganoderma. Its key characteristics include a greater diversity of anticancer active components, higher concentrations, stronger biological activity, and more diversified mechanisms of action.

3.6. Therapeutic effects

The synergistically bio-enhanced anticancer *Ganoderma lucidum*, whose fruiting bodies function as "intelligent biological carriers" capable of efficiently enriching multiple antitumor active components, exerts its effects through multi-component synergy and multi-target mechanisms:

Potent activation of innate and adaptive immune defenses, significantly enhancing immune surveillance.

Effective inhibition of cancer cell proliferation, with strong induction of cancer cell differentiation and apoptosis.

Marked suppression of tumor angiogenesis, invasion, and metastasis.

Effective modulation of the tumor microenvironment, contributing to the maintenance of systemic homeostasis.

Significant enhancement of overall patient immunity, with notable improvement in side effects associated with chemotherapy and radiotherapy, as well as tumor-related complications (such as leukopenia, fever, pain, effusions/ascites, ulcers, and lymphadenopathy).

In animal studies, the overall anticancer efficacy of this product demonstrated clear advantages, in some aspects matching or even surpassing the therapeutic effects of existing chemotherapeutic agents, while simultaneously exhibiting the inherent benefits of natural products—namely, high safety and low toxicity with minimal side effects.

4. Experimental validation

4.1. Antitumor animal experiments

The antitumor animal experiments of this *Ganoderma lucidum* were conducted by the Nayuans (Nayuan) Biopharmaceutical research team. Mouse tumor models were used in the study, with mice randomly divided into a control group and an experimental group. The control group received conventional Ganoderma extract, while the experimental group was administered the anticancer Ganoderma extract.

The experimental results showed that tumor growth in the experimental group was significantly slower than in the control group, with a marked reduction in tumor volume and a significantly improved survival rate. These findings indicate that the anticancer Ganoderma extract possesses significant broad-spectrum antitumor activity, demonstrating strong inhibitory effects across multiple cancer models. Its therapeutic efficacy was superior to that of existing chemotherapeutic drugs, with statistically significant differences.

The following are partial data from antitumor animal experiments involving Ganoderma No. 5 and No. 6:

4.1.1. Efficacy study of Ganoderma No. 5 on human lung cancer A549 xenografts in nude mice

This experiment employed a human tumor xenograft model established in nude mice to evaluate the antitumor effects of sample Ganoderma No. 5. The sample was administered by oral gavage at a dose of 25 ml/kg for 14 consecutive days. When administered once daily, the tumor inhibition rate against human lung cancer A549 xenografts was 30.31%. When administered twice daily, the tumor inhibition rate against human lung cancer A549 xenografts increased to 53.63%. Relevant experimental data are presented in **Figures 1–6**, along with corresponding photographic documentation.

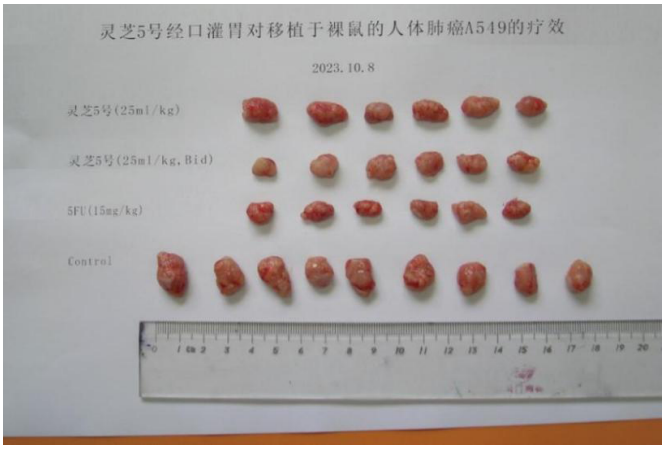

Figure 1. Efficacy of oral administration of *Ganoderma lucidum* No. 5 on human lung cancer A549 xenografts in nude mice

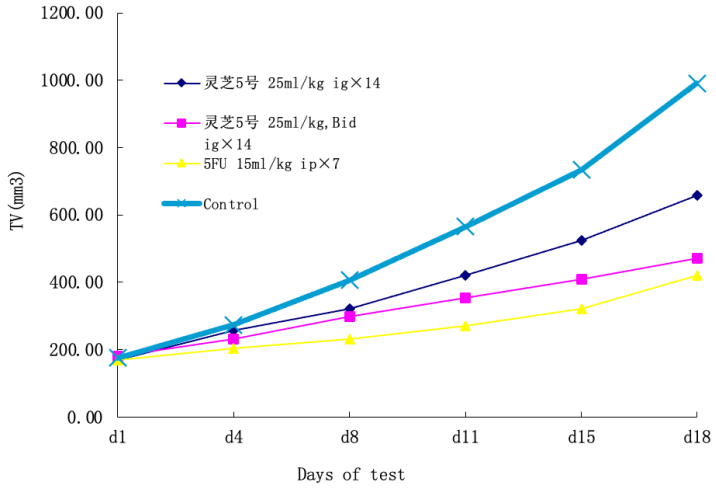

Figure 2. Effect of *Ganoderma lucidum* No. 5 on the relative tumor volume of human lung cancer A549 xenografts in nude mice

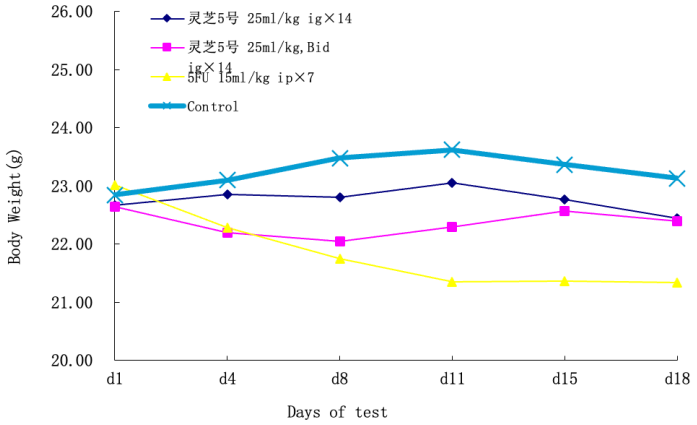

Figure 3. Effect of *Ganoderma lucidum* No. 5 on body weight in nude mice bearing human lung cancer A549 tumors

Table 1. Inhibitory Effect of Ganoderma lucidum No. 5 on Human Lung Cancer A549 Xenografts in Nude Mice. ($\bar{x}$ ±SD)

Group	Dose	Administration	Animal Number		Body Weight (g)	RTV	Tumor Inhibition Rate
	(ml/kg)	Regimen	Start	End	(Post-tumor-removal)	(d18)	%
Control			9	9	22.25±1.42	5.64±1.08	
5FU	15mg/kg	ip×7	6	6	20.80±0.89	2.48±0.30**	55.98
Ganoderma lucidum No. 5 L	25	ig×14, qd	6	6	21.61±0.98	3.93±0.97**	30.31
Ganoderma lucidum No. 5 H	25	ig×14, bid	6	6	21.94±0.85	2.62±0.25**	53.63

Compared with the Control group: *P<0.05, **P<0.01

Figure 4. Inhibitory effect of Ganoderma lucidum No. 5 on human lung cancer A549 xenografts in nude mice

Table 2. Effect of Ganoderma lucidum No. 5 on Tumor Volume of Human Lung Cancer A549 Xenografts in Nude Mice.($\bar{x}$ ±SD)

Group	Dose (ml/kg)	Regimen	TV (mm^3), $\bar{x}$ ±SD					
			d1	d4	d8	d11	d15	d18
Control			175.10±30.96	274.11±55.01	406.59±77.27	565.90±149.70	734.03±213.89	990.87±284.30
5FU	15mg/kg	ip×7	169.29±13.01	203.35±20.91	231.45±19.16	271.64±26.80	320.90±26.11	420.80±64.58
Ganoderma lucidum No. 5	25	ig×14, qd	168.16±11.33	256.57±26.40	321.42±51.83	419.78±74.83	523.39±118.26	657.79±154.43
Ganoderma lucidum No. 5	25	ig×14, bid	181.29±33.73	231.47±35.58	297.64±42.76	353.65±45.80	410.04±60.64	470.99±77.19

Figure 5. Effect of Ganoderma lucidum No. 5 on tumor volume of human lung cancer A549 xenografts in nude mice

Table 3. Effect of Ganoderma lucidum No. 5 on Relative Tumor Volume of Human Lung Cancer A549 Xenografts in Nude Mice. ($\bar{x}$ ±SD)

Group	Dose (ml/kg)	Regimen	RTV, $\bar{x}$ ±SD					
			d1	d4	d8	d11	d15	d18
Control			1.00±0.00	1.57±0.16	2.34±0.35	3.24±0.62	4.19±0.87	5.64±1.08
5FU	15mg/kg	ip×7	1.00±0.00	1.20±0.10** (23.38%)	1.37±0.08** (41.56%)	1.61±0.18** (50.33%)	1.90±0.19** (54.64%)	2.48±0.30** (55.98%)
Ganoderma lucidum No. 5	25	ig×14, qd	1.00±0.00	1.53±0.16 (2.46%)	1.91±0.26* (18.37%)	2.51±0.46* (22.70%)	3.13±0.79* (25.29%)	3.93±0.97** (30.31%)
Ganoderma lucidum No. 5	25	ig×14, bid	1.00±0.00	1.29±0.14** (17.88%)	1.66±0.22** (29.04%)	1.97±0.23** (39.08%)	2.28±0.25** (45.56%)	2.62±0.25** (53.63%)

Compared with the Control group: *P<0.05, **P<0.01. （） Tumor Inhibition Rate

Figure 6. Effect of Ganoderma lucidum No. 5 on the relative tumor volume of human lung cancer A549 xenografts in nude mice

4.1.2. Efficacy study of Ganoderma lucidum No. 5 on human hepatocellular carcinoma Bel7404 xenografts in nude mice

This experiment employed a human hepatocellular carcinoma Bel7404 xenograft model established in nude mice to evaluate the antitumor effects of the sample Ganoderma No. 5. The sample was administered by oral gavage at a dose of 25 ml/kg for 14 consecutive days. When administered once daily, the tumor inhibition rate against human liver cancer Bel7404 was 30.48%. When administered twice daily, the tumor inhibition rate increased to 50.08%, demonstrating a clear dose–response relationship and confirming definite antitumor activity. The positive control drug 5-fluorouracil (5-FU), administered at a dose of 15 mg/kg by continuous intraperitoneal injection for 7 days, achieved a tumor inhibition rate of 55.44%. Relevant experimental data are presented in **Figures 7–14**, along with corresponding photographic documentation.

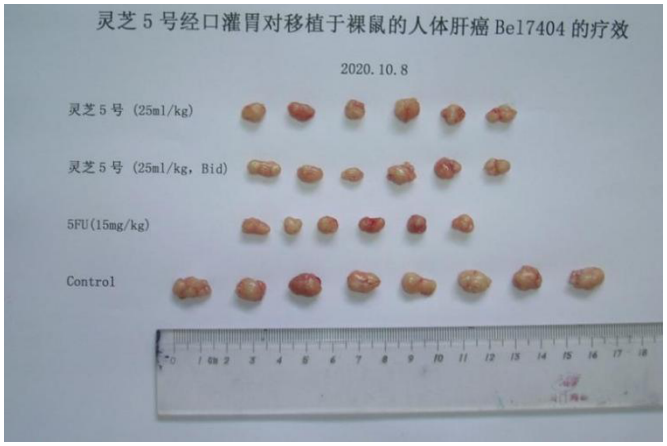

Figure 7. Efficacy of orally administered *Ganoderma lucidum* No. 5 on human hepatocellular carcinoma Bel-7404 Xenografts in Nude mice

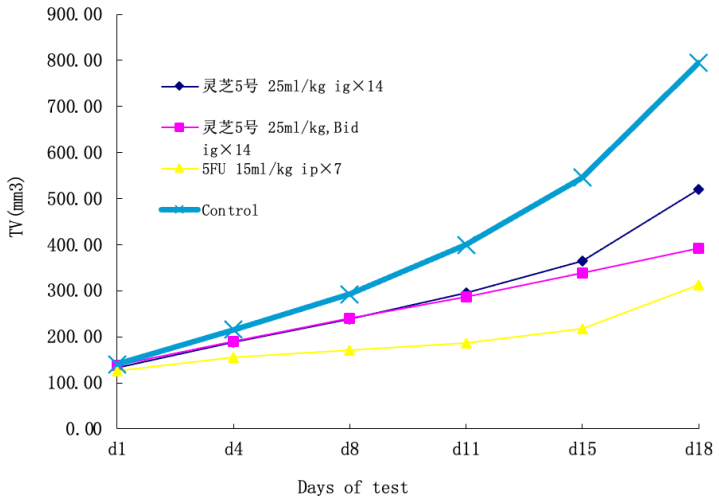

Figure 8. Effect of *Ganoderma lucidum* No. 5 on tumor volume of human hepatocellular carcinoma Bel7404 xenografts in nude mice

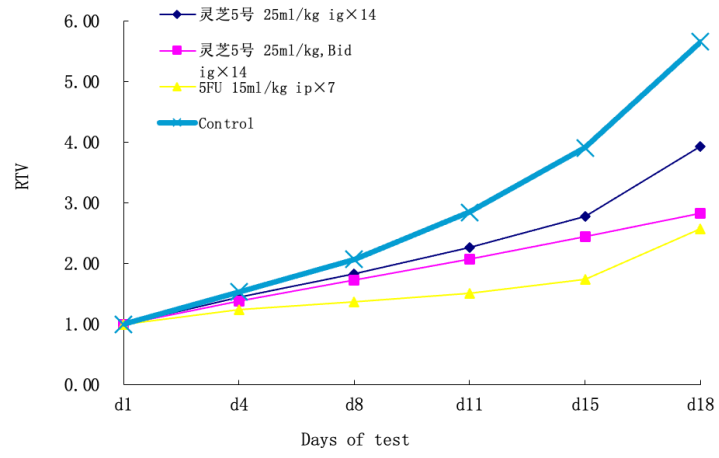

Figure 9. Effect of *Ganoderma lucidum* No. 5 on the relative tumor volume of human hepatocellular carcinoma Bel7404 xenografts in nude mice

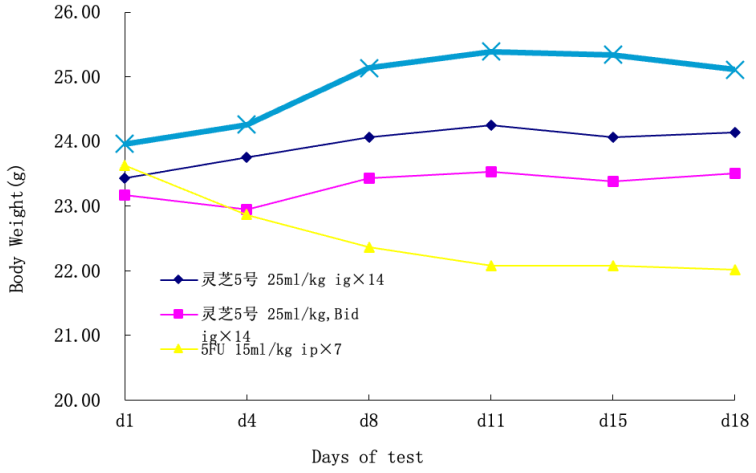

Figure 10. Effect of *Ganoderma lucidum* No. 5 on body weight in nude mice bearing human hepatocellular carcinoma Bel7404 tumors

Table 1. Inhibitory Effect of Ganoderma lucidum No. 5 on Human Hepatocellular Carcinoma Bel-7404 Xenografts in Nude Mice.($\bar{x}$ ±SD)

Group	Dose	Administration	Animal Number		Body Weight (g)	RTV	Tumor Inhibition Rate
	(ml/kg)	Regimen	Start	End	(Post-tumor-removal)	（d18）	%
Control			8	8	24.73±1.38	5.66±0.90	
5FU	15mg/kg	ip×7	6	6	21.38±1.35**	2.52±0.69**	55.44
Ganoderma lucidum No. 5 L	25	ig×14, qd	6	6	23.44±0.87	3.93±0.42**	30.48
Ganoderma lucidum No. 5 H	25	ig×14, bid	6	6	23.23±1.52	2.82±0.51**	50.08

Compared with the Control group: *P<0.05, **P<0.01.

Figure 11. Inhibitory effect of *Ganoderma lucidum* No. 5 on human hepatocellular carcinoma Bel7404 xenografts in nude mice

Table 2. Effect of Ganoderma lucidum No. 5 on Tumor Volume of Human Hepatocellular Carcinoma Bel-7404 Xenografts in Nude Mice.($\bar{x}$ ±SD)

Group	Dose	Regimen	TV (mm^3), $\bar{x}$ ±SD					
	(ml/kg)		d1	d4	d8	d11	d15	d18
Control			140.38±22.36	215.37±43.24	292.22±69.49	399.21±77.50	545.21±110.71	795.37±173.83
5FU	15mg/kg	ip×7	125.37±15.90	154.79±16.68	171.40±19.16	187.03±19.74	216.90±23.66	312.58±77.77
Ganoderma lucidum No. 5	25	ig×14, qd	133.60±18.80	188.25±6.39	238.86±17.76	296.06±26.22	364.77±29.75	519.87±43.28
Ganoderma lucidum No. 5	25	ig×14, bid	138.22±16.96	189.98±30.08	239.64±52.89	286.63±60.18	338.68±73.00	392.52±101.91

Figure 12. Effect of Ganoderma lucidum No. 5 on the tumor volume of human hepatocellular carcinoma Bel7404 xenografts in nude mice

Table 3. Effect of Ganoderma lucidum No. 5 on Relative Tumor Volume of Human Hepatocellular Carcinoma Bel-7404 Xenografts in Nude Mice. ($\bar{x}$ ±SD)

Group	Dose (ml/kg)	Regimen	RTV, $\bar{x}$ ±SD					
			d1	d4	d8	d11	d15	d18
Control			1.00±0.00	1.53±0.16	2.07±0.33	2.84±0.35	3.91±0.66	5.66±0.90
5FU	15mg/kg	ip×7	1.00±0.00	1.24±0.13** (18.77%)	1.37±0.13** (33.67%)	1.50±0.11** (47.28%)	1.74±0.14** (55.52%)	2.52±0.69** (55.44%)
Ganoderma lucidum No. 5	25	ig×14, qd	1.00±0.00	1.44±0.28 (5.77%)	1.82±0.41 (11.50%)	2.27±0.48* (20.15%)	2.78±0.46** (28.81%)	3.93±0.42** (30.48%)
Ganoderma lucidum No. 5	25	ig×14, bid	1.00±0.00	1.38±0.21* (9.73%)	1.73±0.26 (16.59%)	2.07±0.28** (27.27%)	2.44±0.37** (37.40%)	2.82±0.51** (50.08%)

Compared with the Control group: *P<0.05, **P<0.01. () Tumor Inhibition Rate

Figure 13. Effect of Ganoderma lucidum No. 5 on the relative tumor volume of human hepatocellular carcinoma Bel7404 xenografts in nude mice

Table 4. Effect of Ganoderma lucidum No. 5 on Body Weight of Nude Mice Bearing Human Hepatocellular Carcinoma Bel-7404 Xenografts.

Group	Dose (ml/kg)	Regimen	Body Weight (g), $\bar{x}$ ±SD					
			d1	d4	d8	d11	d15	d18
Control			23.96±1.30	24.26±1.73	25.14±1.19	25.39±1.76	25.34±1.89	25.11±1.38
5FU	15mg/kg	ip×7	23.63±0.90	22.87±0.88	22.37±0.94**	22.08±1.23**	22.08±1.50**	22.02±1.69**
Ganoderma lucidum No. 5	25	ig×14, qd	23.43±1.09	23.75±1.14	24.07±1.86	24.25±1.97	24.07±1.56	24.13±1.38
Ganoderma lucidum No. 5	25	ig×14, bid	23.17±1.41	22.95±1.48	23.43±1.76	23.53±1.29	23.38±1.29	23.50±1.35

Compared with the Control group: *P<0.05, **P<0.01.

Figure 14. Effect of Ganoderma lucidum No. 5 on body weight in nude mice bearing human hepatocellular carcinoma Bel7404 xenografts

4.1.3. Efficacy study of Ganoderma lucidum No. 6 on human colorectal cancer HCT116 xenografts in nude mice

This experiment employed a human colorectal cancer HCT116 xenograft model established in nude mice to evaluate the antitumor effects of sample Ganoderma No. 6. The sample was administered by oral gavage twice daily for 13 consecutive days. The tumor inhibition rate against human colorectal cancer HCT116 reached 56.63%. Its inhibitory efficacy was comparable to that of the chemotherapeutic agent 5-fluorouracil (5-FU), administered by daily intraperitoneal injection at 20 mg/kg, while notably avoiding the severe body weight loss typically associated with 5-FU treatment (**Figures 15–18**).

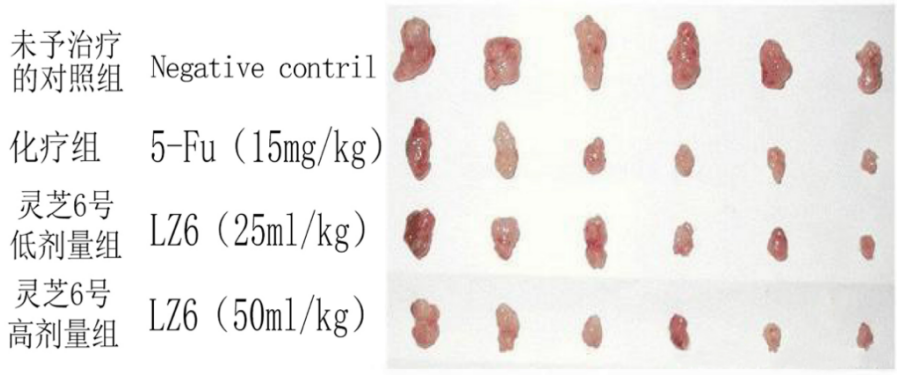

Figure 15. Tumors excised from colorectal cancer nude mice in each group at the end of the experiment

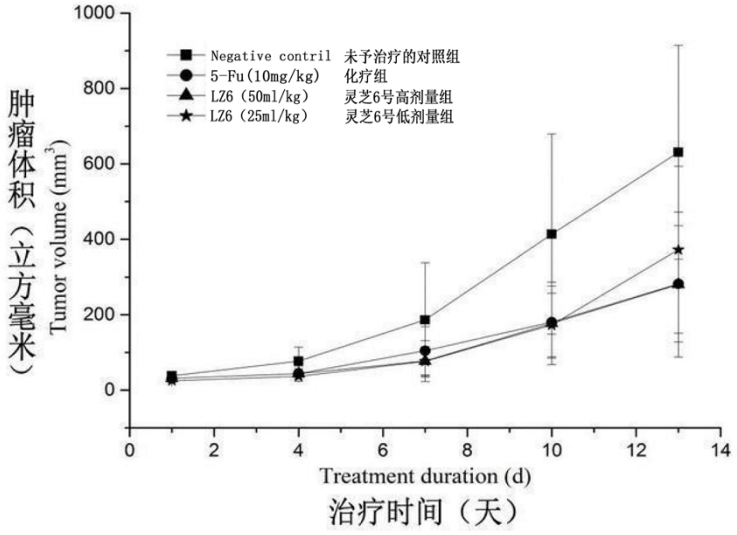

Figure 16. Tumor growth changes in colorectal cancer nude mice in each group during the experiment

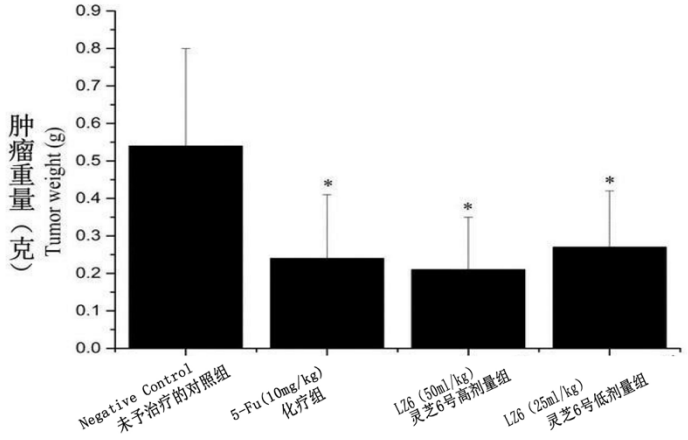

Figure 17. Average tumor weight of colorectal cancer nude mice in each group at the end of the experiment

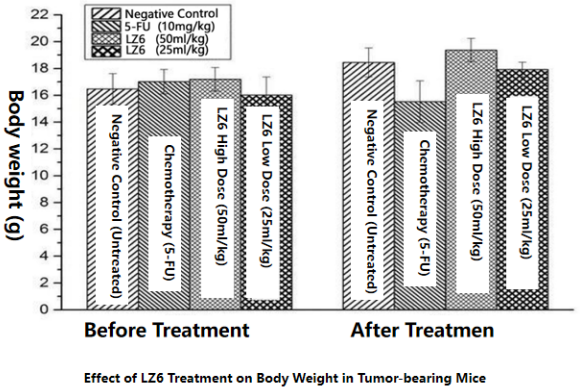

Figure 18. Body weight of colorectal cancer nude mice in each group before and after the experiment

4.2. Safety Evaluation

The safety of the anticancer *Ganoderma lucidum* extract was assessed through acute toxicity and long-term toxicity studies. Experimental results showed that even at high doses, no significant toxic reactions were observed. Indicators such as growth, development, and liver and kidney function in mice remained within normal ranges. This demonstrates that the anticancer Ganoderma extract is safe, non-toxic, and possesses excellent safety profiles.

4.3. Clinical experience feedback

Preliminary clinical observations have accumulated some practical usage experience. Feedback indicates that the therapeutic effects of anticancer Ganoderma largely correspond with the efficacy observed in animal studies. Patients using anticancer Ganoderma not only experienced a certain degree of inhibition of cancer cell growth, but also showed improved immune function. Overall, the therapeutic outcomes were encouraging, providing strong practical support for the further clinical application and promotion of anticancer Ganoderma.

5. Conclusions and outlook

This study successfully developed and validated an innovative cultivation system for anticancer *Ganoderma lucidum* based on the synergistic bio-enhancement strategy of "TCM compound substrate — enzymatic pretreatment — CRISPR-Cas9 gene editing — transgenic metabolic optimization." The integration of four core technologies represents the most significant technical innovation of this research:

Functionalized substrate provides the material basis and source of synergistic effects.

Enzymatic pretreatment overcomes the bottleneck of bioavailability.

CRISPR-Cas9 gene editing enables precise and intelligent engineering of the membrane transport system (enhanced uptake, removal of restrictions, and construction of tunable permeability), representing a pioneering achievement in the field.

Transgenic metabolic optimization allows synergistic enrichment of endogenous and exogenous active components and targeted storage in the fruiting bodies.

The resulting synergistically bio-enhanced anticancer *Ganoderma lucidum* demonstrates a breakthrough in anticancer efficacy compared with traditional Ganoderma, achieving effects comparable to chemical drugs while retaining the advantages of natural origin, safety, multi-target activity, relatively low cost, and scalability. This study not only provides a highly effective anticancer candidate but also establishes an innovative paradigm for

using synthetic biology and advanced biotechnologies to modify medicinal fungi and develop a new generation of biopharmaceuticals.

Future research will focus on elucidating the molecular pharmacological mechanisms underlying its multi-component, synergistic anticancer effects, continuously optimizing cultivation processes to improve yield and quality stability, and advancing standardized clinical trials to accelerate its translation into a safe and effective anticancer therapy. This synergistically bio-enhanced *Ganoderma lucidum* represents a highly promising development direction in the field of cancer biotherapy.

As a traditional medicinal fungus, *Ganoderma lucidum* holds tremendous potential in anticancer applications. Through innovative cultivation methods, this study successfully developed a broad-spectrum anticancer Ganoderma, providing new strategies and approaches for cancer treatment. Animal experiments and preliminary clinical observations confirmed its significant anticancer efficacy and excellent safety profile. With further research and clinical trials, this anticancer *Ganoderma lucidum* is expected to become a safe and effective therapeutic option for cancer patients.

Disclosure statement

The authors declare no conflict of interest.

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