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Effect of low-dose gamma irradiation on pathogen viability and proliferation in mushrooms

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Abstract
Mushrooms are highly perishable commodities prone to microbial contamination, resulting in significant post-harvest losses. Gamma irradiation has emerged as a non-thermal preservation method to reduce microbial load and extend the shelf life of fresh produce. This study investigates the effects of low-dose gamma irradiation (1–2 kGy) on pathogen viability and proliferation in mushrooms. Results demonstrate a significant reduction in microbial populations, including spoilage-causing bacteria and fungi, while maintaining sensory and nutritional quality. The findings highlight the potential of gamma irradiation as a sustainable approach to managing post-harvest losses in mushrooms.

Keywords: Mushrooms, Highly perishable commodities, microbial contamination, post-harvest losses, gamma irradiation, non-thermal preservation

Introduction
m Mushrooms are highly valued for their nutritional content and culinary versatility but are highly susceptible to microbial spoilage due to their high moisture content and porous structure. The rapid growth of spoilage-causing microorganisms, including bacteria and fungi, shortens the shelf life of mushrooms, leading to economic losses and increased food waste. Conventional preservation methods, such as refrigeration and chemical treatments, have limitations in effectively controlling microbial contamination without compromising quality.

Gamma irradiation offers a promising solution to these challenges. By exposing food to ionizing radiation, gamma irradiation inactivates microorganisms by damaging their DNA, inhibiting their ability to reproduce. This non-thermal method is effective at low doses (1–2 kGy) for microbial decontamination while preserving the sensory and nutritional qualities of food. This study aims to evaluate the efficacy of low-dose gamma irradiation in reducing pathogen viability and proliferation in mushrooms, focusing on its potential as a sustainable post-harvest management strategy.

Objective
The objective of this paper is to evaluate the effectiveness of low-dose gamma irradiation (1–2 kGy) in reducing microbial contamination and extending the shelf life of mushrooms while preserving their sensory and nutritional qualities, with a focus on its potential as a sustainable post-harvest management strategy.

Materials and Methods
Fresh mushrooms were purchased from Souq al Arabi in Khartoum, Sudan. The samples were washed, air-dried, and divided into three groups:

- Control (no irradiation)
- Irradiated at 1 kGy
- Irradiated at 2 kGy

Gamma Irradiation
Gamma irradiation was performed using a Cobalt-60 source at a dose rate of 1.2 kGy/hour. The samples were irradiated at 1 kGy and 2 kGy doses in a certified irradiation facility.

Microbial Analysis: Microbial loads were quantified by homogenizing mushroom samples in sterile saline, followed by serial dilution and plating on nutrient agar and potato dextrose agar. Plates were incubated at 30 °C for 48 hours, and colony-forming units (CFU) were enumerated.

Sensory and Nutritional Evaluation: Sensory quality (texture, color, and odor) was assessed by a trained panel using a hedonic scale. Nutritional parameters, including protein and vitamin C content, were measured using standard AOAC methods.

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Results and Discussion

Table 1: Macronutrient Composition of Lactarius deliciosus Post-Irradiation and Storage

Irradiation Dose (kGy)	Storage Time (Days)	Protein (%)	Fat (%)	Carbohydrates (%)	Energy (kcal/100g)
0.0	0	3.50	0.30	4.50	37
0.0	4	3.45	0.28	4.40	36
0.0	8	3.40	0.25	4.30	35
0.5	0	3.48	0.29	4.48	36
0.5	4	3.43	0.27	4.38	35
0.5	8	3.38	0.24	4.28	34
1.0	0	3.46	0.28	4.46	36
1.0	4	3.41	0.26	4.36	35
1.0	8	3.36	0.23	4.26	34

The microbial load in mushrooms showed a significant reduction with increasing doses of gamma irradiation. The bacterial load in the control group was 10^6 CFU/g, which decreased by 75% to 2.5×10^5 CFU/g at 1 kGy and by 95% to 5×10^4 CFU/g at 2 kGy. Similarly, the fungal load in the control group was 10^5 CFU/g, which reduced by 60% to 4×10^4 CFU/g at 1 kGy and by 90% to 1×10^4 CFU/g at 2 kGy. These findings demonstrate a dose-dependent efficacy of gamma irradiation, with 2 kGy providing the most substantial reduction in both bacterial and fungal populations. This reduction highlights the effectiveness of gamma irradiation as a tool for controlling microbial contamination in mushrooms, making it a viable method for enhancing food safety.

Table 2: Antioxidant Activity (EC_{50} values in mg/mL) of Lactarius deliciosus Post-Irradiation and Storage

Irradiation Dose (kGy)	Storage Time (Days)	DPPH Scavenging	Reducing Power	Lipid Peroxidation Inhibition
0.0	0	1.20	0.80	0.90
0.0	4	1.30	0.85	0.95
0.0	8	1.40	0.90	1.00
0.5	0	1.22	0.82	0.92
0.5	4	1.32	0.87	0.97
0.5	8	1.42	0.92	1.02
1.0	0	1.25	0.85	0.95
1.0	4	1.35	0.90	1.00
1.0	8	1.45	0.95	1.05

The sensory evaluation scores showed minimal changes across all treatment groups, indicating that gamma irradiation preserves the sensory attributes of mushrooms. The texture score remained constant at 9 for all groups, while the color and odor scores remained consistent at 8, showing no noticeable deterioration due to irradiation. The overall acceptability scores were slightly reduced from 8.3 in the control group to 8.2 and 8.1 at 1 kGy and 2 kGy, respectively. This slight decline in overall acceptability at higher doses was marginal and within acceptable sensory limits. These results suggest that gamma irradiation effectively maintains the sensory quality of mushrooms, making it a consumer-friendly preservation technique.

Discussion

This study demonstrates the efficacy of low-dose gamma irradiation (1–2 kGy) in significantly reducing microbial populations in mushrooms while maintaining sensory and nutritional quality. The data showed a 75% and 95% reduction in bacterial loads at 1 kGy and 2 kGy, respectively, and a corresponding reduction of 60% and 90% in fungal loads. The slight changes in sensory evaluation scores further validate the potential of gamma irradiation as a post-harvest management strategy. Gamma irradiation's ability to inactivate microorganisms can be attributed to the disruption of microbial DNA, preventing their replication. Similar findings have been reported in studies like those by Mahapatra *et al*. (2015) [3], where gamma irradiation at doses of 1–3 kGy effectively reduced microbial loads in mushrooms without compromising sensory attributes. Their research aligns with the current study, emphasizing the dose-dependent reduction of spoilage-causing microorganisms and the retention of texture, color, and nutritional quality.

Another relevant study by Farkas (2006) [2] confirmed that gamma irradiation at doses up to 2 kGy is effective for microbial decontamination in perishable commodities, including mushrooms. Their findings also highlighted the minimal impact on sensory and nutritional properties, supporting the conclusions of this study. Similarly, Ehlermann (2016) [1] observed that irradiation at doses below 3 kGy is well-tolerated by fresh produce, extending shelf life without compromising consumer acceptance.

A notable comparison can be drawn with conventional methods like refrigeration and chemical preservatives. While refrigeration slows microbial growth, it does not actively reduce the initial microbial load. Chemical treatments, on the other hand, often introduce residues that may affect consumer health and acceptability. In contrast, gamma irradiation offers a non-residual, efficient, and sustainable alternative, aligning with the goals of environmentally friendly food preservation.

The sensory evaluation in this study, which revealed no significant differences in texture, color, and odor across all treatment groups, is consistent with the findings of Lorenz and Lal (2014) [5]. Their work demonstrated that gamma irradiation does not induce significant changes in the physical attributes of treated mushrooms, even at slightly higher doses. The slight decline in overall acceptability scores observed in the present study (From 8.3 in control to

8.1 at 2 kGy) can be attributed to marginal, likely undetectable changes in the sensory profile, which were still within acceptable limits.

The nutritional analysis further corroborates findings from previous studies. Minimal changes in protein content (<5% reduction) and the stability of vitamin C levels observed in this study align with results reported by Fageria (2012) [6] and Lorenz (2014) [5], who emphasized the preservation of macro and micronutrients post-irradiation.

Globally, regulatory bodies like the FAO and WHO have endorsed gamma irradiation as a safe food preservation method, with doses up to 10 kGy approved for various applications. This study's focus on low-dose irradiation (1–2 kGy) places it well within safety limits while achieving effective microbial reduction. The findings complement international recommendations and highlight the potential of gamma irradiation for reducing post-harvest losses in mushrooms, especially in regions like Sudan, where cold chain infrastructure may be limited.

The findings of this study reinforce the role of gamma irradiation in improving food safety and extending shelf life, thereby reducing food waste and contributing to food security. In comparison with refrigeration, which requires continuous energy input, gamma irradiation provides a one-time treatment solution with minimal energy requirements during application. This advantage is particularly relevant for developing countries, where energy resources may be constrained.

In conclusion, the results of this study align closely with existing literature, demonstrating that low-dose gamma irradiation is a reliable, efficient, and consumer-acceptable method for managing microbial contamination and extending the shelf life of mushrooms. By comparing this study with relevant research, it is evident that gamma irradiation offers a competitive edge over traditional methods, paving the way for broader applications in the global food industry.

Conclusion

Low-dose gamma irradiation (1–2 kGy) is a promising technique for managing post-harvest losses in mushrooms. It effectively reduces microbial populations, maintains sensory and nutritional quality, and offers a sustainable alternative to conventional preservation methods. These findings support the broader application of gamma irradiation in the food industry to extend the shelf life of perishable commodities.

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