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EFFECT OF BAMBOO SHOOT FERMENT ON THE METHYLCHOLANTHRENE INDUCED CARCINOGENESIS IN THE MORPHOLOGICAL AND HISTOLOGICAL CHARACTERISTICS IN MICE

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ABSTRACT
The present investigation aims to study the inhibitory effects of fermented medium prepared from the bamboo shoot of *Cephalostachyum capitatum* Munro against tumour induction by the hepatocarcinogen 20-methylcholanthrene (MC) in albino mice, *Mus musculus* (L.). Albino mice were induced to develop tumours by a single injection of MC at a dose of 20 mg/kg body weight. MC-induced tumour development occurred in the liver of the mice. Simultaneous treatment of the mice with fermented medium of bamboo shoot fermentation (FM) was started and continued on alternate days for up to 90 days. The growth rate and percentage survival of the FM-treated animals were significantly higher than those of the MC-induced animals. Gradual histopathological changes were observed in the liver, including atrophy of hepatic cells, necrosis and fibroblastic proliferation with numerous spindle-shaped cells in the thickened endothelial lining of the portal areas, cloudy swelling of the hepatic cells, irregular sinusoidal dilation, and dilatation and congestion of the central vein. Abnormal mitotic divisions, isonucleosis and anisocytosis were observed to varying degrees. Hyperchromatism and Kupffer cell hyperplasia were also noted. Simultaneous treatment with FM after MC induction showed that atrophy, cloudy swelling of the hepatic cells, abnormal mitotic divisions, hyperchromatism, and chromatin clumping were gradually restored towards normal. The FM contains bioactive materials such as amino acids, ascorbic acid, vitamins, proteins, glycogen, minerals, phenols, phytosterols, microorganisms, and enzymes. These substances may have a protective role in tissues through antioxidant defence mechanisms and may thus contribute to protection against carcinogenesis.

KEYWORDS: *Cephalostachyum capitatum*, Methylcholanthrene, fermented media, albino mice.

1. INTRODUCTION

Bamboo shoots are widely consumed as traditional food in several Asian countries and constitute an important component of the dietary practices of communities in Northeast India (Ji et al., 2024). In Manipur, young bamboo shoots are consumed both fresh and in fermented forms, including *Shoibum*, *Shoidon* and *Shoijin*. *Cephalostachyum capitatum* Munro is one of the bamboo species traditionally associated with young-shoot consumption in the region (Chongtham, 2019). These products are valued for their characteristic taste, flavour and texture and remain an important component of the indigenous food culture of Manipur (Nongdam & Tikendra, 2014; Behera & Balaji, 2021; Shahni et al., 2026). In addition to their cultural importance, bamboo shoots have attracted scientific interest because of their nutritional composition and diverse phytochemical constituents (Sharmila et al., 2026).

Fermentation is an established method for preserving and transforming perishable plant-based foods. Microbial growth and enzymatic activity during fermentation can modify carbohydrates, proteins, phenolic compounds and other constituents of the raw material, thereby influencing the nutritional, biochemical and functional properties of the resulting product (Voidarou et al., 2020). Fermented bamboo shoots harbour diverse microbial communities, including lactic acid bacteria, which contribute to acidification and the development of characteristic sensory properties (Jeyaram et al., 2010; Siddiqui et al., 2023). Fermentation may also alter the release, transformation and availability of bioactive compounds. In particular, lactic acid bacterial fermentation has been reported to promote the release and biotransformation of bound phenolic compounds in bamboo shoots (Zhang et al., 2025).

Bamboo shoots contain proteins, amino acids, dietary fibre, vitamins, minerals and secondary metabolites, including phenolic compounds, flavonoids and phytosterols. These constituents have been investigated for antioxidant and other biological activities (Nongdam & Tikendra, 2014; Singhal et al., 2021). Fermentation can further modify the composition and availability of these compounds and may consequently influence the

biological properties of the fermented product. Recent experimental evidence has demonstrated biological effects of fermented bamboo-shoot preparations in animal models. For example, fermented bamboo-shoot products were reported to attenuate inflammatory responses and modulate gut microbiota and microbial metabolites in mice with dextran sulfate sodium-induced ulcerative colitis (Lu et al., 2025). Such findings indicate that fermentation can influence the biological properties of bamboo-shoot products; however, evidence from one experimental model cannot be directly extrapolated to anticancer activity.

Cancer is a complex group of diseases characterized by uncontrolled cellular proliferation, altered cellular regulation and progressive changes in tissue organization. Oxidative stress, chronic inflammation, genomic instability and dysregulation of cellular signalling are among the processes associated with carcinogenesis (Reuter et al., 2010). Natural products and food-derived bioactive compounds have therefore received considerable attention as potential sources of chemopreventive and anticancer agents because of their diverse chemical structures and biological activities (Asma et al., 2022). The presence of these bioactive constituents provides a scientific basis for investigating the potential protective effects of fermented bamboo-shoot preparations against chemically induced carcinogenesis using appropriate experimental models (Chongtham et al., 2014).

Experimental chemical carcinogenesis models provide controlled systems for investigating carcinogen-induced cellular and tissue alterations and for evaluating potential protective interventions (Tejaswi et al., 2026). Polycyclic aromatic hydrocarbons (PAHs) constitute an important class of chemical carcinogens, and methylcholanthrene has been widely used in experimental carcinogenesis. 3-Methylcholanthrene, also referred to as 20-methylcholanthrene (MC), undergoes metabolic activation to reactive intermediates that can interact with cellular macromolecules, including DNA, and thereby contribute to mutagenic and carcinogenic processes (Moorthy et al., 2015). The biological response to chemical carcinogens depends on factors such as dose, route of administration, duration of exposure and tissue susceptibility. Consequently, morphological and histopathological examination provides an important means of assessing carcinogen-associated tissue injury and structural alterations (Clewell et al., 2019).

Although considerable research has examined the nutritional composition, microbial characteristics and antioxidant properties of bamboo shoots and fermented bamboo-shoot products, comparatively limited information is available concerning the effects of fermented *C. capitatum* preparations on carcinogen-associated hepatic alterations (Singhal et al., 2021). This knowledge gap is particularly relevant in Manipur, where fermented bamboo-shoot products are traditionally consumed and represent important indigenous food resources. Their nutritional composition and fermentation-associated biochemical transformations provide a rationale for investigating their biological effects under controlled experimental conditions. Nevertheless, traditional consumption and the presence of potentially bioactive constituents cannot establish protection against carcinogenesis without experimental evidence.

Therefore, the present study investigated the effects of a fermented medium prepared from young shoots of *Cephalostachyum capitatum* Munro in albino mice exposed to 20-methylcholanthrene. Changes in body growth and survival were evaluated, together with morphological and histopathological alterations in the liver following MC exposure and treatment with the fermented bamboo-shoot preparation. The study specifically examined whether treatment with the fermented medium was associated with attenuation of MC-induced hepatic alterations and restoration of tissue morphology towards normal conditions. The findings contribute to the experimental evaluation of a traditionally consumed fermented bamboo-shoot preparation and provide scientific evidence concerning its potential protective or ameliorative effects against carcinogen-associated hepatic changes.

2. MATERIALS AND METHODS

2.1. Collection of bamboo shoots

Young shoots of *Cephalostachyum capitatum* Munro (NAT-in Manipur), measuring 28 ± 1.5 cm in length and approximately 2 cm in diameter, were collected from Bishnupur Market, Manipur, India, located approximately 30 km from Imphal. Freshly collected shoots were transported to the laboratory and processed for the preparation of raw and fermented bamboo-shoot samples.

2.2. Experimental animals

Healthy male albino mice (*Mus musculus* L.), weighing 27 ± 1.5 g, were procured from a CCSEA-registered animal breeding facility and maintained at the Department of Life Sciences, Manipur University, for one month prior to experimentation for acclimatization. Animals were provided a standard mouse diet and water *ad libitum* and maintained at 25–28°C, with a 12:12 h light–dark cycle and 70-80% relative humidity. Mice were housed individually in clean, well-ventilated polypropylene cages (approximately 2.5 × 1.5 ft) containing rice-husk bedding. Standard hygienic conditions were maintained throughout the study, and unnecessary handling was minimized.

All experimental procedures were performed in accordance with the guidelines of the Institutional Animal Ethics Committee (IAEC), Manipur University, under the regulatory framework of the Committee for Control and Supervision of Experiments on Animals (CCSEA), Ministry of Fisheries, Animal Husbandry and Dairying, Government of India. The experimental protocol was approved by the IAEC, Manipur University (Approval No. MU/Dean/LSc/IAEC/Cert/2022/03). Only healthy male mice without apparent signs of disease were included. A total of 27 mice were used and randomly allocated to three experimental groups (n = 9 per group). The experimental design and group allocation were established before commencement of the study.

2.3. Experimental carcinogen

3-Methylcholanthrene (3-MC), also referred to as 20-methylcholanthrene (20-MC), obtained from Sigma Chemical Company, USA, was used as the carcinogenic agent for induction of carcinogenic changes in mice.

2.4. Reagents and chemicals

All reagents and chemicals used in the study were of analytical reagent (AR) grade. Double-distilled water obtained using a glass-distillation system was used throughout the experimental procedures.

2.5. Preparation of raw bamboo-shoot extract

Fresh young bamboo shoots were cut into thin slices and washed two to three times with distilled water. The sliced material (1 g) was homogenized with 10 mL of distilled water using a mortar and pestle, maintaining a sample-to-solvent ratio of 1:10 (w/v). The homogenate was filtered, and the resulting filtrate, with a pH of 6.4, was used for subsequent biochemical analyses.

2.6. Preparation of fermented bamboo-shoot medium

For the preparation of the fermented medium, young bamboo shoots were cut into thin slices and soaked in distilled water at a ratio of 1:10 (w/v) in a glass jar with a lid. The material was allowed to ferment for 10 days at 37°C. After 10 days, the liquid portion became milky white and acidic, with a reported pH of 4.8 ± 2.

2.7. Preparation of Fermented Product Extract

The thin sliced bamboo shoots were soaked in a glass jar and maintained at 37°C for 10 days. After fermentation, the resulting solid fermented product was collected and used for the preparation of the fermented product extract. One gram of the fermented product was homogenized with 10 mL of distilled water using a mortar and pestle. The homogenate was filtered, and the resulting filtrate was used for biochemical analysis.

2.8. Biochemical Analysis

The moisture content was determined using the hot-air oven method described by Hart and Fisher (1971). Acidity was estimated according to the method of AOAC (1970). Reducing sugars were determined following the method of Trinder (1972). Ascorbic acid content was estimated using the method of Roe and Kuether (1943). Calcium was estimated according to Ranganna (1979), while total acid content was determined following the method of Moore and Stein (1948). Riboflavin content was estimated using the method described by Bray and Thorpe (1954). Sodium, potassium and iron contents were determined using a flame photometer (Corning, USA) following the method of Corning (1956). The pH was measured using a Systronics digital pH meter according to the method described by Valsam (1975). Total amino acids were estimated using the ninhydrin method following the procedure of Moore and Stein (1948). Total protein content was determined using the Biuret method with a monoreagent. Total phenolic content was estimated following the method of Bray and Thorpe (1954).

2.9. Microbial Quality

The total bacterial count was determined by the dilution-plate method described by APHA (1976), using tryptone glucose agar medium adjusted to pH 7.0.

2.10. Detection of Pathogenic Bacteria

The presence of potentially pathogenic or indicator bacteria, including faecal streptococci, *Staphylococcus aureus*, *Bacillus cereus*, coliforms, *Escherichia coli* and *Salmonella*, was investigated according to the methods described by APHA (1976).

2.11. Induction of Cancer

(a) Induction of carcinogenesis

A single dose of 3-methylcholanthrene (3-MC; also known as 20-methylcholanthrene) was administered by intraperitoneal injection at a dose of 20 mg/kg body weight for induction of carcinogenesis. For preparation of the injection solution, 0.6 mg of 3-MC was dissolved in 1 mL of olive oil.

(b) Experimental groups

The experiment comprised three groups, with nine animals per group (n = 9), giving a total of 27 animals.

Group I (Control): Animals were maintained as untreated controls.

Group II (3-MC-treated): Animals received a single intraperitoneal injection of 3-methylcholanthrene (3-MC) at a dose of 0.6 mg/animal to induce carcinogenesis.

Group III (3-MC + FM-treated): Following 3-MC induction, animals received 0.5 mL of fermented bamboo-shoot medium (FM) orally on alternate days throughout the treatment period.

(c) Assessment of body weight, mortality and behavioural changes

To assess morphological changes during the experimental period, the body weight of each animal was measured using a digital electronic balance at 15-day intervals. Mortality and general behavioural changes were monitored throughout the experimental period by direct observation.

(d) Collection of tissues

At the end of the experimental period, the animals were sacrificed, and the liver was carefully removed and collected for subsequent morphological, histopathological and other analyses.

2.12. Histopathological Experiments

Buffered 10% neutral formalin was used as the tissue fixative. Liver tissues were fixed in 10% neutral formalin and subsequently processed using standard tissue-processing and dehydration procedures as described by Gurr (1953). Following processing, the tissues were embedded, sectioned, and stained with Delafield's haematoxylin and eosin (H&E) for evaluation of nuclear and cytoplasmic alterations. For cytomorphological examination of

blood cells, Wright's stain was used. Histological sections were examined microscopically and photographed using an Olympus trinocular photomicroscope.

2.13. Statistical Analysis

Experiments were carried out in triplicate and data were represented as Mean ± Standard error (SEM). Statistical Analysis were carried out using GraphPad Prism Version 10.0. A value of $P<0.05$ was considered statistically significant. Different Superscript letters indicate significant differences among groups, whereas values sharing the same superscript letter are not significantly different ($P\geq0.05$).

3. Results and Discussion

Fermentation produced marked biochemical and microbiological changes in the Cephalostachyum capitatum bamboo-shoot preparation. The fermented medium showed higher protein, total amino acids, ascorbic acid, riboflavin, calcium, iron, potassium, sodium and total phenolic contents than the raw extract, whereas reducing sugars decreased markedly. In parallel, pH declined from 6.50 ± 1.00 in the raw extract to 3.80 ± 0.60 in the fermented medium, while total acidity increased from 0.14 ± 0.041% to 0.28 ± 0.036%. These changes are consistent with microbial utilization of fermentable substrates and production of acidic metabolites during bamboo-shoot fermentation (Jeyaram et al., 2010; Singhal et al., 2021). The total bacterial population increased from 10^2-10^4 CFU/g in the raw extract to approximately 10^6 CFU/g in the fermented medium, further supporting active microbial proliferation during fermentation. Similar associations between microbial activity, acidification and biochemical transformation have been reported in fermented bamboo-shoot products (Jeyaram et al., 2010; Li et al., 2023; Jian et al., 2024).

The increase in total phenolic content from 1.05 ± 0.10 to 2.21 ± 0.04 mg/100 mL is particularly relevant because fermentation has been reported to modify the availability of bamboo-shoot phenolics. Singhal et al. (2021) reported changes in phenolic and antioxidant characteristics following fermentation, while Zhang et al. (2025) demonstrated release and biotransformation of bound phenolic compounds during lactic acid bacterial fermentation. However, the present total phenolic assay does not identify individual compounds; therefore, the observed increase represents a compositional change rather than direct evidence of enhanced antioxidant or anticancer activity.

Table 1. Biochemical composition of raw bamboo-shoot extract, fermented product extract and fermented medium

Parameter	Raw bamboo-shoot extract	Fermented product extract	Fermented medium
Moisture content (mg/100 mL)	30.18 ± 0.04^a	35.85 ± 0.09^b	72.16 ± 0.60^c
pH	6.50 ± 1.00^a	4.40 ± 0.80^b	3.80 ± 0.60^c
Protein (mg/100 mL)	0.83 ± 0.03^a	4.01 ± 0.03^b	5.11 ± 0.04^c
Total amino acids (mg/100 mL)	2.40 ± 0.04^a	3.21 ± 0.04^b	4.30 ± 0.17^c
Reducing sugar (mg/100 mL)	53.53 ± 0.09^a	6.39 ± 0.37^b	6.39 ± 0.37^b
Ascorbic acid (mg/100 mL)	0.45 ± 0.04^a	0.95 ± 0.04^b	1.98 ± 0.03^c
Riboflavin (mg/100 mL)	1.16 ± 0.04^a	1.32 ± 0.12^b	8.12 ± 0.66^c
Calcium (mg/100 mL)	0.51 ± 0.05^a	0.80 ± 0.03^b	1.20 ± 0.04^c
Iron (mg/100 mL)	0.36 ± 0.02^a	0.56 ± 0.05^b	0.97 ± 0.03^c
Potassium (mg/100 mL)	0.08 ± 0.04^a	1.02 ± 0.03^b	1.36 ± 0.04^c
Sodium (mg/100 mL)	0.41 ± 0.04^a	0.72 ± 0.05^b	0.86 ± 0.04^c
Phenol (mg/100 mL)	1.05 ± 0.10^a	1.80 ± 0.03^b	2.21 ± 0.04^c
Alkaline phosphatase (IU/L)	25.89 ± 0.56^a	16.60 ± 4.04^b	34.60 ± 21.77^c
Aspartate aminotransferase (ASAT) (IU/L)	79.94 ± 3.45^a	14.09 ± 5.03^b	50.71 ± 43.71^c
Alanine aminotransferase (ALAT) (IU/L)	20.01 ± 43.71^a	27.03 ± 26.27^b	44.62 ± 42.69^c
Total acidity (% lactic acid)	0.14 ± 0.041^a	0.24 ± 0.038^b	0.28 ± 0.036^c

Values are expressed as mean ± standard deviation (SD) of three independent replicates (n = 3). Different superscript lowercase letters (a, b, c) within a row indicate statistically significant differences among groups ($p < 0.05$). Values sharing the same superscript letter are not significantly different.

Following 3-MC exposure, the animals showed progressive deterioration in general appearance, reduced activity and body weight, together with marked increases in liver weight and visible hepatic lesions. Body weight declined from 30.10 g to 24.00 g in the 3-MC group, whereas FM-treated animals increased from 24.70 g at day 90 to 28.90 g at day 180. Liver weight in the 3-MC group increased from 1.17 g to approximately 3.06 g, while that of the FM-treated group decreased from 2.70 g at day 90 to 1.50 g at day 180. These changes indicate substantial systemic and hepatic alterations following prolonged 3-MC exposure and a temporal association between FM administration and improvement in several gross physiological parameters.

Histopathological examination further demonstrated disruption of normal hepatic architecture following 3-MC exposure, including hepatocellular degeneration, cytoplasmic swelling and vacuolation, nuclear pleomorphism,

anisocytosis, anisonucleosis, vascular dilation, hyperplastic nodular changes, abnormal mitotic figures and areas of necrosis. These findings are compatible with the hepatic cellular stress associated with 3-MC exposure. Previous studies have reported increased hepatic reactive oxygen species and lipid peroxidation together with altered antioxidant responses following 3-MC administration (Jin et al., 2014), while 3-MC-mediated activation of AhR and xenobiotic-metabolizing pathways has also been documented (Moorthy et al., 2015). However, oxidative-stress and molecular markers were not measured in the present study; therefore, these mechanisms cannot be directly confirmed.

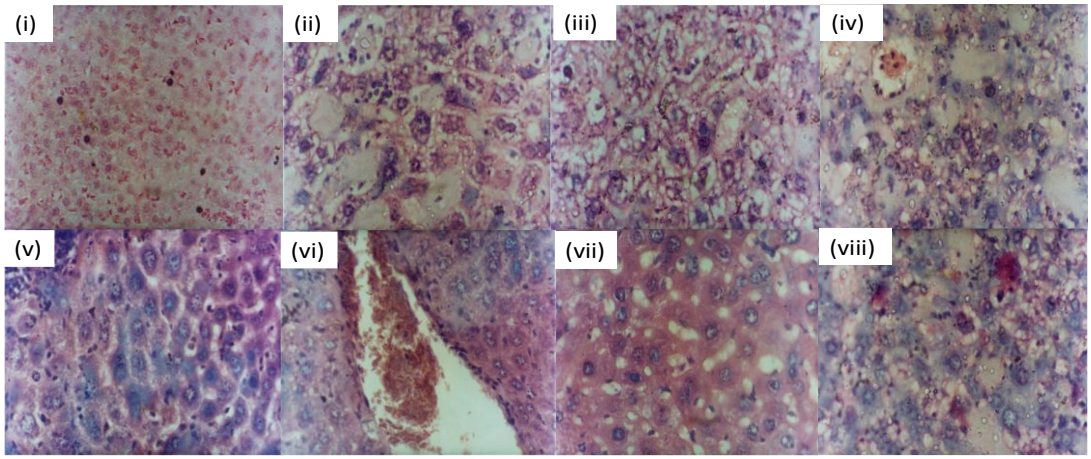
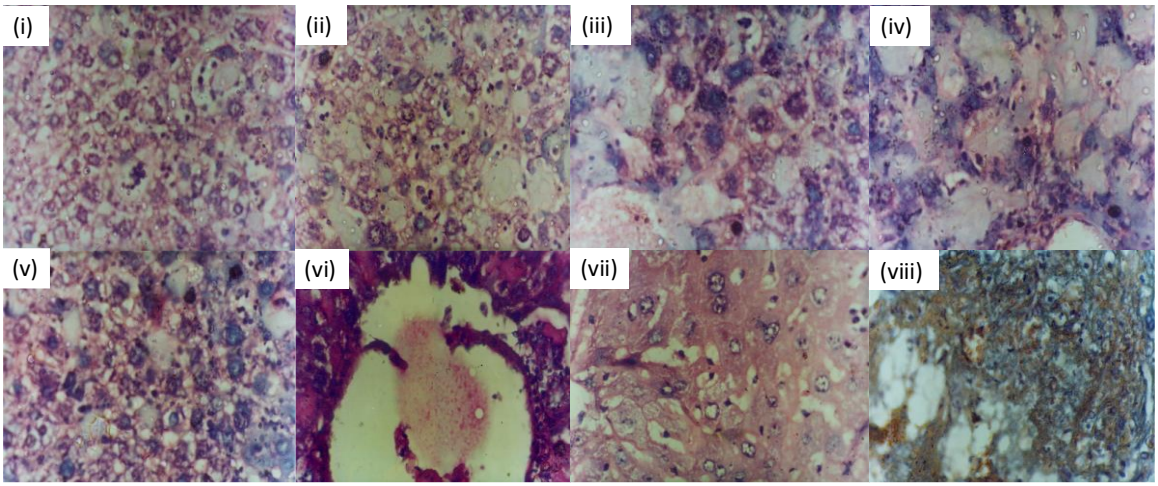


Figure 1. Histopathological alterations in the liver of 3-methylcholanthrene (MC)-treated rats (second set). Representative photomicrographs of hematoxylin and eosin (H&E)-stained liver sections showing: (i) normal hepatic architecture with preserved hepatocytes in the control group; (ii) loss of normal lobular architecture in MC-treated rats; (iii) hepatocellular swelling with cloudy cytoplasm; (iv) chromatin attachment/condensation along the nuclear membrane; (v) cellular pleomorphism and nuclear enlargement; (vi) dilation of the central vein; (vii) anisokaryosis and anisocytosis of hepatocytes; and (viii) proliferation of connective tissue in the liver. Magnification: ×490 for (i-ii) and ×450 for (iii-viii).

Figure 2. Histopathological alterations in the liver of MC-treated rats (second set) after 90 days. Representative photomicrographs of hematoxylin and eosin (H&E)-stained liver sections showing: (i) foamy structure in the cytoplasm of liver cells; (ii) wide foci of hyperplastic nodules in the liver; (iii) sinusoidal dilation with Kupffer cell hyperplasia; (iv) elongated hepatic cells surrounding the hepatic nodules; (v) irregular mitotic division with enlarged nuclei in hepatocytes; (vi) enlarged thrombosis of blood vessels in the periportal area; (vii) chromatin clumping in the nuclei of liver cells; and (viii) formation of necrotic hepatic cells. All sections were stained with H&E and examined at ×450 magnification.



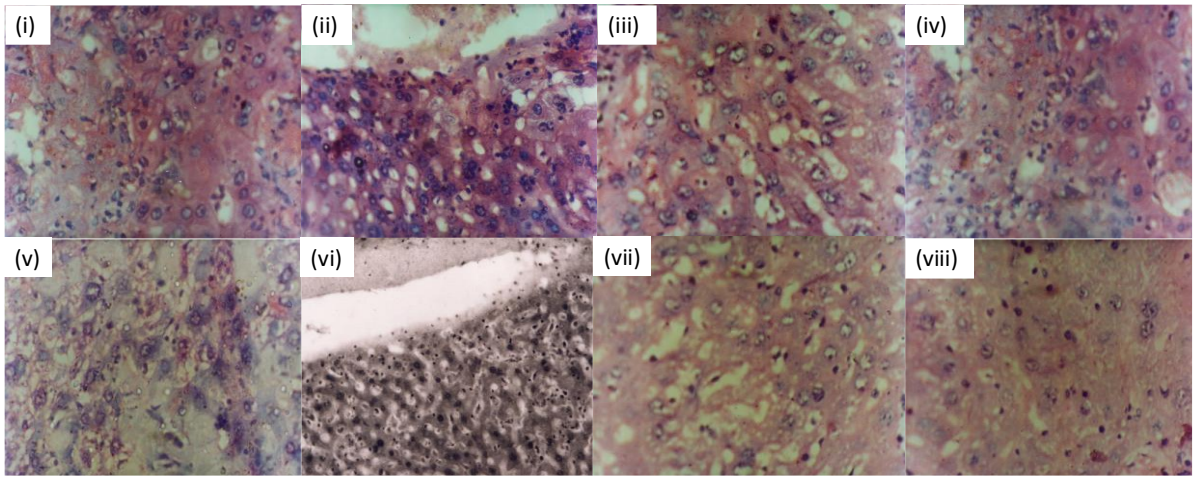


Figure 3. Histopathological changes in the liver of rats after 90 days of simultaneous treatment with 3-methylcholanthrene (MC) and fermented medium (third set). Representative photomicrographs of hematoxylin and eosin (H&E)-stained liver sections showing: (i) restoration of cloudy swelling of the cytoplasm of hepatocytes towards the normal state; (ii) restoration of irregular dilation of the central vein towards normal morphology; (iii) absence of hyperplastic nodular hepatocytes; (iv) gradual restoration of normal mitotic division in hepatocytes; (v) gradual restoration of necrotic hepatocytes towards normal morphology; (vi) restoration of dilated hepatic veins towards the normal state; (vii) restoration of hyperchromatism and abnormal mitotic activity towards normal cellular morphology; and (viii) recovery of necrotic hepatocytes with restoration of anisokaryosis and anisocytosis. All sections were stained with H&E and examined at ×450 magnification.

In contrast, FM-treated animals showed reduced cytoplasmic degeneration, fewer conspicuous abnormal mitotic figures, reduced necrotic areas and improved vascular and hepatocellular morphology. Greater cellular and nuclear uniformity was also observed, with no prominent hyperplastic nodular lesions in the examined sections. Collectively, these findings indicate partial attenuation of the hepatic morphological alterations associated with 3-MC exposure. Nevertheless, the findings should be interpreted as morphological evidence of improvement rather than definitive proof of hepatoprotection, tumour regression or inhibition of carcinogenesis. The observed response may reflect the combined effects of nutritional and phytochemical changes associated with fermentation, but the contribution of individual constituents cannot be established from the present data alone.

Table 2. Changes in body weight and liver weight of experimental mice during the experimental period. Body weight and liver weight of mice in the control, 3-MC-induced and fermented-medium-treated groups monitored over 180 days (n = 9 per group).

No. of days	**Body weight (g)**			**Liver weight (g)**		
	Control	3-MC induced	Fermented-medium treated	Control	3-MC induced	Fermented-medium treated
0	30.40^{a}	30.10^{a}	29.80^{b}	1.18^{a}	1.17^{b}	1.15^{c}
15	30.40^{a}	30.10^{a}	29.75^{b}	1.18^{a}	1.17^{b}	1.15^{c}
30	32.00^{b}	29.00^{a}	29.20^{a}	1.18^{b}	1.41^{a}	1.17^{c}
45	34.60^{b}	28.40^{a}	28.70^{a}	1.18^{c}	1.48^{a}	1.19^{b}
60	35.40^{b}	27.90^{a}	27.00^{a}	1.18^{c}	2.16^{a}	2.14^{b}
75	35.80^{b}	26.50^{a}	26.80^{a}	1.18^{c}	2.66^{a}	2.40^{b}
90	36.10^{b}	25.00^{a}	24.70^{a}	1.19^{c}	3.00^{a}	2.70^{b}
105	36.30^{b}	25.00^{a}	25.50^{a}	1.20^{c}	3.02^{a}	2.30^{b}
120	36.92^{b}	24.80^{a}	26.10^{a}	1.20^{c}	3.02^{a}	2.00^{b}
135	37.10^{a}	24.70^{c}	26.70^{b}	1.21^{c}	3.04^{a}	1.90^{b}
150	37.52^{a}	24.60^{c}	27.50^{b}	1.21^{c}	3.05^{a}	1.80^{b}
165	37.54^{a}	24.44^{c}	28.70^{b}	1.22^{c}	3.05^{a}	1.60^{b}
180	37.60^{a}	24.00^{c}	28.90^{b}	1.23^{c}	3.06^{a}	1.50^{b}
Overall change (%)	+23.68	−20.27	−3.02	+4.24	+161.54	+30.43

Values are expressed as mean ± SEM (n = 9 mice per group). Values sharing the same superscript letter are not significantly different (P > 0.05).

Overall, fermentation substantially modified the biochemical and microbial characteristics of the bamboo-shoot preparation, while FM administration was associated with improvement in body weight, liver weight and several histopathological abnormalities following 3-MC exposure. The findings provide preliminary evidence of an

ameliorative association but do not establish a specific molecular mechanism. LC-MS/MS-based metabolite profiling, together with quantitative histopathological scoring and biochemical and molecular analyses of oxidative stress, inflammation, apoptosis, proliferation and AhR/CYP-associated pathways, would be valuable for identifying the constituents and mechanisms potentially underlying the observed response.

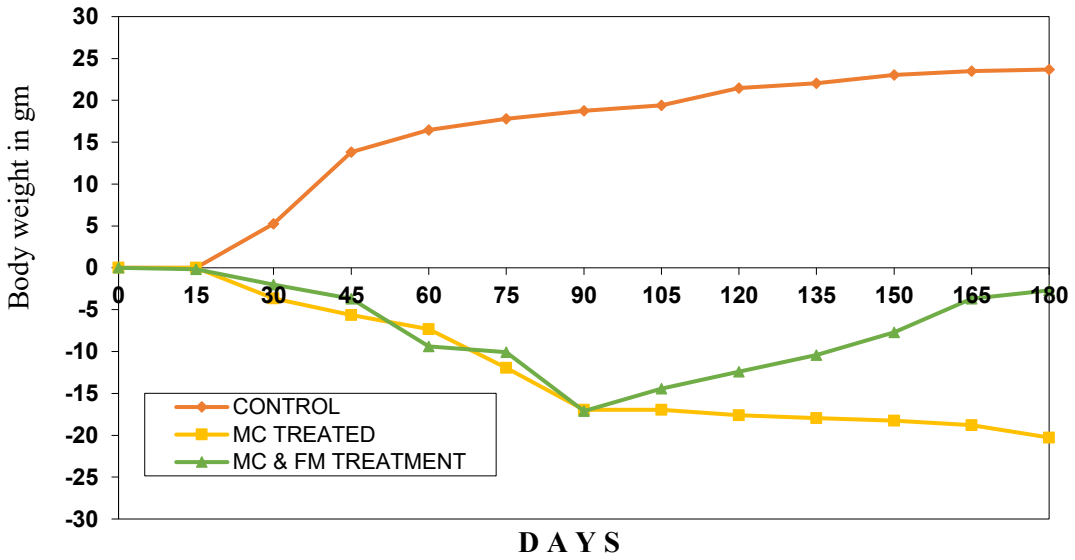


Fig. 2: *Graph showing the increase in body weight of the 3-sets of experimental animals. Changes in body weight of control, 3-MC-induced, and fermented-medium-treated mice during the experimental period. Values represent the mean of three replicates.*

4. CONCLUSION

The fermented medium (FM) exhibited higher levels of several nutritional and bioactive constituents, including amino acids, protein, riboflavin, ascorbic acid, minerals and phenolic compounds, compared with the raw bamboo-shoot and fermented product extracts. In 3-MC-induced Swiss mice, FM administration was associated with improved body-weight trends, reduced liver weight and progressive restoration of hepatic tissue architecture, particularly during the 90–180-day treatment period. These findings suggest a potential protective effect of fermented bamboo-shoot medium against carcinogen-associated hepatic alterations, possibly through the combined action of its antioxidant and fermentation-derived bioactive constituents. However, the absence of specific tumour and molecular biomarkers limits mechanistic interpretation. Further metabolomic, oxidative-stress and molecular studies are warranted to identify the active constituents and underlying mechanisms.

Authors' Contributions

O.R.D.: Conceptualization, methodology, investigation, data collection, and original manuscript preparation; P.N.: Methodology, investigation, data analysis, and manuscript review; K.S.: Data analysis, Conceptualization, literature review, visualization, and original manuscript preparation; J.L.: Investigation, data curation, and manuscript review; K.B.S.: Supervision, conceptualization, project administration, and critical revision of the manuscript; All authors read and approved the final version of the manuscript.

Funding: The authors received no external funding for this study.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Head, Department of Zoology, Manipur University, for providing essential facilities and continuous support throughout the study. The authors sincerely thank Prof. H. Tombi Singh and Prof. Ch. Sarojnalini Devi, Manipur University, for their constant inspiration, guidance, and support during the investigation. The authors also express their sincere gratitude to Dr. Sh. Surchandra Sharma, JNIMS, Imphal, for his valuable assistance in identifying and interpreting the histological changes observed in the experimental mice. The authors further acknowledge the Research Team of the DBT-BUILDER Manipur University Interdisciplinary Life Science Programme for Advanced Research and Education, funded by the Department of Biotechnology (DBT), New Delhi, for their valuable guidance and support in the development and refinement of the research concept.

Conflict of Interest

The authors declare no conflicts of interest

Abbreviations

3-MC	3-Methylcholanthrene
FM	Fermented Medium
ASAT (AST)	Aspartate Aminotransferase
ALAT (ALT)	Alanine Aminotransferase
ALP	Alkaline Phosphatase
H&E	Haematoxylin and Eosin
PAHs	Polycyclic Aromatic Hydrocarbons
SD	Standard Deviation
SEM	Standard Error of the Mean
IAEC	Institutional Animal Ethics Committee
CPCSEA	Committee for Control and Supervision of Experiments on Animals
DBT	Department of Biotechnology
JNIMS	Jawaharlal Nehru Institute of Medical Sciences
IU/L	International Units per Litre
mg/100 mL	Milligrams per 100 Millilitres
DNA	Deoxyribonucleic Acid
ROS	Reactive Oxygen Species

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