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يسر **معامل التأثير والاستشهادات المرجعية للمجلات العلمية العربية (ارسيف – ARCIF)**، أحد مبادرات قاعدة بيانات **"معرفة"** للإنتاج والمحتوى العلمي، إعلامكم بأنه قد **أطلق التقرير السنوي التاسع للمجلات للعام 2024**.

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الجزء الثانى :

أولاً : بحوث علمية محكمة باللغة العربية :

Treatment effect of germinated and fermented radish seeds on cadmium toxicity in experimental rats

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Abstract
The study aims to evaluate the effect of germinated and fermented red radish seeds in alleviating liver and kidney toxicity induced by cadmium in experimentalrats. The results showed that red radish seeds contributed to reducing the elevated levels of certain biochemical markers such as ALT, AST, urea, creatinine, and MDA, while increasing the activity of antioxidant enzymes, leading to a reduction in organ damage, particularly when both .germinated and fermented seeds were used together

Keywords: Detoxification, Seeds, radish, Germination, Fermentation, Cadmium

ملخص:
العنوان : تأثير العلاج ببذور الفجل المنبتة والمخمرة على سمية الكادميوم في فئران التجارب
المؤلفون : عبور محمد محمد عبد الرحمن ، محمد حمدى حجاج ، مروة فريد محمد عبد العليم ، رفيدة طه إسماعيل
تهدف الدراسة إلى تقييم تأثير بذور الفجل الأحمر المنبتة والمخمرة في التخفيف من سمية الكبد والكلى الناجمة عن الكادميوم في فئران التجارب. أظهرت النتائج أن بذور الفجل الأحمر ساهمت في تقليل ارتفاع مستويات بعض المركبات الكيميائية مثل ALT وAST واليوريا والكرياتينين وMDA، كما زادت نشاط إنزيمات مضادة للأكسدة، مما أدى إلى تقليل تلف الأعضاء، خاصة عند استخدام البذور المنبتة والمخمره معا.

الكلمات الدالة : إزالة السمية، بذور، الفجل، الإنبات، التخمير، الكادميوم.

INTRODUCTION

Heavy metals, particularly cadmium (Cd), are toxic elements that adversely affect biological functions in plants, animals, and humans. Classified as human carcinogens, cadmium exposure is mainly associated with lung cancer but is also linked to prostate and renal cancers, with established safety guidelines for drinking water, food, and air exposure **(Sperdouli *et al.*, 2022).** Chronic exposure can lead to significant health issues, including respiratory damage and kidney accumulation, affecting bone density and leading to skeletal lesions **(Singh *et al.*, 2021; Zhu *et al.*, 2024).** Treatment typically involves chelating agents like EDTA, often enhanced with antioxidants for better effectiveness **(Gil *et al.*, 2011).**

Radish (*Raphanus sativus*), belonging to the Brassicaceae family, is valued for its taproots, which are rich in bioactive compounds, including flavonoids and glucosinolates. Germination significantly enhances the nutritional profile of radish seeds, increasing their levels of antioxidants like phenolic acids and flavonoids, making them a vital functional food that can help protect against diseases **(Vicente-Sánchez *et al.*, 2024).** Studies indicate that germination can boost the total phenolic content of radish seeds by 206%, leading to increased antioxidant activity **(Duenas *et al.*, 2009).** This makes radish sprouts a rich source of phytochemicals, surpassing the nutritional value of mature plants **(Gamba *et al.*, 2021).**

Fermentation, particularly lactic acid fermentation, is another method to enhance the nutritional value and shelf life of radish. This process, carried out by lactic acid bacteria, not only preserves food but also creates health-enhancing products, making fermented radish widely consumed across various cultures **(Ahmed *et al.*, 2016).**

The antioxidant defense system is essential for mitigating cadmium toxicity. It employs both enzymatic and non-enzymatic mechanisms to combat oxidative stress, which can lead to cellular damage. Non-enzymatic antioxidants, such as glutathione, vitamins E and C, and carotenoids, play crucial roles in protecting cells from free radicals **(Halliwell, 2007).** Flavonoids specifically contribute by scavenging reactive oxygen species (ROS) and chelating cadmium, thereby reducing oxidative stress and DNA damage, highlighting their protective effects against cadmium-induced harm **(Iranshahi *et al.*, 2015).** Therefore, this study was conducted to evaluate the therapeutic effects of germinated and fermented red radish seeds against cadmium-induced hepatotoxicity and nephrotoxicity in rats.

Materials and Methods

Materials:

-Thirty adult male albino rats (Sprague Dawley strain), weighing (150-200g) were purchased and housed in the Animal House in theAgricultural Research Center, ,Giza Egypt.

-Red radish seeds were obtained from theAgricultural Research Center, ,GizaEgypt. Samples collections were conducted during the month of October 2023.

-Cadmium was obtained from Nile Pharmaceutical Company, Cairo, Egypt.

-Basal diet components: Casein the main source of protein, cellulose, avitamins mixture, asalt mixture, methionine, and corn starch were obtained from Technogene, Chemical Company, El-Dokki, Giza, Egypt.

-Kits for biochemical analysis were purchased from Gamma Trade Company for Pharmaceuticals and Chemicals, Dokki, Giza.

Germination Process:

The red radish seeds were sorted, cleaned from impurities and washed with tap water, then it was filtered. The seeds were surface sterilized by soaking in alcohol for 5 minutes and washed with tap water, then soaked in 5 times their volume of water for

12 hours at room temperature (20-25°C). Then it is filtered from water and germinated on treated cotton in the dark for 3-5 days. The seeds were sprayed with a water spray once a day. After germination the sprouts were dried in an air dryer oven at (40 °C) for 12 hours, then the dried sprouts were milled using a laboratory grinder and added to the rats' diet **(El-Mahdy *et al.*, 1982).**

Fermentation Process:

The radish seeds were milled using a laboratory grinder and sieved (0.5 mm). The radish flour was soaked in 5 times its volume of water (100 g /500 mL) for 24 hours and was allowed to ferment spontaneously with the naturally occurring microorganisms present on the milled seeds (natural fermentation) at room temperature (20-25°C). Then it was filtered from water and the fermented milled seeds mixture was dried in an air dryer oven at (40 °C) for 12 hours **(Carciochi *et al.*, 2016).**

Induction of Cadmium Toxicity:

Thirty adult male albino rats were allocated randomly into 2 groups and received intraperitoneal injections over a 10-day period as follows: The first group (five rats) was intraperitoneally injected with saline solution and served as the -ve controlgroup. Whereas the remaining 25 rats were also intraperitoneally injected with cadmium chloride ($CdCl_2$) at a dose of 2 mg/kg body weight daily to induce toxicity (**Newairy *et al.*, 2007**).

Experimental design:

The animal groups were kept in an atmosphere of filtered, pathogen-free air and water and maintained at a temperature between 20-25°C with a12 h light/dark cycle and relative humidity of 50%. The animals acclimatized for one week as an adaptation period. After the induction, the 25 cadmium toxicity rats were divided into 5 groups as :follows

- Group 2 wasfed a basal diet for six weeks and served as the +ve control group

- Group 3 fed milled red radish seeds as a food supplement at a dose of 10% in the diet for six weeks.
- Group 4 fed ,germinated ,milled dried red radish seeds as a food supplement at a dose of 10% in the diet for six weeks.
- Group 5 fed ,fermented ,milled dried red radish seeds as a food supplement at a dose of 10% in the diet for six weeks.
- Group 6 fed a combination of germinated and ,fermented ,milled dried red radish seeds as a food supplement, with each component comprising 5% of the diet for six weeks.

At the end of the experimental period (6 weeks), rats were fasted overnight. Rats were anesthetized with ether, sacrificed and blood samples were withdrawn from the orbital plexus veinby using fine capillary glass tubesthen centrifuged at 3000 rpm for 15 min to obtain the serum. Serum was frozen at -18°C for biochemical analysis **(Drury and Walligton 1980).** Liver of each rat was quickly dissected for histopathological examination.

Biochemical analysis:

Alanine aminotransferase (ALT) and aspartate aminotransferase (AST) activities were determined according to **IFCC)1980).** Serum urea nitrogen was determined according to the method described by **Tietz)1990).** Serum creatinine was determined by **Young *et al.*)1975).** Catalase (CAT) activity was determined by **Aebi)1984).** Malondialdehyde (MDA) was determined according to **Yoshioka *et al.*)1979).** Total antioxidant capacity (TAC) in blood serum was assayed according to **Koracevic *et al.*)2001).**

Statistical Analysis

The obtained data were exposed to analysis of variance. Duncan's Multiple Range test (> P0.05) was used to appraise the significant differences between the mean values. Values of all attributes are the average of 3 replicates ± standard deviation. The analysis was carried out using the PROC ANOVA procedure of Statistical Analysis System **(SAS, 2006).**

RESULTS AND DISCUSSION

Plants contain antioxidants, which are crucial in the treatment of diseases. Table (1) shows the antioxidant activity (DPPH) of germinated and fermented red radish seeds. In this investigation, it was found that germinated red radish seeds exhibited the highest antioxidant activity (91.41% RSA), which was greater than that of fermented red radish seeds (80.25% RSA). The results indicate that germination enhances the free radical scavenging activity, likely due to an increase in the concentration of bioactive compounds, such as polyphenols and flavonoids. Although fermentation also retained antioxidant activity, the process slightly reduced the overall DPPH scavenging potential compared to germination. Both germinated and fermented red radish seeds demonstrated strong antioxidant activities, which could contribute to their potential therapeutic applications. These findings highlight the superior antioxidant capacity of germinated seeds over fermented ones.

Table (1): Antioxidant Activity of germinated and fermented red radish seeds

parameter	Germinated	Fermented
Antioxidant Activity (DPPH) (RSA %)	91.41	80.25

RSA % = *Relative Scavenging Activity.*

Phenolic compounds are significant secondary metabolites that neutralize or quench free radicals, playing a crucial role as antioxidants and in preserving food by inhibiting or eliminating harmful microorganisms **(Oyawoye *et al.*, 2022).** This difference suggests that the germination process enhances redox properties, increasing the capacity to absorb and neutralize free radicals, quench oxygen species, and decompose peroxides **(Ayoade *et al.*, 2022).** Flavonoids and other polyphenols, the largest group of antioxidants in plants, contribute significantly to this activity **(Vicente-Sánchez *et al*., 2024).** The higher antioxidant activity in germinated seeds reflects their enhanced phenolic content and bioactive properties, highlighting their potential as superior sources of antioxidants.

The data in Table (2) illustrate the effect of germinated and fermented red radish seeds on ALT and AST levels in rats with cadmium toxicity. ALT levels significantly increased in the positive control group (119.21 ± 1.35 u/L) compared to the negative control group (33.56 ± 0.5 u/L). Treatment with 10% red radish seeds significantly reduced ALT levels to 87.66 ± 0.93 u/L, while germinated and fermented seeds further significantly decreased ALT levels to 74.03 ± 1.612 u/L and 63.68 ± 1.35 u/L, respectively compared to the+ve control group. The greatest reduction was observed in the group receiving 5% germinated and 5% fermented seeds, with ALT levels decreasing to 46.08 ± 0.726 u/L.

Similarly, AST levels were significantly elevated in the positive control group (139.62 ± 1.79 u/L) compared to the negative control (45.85 ± 0.502 u/L). Treatment with red radish seeds significantly reduced AST to 107.63 ± 1.47 u/L, with further decreases in the germinated and fermented groups (82.71 ± 1.05 u/L and 70.71 ± 0.273 u/L, respectively). The combination treatment showed the most significant reduction, with AST levels at 59.537 ± 0.869 u/L. Overall, group 6 (combined germinated and fermented seeds) demonstrated the greatest improvement in liver function. All reductions in ALT and AST were statistically significant ($P < 0.05$) compared to the positive control.

The results presented in Table (2) are consistent with findings from previous studies, reinforcing their validity and confirming the hepatotoxic effects of cadmium, which have been widely documented in the literature.

Table (2): The effect of germinated and fermented red radish seeds on liver functions (u/l) in serum in rats with cadmium toxicity

Groups	ALT	AST
Group (1): Control (-)	33.56 ± 0.5 f	45.85 ± 0.502f
Group (2): Control (+)	119.21 ±1.35 a	139.62 ± 1.79a
Group (3): Red Radish seeds (10%)	87.66 ± 0.93 b	107.63 ± 1.47b

Group (4): Germinated Red Radish seeds (10%)	74.03 ± 1.612 c	82.71 ± 1.05c
Group (5): Fermented Red Radish seeds (10%)	63.68 ±1.35 d	70.71 ± 0.273d
Group (6): Mix Germinated and Fermented Red Radish seeds (5%+5%)	46.08 ± 0.726 e	59.537 ± 0.869e

* Data are presented as means ± SD. Data in the same column with different superscript letters are statistically different ($P \leq 0.05$).

Previous research has shown that cadmium exposure induces oxidative stress and liver damage, leading to elevated liver biomarkers, including ALT and AST **(Nakhaee *et al.*, 2019; Reja *et al.*, 2020; Zhou *et al.*, 2022).** In contrast, treatment with red radish seed formulations significantly reduced ALT and AST levels, demonstrating their hepatoprotective effects. For instance, the group treated with 10% red radish seeds significantly reduced ALT and AST levels (87.66 ± 0.93 u/L and 107.63 ± 1.47 u/L, respectively), consistent with studies highlighting the antioxidant properties of radish seeds in mitigating oxidative damage caused by heavy metals **(El-Refai *et al.*, 2018; Hazelhoff *et al.*, 2018).** Germinated red radish seeds further enhanced liver protection, significantly reducing ALT and AST levels to 74.03 ± 1.612 u/L and 82.71 ± 1.05 u/L, respectively, which aligns with findings that germination increases the bioavailability of phytochemicals such as flavonoids and phenolics, known to scavenge free radicals **(Suleiman *et al.*, 2013; Ayoade *et al.*, 2022).** Similarly, fermented red radish seeds demonstrated greater reductions in ALT and AST levels (63.68 ± 1.35 u/L and 70.71 ± 0.273 u/L, respectively), as fermentation enhances bioactive compounds like phenolic acids, which improve antioxidant activity **(Fanoudi *et al.*, 2020; Shahrajabian *et al.*, 2022).**

The most significant improvement was observed in the group treated with a combination of germinated and fermented red radish seeds, with ALT and AST levels decreasing to 46.08 ± 0.726 u/L and 59.537 ± 0.869 u/L, respectively, consistent with research showing that combining different antioxidant-rich treatments produces synergistic effects, maximizing hepatoprotective benefits **(Victoria *et al.*, 2004; Atef *et al.*,**

2013). These results also align with studies demonstrating that plant-based compounds such as sprouts significantly reduce ALT and AST levels and protect against cadmium-induced hepatotoxicity due to their antioxidant and chelating properties **(Souza-Arroyo *et al*., 2022; Charkiewicz *et al*., 2023; Chen *et al*., 2023).**

Overall, the reductions in ALT and AST levels across the treated groups validate the therapeutic potential of germinated and fermented red radish seeds in mitigating cadmium-induced liver damage, further emphasizing their antioxidant, anti-inflammatory, and detoxifying properties.

The results in Table (3) demonstrate the significant impact of germinated and fermented red radish seeds on kidney function markers, including urea and creatinine, in rats with cadmium toxicity. The positive control group, which was injected with cadmium, showed a significant increase in urea and creatinine levels (10.25 ± 0.22 mg/dL and 13.2 ± 0.28 mg/dL, respectively) compared to the negative control group, which exhibited normal kidney function with urea and creatinine levels of 1.83 ± 0.035 mg/dL and 2.54 ± 0.062 mg/dL, respectively.

Table (3): The effect of germinated and fermented red radish seeds on kidney functions (mg/dl) in serum in rats with cadmium toxicity

Groups	Urea	Creatinine
Group (1): Control (-)	1.83 ±0.035f	2.54 ± 0.062f
Group (2): Control (+)	10.25 ± 0.22a	13.2 ± 0.28a
Group (3): Red Radish seeds (10%)	7.78 ± 0.12b	9.27 ± 0.19b
Group (4): Germinated Red Radish seeds (10%)	6.40 ± 0.23c	7.18 ± 0.21c
Group (5): Fermented Red Radish seeds (10%)	4.94 ± 0.013d	5.27 ± 0.17d
Group (6): Mix Germinated and Fermented Red Radish seeds (5%+5%)	3.04 ± 0.032e	4.06 ± 0.31e

* Data are presented as means ± SD. Data in the same column with different superscript letters are statistically different ($P \leq 0.05$).

These elevated levels confirm the nephrotoxic effects of cadmium, which disrupt renal function by inducing oxidative stress, inflammation, and tubular damage **(Tsai *et al*., 2021).**

Treatment with 10% red radish seeds significantly reduced urea and creatinine levels to 7.78 ± 0.12 mg/dL and 9.27 ± 0.19 mg/dL, respectively, consistent with studies showing the antioxidant properties of red radish seeds in mitigating oxidative damage **(El-Refai *et al.*, 2018).** Germinated red radish seeds further improved kidney function, significantly reducing urea and creatinine levels to 6.40 ± 0.23 mg/dL and 7.187 ± 0.212 mg/dL, respectively, which aligns with findings that germination enhances the bioavailability of flavonoids and phenolic compounds, known to protect against oxidative stress **(Suleiman *et al.*, 2013).** Fermented red radish seeds exhibited even greater reductions in urea and creatinine levels (4.94 ± 0.013 mg/dL and 5.27 ± 0.17 mg/dL, respectively), likely due to the increased concentration of bioactive compounds like phenolic acids during fermentation, which have been shown to protect renal tissue **(Fanoudi *et al.*, 2020).** The most significant improvement was observed in the group treated with a combination of germinated and fermented red radish seeds (5% each), with urea and creatinine levels significantly decreasing to 3.04 ± 0.032 mg/dL and 4.06 ± 0.316 mg/dL, respectively. This suggests a synergistic effect of germination and fermentation, maximizing the antioxidant and detoxifying properties of red radish seeds. These findings are consistent with prior research demonstrating the protective effects of plant-based antioxidants, such as flavonoids and phenolic acids, in mitigating heavy metal-induced nephrotoxicity **(Gupta *et al.*, 2019; Mumtaz *et al.*, 2020).** Overall, these results highlight the therapeutic potential of germinated and fermented red radish seeds, particularly in combination, as effective interventions against cadmium-induced kidney damage.

The data in Table (4) illustrate the effects of germinated and fermented red radish seeds on malondialdehyde (MDA), a marker of oxidative stress, and catalase (CAT), an antioxidant enzyme, in rats with cadmium toxicity. The negative control group (Control -), fed a basal diet without cadmium exposure, exhibited the lowest MDA levels (0.81 ± 0.003 nmol/mL) and the highest CAT activity (4.88 ± 0.17 U/mg protein), reflecting a healthy oxidative balance and functional antioxidant defense. In contrast, the positive control group (Control +), exposed to cadmium, showed a significant increase in MDA levels (5.02 ± 0.05 nmol/mL) and a dramatic reduction in CAT activity (0.95 ± 0.012 U/mg protein), confirming the oxidative stress induced by cadmium toxicity.

Table (4): The effect of germinated and fermented red radish seeds on oxidative stress in rats with cadmium toxicity

Groups	MDA nmol/ml	CAT u/mg
Group (1): Control (-)	0.81 ± 0.003f	4.88 ±0.17a
Group (2): Control (+)	5.02 ± 0.05a	0.95 ± 0.012f
Group (3): Red Radish seeds (10%)	3.92 ±0.054b	1.89 ± 0.023e
Group (4): Germinated Red Radish seeds (10%)	3.22 ± 0.136c	2.73 ± 0.131d
Group (5): Fermented Red Radish seeds (10%)	2.69 ±0.015d	3.0 ± 0.024c
Group (6): Mix Germinated and Fermented Red Radish seeds (5%+5%)	1.86 ± 0.026e	3.91 ± 0.038b

* Data are presented as means ± SD. Data in a row with different superscript letters are statistically different ($P \leq 0.05$).

This aligns with prior studies demonstrating that cadmium exposure disrupts cellular redox balance, increases lipid peroxidation, and impairs antioxidant enzyme activity **(Suleiman *et al.*, 2013; Tsai *et al.*, 2021).** Treatment with 10% red radish seeds significantly reduced MDA levels (3.92 ± 0.054 nmol/mL) and moderately improved CAT activity (1.89 ± 0.023 U/mg protein) compared to the positive control, consistent with the known antioxidant properties of red radish seeds **(El-Refai *et al.*, 2018).** Germinated red radish seeds provided greater protection, significantly reducing MDA levels to 3.22 ± 0.136 nmol/mL and significantly increasing CAT activity to 2.73 ± 0.131 U/mg protein, likely due to the enhanced bioavailability of antioxidant compounds such as flavonoids and phenolics during germination **(Suleiman *et al.*, 2013; Ayoade *et al.*, 2022).** Fermented red radish seeds further improved outcomes, significantly lowering MDA levels to 2.69 ± 0.015 nmol/mL and significantly raising CAT activity to 3.0 ± 0.024 U/mg protein, likely because fermentation increases the concentration of bioactive compounds like phenolic acids, which enhance antioxidant defense mechanisms **(Fanoudi *et al.*, 2020).** The most notable improvement was observed in the group treated with a combination of germinated and fermented seeds, where MDA levels were significantly reduced to 1.86 ± 0.026 nmol/mL, and CAT activity was significantly restored to 3.91 ± 0.038 U/mg protein. These results highlight the synergistic effect of combining germination and fermentation, which maximizes the antioxidant potential of red radish seeds and provides the strongest protection against cadmium-induced oxidative stress. Overall, the data confirm the protective effects of germinated and fermented red radish seeds in mitigating oxidative damage, as supported by previous studies that emphasize the role of plant-based antioxidants in reducing lipid peroxidation and restoring antioxidant enzyme activity **(Gupta *et al.*, 2019; Mumtaz *et al.*, 2020; Shahrajabian *et al.*, 2022).** These findings underscore the therapeutic potential of red radish seeds, particularly when germinated and fermented, as a natural intervention against cadmium-induced oxidative stress.

Liver was examined by a histological approach and the photomicrographs of hematoxylin – eosin-stained liver are illustrated. Liver histopathological results depicted in Photos 1–8 reveal significant differences in liver tissue alterations between cadmium-fed rats and those treated with various red radish seed formulations. In the Control (-) group (Photo 1), liver tissue displayed no histopathological changes, with a normal central vein and hepatocyte arrangement, indicating healthy liver architecture in the absence of cadmium toxicity. In contrast, the control (+) group (Photo 2), exposed to cadmium, showed central vein dilatation and congestion, reflecting significant liver damage due to cadmium-induced oxidative stress and inflammation. This highlights the severe hepatotoxic effects of cadmium exposure. Treatment with red radish seeds (Photo 3) partially protected the liver, showing mild mononuclear inflammatory cell infiltration in the portal area, consistent with the antioxidant properties of red radish seeds. However, treatment with germinated red radish seeds (Photo 4) showed more intense mononuclear inflammatory cell infiltration in the portal area and fibroplasia, suggesting improved but incomplete protection against cadmium toxicity, likely due to enhanced bioavailability of antioxidants through germination. Fermented red radish seeds (Photos 5 and 6) demonstrated greater protective effects, with only mild mononuclear inflammatory cell infiltration observed in the portal area (Photo 5) and hepatic parenchyma (Photo 6). Fermentation likely increased the concentration of bioactive compounds such as phenolic acids, which improved the liver's antioxidant defense. The most notable improvement was observed in the group treated with a combination of germinated and fermented red radish seeds (Photos 7 and 8), where liver tissue showed an apparently normal centribular area with no significant histopathological alterations. This suggests a synergistic effect of germination and fermentation, maximizing the antioxidant and anti-inflammatory properties of red radish seeds and restoring liver tissue to near-normal conditions. These results confirm cadmium's hepatotoxic effects while highlighting the protective potential of red radish seeds, particularly when germinated and fermented. The combined treatment demonstrated the greatest efficacy in mitigating cadmium-induced liver damage and restoring normal liver architecture.

The results presented in Photos 1–6 align closely with findings from previous research, confirming their validity. The observed histopathological alterations in the Control (+) group exposed to cadmium, including central vein dilatation, congestion, and inflammatory cell infiltration, are consistent with well-documented effects of cadmium-induced hepatotoxicity. Cadmium disrupts cellular redox homeostasis, induces oxidative stress, and triggers inflammation, leading to structural and functional liver damage **(Suleiman *et al.*, 2013; Tsai *et al.*, 2021).** These effects are reflected in the significant damage observed in the liver tissue of the positive control group.

The partial protection provided by treatments with red radish seeds is supported by prior studies demonstrating the antioxidant properties of radish-derived phytochemicals, which help mitigate oxidative stress and inflammation **(El-Refai *et al.*, 2018).** Specifically, germinated red radish seeds show enhanced protective effects, as germination increases the bioavailability of antioxidant compounds such as flavonoids and phenolics, which are known to scavenge free radicals and reduce lipid peroxidation **(Ayoade *et al.*, 2022).** This explains the reduction in inflammation and fibroplasia observed in the group treated with germinated seeds.

Fermented red radish seeds provide even greater hepatoprotection, as evidenced by the milder inflammatory changes in the portal area and hepatic parenchyma. Fermentation increases the concentration of bioactive compounds like phenolic acids, which have potent antioxidant and anti-inflammatory properties **(Fanoudi *et al.*, 2020).** These findings corroborate research indicating that fermentation enhances the therapeutic potential of plant-based treatments by improving their bioactivity and bioavailability.

The most significant improvement observed in the group treated with a combination of germinated and fermented red radish seeds reflects a synergistic effect between the two processes. Previous studies have highlighted the benefits of combining germination and fermentation to maximize the antioxidant, anti-inflammatory, and detoxifying properties of plant-derived compounds **(Mumtaz *et al.*, 2020; Shahrajabian *et al.*, 2022).** The near-normal liver architecture in this group underscores the effectiveness of this combined approach in mitigating cadmium-induced hepatotoxicity.

Overall, these results are consistent with prior research demonstrating the role of plant-based antioxidants in protecting against heavy metal-induced liver damage. The findings validate the therapeutic potential of germinated and fermented red radish seeds, particularly when used in combination, as an effective intervention to combat cadmium-induced liver injury. This highlights the relevance of dietary interventions utilizing antioxidant-rich plants as a cost-effective and natural strategy to mitigate the adverse effects of heavy metal toxicity.

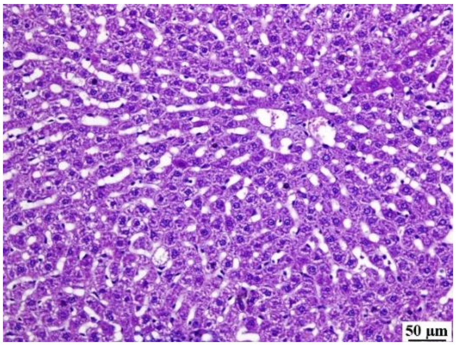

Photo 1. Control (-ve) there was no histopathological alteration and the normal histological structure of the central vein.

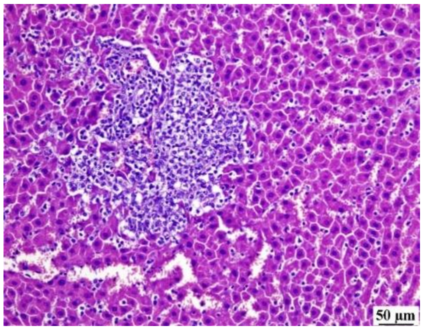

Photo 2. Control (+ve) induced by cadmium chloride showed dilatation and congestion were detected in the central vein.

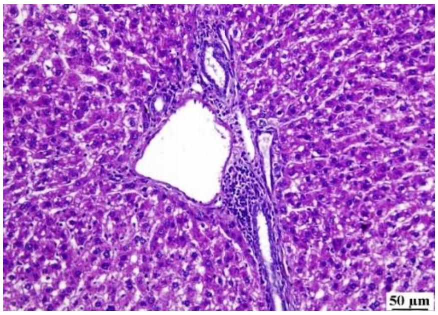

Photo 3. Treated by milled red radish seeds showed mild mononuclear inflammatory cells infiltration in the portal area.

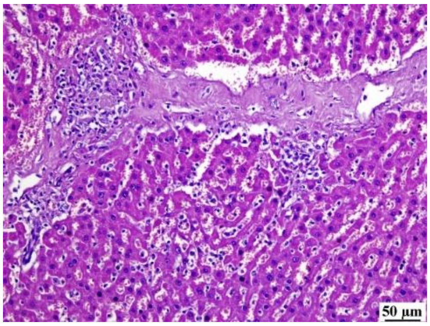

Photo 4. Treated by germinated red radish seeds showed intense mononuclear inflammatory cells infiltration in the portal area with fibroplasia

Histological changes in the liver stained with (Hand E X50).

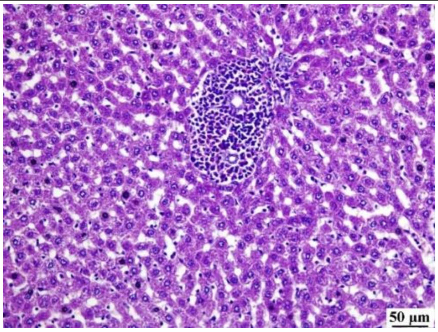

Photo 5. Treated by fermented red radish seeds showed mild mononuclear inflammatory cells infiltration in the portal area

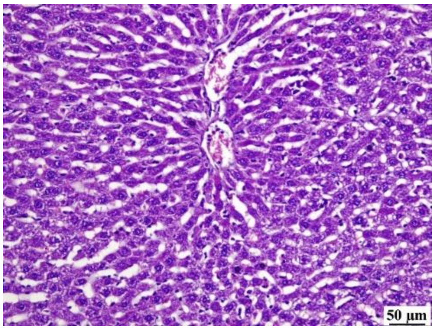

Photo 6. Treated by mix germinated and fermented red radish seeds showed apparently normal centrilobular area

Histological changes in the liver stained with (Hand E X50)

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