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Research Article

Comparative Analysis of Selenium and Quercetin Nanoparticles for their Antioxidant and Hepatoprotective Effects Against Acrylamide-Induced Liver Toxicity in Male Albino Wistar Rats

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Abstract: Acrylamide, a potential occupational carcinogen, is a natural by-product formed during the thermal processing of starchy foods and roasted coffee beans. Recent studies have also reported high levels of acrylamide in various thermally treated fast foods in Saudi Arabia. This study aims to meet the critical need for effective antioxidant therapies to mitigate acrylamide-induced liver damage. By comparing the protective effects of selenium and quercetin nanoparticles, it seeks to identify the more potent nano-antioxidant, thereby contributing to the advancement of safer and more efficient strategies for preventing chemically induced hepatotoxicity. Twenty adult male Albino Wistar rats were randomly divided into four groups: control, acrylamide-treated, acrylamide + SeNP, and acrylamide + QNP. Acrylamide exposure (Acrylamide exposure (50 mg/kg/day, orally for 21 days)) significantly elevated serum levels of cholesterol (CHO), triglycerides (TG), low-density lipoprotein (LDL), alanine transaminase (ALT), aspartate transaminase (AST), creatinine, and urea, cholesterol (233.33 ± 7.50 mg/dL), (238.33 ± 4.93 mg/dL), (67.33 ± 2.51 mg/dL), (80.33 ± 3.51 U/L), and AST (80.00 ± 3.00 U/L) respectively, compared to the control group (CHO: 155.33 ± 8.02, TG: 150.00 ± 7.93, LDL: 39.33 ± 4.16, ALT: 16.66 ± 3.78, AST: 22.66 ± 2.08). while significantly reducing glutathione (GSH) and superoxide dismutase (SOD) levels in liver tissues compared to the control group. Treatment with SeNPs and QNPs led to a marked reduction in these altered biochemical parameters and improved liver histopathology. In conclusion, selenium and quercetin nanoparticles exhibited a protective effect against acrylamide-induced hepatotoxicity in male Albino Wistar rats, suggesting their potential use in mitigating liver damage caused by environmental toxins.

Keywords: Acrylamide, Selenium, Quercetin, Hepatotoxicity, Nanomedicine, Oxidative Stress.

1. INTRODUCTION

Acrylamide is a substance that can be found in both the environment and various industrial processes, and it is considered a potential occupational carcinogen [1]. It naturally forms when starchy foods, like potatoes and grains, or roasted coffee beans are heated, especially during cooking methods like frying, baking, or roasting [2]. In addition to its occurrence in food, acrylamide is also

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used in several industrial applications, such as the production of plastics, paper, and even in sewage treatment and cigarette smoke [3]. Some consumer products, including food packaging and adhesives, may also contain acrylamide [4]. Although it is likely that acrylamide has been present for as long as humans have cooked starchy foods, it wasn't until April 2002 that the Swedish National Food Administration (SNFA) made the public aware that certain food preparation methods could lead to the formation of acrylamide [5]. This discovery highlighted how prolonged heat treatments of certain foods at temperatures of 120 °C or higher could result in significant amounts of acrylamide [6]. Though no official maximum concentration has been set for acrylamide in food, the World Health Organization (WHO) suggests that the acceptable limit for acrylamide in drinking water is 0.5 mg/L [7]. Studies conducted by SNFA and Stockholm University found varying levels of acrylamide in different foods, with protein-rich foods containing moderate amounts (5-50 mg/kg) and carbohydrate-rich foods containing much higher levels (150-4,000 mg/kg) [8]. Foods that are typically free from acrylamide include those that are boiled or prepared without heat [9]. It is now well-established that there is a link between dietary habits and the development of various diseases, including cancer. The consumption of processed foods has been shown to expose individuals to a variety of harmful substances, such a s heterocyclic aromatic amines, polycyclic aromatic hydrocarbons, acrylamide, and nitrosamines. These compounds are known for their mutagenic and carcinogenic properties, which can have detrimental effects on health. As a result, ensuring the production of safe and healthy food has become a critical focus within the food industry [10].

Acrylamide forms in starchy foods when heated above 120 ºC, such as fried potatoes, bread, cookies, and coffee. This compound is primarily produced through a reaction between the amino acid asparagine and a carbonyl-containing substance during high-temperature cooking [11]. A recent study assessing acrylamide levels in thermally-treated foods from Saudi Arabia found that chips contained acrylamide levels ranging from 28 to 954 µg/kg, while labneh and mint had lower levels (28 µg/kg). Acrylamide concentrations in nuts and dried fruits ranged from 2 to 93 µg/kg, and in products like cookies, pastries, cocoa, chocolate, olives, cheese, and grains, levels varied from 26 to 234 µg/kg [12]. The variation in acrylamide levels can be attributed to factors such as food type, cooking methods, and temperature and duration of heating [13]. Another study highlighted a higher risk of acrylamide exposure through cafeteria foods in Jeddah schools, which poses a significant health concern.

In Denmark, the average daily dietary intake of acrylamide is estimated to be 0.27 mg/kg body weight for females and 0.36 mg/kg body weight for males [14]. Similarly in the United States, the estimated average acrylamide exposure is around 0.44 mg/kg body weight per day, which is comparable to levels in the Netherlands [15]. Laboratory research has shown that acrylamide exposure can cause neurological and reproductive toxicity, and it is associated with an increased risk of cancer. Recognized as a neurotoxin over 60 years ago [16], acrylamide exposure in both humans and animals has been linked to symptoms such as ataxia, muscle weakness, weight loss, peripheral edema, and degeneration of axons in both the peripheral and central nervous systems [17]. In pregnant animals, exposure to acrylamide resulted in significant retinal abnormalities in offspring, including ganglion cell degeneration at early stages of development [18]. Additionally, acrylamide has been shown to be toxic to human retinal pigment epithelium cells [19]. Acrylamide is also considered a potential carcinogen, largely due to its genotoxic effects [20]. Researchers at the Fred Hutchinson Center for Cancer Research showed that eating French fries, fried chicken and donuts at least once a week is associated with an increase in the risk of prostate cancer in men. Oral Acrylamide exposure in Albino Wistar Rats resulted in tumors in multiple organs, whereas Acrylamide exposure in humans increases the risk of acquiring cancer [21]. The nanomedicine concept has emerged as a new rising star in the therapeutics field due to its numerous distinct advantages. Nanomedicine is based on a variety of techniques and is related with many types of medications. The increased safety of nanomedicine is a well acknowledged benefit [22]. Nanoparticles are highly distributed solid supramolecular structures composed of organic or inorganic components that are preferably less than 500 nm. The small surface area of nanoparticles provides more accessibility for improved surface functionality within a given volume [23]. These structures have the potential to significantly improve the pharmacokinetics and therapeutic

indices of a wide range of medications, including small compounds, genes, peptide- and protein-based therapies, and diagnostic agents [24-26].

Nanotechnology is an interdisciplinary field that bridges science and medicine, with diverse applications in molecular imaging, diagnostic methods, and precision therapy [27]. Nanoparticles within the mesoscopic size range of 5–100 nm possess vast surface areas and functional groups, enabling their conjugation with therapeutic agents. As a result, they function as adaptable delivery vehicles capable of transporting huge amounts of pharmaceuticals and natural ingredients with better efficacy [28]. Nanotechnology refers to the interactions between cellular and molecular components, artificial materials, and clusters of atoms or molecular fragments, which are engineered into extremely small particles ranging from 1 to 100 nm. Nanometer-sized particles exhibit unique optical, electrical, and structural properties that are not present in individual molecules or bulk materials. This concept of nanoscale devices has paved the way for the development of biodegradable, self-assembled nanoparticles, which are being designed for the targeted delivery of medicinal agents [29]. Since prehistoric times, humans have employed natural goods (natural active substances) to treat a variety of ailments. Natural items have also been employed in the prevention and treatment of different ailments in recent times, which remains an elusive objective in medicine. Nanotechnology can be exploited to increase the systemic delivery and bioavailability of any natural product. Nanoparticle-mediated delivery can also be employed for sustaining the release of natural products, prolonging their action and reducing their frequency of administration [30, 31]. Herein, we assessed the utilization of nanoparticles for the delivery of natural products to target sites to protect and prevent the deleterious health effects of Acrylamide on different body organs and their functions. Quercetin nanoparticles (QNP) are well known anti- inflammatory, antioxidative and anti-allergy agents, which prevent the body from releasing histamine and other inflammatory factors [32]. Selenium nanoparticles (SeNP) have gained much interest compared to other selenium-containing compounds due to their low toxicity and selectivity on cancer cells and minimum or no effect on normal cells. Selenium nanoparticles are studied and used for their potential in recent decades. They play several important roles in treatment of many diseases including immune diseases, diabetes mellitus and, various neurological diseases Furthermore, the polyvalent surface of selenium nanoparticles enables them to engage through covalent and non-covalent bonds with a wide range of chemical substances. Any charges on their surface can be attached to different positive and negatively charged groups, indicating their high adsorption capacity [33]. The aim of our study is to reduce the side-effect related with the Acrylamide consumption using different nanoparticle coated natural molecules (Quercetin and selenium nanoparticles). This study highlights the significant hepatotoxic effects of acrylamide and demonstrates the protective role of selenium and quercetin nanoparticles in mitigating oxidative stress, liver damage, and lipid peroxidation. By using nanoparticle formulations, the study enhances the therapeutic potential of these natural antioxidants through improved bioavailability. These findings provide a strong preclinical basis for developing nanotechnology-based interventions to counteract chemical-induced liver toxicity, with promising implications for preventive healthcare and future clinical applications.

2. MATERIALS AND METHODS

2.1. Chemicals

Acrylamide dry crystals (A8887-100G) were obtained from sigma chemicals Co, USA. Quercetin and selenium nanoparticles (7782-49-2) (40 nm) were obtained from Sigma-Aldrich, USA. All chemicals were of commercially grade and kept at 4 ºC.

2.2. Experimental Animals

Twenty adult male Albino Wistar Rats (160-220 g) were maintained on a standard pellet diet and housed in appropriate cages in controlled environmental condition with free access to water a*d libitum*.

2.3. Experimental Design

Animals were divided into four groups (5 animals each):
Group 1 (control): Animals were administered with 1 ml of physiological saline orally by gavage.
Group 2 (Acrylamide): Animals were administered with Acrylamide (3 mg/kg per day) orally by

gavage for 14 days.
Group 3 (Acrylamide+ Q): Animals were administered with Acrylamide plus QNP (Quercetin nanoparticles) (3 mg/kg per day) orally by gavage for 14 days.
Group 4 (Acrylamide+ S): Animals were administered with Acrylamide plus SeNP (Selenium nanoparticles) (3 mg/kg per day) orally by gavage for 14 days.

2.4. Liver Sample

Ether was used to anesthetize before surgical dissection and examination of the liver. Light microscope was employed to study the histopathological changes; the tissues were fixed in 10% formalin for future use [34].

2.5. Biochemical Analysis

Lipid profile was done by using colorimetric kits supplied by Bio-diagnostic, Egypt [35, 36]. The total protein was determined by Biuret method [37]. The estimation of aspartate-aminotransferase (AST) and alanine-aminotransferase (ALT) was carried out according to the method originally developed by Reitman and Frankel [38].

2.6. Determination of Liver Antioxidant Enzymatic Biomarkers

MDA (Malondialdehyde) (nmoL/g tissue) was determined in liver homogenate by a colorimetric assay according to the method established by Satoh [39]. Hepatic GSH (mg/g tissue) was assayed in liver homogenate according to the method developed by Moron *et al*. [40]. Superoxide dismutase (SOD) was evaluated according to the method described by Marklund and Marklund [41].

2.7. Histopathological Investigations

Hepatic tissue slices embedded in paraffin (5 μm) were cut using a sliding microtome (Leica RM2135 Rotary Microtome, Wichita, KS, USA) and stained with hematoxylin and eosin (H&E) stain for a later light microscope histological analysis using the light microscope 46 [42].

2.8. Statistical Analysis

Values are presented as Mean ± SD. Statistical analysis was performed using one-way ANOVA, with a significance level set at $P < 0.05$.

3. RESULTS

3.1. Biochemical Analysis

3.1.1. Levels of lipid profile

Acrylamide treatment in male Albino Wistar rats resulted in a significant elevation in serum cholesterol (CHO), triglycerides (TG), and low-density lipoprotein (LDL) levels, with mean ± SE values of 233.33 ± 7.50, 238.33 ± 4.93, and 67.33 ± 2.51 mg/dL, respectively, compared to the control group (155.33 ± 8.02, 150.00 ± 7.93, and 39.33 ± 4.16 mg/dL, respectively). However, co-administration of selenium led to a notable reduction in these lipid parameters (CHO: 219.66 ± 11.67, TG: 218.33 ± 4.50, LDL: 50.33 ± 17.50 mg/dL), while quercetin treatment also demonstrated a similar lipid-lowering effect (CHO: 219.66 ± 11.71, TG: 213.00 ± 8.15, LDL: 55.66 ± 10.69 mg/dL), when compared to the acrylamide-only treated group. These findings suggest a potential protective role of selenium and quercetin against acrylamide-induced dyslipidemia (Figure 1).

3.1.2. Liver function markers

Administration of acrylamide to male Albino Wistar rats resulted in a marked and significant elevation in serum alanine aminotransferase (ALT) and aspartate aminotransferase (AST) levels, with values of 80.33 ± 3.51 and 80.00 ± 3.00 U/L, respectively, compared to the control group (16.66 ± 3.78 and 22.66 ± 2.08 U/L, respectively). However, treatment with selenium and quercetin nanoparticles effectively attenuated this increase. Selenium nanoparticles reduced ALT and AST levels to 57.66 ± 8.02 and 68.00 ± 4.35 U/L, respectively, while quercetin nanoparticles brought them down to 59.00 ± 4.58 and 65.00 ± 5.56 U/L, respectively (Figure 2). These results suggest a protective effect of selenium and quercetin nanoparticles against acrylamide-induced hepatic injury.

3.2. Oxidative Stress Biomarkers

Acrylamide administration significantly reduced the levels of key antioxidant enzymes glutathione (GSH) and superoxide dismutase (SOD), with

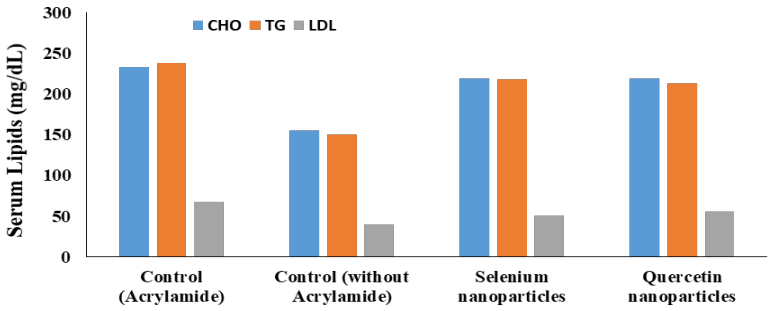

Fig. 1. Lipid profile of male Wistar rats treated with acrylamide, selenium and quercetin nanoparticles.

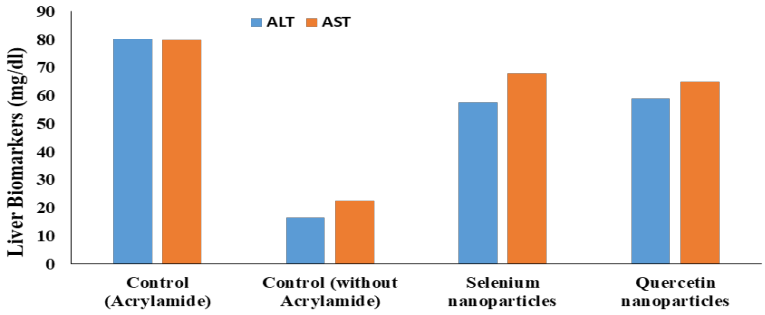

Fig. 2. Liver enzyme biomarkers of male Wistar rats treated with acrylamide, selenium and quercetin nanoparticles.

mean ± SE values of 306.33 ± 5.03 and 568.66 ± 8.50 U/mg protein, respectively, compared to the normal control group (365.00 ± 12.76 and 652.33 ± 14.04 U/mg protein, respectively). Co-treatment with selenium and/or quercetin nanoparticles markedly attenuated oxidative stress, as evidenced by improved levels of these antioxidants compared to the acrylamide-only group. Furthermore, malondialdehyde (MDA), a key indicator of lipid peroxidation, was significantly elevated in the acrylamide-treated group (2.06 ± 0.37 nmol/mg protein) relative to the control group (0.66 ± 0.04 nmol/mg protein. Treatment with selenium and quercetin nanoparticles resulted in a noticeable reduction in MDA levels to 1.05 ± 0.16 and 1.47 ± 0.14 nmol/mg protein, respectively. These findings highlight the considerable protective effect of selenium and quercetin nanoparticles in mitigating acrylamide-induced oxidative damage (Figure 3).

3.3. Liver Histopathology

Histological evaluation of liver sections from the control group revealed normal hepatic architecture, characterized by well-organized hepatocytes (H), centrally located central veins (CV), and regularly spaced, open sinusoids (S), reflecting normal hepatic function [34]. Conversely, the liver tissues from the acrylamide-treated group demonstrated substantial pathological alterations. These included congested blood vessels (red arrows), swollen hepatocytes (H), focal necrotic areas (black arrows), and signs of focal perivascular fibroplasia with mild leukocytic cell infiltration (arrowhead). Additionally, sinusoids appeared narrowed or completely occluded (S). These changes are indicative of hepatocellular degeneration, inflammation, and

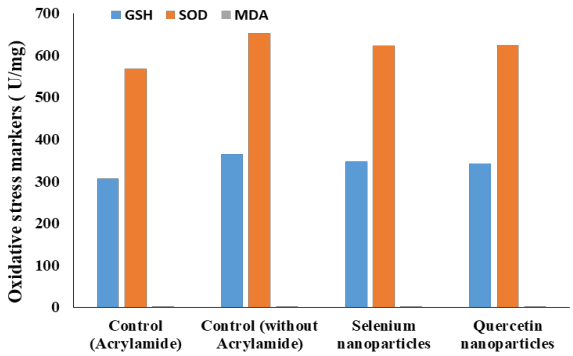

Fig. 3. Oxidative Stress biomarkers of male Wistar rats treated with Acrylamide, selenium and quercetin nanoparticles.

oxidative stress-induced damage, which are well-documented consequences of acrylamide toxicity. In the group treated with selenium nanoparticles, partial histological improvement was observed. Although congested central veins (CV), swollen hepatocytes (H), and occluded sinusoids (S) were still present (red arrows), the degree of tissue damage was noticeably less severe than in the acrylamide-only group. Selenium's antioxidant and anti-inflammatory properties likely contributed to this protective effect. The quercetin nanoparticle-treated group exhibited near-normal liver histology. Hepatocytes (H), central veins (CV), and sinusoids (S) appeared mostly intact, with only mild residual lesions. This suggests that quercetin nanoparticles conferred a more pronounced hepatoprotective effect, possibly due to their potent free radical scavenging and membrane-stabilizing. These histological findings corroborate the biochemical results and underscore the potential of selenium and quercetin nanoparticles in mitigating acrylamide-induced hepatotoxicity (Figure 4). The negative control group represents the normal hepatocytes (H), central veins (CV) and opened sinusoids (S). The Acrylamide treated group showed congested blood vessels (red arrows), swollen hepatocytes (H), focal necrotic area (black arrow), and focal perivascular fibroplasia with few leukocytic cells infiltration (arrowhead), narrowed or occluded sinusoids (S). Selenium treated group showed congested central veins (CV) (red arrows), swollen hepatocytes (H), and occluded sinusoids (S). Quercetin treated group has showing normal hepatocytes (H), central veins and opened sinusoids (S) with partially relieved lesions (Figure 4).

4. DISCUSSION

Acrylamide poses significant risks to human health due to its toxic properties. Acrylamide causes the generation of free radicals through upsetting the balance between oxidative stress and antioxidants in the cells [42]. Acrylamide is a well-known agent which causes the disturbance in blood and cellular lipid ratio [43], which are considered to be risk factors for cardiovascular diseases [44]. The present study stated that, the exposure of male Albino Wistar Rats with Acrylamide induced a significant rise in lipid profile (TCH, TG, and LDL) compared to control group. Acrylamide causes the enhanced production of free radicals resulting in the accumulation of cholesterol due to biosynthesis and decreased cholesteryl ester hydrolysis [45]. In addition, the selenium and/or quercetin nanoparticles treatment

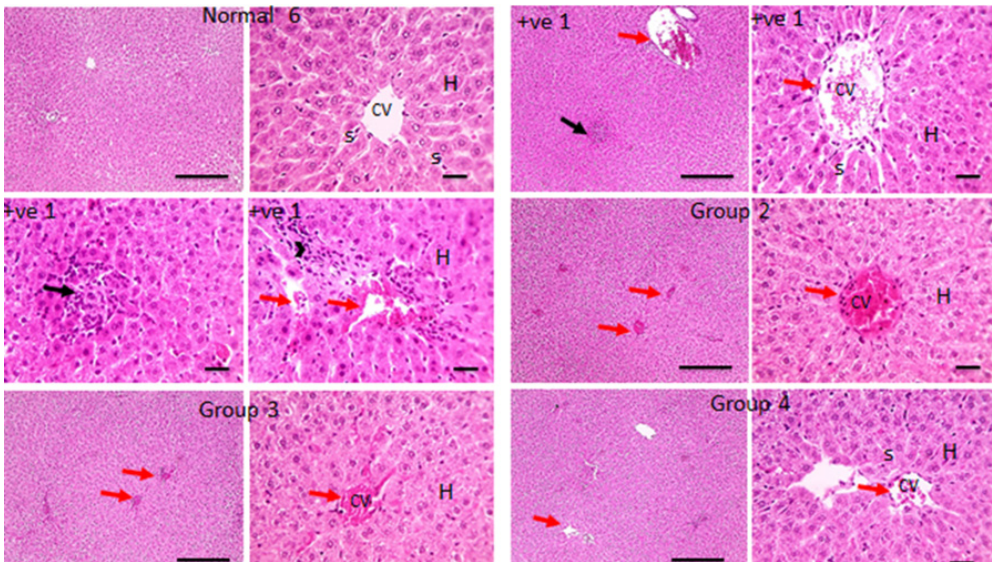

Fig. 4. In the negative control group (Without any treatment) (Group 6), liver sections displayed normal architecture, with healthy hepatocytes (H), clear central veins (CV), and open sinusoids (S). In the positive-control (acrylamide treated) (Group 1), however, there was evidence of vascular congestion (red arrows), swollen hepatocytes, focal necrosis (black arrow), perivascular fibroplasia with sparse leukocyte infiltration (arrowhead), and narrowed or occluded sinusoids. Groups 2 and 3 (treated with selenium and quercetin respectively) still showed congested central veins, swollen hepatocytes, and sinusoidal blockage, although to a slightly lesser degree. In Group 4, these lesions were partially alleviated, with reduced congestion and cellular swelling. Finally, Group 5's liver sections closely resembled normal tissue, exhibiting healthy hepatocytes, unobstructed central veins, and fully open sinusoids.

induced reduction the lipid profile when compared to Acrylamide alone. Our finding was in consistence with the result of similar studies [46, 47]. Urea and creatinine are nitrogenous by-product of body metabolism. In present study, Acrylamide treatment to male Albino Wistar Rats significantly increases the serum urea and creatinine levels in comparison to control group while the selenium and quercetin nanoparticles administration mitigated these effects. The results come to an agreement with results of Uthra *et al.* [44] who stated that the levels of urea and creatinine were disrupted by Acrylamide and the treatment with quercetin restored theses indices towards normal levels. Our findings are consistent with the study by Sengul *et al.* [48], which reported a significant decrease in urea and creatinine levels due to acrylamide intoxication. These acrylamide-induced changes were effectively mitigated by selenium treatment. Similarly, the results of this study revealed a notable increase in liver enzymes following acrylamide exposure compared to the control group, likely attributable to oxidative stress and hepatic inflammation caused by acrylamide [49]. However, treatment with nanoparticles resulted in a significant reduction in these levels, highlighting the liver-protective effects of both quercetin and selenium. When compared with controls, the acrylamide-treated rats showed a pronounced rise in ALT and AST activities, reflecting liver injury induced by acrylamide exposure. These results are coincided with the finding of Hamdy *et al.* [50] and Rivadeneyra-Domínguez *et al.* [51]. Since the human body's primary organs for detoxification are the liver, the degenerative alterations were seen in this study point to a variety of Acrylamide effects [52]. Our study showed that MDA in the hepatocytes was increased significantly, due to Acrylamide exposure and increase was inhibited upon treatment with selenium and quercetin nanoparticles. The present study results are consistent with the studies carried out by various researchers such as Liu *et al.* [53], Sengul *et al.* [48] and Karimi *et al.* [54]. It was observed that acrylamide exposure led to oxidative stress, which was effectively mitigated by the use of antioxidants. In the group exposed to acrylamide, a notable reduction in SOD and GSH levels was detected. However, treatment with nanoparticles restored these levels when compared to the group that received acrylamide alone. These finding were in agreement with other scientists as well [55], who reported that both selenium and vitamin C prevent the damage in the liver and boosted up the redox state in male mice. In addition, these results parallel to those verified by Sengul *et al.* [46] and Uthra *et al.* [43]. Mahdavinia *et al.* [56] reported that quercetin exhibits a protective role against bisphenol-A-induced mitochondrial damage in the liver of Albino Wistar rats. Furthermore, a recent study demonstrated that quercetin, whether administered alone or in combination, effectively corrected the altered parameters associated with the toxicity of copper oxide nanoparticles in rats [57]. In the present study, histopathological analysis corroborated the biochemical findings of acrylamide-induced toxicity in male Albino Wistar rats, aligning with the observations reported by Uthra *et al.* [43]. In the same way, other reports supported our finding and revealed substantial changes in mice and Albino Wistar Rats, and these changes were mitigated using quercetin and selenium nanoparticles respectively [55, 57, 58]. Overall, this study confirms the significant health risks associated with acrylamide exposure, particularly its detrimental effects on lipid metabolism and liver health. Acrylamide-induced oxidative stress leads to elevated lipid profiles, including total cholesterol, triglycerides, and LDL, as well as increased urea and creatinine levels, signaling hepatic and renal impairment. These outcomes support earlier findings on acrylamide's capacity to disrupt metabolic balance and induce oxidative damage. Importantly, the study demonstrates that selenium and quercetin nanoparticles exhibit marked hepato- and nephro-protective effects. Through their potent antioxidant properties, both nanoparticles effectively reduced malondialdehyde (MDA) levels and normalized key antioxidant enzymes, thereby mitigating acrylamide-induced oxidative damage. Biochemical and histopathological analyses confirmed that nanoparticle treatment significantly restored liver and kidney function, reduced lipid abnormalities, and corrected enzyme imbalances. From a practical standpoint, these findings underscore the value of nanoparticle-based interventions in waste recycling, where agricultural or industrial sources of selenium or quercetin could be converted into effective nanotherapeutics. This not only provides economic benefits by lowering material costs and enhancing product value, but also supports sustainable biomedical innovation. However, the potential toxicity of nanoparticles to biological systems necessitates thorough safety evaluations and dose standardization before clinical or commercial use. In comparing

the two nanoparticles, selenium nanoparticles demonstrated slightly superior efficacy in restoring biochemical parameters, likely due to their role in the glutathione peroxidase system, while quercetin nanoparticles offered broader antioxidant effects and better cellular tolerance. This suggests that while both are effective, their mechanisms and safety profiles may be suited to different clinical contexts. Overall, the results advocate for further exploration into nanoparticle-based antioxidants as a cost-effective, scalable, and clinically relevant approach to counteracting environmental toxin-induced damage.

5. CONCLUSIONS

In conclusion, this study confirms the significant health risks associated with acrylamide exposure, particularly its detrimental effects on lipid metabolism, and liver health. Acrylamide-induced oxidative stress leads to a rise in lipid profiles, including total cholesterol, triglycerides, and LDL, as well as increased levels of urea and creatinine, which are indicative of impairment. These findings align with previous research indicating that acrylamide disrupts normal metabolic processes and promotes oxidative damage. It was apparent from our results that selenium and quercetin nanoparticles have hepato-protective and nephro-protective effects through its antioxidant and ameliorative effect against Acrylamide induced toxicity by decreasing the MDA level and normalization of other antioxidative enzymes. The administration of selenium and quercetin nanoparticles effectively reduced the negative effects of acrylamide. Both nanoparticles significantly reduced elevated lipid profiles, normalized urea and creatinine levels, and alleviated liver enzyme abnormalities. The protective effects observed with selenium and quercetin nanoparticles are consistent with their known antioxidant properties, which counteract acrylamide-induced oxidative stress and support cellular health. Histopathological analysis further confirmed the biochemical improvements brought about by these treatments, reinforcing their potential as therapeutic agents against acrylamide toxicity. Overall, this study highlights the protective efficacy of selenium and quercetin nanoparticles in mitigating acrylamide-induced damage and suggests their potential for therapeutic use in combating oxidative stress-related disorders. The present study holds promising translational potential, particularly in advancing therapeutic strategies for specific disease or condition, e.g., neurodegenerative disorders, cancer, metabolic syndromes. By bridging the gap between preclinical research and clinical application, this work lays the foundation for future interventions that can be tailored for human use. The nanoparticle-based delivery of quercetin and selenium in this study not only enhanced their bioefficacy but also validated their protective roles against acrylamide-induced oxidative and histological damage. By leveraging the unique properties of nanotechnology; such as improved solubility, targeted delivery, and enhanced cellular activity; this study provides compelling evidence for the future use of QNPs and SeNPs as viable therapeutic interventions against toxin-induced metabolic and organ-specific pathologies.

6. ETHICAL STATEMENT

The study was conducted in accordance with ethical guidelines and principles for the care and use of laboratory animals. All experimental procedures involving the use of male Albino Wistar rats were approved by Egyptian Network of Research Ethics Committees. The study adhered to the guidelines set by ENREC. Efforts were made to minimize animal suffering and ensure humane handling throughout the course of the experiment.

7. ACKNOWLEDGMENTS

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8. CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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