Ameliorative Effect of Sesamin in Cisplatin-Induced Nephrotoxicity in Rats by Suppressing Inflammation, Oxidative/Nitrosative Stress, and Cellular Damage

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Running title: Sesamin and cisplatin nephrotoxicity

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Summary

Nephrotoxicity of cisplatin (CP) involves renal oxidative stress and inflammation, and sesamin (a major liganin in many plants) has strong antioxidant and antiinflammatory actions. Therefore, we investigated here the possible mitigative action of sesamin on CP nephrotoxicity in rats. Sesamin was given orally (5 mg/kg/day, 10 days), and on the 7th day, some of the treated rats were injected intraperitoneally with either saline or CP (5mg/kg). On the 11th day, rats were sacrificed, and blood and urine samples and kidneys were collected for biochemical estimation of several traditional and novel indices of renal damage in plasma and urine, several oxidative and nitrosative indices in kidneys, and assessment of histopathological renal damage. CP significantly and adversely altered all the physiological, biochemical and histopathological indices of renal function measured. Kidneys of CP-treated rats had a moderate degree of necrosis. This was markedly lessened when CP was given simultaneously with sesamin. Sesamin treatment did not significantly alter the renal CP concentration. The results suggested that sesamin had ameliorated CP nephrotoxicity in rats by reversing the CP – induced oxidative stress and inflammation. Pending further pharmacological and toxicological studies sesamin may be considered a potentially useful nephroprotective agent.

Key words: Cisplatin • nephrotoxicity • sesame oil • sesamin • rats
Introduction

Cisplatin (CP) is a major and potent platinum-based antineoplastic agent that is used in the treatment of a wide range of cancers, including otherwise resistant solid tumors. It is currently among the most widely used agents in the chemotherapy of lymphomas, stomach, esophageal, pancreatic, bladder, head and neck, lung, ovarian, and testicular cancers (Dasari and Tchounwou. 2016, Ojima et al. 2018). Nephrotoxicity is known to be the dose-limiting side effect of CP-based chemotherapy in cancer patients that leads to acute kidney injury (AKI), followed by chronic renal problems (Latcha et al. 2016, Skinner. 2018). CP – induced AKI is a complex process, and has often poor prognosis (Sharp and Siskind. 2017). Wider usage of CP is hampered by nephrotoxicity, as about 25-40% of the cancer patients exhibit a progressive decline in renal function after one dose of CP, and more than 70% of children given CP experience renal dysfunction (Hoek et al. 2016, Karasawa and Steyger. 2015).

Currently, there are no completely effective approaches available to prevent CP nephrotoxicity during chemotherapy (Crona et al. 2017). Although the pathogenesis of CP nephrotoxicity is not entirely clear, it is known that CP activates multiple signaling pathways in renal tubular cells, leading to inflammation, oxidative stress, tubular cell injury, and death (Karasawa and Steyger. 2015, Zhu et al. 2015).

Various strategies, including the use of drugs and phytochemical supplements, have been attempted to either ameliorate or prevent CP nephrotoxicity (Heidari-Soreshjani. 2017, Crona. 2017). These include naturally-occurring and synthetic antioxidants, modulators of nitric oxide, diuretics, cytoprotective and antiapoptotic agents (Ali and Al Moundhri.
2006, Pabla and Dong. 2008, Nematbakhsh et al. 2017). Data from animal and limited human studies suggest that use of these approaches may improve oncological outcomes and mitigate toxicity (Prasad. 2004).

Sesame seeds and oil have been widely used in human diet as a healthy food for thousands of years (Namiki 2007, Guo et al. 2016). Sesame oil has also been utilized in traditional medicine in, for example, India and the Middle East (Namiki 2007). Sesamin is the most abundant lignan in sesame oil, usually about 0.4% (Fukuda et al. 1998, Namiki 2007). It has antiinflammatory (Fan et al. 2017a), antioxidant (Wan et al. 2015, and antiapoptotic (Fan et al. 2017b) actions. As CP nephrotoxicity involves inflammation, oxidative stress and apoptosis (Pabla and Dong et al. 2008, Sharp and Siskind. 2017), we thought it worthwhile testing whether sesamin, at a safe dose that have been successfully used before (Tomimori et al. 2017), could ameliorate CP-induced nephrotoxicity.

**Materials and methods**

*Ethics statement*

Ethical approval for conducting the work was obtained from Sultan Qaboos University (SQU) Animal Ethics Committee (SQU/AEC/2017-15). All procedures involving animals and their care were carried out in accordance with international laws and policies (EEC Council directives 2010/63/EU, 22 September, 2010 and NIH Guide for the Care and Use of Laboratory Animals, NIH Publications, 8th edition, 2011).

*Chemicals*

Sesamin, carboxymethyl cellulose and platinum standard solution were purchased from Sigma-Aldrich Corporation (St. Louis, MO, USA), CP from Mylan S.A.S. (Saint-Priest,
France), and tumor necrosis factor alpha (TNF-α), cystatin C, interleukin-1β (IL-1β), transforming growth factor (TGF-β1) and neutrophil gelatinase-associated lipocalin (NGAL) ELISA kits from Thermo Fisher Scientific, Inc. (Waltham, MA, USA). Renalase ELISA kit was purchased from Cusabio Biotech Co., Ltd. (Wuhan, Hubei Province, P. R. China), and superoxide dismutase (SOD), catalase (CAT), glutathione reductase (GR), total antioxidant capacity (TAC), and malondialdehyde (MDA) assay kits from BioVision, Inc. (Milpitas, CA, USA). Total nitrite oxide assay kit, T-cell immunoglobulin and mucin domain 1 (TIM-1) or kidney injury molecule -1 (KIM-1), and liver-type fatty acid–binding protein (L-FABP) ELISA kits were purchased from R&D Systems, Inc. (Minneapolis, MN, USA). N-acetyl-β-D-glucosaminidase (NAG) was obtained from Diazyme Laboratories, Inc. (Poway, California, USA), and myeloperoxidase (MPO) assay kit from Abcam, Inc. (Cambridge, UK). Nuclear factor erythroid 2–related factor 2 (Nrf 2) ELISA kit was obtained from Cloud Clone Corp. (Katy, TX, USA). Urea, creatinine, uric acid, calcium, phosphorus and albumin were measured using an automated biochemical analyzer, Mindray BS-120 chemistry analyzer, from Shenzhen Mindray Bio-Medical Electronics Co. (Shenzhen, P. R. China).

**Animals and treatments**

Male Wistar rats, eight-weeks old and weighing about 200 g were obtained from Sultan Qaboos University Small Animal House. The rats (n = 36) were given free access to water, and a standard nutritionally-adequate laboratory chow diet (Oman Flour mills, Muscat, Oman). They were kept at an ambient temperature of $22\pm2^\circ C$, humidity of 60 % and maintained at 12 h/12 h light: dark cycle (light from 6:00 to 18:00).
Two experiments were conducted as follows:

A. After five days of acclimatization, the rats were randomly assigned to four groups and treated as follows:

1. The **first** (Control) received oral saline (0.4 ml/kg) only for 10 consecutive days.

2. The **second** group was treated as in group one, but also injected intraperitoneally (i.p.) with CP at a dose of 5 mg/kg, once on the 7th day of treatment.

3. The **third** group was treated as in group one, but also given sesamin (5 mg/kg/day) orally for 10 days.

4. The **fourth** group was treated with sesamin (5 ml/kg/day) orally for 10 days, and CP on the 7th day of treatment, as in the second group.

B. A similar experiment was carried out in which sesamin was replaced with sesame oil (5 ml/kg/day) orally for 10 days, and CP was injected i.p. on the 7th day.

The doses of sesamin, sesame oil, and CP were selected encompassing doses mentioned in previously published studies, viz Soliman *et al*. 2014, Tomimori *et al*. 2017, and Ali *et al*. 2011 respectively.

One day before the rats were killed, urine of each rat was collected over a 24-hr period, and its volume measured. Immediately after the end of the treatment period, rats were anesthetized with a combination of ketamine (60 mg/kg) and xylazine (5 mg/kg) given i.p. Blood was then collected from the inferior vena cava in heparinized tubes and centrifuged at 900 g for 15 min, at 5°C to separate plasma. The plasma harvested was stored frozen at −80°C pending biochemical analyses within ten days. The rats were then sacrificed by an overdose of anesthesia. The kidneys were removed from the rats, washed with ice-cold saline, blotted with a piece of filter paper and weighed. A small piece from
the left kidney was fixed in 10% buffered formalin. The cortex of the right kidney was excised from the medulla. Part was stored immediately deep frozen at −80°C for measuring platinum concentration and part was rapidly homogenized in ice-cold saline to produce 10% (w/v) tissue homogenate for other biochemical measurements.

*Biochemical analysis*

Plasma urea, creatinine, uric acid, calcium (Ca), phosphorus (P) and urine albumin and creatinine were measured by an autoanalyzer, as described before (Al Suleimani et al. 2017). Plasma TNF-α, cystatin-C, IL-1β, renalase and NGAL were measured using ELISA kits.

Kidney SOD, CAT, GR, TAC, nitrite, nitrate and total nitric oxide (NO) as well as urinary albumin, creatinine and urine albumin-to-creatinine ratio (UACR), kidney injury molecule-1 (KIM-1), fatty acids -binding proteins (FABP), and N-acetyl-β-D-glucosaminidase (NAG) activity were measured as described before using spectrophotometry and ELISA kits (Ali et al. 2013, Ali et al. 2018).

*Measurement of plasma platinum concentration*

The concentration of CP (as platinum) in plasma was measured by a standard method of inductively coupled plasma atomic emission spectrometry using an emission wavelength of 265.945 nm, at the Central Analytical and Applied Research Unit, College of Science, SQU, Oman. Platinum atomic absorption spectrophotometer standard solution was used to construct the standard curve.

*Histopathological analysis*
Kidneys were excised, washed with ice-cold saline, blotted with filter paper and weighed. Each kidney was cassetted and fixed directly in 10% neutral formalin for 24 h, which was followed by dehydration in increasing concentrations of ethanol, clearing with xylene and embedding in paraffin. Four-μm sections were prepared from paraffin blocks and stained with hematoxylin and eosin (H &E). The stained sections were evaluated blindly using light microscopy. The extent of necrosis was measured using Image J software (NIH, USA).

Statistical analysis

Data were given as mean ± SEM, and were analyzed by one-way analysis of variance followed by Bonferroni’s multiple comparison test (GraphPad Prism version 5.03, San Diego, CA, USA); P less than 0.05 was considered statistically significant.

Results

Physiological findings

CP treatment caused a significant reduction in the body-weight of the rats and a significant rise in their kidney weight, relative to the body-weight, and in their urinary output 24 hr after the end of treatment (P < 0.05). These changes were significantly mitigated when sesamin was given concomitantly with CP. Treatment with sesamin alone did not cause significant changes in the above parameters (Table 1).

Plasma biochemical indices of renal damage

As shown in Table 2, CP treatment significantly increased creatinine, urea and uric acid, and P concentrations, and decreased that of Ca in plasma, when compared with the control values. CP also increased the activity of the enzyme NGAL. Sesamin was without
any significant effect on these analytes. Sesamin given together with CP significantly mitigated the actions of CP mentioned above.

**Urinary biochemical indices of renal function**

These results are shown in Table 3. CP treatment significantly increased the urinary concentrations of KIM and L-FABP, NAG activity, and the urine albumin-to-creatinine ratio ($P < 0.05$). CP treatment significantly decreased creatinine clearance ($P < 0.05$).

**Inflammatory biomarkers in plasma**

The results are shown in Fig 1. CP treatment significantly increased the concentrations of TNF-$\alpha$, cystatin C, IL-1$\beta$, TGF-$\beta$1, and MPO activity, and significantly decreased that of renalase ($P < 0.001$). These actions were significantly mitigated when sesamin was given with CP. Treatment with sesamin alone did not significantly affect any of these analytes.

**Plasma platinum concentrations**

The concentration of platinum in the plasma (in ppm) from cisplatin-treated rats was $0.063 \pm 0.009$, and $0.056 \pm 0.003$ in the plasma from rats treated with cisplatin and sesamin ($P > 0.1$). The insignificant reduction in the latter group amounted to about 11%.

**Oxidative and nitrosative stress indices in renal homogenates**

The results of the oxidative stress are depicted in Fig 2. CP treatment significantly decreased the activities of SOD, CAT and GR, and TAC concentration ($P < 0.0001$, except for the result of CAT, which was at the level of $P < 0.05$). Treatment with sesamin alone significantly increased renal SOD activity ($P < 0.0001$), and slightly and insignificantly increased the levels of the other analytes. CP treatment significantly
increased the Nrf2 and MDA concentrations ($P < 0.0001$), an action that was significantly reversed by concomitant treatment with sesamin ($P < 0.0001$).

The results on the nitrosative stress are shown in Fig 3. CP significantly increased the renal nitrate concentration and the nitrate / nitrite ratio ($P < 0.05$). Concomitant sesamin treatment to CP – treated rats significantly decreased the nitrate / nitrite ratio ($P < 0.05$) to control level.

_Renal Histopathology_

The results of renal histopathology examinations are presented in fig. 4 and table 4. The control group (saline IP) showed normal kidney architecture and histology (score 0) {fig. 4 A & B}. The cisplatin (IP) treated group, showed acute tubular necrosis in $52 \pm 3.6\%$ of examined tissue areas (score 3), showing tubular distention with necrotic material involving loss of brush border, tubular dilatation, tubular cells necrosis, tubular nuclear pyknosis, tubular nuclear enlargement with hyperchromasia, tubular cells flattening, macrophages within the lumen, epithelial cells within the lumen and intra-luminal eosinophilic material {fig. 4 (C & D)}. The sesamin-treated group showed normal kidney architecture and histology (score 0) {fig. 4 (E & F)}. The (cisplatin + sesamin)-treated group showed dramatic improvement in the histological appearance when compared with the cisplatin-treated group. There was no morphological evidence of acute tubular necrosis in the examined areas (score 0) {fig. 4 (G & H)}.

_Sesame oil_

Sesame oil, at the dose used, did not significantly alter any of the parameters studied in the sesamin experiment described above (data not shown).
Discussion

In this work, we have found that sesamin (5 mg/kg) was highly and significantly effective in mitigating the physiological, biochemical and histopathological damage induced by CP, without causing any overt adverse effects.

Sesame oil, at the dose used, did not significantly alter any of the parameters studied in the sesamin experiment described above. Raw sesame oil contains 0.5–1.1 % sesamin (Mahendra Kumar and Singh, 2015). The low amount of sesamin the oil may account for its inability to mitigate the indices of renal damage caused CP.

CP is considered the cornerstone of therapy for many types of solid tumors (Crona et al. 2017). Despite many studies, the mechanisms underlying the side effects induced by CP are not fully elucidated, but have been suggested to be multi-factorial in nature (Miller et al. 2010, Wilmes et al. 2015). These mechanisms include the generation of reactive oxygen and nitrogen species, inflammation and apoptosis. The former interferes with the antioxidant defense system and causes oxidative damage in tissues, and reaction with thiols in protein and glutathione, leading to cell dysfunction. Inflammation could be instigated by damage to the renal epithelial cells, and may augment renal injury and dysfunction in vivo (Miller et al. 2010).

In this work, injection of rats with CP (5 mg/kg) caused a significant decrease in total body weight as well as an increase in kidney/body weight ratio when compared with the control group. The decrease in body weight seen in the CP-treated rats may be due to the gastrointestinal toxicity of the drug (Shahid et al. 2018) or possibly to the injured renal tubules, and the consequent inability of the tubular cells to reabsorb water, increased
urine volume voided leading to dehydration and loss of body weight (Ali et al. 2008). This renal tubular damage resulted in acute nephrotoxicity reflected in the significant changes in the physiological, biochemical and other indices, as previously reported (Ali et al. 2014, Ali et al. 2018). These results were supported by light microscopic examination of renal tissues that showed clear pathological changes. Renal structure and function were significantly improved by treatment with sesamin (5 mg/kg).

Among the mechanisms involved in sesamin amelioration of CP-induced nephrotoxicity, are the significant reduction in oxidative and nitrosative stress, apoptosis and inflammation. Oxidative stress is known to have a critical and causal role in CP-induced nephrotoxicity and that it mediates a rise in lipid peroxidation, which is a reliable oxidative stress marker, and nitric oxide increases inflammation and oxidative processes (Meng et al. 2017). Sesamin at the relatively low dose used here was effective in significantly abrogating these actions, confirming its strong antioxidant actions. CP is taken up in renal tubular cells in high concentrations, leading to its accumulation and tubular cell injury and death, culminating in acute renal failure (Miller et al. 2010).

We have found that CP treatment significantly increased the renal content of (Nrf2), an essential homeostasis master regulator of tolerance to redox stress, and this action was mitigated by sesamin administration. The increase in Nrf2 has recently been implicated in the cellular defense against CP nephrotoxicity (Shelton et al, 2013). It has recently been reported that sesamin (at a single dose of 25–100 mg/kg) given orally one hour before intraperitoneal injection of lipopolysaccharide (LPS) was effective in protecting mice from LPS-induced acute kidney injury (AKI) by reducing renal oxidative stress, inflammation, and apoptosis (Rousta et al. 2018).
The pathogenesis of CP nephrotoxicity, involves inflammation as a major factor, and CP is known to activate the NF-κB pathway, that facilitate the increase in several inflammatory cytokines such as TNF-α and the IL-1β. Both cytokines have been increased in our experiment by CP, an action that was significantly antagonized by sesamin treatment. Cystatin, in addition to being a reliable renal biomarker in both acute kidney injury and chronic kidney disease (Ali et al, 2018), is also considered a biomarker for inflammation (Deyà-Martínez et al. 2016).

We used in this work the relatively novel biomarkers TGF-β1, which is used as biomarker in cardiovascular diseases (Mukherji et al. 2017), and lately as a biomarker in surgery-induced renal fibrosis in rat (Ma et al. 2018). Here, we found that its concentration in plasma is significantly increased in CP-induced nephrotoxicity, and that sesamin significantly ameliorated that action.

Probably for the first time, we used the activity of the relatively novel enzyme renalase as a biomarker of renal health in rats with CP nephrotoxicity. Renalase was used before as a biomarker for cardiovascular disease (Schlaich et al. 2018). Here we have found that CP treatment induces a significant inhibition of the enzyme, whereas sesamin alone causes the opposite action. (Fig. 1). When sesamin was given to CP-treated rats, the enzyme activity was significantly raised to about 80% of the control value. Our results indicate that plasma renalase activity is negatively correlated with renal health in rats, and is different from results in humans with chronic kidney disease, where a significant increase has been observed. This reason(s) for the difference is not certain, but may be due to species difference (Quelhas-Santos and Pestana, 2014, Baek et al. 2017).
Previous studies have shown that some agents can reduce CP-induced nephrotoxicity by decreasing the accumulation of platinum renal levels (Kimoto et al. 2013), and some agents mitigate CP nephrotoxicity without significantly affecting these levels (Ali et al. 2013).

It was of interest to note that the ameliorative action of sesamin on CP nephrotoxicity was not related to any possible reduction of CP accumulation in the plasma, as we found only a slight (about 11%) and insignificant reduction in the concentration of platinum in plasma of sesamin-treated rats. It is established that a significant rise in CP concentrations in the kidneys and plasma occurs in cases of nephrotoxicity (Darwish et al. 2017).

Further experiments are warranted to determine the specific molecular pathways by which the nephroprotective action of sesamin is carried out. Several molecular pathways have previously been suggested to explain the salutary action of sesamin in various experimentally-induced conditions. For example, sesamin has been reported to protect against cardiac remodeling in rodents induced by transverse aortic constriction via the Sirt3/ROS pathway (Fan et al. 2017), several dietary restriction-related signaling pathways, including processes requiring SIRT1, TOR, and AMPK in *Caenorhabditis elegans*, and the inhibition of the TLR4 expression and NF-κB activation in LPS-induced acute lung injury in mice (Qiang et al. 2016). NF-κB activation, toll-like receptor 4 (TLR4), cyclooxygenase-2 (COX2), tumor necrosis factor α (TNF-α), interleukin-6, DNA fragmentation), and Nrf2 have been suggested to be the mechanisms involved in LPS-induced AKI in mice (Rousta et al. 2018).

**Conclusion**
The present work has presented experimental evidence that sesamin is useful in mitigating adenine – induced CKD in rats, through attenuation of several inflammatory, oxidative and nitrosative stress parameters. No overt untoward actions have been found from sesamin treatment. Further studies into the specific molecular mechanism(s) of the beneficial action of sesamin are warranted. Pending further pharmacological and toxicological studies, clinical testing of sesamin as a dietary supplement in patients with AKI and other renal diseases may also be warranted.

**Declaration of conflicting interests**

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**Acknowledgments:**

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**References**


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ALI BH, CAHLIKOVÁ L, OPLETAL L, KARACA T, MANOJ P, RAMKUMAR A, AL SULEIMANI YM, AL ZA'ABI M, NEMMAR A, CHOCHOLOUSOVA-


Figure legends

**Figure 1.** The plasma concentration of tumor necrosis factor (TNF-α), interleukin (IL-1β), transforming growth factor (TGF-β1), cystatin C, renalase, and the renal activity of myeloperoxidase (MPO) in control rats, and rats treated with cisplatin or sesamin (separately or in combination). Each column and vertical bar represents mean ± SEM (n = 6).

Differences between the groups were assessed by one-way analysis of variance (ANOVA) followed by Bonferroni’s multiple comparison test.

**Figure 2.** The renal concentration or activity of superoxide dismutase (SOD), catalase (CAT), glutathione reductase (GR), total antioxidant capacity (TAC), malondialdehyde (MDA), and nuclear factor erythroid 2-related factor 2 (Nrf2) in control rats, and rats treated with cisplatin or sesamin (separately or in combination). Each column and vertical bar represents mean ± SEM (n = 6).

Differences between the groups were assessed by one-way analysis of variance (ANOVA) followed by Bonferroni’s multiple comparison test.

**Figure 3.** The renal concentration of total nitric oxide (NO), nitrite and nitrate, and the nitrate/nitrite ratio in control rats, and rats treated with cisplatin or sesamin (separately or in combination). Each column and vertical bar represents mean ± SEM (n = 6).
Differences between the groups were assessed by one-way analysis of variance (ANOVA) followed by Bonferroni’s multiple comparison test.

**Figure 4.** Representative micrographs of kidney sections from control rats, and rats treated with cisplatin or sesamin (separately or in combination), stained with hematoxylin and eosin (H & E). The control (A and B) and sesamin-treated group (E & F) show normal kidney architecture and histology. The cisplatin-treated group (C & D) shows acute tubular necrosis in 52 ± 3.62% of examined tissue areas (thin arrows) with tubular distention with necrotic material. The (cisplatin + sesamin)-treated group (G & H) shows dramatic improvement in the histologic appearance with absence of acute tubular necrosis and complete recovery of injured tubules.
Table 1. Effect of treatment with sesamin (SM) on some physiological parameters in rats with cisplatin (CP)-induced acute kidney injury (AKI).

<table>
<thead>
<tr>
<th>Parameters/Treatment</th>
<th>Control</th>
<th>CP (5 mg/kg)</th>
<th>SM (5 mg/kg)</th>
<th>CP + SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in body weight (%)</td>
<td>16.77 ± 1.29</td>
<td>8.44 ± 1.76a</td>
<td>20.07 ± 1.10</td>
<td>14.94 ± 0.99b</td>
</tr>
<tr>
<td>Relative kidney weight (%)</td>
<td>0.58 ± 0.01</td>
<td>0.69 ± 0.03a</td>
<td>0.57 ± 0.01</td>
<td>0.62 ± 0.01b</td>
</tr>
<tr>
<td>Urine flow (µl/min)</td>
<td>6.25 ± 0.36</td>
<td>9.95 ± 0.66a</td>
<td>5.67 ± 0.42</td>
<td>8.68 ± 0.61a</td>
</tr>
<tr>
<td>Food intake (g)</td>
<td>21.33 ± 1.20</td>
<td>17.20 ± 2.14a</td>
<td>21.63 ± 1.13</td>
<td>19.30 ± 0.48</td>
</tr>
<tr>
<td>Feces output (g)</td>
<td>8.17 ± 0.91</td>
<td>5.97 ± 0.76a</td>
<td>9.70 ± 0.80</td>
<td>6.82 ± 0.40</td>
</tr>
</tbody>
</table>

The values in the tables are mean ± SEM (n = 6).

Sesamin (5 mg/kg/day) was given to the rats by oral gavage for 10 days, and on the 7th day, AKI was induced by injecting a single dose of CP (5 mg/kg), intraperitoneally. On the 10th day of treatment, the rats were placed in metabolic cages to collect urine. The rats were sacrificed on the 11th day.

Different superscripts indicate significance as follows (P < 0.05 was considered significant):

a denotes significance of Control group vs different groups,
b denotes significance of CP group vs. (CP + SM)-treated group.
Table 2. Effect of treatment with sesamin (SM) on some indices of renal damage in plasma of rats with cisplatin (CP)-induced acute kidney injury (AKI).

<table>
<thead>
<tr>
<th>Parameters/Treatment</th>
<th>Control</th>
<th>CP (5 mg/kg)</th>
<th>SM (5 mg/kg)</th>
<th>CP + SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>NGAL (ng/ml)</td>
<td>27.36 ± 2.27</td>
<td>138.86 ± 9.05&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30.76 ± 2.81</td>
<td>95.06 ± 7.26&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Creatinine (μmol/l)</td>
<td>18.35 ± 1.08</td>
<td>121.37 ± 7.72&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.88 ± 0.54</td>
<td>56.72 ± 2.48&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Urea (mmol/l)</td>
<td>5.70 ± 0.37</td>
<td>13.42 ± 0.81&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.76 ± 0.24</td>
<td>9.88 ± 0.57&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Uric acid (μmol/l)</td>
<td>46.67 ± 3.85</td>
<td>89.97 ± 5.75&lt;sup&gt;a&lt;/sup&gt;</td>
<td>38.95 ± 2.22</td>
<td>67.28 ± 5.56&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Phosphorus (mmol/l)</td>
<td>0.55 ± 0.05</td>
<td>1.27 ± 0.12&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.54 ± 0.05</td>
<td>0.89 ± 0.05&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Calcium (mmol/l)</td>
<td>1.15 ± 0.06</td>
<td>0.69 ± 0.05&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.03 ± 0.09</td>
<td>0.92 ± 0.05&lt;sup&gt;a,b&lt;/sup&gt;</td>
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</table>

The values in the tables are mean ± SEM (n = 6).

Sesamin (5 mg/kg/day) was given to the rats by oral gavage for 10 days, and on the 7th day, AKI was induced by injecting a single dose of cisplatin (5 mg/kg), intraperitoneally.

NGAL: Neutrophil gelatinase-associated lipocalin.

Different superscripts indicate significance as follows (P < 0.05 was considered significant):
<sup>a</sup> denotes significance of Control group vs different groups,
<sup>b</sup> denotes significance of CP group vs. (CP + SM)-treated group.
Table 3. Effect of treatment with sesamin (SM) on some urinary indices in rats with cisplatin (CP)-induced acute kidney injury (AKI).

<table>
<thead>
<tr>
<th>Parameters/Treatment</th>
<th>Control</th>
<th>CP (5 mg/kg)</th>
<th>SM (5 mg/kg)</th>
<th>CP + SM</th>
</tr>
</thead>
<tbody>
<tr>
<td>KIM-1 (pg/ml)</td>
<td>221.64 ± 13.08</td>
<td>532.40 ± 6.86&lt;sup&gt;a&lt;/sup&gt;</td>
<td>202.09 ± 20.61</td>
<td>399.69 ± 21.05&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>L-FABP (ng/ml)</td>
<td>0.82 ± 0.07</td>
<td>6.83 ± 0.38&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.90 ± 0.10</td>
<td>5.35 ± 0.32&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>NAG activity (IU/l)</td>
<td>3.16 ± 0.27</td>
<td>14.72 ± 0.84&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.12 ± 0.19&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.26 ± 0.34&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Creatinine clearance (mL/min)</td>
<td>3.10 ± 0.22</td>
<td>0.54 ± 0.04&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.24 ± 0.20</td>
<td>1.28 ± 0.10&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>UACR (mg/mmol)</td>
<td>423.89 ± 10.55</td>
<td>789.83 ± 27.36&lt;sup&gt;a&lt;/sup&gt;</td>
<td>405.33 ± 13.13</td>
<td>571.16 ± 28.84&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Values in the table are means ± SEM (n = 6).
Sesamin (5 mg/kg/day) was given to the rats by oral gavage for 10 days, and on the 7<sup>th</sup> day, AKI was induced by injecting a single dose of cisplatin (5 mg/kg), intraperitoneally. On the 10<sup>th</sup> day of treatment, the rats were placed in metabolic cages to collect urine.

KIM-1: Kidney injury molecule-1; L-FABP: Liver-type fatty acid–binding protein; NAG: N-acetyl-β-D-glucosaminidase (NAG); UACR: Urine albumin-to-creatinine ratio.

Different superscripts indicate significance as follows (P < 0.05 was considered significant):
<sup>a</sup> denotes significance of Control group vs different groups,
<sup>b</sup> denotes significance of CP group vs. (CP + SM)-treated group.
Table 4. Effect of treatment with sesamin (SM) on necrosis in the kidneys of rats with cisplatin (CP)-induced acute kidney disease (AKD).

<table>
<thead>
<tr>
<th>Parameters/Treatments</th>
<th>Control</th>
<th>CP (5 mg/kg)</th>
<th>SM (5 mg/kg)</th>
<th>CP + SM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Percentage of necrosis</strong></td>
<td>0.0 ± 0.0</td>
<td>52.0 ± 3.6\textsuperscript{a}</td>
<td>0.0 ± 0.0</td>
<td>0.0 ± 0.0\textsuperscript{b}</td>
</tr>
<tr>
<td><strong>Score of necrosis</strong></td>
<td>0.0 ± 0.0</td>
<td>3.0 ± 0.0\textsuperscript{a}</td>
<td>0.0 ± 0.0</td>
<td>0.0 ± 0.0\textsuperscript{b}</td>
</tr>
</tbody>
</table>

The values in the tables are mean ± SEM (n = 6)

Different superscripts indicate significance as follows, where $P < 0.05$:
\textsuperscript{a} denotes significance of control group vs different groups,
\textsuperscript{b} denotes significance of CP group vs. (CP + SM)-treated group.
Fig. 2.
Fig. 3