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Original Research Article

Alleviation of clastogenic, hematotoxic, and nephrotoxic effects of Potassium dichromate by hydro-ethanol extract of *Moringa oleifera* in rats

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Abstract

Purpose: Chromium (VI) is a human carcinogen associated with tissue toxicity, affecting blood and kidneys. The adverse effects of current intervention regimens necessitate investigation into potential antidotes from medicinal flora such as *Moringa oleifera* Lam (M. oleifera), which exhibits notable pharmacological attributes. This study assesses the impact of the hydro-ethanol extract of M. oleifera (HEMO) on potassium dichromate [$K_2Cr_2O_7$]-induced clastogenicity, hematotoxicity, and nephrotoxicity.

Methods: Thirty male Wistar rats were divided equally into six groups. They were treated with 12 mg/kg $K_2Cr_2O_7$, 3.5 mg/kg, and 7 mg/kg HEMO either alone or in combination. The $K_2Cr_2O_7$ was given intraperitoneally once weekly, while HEMO was given orally daily for 5 weeks. Control rats had distilled water daily for 5 weeks by gavage.The levels of bone marrow micronucleated polychromatic erythrocytes (mPCEs), packed cell volume (PCV), white blood cells (WBC), neutrophils, lymphocytes, relative kidney weight (RKW), blood urea and creatinine were assessed following the 5-week treatment period and sacrifice. Renal malondialdehyde (MDA), superoxide dismutase (SOD), and glutathione-S-transferase (GST) were also determined. Additionally, renal histopathology and HPLC determination of polyphenols and flavonoids in HEMO were conducted.

Results: The HEMO and $K_2Cr_2O_7$ combination reduced mPCES, WBC, KWT, RWT, urea, creatinine, and renal MDA compared to the $K_2Cr_2O_7$-treated group. However, HEMO augmented PCV, SOD, and GST in contrast to $K_2Cr_2O_7$ and improved renal histology. The HEMO is rich in flavonoids including kaempferol, ferrulic acid, and amentoflavone that could protect against chromium(VI)-induced toxicities.
Conclusion: The HEMO has the potential for use in the management and treatment of chromium(VI) toxicity.

Keywords: Chromium(VI), *Moringa oleifera*, micronucleated polychromatic erythrocytes, oxidative stress, antioxidants, hematology, nephrotoxicity, high-performance liquid chromatography

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INTRODUCTION

Chromium (Cr) (VI) is a poisonous heavy metal and an environmental contaminant that poses significant public health concerns, particularly in occupational settings like electroplating, welding, and painting, areas with industrial contamination, and patients with metal-metal prosthesis.[1] A good number of studies have linked Cr (VI) exposure to a myriad of health problems, including various forms of cancer, liver damage, reproductive health issues, developmental toxicity, cardiovascular diseases, and renal injury.[2] The insidious effects of Cr (VI) on biological systems have been extensively studied in various animal models, which have illuminated the pathways through which Cr (VI) inflicts damage. The carcinogenic potential of Cr (VI) is primarily attributed to its metabolites, pentavalent and trivalent chromium.[3] The metabolites exert their effects by producing radicals including hydroxyl radicals during the reoxidation process by cellular hydrogen peroxide, and by forming complexes with cellular macromolecules, leading to disruption of cellular signaling pathways and various forms of DNA damage through DNA strand breaks, formation of chromium-DNA adducts, and DNA-protein cross-links.[4] Additionally, in animal tissues including the liver, blood, and kidneys, Cr (VI) induces oxidative stress, marked by a rise in lipid peroxidation, compromising cellular integrity and function.[5,6] Concomitantly, Cr (VI) exposure results in the inactivation of key antioxidants crucial for mitigating oxidative stress.[7]

Given the health hazards of Cr (VI), treatment strategies have traditionally involved chelating agents such as tetraacetic 2,3-dimercaprol acid and calcium disodium ethylenediamine.[8] However, the adverse effects associated with these treatments such as fatigue, headache, fever, nasal congestion, lacrimation, mucocutaneous lesions, glycosuria, myalgia, hepatotoxicity, increased urinary frequency, hypotension, and gastrointestinal symptoms, have led researchers to explore alternative therapies. There is evidence that dietary antioxidants and phytochemicals from medicinal plants protect against heavy metal toxicity, including the attenuation of Cr (VI) toxicity.[8]

Moringa oleifera Lam (M. oleifera), commonly known as the "miracle tree," is a perennial tropical deciduous arbor belonging to the family Moringaceae, is native to parts of Afghanistan, Bangladesh, India, and Pakistan, and has been naturalized in almost all tropical and subtropical regions of the world including Nigeria.[9] The M. oleifera tree grows to 10-15 m in height with grey bark. The 6-70 m long alternately paired leaves are tripinnate, with 4-6 pairs of oval, dark green leaflets about 2 cm in length and breadth. Its 1.0–1.5 cm long and 2.0 cm wide yellowish-white pentamerous flowers are attached to axillary inflorescences. The fruit resembles a drumstick, transitioning from green to dark brown at maturity. It contains 15-20 round or triangular seeds about 1.5 cm in diameter, surrounded by three transparent wings.

Remarkable adaptability and utility have made *M. oleifera* an invaluable resource in combating nutritional deficiencies, as it is considered among the most affordable and reliable sources of essential nutrients.[10] The leaves of *M. oleifera* are highly regarded for their nutritional value and richness in vitamins and minerals.[11] Various parts of the plant are traditionally used in treating ailments like cancer, hypertension, ulcers, splenomegaly, arthritis, depression, diarrhea, viral diseases, inflammation, anemia, liver diseases, diuresis, and kidney stones.[12] In addition, the antimicrobial, anti-diabetic, antifungal, antioxidant, wound healing, immunomodulatory activity, diuretic, antiproliferative, and anticancer activities of different extracts of the leaves have been pharmacologically validated.[13,14,15,16,17]

M. oleifera leaves have been shown to exert beneficial effects against environmental toxicants, including heavy metals, that disrupt cellular homeostasis and function. For instance, leaf extracts of M. oleifera were recently shown to reduce the toxicities of some heavy metals in *Saccharomyces cerevisiae*.[18] Similarly, M. oleifera leaves ameliorated sodium arsenate-induced genotoxicity and reproductive outcomes in mice.[19] In addition, lead acetate-induced nephrotoxicity in mice has also been shown to be ameliorated by M. oleifera leaf extract.[20] Moreover, our research findings have shown that the hydro-ethanol extract of M. oleifera (HEMO) reduced the negative impact of chromium(VI) in the liver.[21] However, there is a dearth of information on its potential impact on potassium dichromate ($K_2Cr_2O_7$)-induced toxicities in other tissues. In the current study, the potential of HEMO against $K_2Cr_2O_7$-induced clastogenicity (chromosomal damage), hematotoxicity (blood toxicity), and nephrotoxicity (kidney damage) was investigated in rats.

MATERIALS AND METHODS

Reagents

Potassium dichromate ($K_2Cr_2O_7$) was obtained from Sigma Chemical Co. in St. Louis, MO. Urea kits (Randox Laboratories Ltd, UK) were used for

the experiment. All other reagents utilized were analytical-grade chemicals.

Moringa extract

The first step involved gathering fresh *M. oleifera* leaves from the horticulture garden (6.689606 North and 3.165886 East) at Bells University of Technology, Ota, Nigeria in November 2023. Samples were taken to the herbarium at the University of Lagos, Lagos, for identification. A voucher number 100415 was assigned following registration. The leaves were air-dried, milled and 100g of milled the leaves was extracted with 500 ml of 70% ethanol as previously documented.[21]

Experimental animals and treatment

In this study, we utilized 30 male Wistar albino rats, ranging from 10 to 12 weeks old, each weighing approximately 120 grams on average. These animals were procured from the Department of Physiology's animal facilities at the University of Ibadan, Nigeria. They were housed in polypropylene cages and maintained in the institutional animal house, where they were kept in standard environmental conditions. They were sustained on a standard laboratory diet with unrestricted access to water. The care and maintenance of these animals adhered strictly to established guidelines.[22] Ethical approval (NHREC/08/10-2015) was granted by the Federal Medical Centre located in Abeokuta, Ogun State, Nigeria before the commencement of the experiment.

Experimental design

To ensure uniformity in the initial body weights across all experimental groups, rats were systematically allocated into six groups of 5 rats each in a manner that ensured similar average body weight across the groups. During the five-week study, control groups were given water (group 1) by gavage daily and 12 mg/kg body weight of $K_2Cr_2O_7$ (group 2) was injected via intraperitoneal (i.p.) route once every Friday. Rats in the test groups were subjected to once daily oral doses of 3.5 and 7.0 mg/kg body weight of HEMO alone (groups 3 and 4) and combined with a weekly i.p. dose of 12 mg/kg body weight of $K_2Cr_2O_7$ (groups 5 and 6) every Friday, as detailed in Figure 1. Both $K_2Cr_2O_7$ and HEMO were dissolved in water before administration, with dosage levels selected based on findings from prior studies.[23,24] A day after the end of treatment, the rats' final body weights were recorded, and blood was obtained from the retro-orbital plexus of each rat into heparin and EDTA-containing tubes. After, the blood collection, the rats were euthanized via cervical dislocation and quickly dissected.

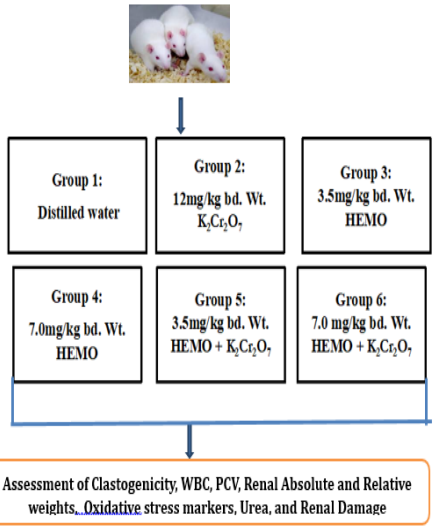


Figure 1: Experimental design chart for treatment administration per experimental group

Thereafter, the kidneys of each rat were harvested, weighed, and analyzed for oxidative stress indicators and histopathological changes.

Micronucleus assay

After sacrifice, the femurs of each experimental animal were removed, and then using a needle and syringe the bone marrow was extracted. The bone marrow samples were then prepared on a slide for microscopic examination as previously reported.[25]

Determination of Hematological Indices

The PCV was determined using the standard hematocrit method. Capillary tubes were used to draw blood to about two-thirds of their volumes from the EDTA-containing tubes. The tube was sealed at one end with plasticine and centrifuged at 4000 rpm for 5 minutes. Following centrifugation, the capillary tubes were placed in a hematocrit reader and the percentage packed cells were recorded. The white blood cell (WBC) was determined by adding the blood collected in EDTA tubes to Turk's solution in the ratio 1: 18 respectively. A few drops of the resulting mixture were carefully put under a coverslip and placed on the counting chamber of a hemocytometer. An Olympus microscope set at X 40 magnification was used to determine the white blood cell count after allowing the mixture to settle.The percentage of neutrophils and lymphocytes was determined as mentioned previously.[23]

Absolute and Relative Kidney Weight Determination

Both kidneys of each rat were weighed, and the value obtained was recorded as absolute kidney weight (KWT). The relative kidney weight (RKW) in percentage was obtained by dividing the KWT of each rat by its final body weight and multiplying the product by 100.[26]

Determination of Oxidative Stress Markers

The oxidative stress parameters were determined in the supernatant obtained from homogenization and centrifugation of the right kidney harvested from each rat.[24] Malondialdehyde (MDA),[27] superoxide dismutase (SOD),[28] and glutathione-S-transferase (GST),[29] were measured through established methodologies.

Evaluation of Renal Function Markers

Heparinized blood samples were centrifuged and decanted as earlier reported.[24] The concentrations of urea and creatinine were determined with Randox diagnostic kits (United Kingdom) based on the producer's instructions.

Histopathology

The harvested left kidney of each rat was collected postmortem and fixed immediately in 10% formalin buffer. Basic procedures such as dehydration in a graded ethanol solution, washing in xylene, embedding in paraffin, sectioning, sample fixation, deparaffinizing, staining, and counter-staining using eosin and hematoxylin were done as described recently.[25] Finally, the prepared slides were examined under a light microscope (Olympus BX 41) to study the organ's pathological changes.

High-performance liquid chromatography (HPLC)

The quantity of some flavonoids present in HEMO was determined using HPLC. To carry out this procedure, the HEMO (1.0 mg) was reconstituted in 1.0 ml absolute methanol and analyzed as detailed earlier.[24]

Statistical analysis

The results were subjected to statistical analysis using a one-way analysis of variance conducted with version 17 of the Statistical Package for the Social Sciences (Chicago, IL, USA). The Duncan Multiple Range Test was employed in identifying differences among the mean values of different groups. Statistical significance was established at least when $p < 0.05$.

RESULT AND DISCUSSION

Exposure to Cr (VI) such as $K_2Cr_2O_7$ has been shown to have carcinogenic, hematologic, and nephrotoxic effects, through overproduction of ROS, oxidative DNA damage, and formation of adducts of Cr-DNA.[30,31,32] *Moringa oleifera* is enriched with phytochemicals that can induce anti-inflammatory, antioxidant, and other chemoprotective effects in a range of biomedical models.[13,17] The potential of the hydro-ethanolic leaf extract of *Moringa oleifera* (HEMO) in relieving the clastogenic, hematologic, and nephrotoxic effects of $K_2Cr_2O_7$ was assessed in this study. The results revealed that concomitant administration of HEMO reduced the incidence of micronuclei formation and toxicity to blood and renal cells of $K_2Cr_2O_7$-intoxicated rats.

The degree of induction of mPCEs in the cells of bone marrow is revealed in Figure 2. As expected, there was a substantial ($p < 0.01$) rise in the frequency of micronucleus formation in the animals treated with $K_2Cr_2O_7$ when contrasted with the control. However, no significant difference was noted in the groups given the different concentrations of HEMO alone, in comparison with the control. A dose-dependent significant ($p < 0.01$) decrease in mPCES was recorded when $K_2Cr_2O_7$ was combined with HEMO in comparison to the $K_2Cr_2O_7$-treated group.

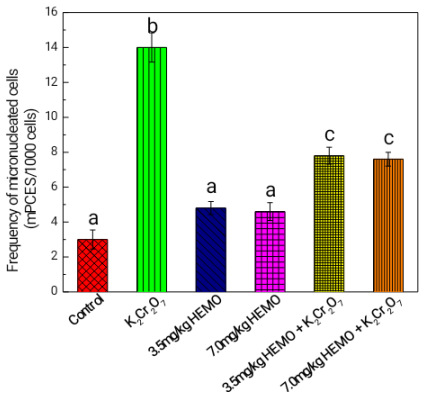
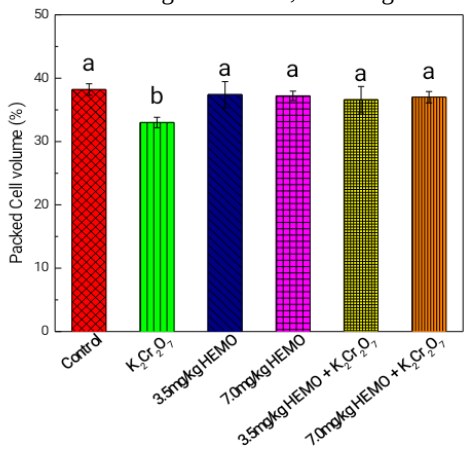


Figure 2: Degree of induction of mPCEs in the bone marrow cells of test and control animals. Values with different superscripts are significantly different.

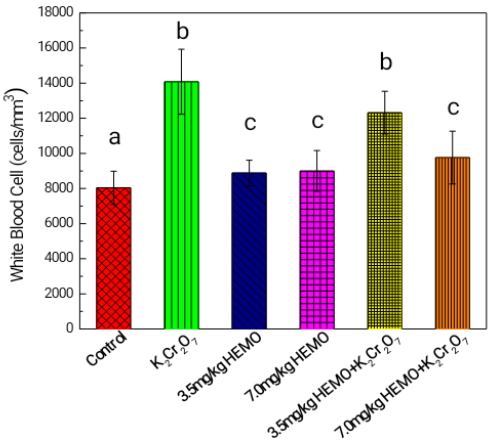
Legend: HEMO; hydro-ethanol extract *Moringa oleifera*; MPCEs: micronucleated polychromatic erythrocytes

Assessment of the frequency of mPCEs is one of the most successful and reliable assay markers for genotoxic carcinogens. The approximately 5-fold increase observed in the frequency of mPCEs in the $K_2Cr_2O_7$-treated rats is an indication of chromosomal damage. This finding is consistent with past observations from our laboratory.[5,23] The increased frequency of induction of mPCEs observed in the $K_2Cr_2O_7$-treated rats may be due to chromium-generated intermediates and free radicals that can attack DNA leading to chromosomal breakage. However, the antagonistic effect observed in the HEMO and $K_2Cr_2O_7$ groups, suggests a promising potential protective and/or therapeutic effect of HEMO in repairing chromosomal damage and protecting against carcinogenesis.

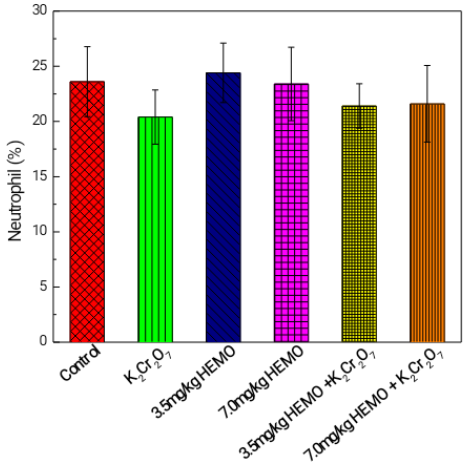
The results of some hematological indices obtained following treatment with $K_2Cr_2O_7$ and HEMO are presented in Figure 3. The PCV was similar across the groups except for the $K_2Cr_2O_7$-treatment group which had significantly ($p< 0.05$) reduced PCV.



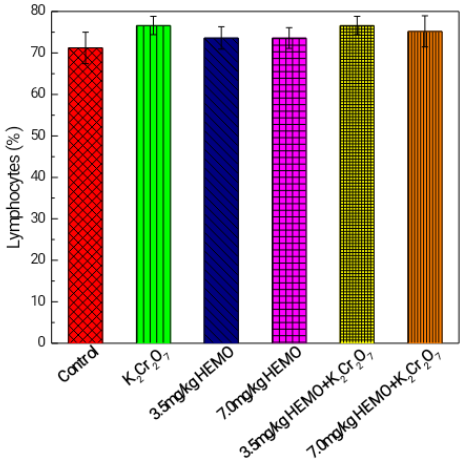
Packed Cell Volume



White Blood Cell



Neutrophil



Lymphocytes

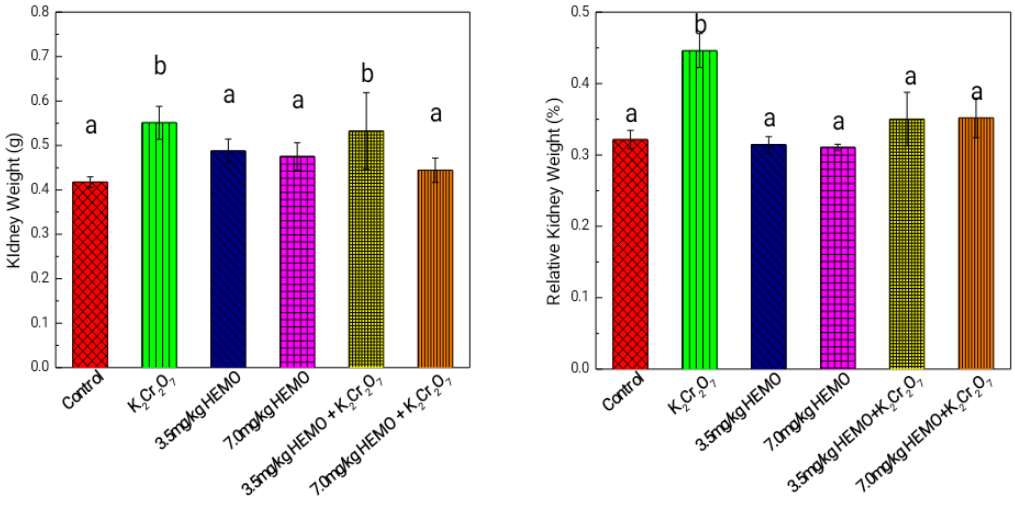
Figure 3: Hematological indices in test and control animals. Values with different superscripts are significantly different. Legend: HEMO; hydro-ethanol extract *Moringa olifera*

However, a marked ($p<0.01$) increase in WBC was recorded in the $K_2Cr_2O_7$-treated rats. Administration of HEMO alone at different doses also led to a significant rise in WBC when equated to the negative control group, but these increases were minimal in comparison to the $K_2Cr_2O_7$-treated group. Simultaneous treatment with HEMO and $K_2Cr_2O_7$ resulted in a dose-dependent reduction of WBC. The percentage of neutrophils and lymphocytes were similar across groups, albeit

the lowest and highest values of neutrophils and lymphocytes respectively were recorded in the $K_2Cr_2O_7$-treated group. Chromium (VI) exposure is well-known to cause anemia in humans and rodents. The decline in PCV provoked by $K_2Cr_2O_7$ could be an indication of anemia. This result corresponds to our previous observation.[23] The reduction of PCV may be indicative of disruptions in erythropoiesis and erythrocyte integrity possibly due to Cr(VI)-induced DNA damage and radical generation. Cr (VI) and its intermediates, IV and V are capable of oxidizing Fe (II) to Fe (III) iron, resulting in perturbation of Fe absorption and homeostasis as well as its incorporation into proteins including hemoglobin.[33] Additionally, in Cr (VI)-sensitive tissues such as erythrocytes, chromium (VI) was reduced to Cr (III), which can displace Fe in ferritin and heme.[31] Furthermore, damaged DNA contained in micronuclei is impenetrable to DNA repair agents. Consequently, affected cells are dragged into early apoptosis.[34] Moreover, Cr (VI) transforms erythrocytes into echinocytes in many animal models.[35] In contrast, $K_2Cr_2O_7$ administration increased WBC, which tallies with our previous results.[23] Increased WBC is associated with inflammation.[35] Additionally, it may depict a general immune response against Cr VI-related stress and tissue damage.[36] The anemic, inflammatory, and immunostimulatory effects of $K_2Cr_2O_7$ were however restored by HEMO as evident by modulation of PCV and WBC to near-control value. Thus, suggesting that HEMO boosts red blood production and exerts anti-inflammatory and immuno-modulatory activities against $K_2Cr_2O_7$. *Moringa oleifera* leaf reverses iron-deficiency anemia in patients and animal models.[37,38,39] Its high Fe content could replenish the lost one during Cr (VI) intoxication. In addition, the leaf is rich in vitamins C and A which promotes iron absorption and erythropoiesis.[40,41] Moreover, the immuno-modulatory and anti-hematotoxic action of the extract was recently attributed to its antioxidant activity.[39,42]

The kidney weight (KWT) and relative kidney weight (RKW) of rats administered HEMO and $K_2Cr_2O_7$ alone and in combination are shown in Figure 4. The KWT and RKW were similar in all the groups except those administered $K_2Cr_2O_7$ alone that had significant ($p < 0.05$) increases in both parameters compared to the control. The kidney is a sensitive target of Cr (VI) toxicity.[43] The observed increase in KWT and RKW in the $K_2Cr_2O_7$-administered group is in tandem with our recent data and suggestive of renal injury and inflammation.[5] The potential of HEMO to protect the kidneys against $K_2Cr_2O_7$-induced renal inflammation was demonstrated by the reversal of KWT and RKW towards the control value. The impact of $K_2Cr_2O_7$ and HEMO on oxidative stress indices is displayed in Figure 5. Rats treated with $K_2Cr_2O_7$ showed a considerable ($p<0.001$) increase in kidney MDA compared to the control. The MDA was similar to the control in the HEMO-alone treated groups. However, when the animals were simultaneously treated with $K_2Cr_2O_7$ and HEMO, a dose-dependent reduction in MDA was noticed in comparison to the control. Administration of $K_2Cr_2O_7$ resulted in significant ($p<0.05$) reductions in kidney SOD and GST activities, compared to the control value. There were, however, no significant differences in the activities of both enzymes among the other groups. The induction of lipid peroxidation by $K_2Cr_2O_7$ signified by enhanced MDA generation and reduction of antioxidants, SOD, and GST is suggestive of oxidant-antioxidant disequilibrium. These results correlate with studies that linked Cr (VI) renal toxicity to oxidative stress.[44,45] The recorded reduction in anti-oxidative enzymes, SOD and GST in rats administered $K_2Cr_2O_7$ may be caused by exhaustion of the enzymes in countering $K_2Cr_2O_7$-induced ROS production. Interestingly, HEMO co-administration with $K_2Cr_2O_7$ exerts anti-oxidative action by reducing MDA and augmenting both SOD and GST activities. Moreover, HEMO is endowed with antioxidant and chelating activities, which can aid the removal of renal free radicals and chromium ions.[12]

The concentration of urea and creatinine in the test and control group is shown in Figure 6. Administration of $K_2Cr_2O_7$ led to marked ($p<0.01$) increases in urea and creatinine in comparison to control values. Interestingly, simultaneous administration of HEMO at both doses with $K_2Cr_2O_7$ resulted in significant ($p < 0.05$) reductions of plasma urea and creatinine compared to the $K_2Cr_2O_7$-treated animals. The urea concentration recorded for the rats that received HEMO was similar, except for the group that was given 7.0 mg/kg HEMO alone, which had a slight but significant ($p<0.05$) increase in urea compared to the control. The value was, however, significantly lower than what was recorded in the rats that were given $K_2Cr_2O_7$ alone.

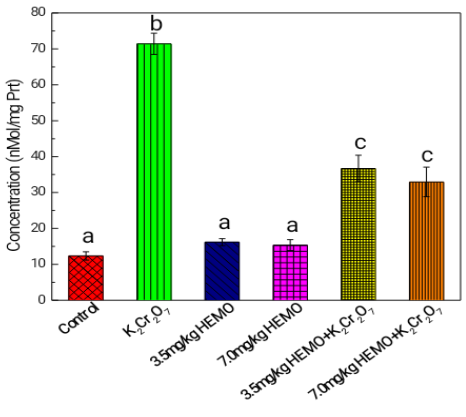


Kidney Weight Relative Kidney Weight

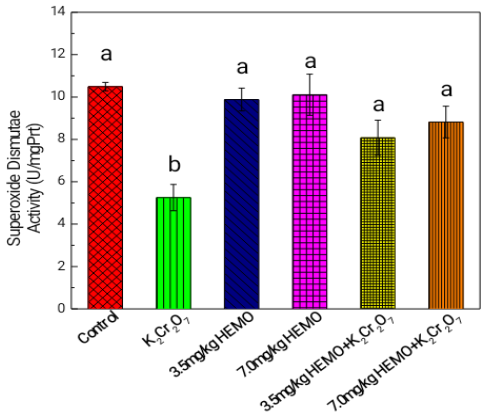
Figure 4: Kidney weight and Relative kidney weight of test and control animals. Values with different superscripts are significantly different Legend: HEMO; hydro-ethanol extract *Moringa oleifera*

Disequilibrium in oxidant-antioxidant balance in the kidney damages renal membrane integrity and impairs detoxification and renal function. In the present study, $K_2Cr_2O_7$-induced renal function impairment was confirmed by elevated urea and creatinine in the treated group. Elevation of urea and creatinine levels reflect a disturbance in homeostasis and may be caused by their enhanced synthesis and/or reduced kidney removal of both compounds. Cr (VI) accumulates in the necrosis-prone proximal tubule and interfere with the renal transport system and waste removal.[43] In contrast, HEMO's positive modification of renal health and function was demonstrated by the reduction of urea and creatinine. Moreover, the reduction of these biomarkers was consistent with decreased MDA coupled with augmentation of GST and SOD in co-exposed groups. It may therefore imply that the observed improvement in kidney health and function may be related to the antioxidant action of HEMO.

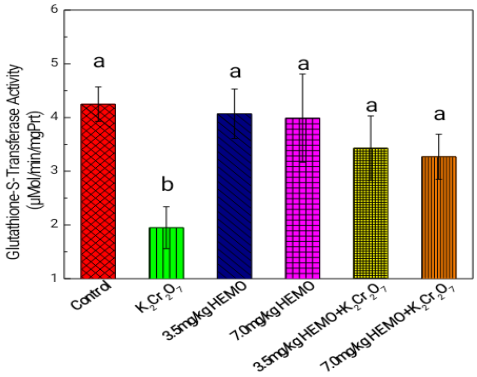
The effect of HEMO on renal lesions caused by $K_2Cr_2O_7$ administration presented in Figure 7 reveals that $K_2Cr_2O_7$ administration resulted in severe peritubular cellular infiltration (red arrowhead), marked renal tubular necrosis (red arrow) and mild glomerular mass depletion (star). In contrast, the renal architecture in the groups fed HEMO alone was normal. Tubular necrosis was found in the kidneys of the groups that were concomitantly administrated either of the two doses of HEMO and $K_2Cr_2O_7$. The lesions observed in rats administered $K_2Cr_2O_7$ confirmed its deleterious impact on renal histology. Cr (VI)-induced oxidative stress and urea elevation promote disruption of cellular membrane integrity, mitochondria injury, and renal cell death.[45]



Malondialdehyde

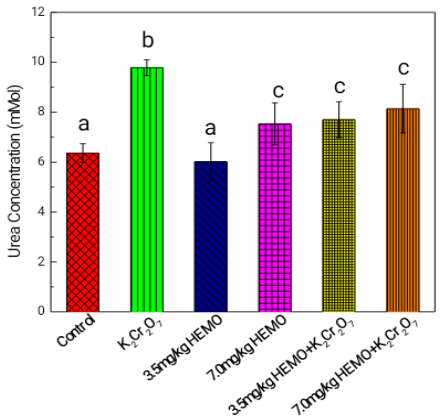


Superoxide Dismutase

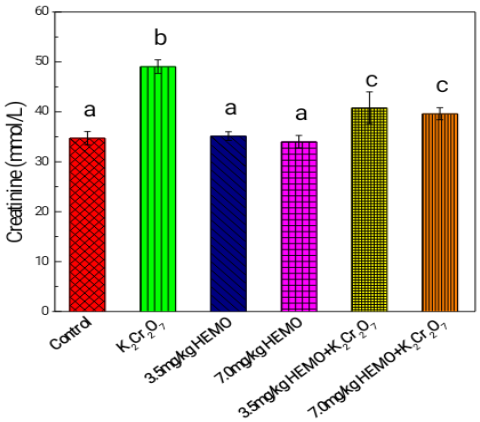


Glutathione-S-Transferase

Figure 5: Some kidney oxidative stress indices in test and control rats. Values with different superscripts are significantly different. Legend: HEMO; hydro-ethanol extract *Moringa oleifera*



Urea



Creatinine

Figure 6: Plasma urea and creatinine in test and control rats. Values with different superscripts are significantly different. Legend; HEMO; hydro-ethanol extract *Moringa oleifera*

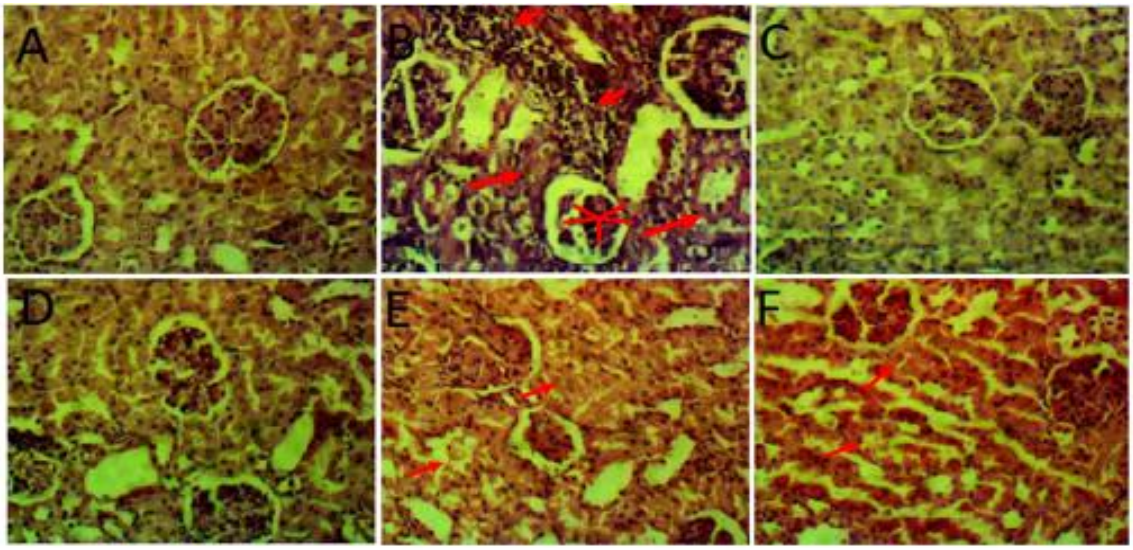


Figure 7: The potential of hydro-ethanol extract of *M. oleifera* in ameliorating $K_2Cr_2O_7$-renal injury. A. Control with normal renal architecture B. $K_2Cr_2O_7$-treated rats with severe peritubular cellular infiltration (arrowhead), marked renal tubular necrosis (red arrow), and mild glomerular mass depletion (star). C. kidney of rats administered 3.5mg/kg HEMO with normal architecture D Kidney of rats administered 7.0 mg/kg HEMO with normal architecture D&E. rats in the combined exposure groups with attenuated lesion, tubular necrosis.

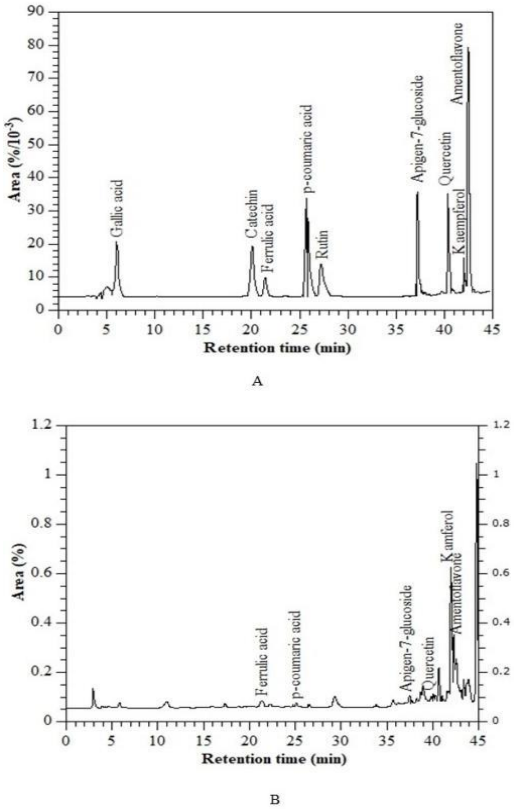


Figure 8: The HPLC profiles of some phenolics in Standard (A) and HEMO (B)

Table 1: Concentration of some phenolics in HEMO

SN	Flavonoids	Concentration (µg/g)
1	Catechin	6.483±0.59
2	Ferrulic acid	196.763± 3.67
3	p- coumaric	19.349±0.26
4	Rutin	11.628±0.51
5	Apigen-7-glucoside	80.109±1.22
6	Quercertin	40.946±0.89
7	Kaempferol	2148.112±57.94
8.	Amentoflavone	168.306±3.35

However, the nephroprotective action of HEMO was supported by less intense lesions in co-treatment groups. A similar amelioration was observed recently in another model of nephrotoxicity.[46]

The chromatograms and quantity of the different phenolics and flavonoids that are in HEMO are presented in Figure 8 and Table 1 respectively. The HEMO is enriched with phenolics and flavonoids. Their increasing concentration is catechin<rutin< p-coumaric acid < quercetin < apeginin-7-glycoside < amentoflavone < ferrulic acid < kaempferol. Generally, the beneficial effects of HEMO are attributable to the health-promoting secondary metabolites, especially polyphenols and flavonoids found in it. The polyphenols and flavonoids in HEMO have interesting antioxidant activities against toxicants including heavy metals. Kaempferol ameliorated cadmium chloride-induced renal dysfunction and renal pathologies by stimulating

antioxidant defenses including nrf-2, while down-regulating apoptotic and inflammatory proteins such as caspase-3 and NF-κB.[47] Ferrulic acid consumption was also found to improve hepato-renal oxidative damage caused by arsenic and cadmium intoxication.[48,49] Moreover, quercetin was recently demonstrated to protect oocytes against chromium(VI)-induced oxidative stress.[50] Other valuable phytochemicals including ascorbic acid and carotenoids,[10] in *M. oleifera* could work in synergy with those reported here to ameliorate the clastogenic, hematotoxic, and nephrotoxic effects of $K_2Cr_2O_7$.

CONCLUSION

The findings suggest that ethanol extract of *Moringa oleifera* has anticlastogenic, anti-hemotoxic, and nephroprotective effects against chromium(VI) toxicity ascribable to its antioxidant actions. It may therefore be promising in clinical therapy of chromium(VI) intoxication.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS DECLARATION

The authors hereby declare that the works presented in this article are original and that any liability for claims relating to the content of this article will be borne by them.

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