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Influence of Red Clay Minerals on Lead-induced Liver and Testicular Oxidative Stress and Histological Alteration in Rats

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Abstract

The aim of this work is to assess the impact of red clay on the physiological and biochemical alterations in rats exposed to lead acetate. The experimental study was carried out in the laboratory on 18 male Wistar rats, which were divided into three groups of six rats in each, the first group served as control, the second group contaminated with lead, and the third group contaminated with lead and treated with red clay. Some biochemical, haematological, and oxidative stress parameters are analysed. Regarding the characterization of the clay, the results of infrared spectroscopy and X-ray spectroscopy indicate the presence of several bands indicating the mineral richness of red clay. From the analysis of our results, we observe a considerable change in the body weight, and an increase in the relative weight of liver and testis in the rats contaminated with lead compared to control. The results also show a significant decrease ($p < 0.001$) in the serum calcium and iron. However, serum transaminases (GPT, GOT) activities are increased in the rats contaminated with lead in comparison with control. The results obtained reveal also a decrease in the Hb, HCT, and MCV levels and in the GSH concentration and an increase in the PLT, MDA, GST, and SOD levels compared to control. Also the results clearly show alterations in the structures of the liver and testis in comparison with the controls. Treatment with red clay partially ameliorates the previous parameters, with protection and regeneration of the tissue against free radical attacks caused by lead. In conclusion, this study shows that treatment with red clay induces a positive effect against lead toxicity at molecular and tissue level.

1. Introduction

Lead is a naturally occurring, inorganic heavy metal that is mostly absorbed through the gastrointestinal and respiratory systems [1]. Due to its extreme poisonousness and widespread distribution in the environment, exposure to this element continues to pose a major threat to human health [2]. It can build up in the body and cause disruptions, particularly to the kidneys, neurological system, blood, gastrointestinal tract, and cardiovascular system [3]. Reactive oxygen species (ROS) production, which leads to an imbalance between the pro-oxidant and antioxidant systems, is the explanation for Pb toxicity [4]. The organism may suffer structural and functional harm as a result of this imbalance [5]. All of this suggests that lead toxicity results in oxidative stress [6]. When cells are under oxidative stress, they display a variety of dysfunctions because ROS have harmed their DNA, proteins, and lipids. This metal's toxicity may be brought on by oxidative tissue damage [7]. Several metals are used to counteract lead's effects [8]. Clays are substances found throughout the earth's crust. Given their ubiquity and particular characteristics [9], there are different classifications of clays; the most classic is based on the thickness and structure of the sheet [10], which is composed mainly of silica and alumina [11]. Clays and clay minerals are significant components of the health product industry. As a

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result, clay minerals are essential ingredients in many pharmaceutical formulations, where they serve as excipients and perform various technological tasks [12,13]. The applications of clays are favored by their colloidal size and crystalline structure. The specific function they have in any formulation depends both on their physical properties and their chemical characteristics [14]. Clays are also used as adsorbents and protectors in topical and systemic formulations in the treatment of acne, leg ulcers, inflammatory bowel disease, and kidney failure [15]. Also in folk medicine in our region, there are many medical uses for clays, as it has been used for a long time as an antiseptic for wounds, against worms in hair, and also against stomach diseases. In light of this data, the present work was carried out to estimate the protective effect of red clays against lead toxicity in rats.

2. Materials and Methods

2.1. Type of clay layer

There are different classifications of clays, the most classic is based on the thickness and structure of the sheet (Figure 1). The sheet consists of a tetrahedral layer and an octahedral layer. It is qualified as T: O or type 1:1. Its thickness is approximately 7 Å [16].

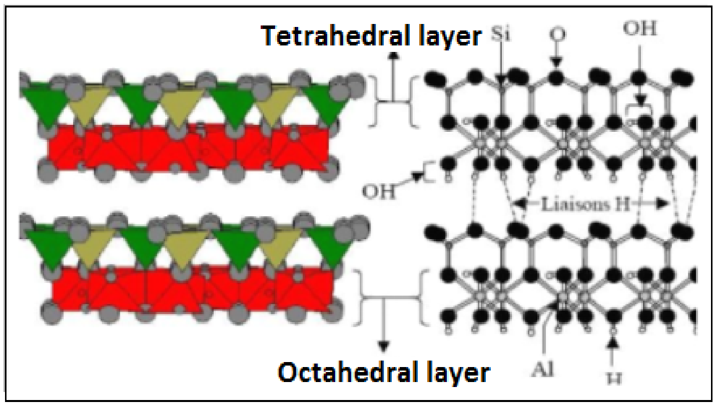

Figure 1. Structure of sheet of clay.

2.2. Clay materials and preparation

Most clay minerals are in leaf shapes; the structure of the sheets is determined by the arrangement of oxygen and hydroxyl [17]. Four main ions form the structure of the sheets: Si^{4+} and Al^{3+} ions, and the hydroxyl ion OH^-. In addition, depending on the type of clay, other ions are also encountered such as Fe^{3+}, Ca^{2+}, and Mg^{2+}. These ions are in the sheet arranged in a compact structure [18]. Clay was taken from the "BELDAT OMAR "Wilayat of Touggourt collector, as shown in the Figure 2, which shows that the soil of the Beldat omar region contains 42٪ mineral clays; the rest is silt and sand. We cleaned the clay, and then crushed it with a mortar.

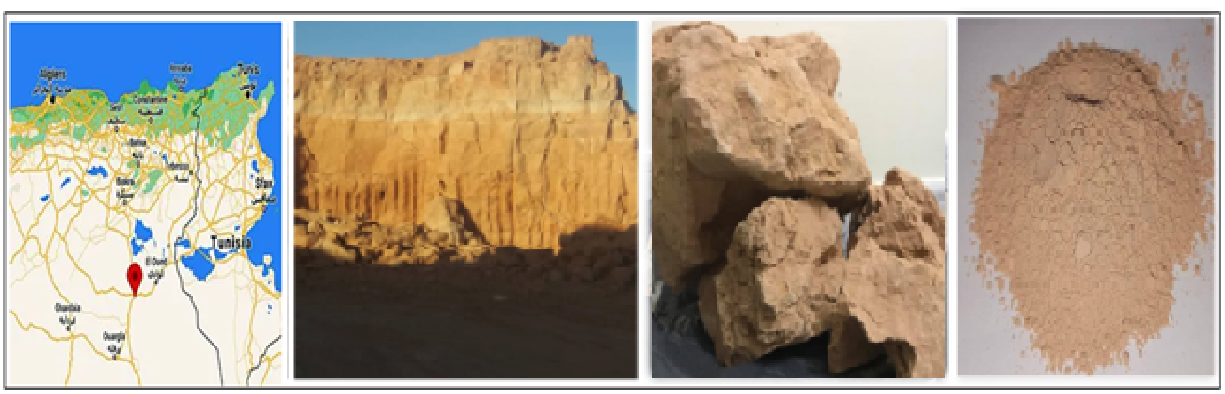

Figure 2. Geographic red clay sampling area.

2.3. Characterization of clay

The characterization of red clays was identified by Fourier transform infrared spectroscopy (FT-IR) and X-ray powder diffraction (XRD) analysis. For FT-IR analysis, the vibrational spectra for all samples were obtained using a JENWEY, Thermo Scientific iS5, PROTO AXRD Benchtop FT-IR spectrometer, equipped with an infrared source. Disks of 15-mm diameter and 1–2-mm thickness, consisting of approximately 0.5 mg sample gently dispersed in 150 mg of KBr, were carefully heated at 100 $^{\circ}C$ to minimize the amount of the absorbed water. Disks were then immediately and thoroughly scanned in the wavenumber region of 4000–400 cm^{-1}. A Thermo Scientific Apreo S apparatus diffractometer was used for the XRD analysis. Diffraction patterns of the samples were recorded by the step scanning from 4 to 70 degrees (2θ), with a step size of 0.02° and counting for 5 s per step at 40 kV and 30 mA.

2.4. Animals care and experimental design

Our study was carried out on twenty male female rats of the Wistar type, coming from the Pasteur Institute of Algiers, aged between eight and ten weeks with a weight of 165.05 ± 4.83. The animals are raised in the animal house of the faculty of nature and life sciences, at Echahid Hamma Lakhdar-El-Oued University. They underwent a period of adaptation to animal house conditions for about 3 weeks at a temperature of 19.600 ± 0.354 C$^{\circ}$. The rats were housed in plastic cages and fed a standard diet. The department of cellular and molecular biology at El-Oued University's ethics committee examined and gave its blessing to all animal experimentation protocols (approval number: 36 EC/DCMB/FNSL/EU2021). After the adaptation period, the rats were divided into four groups of five rats each; the rats were treated as follow for 20 days:

Group 1 (T): Healthy rats (control).

Group 2 (Pb): Rats contaminated with lead acetate in drinking water for 41 days.

Group 3 (Pb + Clay): Rats contaminated with lead acetate and treated with red clay in food for 21 days.

The lead acetate $(CH_3COO)_2$ Pb was dissolved in distilled water at a dose (٤ ppm). The treatment with clays was done at the rate of 5% of the diet.

2.5. Sacrifice and collection of blood and organs

Following a 16-hour fast, the rats were sedated with chloroform (94%) and killed (by decapitation). When the rats were sacrificed, blood samples were collected in EDTA tubes for FNS and biochemical analyses. After, centrifugation of the blood at 3000 rpm for 15 minutes. The plasma obtained was stored at a temperature of -20 $^{\circ}C$ until the time of biochemical analyzes (Calcemia, iron, GOT, GPT). The liver and testis were carefully removed, rinsed with NaCl (0.9%), then weighed. The organ homogenates were prepared for the determination of oxidative stress parameters (malondialdehyde (MDA), superoxide dismutase (SOD), gluthaion S transferase (GST), and reduced glutathione (GSH). Part of liver and tests was fixed in formalin (10%) in order to carry out the histological study.

2.6. Biochemical, hematological, and oxidative stress biomarkers

The biochemical parameters were determined by methods using commercial reagent kits using auto-analyzer. The determination of hematological parameters was performed using fully auto blood cell counter (ERMA). The levels of malondialdehyde in rat tissue homogenates was determined by the thiobarbituric acid method, as descripted in the method of Yagi 1976 [19]. The amount of reduced glutathione in tissues was determined according to the method of Weckbecker and Cory, 1988 [20]. The GST and SOD activities were measured spectrophotometrically by the method of Habig *et al.* [21] and Beauchamp and Fridovich [22], respectively.

2.7. Histopathological study of liver and testis tissue

The liver and testicular tissues were taken out after the rats were killed and placed in a fixative (solution formaldehyde) before being used to prepare the slices. Graduated series of ethanol, toluene (36% Whish), escalating dehydration, immersion in paraffin, and hematoxylin and eosin staining. An optical microscope was used to do the histopathological analysis.

2.8. Statistical analysis

Our statistical study was carried out by the Minitab software using (Student t test) to compere means among our different experimental groups; differences were considered statically significant at $p < 0.05$.

3. Results

3.1. Fourier transform infrared spectroscopy

Infrared spectroscopy (FT-IR) of clay is shown in Figure 3. The presence of several band indicates the mineral richness of red clay. The OH group vibration elongation is commonly seen in bands at about 3700 and 3400 cm^{-1}. The atmospheric CO_2 may be responsible for the peak at roughly 2360 cm^{-1}. The presence of adsorbed water in clay may be responsible for the absorption band at 1656 cm^{-1}. The vibration of calcite is connected to the absorption band about 1430 cm^{-1}. Si-O is thought to be the source of the band at 1032 cm^{-1}, while Al-OH-Al deformation vibration is suggested by the band at 920–910 cm^{-1}. Near 790 and 690 cm^{-1}, quartz peaks with various Si-O and Si-O-Al vibrations were found.

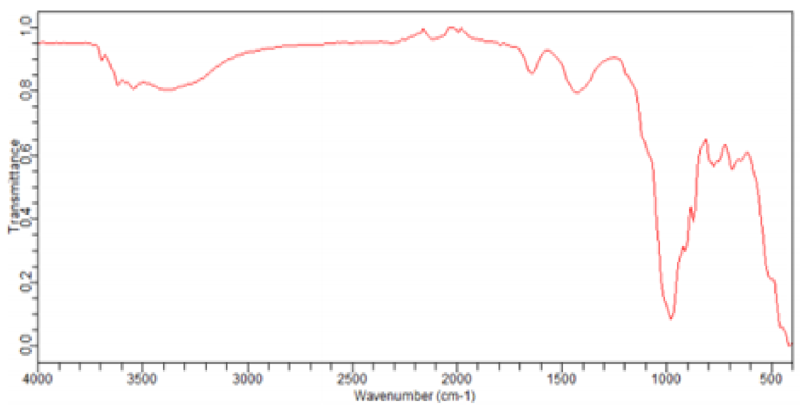

Figure 3. FT-IR spectrum of red clay.

3.2. X-Ray Diffraction (XRD)

The results of XRD are presented in Figure 4, which show the different elements present in clay. One should notice that a spectrum is composed of quartz (Q), montmorillonite (M), kaolinite (K), and gibbsite (Gi). Through diffractogram analysis, samples consisted of kaolinite (K) (31.15%), according to peaks $2\theta = 29^{\circ}$, 51.5°, and 60.3°, montmorillonite clay minerals (M) (25.06%), according to peaks $2\theta = 7.3^{\circ}$, 35.6°, and 69.4°. In addition, gibbsite (Gi) (6.82%) ($2\theta = 43.1^{\circ}$ and $55'.0^{\circ}$), and quartz (Q) (37.36%) accessory minerals were found, in accordance with peaks $2\theta = 22.5^{\circ}$, 28.1°, 38.6°, 46.3°, and 55.3°.

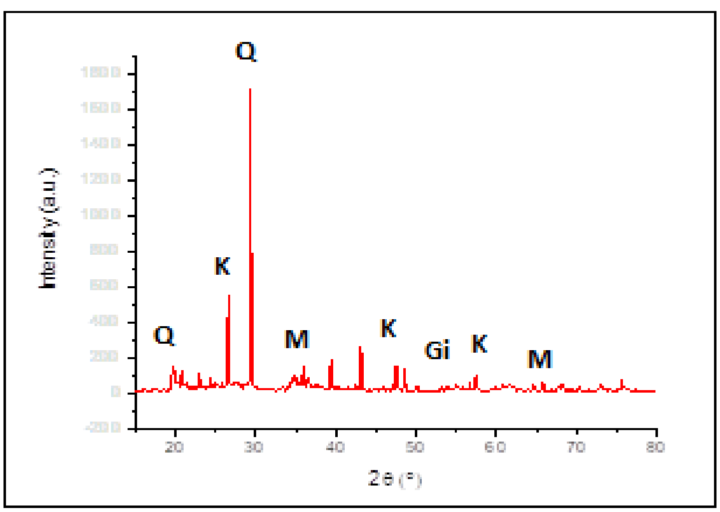

Figure 4. XRD spectrum of red clay.

3.3. Study of body weight and relative organ weight

From our results shown in Table 1, the body weight gain was affected by lead; indeed, we noticed that the lead exposure rats decrease the weight gain of the rats remarkably compared to the control rats. For the treatment groups by clay (Pb + clay), we also saw a significant increase in weight gain compared to the control group and the Pb group. In addition, the results obtained show that there is a very highly significant increase in the relative weight of liver ($p < 0.05$) and testis ($p < 0.001$) in the pb group compared to the control. In the groups treated with red clay, we found a significant improvement ($p < 0.001$) in the relative weight of these organs compared to the lead group.

Table 1. Initial body weight, body weight gain, and relative organ weight in the control group and the experimental groups.

Parameters		Control (n = 6)	Pb (n = 6)	Pb + Clay (n = 6)
Initial weight (g)		150 ± 6.58	168.2 ± 1.03	172.6 ± 3.63
Body weight gain (g/day/rat)		1.82 ± 3.92	1.43 ± 1.28***	1.61 ± 2.69^{*a}
Relative weight (%)	Liver	2,62 ± 0,0105	3,10 ± 0,154*	2,58 ± 0,0183^{*c}
	Testis	1,56 ± 0,048	1,73 ± 0,022***	1,33 ± 0,0065^{***c}

* p <0.05; ** p <0.01; *** p <0.001 comparison with the control group. ^{a} p < 0.05; ^{b} p <0.01; ^{c} p < 0.001 comparison with the lead group.

3.4. Hematological and biochemical parameters

The results of our study (Table 2) show that lead acetate contamination leads to a very highly significant decrease ($P < 0.001$) in serum calcium, serum iron, hemoglobin (HGB), RBC, hematocrit (HCT), and mean corpuscular volume (MCV) levels; on the other hand, we noticed a very highly significant increase ($p < 0.001$) in serum transaminases activities (GOT and GPT) and platelets (PLT) level when compared to the control rats. Red clay treatment improves the most of previous parameters compared to Pb group, with no significant changes to the rest of markers.

Table 2. Biochemical and hematological parameters in control and experimental groups.

Parameters	Control (n = 6)	Pb (n = 6)	Pb + Clay (n = 6)
Serum calcium (mg/L)	35.00 ± 0.89	31.66 ± 0.44***	33.75 ± 0,31^{***a}
Serum iron (mg/L)	0.23 ± 0.05	0.15 ± 0.004***	0.33 ± 0,0491^{b}
Serum GOT (UI/L)	147.5 ± 14.5	305.00 ± 4.02***	201,00 ± 9,35^{***c}
Serum GPT (UI/L)	54.50 ± 1.12	65.33 ± 1.74***	57,33 ± 5,34^{**a}
WBC ($\times 10^{9}$ /L)	7.45 ± 0.24	6.42 ± 0.840	6,66 ± 0,35
RBC ($\times 10^{12}$/L)	8.670 ± 0.36	8.07 ± 0.0724	9.05 ± 0.16^{*a}
HGB (g/dL)	15.30 ± 0.60	13.56 ± 0.060***	14,620 ± 0,23^{*b}
HCT (%)	45.38 ± 1.82	40.16 ± 0.333***	44. 58 ± 0.162^{***a}
MCV (Fl)	52.45 ± 0.85	46.98 ± 0.383***	49.90 ± 0.48^{***a}
PLT ($\times 10^{9}$/L)	758.67 ± 6.93	870.8 ± 12.3***	815.3 ± 34.7^{b}

* p < 0.05; ** p < 0.01; *** p < 0.001 comparison with the control group. ^{a} p < 0.05; ^{b} p < 0.01; ^{c} p < 0.001 comparison with the Pb group.

3.5. Oxidative stress parameters

Our result illustrated in Table 3 show a significant increase in lipid peroxidation (MDA) levels, SOD, and GST activities in liver and test and a significant decrease ($P < 0.001$) in reduced glutathione (GSH) in the liver, and testis of rat's exposure to lead compared to control group. On the other hand, in rats treated with clay, results show a significant decrease in the MDA, SOD, and GST levels and a significant increase ($P < 0.001$) in GSH concentration in all tissues studies.

Table 3. Oxidative stress parameters in liver and testis of control and experimental groups.

Parameters		Control (n = 6)	Pb (n = 6)	Pb + Clay (n = 6)
MDA (nmol/g tissue)	liver	6.764 ± 0.544	$18.76 \pm 1.60^{***}$	$11.98 \pm 1.07^{**c}$
	testis	1.9112 ± 0.09	3.047 ± 0.702^{NS}	$1.676 \pm 0..161^{c}$
GSH (nmol/g tissue)	liver	24.93 ± 6.49	$11.37 \pm 1.54^{***}$	$58.72 \pm 3.00^{***c}$
	testis	21.63 ± 2.62	$5.631 \pm 0.88^{***}$	19.63 ± 1.31^{C}
SOD (UI/g tissue)	liver	16.76 ± 0.27	$17.54 \pm 0.03^{***}$	16.77 ± 0.23^{a}
	testis	13.63 ± 1.94	$17.84 \pm 0.02^{***}$	$17.06 \pm 0.13^{***a}$
GST (nmol/min/g tissue)	liver	0.41 ± 0.023	$3.97 \pm 0.23^{***}$	$0.37 \pm 0.03^{*c}$
	testis	0.25 ± 0.02	$0.38 \pm 0.01^{***}$	$0.29 \pm 0{,}013^{**c}$

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$ comparison with the control lot. ^{a} $p < 0.05$; ^{b} $p < 0.01$; ^{c} $p < 0.001$ comparison with the lead batch.

3.6. Testis histological study

In the testis histological sections, photomicrograph of the testis tissues of control showing the normal tissue structure with spermatozoon, spermatid, spermatocyte, Sertoli cell and basal lamina of eptilieume spermatogonia and normal nucleus, we observe the different stages of spermatogenesis. In testis cells, treatment with lead for 21 days causes a marked cell lysis (damage to the level of tissue) and causes fairly marked cell necrosis. Necrosis predominantly peripetous, sometimes decreased rate of sperm production and/or degeneration, and abnormalities in the structure of the walls of the seminiferous tube (deformation of cells) and increase in the void between the cell. For rats treated with red clay for 21 days, we noticed an improvement in testis tissues levels (Figure 5).

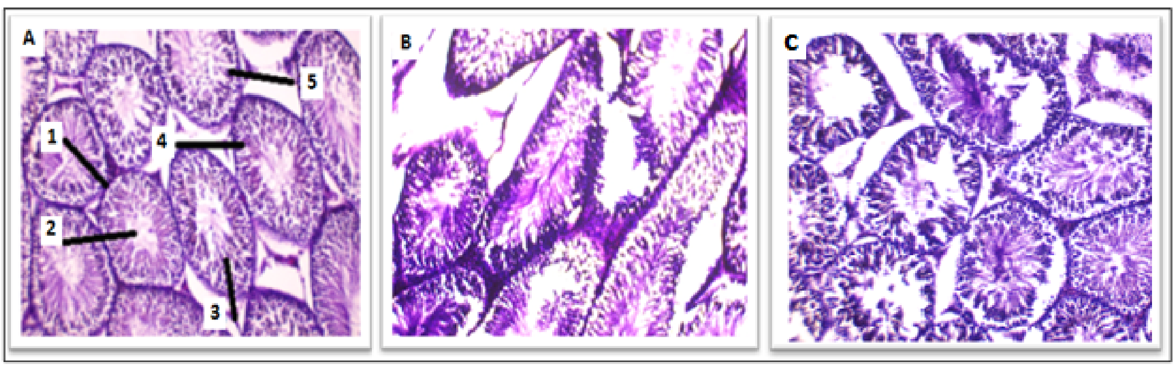

Figure 5. Photomicrograph of histopathological examination of testis sections of control (A), Pb group (B), and group treated with red red clay (C). Coloration with hematoxylin and eosin (x40). (1- basal lamina of eptilieume spermatogonia/2- spermatozoon/3- spermatid/4- spermatocyte /5-, sertoli cell).

3.7. Liver histological study

In the liver histological sections (Figure 6), photomicrograph of control showing the normal tissue structure with striations and branched appearance and normal nucleus. In liver cells, treatment with lead for 21 days causes a marked cell lysis (damage to the level of tissue), and causes fairly marked cell necrosis. Necrosis predominantly peripetous, sometimes pericentrolobular and usually accompanied by fairly significant sinusoidal inflammation. Scattered vacuolations are also observed as well as macrocytic steatosis. For rats treated with red and red clay for 21 of them noticed an improvement in liver tissue level.

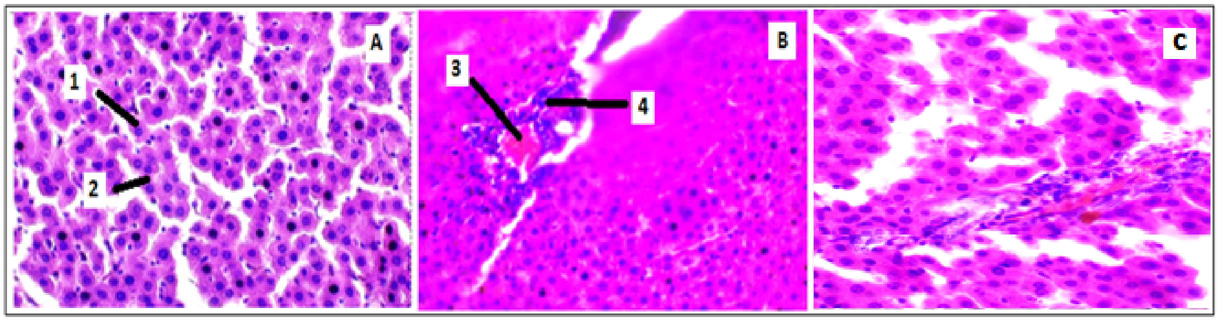

Figure 6. Photomicrograph of histopathological examination of liver sections of control (A), Pb group (B), and group treated with red clay (C). Coloration with hematoxylin and eosin (x40); (1 nucleus/2-hepatic cell/3-necrosis/4- hemorrhage).

4. Discussion

Regarding clay characterization, infrared spectroscopy has demonstrated the presence of many bands that point to the mineral richness of red clay. The minerals quartz (Q), montmorillonite, kaolinite, and gibbsite make up the XRD spectrum's findings. The raw clay had distinct peaks at 2θ values at 12°, 29°, and 38° value that correlate to d values of 7.17° and 3.58° typical of the mineral kaolinite and are typical reflections of the clay mineral kaolinite [23, 24]. In *in-vivo* study, results show a hepatomegaly, high testis weight, changes in haematological, and biochemical parameters in rats exposed to lead. This is explained by testis and hepato-toxicity caused by the build-up of lead in these target organs. Lead-induced necrosis and apoptosis on these organs may be the cause of this rise in relative organ weight [25]. On the other hand, Lead inhibits delta-aminolevulinic acid dehydratase (ALAD) [26] by binding to SH groups (thioloprive mechanism), which causes many enzymatic systems to become inactive and results in a variety of consequences. They primarily concern erythropoiesis at low but persistent exposure levels (anemia) Lead affects the three enzymatic systems of heme production (ALA synthetase, ALA dehydrase, and ferrochelatase) at the hematological level, leading to an increase in erythrocyte protoporphyrins and a buildup of ALA (delta amino levulinic acid) in blood and urine [27]. Hypochromic microcytic anemia with sideroblastic erythropoiesis, anemia hemolytic, and leuco erythroblastic blood smear are among the haematological symptoms of lead poisoning. Pyrimidine 5'-nucleotidase suppression leads to the well-known basophilic stippling and hemolysis, whereas inhibition of heme synthesis-related enzymes results in hypochromic microcytic anemia and sideroblastic erythropoiesis [28]. In addition, Layer double hydroxides have the potential to be a good adsorbent to remove arsenic or other heavy metal from contaminated waters due to high surface area and high anion exchange capacity [29]. Concerning the biochemical parameters, results show an increase in transaminases activities and a decrease in iron and calcium level in lead rats. Due to lead's high affinity for the thiol groups in hepatic cell membranes, which causes hepatic necrosis and the release of GOT and GPT activities in serum, the liver is a significant target for lead [30] and transaminase leakage into the bloodstream could be caused by liver disease [31]. Results of a decrease in calcium levels because lead enters the cell and builds up in the mitochondria because it competes with calcium when the calcium channels open. By interfering with the hormonal signal's ability to travel, it prevents the activation of Ca^{++}-dependent proteins [32]. Increases in the gastrointestinal absorption of Ca^{+2} increases the excretion of Ca^{+2} by the kidneys, as well as the interaction between Pb^{+2} and Ca^{+2} for storage in bone, which changes calcium homeostasis [33]. About iron level, a unique side-effect of iron shortage that might be separated from lead intoxication, which is characterized by a decrease in blood ALAD activity and an increase in protoporphyrin level (ZPP) [34]. Conventional methods such as precipitation, coagulation, adsorption and ion exchangers, membrane filtration, and polymer ligand exchangers are used for heavy metal removal. Among these technologies, adsorption is considered to be one of the low-cost and easily feasible techniques [35]. These improvements are due to the components of clay as it contains many minerals such as iron, zinc, magnesium and calcium [36] that benefit the body and work to compensate for iron and calcium deficiency and inhibit the spread of lead, which can reduce its toxicity at the level of the testicles and liver. GOT and GPT transaminase enzyme activities in lead-contaminated rats was enhanced by clay treatments containing zinc and magnesium. These antioxidants can reduce the leakage of enzymes into plasma by stabilizing the hepatic cell membrane and shielding hepatocytes from the harmful effects of lead [37]. The results of the analysis of the effect of lead on markers of oxidative stress and histological section in liver and testis show that lead affects these markers by increasing the level lipid peroxidation, GST and SOD activities and decreasing the GSH level in rats lead poisoning, which indicates oxidative stress state due to the increased ROS production, oxidative DNA damage, mitochondrial malfunction, decreased GSH levels, antioxidant enzyme activity reduction, and eventually apoptosis are seen [38]. Lead toxicity also results in a very noticeable cell lysis (damage to hepatic and testicular tissue). Necrosis that is primarily periportal, occasionally pericentrolobular, and most frequently accompanied by moderately severe sinusoidal inflammation. Along with macrocytic steatosis, scattered vacuolations are also seen [39]. Changes in the composition of fatty acid membranes are another route of lead-induced oxidative membrane degradation. Since there is a relationship between the length of the fatty acid chain, its unsaturation, peroxide activity, and membrane sensitivity, a rise in arachidonic acid causes membrane lipid peroxidation to worsen [40]. Treatment with red clay causes an ameliorate in cell damage and oxidative stress in liver and testis. Among composition of clay are silicon, magnesium, aluminium, calcium, sulfur, iron, phosphorus, zinc and copper [41]. Microelements like iron (Fe), copper (Cu), and zinc (Zn) are necessary for living things to function properly. These substances affect enzyme function, control gene expression, participate in protein synthesis, and take part in a variety of processes such as cell metabolism and antioxidant and anti-inflammatory defences [42].

5. Conclusions

To conclude, numerous parameters including function liver and testis markers, histological sections, and oxidative stress parameters were altered by high dietary lead intake including calcium and iron deficiencies. However, adding red clay to a diet has beneficial effects by lessening the physiological changes brought on by lead exposure.

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تاثیر مواد معدنی خاک رس قرمز بر استرس اکسیداتیو کبد و بیضه ناشی از سرب و تغییرات بافتی در موش صحرایی

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چکیده:

هدف از این کار ارزیابی تاثیر خاک رس قرمز بر تغییرات فیزیولوژیکی و بیوشیمیایی در موش‌های در معرض استات سرب است. این مطالعه تجربی در آزمایشگاه بر روی ۱۸ موش صحرایی نر نژاد ویستار انجام شد که در هر گروه به سه گروه ۶ تایی تقسیم شدند، گروه اول به عنوان شاهد، گروه دوم آلوده به سرب و گروه سوم آلوده به سرب و تیمار شدند. با خاک رس قرمز برخی از پارامترهای بیوشیمیایی، خونی و استرس اکسیداتیو آنالیز می‌شوند. با توجه به خصوصیات خاک رس، نتایج طیف سنجی مادون قرمز و طیف سنجی اشعه ایکس وجود چندین نوار را نشان می‌دهد که بیانگر غنای معدنی خاک رس قرمز است. پس از تجزیه و تحلیل نتایج، ما شاهد تغییر قابل توجهی در وزن بدن و افزایش وزن نسبی کبد و بیضه در موش‌های آلوده به سرب نسبت به گروه شاهد هستیم. نتایج همچنین کاهش معنی داری ($p<۰/۰۰۱$) در کلسیم و آهن سرم را نشان می‌دهد. با این حال، فعالیت ترانس آمینازهای سرم (GOT ،GPT) در موش‌های آلوده به سرب در مقایسه با گروه شاهد افزایش یافته است. نتایج به‌دست‌آمده همچنین کاهش سطوح Hb، HCT، MCV و غلظت GSH و افزایش سطوح PLT، MDA، GST و SOD را نسبت به شاهد نشان می‌دهد. همچنین نتایج به وضوح تغییرات در ساختار کبد و بیضه را در مقایسه با گروه شاهد نشان می‌دهد. با محافظت و بازسازی بافت در برابر حملات رادیکال‌های آزاد ناشی از سرب، درمان با خاک رس قرمز تا حدودی پارامترهای قبلی را بهبود می‌بخشد. در نتیجه، این مطالعه نشان می دهد که تیمار با خاک رس قرمز اثر مثبتی را در برابر سمی بودن سرب در سطح مولکولی و بافتی ایجاد می‌کند.

کلمات کلیدی: سرب، سمیت، استرس اکسیداتیو، موش صحرایی ویستار.