Effect of Phenanthrene Exposure on the Total Antioxidant Capacity, Catalase, Superoxide Dismutase and Xanthine Oxidase, of the Liver.

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ABSTRACT

Phenanthrene, an aromatic compound, represents the majority of polycyclic aromatic hydrocarbons found in the environment. Sources include, burnt smoky coal particles, soil and sediment, diesel emissions, tobacco and food smoke. The aim of the study was to determine the effect of phenanthrene on oxidative stress markers in male wistar rats. Fifty healthy rats weighing between 100 and 180g were used for this study. They were administered phenanthrene via oral gavage at 5mg and 10mg over 21days, 180mg and 900mg once. Results of the experiment showed significant increase in Superoxide dismutase, Xanthine oxidase levels and in Total antioxidant capacity. Phenanthrene increased oxidative stress, in male wistar rats.

BACKGROUND

Phenanthrene is an aromatic compound with three benzene rings forming the main structure. It was discovered in coal tar by E. Ostermayer in 1872. Phenanthrene derivatives are compounds obtained by transformation and derivation of new compounds from the already existing structure of phenanthrene. These derivatives consist of: mono-substituted phenanthrene, diametrical phenanthrene, polysubstituted phenanthrene, phenanthrequinone and dihydrophenanthrene. (Li *et al*., 2022). Phenanthrene represents the majority of polycyclic aromatic hydrocarbons found in the environment. It is found in a variety of areas including: burnt smoky coal particles (Mumford *et al*., 1995), soil and sediment, diesel emissions (Westerholm *et al*., 2001), tobacco and food smoke (Marti-Cid *et al*, 2008). Phenanthrene has a low molecular weight and is not normally carcinogenic (Martins *et al*., 2013). It is one of the most commonly found polycyclic aromatic hydrocarbons in the environment, largely due to the abundant amounts found in petroleum, creosote and coal tar in sediments (Santana *et al*., 2015). Phenanthrene is a very dangerous chemical commonly found in air, soil and water (Kang *et al*., 2023). It is a type of polycyclic aromatic hydrocarbon that poses a serious threat to the lives of people exposed to it (Li *et al*., 2024). Exposure to phenanthrene for a long period of time makes an animal highly susceptible to hepatotoxicity (Hong *et al*., 2017).

The liver, the largest internal organ in the body, plays a crucial role in secretion, digestion, blood detoxification and nutrient storage (Kubes *et al*., 2018). It is extremely vulnerable to toxicants because constant exposure of hepatocytes to environmental toxins can significantly impair liver function and ultimately cause liver damage (Zheng *et al*., 2011). The effect of phenanthrene on the liver is not completely known, as most research done on the effects of phenanthrene in the liver has focused on aquatic animals (Yin *et al*., 2007), which do not share the same phenotype as humans and as such cannot be used to understand how phenanthrene will affect the human internal structure. For this reason, it is important to investigate the effect of phenanthrene on male wistar rats, which share similar internal structure to that of humans. The aim of the study was to determine the effect of phenanthrene exposure on oxidative stress markers of male wistar rats.

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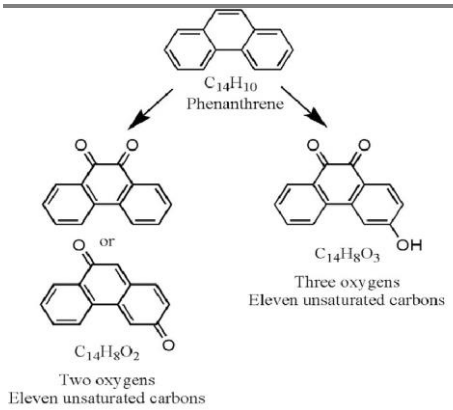

Structure of Phenanthrene (Hintze *et al*., 2010).

MATERIALS AND METHODS

Fifty healthy rats weighing between 100 and 180g were used for this study. The animals were obtained from the animal house of Igbinedion University, Okada, Edo State and they were distributed randomly into five well ventilated plastic cages with wood beddings with 10 rats each, where they were kept for two weeks before commencement of the experiment for acclimatization. They were fed with pelletized commercially prepared growers mash purchased in a local store in Okada, Edo State and had access to water. They were housed at standard laboratory conditions under 12h light/12h dark cycle. The cages were continuously kept clean every day to ensure good hygiene and prevent the animals from disease.

The animals were randomly assigned into five groups of ten rats per group. They were administered phenanthrene via oral gavage at 5mg and 10mg over 21days, 180mg and 900mg once.

Analytical Procedure

The Phenanthrene administration was done for 21 days. At the end of the experiment, the rats were weighed and blood samples collected through retro-orbital puncture for hematological analysis. Biochemical analysis was carried out using spectrophotometric method. The antioxidant assay was done using standard procedure and protocol (Westerfield et al. 1959).

Ethical Principles

Permission to carry out the research work was given by the department of Physiology Igbinedion University Okada. The research work followed ethical guidelines on animal handling protocol as provided by the department of Physiology Igbinedion University Okada.

RESULTS

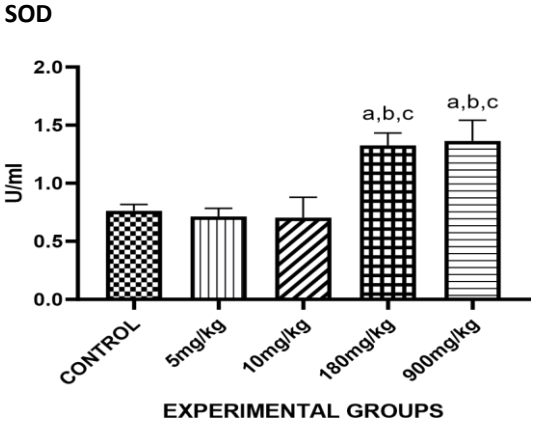

Fig 1. Effect of Phenanthrene (Phe) on Superoxide Dismutase (SOD) in the liver.

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Bars are expressed in (1.327 ± 0.05302), (1.364 ± 0.07305). a, b, c represent significant differences when compared with control, 5mg and 10mg groups respectively. ($p<0.05$).

Figure 1 showed the effect of Phenanthrene on Superoxide Dismutase (SOD) in the liver. There was a significant increase in the levels of SOD in the 180mg and 900mg groups when compared with control. There was significant increase in levels of SOD in the 180 and 900mg groups when compared with 5mg group. There was significant increase in levels of SOD in the 180 and 900mg groups when compared with 10mg group. Meanwhile, there was no statistically significance difference between 900mg group when compared to 180 group. There was no significance difference between 10mg group when compared to 5mg group and control. There was also no significant difference between 5mg group when compared with control.

Catalase

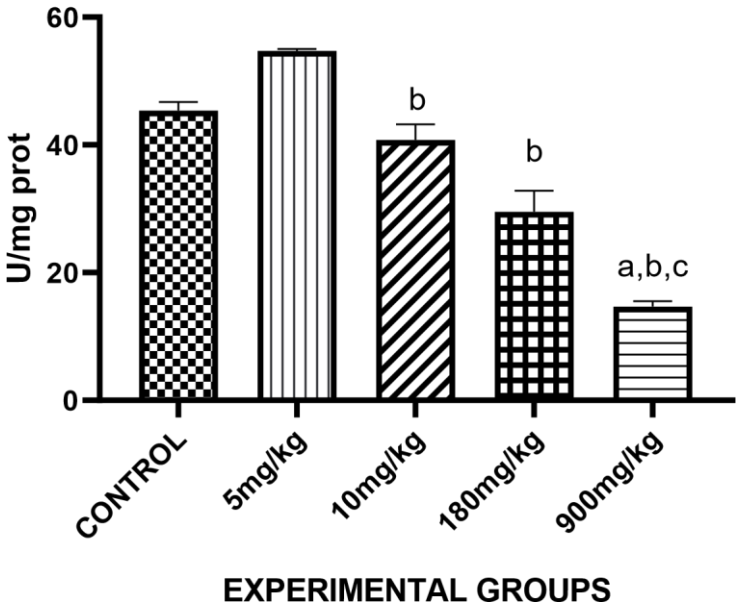

Fig 2: Effect of Phenanthrene (Phe) on catalase (CAT) in the liver.

Bars are expressed in (64.71 ± 10.22), (14.69 ± 0.4072). a, b, c, represent significant differences when compared with control group, 5mg group and 10mg group respectively. ($p<0.05$).

Figure 2, showed the effect of Phenanthrene on catalase in the liver. There was a significant increase in the level of catalase in the 5mg group when compared with control. There was significant decrease in the level of catalase in 900mg group when compared with control. There was significant decrease in 10mg, 180mg and 900mg group when compared with 5mg group. There was a significant decrease in 900mg group when compared with 10mg group. Meanwhile, there was no significance in 10mg and 180mg group when compared with control group.

TAC

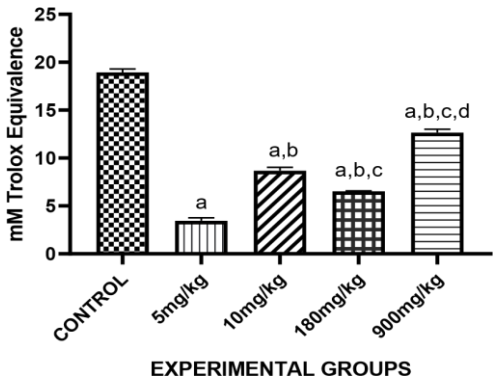

Figure 3: Effect of Phenanthrene (Phe) on Total Antioxidant Capacity assay (TAC) in the liver.

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Bars are expressed in (3.450 ± 0.1559), (8.685 ± 0.1381), (6.537 ± 0.01827), (12.66 ± 0.1795). a, b, c, d represent significant differences when compared with 5mg/kg, 10mg/kg, 180mg/kg and 900mg/kg groups respectively ($p<0.05$).

Figure 3 showed the effect of Phenanthrene on Total Antioxidant Capacity assay (TAC) in the liver. There was significant decrease in levels of TAC in 5mg, 10mg, 180mg and 900mg groups when compared to control. There was significant increase in levels of TAC in 10mg, 180mg and 900mg groups when compared with 5mg group. There was significant decrease in levels of TAC in 180mg group when compared with 10mg group. There was significant increase in levels of TAC in 900mg group when compared with 10mg group. There was significant increase in levels if TAC in 900mg group when compared with 180mg group.

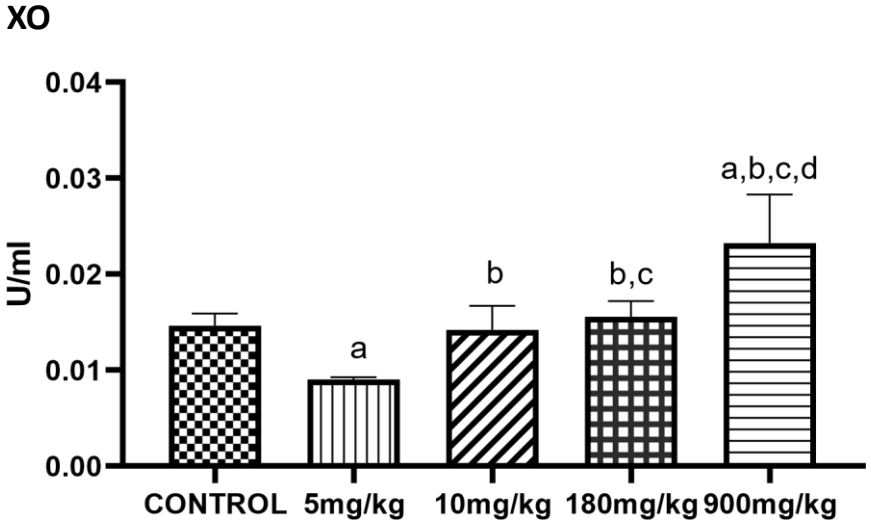

Fig 4: Effect of Phenanthrene (Phe) on Xanthine Oxidase (XO) in the liver.

Bars are expressed in (0.009 ± 9.364), (0.02321 ± 0.002071). a, b, c, d represent significant differences when compared to control groups, 5mg, 10mg and 180mg respectively. ($p<0.05$).

Figure 4, showed the effect of Phenanthrene on Xanthine Oxidase (XO) in the liver. There was a significant decrease in the level of XO in the 5mg group when compared with control. There was a significant increase in the level of XO in 900mg group when compared with control. There was a significant increase in level of XO in 10mg, 180mg and 900mg group when compared to 5mg group. There was a significant increase in level of XO in 180mg and 900mg groups when compared to 10mg group. There was a significant increase in level of XO in 900mg group when compared to 180mg group. There was no significant difference between 10mg and 180mg group when compared with control group.

DISCUSSION

Oxidative stress is known to be an important mechanism of Polycyclic Aromatic Hydrocarbon (PAH) -induced toxicity (Shi *et al.,* 2005). PAHs have been shown to be associated with a variety of toxic effects including oxidative stress, inflammation, and immunological disorders, after they are metabolically activated to electrophilic intermediates. These reactive intermediates are able to covalently bind to DNA or participate in redox cycles. This process leads to an overproduction of reactive oxygen species, also known as ROS (Omayma *et al.,* 2016). Antioxidant defenses, which include enzymes such as superoxide dismutase (SOD) and catalase (CAT); can be induced by a mild oxidative stress as a compensatory response. However, a severe oxidative stress suppresses the activities of these enzymes and can lead to oxidative damage. (Yin *et al.,* 2007). Phenanthrene can accumulate in the liver and induce OH production, leading to oxidative stress that alters the activities of antioxidant enzymes such as catalase and superoxide dismutase (Yin *et al.,* 2007).

Superoxide dismutase (SOD) is the first detoxification enzyme and the most powerful antioxidant in the cell (Ighodaro and Akinloye, 2017). It acts as a first line of defense against reactive oxygen species and helps neutralize the superoxide ion of the free radical (Ighodaro and Akinloye, 2017). In this study, the results show a significant increase in superoxide dismutase levels in the 180mg and 900mg groups in comparison to control. This is possibly due to oxidative stress in the liver of these groups, as increased superoxide ion in the cells stimulates the first-order antioxidant enzyme superoxide dismutase to begin oxidizing superoxide anion to hydrogen peroxide and molecular oxygen (Ighodaro and Akinloye, 2017). However, this may cause the accumulation of hydrogen peroxide in the cells. This accumulation will lead to significantly increased amounts of hydrogen peroxide in the cells. This significant increase in the amount of Hydrogen Peroxide in the cells is also known as high levels of hydrogen peroxide in the cells, which is extremely toxic (Ighodaro and Akinloye, 2017). This finding is similar to that in the study carried out by (Ma *et al.,* 2020), where administration of phenanthrene led to increased superoxide dismutase levels.

Catalase is a common antioxidant enzyme that is found in almost all living tissues that utilize oxygen. Its function is to convert hydrogen peroxide to water and oxygen, thereby neutralizing it (Ighodaro and Akinloye, 2017). This is because Hydrogen Peroxide accumulated at high levels in the body can cause cell damage and oxidative stress (Ighodaro and Akinloye, 2017). Oxidative stress is a phenomenon that occurs when the number of reactive oxygen species in the cells is significantly greater than the number of antioxidants needed to neutralize them (Silvestrini *et al.,* 2023).Catalase levels were measured using spectrophotometry. In this study, the results show a decrease in catalase in the 900mg group in comparison to the control group, which may have been as a result of oxidative stress. (Pal *et al.,* 2023). This decrease in Catalase could have been as a result of the increase in Superoxide dismutase levels. Because the superoxide dismutase is "working overtime" to oxidize the ever increasing levels of superoxide ion in the cells, there becomes excess hydrogen peroxide for the catalase to "clean up". The more that catalase is being utilized to oxidize the hydrogen peroxide into oxygen and water, with an ever increasing amount of hydrogen peroxide levels, the less catalase there is to perform any antioxidant activity. Eventually, the number of hydrogen peroxide levels significantly increases more than the levels of catalase needed to oxidize it. This leads to oxidative stress (Ighodaro and Akinloye, 2017). This is similar to the work of (Ma *et al.,* 2020) where administration of environmental toxicant Phenanthrene also led to decrease in catalase. It is also similar to the work of Yin *et al.,* 2007, in which catalase also reduced upon exposure to phenanthrene.

Total Antioxidant capacity is a measure of the ability of a biological system to neutralize oxidants and free radicals (Silvestrini *et al.,* 2023). It is an important biochemical in medical and nutritional studies, as it provides insight into the overall antioxidant status and oxidative stress in the body (Kusano and Ferrari, 2008). In this study, there was a significant decrease in total antioxidant capacity levels in the 5mg, 10mg, 180mg and 900mg groups in comparison to the control group. This might have been as a result of oxidative stress in the livers of these groups (Pal *et al*., 2023), impairing the ability of their antioxidants to combat against the reactive oxygen species over produced as a result of the environmental toxicant phenanthrene in their livers (Ma *et al*., 2020).

Xanthine oxidase is a form of xanthine oxidoreductase, a type of enzyme that generates reactive oxygen species. These enzymes catalyze the oxidation of hypoxanthine to xanthine and further catalyze xanthine to uric acid (Battelli *et al.,* 2014). During severe liver damage, xanthine oxidase is released into the blood, so a blood assay for xanthine oxidase is a way to determine if severe liver damage occurred (Pacher *et al.,* 2006). In this study there was a significant increase in xanthine oxidase levels in 900mg/kg group of the rats in comparison to control. This might have resulted in accumulation of uric acid in the joints of the 900mg/kg group, causing various diseases (Battelli *et al.,* 2014). There was a significant decrease in the 5mg/kg group in comparison to control, probably as a result of superoxide anion suppression by the increase in superoxide dismutase levels in the study, and might have resulted in inhibition of uric acid formation by xanthine oxidase itself (Rodriguez *et al.,* 2020).

CONCLUSION

Phenanthrene increased oxidative stress markers in male wistar rats.

Conflict of Interest

Authors declare no conflict of interest

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REFERENCES

1. Apak, R., Guclu, K., Ozyurek, M., Karademir, S.E. (2004) Novel Total Antioxidant Capacity index for dietary polyphenols and vitamins C and E, using their cupric ion reducing capability in the presence of neocuproine: CUPRAC method Journal of Agricultural Food Chemistry **52**:7970-7981
2. Brentnall, M., Rodriguez-Menocal, L., Ladron de Guevara, R., Cepero, E., Boise, L.H. (2013). Caspase9, caspase-3 and caspase-7 have distinct roles during intrinsic apoptosis BMC Cell Biology **14(1)**32.
3. Brook, R., (2008). Cardiovascular effects of air pollution Clinical Science. (London). **115:** 175-187.
4. Battelli, M.G., Polito, L., Bolognesi, A. (2014). Xanthine oxidoreductase in atherosclerosis pathogenesis: Not only Oxidative Stress Atherosclerosis **237:** 562-567.
5. Brumbarova, T., Ivanov, R. (2014). Perl's staining for histochemical detection of iron in plant samples Bio-protocol **4:** 12-45.
6. Cottone, S., Lorito, M.C., Riccobene, R., Nardi, E., Mule, G., Buscemi, S., Geraci, C., Guaneri, M., Arsena, R., Cerasola, G. (2008) Oxidative Stress, inflammation and cardiovascular disease in chronic renal failure Journal of Nephrology **21:**175-179.
7. Ciencewicki, J., Trivedi, S., Kleeberger, S.R. (2008). Oxidants and the pathogenesis of lung diseases Journal of Allergy and Clinical Immunology **122:** 456-468.
8. Cheng, Y.M., Lim, P.S., Wei, Y.H. (2002) Increase in oxidative damage to lipids and proteins in skeletal muscle of uremic patients Free radical research **36** (3), 295-302.
9. Chelikani P, Fita I, Loewen PC. (2004) Diversity of structures and properties among catalases. Cell Mol Life Sci **61**(2), 192-208.
10. Dennis, R.A., Trappe, T.A., Simpson, P., Carroll, C., Huang, B.E., Nagarajan, R., Bearden, E., Gurley, C., Duff, G.W., Evans, W.J., Kornman, K., Peterson, C.A. (2004). Interleukin-1 polymorphisms are associated with the inflammatory response in human muscle to acute resistance exercise The journal of physiology **560**: 617-626.
11. Fatokun, A., Stone, T. and Smith, R.; (2008) Front. Biosci. **13:** 3288-3311
12. Goth L. (1991) A simple method for determination of serum catalase activity and revision of reference range. Clinical Chemistry; 143-152
13. Guicciardi, M.E., Malhi, H., Mott, J.L., Gores, G.J. (2013). Apoptosis and Necrosis in the liver Comprehensive Physiology **3:**2
14. Goth L, Nemeth H, Meszaros I. (1983). Serum catalase activity for detection of hemolytic diseases. Clinical Chemistry **29**: 741-742.
15. Guo, Z., Kang, Y., Wu, H., Li, M., Hu, Z., Zhang, J. (2023). Enhanced removal of phenanthrene and nutrients in Wetland sediment with metallic bio char: performance and mechanisms Chemosphere **327**:138-523.
16. Hintze, P.E., Buhler, C.R., Schuerger, A.C., Calle, L.M., Calle, C.I. (2010). Alteration of five organic compounds by glow discharge plasma and UV light under simulated Mars conditions Elsevier **208**: 749757.
17. Hong, X., Qin, J., Chen, R., Yuan, L., Zha, J., Huang, C., Li, N., Ji, X., Wang, Z. (2017). Phenanthreneinduced apoptosis and its underlying mechanism. Environmental science and technology **51:** 1439714405.
18. Ighodaro, O.M. and Akinloye, O.A. (2018). First-line defence antioxidants- superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx): Their fundamental role in the entire antioxidant defense grid Alexandria Journal of Medicine **54**: 287-293.
19. Julien, O., Wells, J.A. (2017). Caspases and their substrates Cell death and differentiation **24**: 1380-1389.

20. Jaeschke, H., Gujral, J.S., Bajt, M.L. (2004). Apoptosis and Necrosis in Liver disease Liver International **24:** 85-89.
21. Kusano, C. and Ferrari, B. (2008). Total antioxidant capacity: a biomarker in biochemical and nutritional studies Journal of Molecular Cell Biology **7:**1-15.
22. Krishnamurthy and Wadhwani, (2012). Antioxidant enzymes and human health Antioxidant Enzyme **1:** 3-
23. 18.
24. Li, J., Peng, W., Yin, X., Wang X., Liu, Z., Liu, Q., Deng, Z., Lin, S., Llang. R. (2024). Identification of an efficient phenanthrene-degrading pseudarthrobacter sp. L1AW and characterization of its metabolites and catabolic pathway Journal of Hazardous materials **465**: 133-138.
25. Li, H., Li, L., Xu, H., Du, H., Wang, L. (2022). Insights into phenanthrene attenuation by hydroxyl radicals from reduced iron-bearing mineral oxygenation Journal of Hazardous materials **439:** 129-658.
26. Mumford, J.L., Li, X., Hu, F., Lu, X.B., Chuang, J.C. (1995). Human exposure and dosimetry of polycyclic aromatic hydrocarbons in urine from Xuan Wei, China with high lung cancer mortality associated with exposure to unvented coal smoke Carcinogenesis, **16**: 3031-3036.
27. Manco, R., Leclerq, I.A., Clerbaux, L.A. (2018). Liver regeneration: different sub-populations of parenchymal cells at play choreographed by an injury specific microenvironment International Journal of Molecular Sciences **19**: 4115.
28. Magnani, L., Gaydou, M. and Jean C.H. (2000). Spectrophotometric measurement of antioxidant properties of flavones and flavonols against superoxide anion, Anal. Chim. Acta, **411**: 209-216.
29. Marklund, S. and Marklund, G. (1974) Involvement of the superoxide anion radical in the autooxidation of pyrogallol and a convenient assay for superoxide dismutase. Eur. J. Biochem., 47: 469-474.
30. Martins, M., Costa, P.M., Ferreira, A.M., Costa, M.H. (2013). Comparative DNA damage and oxidative effects of carcinogenic sediment-bound PAHs in the gills of a bivalve Aquatic Toxicology **142**: 85-95.
31. Ma, H., Wang, H., Zhang, H., Guo, H., Zhang, W., Hu, F., Yao, Y., Wang, D., Li, C., Wang, J. (2020). Effects of phenanthrene on oxidative stress and inflammation in lung and liver of female rats Environmental toxicology **35**: 37-46.
32. Marti-Cid, R., Llobet, J.M., Castell, V., Domingo, J.L. (2008). Evolution of the dietary exposure to polycyclic aromatic hydrocarbons in Catalonia, Spain Food and Chemical Toxicology **46**: 3163-3171.
33. Norata, G.D., Pirillo, A., Catapano, L. (2006). Modified HDL: Biological and physiopathological consequences Nutrition, metabolism and cardiovascular diseases **16**: 371-386.
34. Nassir, F., Rector, S.R., Hammoud, G.M., Ibdah, J.A. (2015). Pathogenesis and prevention of hepatic steatosis Journal of Gastroenterology and Hepathology **11:**3.
35. Omayma E.A., Sawsan, M.A., El Nady, M.M. (2016). Application of polycyclic aromatic hydrocarbons in identification of organic pollution in seawater around Alexandria coastal Area, Egypt Journal of Environmental Life Science **1:** 39-55.
36. Owumi, S.E., Otunla, M.T., Elerewe, O.O., Arunsi, U.O. (2023). Co-exposure to aflatoxin B1 and therapeutic coartem worsens hepatic and renal function through enhanced oxido-inflammatory responses and apoptosis in rats Toxicon **222:** 106-988.
37. Pal, S., Singh, A., Chattopadhyay, A. and Goswami, A. (2023). Oxidative Stress and its implications in various diseases: A comprehensive review. Current Issues in Molecular Biology, **45:** 6651-6666.
38. Pacher, P., Nivorozhkin, A., Szabo, C. (2006). Therapeutic effects of xanthine oxidase inhibitors: renaissance half a century after the discovery of allopurinol Pharmacological reviews **58(1)** 87-114.
39. Rishi, P., Arora, S., Kaur, U.J., Chopra, K., Kaur, I.P. (2017). Better Management of Alcohol Liver Disease Using a 'Microstructured Synbox' System Comprising plantarum and EGCG Journals PLOS One **12**: 780910.
40. Reiter, E.B., Escher, B.I., Siebert, U., Jahnke, A. (2022). Environment International **165**: 107-337.
41. Rass, P., Goth, L., Pay, A. (2004). Catalase enzyme mutations and their association with diseases Molecular Diagnosis **8**(3) 141- 149.
42. Rodriguez, S.A., Murray, A.P., Leiro, J.M. (2020). Xanthine Oxidase Inhibition by Aqueous Extract of Limonium brasiliense (Plumbaginaceae).
43. Santana, J.L., Massone, C.G., Valdes, M., Vazquez, R., Lima, L.A., Olivares-Rieumont, S. (2015). Occurrence and source appraisal of polycyclic aromatic hydrocarbons (PAHs) in surface waters of the Almendares River, Cuba. Archives of environmental contamination and toxicology **69**: 143-152.

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44. Silvestrini, A., Meucci, E., Ricerca, B.M. and Mancini, A. (2023). Total antioxidant capacity: Biochemical aspects and clinical significance. International Journal of Molecular Sciences, **24:** 10-978.
45. Shi, Z., Tao S., Pan, B., Fan, W., He, X.C., Zuo, Q., Wu, S.P., BG, Li., Cao, J., Liu, W.X., Xu, F.L., Wang, X.G., Shen, W.R., Wong, P.K. (2005). Contamination of rivers in Tianjin, China by polycyclic aromatic hydrocarbons. Environmental Pollution **134** (1), 97-111.
46. Wang, L., Du, H., Xu, H., Li, H., Li, L. (2022). Insights into phenanthrene attenuation by hydroxyl radicals from iron-bearing mineral oxygenation Journal of Hazardous Materials, **439**: 129-658.
47. Westerfield, P.E. (1959). The development of an electronic device to measure the velocity, acceleration and jerk of shaft rotation University of Wyoming **12:** 157-159.
48. Westerholm, R., Christensen, A., Tornqvist, M., Ehrenberg, L., Rannug, U., Sjogren, M., Rafter, J., Soontjens, C., Almen, J., Gragg, K. (2001). Comparison of exhaust emissions from Swedish environmental classified diesel fuel (MK1) and European Program on Emissions, Fuels and Engine Technologies (EPEFE) Reference Fuel: A chemical and Biological Characterization, with Viewpoints on Cancer Risk Environmental science and technology **35**: 1748-1754.
49. Yin, Y., Jia, H., Sun, Y., Yu, H., Wang, X., Wu, J., Xue, Y. (2007). Bioaccumulation and ROS generation in liver of Carassius auratus, exposed to phenanthrene Comparative Biochemistry and Physiology Part C: Toxicology and Pharmacology **145**: 288-293.
50. Zheng, J.L., Parfett, C., Williams, A., Yagminas, A., Zhou, G., Douglas, G.R., Yauk, C.L. (2011). Assessment of subclinical, toxicant-induced hepatic gene expression profiles after low-dose, short term exposures in mice Regulatory Toxicology and Pharmacol*ogy* **60:** 54-72.