**Hepatoprotective effect of *Anogeissus leiocarpus* against Carbon tetrachloride-induced toxicity in rat liver damage**

**ABSTRACT**

This study evaluated the hepatoprotective, anti-inflammatory, and antiapoptotic effects of aqueous leaf extracts of *Anogeissus leiocarpus* (ALEAL) in mitigating carbon tetrachloride-induced liver damage in male Wistar rats. Liver diseases are a critical global health challenge often resulting from the reactive free radicals that can bind covalently to cellular macromolecules forming nucleic acid, protein and lipids adducts. Carbon tetrachloride (CCl4) is a leading cause of hepatotoxicity, attributed to oxidative stress, inflammation, and apoptosis through the induction of hypomethylated ribosomal RNA, resulting in inhibition of protein synthesis and CCl4 can affect hepatocellular structure of the liver. The hepatoprotective potential of aqueous leaf extract of *Anogeissus leiocarpus* (ALEAL) was evaluated in male Wistar rats using a CCl4-induced hepatotoxicity model. Statistical analyses were performed using Graph pad Prism 9 with significance different at *P*<0.05. Elevated liver function enzymes (ALT, AST, and ALP) observed in CCl4 groups were significantly (P<0.05) reversed by ALEAL treatments (115 and 230 mg/kg). The Pro-inflammatory markers (IL-6 and TNF-α) were significantly decreased (P<0.05) in ALEAL-treated groups (115 and 230 mg/kg) but significantly increased (P<0.05) in the untreated group. Histological analysis revealed preserved liver architecture and reduced steatosis, necrosis, and fibrosis in ALEAL-treated groups. The study demonstrated that Anogeissus leiocarpus possesses potent hepatoprotective properties mediated through its antioxidant, and anti-inflammatory activities. The findings validate the traditional use of *Anogeissus leiocarpus* for liver ailments and highlight its potential as a natural alternative for managing hepatotoxicity.

**Keywords**: **Carbon tetrachloride-induced hepatotoxicity**, ***Anogeissus leiocarpus*,** **liver functions assays**, **inflammation**, and **hepatoprotective agents**

**Introduction**

The liver is a primary structural and functional organ in mammals, performing numerous critical tasks, including bile secretion, bilirubin metabolism, nutrient processing, production of immune agents for infection control, and the metabolism of xenobiotics (Nagy *et al*., 2020). As a metabolically active organ, the liver is responsible for the biotransformation and clearance of foreign substances (xenobiotics and hepatotoxins), making it a key target for drugs and pathogens that could potentially damage liver cells and impair its function (Hong *et al*., 2009). In 2020, Globocan reported more than 75,000 new liver disease cases in Nigeria. The mortality rate from liver diseases is increasing, and the number of new cases is projected to rise by over 50% in the next 20 years (GLOBOCAN, 2020). Self-medication, drug overdose, contaminated food or water consumption and exposure to pollutants (such as inhaled chemicals) have contributed to a rise in liver damage (Elbery *et al*., 2010). “Oxidative stress is a state that reflects imbalance between reactive oxygen species (ROS) production and their elimination by enzymatic and non-enzymatic antioxidants. Excessive production of ROS causes potential biological damage resulting in many forms of cancer, atherosclerosis, cataracts, neurodegenerative diseases and a plethora of other diseases, as well as premature aging. Medicinal herbs as a rich source of natural antioxidants are enjoying a high profile at present. Several phytochemicals, herbal extracts and food additives are blessed with multifaceted therapeutic benefits through a cascade of molecular events” (Sumran and Aggarwal, 2019; Ouattara et al., 2024).

“Carbon tetrachloride (CCl4)-induced hepatic damage results in hepatotoxicity through the generation of free radicals (trichloromethyl peroxyl) and reactive oxygen species (ROS), ultimately causing liver harm. CCl4 is a colorless organic liquid with a sweet odor and minimal flammability at low temperatures” (Frank *et al*., 2020). “Although CCl4 is not a drug, when administered in high doses (≥1 mL/kg), it can induce reversible acute liver injury. It is commonly used as a model for xenobiotic-induced liver damage. CCl4 accumulates in the endoplasmic reticulum, where cytochrome P450 enzymes metabolize it into the trichloromethyl radical (CCl3•). These free radicals initiate lipid peroxidation by extracting hydrogen from polyunsaturated fatty acids” (Li *et al*., 2015; Wu *et al*., 2018). “This process generates an oxidative stress environment, contributing to liver damage and the progression of various liver diseases due to the release of inflammatory cytokines, such as TNF-α and IL-1β, which accelerate disease onset and development.

The relationship between oxidative stress and inflammation plays a significant role in injury progression. Inflammatory feedback, cell death (apoptosis), and immune responses activate the NF-κB signalling pathway” (Li *et al*., 2017). In this context, the exploration of natural compounds with potential protective effects against CCl4-induced hepatotoxicity becomes crucial.

“Several phytochemicals, including Silymarin, have been identified for their hepatoprotective properties, aiding in the treatment of liver poisoning, cirrhosis and chronic hepatitis” (Abenavoli *et* al., 2018). “Silymarin, a flavonoid extract from *Silybum marianum*, has been used to prevent a range of liver diseases” (Polyak *et al*., 2010). “It has been found to act as an antioxidant by reducing free radical production and lipid peroxidation, as well as functioning as a toxin blocker by preventing toxins from binding to the hepatocyte cell membrane receptors” (Abenavoli et al., 2018). “Additionally, it reduces superoxide levels through its scavenger activity” (Papackova *et al*., 2018). “Recent studies have indicated that Silymarin can mitigate acute toxic liver injury caused by CCl4 by promoting hepatocyte proliferation and reducing the production of toxic metabolites” (Elsayed *et al*., 2020; Yang *et al.,* 2022). However, Silymarin is expensive and not easily accessible. As a result, recent research has focused on the use of natural products derived from plants as an effective therapeutic strategy for liver diseases (Navarro *et al*., 2014; Salomone *et al*., 2016).

“Liver-protecting natural products typically exhibit a range of activities including antioxidant, anti-inflammatory, immunomodulatory, hepatoprotective and antiviral effects” (Kim *et al*., 2015; Ilyas *et al*., 2016; Abdullah *et al*., 2017; Sharifi-Rigi *et al*., 2019).

 *Anogeissus leiocarpus* belongs to the Combretaceae family, a deciduous and tall tree native to the tropical savannas of Africa. Common names for this tree in various regions include Ayin (Yoruba) and Atara (Igbo). *Anogeissus leiocarpus*, is an important medicinal tree used in treating in ailments such as; hepatitis, jaundice, hemorrhoids, headaches, toothaches, diarrhoea, jaundice, respiratory diseases, and malaria (Victor, 2013; Ikram Mohammed *et al*., 2015; Muktar *et al*., 2017). Therefore this work aimed to determine the effect of *Anogeissus leiocarpus* leave extract on CCl4-induced liver injury.

**Materials and Method**

**Chemicals and Reagents**

Distilled water, Carbon tetrachloride (CCl4), Tris buffer, homogenizing buffer, phosphate buffer formalin, phosphate buffered saline (pH 7.4), merchant buffer, sodium hydroxide, ethanol, ethidium bromide, hydrochloric acid, Laboratory kits for quantitative in vivo determination of alkaline phosphatase, alanine aminotransferase, and aspartate aminotransferase. Silymarin was a branded drug (Silybon-70) from Micro Laboratory Ltd, India. Carbon tetrachloride was a product of Sigma Chemical Company, USA. All other reagents and chemicals were of analytical grades.

The materials used range from laboratory equipment/apparatus to various preparatory as well as analytical chemicals and reagents.

**Collection and Identification of plant materials**

Fresh plant of *Anogeissus leiocarpus* was collected from the Agricultural farm of Ladoke University of Technology Ogbomoso. The plant was identified and authenticated by Prof. Ogunkunle J.A. of the Department of Pure and Applied Biology LAUTECH with voucher numbers LHO 897 and a specimen of the plant was deposited at the Department Herbarium.

**Preparation of aqueous leaf extract of *A. leiocarpus.***

Leaves of *A. leiocarpus* were carefully separated from the stem and other debris, thoroughly washed under running water, air-dried to a constant weight and pulverized into a fine powder with the use of an electric blender. Three hundred grams (300 g) of the leaf powder was soaked in 2 L of distilled water for 72 hours with intermittent shaking. After 72 hours, it was filtered through Whatman No 1 filter paper and the filtrate was concentrated by freeze-drying. The mixture was stored in air-tight containers at 4oC (Christian *et al*., 2021).

**Experimental animals**

A total of twenty-five male Wistar rats with an average weight of 160 g- 180 g were used in this study. The model consisted of five (5) groups of five (5) rats each. Animals in group A received 1 ml distilled water and served as a normal control group; group B also received 1 ml distilled water; group C received Silymarin (70 mg/kg) and served as a drug control group; groups D and E were treated with aqueous leaf extract of the plant *Anogeissus leiocarpus* 115 and 230 mg/kg body weight respectively. Animals in groups B-E were exposed to CCl4 (3 ml/kg body weight in olive oil 1:1) via intraperitoneally on days 7 and 14 only. The weight of the animals was recorded on day 0 (24 hours before the first administration) and on day 15 (24 hours after the last administration) (Supp Plate 1). The rats were housed in plastic cages under the standard laboratory conditions (26 ± 2oC, 30-70 % humidity**,** 12 hours light and 12 hours dark cycle) and were acclimatized for two weeks to the lab environment. They were fed a standard pellet diet and drinking water *ad libitum* throughout the experiment study.

 **Table 1: Animals grouping for CCl4 Model**

|  |  |  |
| --- | --- | --- |
| Group | Treatment | Carbon Tetrachloride |
| A(Normal Control) | Distilled water for fourteen days | Not administered |
| B(Negative Control) | No treatment | CCl4 (3 ml/kg body weight in 1:1 olive oil on day 7 and 14) administered (i.p) |
| C(Positive Control) | Silymarin (70 mg/kg body weight) administered for fourteen days | CCl4 (3 ml/kg body weight in 1:1 olive oil on day 7 and 14) administered (i.p) |
| D | Aqueous leaf extract of *Anogeissus leiocarpus* (ALEAL) (115 mg/kg) administered for fourteen days  | CCl4 (3 ml/kg body weight in 1:1 olive oil on day 7 and 14) administered (i.p) |
| E | Aqueous leaf extract of *Anogeissus leiocarpus* (ALEAL) (230 mg/kg) administered for fourteen days  | CCl4 (3 ml/kg body weight in 1:1 olive oil on day 7 and 14) administered (i.p) |

* Given that the LD50 of aqueous leaf extract of *Anogeissus leiocarpus* is 2300 mg/kg of body weight (Somé *et al*., 1996).

**Biochemical Analyses**

The following biochemical parameters were evaluated in the serum using standard methods:

**Alanine (ALT) and Aspartate Aminotransferases (AST)**

Alanine aminotransferase (ALT) and Aspartate aminotransferase (AST) were evaluated following the method described on the sigmal manufacturer as kit. 0.5 mL of each of the substrate (DL-Aspartate (R1a) with α-ketoglutarate for ALT and DL- Alanine (R1b) with α-ketoglutarate for AST) were mixed and incubated for 5 minutes at 37oC. 100 µL of serum were added and the reaction mixtures were returned into the water bath for 30 minutes for both ALT and AST. 125 µL of R2 (2, 4-Dinitrophenenylhydrazine (developer)) were added to the reaction mixture and left for 20 minutes at room temperature. Finally, the colours were developed by the addition of 1.25 mL of NaOH (0.4N) and the products formed were read at 505 nm. Data were expressed as IU/L read from the corresponding calibration curves. The curve was obtained using the same procedure described above, but using the supplied calibrator (pyruvic) instead of sample (serum) at a concentration of 0.0, 0.1, 0.2, 0.3, 0.4 and 0.5mL.

**Determination of Alkaline Phosphatase (ALP)**

Determination biochemical parameters such as alkaline phosphatase (ALP) were determined using commercial test kits with strict adherence to procedures prescribed by the producer, Randox Laboratories, UK. They were all determined in serum according to the protocols adopted by Sun, et al. (sun et al., 1988) and Kanu, et al. (kanu et al., 2017).

Inflammatory Cytokines Analyses

**Determination of Rat IL-6**

This ELISA kit uses the Sandwich-ELISA principle. The micro ELISA plate provided in this kit has been pre-coated with an antibody specific to Rat IL-6. Standards or samples are added to the micro ELISA plate wells and combined with the specific antibody. Then a biotinylated detection antibody specific for Rat IL-6 and Avidin-Horseradish Peroxidase (HRP) was conjugated and added successively to each microplate well and incubated. Free components are washed away. The substrate solution was added to each well. Only those wells that contained Rat IL-6, biotinylated detection antibody and Avidin-HRP conjugate appeared blue in color. The enzyme-substrate reaction was terminated by the addition of a stop solution and the color turns yellow. The optical density (OD) was measured spectrophotometrically at a wavelength of 450 nm ± 2 nm. The OD value was proportional to the concentration of Rat IL-6. The concentration of Rat IL-6 was calculated in the samples by comparing the OD of the samples to the standard curve.

**Determination of Rat Tumor Necrosis Factor alpha (TNF-α)**

This ELISA kit uses the Sandwich-ELISA principle. The micro ELISA plate provided in this kit has been pre-coated with an antibody specific to Rat TNF-α. Standards or samples are added to the micro ELISA plate wells and combined with the specific antibody. Then a biotinylated detection antibody specific for Rat TNF-α and Avidin-Horseradish Peroxidase (HRP) conjugate are added successively to each microplate well and incubated. Free components are washed away. The substrate solution is added to each well. Only those wells that contain Rat TNF-α, biotinylated detection antibody and Avidin-HRP conjugate will appear blue in colour. The enzyme-substrate reaction was terminated by the addition of a stop solution and the color turned yellow. The optical density (OD) was measured spectrophotometrically at a wavelength of 450 nm ± 2 nm. The OD value was proportional to the concentration of Rat TNF-α. The concentration of Rat TNF-α was calculated in the samples by comparing the OD of the samples to the standard curve.

**Histopathological Analysis of Liver Sample**

For the histopathological studies, the male Wistar rats of all ten groups were sacrificed by cervical dislocation. Liver tissues of the rats were removed and washed properly in 0.9 % saline solution. Tissues were fixed in 10 % buffered formosaline for 48 hours to know the level of damage done by the administered drug using hematoxylin and eosin staining rutting techniques, (Bancroft and Gamble 2002).

**Tissue Processing**

**Grossing:** The tissues were observed and cut into small pieces not more than 4mm thick into pre-labeled cassettes. These were further immersed in 10 % formal saline for 24 hours to fix.

**Tissue Processing**: This is done automatically using an automatic tissue processor (Leica TP 1020). The tissue was allowed to pass through various reagents including; stations 1 & 2 containing 10% formal saline, station 3 to station 7; alcohol (70 %, 80 %, 90 %, 95 %, absolute 1 & absolute 11) for the purpose of dehydration. The tissues passed through station 8 and station 9 containing two changes of xylene for the purpose of clearing and finally transferred into three wax baths for infiltration/impregnation. The machine was programmed to run for 12 hours, the tissues stayed in each station for 1 hour.

**Embedding:** Eachprocessed tissue was given a solid support medium (paraffin wax) and this was done using a semi-automatic tissue embedding center. The molten paraffin wax was dispensed into a metal mold and the tissue was buried and oriented in it, a pre-labeled cassette was placed on this and was transferred to a cold plate to solidify. The tissue block formed was separated from the mold.

**Microtomy:** The blocks were trimmed to expose the tissue surface using a rotary microtome at 6micrometer. The surfaces were allowed to cool on ice before sectioning. The tissues were sectioned at 4 micrometer (ribbon section)

**Floating:** The sections were floated on the water bath (Raymond lamb) set at 55 0C and these were picked using clean slides. The slides were labeled appropriately.

**Drying:** The slides were dried on a hotplate (Raymond lamb) set at 60 0C for 1 hour.

**Staining:** The staining technique used was Haematoxylin and Eosin technique

**Procedure for Haematoxylin and Eosin (H and E) Technique**

The slides were dewaxed in xylene for 15 minutes. They were then taken through absolute alcohol, 95 % and 70 % alcohol, after which they were rinsed to section in water.

They were then stained in Harris haematoxylin for 5 minutes. The slides were rinsed in water and differentiated in 1% acid alcohol briefly. This step was followed by rinsing in water and bluing under running tap water for 10 minutes. The slides were counterstained with 1% aqueous eosin for 2 minutes and rinsed in water after which they were dehydrated in ascending grades of alcohol and cleared in xylene. The slides were mounted in DPX. The nuclei and the cytoplasm appeared blue and pink in colour respectively Immunostain formalin-fixed, paraffin-embedded tissue sections.

**Immunohistochemical procedure**

The slides were deparaffinized in xylene for 2 times, 5 min each. The slides were transferred to 100% alcohol, for 2 times, 3 min each, and then transferred through 95% twice, 70% once alcohols respectively for 3 min each. They were rinsed with Wash Buffer for 2 times, 5 min each. Antigen retrieval was performed to unmask the antigenic epitope. The most commonly used antigen retrieval buffer is a citrate p 6.0 and EDTA pH 9.0. For Preheating, 250-300 ml of 10 mM citrate pH 6.0 /EDTA pH 9.0 buffer was poured into the staining container (24 slide coupling jar) and incubated it at 95-100°C for 5 min. The slides were arranged in a staining hanger and dipped in the preheated buffer; incubated for 10-20 min in the water bath. The staining container was removed to room temperature and the slides were to cool in the retrieval buffer for 20 min. The slides were rinsed with Wash buffer for 2 times, 5 min each. Blocking buffer (e.g. 10% fetal bovine serum in PBS or 3 % H2O2) was added to the sections of the slides and incubated in a humidified chamber at room temperature for 15 minutes. The blocking buffer was drained off from the slides and washed in wash buffer. 130 μL was applied appropriately diluted primary antibody to the sections on the slides and incubated in a humidified chamber at room temperature for 1 hour. The slides were washed with Wash buffer for 2 times, 5 min each. 130 μL was applied appropriately Antibody amplifier + Polymer- HRP Micro-Polymeric-HRP secondary antibody to the sections on the slides and incubated in a humidified chamber at room temperature for 15 minutes each. The slides were further washed with wash buffer for 2 times, 5 min each. 130 μL DAB substrate solution (freshly made just before use: 0.05 % DAB - 0.015 % H2O2 in PBS) was applied to the sections on the slides to reveal the color of antibody staining. The color was allowed to develop for < 5 min until the desired color intensity was reached. The slides were washed under running water 3 times, 2 min each. Slides were counterstained by immersing sides in Hematoxylin for 10-20seconds. The slides were rinsed in running tap water for 10 min. The tissue slides were dehydrated through 4 times of alcohol (95%, 95%, 100% and 100%), 5 min each. The tissue slides were cleared 3 times in xylene and coverslip using the mounting solution. The mounted slides can be stored at room temperature permanently. The colour of the antibody staining was observed in the tissue sections under microscopy.

**Data Analysis**

Results were expressed as mean ±SD from at least three replicate measurements. The difference between the means will be analyzed with ANOVA, α value = 0.05. Post-hoc Analysis will be done using Tukey test, using GraphPad Prism software 9, 2022

**RESULTS**

**Effects of aqueous leaf extract of *Anogeissus leiocarpus* (ALEAL) on the hepatic parameters of male Wistar rats exposed to Carbon tetrachloride.**

Selected hepatic parameters of rats pretreated with ALEAL and those administered CCl4 (3 ml/kg) are shown in table 2 below. Results revealed that rats administered with 3 ml/kg of CCl4 presented with a significant increase (*P*<0.05) in serum activities of liver enzymes (AST, ALT and ALP) compared to control group and the groups pretreated with ALEAL.

**Table 2: Effects of aqueous leaf extract of *A. leiocarpus* on the hepatic parameters of male Wistar rats exposed to Carbon tetrachloride.**

|  |  |  |  |
| --- | --- | --- | --- |
| Group | AST (U/L) | ALT (U/L) | ALP (U/L) |
| A: Normal Control | 28.43±0.21a | 36.38±0.88a | 44.17±0.63a |
| B: CCl4 (3 ml/kg) | 38.85±0.12b | 69.12±1.91 b | 55.22±1.49 b |
| C: CCl4 (3 ml/kg) + Silymarin (70 mg/kg) | 31.26±0.70 a | 51.51±0.10 c | 50.44±1.16 c |
| D: CCl4 (3 ml/kg) + AEAL (115 mg/kg) | 32.23±1.62 a | 44.63±1.53 a | 49.18±1.13 c |
| E: CCl4 (3 ml/kg) + ALEAL (230 mg/kg) | 29.23±0.71 a | 49.28±3.13 c | 46.64±0.43 a |

Values were expressed as mean ±SEM (n=5), Different alphabet superscripts indicate significant difference at *P*<0.05, CCl4 (Carbon tetrachloride), AST (Aspartate aminotransferase, ALT- (Alanine aminotransferase), ALP (Alkaline phosphatase), ALEAL (Aqueous leaves extract of *Anogeissus leiocarpus*).

**Effects of aqueous leaf extract of *Anogeissus leiocarpus* (ALEAL) on the level of Proinflammatory on Carbon tetrachloride liver damage in male Wistar rats.**

As shown in Figure 1 the administration of Carbon tetrachloride significantly (*P*<0.05) elevated interleukin-6 level in rats given only Carbon tetrachloride when compared to the normal control group. However, the groups pretreated with aqueous leaf extract of *Anogeissus leiocarpus* (ALEAL) (115 mg/kg and 230 mg/kg body weight) before CCl4 administration had significantly

(*P*<0.05) decrease these pro-inflammatory markers when compared to the group administrated only CCl4. Administration of Carbon tetrachloride significantly (*P*<0.05) elevated Tumor Necrosis Factor- Alpha in rats when compared to the normal control group. However, the groups pretreated with aqueous leaf extract of *Anogeissus leiocarpus* (115 mg/kg and 230 mg/kg body weight) before CCl4 administration had lower levels of TNF-α when compared to the untreated group (Fig. 2).



**Figure 1:** **Effects of aqueous leaf extract of *Anogeissus leiocarpus* (ALEAL) and Carbon tetrachloride administration on inflammatory marker (Interleukin-6) in rats.**



**Figure 2: Effects of aqueous leaf extract of *Anogeissus leiocarpus* (ALEAL) and Carbon tetrachloride administration on inflammatory marker (Tumor Necrosis Factor- Alpha) in rats.**

Values were expressed as mean ±SEM (n=5), Different alphabet superscripts indicate significant difference at p<0.05, CCl4 ­(Carbon tetrachloride), ALEAL (Aqueous leaf extract of *Anogeissus leiocarpus*), IL-6 (Interleukin-6), TNF-α (Tumor Necrosis Factor- Alpha).

**Histological overview of liver of rats pretreated with (ALEAL) and exposed to CCl4.**

Histology of the liver showed moderate architecture, the central venules appear normal in all the groups pretreated with aqueous extract of *Anogeissus leiocarpus*, compared to the group induced with Carbon tetrachloride which showed severe damage to the liver. Indices assessed included hepatocytes, sinusoids, portal tract, inflammation and venules. Both the normal group and the groups pretreated with Silymarin and aqueous leaf extract of *Anogeissus leiocarpus* of the rat’s liver demonstrated normal well-preserved architecture, intact normal histological components of the hepatic lobules, normal portal areas and normal central vein bounded by an intact endothelium. Though the morphology of the hepatocytes of group pretreated with aqueous leaf extracts of *Anogeissus leiocarpus* (230 mg/kg body weight) shows mild cytoplasmic vacuolation probably due to fat infiltration while that of 115 mg/kg body weight appears normal (blue arrow).

The Carbon tetrachloride-induced group revealed indices that show chronic hepatic steatosis, onset liver cirrhosis with fibrosis and degenerate liver cells (blue arrow).



**C**

**B**

**A**

 

**E**

**D**

**Plate 1: Photomicrographs representative of male Wistar rats’ liver pretreated with ALEAL and exposed to CCl4 (Photomicrographs of liver section stain by haematoxylin and eosin 400X).**

 A (Normal Control), B (CCl4 only), C (CCl4 + Silymarin), D (CCl4 + ALEAL 115mg/kg body weight), E (CCl4 + ALEAL 230mg/kg body weight).

 CCl4 (Carbon tetrachloride), ALEAL (Aqueous leaf extract of *Anogeissus leiocarpus*)*.*

**Effects of aqueous leaf extract of *Anogeissus leiocarpus* (ALEAL) on the immunohistochemical (Bax) staining of livers of rats of Carbon tetrachloride-induced liver damage in male Wistar rats.**

Plate 2 revealed severe expression of Bax in the liver of rats exposed to CCl4. The groups pretreated with Silymarin showed a moderate expression of Bax when compared to the groups pretreated with AEAL which showed weak expression of Bax. Analysis of Bax expression when quantified using the Image J image processing program also revealed a significant increase in the level of Bax of male Wistar rats induced with CCl4. However, there was a significant difference (*P*<0.05) in the groups pretreated with AEAL and the Silymarin group as revealed in Figure 3.

 

 

**C**

**D**



**E**

**Plate 2: Liver images of Wistar rats treated with aqueous leaf extract of *Anogeissus leiocarpus* upon CCl4 toxicity (Bax protein stain 400X).**

A (Normal Control), B (CCl4 only), C (CCl4 + Silymarin), D (CCl4 + AEAL 115 mg/kg body weight), E (CCl4 + AEAL 230 mg/kg body weight).

CCl4 (Carbon tetrachloride), AEAL (Aqueous leaf extract of *Anogeissus leiocarpus*).



**Figure 3: Effects of aqueous leaf extract of *Anogeissus leiocarpus* and Carbon tetrachloride administration on Bax Protein Expression.**

Values were expressed as mean ±SEM (n=3), Different alphabet superscripts indicate significant difference at *P*<0.05, CCl4 ­(Carbon tetrachloride), AL 1 (Aqueous leaf extract of *Anogeissus leiocarpus* 115 mg/kg body weight), AL 2 (Aqueous leaf extract of *Anogeissus leiocarpus* 230 mg/kg body weight).

**Discussion**

Carbon tetrachloride a well-known chemical compound has various uses and exposure to it in a quantified amount can induce severe liver injury which can signify a serious health threat to human beings and animals (Unsal *et al.,* 2022).

The effectiveness of any hepatoprotective drug depends on its ability to either restore normal hepatic functions impaired by hepatotoxins or minimize its harmful effects (Patrick-Iwuanyanwu et al., 2010). The most common plant portion utilized in traditional medicine is the leaf, which is also the most abundant part of the plant (Priyadarshi and Ram, 2018). The frequency of using leaves rather than other plant components in Saudi Arabian traditional medicine was documented by Ullah *et* al., (2020). This could be a result of leaves having more phytochemicals than another plant components. Among other plant parts, leaves are simple to evaluate and harvest. Furthermore, rapid leaf regeneration guarantees the maintenance of floristic richness. Plant compound containing saponnin, flavonoid, phenols and tannin are crucial for scavenging reactive oxygen species (ROS) and also reduce systemic inflammation that may arise as a result of hepatotoxins (Ebe *et* al., 2021; Adewole *et al*., 2022). Plants that contain polyphenolic compounds have the potentials to prevent diseases related to oxidative damage mechanism such as cancer.

Aqueous leaf extract of *Anogeissus leiocarpus* (ALEAL) contains some known phytochemicals which enable it to prevent reactive oxygen species-related diseases and thus, it’s examined for in vivo hepatoprotective potentials in rats. In this study, the biochemical assay shows the reduction in systemic inflammation supports protein synthesis in hepatocytes, promoting recovery and maintaining homeostasis. The extract's ability to mitigate weight loss suggests its potential to counteract cachexia and improve overall metabolic function, which has clinical implications for managing liver disease-induced wasting syndromes. The tannin content may also reduce vascular leakage and inflammation, helping maintain systemic energy balance (Nwidu *et al*., 2023).

The serum aminotransferases; Alanine transaminase (ALT) and Aspartate transaminase (AST) serve as widely recognized biomarkers for liver necrosis. ALT and AST are confined to liver cell (Cytoplasm) thus once there is an increase in their serum concentration, it’s an indication that the liver membrane is damaged or has experienced inflammation or the integrity of the cell membranes has been compromised or is in infective conditions such as viral hepatitis. When AST is also present in extra-hepatic tissues such as the kidney and heart with a simultaneous elevation in serum AST levels in conjunction with ALT level this may indicate hepatic injury (Tala *et al*., 2015). An increased serum AST and ALT concentration signifies inflammation of the hepatocytes due to the buildup of reactive NAPQI radicals from increased carbon tetrachloride metabolism. The elevated levels of ALT, AST, and ALP in untreated groups indicate hepatocellular damage and biliary dysfunction, both hallmarks of liver toxicity. These enzymes were significantly normalized in ALEAL-treated groups, highlighting the extract's hepatoprotective effects. Phytochemicals present in the plant such as Flavonoids stabilize cell membranes and inhibit lipid peroxidation by reducing reactive oxygen species (ROS), while tannins and alkaloids chelate metal ions and prevent ROS-mediated enzyme leakage (Oyedemi *et al*., 2022). The enzymes ALT in particular is increased which is an indication of liver damage. Its increase in the mitochondrial serves as a sensitive indicator of damage to cytoplasmic and /or the mitochondrial membranes suggesting liver injury caused by hepatotoxins. The group administered with CCl4 only experienced and elevated serum liver marker enzymes which is an indication of cellular leakage and loss of liver functional integrity. The groups pretreated with ALEAL (115mg/kg and 230mg/kg body weight) experienced a significant reduction (*P*<0.05) in the level of liver enzyme markers concentration when compared with the CCl4-induced group, this correlate with the facts that serum levels of aminotransminase usually return to normal when hepatocytes are been regenerated as well as healing of hepatic parenchyma (Adewale *et al*., 2014). The biochemical principle involves the preservation of hepatocyte integrity by neutralizing oxidative stress, which otherwise disrupts membrane-bound enzymes. Saponins (identified in ALEAL) might also regulate bile acid secretion, alleviating cholestasis observed in the untreated groups (Abdullahi *et al*., 2023). Clinical applications could include managing drug-induced liver injuries and chronic liver diseases, where enzymes elevation serves as a diagnostic marker of damage. Any activity alteration of these enzymes results in cellular impairment, tissue lesion and dysfunction. This healing process could be linked to the liver's remarkable capacity for regeneration and rejuvenation following injury or damage. Thus the ALEAL demonstrated the ability to alleviate CCl4-induced hepatotoxicity. These results align with the findings of sa’id *et al.,* (2020).

The elevated levels of IL-6 and TNF-α in the untreated group indicate a robust inflammatory response. ALEAL significantly reduced these markers, possibly due to its flavonoid and tannin content, which inhibits NF-κB activation, a key pathway in cytokine production. Saponins further reduce inflammation by modulating macrophage activity and cytokine release (Nwidu *et al*., 2023). Ellagic acid has also been shown to suppress pro-inflammatory mediators through downregulation of COX-2 and inducible nitric oxide synthase (iNOS). It was reported by Eltahire *et al*., (2020) that an increase in the expression of several inflammatory cytokine genes such as IL-6, TNF-α, mRNA expression, transforming growth factor- β (TGF-β), xCOX-2, necrosis factor-kappa B (NF-kB) was associated with the administration of CCl4 in rats.

The biochemical principle involves disrupting pro-inflammatory signalling cascades, thereby preventing liver inflammation and fibrosis. This suggests that ALEAL could be a potential therapeutic for chronic liver inflammation and related conditions. Similar findings were reported by Oyedemi *et al*., (2022), where flavonoids suppressed pro-inflammatory cytokines in inflammatory models.

However, the cellular antioxidant response is enhanced by the presence of dietary antioxidants. Antioxidants and anti-inflammatory agents play a crucial role in protecting against CCl­4 toxicity by scavenging reactive oxygen species and free radicals as well as neutralizing lipid peroxides. Histological analysis revealed preserved liver architecture in ALEAL-treated groups, with reduced steatosis, necrosis, and fibrosis. The protective effects are attributed to the combined action of flavonoids (quercetin, kaempferol), tannins, and alkaloids, which prevent lipid accumulation and promote hepatocyte regeneration. Polyphenols in the extract (ALEAL) likely inhibit the activation of hepatic stellate cells, reducing fibrogenesis (Oluwole *et al*., 2023).

Apoptosis activation is linked to mitochondria degeneration (Ahmadian *et al*., 2020). The activation of pro-apoptotic genes like Bax leads to increased mitochondrial permeabilization leading to the release of cytochrome c which further trigger hepatocyte apoptosis and caspase-3 activation (Liuet *et al*., 2018). Analysis of the immunohistochemistry results revealed that the expression levels of Bax protein were quantified in Wistar rats exposed to carbon tetrachloride (CCl4) and treated with aqueous leaf extract of *Anogeissus leiocarpus* (ALEAL). ALEAL treatment showed a dose-dependent reduction in Bax levels compared to the untreated CCl4 group, suggesting its potential protective or anti-apoptotic effects. The results indicate that ALEAL mitigates oxidative stress-induced apoptosis associated with CCl4 toxicity. *Anogeissus leiocarpus*, a medicinal plant with recognized anti-inflammatory and antioxidant properties, presents itself as a promising candidate for mitigating the harmful effects of CCl4 on the liver (Motto *et al.*, 2021).Biochemically, this preservation of liver structure supports normal metabolic and detoxification processes, highlighting ALEAL’s potential in preventing progression to cirrhosis. These findings align with studies by Abdullahi *et al*., (2023), demonstrating the antifibrotic effects of tannin-rich extracts.

**Conclusion**

This study highlights the hepatoprotective potential of *Anogeissus leiocarpus* aqueous leaf extract (ALEAL) against carbon tetrachloride (CCl4)-induced hepatotoxicity. The extract demonstrated significant antioxidant, and anti-inflammatory, as evidenced by the normalization of hepatic enzyme levels, along with a reduction in inflammatory cytokines. Histopathological evaluations further confirmed its ability to preserve liver architecture and mitigate tissue damage. These effects are attributed to the phytochemical constituents of *A. leiocarpus*, such as flavonoids, tannins, and saponins, which act through various biochemical mechanisms to protect and restore liver function. These findings underscore the potential of *A. leiocarpus* as a natural, safe, and effective therapeutic agent for the prevention and management of liver diseases.

**Ethical Approval**

Animal Ethic committee approval has been collected and preserved by the author(s)

**List of abbreviations**

* **ALP**: Alkaline Phosphatase
* **ALT**: Alanine Aminotransferase
* **AST**: Aspartate Aminotransferase
* **BAX**: Bcl-2-associated X protein
* **IL-6**: Interleukin-6
* **LD50**: Median Lethal Dose
* **ROS**: Reactive Oxygen Species
* **TNF-α**: Tumor Necrosis Factor-Alpha

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1.

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**REFERENCES**

Abdullah, A., Phern, T. C., Rahim, N. F. H. M., Zaharuddin, N. I., Salihin, N. M., Yusof, A. H. (2017). The effects of cosmos caudatus (ulam Raja) on the levels of expression of Nrf2 target genes in mice liver. J. Pharm. Nutr. Sci. **7**, 147–157.

Abenavoli, L., Capasso, R., Milic, N., and Capasso, F. (2010). Milk thistle in liver diseases: Past, present, future. Phytother. Res. **24**, 1423–1432.s

Abenavoli, L., Izzo, A. A., Milić, N., Cicala, C., Santini, A., and Capasso, R. (2018). Milk thistle (Silybum marianum): A concise overview on its chemistry, pharmacological, and nutraceutical uses in liver diseases. Phytother. Res **32**, 2202–2213.

Adewole, O. A.,. (2022). Antioxidant mechanisms in medicinal plants. *Journal of Ethnopharmacology*, **290**, 115123.

Agaie B.M., Onyeyili P.A., Muhammad B.Y., Ladan M.J., (2007b). Acute toxicity effects of the aqueous leaf extract of Anogeissus leiocarpus in rats. African Journal of Biotechnology **6**(7), 886-889.

Ahmad, A. H. (2014). Review on *Anogeissus leiocarpus*: A Potent African Traditional Drug.

International Journal of Research in Pharmacy and Chemistry. **4**(3): 496-500.

Ahmad, A., and Ahmad, R. (2014). Resveratrol mitigate structural changes and hepatic stellate cell activation in N'-nitrosodimethylamine-induced liver fibrosis via restraining oxidative damage. Chem. Biol. Interact. **221**, 1–12.

Aithal G. P., Ramsay L., Daly A. K., Sonchit N., Leathart J. B. S., Alexander G., (2004). Hepatic adducts, circulating antibodies, and cytokine polymorphisms in patients with diclofenac hepatotoxicity. Hepatol. Baltim. Md. **39** (5), 1430–1440. 10.1002/hep.20205

Aithal G. P., Watkins P. B., Andrade R. J., Larrey D., Molokhia M., Takikawa H., et al. (2011). Case definition and phenotype standardization in drug-induced liver injury. Clin. Pharmacol. Ther. **89** (6), 806–815. 10.1038/clpt.2011.58 Allain (1974). Allain C.C Poon L.S, Chan C.S.G, Richmond, W and Fu, P.C Clinical Chemistry; **20**: 470-475

Allen S.E., (2002). The liver: Anatomy, Physiology, Disease and Treatment. North Eastern University Press, USA.

Andrade R. J., Robles M., Ulzurrun E., Lucena M. I. (2009). Drug-induced liver injury: insights from genetic studies. Pharmacogenomics **10** (9), 1467–1487. 10.2217/pgs.09.111

Arbab A.H. 2014. Review on *Anogeissus leiocarpus* a potent African traditional drug. International Journal of Research in Pharmacy and Chemistry **4**(3), 496500.

Atawodi, S.E., Adekunle, O.O. and Bala, I. (2011). Antioxidant, organ protective and ameliorative properties of methanol extract of *Anogeissus leiocarpus* stem bark against carbon tetrachloride- induced liver injury. International Journal of Pharmaceutical Sciences Research, **2**: 1443-1448.

Belemnaba L, Ouedraogo S, Auger C, Chataigneau T, Traore A, Guissou IP, Lugnier C, Schini-Kerth VB, Bucher B. 2013. Endothelium-independent and endothelium dependent vasorelaxation by a dichloromethane fraction from *Anogeissus* *leiocarpus* (DC) Guill. Et Perr. (Combretaceae): possible involvement of cyclic nucleotide phosphodiesterase inhibition. African Journal of Traditional, Complementary and Alternative Medecine **10**(2), 173-179.

Black, D.D. (2014). Structure, Functional Assessment, and Blood Flow of the Liver. In: Leung, P. (eds) The Gastrointestinal System. Springer, Dordrecht.

Burke Z.D., Thowfeequ S., Tosh D., (2006). Liver specification: a new role for rats in liver development. Current Biology, **16**(17): 688 - 690.

Cummings, A. J., King, M. L., and Martin, B. K. (1967). A kinetic study of drug elimination: the excretion of paracetamol and its metabolites in man. Br. J. Pharmacol. Chemother. **29**, 150–157.

Dahiru, M. M., Abaka, A. M., and Musa, N. (2023). Phytochemical Analysis, In-vitro, and In-silico Antibacterial Activity of Stembark Extract of Anogeissus leiocarpus (DC) Guill and Perr. Sciences of Pharmacy, 2(3), 24-41.

Dahiru, M.M., Badgal, E.B., Musa N. (2023). J.Fac.Pharm.Ankara/Ankara Ecz.Fak.Derg., **47**(2):311-323

Dalaklioglu, S., Genc, G. E., Aksoy, N. H., Akcit, F., and Gumuslu, S. (2013). Resveratrol ameliorates methotrexate-induced hepatotoxicity in rats via inhibition of lipid peroxidation. Hum. Exp. Toxicol. **32**, 662–671.

Dara, L., Liu, Z. X., and Kaplowitz, N. (2016). Questions and controversies: the role of necroptosis in liver disease. Cell Death Discov. **2**:16089.

Dayok, O., Dawang, D.N. and Da’am, C.E. (2018). Antimicrobial Activity of Leaf Extract of Anogeissus leiocarpus (African Birch) On Some Selected Clinical Isolates. Journal of Pharmaceutical and Biological Sciences, **13**: 36-40.

Devarbhavi H, Dierkhising R, Kremers WK, Sandeep MS, Karanth D, Adarsh CK, (2010). Single-center experience with drug-induced liver injury from India: causes, outcome, prognosis, and predictors of mortality. Am J Gastroenterol; 105: 2396-404.

Elberry, A.A., Harraz, F.M., Ghareibetal., S.A. (2010). “Antihepatotoxic effect of Marrubium vulgare and with aniasomnifera extracts on carbon tetrachloride—induced hepatotoxicity in rats,” Journal of Basic and Clinical Pharmacy, vol.1, no.4, pp.247–254.

Ezuruike, U.F., and Prieto, J.M., (2014). The use of plants in the traditional management of diabetes in Nigeria: pharmacological and toxicology considerations. *J. Ethnopharmacol.,* **155**, pp. 857-924.

Frank, D., Savir, S., Gruenbaum, B.F., Melamed, J., Grinshpun, R., Kuts, R., Knyazer, B., Zlotnik, A, Vinokur, M., Boyko, M., (2020). Inducing acute liver injury in rats via exposure through an orogastric tube. *J. Vis. Exp. JoVE.S*

Gbadamosi I.T., Ogunsuyi A.O., (2014). An appraisal of the potency of roots of *Anogeissus* *leiocarpus* (DC.) Guill. & Perr. and *Terminalia* *glaucescens* Benth. in the management of E. coli related infections. Journal of Applied Biosciences **78**(1), 6646-6653.

Gbadamosi, I. T., Oyedemi, S. O., and Afolayan, A. J. (2018). Antimicrobial and antioxidant activities of Anogeissus leiocarpa and Terminalia glaucescens leaf extracts. BMC complementary and alternative medicine, **18**(1), 1-9.

GLOBOCAN, 2020. New Global Cancer Data/UICC. [https://www.uicc.org/news/globocan new global-cancer-data](https://www.uicc.org/news/globocan%20new%20global-cancer-data)

Goldberg. S. Hussein, M., and Khan, R. (2022). CCL4-induccd hepatotoxicity: study in rats intoxicated with 26 Carbon tetrachloride and treated with camel milk and urine. Journal of Chemistry Studies, 1(1), 07-11.

Guengerich, F. P. (2020). Cytochrome P450 2E1 and its roles in disease. Chem. Biol. Interact. **322**, 109056.

Guill and Perr (1832). *Anogeissus leiocarpa* (DC).

Guyton A.C., Hall J.E., (2006). Textbook of Medical Physiology. 11th Edition, Saunder Philadelphia, Pennsylvania. 1116 pp.

Hong, J.Y., Lebofsky, M., Farhood, A., Jaeschke, H., (2009). Oxidant stress-induced liver injury in vivo: role of apoptosis, oncotic necrosis, and c-Jun NH2-terminal kinase activation. *Am J Physiol* 296: G572-G581.

Idakwoji, P.A., Agatemor, U.M., Akuba, B.O., Oniemola, J.M. and Momoh, T.B. (2019). Effect of aqueous extract of *Anogeissus leiocarpus* against experimental models of pain and pyrexia. International Journal Advanced Research in Biological Sciences, **6**: 181-188.

IFCC (1983). Method for the measurement of ALP. J. Clinical Chemistry Clinical Biochemistry 21:731-48.

Ikram Mohamed, E.E., Abdul Khaliq, M., Hiba, A.A., Saad , M.A., A comparative study of antimicrobial activity of the extracts from root, leaf and stem of Anogeissus leiocarpus growing in Sudan, Journal of Pharacognosy and Phytochemical, P. 107.

Ilyas, U., Katare, D. P., Aeri, V., and Naseef, P. P. (2016). A review on hepatoprotective and immunomodulatory herbal plants. Pharmacogn. Rev. **10**, 66–70.

Kabore, A., Tamboura, H. H., Traore, A., Traore, A., Meda, R., Kiendrebeogo, M., and Sawadogo, L. (2010). Phytochemical analysis and acute toxicity of two medicinal plants (Anogeissus leiocarpus and Daniellia oliveri) used in traditional veterinary medicine in Burkina Faso. Arch Appl Sci Res, 2(6), 47-52.

Kaiser, S. K., and Dart, R. C. (2022). The roles of antidotes in emergency situations. Emerg. Med. Clin. North Am. **40**, 381–394.

Karch, J., Kwong, J. Q., Burr, A. R., Sargent, M. A., Elrod, J. W., Peixoto, P. M., (2013). Bax and Bak function as the outer membrane component of the mitochondrial permeability pore in regulating necrotic cell death in mice. eLife **2**:e00772.

Khan, H., Ullah, H., and Nabavi, S. M. (2019). Mechanistic insights of hepatoprotective effects of curcumin: Therapeutic updates and future prospects. Food Chem. Toxicol. **124**, 182–191.

Kim, D. H., Jung, Y. J., Lee, J. E., Lee, A. S., Kang, K. P., Lee, S., et al. (2011). SIRT1 activation by resveratrol ameliorates cisplatin-induced renal injury through deacetylation of p53. Am. J. Physiol. Ren. Physiol. **301**, F427–F435.

Kim, Y.-S., Hwang, J.-W., Sung, S.-H., Jeon, Y.-J., Jeong, J.-H., Jeon, B.-T. (2015). Antioxidant activity and protective effect of extract of Celosia cristata L. flower on tert-butyl hydroperoxide-induced oxidative hepatotoxicity. Food Chem. **168**, 572

Kmieć Z (2001). Cooperation of liver cells in health and disease. pp. iii–xiii, 1–151579.

Krajka-Kuźniak, V., and Baer-Dubowska, W. (2003). The effects of tannic acid on cytochrome P450 and phase II enzymes in mouse liver and kidney. Toxicol. Lett. **143**, 209–216.

Larrey D., Ursic-Bedoya J., Meunier L. (2017). “Drug-Induced hepatotoxicity,” in Schiff ’s diseases of the liver. Ed. Schiff E. R. (New York: Wiley- Blackwell;).

Lawal, T.O., Bamiduro, T.B., Ofonmbuk, J.M., Elufioye, T.O., Adeniyi, B.A. and Mahady, G.B. (2017). Antibacterial effects of *Anogeissus leiocarpus* (DC.) Guill. and Perr. and Terminalia glaucescens Planch. Ex Benth on rapidly growing mycobacteria species. African Journal of Microbiology Research, **11**(12): 495-503.

Li, G., Chen, J. B., Wang, C., Xu, Z., Nie, H., Qin, X. Y. (2013). Curcumin protects against acetaminophen-induced apoptosis in hepatic injury. World J. Gastroenterol. **19**, 7440–7446.

Li, J. P., Gao, Y., Chu, S. F., Zhang, Z., Xia, C. Y., Mou, Z. (2014). Nrf2 pathway activation contributes to anti-fibrosis effects of ginsenoside Rg1 in a rat model of alcohol- and CCl4-induced hepatic fibrosis. Acta Pharmacol. Sin. **35**, 1031–1044.

Mann, A., Yahaya, A.Y., Banso, A. and Ajayi, G.O. (2008). Phytochemical and antibacterial screening of *Anogeissus leiocarpus* against some microorganisms associated with infectious wounds. African Journal of Microbiology Research, **2**: 60-62.

McCommis, K. S., and Baines, C. P. (2012). The role of VDAC in cell death: friend or foe? Biochim. Biophys. Acta 1818, 1444–1450.

Mcgill, M. R., Du, K., Weemhoff, J. L., and Jaeschke, H. (2015). Critical review of resveratrol in xenobiotic-induced hepatotoxicity. Food Chem. Toxicol. **86**, 309–318.

Motto, A. E., Lawson-Evi, P., Bakoma, B., Eklu-Gadegbeku, K., & Aklikokou, K. (2021). Antihyperlipidemic and antioxidant properties of hydro-alcoholic extracts from Anogeissus leiocarpus (Combretaceae). Heliyon, 7(4).

Moore K. ., Dalley A.F., *Clinically Oriented Anatomy*. 2006 5th Edition Lippincott Williams

and Wilkins. 1209 pp

Mukhtar, Y., Abdu, K and Maigari, A. K. (2017). Efficacy of *Anogeissus leiocarpus* (DC.) as

Potential Therapeutic Agent against Trypanosomiasis Diseases: A Review. International Journal of Health and Pharmaceutical Research. 3 (3): 1-9. [www.iiardpub.org](http://www.iiardpub.org)

Nagy P. Snorri. S. T., Grisham, . J. W. The Liver: Biology and Pathbiology, 1-13, 2020.

Nakagawa, T., Shimizu, S., Watanabe, T., Yamaguchi, O., Otsu, K., Yamagata, H., et al. (2005). Cyclophilin D-dependent mitochondrial permeability transition regulates some necrotic but not apoptotic cell death. Nature **434**, 652–658.

Namadina, M.M., Muktar, A.U., Karaye, S.I., Musa, F.M., Bah, I.H., Maitama, F.Y., (2021). Phytochemical constituents and antibacterial activities of indigenous chewing stick (*Anogeissus leiocarpus)* stem. Bayero Journal of Pure and Applied Sciences, **14**(1), 85-94.

Nourjah, P., Ahmad, S. R., Karwoski, C., and Willy, M. (2006). Estimates of acetaminophen (Paracetamol)-associated overdoses in the United States. Pharmacoepidemiol. Drug Saf. **15**, 398–405.

Nwachukwu, E. O., Udeh, N. E., and Udegbunam, S. O. (2015). Phytochemical composition and antimicrobial activity of Anogeissus leiocarpa (DC). Guill and Perr. (Combretaceae) leaf extract. Journal of Medicinal Plants Studies, **3**(2), 01-05.

Nwidu, L.L., (2023). Flavonoids in liver disease management. *Nigeria Journal of Science,* 120(1), 65-78.

Olabanji, S.O., Adesina, S.K., Ceccato, D., Buoso, M.C., and Moschina, G (2007). PIXE Analysis of some Medicinal plant used in cleaning Teeth in Southwestern Nigeria. *Biological Trace Element Research,* **116**:171-184

Olugbami, J. O., Gbadegesin, M. A., and Odunola, O. A. (2014). In vitro evaluation of the antioxidant potential, phenolic and flavonoid contents of the stem bark ethanol extract of Anogeissus leiocarpus. African journal of medicine and medical sciences, **43**(Suppl 1), 101.

Olugbami, J. O., Damoiseaux, R., France, B., Onibiyo, E. M., Gbadegesin, M. A., Sharma, S and Odunola, O. A. (2017). A comparative assessment of antiproliferative properties of resveratrol and ethanol leaf extract of Anogeissus leiocarpus (DC) Guill and Perr against HepG2 hepatocarcinoma cells. BMC complementary and alternative medicine, **17**(1), 1-11.

Oluwole, T. D., (2023). Lipid-modulating properties of saponins. *International Journal of Medicinal Plants Research*, **13**(5), 345-356.

Ouedraogo A, Kakai RG and Thiombiano A. (2013). Population structure of the widespread species, *Anogeissus leiocarpa* (DC.) Guilt. & Perr. across the climatic gradient in West Africa semi-arid area. South African Journal of Botany.**88**:286-295.

Ouedraogo, B., Yoda, J., Kini, F., Ouedraogo, J. C., Lompo, M., and Ouedraogo, S. (2020). Research of Bioactive Chemical Markers in Trunk Bark Extracts of *Anogeissus leiocarpa*, a Traditional Herbal Remedy for Hypertension. vol, **8**, 6-12.

Owoseni, A.A. and Ogunnusi, T. (2006). Antibacterial effects of three selected chewing sticks extracts on *Lactobacillus sp.* International Journal Tropical Medicine, **1**(3): 103-106.

Oyedemi, S. O., (2022). Polyphenols as ROS scavengers in liver protection. *Phytomedicine*, 104, 154306.

Papackova, Z., Heczkova, M., Dankova, H., Sticova, E., Lodererova, A., Bartonova, L. (2018). Silymarin prevents acetaminophen-induced hepatotoxicity in mice. PLoS One 13, e0191353.

Patrick-Iwuanyanwu K.C., Wegwu M.O., Okiyi J.K., (2010). Hepatoprotective effects of African locust beans and Negro pepper in CCl4-induced liver damage on Wistar albino rats. International Journal Pharmacology; 6(5): 744:749.

Polyak, S. J., Morishima, C., Lohmann, V., Pal, S., Lee, D. Y., Liu, Y., (2010). Identification of hepatoprotective flavonolignans from silymarin. Proc. Natl. Acad. Sci. U. S. A. **107**, 5995–5999.

Radi, R., Peluffo, G., Alvarez, M. N., Naviliat, M., and Cayota, A. (2001). Unraveling peroxynitrite formation in biological systems. Free Radic. Biol. Med. **30**, 463–488.

Rousta, A. M., Mirahmadi, S. M., Shahmohammadi, A., Mehrabi, Z., Fallah, S., Baluchnejadmojarad, T., (2022). Therapeutic potential of isorhamnetin following acetaminophen-induced hepatotoxicity through targeting NLRP3/NF-κB/Nrf2. Drug Res. (Stuttg) **72**, 245–254.

Rufai, H., Nzelibe, H.C., and Abarsh, M.M., (2021). Science World Journal Vol. 16(No 3).

Sa’id, (2020). *A Journal of Biol. GMB,* 3(3): 12-21, 54697.SS

Salih, E.Y.A., Kanninen, M., Luukkanen, O., Hiltunen, R. and Vuorela, H. (2017). Tannins, flavonoids and stilbenes in extract of African savanna woodland trees *Terminalia brownie,* *Terminalia laxiflora* and *Anogeissus leiocarpus* showing promising antibacterial potential. South African Journal of Botany, 108: 370-386.

Sgro C., Clinard F., Ouazir K., Chanay H., Allard C., Guilleminet C., et al. (2002). Incidence of drug-induced hepatic injuries: a French population-based study. Hepatol Baltim Md. **36** (2), 451–455.

Shakya, A.K., (2020). Drug-induced Hepatotoxicity and Hepatoprotective Medicinal plant. Indira Gandhi National University **54**(2):234-250.

Sharifi-Rigi, A., Heidarian, E., and Amini, S. A. (2019). Protective and anti-inflammatory effects of hydroalcoholic leaf extract of Origanum vulgare on oxidative stress, TNF-α gene expression and liver histological changes in paraquat-induced hepatotoxicity in rats. Archives Physiology Biochem. **125**, 56–63.

Shuaibu, M.N., Pandey, K., Wuyep, P.A., Yanagi, T., Hirayama, K., Ichinose, A., Tanaka, T., Kouno, I., (2008). Castalagin from *Anogeissus leiocarpus* mediates the killing of Leishmania in vitro. *Parasitology Research*. **103**(6):1333-1338.

Shuaibu, M.N. (2008a). Castalagin from *Anogeissus leiocarpus* mediates the killing of Leishmania in vitro. *Parasitology Research*. **103**(6):1333-1338.

Shutterstock (2023). Human liver anatomy structure diagram schematic raster illustration. Medical Sciena educational illustration, Stock illustration ID: 2369950541.

Sileikyte, J., Blachly-Dyson, E., Sewell, R., Carpi, A., Menabo, R., Di Lisa, F. (2014).

Regulation of the mitochondrial permeability transition pore by the outer membrane does not involve the peripheral benzodiazepine receptor (Translocator Protein of 18 kDa (TSPO)). J. Biol. Chem. **289**, 13769–13781.

Teschke, R. (2018). Liver injury by carbon tetrachloride intoxication in 16 patients treated with forced ventilation to accelerate toxin removal via the lungs: A clinical report. Toxics, **6**(2):25.

Tietz (2012). Textbook of Clinical Chemistry and Molecular Diagnostics. Burtis, C.A,. Ashwood, E.R.; 5th edition, WB Saunders Comp.

Tipple. T. E., and Rogers, L. K. (2012). Methods for the determination of plasma or tissue

glutathione levels. Methods in molecular biology (Clifton. N.J.), 889, 315- 324.

Unsal V, Cicek M, Sabancilar I. (2020). Toxicity of carbon tetrachloride, free radicals androle of antioxidants.

Wang, P., Wang, P., Liu, B., Zhao, J., Pang, Q., Agrawal, S. G., (2015). Dynamin-related protein Drp1 is required for Bax translocation to mitochondria in response to irradiation-induced apoptosis. Oncotasrget **6**, 22598–22612.

Wang, J., Luo, W., Li, B., Lv, J., Ke, X., Ge, D., (2018). *Sagittaria sagittifolia* polysaccharide protects against isoniazid- and rifampicin-induced hepatic injury via activation of nuclear factor E2-related factor 2 signaling in mice. J. Ethnopharmacol. **227**, 237–245.

Watt, A.J., Zhao, R., Li, J., Duncan S.A., (2007). Development of the mammalian liver and ventral pancreas is dependent on GATA4. *BMC Developmental Biology*. **16**(17), 688-690.

Weber, L.W., Boll, M., Stampfi, A., (2003). Hepatotoxicity and mechanism of action of haloalkanes: Carbon tetrachloride as a toxicological model. Crit Rev Toxicol.

33(2):105-36.

Win, S., Than, T. A., Min, R. W., Aghajan, M., and Kaplowitz, N. (2016). c-Jun N-terminal kinase mediates mouse liver injury through a novel SAB (SH3BP5)-dependent pathway leading to inactivation of intramitochondrial Src. Hepatology **63**, 1987–2003.

Xu, G. B., Xiao, Y. H., Zhang, Q. Y., Zhou, M., and Liao, S. G. (2018). Hepatoprotective natural triterpenoids. Eur. J. Med. Chem. **145**, 691–716.

 Yadav U., Hugo A., Boon K.E., Yadav S., and Shrestha K.K. (2010). Indigenous use and bio-efficacy of medicinal plants in the Rasuwa District, Central Nepal. Journal of Ethnobiology and Ethnomedicine 6: 3,doi:10.1186/1746-4269-6-3.

Yuan, L., and Kaplowitz, N. (2013). Mechanisms of drug-induced liver injury. Clin. Liver Dis. **17**, 507–518, vii.

Zhang. Q W. Lin, LG. and Ye, WC. (2018). Techniques for extraction and isolation of natural products: a comprehensive review. Chin Med **13**. 20

Zhu, P., Li, J., Fu, X., and Yu, Z. (2019). Schisandra fruits for the management of drug-induced liver injury in China: A review. Phytomedicine **59**, 152760.

Sumran, G., Aggarwal, A. Prospect of Indian herbs as sources of antioxidants in combating oxidative stress. Chemistry & Biology Interface 2019, 9 (1), 1-20.

Ouattara AL, Abou O, Tano DK, Koffi AJ. Phenolic Compound Content and Antioxidant Activity of Extracts from the Leaves of Anogeissus leiocarpus (Combretaceae), a Plant Used in the North of Côte d’Ivoire for the Traditional Treatment of Gastrointestinal Disorders in Broiler Chickens. Int. J. Biochem. Res. Rev. [Internet]. 2024 Mar. 30 [cited 2025 Mar. 7];33(4):52-61. Available from: https://journalijbcrr.com/index.php/IJBCRR/article/view/869