Original Article

Hepatoprotective and antioxidant activities of *Spondias mombin* leaf and stem extracts against carbon tetrachloride-induced hepatotoxicity

Lucky L. Nwidu, PhD, Ekramy Elmorsy, PhD, Yibala I. Oboma, MSc and Wayne G. Carter, PhD

Departments of Experimental Pharmacology and Toxicology, Faculty of Pharmaceutical Sciences, University of Port Harcourt, Choba, East West Road, Rivers State, Nigeria

Department of Forensic Medicine and Clinical Toxicology, Faculty of Medicine, Mansoura University, Egypt

Department of Medical Laboratory Science, Faculty of Basic Medical Sciences, College of Health Sciences, Wilberforce Island, Bayelsa State, Nigeria

School of Medicine, University of Nottingham, Royal Derby Hospital Centre, Derby, UK

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Objective: *Spondias mombin* L. is a tree used in folk medicine in Nigeria for the treatment of hepatitis. This study was carried out to comparatively evaluate the hepatoprotective and antioxidant effects of *S. mombin* leaf and stem (SML and SMS) methanolic extracts in a rat model of carbon tetrachloride (CCl4)-induced hepatotoxicity.

Methods: Forty-two rats were distributed into seven groups. Groups A and B received water; groups C and D received 500 and 1000 mg/kg SML extract, respectively; groups E and F received 500 and 1000 mg/kg SMS extract, respectively; and group G received 100 mg/kg silymarin. Water, the two extracts, and silymarin were administered daily by oral gavage for 7 days. Hepatotoxicity was induced in groups B to G by the administration of CCl4 once on the seventh day. After 48 h, rats were sacrificed, and tissues and serum samples were examined for histological and biochemical indices of hepatotoxicity.
Results: Administration of CCl₄ resulted in liver injury with significant elevation in the hepatocellular injury markers alanine aminotransferase (ALT), aspartate aminotransferase (AST), alkaline phosphatase (ALP), total bilirubin (TBIL), and conjugated bilirubin (CBIL), associated with a significant reduction in total circulatory protein. Pretreatment with SML and SMS extracts at both doses significantly ameliorated liver injury; lowered ALT, AST, ALP, TBIL, and CBIL levels; elevated cellular glutathione levels as well as catalase and superoxide dismutase activities; and decreased the levels of thiobarbituric acid reactive substances.

Conclusion: This study provides preliminary evidence supporting the potential therapeutic benefit of S. mombin in xenobiotic-induced hepatotoxicity.

Keywords: Hepatoprotection; Hepatotoxicity; Oxidative stress; Spondias mombin L.

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Introduction

Liver diseases are major causes of illness and death worldwide, and constitute a public health challenge that requires the development of new therapeutic options. Investigating the hepatoprotective effects of medicinal plants in laboratory animals is an important initial step in evaluating the safety of the development of new therapeutic options. Investigating the hepatoprotective effects of local phytoextracts rich in natural antioxidants has provided safe and effective alternatives for the treatment of hepatotoxicity. Many previous reports have demonstrated the hepatoprotective effects of local phytoextracts rich in natural antioxidants and several bioactive compounds and plant extracts have been investigated for their hepatoprotective and antioxidant effects.

Phenolic compounds found in several plants are usually associated with multiple biological activities such as free radical scavenging activities. It has been suggested that natural antioxidants found in food, such as phenolic compounds or flavonoids, might play an important role in the prevention of oxidative stress-related disorders and in the reduction of premature mortality. Flavonoids are certainly ubiquitous in the epidermal cells of many plant parts and exist in both glycoside and non-glycoside forms. Spondias mombin L. (Anacardiaceae) is commonly known as hog plum (English), akika (Yoruba), ijikka (Igbo), tsadarmaser (Hausa), chabubu (Fulani), nsukakara (Efik), and atoa (Ashanti). It is a deciduous erect tree, which grows up to 15−20 m high, with a trunk that is 60−75 cm wide. S. mombin is commonly found in the tropical Americas, including the West Indies, and has also been naturalized in parts of Africa, including Ghana, and some parts of Asia. In ethnomedicine, S. mombin parts, including the stem bark, leaves, and roots, have been used for the treatment of various conditions. S. mombin possesses antimicrobial and antiviral activities. Its leaves show anti-inflammatory, anthelmintic, hematinic, and sedative activities, while its stem bark possesses anti-mycobacterial activity. In a previous study, phytochemical screening indicated that S. mombin leaf (SML) contains tannins, saponins, alkaloids, flavonoids, and phenols. It is also rich in ascorbic acid and niacin, and contains riboflavin and thiamine.

The hepatoprotective effects of Ocimum gratissimum and SML have been previously evaluated in rats after intoxication with dimethylnitrosamine. However, the effects of SML and S. mombin stem (SMS) on carbon tetrachloride (CCl₄)-induced hepatotoxicity have not yet been assessed. Thus, the aim of this study was to establish whether SML and SMS methanolic extracts show hepatoprotective effects against CCl₄-induced hepatotoxicity in rats.

Materials and Methods

Chemicals and reagents

CCl₄, silymarin, diethyl ether, and methanol were purchased from Sigma–Aldrich, St. Louis, Missouri, USA. Diagnostic kits for serum alanine aminotransferase (ALT), aspartate aminotransferase (AST), alkaline phosphatase (ALP), conjugated bilirubin (CBIL), and total bilirubin (TBIL) were purchased from Randox Laboratories Ltd., London, UK. All other chemicals and solvents were of the highest commercially available grade (analytical grade) and were obtained either from Sigma–Aldrich or Merck, UK.

Plant collection and validation

Fresh leaves and stems of S. mombin L. were collected from Obafemi Awolowo University campus in January 2015. The plant was identified and authenticated by Dr. Oladele Adewunmi, a Taxonomist at the Forestry Department, University of Port Harcourt, Nigeria, where specimens of SML (2015) and SMS (2016) were deposited.

Preparation of S. mombin leaf and stem methanolic extracts

Three hundred grams of S. mombin L. fresh leaves and stem barks were weighed, air dried, and powdered. Then, powdered leaves and stems were extracted by the cold extraction method (maceration) using methanol as a solvent; SML and SMS powders were soaked in one liter of 50% methanol for 3 days, during which the mixture was shaken twice daily to promote extraction. The solvent was filtered over a layer of gauge and the filtrate was evaporated to dryness in vacuo. The obtained yields were 7.1% and 3.1% for SML and SMS, respectively. The extracts were stored in a refrigerator for up to 4 weeks for subsequent use in assays.

Phytochemical screening

The methanolic extracts of SML and SMS were quantitatively assayed for the presence of phytochemicals such as saponins, tannins, alkaloids, terpenoids, cardiac glycosides, and flavonoids using standard procedures.
Experimental animals

Forty two healthy Wistar rats of both sexes (21 male rats and 21 female rats) weighing 320–355 g were purchased from the animal house of the Pharmacology Department, Faculty of Pharmacy, Niger Delta University, Bayelsa State, Nigeria. Animals were acclimatized for one week prior to experimentation. All animals were fed a standard chow diet and were given access to water ad libitum. Experimental techniques and protocols used in this study follow the “Guide to the Care and Use of Animals in Research and Teaching” as adopted and approved by Niger Delta University Institutional Animal Care and Use Committee on 20/02/2015 with an approval number NDU/2014/007.

Acute toxicity study

An acute toxicity study was carried out to determine the approximate median lethal doses of SML and SMS extracts in Albino mice (25–30 g) of both sexes. Mice were distributed into eight groups, three mice per group, and were administered single doses of SML and SMS extracts (100, 500, 1000, 2000, 3000, 4000, and 5000 mg/kg) intraperitoneally. Treated animals were monitored for 24 h for mortality and behavioral changes consistent with toxicity.

Experimental design

A total of 42 rats were weighed and distributed into seven groups, six rats per group (three males and three females). In groups A (negative control) and B (positive control), rats received 0.2 mL/kg distilled water. In groups C and D, rats received 500 and 1000 mg/kg SML extract, respectively, dissolved in distilled water. In groups E and F, rats received 500 and 1000 mg/kg SMS extract, respectively, dissolved in distilled water. In group G, rats received 100 mg/kg silymarin suspended in distilled water. Distilled water, SML and SMS extracts, and silymarin were administered daily by oral gavage for 7 days. On the seventh day, 1 h after administration, all groups except group A received a gavage for 7 days. On the seventh day, 1 h after administration. The hemoglobin concentration, packed cell volume, red blood cell count, mean corpuscular hemoglobin, mean corpuscular hemoglobin concentration, mean corpuscular volume, white blood cell count, and platelet count were measured and recorded daily throughout the 7 days of the experiment.

Forty eight hours after CCl4 administration, rats were anesthetized using diethyl ether and then sacrificed. Blood was collected by cardiac puncture into an EDTA vacutainer for determination of hematological parameters using the Automated Hematology Analyzer KK-21 (SYSMEX Corporation, Japan). The hemoglobin concentration, packed cell volume, red blood cell count, mean corpuscular hemoglobin, mean corpuscular hemoglobin concentration, mean corpuscular volume, white blood cell count, and platelet count were determined. For biochemical assessment, blood samples were centrifuged at 3000 rpm for 10 min at 4 °C, and serum was separated into vacutainer vials and stored at −80 °C for subsequent analysis. Livers were immediately collected, perfused with ice cold normal saline (0.9% sodium chloride), and transported on dry ice from the Pharmacology laboratory, Faculty of Pharmacy, Niger Delta University, Nigeria, to the School of Medicine, University of Nottingham, Royal Derby Hospital Centre, Derby, UK, where they were stored at −80 °C for subsequent use in further analyses.

Assessment of biochemical parameters

Serum levels of ALT, AST, ALP, CBIL, TBIL, and total protein (TP) were assessed using Randox diagnostic kits. These analyses were performed at the Department of Chemical Pathology, Niger Delta University Teaching Hospital, Okolobiri, Bayelsa state, Nigeria.

Measurement of oxidative stress markers

Liver sections (100 mg) were dried and homogenized in 100 mL of 5 mM Tris/HCl buffer (pH 7.4), 1 mM EDTA, and complete, Mini, EDTA-free Protease Inhibitor Cocktail tablet (Roche). Homogenates were then centrifuged at 10,000 rpm for 10 min at 4 °C and the clear supernatant was collected for the estimation of reduced glutathione (GSH), superoxide dismutase (SOD), catalase (CAT), and thiobarbituric acid reactive substances (TBARS). Assessment of GSH was carried out based on the method published by Ellman et al. with slight modifications as follows: the homogenate (0.2 mL) was mixed with 25% trichloroacetic acid and centrifuged at 3000 rpm for 10 min, then the supernatant (~0.2 mL) was mixed with 10 mM DTNB in the presence of phosphate buffer (0.1 M, pH 7.4), and the absorbance was read at 420 nm. Determination of CAT was performed based on the method described by Aebi, which relies upon the ultraviolet absorption of hydrogen peroxide that can be measured at 240 nm in the presence of 50 mM phosphate buffer. Hydrogen peroxide decomposition was monitored in a 96 well quartz plate using a Spectramax microplate reader (ThermoFisher, Stafford, UK). Catalase activity was expressed as units/mg protein. Liver cytosolic SOD activity was measured according to the method described by Kakkar et al. Finally, extent of lipid peroxidation was determined spectrophotometrically by measuring malondialdehyde levels, as described by Draper and Hadley.

Histopathological investigation

Liver specimens from each rat were cut into pieces (approximately 6 mm3 in size), fixed in phosphate buffered 10% formaldehyde, and embedded in paraffin wax. Then, 5-μm-thick sections were cut, fixed onto glass slides, and stained with hematoxylin and eosin (H&E). Slides were examined under a high-resolution microscope (Olympus BX60MF, Japan), and photomicrographs were taken at a magnification of ×400.

Statistical analysis

All statistical analyses were performed using Prism 5 (GraphPad Software Inc., San Diego, California, USA). Unless otherwise specified, results were expressed as mean ± standard error of mean (SEM). One-way analysis of variance (ANOVA) was used to compare group data, followed by Tukey’s multiple comparisons test. A p value < 0.05 was considered statistically significant.
Results

Phytochemical constituents in SML and SMS

Preliminary phytochemical screening of SML and SMS extracts revealed the presence of alkaloids, reducing sugars, saponins, and tannins [Table 1]. The SMS extract was found to contain more saponins and tannins than the SML extract. However, regarding other qualitative assays, both extracts were similar.

Acute toxicity study of SML and SMS in mice

Treated mice were monitored for mortality and no signs of toxicity were observed up to 24 h after extract administration of single dose (intraperitoneally) of either SML or SMS extracts (100–5000 mg/kg). Consequently, we chose two doses, 1/10 and 1/5 of the maximal dose examined (5000 mg/kg), i.e., 500 and 1000 mg/kg, for both extracts as the experimental doses.

Body weight changes throughout the study period

The effect of CCl4 administration as well as pretreatment with SML and SMS extracts on the body weights of rats throughout the course of the experimental study is presented in Figure 1.

Significant changes in the body weights of the rats were observed in each group throughout the time course of the experiment (two-way ANOVA, p < 0.0001). However, when investigating the effects of the treatments, no significant differences were found between body weight changes in the treated groups and the CCl4-induced group (p = 0.506). Pretreatments with 500 and 1000 mg/kg SMS extract were associated with 3.5% and 4.3% increase in body weights, respectively.

Effect of SML and SMS on biochemical and histological markers of hepatotoxicity

To assess the hepatoprotective effects of SML (500, 1000 mg/kg) and SMS (500, 1000 mg/kg) extracts in CCl4-induced hepatotoxicity, serum ALT, AST, ALP, TP, CBIL, and TBIL levels were assessed [Table 3]. Administration of CCl4 resulted in hepatocellular toxicity demonstrated by a significant (p < 0.001–0.05) elevation in serum ALT (102%), AST (58%), ALP (27%), and TBIL (62%) levels, and a significant (p < 0.001) decrease in TP (54%), compared to the negative control group.

Pretreatment with 500 and 1000 mg/kg SML extract decreased serum levels of ALT by 7% and 46%; AST by 54% and 91%; ALP by 33% and 31%; TP by 97% and 116%; CBIL by 75% and 88%; and TBIL by 62% and 41%, respectively, compared to the positive control (CCl4-induced) group. Regarding SMS extract, pretreatment with 500 and 1000 mg/kg lowered serum levels of ALT by 4% and 37%; AST by 47% and 83%; ALP by 27% and 23%; TP by 111% and 119%; CBIL by 8% and 31%; and TBIL by 59% and 55%, respectively, compared to the positive control group. Moreover, pretreatment with SML and SMS extracts counteracted the CCl4-induced decrease in TP; pretreatment with 500 and 1000 mg/kg SML extract significantly (p < 0.001) increased serum TP levels by 97% and 116%, respectively, while 500 and 1000 mg/kg SMS extract significantly (p < 0.001) increased serum TP levels by 111% and 119%, respectively, compared to the positive control group. The standard antioxidant silymarin (100 mg/kg) significantly (p < 0.001) increased the serum level of TP by 116% and significantly (p < 0.05–0.001) decreased serum levels of ALT, AST, ALP, CBIL, and TBIL (p < 0.05) by 22%, 90%, 22%, 31%, and 36%, respectively, compared to the CCl4-induced group.

The effects of pretreatment with SML and SMS extracts (500 and 1000 mg/kg) and silymarin (100 mg/kg) on liver histology of CCl4-induced rats are presented in Figure 2.

Effect of SML and SMS on Haematological indices

Extracts at either 500 or 1000 mg/kg did not have any significant effect on the haematological indices evaluated, except SMS at 500 mg/kg which induced a significant (p < 0.05) change in PCV when compared to the CCl4 intoxicated group (Table 2).

Effect of SML and SMS on oxidative stress markers

Glutathione levels decreased by 48%, CAT and SOD activities decreased by 59% and 30%, respectively, and TBARS levels increased by 67% following intoxication with CCl4 (Figure 3). In contrast, pretreatment with SML and SMS extracts (1000 mg/kg) significantly increased GSH levels by 42% (p < 0.05) and 50% (p < 0.01), respectively, while pretreatment with silymarin (100 mg/kg) significantly (p < 0.001) increased GSH levels by 74%. Similarly, both CAT and SOD enzyme activities were significantly

| Phytochemicals          | Observations                          | Extract       |
|-------------------------|---------------------------------------|---------------|
|                         |                                       | SML Extract   | SMS Extract  |
| Reducing sugars         | Reddish brown precipitate upon heating| +             | +            |
| Cardiac glycosides      | Brick red precipitate                  | +             | +            |
| Saponins                | Persistent froth unbroke upon standing| + +           | + + +        |
| Tannins                 | Blue black precipitate                 | + + +         | + + +        |
| Flavonoid               | Resultant solution turns yellow        | + + +         | + + +        |

(+) to (+++) = detected in moderate to abundant quantities.
Table 2: Effect of Spondias mombin leaf and stem extracts on hematological parameters.

| Parameters | Group A | Group B | Group C | Group D | Group E | Group F | Group G |
|-----------|---------|---------|---------|---------|---------|---------|---------|
| PCV (%)   | 42 ± 3.2| 49 ± 7.9| 44 ± 3.5| 42 ± 3.9| 40 ± 6.2\* | 44 ± 6.5| 49 ± 3.1|
| Hb (g/dl) | 12 ± 0.6| 14 ± 2.1| 13 ± 1.8| 11 ± 0.7| 12 ± 0.8| 13 ± 2.3| 13 ± 0.6|
| WBC (×10^3 cells/μL) | 13 ± 4.9| 7 ± 4.2| 9 ± 0.4| 11 ± 7.7| 11 ± 4.2| 8 ± 2.3| 13 ± 4.5|
| PLT (×10^3 cells/μL) | 468 ± 280| 459 ± 366| 761 ± 1.4| 284 ± 316| 500 ± 288| 446 ± 306| 642 ± 322|
| RBC (×10^6 cells/μL) | 7 ± 1.3| 7 ± 1.2| 6 ± 0.0| 6 ± 1.1| 7 ± 0.8| 7 ± 0.9| 8 ± 0.3|
| MCV (%)   | 63 ± 2.5| 65 ± 2.0| 65 ± 7.1| 66 ± 4.4| 62 ± 2.6| 63 ± 0.8| 65 ± 4.2|
| MCH (pg)  | 17 ± 2.0| 18 ± 0.3| 18 ± 1.7| 18 ± 0.5| 17 ± 0.7| 19 ± 1.4| 18 ± 1.2|
| MCHC (g/dl)| 27 ± 2.7| 28 ± 0.5| 28 ± 0.4| 27 ± 2.1| 26 ± 2.1| 30 ± 2.5| 27 ± 2.1|
| NEU (%)   | 32 ± 8.2| 44 ± 13| 37 ± 7.1| 40 ± 14| 52 ± 13| 39 ± 7.2| 38 ± 5.4|
| LYM (%)   | 63 ± 8.0| 44 ± 13| 57 ± 9.9| 51 ± 15| 42 ± 14| 54 ± 9.3| 54 ± 7.3|
| MEB (%)   | 6 ± 2.4| 10 ± 4.1| 6 ± 2.1| 9 ± 2.1| 6 ± 3.5| 8 ± 3.1| 7 ± 4.3|

Data are presented as mean ± SEM, n = 6. Statistical analysis was performed using one-way ANOVA. Group A received 0.2 mL/kg distilled water; group B was administered 1 mL/kg CCl4; groups C and D were pretreated with 500 and 1000 mg/kg SML extract, respectively, and were administered 1 mL/kg CCl4; group G was pretreated with 100 mg/kg silymarin and was administered 1 mL/kg CCl4. The asterisk (*), p < 0.05 is significantly different from Group B (positive control). Statistical analysis was performed using one way ANOVA.

Abbreviations: PCV: packed cell volume; Hb: hemoglobin concentration; WBC: white blood cell count; PLT: platelet count; RBC: red blood cell count; MCV: mean corpuscular volume; MCH: mean corpuscular hemoglobin; MCHC: mean corpuscular hemoglobin concentration; NEU: neutrophil count; LYM: lymphocyte count; MXD: mixture (monocytes, basophils, and eosinophils) count.

Figure 1: The effect of CCl4 intoxication and pretreatment with Spondias mombin leaf and stem extracts on body weights of the experimental rats throughout the course of the experiment. Data are presented as mean ± SD. a, b, c; significant difference from body weight on day 0, p < 0.05, p < 0.01, p < 0.001, respectively.

Table 3: Effect of the different treatments on biochemical markers of hepatotoxicity.

| Treatment | Dosing Regimen | ALT (U/L) | AST (U/L) | ALP (U/L) | TP (g/dl) | CBIL (μmol/L) | TBLI (μmol/L) |
|-----------|----------------|-----------|-----------|-----------|-----------|---------------|---------------|
| Control (water) | 0.0 | 115.8 ± 1.2 | 212.6 ± 3.1 | 62.0 ± 2.1 | 85.2 ± 1.9 | 1.1 ± 0.04 | 3.4 ± 0.2 |
| CCl4 | 1 ml/kg CCl4 | 233.5 ± 2.3\* | 336 ± 25.8\* | 79.0 ± 4.0\* | 38.8 ± 1.1\* | 1.6 ± 0.1\b | 8.5 ± 0.3\a |
| SML | 500 mg/kg | 216 ± 2.6 | 154.7 ± 2.7\* | 52.8 ± 1.1\* | 76.3 ± 3.7\* | 0.4 ± 0.17c | 3.2 ± 0.9\* |
| 1000 mg/kg | 126.7 ± 16.9\* | 31.3 ± 1.5\* | 54.3 ± 1.8\* | 84.0 ± 1.7\* | 0.2 ± 0.03b | 5.0 ± 0.6\a |
| SMS | 500 mg/kg | 220.3 ± 5.2 | 177.3 ± 4.7\* | 57.3 ± 1.2 | 82.0 ± 0.6\* | 0.2 ± 0.1c | 3.5 ± 0.9\* |
| 1000 mg/kg | 147.3 ± 9.4\* | 55.8 ± 3.3 | 60.8 ± 0.9b | 84.8 ± 0.9c | 1.1 ± 0.1b | 3.8 ± 0.3b |
| Silymarin | 100 mg/kg | 182.4 ± 21.9 | 34.4 ± 1.4c | 61.6 ± 4.7b | 84.0 ± 1.1c | 1.1 ± 0.1b | 5.4 ± 0.9a |

Values are represented as mean ± SEM, n = 6. Statistical analysis was performed using one-way ANOVA. Results of the CCl4-induced group are compared to those of the negative control group (receiving water only), and results of the SML, SMS, and silymarin-treated groups are compared to those of the positive control (CCl4-induced) group. * p < 0.05; b p < 0.01; * p < 0.001. ALT: alanine aminotransferase; AST: aspartate aminotransferase; ALP: alkalinephosphatase; TP: total protein; CBIL: conjugated bilirubin; TBLI: total bilirubin.
(p < 0.05) increased by 28% and 18%, respectively, by pretreatment with SML extract (1000 mg/kg), and were significantly (p < 0.05) increased by 41% and 20%, respectively, by pretreatment with SMS extract (1000 mg/kg).

Discussion

Hepatotoxicity of different types and origins constitutes a major public health concern. Oxidative stress is implicated in...
the pathogenesis of liver diseases. Accordingly, since natural antioxidants in plants and plant extracts could ameliorate free radical-induced oxidative stress, they could be beneficial in the treatment of liver diseases. In this study, the effects of SML and SMS extracts on the body weights of rats, their hematological indices, hepatic enzymes, and the hepatic antioxidant system were examined to reveal whether bio-molecules present in these plants could offer hepato-protection against CCl4-induced cellular insult.

It is important to investigate drug-induced body weight changes as they may provide an important indicator of drug effects. Previously, an increase in the body weights of laboratory animals was demonstrated following a sub-acute toxicity study of Enantia chlorantha aqueous extract.44 In contrast, a decrease in the body weights of experimental rats after the administration of the ethanolic extract of E. chlorantha stem bark has also been reported.45 Previous studies have used body weight changes for assessment of responses to S. mombin drug therapy.33 Our results showed a dose-dependent but non-significant increase in the body weights of rats treated with SMS extract, and this is in agreement with previous reports demonstrating S. mombin-induced weight loss and appetite suppression.33

Neither the toxicant (CCl4) nor the assessed hepatoprotective agents (SML and SMS extracts and silymarin) induced significant changes in hematological parameters. This indicates the absence of acute adverse effects on hematopoiesis. Low platelet counts have been associated with severe cases of liver cirrhosis.46 However, platelet upregulation was observed only with the lower dose of SML, and was non-significant.

The effects of SML and SMS methanolic extracts on hepatic lipid accumulation in fatty liver diseases and on resolution of acute intoxication were examined by histopathological investigation of liver tissue specimens. CCl4 administration resulted in damage to the normal histological architecture of hepatocytes as demonstrated by necrosis and membrane lipid peroxidation, which are common histopathological findings with CCl4-induced liver damage.47,48 Rats pretreated with SML and SMS for 7 days before challenging with CCl4 demonstrated partial resolution of CCl4-induced alterations in the molecular architecture of hepatocytes.

Moreover, CCl4 administration resulted in hepatotoxicity with significantly elevated serum levels of AST, ALT, ALP, CBIL, and TBIL. Elevation in serum aminotransferases is a well-known indicator of liver injury. Previous studies have also shown that hepatic damage caused by CCl4 administration is associated with an increase in the activities of both serum aminotransferases and ALP.49 Both plant extracts at both doses were effective at significantly lowering CBIL, TBIL, and ALP levels compared to the positive control. However, the effect of the SML extract was stronger than that of the

Figure 3: The effect of CCl4 intoxication and pretreatment with Spondias mombin leaf and stem extracts on oxidative stress markers. Levels of GSH, CAT, SOD, and TBARS were measured in homogenized liver samples. Results of the positive control (CCl4-intoxicated) group are compared to those of the negative control group (receiving water only), and results of the SML, SMS, and silymarin-treated groups are compared to those of the positive control group. *p < 0.05; **p < 0.01; ***p < 0.001. GSH: reduced glutathione; CAT: catalase; SOD: superoxide dismutase; TBARS: thiobarbituric acid reactive substances.
Administration of CCl4 resulted in a five-fold decrease in oxidative stress within a milieu deficient in antioxidants. The higher dose (1000 mg/kg) of both extracts was more effective at lowering serum ALT and AST levels than the lower dose (500 mg/kg), with SMS extract being more effective than SML extract. In addition, CCl4 administration resulted in significant reduction in TP levels. However, pretreatment with SML and SMS extracts significantly normalized TP levels compared to CCl4-induced hepatotoxicity. These results provide the premise that requires further investigation of the promising therapeutic potential of 

The protective effects of plant extracts against CCl4-induced hepatotoxicity has been attributed to the presence of endogenous phytochemicals such as flavonoids, tannins, triterpenoids, and alkaloids. Flavonoids represent the most common and extensively distributed group of plant polyphenols, and serve as free radical scavengers and strong antioxidants such as vitamins C and E, antioxidants such as GSH, and redox regulatory enzymes such as CAT, SOD, and glutathione peroxidase. These functional and morphological changes in the cellular membrane and death of hepatocytes all result in leakage of hepatic enzymes. The oxidation of fatty acids by CCl4 liberates lipid peroxides, which are free radicals that further exacerbate the state of oxidative stress within a milieu deficient in antioxidants.

The mechanisms of defense against free radicals include mobilization of radical scavengers and chain terminators such as vitamins C and E, antioxidants such as GSH, and redox regulatory enzymes such as CAT, SOD, and glutathione peroxidase. Tannins, saponins, alkaloids, flavonoids, phenols, and ascorbic acid, which were reported to be abundant in SML extracts, might play an important role in its antioxidant effect. Hence, we evaluated the effects of SML and SMS extracts on GSH levels, CAT and SOD activities, and TBARS levels. Our results demonstrated that SML and SMS extracts significantly reversed the CCl4-induced marked elevation in TBARS levels. Different experimental models inducing hepatic fatty infiltration have reported depletion in liver GSH stores, and investigated the pathophysiological consequences of GSH depletion in relation to free radical generation. Serum GSH is a sensitive biomarker of the antioxidant status, playing a pivotal defensive role against oxidative insults as an endogenous scavenger of free radicals. Administration of CCl4 resulted in a five-fold decrease in GSH levels, compared to negative control rats. However, this effect was significantly counteracted in a dose-dependent manner by pretreatment with SML and SMS extracts. This implies that SML and SMS extracts could enhance the antioxidant capacity by elevating GSH concentrations, thereby ameliorating oxidative stress-induced damage, and this reflects the presence of free radical scavengers in S. mombin. Certainly, the liver is reported to maintain GSH even when experiencing elevated lipid peroxidation through supportive and compensatory mechanisms.

The role of SOD as an antioxidant is to convert superoxide to hydrogen peroxide, thereby protecting against the pervasive harmful effects of superoxide. The ability of SML and SMS extracts to elevate SOD activity, which had been decreased by CCl4 intoxication, might be partly responsible for their hepatoprotective effects. Similarly, pretreatment with SML and SMS extracts induced an elevation in CAT activity, which is a hydrogen peroxide scavenger. Collectively, we hypothesize that the elevation of SOD and CAT activities, as well as GSH levels in S. mombin-treated groups will augment the endogenous antioxidant system.

The restorative effects of silymarin on liver cytoarchitecture after CCl4 treatment may leave the liver with scar tissue due to extensive fibrosis. However, this was not observed in rats treated with SMS extract (1000 mg/kg). Hence, cellular regeneration associated with S. mombin treatment might have been mediated by activation of liver stem cells. Moreover, the amelioration of CCl4-induced damage by SML and SMS pretreatment might be attributed to membrane stabilization, which prevents the leakage of cellular contents, as suggested by previous studies investigating the hepatoprotective properties of Vernonia amygdalina, Rumex crispus, Chrysophyllum albium, Ocimum gratissimum, and S. mombin. The protective effects of plant extracts against CCl4-induced hepatotoxicity has been attributed to the presence of endogenous phytochemicals such as flavonoids, tannins, triterpenoids, and alkaloids. Flavonoids represent the most common and extensively distributed group of plant polyphenols, and serve as free radical scavengers and strong antioxidants that could protect against oxidative stress-induced cellular damage. Flavonoids and saponins were reported to be present in S. mombin leaves. Antioxidant chemicals in S. mombin, particularly polyphenols, could contribute to its antioxidant and hepatoprotective activities. However, further research is required to isolate the bioactive compounds found in SML and SMS extracts and characterize the biochemical mechanisms responsible for their antioxidant and hepatoprotective activities. This work is being implemented in our laboratory and may well lead to the identification of one or more substances of potential clinical benefit in treatment of liver diseases.

**Conclusion**

In this study, both SML and SMS extracts were found to exhibit hepatoprotective effects by stabilizing hepatocyte cell membranes, promoting repair of injured hepatic tissues, enhancing free radical scavenging effects, and augmenting endogenous antioxidant systems, thereby limiting oxidative insults. These results provide the premise that requires further investigation of the promising therapeutic potential of S. mombin in liver damage and oxidative stress-induced diseases.

**Authors’ contributions**

Conception and design, collection and assembly of data, drafting of the article and final approval of the article, administrative, technical and logistic support: LLN. Analysis and interpretation of data, statistical expertise: EE. Critical revision of the article for the important intellectual content, provision of study materials and obtaining of funding: WGC. All authors have critically reviewed and approved the final draft and are responsible for the content and similarity index of the manuscript.

**Conflict of interest**

The authors have no conflict of interest to declare.
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