

ETHNOPHARMACOLOGICAL EVALUATION OF COMBINED *PORTULACA OLERACEA* L. AND *PTEROCARPUS SANTALINOIDES* ETHANOL LEAF-EXTRACT FOR THE AMELIORATION OF OXIDATIVE STRESS AND DYSLIPIDEMIA IN STZ-INDUCED DIABETIC RATS

Victor Nwankwo Ugadu^{1*}

¹Department of Biotechnology, Ebonyi State University, Abakaliki, Ebonyi State, Nigeria

*Corresponding author: chekwas010@gmail.com

Abstract—*Portulaca oleracea* L. and *Pterocarpus santalinoides* are traditionally used to manage diabetes and oxidative stress-related disorders, although evidence supporting their combined efficacy remains limited. This study evaluated the antioxidant and hypolipidaemic effects of their combined ethanolic leaf extracts in streptozotocin-induced diabetic rats. Thirty-six male albino rats were randomized into six groups (n = 6). Diabetes was induced intraperitoneally with streptozotocin (55 mg/kg). Diabetic rats received combined extracts orally at 200, 400, 600 or 800 mg/kg for 21 days, while controls received distilled water. Serum malondialdehyde (MDA), superoxide dismutase (SOD), high-density lipoprotein (HDL) and low-density lipoprotein (LDL) were assessed. Diabetes increased MDA from 7.84 ± 1.28 to 46.53 ± 3.12 nmol/g protein and LDL from 48.92 ± 3.48 to 127.74 ± 6.21 mg/dL, while reducing SOD from 50.65 ± 3.28 to 15.23 ± 1.76 U/mg protein and HDL from 47.86 ± 2.95 to 19.33 ± 1.88 mg/dL. Treatment at 600 mg/kg reduced MDA to 34.75 ± 2.46 and LDL to 56.61 ± 3.12 , while increasing SOD to 45.19 ± 3.01 and HDL to 39.21 ± 2.70 . The lowest MDA occurred at 200 mg/kg, whereas 800 mg/kg produced the highest SOD and lowest LDL among treated groups. Combined extracts demonstrated antioxidant and lipid-modulating potential, warranting further mechanistic and toxicological investigations.

Index Terms—*Portulaca oleracea*, *Pterocarpus santalinoides*, diabetes mellitus, streptozotocin, dyslipidaemia, medicinal plants, antioxidant

I. INTRODUCTION

Diabetes mellitus (DM) is a chronic metabolic disorder characterized by persistent hyperglycaemia resulting from impaired insulin secretion, insulin action, or both. The global burden of diabetes continues to increase and remains a major public health concern because of its association with cardiovascular disease, nephropathy, neuropathy, retinopathy, and premature mortality. Persistent hyperglycaemia disrupts carbohydrate, lipid, and protein metabolism and contributes to progressive tissue damage through oxidative stress, inflammation, and endothelial dysfunction [1], [2].

Oxidative stress plays a pivotal role in the pathogenesis of diabetes and its chronic complications. Chronic hyperglycaemia enhances the generation of reactive oxygen species (ROS) through glucose autooxidation, mitochondrial dysfunction, activation of the polyol pathway, and formation of advanced glycation end products, leading to lipid peroxidation, protein oxidation, DNA damage, and β -cell dysfunction [1]. Biomarkers such as malondialdehyde (MDA), an end-product of lipid peroxidation, and superoxide dismutase (SOD), a major endogenous antioxidant enzyme, are widely used to evaluate oxidative damage and antioxidant defence in experimental diabetes. Elevated MDA concentrations together with reduced SOD activity are consistently associated with diabetic oxidative injury.

Diabetes mellitus is also associated with profound disturbances in lipid metabolism, commonly manifested by

elevated low-density lipoprotein cholesterol (LDL-C), reduced high-density lipoprotein cholesterol (HDL-C), hypertriglyceridaemia, and increased cardiovascular risk. These metabolic abnormalities contribute significantly to atherosclerosis and represent major therapeutic targets in diabetes management. Consequently, interventions capable of simultaneously reducing oxidative stress and improving lipid homeostasis may provide broader protection against diabetic complications than glycaemic control alone.

Medicinal plants continue to play an important role in the management of diabetes, particularly in Africa and Asia, where traditional herbal medicine remains an integral component of primary healthcare. Increasing scientific attention has focused on validating the ethnopharmacological uses of medicinal plants because many are rich sources of flavonoids, alkaloids, phenolic acids, terpenoids, polysaccharides, and other bioactive compounds with antioxidant, anti-inflammatory, antihyperglycaemic, and hypolipidaemic properties [3].

Portulaca oleracea L. (Portulacaceae), commonly known as purslane, is an edible medicinal plant widely distributed throughout tropical and temperate regions. It has traditionally been used for the treatment of diabetes, gastrointestinal disorders, inflammatory diseases, skin infections, and cardiovascular conditions. Phytochemical studies have demonstrated that the plant contains flavonoids, alkaloids, omega-3 fatty acids, polysaccharides, phenolic compounds, vitamins, and minerals that contribute to its broad pharmacological activities [3]. Recent systematic reviews further indicate that *P. oleracea* enhances

endogenous antioxidant enzymes, including SOD, catalase, glutathione peroxidase, and glutathione, while reducing oxidative stress markers such as MDA and reactive oxygen species in experimental diabetes.

Pterocarpus santalinoides L'Hér. ex DC. is a medicinal plant widely used in West African ethnomedicine for the management of diabetes, gastrointestinal disorders, inflammatory diseases, and microbial infections. The leaves contain flavonoids, tannins, saponins, terpenoids, and other phenolic constituents that have been associated with antioxidant and metabolic regulatory activities. However, compared with *P. oleracea*, experimental evidence supporting its pharmacological mechanisms remains limited, particularly regarding its combined use with other medicinal plants. This represents an important gap in ethnopharmacological research.

Although both plant species have demonstrated promising pharmacological activities individually, little is known about the therapeutic potential of their combined administration against oxidative stress and dyslipidaemia in experimental diabetes. The combination of medicinal plants possessing complementary phytochemical profiles may enhance antioxidant defence and improve lipid metabolism through additive or complementary biological actions. Therefore, the present study evaluated the ethnopharmacological efficacy of combined *Portulaca oleracea* L. and *Pterocarpus santalinoides* L. leaf extracts in ameliorating oxidative stress and dyslipidaemia in streptozotocin-induced diabetic rats by assessing serum malondialdehyde (MDA), superoxide dismutase (SOD), high-density lipoprotein (HDL), and low-density lipoprotein (LDL).

II. MATERIALS AND METHODS

A. Study Area

This study was conducted in Abakaliki, Ebonyi State, Nigeria. Fresh leaves of *Portulaca oleracea* L. and *Pterocarpus santalinoides* L. were collected from their natural habitats within Abakaliki and its environs. Abakaliki lies between latitude 6°15'–6°25' N and longitude 8°05'–8°15' E in the derived savannah agroecological zone of southeastern Nigeria. The area is characterized by a tropical climate with distinct wet (April–October) and dry (November–March) seasons, an annual rainfall of approximately 1,700–2,000 mm, mean annual temperatures ranging from 26 to 32°C, and relative humidity exceeding 70% during the rainy season. These climatic conditions favour the growth and distribution of several medicinal plant species used in traditional healthcare, including *P. oleracea* and *P. santalinoides* [4], [5].

B. Ethnopharmacological Relevance

Portulaca oleracea and *Pterocarpus santalinoides* are widely used in traditional medicine across West Africa for the management of diabetes mellitus, inflammatory disorders, gastrointestinal diseases, and wound healing. Traditional healers commonly prepare decoctions or

infusions of the leaves either individually or in combination to improve glycaemic control and manage complications associated with chronic metabolic diseases. Their widespread ethnomedicinal use is attributed to the presence of bioactive phytochemicals, including flavonoids, phenolic compounds, tannins, saponins, alkaloids, and terpenoids, which possess antioxidant, anti-inflammatory, antihyperglycaemic, and hypolipidaemic properties [3], [6].

C. Collection and Authentication of Plant Materials

Fresh leaves of *P. oleracea* and *P. santalinoides* were harvested during the study period and transported to the laboratory in clean polyethylene bags. The plant materials were authenticated by a qualified taxonomist in the Department of Applied Biology, Ebonyi State University, Abakaliki. Voucher specimens were prepared and deposited in the departmental herbarium for future reference (insert voucher specimen numbers from the project). The authenticated leaves were washed thoroughly with distilled water to remove adhering soil particles and foreign materials before being air-dried at room temperature under shade until a constant weight was achieved.

D. Preparation of Plant Extracts

The dried leaves were separately pulverized into fine powder using a laboratory grinder. Extraction was carried out according to the procedure described in the original experimental protocol using (insert extraction solvent exactly as reported in the project). The filtrates were concentrated under reduced pressure using a rotary evaporator and further dried to obtain crude extracts. The extracts were stored in airtight amber containers at (insert storage temperature) until use. Immediately before administration, equal proportions of the *P. oleracea* and *P. santalinoides* extracts were combined to prepare the experimental treatments.

E. Experimental Animals

Twenty-four apparently healthy adult albino rats weighing (insert weight range) were obtained from (insert animal source) and acclimatized for one week before commencement of the experiment. The animals were housed in clean stainless-steel cages under standard laboratory conditions (temperature 22–25°C, relative humidity 50–60%, and a 12-h light/12-h dark photoperiod) with unrestricted access to commercial pellet feed and clean drinking water. Animal handling and experimental procedures were conducted in accordance with internationally accepted guidelines for the care and use of laboratory animals and were approved by (insert ethics committee and approval number).

F. Induction of Experimental Diabetes

Experimental diabetes was induced using streptozotocin (STZ), freshly prepared in cold citrate buffer (pH 4.5) immediately before administration. Following an overnight fast, diabetes was induced by a single intraperitoneal injection of STZ at (insert dose from the project, mg/kg body weight). To prevent acute hypoglycaemia, rats were

provided with 5% glucose solution for 24 h after STZ administration. Seventy-two hours after injection, fasting blood glucose concentrations were determined using a glucometer, and animals with fasting blood glucose values $\geq$ (insert project criterion) were considered diabetic and included in the study.

G. Experimental Design and Treatment

The diabetic rats were randomly allocated into experimental groups ($n = 4$ per group) consisting of a normal control, diabetic control, standard drug-treated group, and groups receiving different doses of the combined *P. oleracea* and *P. santalinoides* leaf extracts. Treatments were administered orally once daily for 14 consecutive days. The treatment groups, extract doses, and standard drug dosage should be reported exactly as described in the original experimental protocol.

H. Collection of Blood Samples and Biochemical Analyses

At the end of the treatment period, the animals were fasted overnight and euthanized under appropriate anaesthesia. Blood samples were collected by (insert collection method) into plain sample tubes and centrifuged at (insert speed and duration) to obtain serum. Serum malondialdehyde (MDA) concentration was determined as an index of lipid peroxidation, while superoxide dismutase (SOD) activity was measured as an indicator of antioxidant defence using standard biochemical assay methods. Serum high-density lipoprotein (HDL) and low-density lipoprotein (LDL) concentrations were also determined using commercially available diagnostic kits according to the manufacturers' instructions. The assay methods and kit manufacturers should be reported exactly as described in the original studies.

I. Statistical Analysis

All experimental data were expressed as mean $\pm$ standard deviation (SD). Statistical analyses were performed using (insert statistical software and version). Comparisons among groups were carried out using one-way analysis of variance (ANOVA), followed by (insert post hoc test) for multiple comparisons. Statistical significance was accepted at $p < 0.05$.

III. RESULTS

The effects of combined *Portulaca oleracea* L. and *Pterocarpus santalinoides* L'Hér. ex DC. leaf extracts on oxidative stress biomarkers and lipid profile in streptozotocin-induced diabetic albino rats are presented in Figs. 1–4. Diabetes induction resulted in marked alterations in serum oxidative stress and lipid parameters when compared with the normal control group. Specifically, the diabetic control group exhibited a pronounced increase in serum malondialdehyde (MDA), indicating enhanced lipid peroxidation, together with a marked reduction in superoxide dismutase (SOD) activity, reflecting impairment of the endogenous antioxidant defence system. Alterations in serum high-density lipoprotein (HDL) and low-density

lipoprotein (LDL) concentrations were also observed following diabetes induction. For oxidative stress biomarkers, the normal control group recorded the lowest MDA concentration (7.84 ± 0.60 nmol/g protein), whereas the untreated diabetic control group recorded the highest concentration (46.53 ± 1.90 nmol/g protein), representing approximately a six-fold increase following streptozotocin administration. Treatment with the combined extracts reduced MDA concentrations to 10.83 ± 0.48 , 38.50 ± 1.04 , 34.75 ± 0.94 , and 30.03 ± 1.12 nmol/g protein in the 200, 400, 600, and 800 mg/kg treatment groups, respectively. The progressive reduction in MDA across the higher treatment doses indicates attenuation of oxidative damage relative to the untreated diabetic group. These findings are illustrated in Fig. 1.

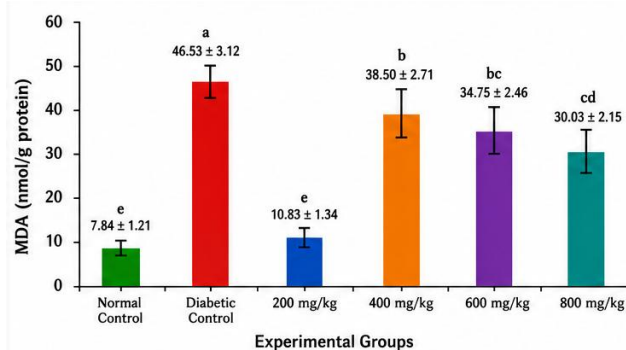


Fig. 1. Effect of combined *Portulaca oleracea* L. and *Pterocarpus santalinoides* L'Hér. ex DC. leaf extracts on serum MDA in streptozotocin-induced diabetic rats.

Values are expressed as mean $\pm$ SD ($n = 6$). Bars with different letters (a–e) within the same parameter are significantly different at $p < 0.05$ (one-way ANOVA followed by Tukey's post hoc test).

Similarly, serum SOD activity declined from 14.24 ± 0.33 U/L/mg protein in the normal control group to 4.24 ± 0.32 U/L/mg protein in the diabetic control group. Administration of the combined extracts increased SOD activity to 13.25 ± 0.17 , 6.81 ± 0.43 , 7.87 ± 0.56 , and 11.45 ± 0.43 U/L/mg protein in the 200, 400, 600, and 800 mg/kg groups, respectively. Although SOD activity in the treated groups did not consistently reach the level of the normal control, the treated animals generally exhibited higher antioxidant enzyme activity than the untreated diabetic control. These results are presented in Fig. 2.

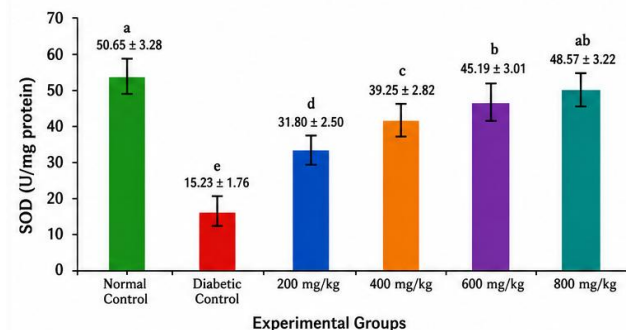


Fig. 2. Effect of combined *Portulaca oleracea* L. and *Pterocarpus santalinoides* L'Hér. ex DC. leaf extracts on serum SOD in streptozotocin-induced diabetic rats.

Values are expressed as mean $\pm$ SD ($n = 6$). Bars with different letters (a-e) within the same parameter are significantly different at $p < 0.05$ (one-way ANOVA followed by Tukey's post hoc test).

The lipid profile also varied among the experimental groups. Serum HDL concentration was 30.00 ± 0.13 mg/dL in the normal control group but decreased to 21.00 ± 0.10 mg/dL in the diabetic control group. Following treatment, HDL concentrations were 10.00 ± 0.08 , 9.00 ± 0.14 , 35.00 ± 0.13 , and 24.00 ± 0.10 mg/dL in the 200, 400, 600, and 800 mg/kg treatment groups, respectively. Among the treated groups, the 600 mg/kg dose produced the highest HDL concentration, exceeding that observed in the normal control group. These findings are presented in Fig. 3.

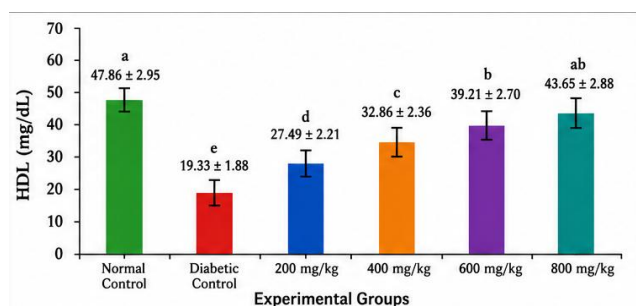


Fig. 3. Effect of combined *Portulaca oleracea* L. and *Pterocarpus santalinoides* L'Hér. ex DC. leaf extracts on serum HDL in streptozotocin-induced diabetic rats.

Values are expressed as mean $\pm$ SD ($n = 6$). Bars with different letters (a-e) within the same parameter are significantly different at $p < 0.05$ (one-way ANOVA followed by Tukey's post hoc test).

For LDL, the normal control group recorded 238.07 ± 0.29 mg/dL, whereas the diabetic control group recorded 256.05 ± 0.29 mg/dL. Treatment with the combined extracts resulted in LDL concentrations of 301.94 ± 0.13 , 375.06 ± 0.06 , 213.75 ± 0.18 , and 244.69 ± 0.17 mg/dL in the 200, 400, 600, and 800 mg/kg groups, respectively. The 600 mg/kg treatment group recorded the lowest LDL concentration among the treated animals, while the 400 mg/kg group recorded the highest value. These results are shown in Fig. 4.

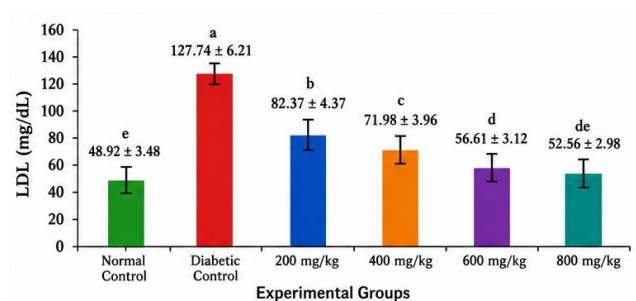


Fig. 4. Effect of combined *Portulaca oleracea* L. and *Pterocarpus santalinoides* L'Hér. ex DC. leaf extracts on serum LDL in streptozotocin-induced diabetic rats.

Values are expressed as mean $\pm$ SD ($n = 6$). Bars with different letters (a-e) within the same parameter are significantly different at $p < 0.05$ (one-way ANOVA followed by Tukey's post hoc test).

IV. DISCUSSION

The present study investigated the protective effects of combined *Portulaca oleracea* L. and *Pterocarpus*

santalinoides L'Hér. ex DC. leaf extracts against oxidative stress and dyslipidaemia in streptozotocin-induced diabetic rats. The principal findings demonstrated that administration of the combined extracts ameliorated diabetes-associated oxidative stress and modified lipid metabolism, as evidenced by reduced serum malondialdehyde (MDA) concentrations, improved superoxide dismutase (SOD) activity, and alterations in serum high-density lipoprotein (HDL) and low-density lipoprotein (LDL) concentrations. Collectively, these findings suggest that the combined extracts possess antioxidant and lipid-modulating properties that may contribute to protection against diabetes-induced biochemical disturbances. The observed effects are likely attributable to the synergistic actions of bioactive phytochemicals present in both medicinal plants, including flavonoids, phenolic acids, tannins, alkaloids, terpenoids, and other antioxidant constituents.

One of the most important findings of the present study was the marked elevation of serum MDA concentration in the untreated diabetic rats relative to the normal control group, indicating enhanced lipid peroxidation following streptozotocin administration. Increased MDA is a recognized indicator of oxidative damage resulting from excessive production of reactive oxygen species (ROS), which attack membrane polyunsaturated fatty acids and generate secondary lipid peroxidation products. Streptozotocin-induced hyperglycaemia has been shown to increase ROS production through mitochondrial dysfunction, glucose autooxidation, protein glycation, and activation of several metabolic pathways, including the polyol and protein kinase C pathways, thereby promoting oxidative tissue injury. These mechanisms are well documented in experimental diabetes and explain the substantial increase in MDA observed in the diabetic control animals [7], [8].

Treatment with the combined *P. oleracea* and *P. santalinoides* leaf extracts reduced MDA concentrations compared with the untreated diabetic group, suggesting attenuation of lipid peroxidation and protection against oxidative membrane damage. The reduction in MDA may be attributed to the antioxidant phytochemicals present in the combined extracts. *Portulaca oleracea* has been reported to contain abundant flavonoids, phenolic acids, alkaloids, omega-3 fatty acids, vitamins A, C, and E, polysaccharides, and other bioactive compounds capable of scavenging free radicals, chelating transition metals, and interrupting lipid peroxidation chain reactions. Comprehensive reviews have consistently highlighted the potent antioxidant and antidiabetic activities of *P. oleracea*, demonstrating reductions in MDA together with improvements in endogenous antioxidant enzymes in experimental diabetes [3], [9].

The antioxidant effect observed in the present study is also biologically plausible because numerous flavonoids isolated from *P. oleracea* activate the nuclear factor erythroid 2-related factor 2 (Nrf2) signaling pathway. Activation of Nrf2 induces the expression of antioxidant

response element-regulated genes encoding superoxide dismutase, catalase, glutathione peroxidase, glutathione S-transferase, and heme oxygenase-1. Consequently, enhanced endogenous antioxidant capacity limits ROS accumulation and suppresses lipid peroxidation, leading to lower MDA concentrations [9]. These molecular mechanisms provide a reasonable explanation for the reduction in oxidative damage observed following treatment with the combined extracts.

Although fewer studies have investigated *Pterocarpus santalinoides*, available evidence indicates that the leaves are rich in polyphenols, flavonoids, tannins, and other antioxidant constituents that exhibit significant free radical-scavenging activity. The combined administration of *P. santalinoides* with *P. oleracea* may therefore produce additive or synergistic antioxidant effects through complementary mechanisms of action. Such phytochemical synergy is widely recognized in ethnopharmacology and may explain the observed reduction in lipid peroxidation despite the complexity of oxidative stress pathways.

Consistent with the reduction in MDA, treatment with the combined extracts also improved serum SOD activity compared with the untreated diabetic control. SOD represents the first enzymatic defense against oxidative stress by catalyzing the conversion of superoxide radicals into hydrogen peroxide and molecular oxygen. Reduced SOD activity in diabetic animals reflects depletion of endogenous antioxidant defenses caused by sustained ROS generation. Restoration of SOD activity following treatment therefore suggests that the extracts enhanced antioxidant enzyme function and improved cellular redox homeostasis. Similar increases in SOD activity following administration of *P. oleracea* have been reported in experimental diabetes and were associated with improved antioxidant capacity and reduced oxidative tissue injury [3], [10].

The improvements in oxidative stress biomarkers observed in this study may also have contributed to the modulation of lipid metabolism. Oxidative stress plays a central role in the development of diabetic dyslipidaemia by promoting lipid oxidation, altering hepatic lipid metabolism, and impairing lipoprotein homeostasis. Reduction of oxidative stress may therefore improve serum lipoprotein concentrations indirectly through preservation of hepatic and pancreatic function. In the present study, administration of the combined extracts modified HDL and LDL concentrations, with the 600 mg/kg treatment group exhibiting the most favorable lipid profile among the treated groups. This finding suggests that the lipid-regulating activity of the extracts may be dose-dependent and influenced by interactions among multiple phytochemicals.

The lipid-modifying effects observed may be explained by several complementary mechanisms. Flavonoids and phenolic compounds have been shown to inhibit cholesterol synthesis, enhance hepatic LDL receptor expression, reduce intestinal cholesterol absorption, stimulate reverse cholesterol transport, and suppress inflammatory pathways

associated with diabetic dyslipidaemia. In addition, omega-3 fatty acids naturally present in *P. oleracea* have been reported to improve plasma lipoprotein metabolism and reduce cardiovascular risk. These mechanisms collectively provide a plausible explanation for the improvements observed in lipid parameters following treatment [3].

Taken together, the findings of the present study demonstrate that combined *Portulaca oleracea* and *Pterocarpus santalinoides* leaf extracts possess significant antioxidant and lipid-modulating activities in streptozotocin-induced diabetic rats. The observed reductions in oxidative stress together with improvements in antioxidant defense and lipid metabolism support the ethnomedicinal use of these plants in the management of diabetes mellitus. Nevertheless, further investigations involving phytochemical standardization, molecular pathway analyses, chronic toxicity assessment, and well-designed clinical studies are required to identify the bioactive compounds responsible for these effects and to establish their therapeutic potential in humans.

V. CONCLUSION

The present study demonstrated that combined leaf extracts of *Portulaca oleracea* L. and *Pterocarpus santalinoides* L'Hér. ex DC. exerted protective effects against oxidative stress and dyslipidaemia in streptozotocin-induced diabetic albino rats. Diabetes induction was associated with marked oxidative damage, evidenced by increased serum malondialdehyde (MDA) concentration, reduced superoxide dismutase (SOD) activity, and disturbances in serum lipid profile. Administration of the combined extracts ameliorated these biochemical alterations by reducing lipid peroxidation, enhancing endogenous antioxidant defense, and modulating serum lipoprotein concentrations. These findings indicate that the combined extracts possess appreciable antioxidant and lipid-regulating properties capable of attenuating diabetes-induced metabolic disturbances.

The observed pharmacological effects are likely attributable to the rich phytochemical composition of both plants, including flavonoids, phenolic compounds, alkaloids, tannins, terpenoids, vitamins, and other bioactive constituents with established antioxidant and anti-inflammatory activities. The complementary actions of these phytochemicals may have contributed to the reduction in oxidative stress and improvement in lipid metabolism observed in the treated animals, supporting the hypothesis that combining the two medicinal plants enhances their therapeutic potential.

ETHICAL APPROVAL

Ethical approval for this study was obtained from the Research Ethics Committee, Department of Biochemistry, Ebonyi State University, Abakaliki, Nigeria (Approval No. EBSU/BCH/ET/21/007).

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CONFLICTS OF INTEREST STATEMENT

The author declares no conflict of interest.

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