

ORIGINAL RESEARCH

Effects of *Moringa oleifera* Leaf Extract on Serum 8-OHdG Levels in Alloxan-Induced Diabetic Rats

Yuhendri Putra^{1,3}, Arni Amir^{2*}, Eti Yerizel², Hasmiwati²

¹Doctoral Biomedical Program, Faculty of Medicine, Universitas Andalas, Padang, Sumatera Barat, Indonesia

²Faculty of Medicine, Universitas Andalas, Padang, Sumatera Barat, Indonesia

³Faculty of Nursing and Public Health, Universitas Prima Nusantara Bukittinggi, Sumatra Barat, Indonesia

Correspondence: Arni Amir. Email: hamir4967@gmail.com

ARTICLE HISTORY

Received: 24 May 2026

Revised: 05 October 2026

Accepted: 07 October 2026

Published: 12 October 2026

ARTICLE IDENTIFIERS

Volume 6 - **Issue** 3 - 2026

Pages 483-489

DOI: [10.56338/jphp.v6i3.11226](https://doi.org/10.56338/jphp.v6i3.11226)

ABSTRACT

Introduction: Oxidative stress contributes to the pathogenesis and complications of diabetes mellitus through excessive production of reactive oxygen species, which can lead to oxidative DNA damage. Serum 8-Hydroxy-2'-Deoxyguanosine (8-OHdG) is widely used as a biomarker of oxidative DNA damage. *Moringa oleifera* leaves contain various antioxidant compounds that may help modulate oxidative stress under diabetic conditions. This study aimed to evaluate the effects of *Moringa oleifera* leaf extract on serum 8-OHdG levels in alloxan-induced diabetic rats.

Methods: This exploratory, randomized, post-test-only experiment included 25 male Wistar rats allocated to five groups (n = 5/group): non-diabetic control, alloxan-exposed diabetic control, and alloxan-exposed groups receiving *Moringa oleifera* leaf extract at 250, 500, or 1000 mg/kg body weight orally once daily for 14 days. Alloxan monohydrate was administered intraperitoneally at 150 mg/kg body weight. A fasting glucose level ≥ 200 mg/dL at 72 hours defined eligibility for the diabetic groups. Serum 8-OHdG was measured by enzyme-linked immunosorbent assay (ELISA), and group means were compared using one-way ANOVA with $p < 0.05$ as the significance threshold.

Results: Serum 8-OHdG did not differ significantly among groups ($F(4,20) = 1.55$; $p = 0.227$). The 500 mg/kg group had the numerically lowest mean (0.367 ± 0.036 ng/mL), but this observation did not establish a treatment effect or an optimal dose. The diabetic control mean (0.416 ± 0.073 ng/mL) was not higher than the non-diabetic control mean (0.468 ± 0.108 ng/mL).

Conclusion: This exploratory study did not demonstrate a statistically significant effect of *Moringa oleifera* leaf extract on serum 8-OHdG under the tested conditions. The observed numerical variation should be interpreted cautiously and does not establish antioxidant efficacy or an optimal dose. Larger, adequately powered studies with standardized extract characterization, longitudinal glycemic assessment, and additional oxidative stress markers are warranted.

Keywords: *Moringa oleifera*; Diabetes Mellitus; Oxidative Stress; 8-OHdG; Antioxidant

INTRODUCTION

Diabetes mellitus (DM) remains a major global public health problem and is associated with substantial morbidity and mortality because of its chronic metabolic and vascular complications. According to the International Diabetes Federation, approximately 537 million adults were living with diabetes worldwide in 2021, and the prevalence is expected to continue increasing in the coming decades (1). Persistent hyperglycemia contributes to the development of diabetic complications through several interconnected biochemical pathways, particularly oxidative stress and chronic inflammation (2,3).

Oxidative stress occurs when the generation of reactive oxygen species (ROS) exceeds the capacity of endogenous antioxidant defense systems. Under diabetic conditions, excessive ROS production may promote cellular injury through lipid peroxidation, protein oxidation, mitochondrial dysfunction, and nucleic acid damage (3,4). Hyperglycemia-induced oxidative stress has also been implicated in endothelial dysfunction and progression of both microvascular and macrovascular complications in diabetes mellitus (5).

Among various forms of oxidative damage, oxidative DNA injury has received increasing attention because of its association with cellular dysfunction and disease progression. One of the most widely used biomarkers of oxidative DNA damage is 8-OHdG, which is generated through oxidative modification of guanine bases within DNA molecules (6). Elevated levels of 8-OHdG have been reported in patients with diabetes mellitus and are considered indicative of increased oxidative stress and impaired antioxidant defense mechanisms (7). Increased circulating or urinary 8-OHdG concentrations have also been associated with vascular complications, chronic inflammation, and poor glycemic control in diabetic individuals (8).

Because oxidative stress is implicated in diabetic complications, plant-derived antioxidants have been investigated as potential experimental interventions. Their biological effects depend on exposure, composition, and cellular context; antioxidant activity cannot be inferred solely from natural origin (9,10).

Among medicinal plants with potential antioxidant properties, *Moringa oleifera* has been widely studied because of its rich nutritional composition and broad pharmacological activities. *Moringa oleifera* leaves contain several antioxidant constituents, including quercetin, chlorogenic acid, kaempferol, vitamin C, carotenoids, and polyphenolic compounds (11,12). Previous experimental studies have demonstrated that administration of *Moringa oleifera* extract may improve glycemic status and reduce oxidative stress in diabetic animal models (13,14). In addition, *Moringa oleifera* has been reported to modulate endogenous antioxidant enzymes such as superoxide dismutase, catalase, and glutathione peroxidase (15).

Existing *Moringa oleifera* research has emphasized glycemic outcomes, lipid peroxidation, and antioxidant defenses (14,15). Serum 8-OHdG assesses a different outcome: oxidative DNA injury; however, evaluating this marker is informative only when its response in the experimental model and the performance of the assay are adequately characterized (6,8). This study therefore examines a specific biomarker outcome rather than assuming that previously reported antioxidant effects extend to serum 8-OHdG.

Alloxan-induced models provide an experimental approach to pancreatic β -cell injury and hyperglycemia through ROS-related mechanisms (16,17). However, the induction procedure alone does not establish that hyperglycemia persists throughout treatment or that oxidative DNA damage is increased at the sampling endpoint. These features require direct verification when interpreting an antioxidant intervention.

This study aimed to compare endpoint serum 8-OHdG concentrations between control groups and rats receiving *Moringa oleifera* leaf extract after alloxan exposure. Medicinal plant standardization and phytopharmaceutical development provide a rationale for future research, but this small, single-biomarker experiment was not designed to establish clinical benefit, a therapeutic dose, or a public health intervention.

METHODS

Research Design

This exploratory laboratory study used a randomized, post-test-only control-group design to compare endpoint serum 8-OHdG concentrations across five groups. Twenty-five rats were assigned to the groups by simple randomization ($n = 5/\text{group}$). Experimental procedures and reporting were organized with reference to ARRIVE 2.0 recommendations (18).

Study Animals

A total of 25 healthy male Wistar rats (*Rattus norvegicus*), aged 8–10 weeks and weighing 180–220 g, were used in this study. Male rats were selected to minimize hormonal variations that could influence oxidative stress parameters. The animals were obtained from a certified laboratory animal facility and acclimatized for seven days before intervention under controlled environmental conditions, including room temperature of 22–25 °C, relative humidity of 50–60%, and a 12-hour light/dark cycle. Standard pellet feed and water were provided ad libitum throughout the study period (17,18).

Induction of Diabetes Mellitus

Experimental diabetes mellitus was induced using alloxan monohydrate (Sigma-Aldrich®, USA) administered as a single intraperitoneal injection at 150 mg/kg body weight and dissolved in sterile normal saline. Alloxan selectively damages pancreatic β -cells through reactive oxygen species-mediated mechanisms, leading to insulin deficiency and hyperglycemia (16). To prevent severe hypoglycemia after induction, the animals received 5% glucose solution for 24 hours. Fasting blood glucose was measured 72 hours after induction using tail-vein sampling and a glucometer. Rats with fasting glucose ≥ 200

mg/dL were considered diabetic and included in the experimental groups (17). This 72-hour measurement served as the post-induction eligibility assessment; endpoint glucose monitoring was outside the 14-day intervention protocol.

Preparation of *Moringa oleifera* Leaf Extract

Fresh *Moringa oleifera* leaves were collected from local cultivation areas and identified by a botanist from the Faculty of Pharmacy, Universitas Andalas. The leaves were washed, air-dried at room temperature, and ground into fine powder. Extraction was performed by maceration with 70% ethanol for 72 hours with intermittent stirring. The extract was filtered and concentrated using a rotary evaporator under reduced pressure to obtain a viscous crude extract. The extract was stored at 4 °C and reconstituted in distilled water before administration (12,14). The administered doses refer to crude extract mass. Quality control comprised botanical identification and standardized extraction and storage conditions; quantitative phytochemical standardization, extract-yield determination, and active-compound quantification were outside the study protocol.

Experimental Grouping and Treatment Protocol

Twenty-five rats were allocated to five groups ($n = 5/\text{group}$) using simple randomization. The groups were as follows:

Non-diabetic control: rats receiving distilled water without alloxan induction.

Diabetic control: alloxan-exposed rats meeting the post-induction glucose entry criterion and receiving distilled water.

Treatment group P1 (diabetic rats receiving *Moringa oleifera* extract 250 mg/kg body weight)

Treatment group P2 (diabetic rats receiving *Moringa oleifera* extract 500 mg/kg body weight)

Treatment group P3 (diabetic rats receiving *Moringa oleifera* extract 1000 mg/kg body weight)

The extract was administered orally once daily by gastric gavage for 14 consecutive days. Body weight and general clinical condition were monitored throughout the intervention period.

The dose range was used as an exploratory escalation within the preclinical design. A prior alloxan-rat experiment used an aqueous *Moringa oleifera* leaf extract at 250 mg/kg (19), providing pharmacological context for the low-dose group. Because the present study used a 70% ethanolic crude extract, the 500 and 1000 mg/kg groups were interpreted as exploratory doses rather than established equivalent, optimal, or therapeutic dose levels. Body weight, general clinical condition, and mortality were monitored throughout the 14-day intervention.

Blood Collection and Serum Preparation

At the end of the treatment period, animals were fasted overnight and anesthetized using ketamine-xylazine combination anesthesia. Blood samples were collected through cardiac puncture under sterile conditions. Samples were centrifuged at 3000 rpm for 10 min to separate serum, which was then stored at -20°C until biochemical analysis was performed.

Measurement of Serum 8-OHdG

Serum 8-OHdG levels were measured using a commercially available rat enzyme-linked immunosorbent assay (ELISA) kit (BT LAB Bioassay Technology Laboratory, Shanghai, China; Cat. No. E0031Ra; 96-test format) according to the manufacturer's instructions. Serum samples and standards were prepared following the standardized assay procedures provided by the manufacturer. Absorbance was measured using a microplate reader at a wavelength of 450 nm, and concentrations were calculated from the standard calibration curve. The assay kits were stored at $2-8^{\circ}\text{C}$ before use to maintain reagent stability. Results were expressed in ng/mL (6).

Data Collection Procedures

The primary outcome was endpoint serum 8-OHdG concentration. Fasting glucose measured 72 hours after alloxan exposure was used to determine eligibility for the diabetic groups. The protocol focused on this endpoint and did not include baseline serum 8-OHdG, endpoint glucose, insulin, or additional metabolic or oxidative stress biomarkers. Laboratory procedures and biochemical analyses were conducted by trained personnel using standardized operating procedures.

Statistical Analysis

Data were analyzed using Statistical Package for the Social Sciences (SPSS) version 25.0. Values are presented as mean $\pm$ standard deviation (SD), with each rat serving as the experimental unit ($n = 5/\text{group}$). The Shapiro–Wilk test and Levene's test were used to assess normality and homogeneity of variance, respectively. The primary between-group comparison was performed using one-way ANOVA with $p < 0.05$ as the significance threshold. Eta squared (η^2) was interpreted descriptively as the proportion of observed variability attributable to between-group differences rather than as evidence of treatment efficacy (20). A prospective sample-size calculation was not part of this exploratory experiment. Given the small group sizes, the non-significant result was interpreted as insufficient evidence of a treatment effect rather than evidence of equivalence, and no pairwise significance claims were made because the omnibus ANOVA was non-significant.

Blinding

Intervention administration was unblinded. Serum assays were performed by trained laboratory personnel using standardized operating procedures and manufacturer-specified ELISA conditions. The absence of intervention blinding was treated as a methodological limitation when interpreting the findings.

Ethical Approval

Ethical approval was obtained from the Research Ethics Committee of the Faculty of Medicine, Universitas Andalas, Indonesia (Approval No: 173/UN.16.2/KEP-FK/2025). The study followed institutional animal-care standards and the Guide for the Care and Use of Laboratory Animals, with ARRIVE 2.0 used as reporting guidance (18). All 25 allocated animals completed the experiment and were included in the analysis; no mortality or exclusions occurred. Animals were monitored throughout the experiment for severe behavioral changes, inability to access food or water, and significant physical deterioration as humane-endpoint indicators requiring early intervention.

RESULTS

All 25 male Wistar rats completed the experimental protocol and were included in the final analysis ($n = 5/\text{group}$), with no mortality or exclusions. Rats in the alloxan-exposed groups met the fasting glucose eligibility criterion of $\geq 200 \text{ mg/dL}$ at 72 hours after induction. The 72-hour glucose assessment confirmed eligibility for the diabetic groups; endpoint glucose was not part of the 14-day intervention protocol.

Serum 8-OHdG levels were measured to evaluate oxidative DNA damage after administration of *Moringa oleifera* leaf extract in alloxan-induced diabetic rats. The mean serum 8-OHdG levels in each experimental group are presented in Table 1.

Table 1. Serum 8-OHdG Levels in Experimental Groups

Group	Treatment	n	Mean $\pm$ SD (ng/mL)
Negative Control	Non-diabetic	5	0.468 ± 0.108
Positive Control	Diabetic	5	0.416 ± 0.073
P1	<i>Moringa oleifera</i> 250 mg/kg BW	5	0.439 ± 0.032
P2	<i>Moringa oleifera</i> 500 mg/kg BW	5	0.367 ± 0.036
P3	<i>Moringa oleifera</i> 1000 mg/kg BW	5	0.415 ± 0.056

The negative control group had a mean serum 8-OHdG level of $0.468 \pm 0.108 \text{ ng/mL}$, whereas the diabetic control group showed a mean level of $0.416 \pm 0.073 \text{ ng/mL}$. Among the treatment groups, the 250 mg/kg body weight group had a mean serum 8-OHdG concentration of $0.439 \pm 0.032 \text{ ng/mL}$. The lowest mean value was observed in the 500 mg/kg body weight group ($0.367 \pm 0.036 \text{ ng/mL}$), whereas the 1000 mg/kg body weight group had a mean concentration of $0.415 \pm 0.056 \text{ ng/mL}$. Shapiro–Wilk and Levene’s tests were nonsignificant ($p > 0.05$), and one-way ANOVA was used for the between-group comparison.

One-way ANOVA showed no statistically significant difference in serum 8-OHdG among the five groups ($F(4,20) = 1.55$; $p = 0.227$). The effect-size estimate ($\eta^2 = 0.24$) described between-group variability but, given the nonsignificant omnibus test and small group size, was not interpreted as evidence of treatment efficacy. The 500 mg/kg group had the numerically lowest mean, but no statistically supported pairwise superiority, dose-response relationship, or optimal dose was established.

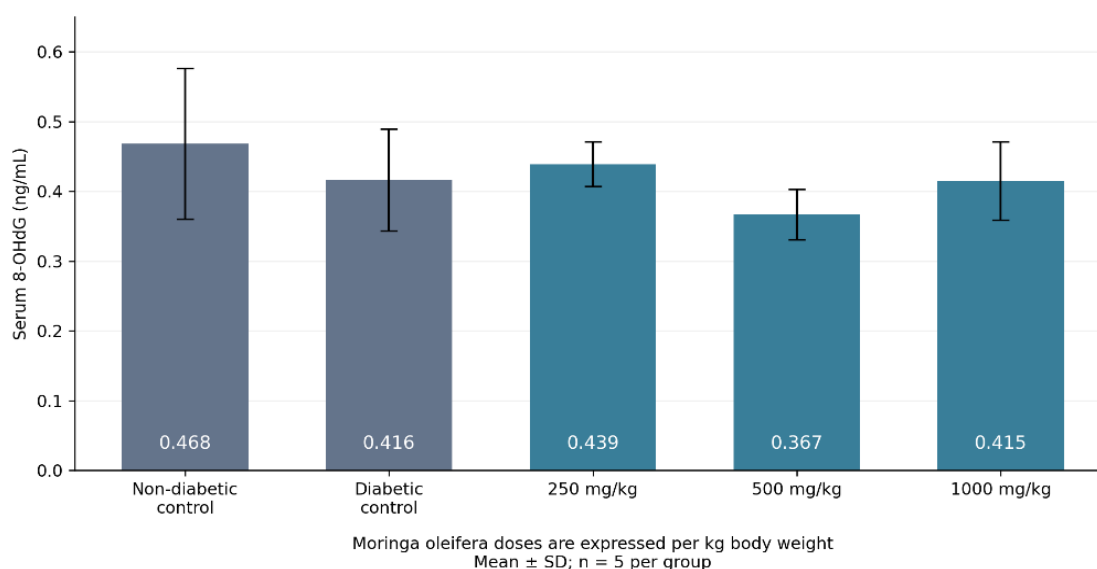


Figure 1. displays the reported group means and SDs. This descriptive visualization contains no pairwise significance annotations.

Figure 1. Endpoint serum 8-OHdG concentrations. Bars show the means and error bars show SDs from Table 1 ($n = 5/\text{group}$); individual animal values are not displayed. Treatment labels follow the Methods and Table 1: 250, 500, and 1000 mg/kg body weight. The reported omnibus ANOVA was nonsignificant ($F(4,20) = 1.55$; $p = 0.227$). No statistically supported pairwise differences or optimal dose were established.

DISCUSSION

This study did not demonstrate a statistically significant difference in endpoint serum 8-OHdG among the control and *Moringa oleifera* treatment groups. This result represents an exploratory null finding under the tested conditions. The diabetic control mean was lower than the non-diabetic control mean, so the model did not show the expected direction of change in endpoint 8-OHdG against which a protective treatment effect could be evaluated.

Oxidative stress is a plausible target in diabetes research: hyperglycemia-related mitochondrial and biochemical pathways can contribute to oxidative injury ([2,3,5,21,22](#)). DNA injury is one component of this process ([4,6,8](#)). However, this mechanistic background does not demonstrate that the pathway was increased in the present animals or modified by the administered extract.

The diabetic control mean was numerically lower than the non-diabetic control mean. Although 8-OHdG is widely used as an oxidative DNA damage marker ([6-8](#)), this control pattern limits the inference that oxidative DNA injury increased at the study endpoint. Possible contributors include sampling time, variability in model severity, and assay-related variability. A single serum measurement also cannot identify the affected tissue or distinguish DNA damage from repair and clearance processes. These factors restrict interpretation of treatment-control differences.

Interpretation of Key Findings

The mean serum 8-OHdG concentration of 0.367 ng/mL in the 500 mg/kg group represents a numerical observation within a nonsignificant omnibus comparison. It does not establish an extract-attributable antioxidant effect, superiority over either control, or an optimal dose. The η^2 value is therefore interpreted as a descriptive measure of between-group variability rather than as evidence of efficacy ([20](#)).

Nonlinear antioxidant responses and hormesis have been discussed in the broader literature ([23,24](#)), but the present experiment did not test a formal dose-response model and included no additional tissue, inflammatory, or oxidative-stress biomarkers to support that mechanism. Accordingly, the observed dose pattern is treated as descriptive rather than as evidence of hormesis or an optimal intermediate dose.

The nonsignificant result does not establish equivalence or exclude every biologically relevant effect. With five animals per group, limited precision and statistical power remain important considerations ([20,25](#)). The $p = 0.227$ result is therefore interpreted as insufficient evidence of a between-group effect under the present design.

Comparison with Previous Studies

Previous experimental and review literature describes glycemic and antioxidant outcomes after *Moringa oleifera* administration ([13-15,26](#)). In contrast, the present study did not demonstrate a significant between-group difference in serum 8-OHdG. Abd Eldaim et al. used an aqueous leaf extract at 250 mg/kg and evaluated hepatic antioxidant defenses and lipid peroxidation in alloxan-exposed rats ([19](#)). Those endpoints and that preparation differ from the present serum 8-OHdG measurement and 70% ethanolic crude extract; the study therefore provides biological context rather than direct confirmation of the present result or validation of the higher doses.

Moringa oleifera composition and processing vary, and the plant contains multiple potentially bioactive constituents ([11,12,27,28](#)). Reviews of antioxidant biology and extraction methods emphasize that chemical composition and experimental context influence biological responses ([9,10,29](#)). Because the present extract was used as a crude 70% ethanolic preparation, differences in extract composition, outcome selection, treatment duration, sample size, and metabolic status may contribute to differences from earlier studies. General accounts of diabetes-related oxidative stress and inflammation ([30-32](#)) provide mechanistic context but do not substitute for direct evidence from the present model.

Limitations and Cautions

The exploratory sample size and absence of a prospective sample-size calculation limit precision and the ability to detect small differences. Only endpoint serum 8-OHdG was measured, so baseline variability and within-animal change could not be evaluated. The effect-size estimate was interpreted descriptively, and the nonsignificant result was not treated as evidence of equivalence.

The protocol assessed fasting glucose after alloxan induction but did not include endpoint glucose, insulin, or additional metabolic measurements. The unexpected control-group pattern therefore limits inference about the relationship between glycemic status, oxidative DNA injury, and treatment. The study also did not include a standard pharmacological or antioxidant comparator, limiting assessment of assay responsiveness to a known intervention.

The extract was administered as a nonstandardized 70% ethanolic crude preparation, so dose interpretation is based on crude extract mass rather than quantified active constituents. The 500 and 1000 mg/kg groups were exploratory doses. These features limit reproducibility and prevent designation of a therapeutic, optimal, or safety-validated dose from the present data. Intervention administration was unblinded, which may increase the risk of performance or observational bias. Group allocation used simple randomization, and all allocated animals completed the experiment with no exclusions. Standardized assay procedures reduced analytical variability, but they do not remove the interpretive limitation created by an unblinded intervention.

Recommendations for Future Research

Future experiments should predefine the primary outcome and sample-size justification, document the randomization and blinding procedures in detail, and use standardized, chemically characterized extracts. Dose selection should be supported

by preparation-matched pharmacological and safety evidence. Repeated glucose assessment together with baseline and endpoint oxidative-injury measurements would strengthen model verification. Additional endpoints may include superoxide dismutase, catalase, glutathione peroxidase, lipid peroxidation, and inflammatory markers, ideally with a suitable pharmacological or antioxidant comparator (29,33). These steps would provide a stronger basis for evaluating translational relevance.

CONCLUSION

Moringa oleifera leaf extract did not demonstrate a statistically significant effect on endpoint serum 8-OHdG in this exploratory experiment. The numerically lowest mean at 500 mg/kg represents descriptive variation and does not establish antioxidant efficacy, a dose-response relationship, or an optimal dose.

Interpretation is limited by the small sample, use of a crude extract without quantitative standardization, lack of endpoint glycemic monitoring, and the control pattern in which diabetic 8-OHdG was not higher than non-diabetic 8-OHdG. These findings neither establish therapeutic benefit nor demonstrate equivalence. Further adequately powered, standardized, and transparently reported studies are warranted before translational claims are considered.

DECLARATIONS

Author contributions: T Yuhendri Putra contributed to conceptualization, study design, laboratory investigation, data collection, statistical analysis, interpretation of findings, and manuscript drafting. Arni Amir contributed to supervision, methodology development, critical revision of the manuscript, and final approval of the submitted version. Eti Yerizel contributed to laboratory analysis, data interpretation, and manuscript review. Hasmiwati contributed to methodological supervision, validation of laboratory procedures, and critical evaluation of the manuscript. All authors read and approved the final version of the manuscript.

Conflicts of interest: The authors declare that there are no conflicts of interest related to this study. The authors have no financial, personal, institutional, or other relationships that could inappropriately influence or bias the work reported in this manuscript.

Declaration of Generative AI And AI-Assisted Technologies in the Writing Process: The authors declare that ChatGPT, developed by OpenAI, and Grammarly were used exclusively to assist with word choice, sentence construction, language refinement, and grammatical improvement during manuscript preparation. These AI-assisted tools were utilized solely to enhance the clarity, readability, and linguistic quality of the manuscript without altering its scientific meaning or substantive content. All scientific content, data analysis, interpretation of findings, and final decisions regarding the manuscript were independently reviewed, verified, and approved by the authors. The authors take full responsibility for the accuracy, originality, scientific validity, and integrity of the manuscript.

Source of Funding Statements: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors. All research activities, including laboratory analysis and manuscript preparation, were independently supported by the authors. The authors confirm that no external funding body had any role in the study design, data collection, data analysis, interpretation of findings, or preparation of the manuscript.

Acknowledgments: The authors would like to express their sincere gratitude to the Faculty of Medicine, Universitas Andalas, Padang, Indonesia, for providing laboratory facilities and technical support during the study. The authors also thank all laboratory staff and colleagues who assisted in animal handling, sample processing, and biochemical analysis throughout the research process.

REFERENCES

1. International Diabetes Federation. *IDF Diabetes Atlas*. 10th ed. Brussels: International Diabetes Federation; 2021. Available from: <https://diabetesatlas.org/resources/previous-editions/>
2. Brownlee M. The pathobiology of diabetic complications: a unifying mechanism. *Diabetes*. 2005;54(6):1615–1625. DOI: <https://doi.org/10.2337/diabetes.54.6.1615>
3. Giacco F, Brownlee M. Oxidative stress and diabetic complications. *Circ Res*. 2010;107(9):1058–1070. DOI: <https://doi.org/10.1161/CIRCRESAHA.110.223545>
4. Halliwell B, Gutteridge JMC. *Free Radicals in Biology and Medicine*. 5th ed. Oxford: Oxford University Press; 2015.
5. Forbes JM, Cooper ME. Mechanisms of diabetic complications. *Physiol Rev*. 2013;93(1):137–188. DOI: <https://doi.org/10.1152/physrev.00045.2011>
6. Valavanidis A, Vlachogianni T, Fiotakis C. 8-OHdG : a critical biomarker of oxidative stress and carcinogenesis. *J Environ Sci Health C Environ Carcinog Ecotoxicol Rev*. 2009;27(2):120–139. DOI: <https://doi.org/10.1080/10590500902885684>
7. Wu LL, Chiou CC, Chang PY, Wu JT. Urinary 8-OHdG: a marker of oxidative stress to DNA and a risk factor for cancer, atherosclerosis and diabetes. *Clin Chim Acta*. 2004;339(1–2):1–9. DOI: <https://doi.org/10.1016/j.cccn.2003.09.010>
8. Evans MD, Dizdaroglu M, Cooke MS. Oxidative DNA damage and disease: induction, repair and significance. *Mutat Res*. 2004;567(1):1–61. DOI: <https://doi.org/10.1016/j.mrrev.2003.11.001>
9. Forman HJ, Davies KJA, Ursini F. How do nutritional antioxidants really work: nucleophilic tone and para-hormesis versus free radical scavenging. *Free Radic Biol Med*. 2014;66:24–35. DOI: <https://doi.org/10.1016/j.freeradbiomed.2013.05.045>
10. Bouayed J, Bohn T. Exogenous antioxidants—double-edged swords in cellular redox state. *Oxid Med Cell Longev*. 2010;3(4):228–237. DOI: <https://doi.org/10.4161/oxim.3.4.12858>
11. Fahey JW. *Moringa oleifera*: a review of the medical evidence for its nutritional, therapeutic, and prophylactic properties. *Trees Life J*. 2005;1:5. Available from: <https://moringafarms.com/wp-content/uploads/2014/05/Moringa-oleifera-A-Review-of-the-Medical-Evidence-for-Its-Nutritional-Therapeutic-and-Prophylactic-Properties.-Part-1.pdf>
12. Anwar F, Latif S, Ashraf M, Gilani AH. *Moringa oleifera*: a food plant with multiple medicinal uses. *Phytother Res*. 2007;21(1):17–25. DOI: <https://doi.org/10.1002/ptr.2023>
13. Jaiswal D, Rai PK, Kumar A, Mehta S, Watal G. Effect of *Moringa oleifera* Lam. leaves aqueous extract therapy on hyperglycemic rats. *J Ethnopharmacol*. 2009;123(3):392–396. DOI: <https://doi.org/10.1016/j.jep.2009.03.036>

14. Mbikay M. Therapeutic potential of *Moringa oleifera* leaves in chronic hyperglycemia and dyslipidemia: a review. *Front Pharmacol.* 2012;3:24. DOI: <https://doi.org/10.3389/fphar.2012.00024>
15. Vergara-Jimenez M, Almatrafi MM, Fernandez ML. Bioactive components in *Moringa oleifera* leaves protect against chronic disease. *Antioxidants (Basel).* 2017;6(4):91. DOI: <https://doi.org/10.3390/antiox6040091>
16. Szkudelski T. The mechanism of alloxan and streptozotocin action in β -cells of the rat pancreas. *Physiol Res.* 2001;50(6):536–546. Available from: <https://www.biomed.cas.cz/physiolres/2001/issue6/pdf/szkudelski.pdf>
17. King AJF. The use of animal models in diabetes research. *Br J Pharmacol.* 2012;166(3):877–894. DOI: <https://doi.org/10.1111/j.1476-5381.2012.01911.x>
18. Percie du Sert N, Hurst V, Ahluwalia A, Alam S, Avey MT, Baker M, et al. The ARRIVE guidelines 2.0: updated guidelines for reporting animal research. *PLoS Biol.* 2020;18(7):e3000410. DOI: <https://doi.org/10.1371/journal.pbio.3000410>
19. Abd Eldaim MA, Shaban Abd Elrasoul A, Abd Elaziz SA. An aqueous extract from *Moringa oleifera* leaves ameliorates hepatotoxicity in alloxan-induced diabetic rats. *Biochem Cell Biol.* 2017;95(4):524–530. DOI: <https://doi.org/10.1139/bcb-2016-0256>
20. Nakagawa S, Cuthill IC. Effect size, confidence interval and statistical significance: a practical guide for biologists. *Biol Rev Camb Philos Soc.* 2007;82(4):591–605. DOI: <https://doi.org/10.1111/j.1469-185X.2007.00027.x>
21. Nishikawa T, Edelstein D, Du XL, Yamagishi SI, Matsumura T, Kaneda Y, et al. Normalizing mitochondrial superoxide production blocks three pathways of hyperglycaemic damage. *Nature.* 2000;404(6779):787–790. DOI: <https://doi.org/10.1038/35008121>
22. Rolo AP, Palmeira CM. Diabetes and mitochondrial function: role of hyperglycemia and oxidative stress. *Toxicol Appl Pharmacol.* 2006;212(2):167–178. DOI: <https://doi.org/10.1016/j.taap.2006.01.003>
23. Halliwell B. The antioxidant paradox: less paradoxical now? *Br J Clin Pharmacol.* 2013;75(3):637–644. DOI: <https://doi.org/10.1111/j.1365-2125.2012.04272.x>
24. Calabrese EJ. Hormesis: path and progression to significance. *Int J Mol Sci.* 2018;19(10):2871. DOI: <https://doi.org/10.3390/ijms19102871>
25. Button KS, Ioannidis JPA, Mokrysz C, Nosek BA, Flint J, Robinson ESJ, et al. Power failure: why small sample size undermines the reliability of neuroscience. *Nat Rev Neurosci.* 2013;14(5):365–376. DOI: <https://doi.org/10.1038/nrn3475>
26. Mthiyane FT, Dlodla PV, Ziqubu K, Mthembu SXH, Muvhulawa N, Hlengwa N, Nkambule BB, Mazibuko-Mbeje SE. A review on the antidiabetic properties of *Moringa oleifera* extracts: focusing on oxidative stress and inflammation as main therapeutic targets. *Front Pharmacol.* 2022;13:940572. DOI: <https://doi.org/10.3389/fphar.2022.940572>
27. Leone A, Spada A, Battezzati A, Schiraldi A, Aristil J, Bertoli S. Cultivation, genetic, ethnopharmacology, phytochemistry and pharmacology of *Moringa oleifera* leaves: an overview. *Int J Mol Sci.* 2015;16(6):12791–12835. DOI: <https://doi.org/10.3390/ijms160612791>
28. Gopalakrishnan L, Doriya K, Kumar DS. *Moringa oleifera*: a review on nutritive importance and its medicinal application. *Food Sci Hum Wellness.* 2016;5(2):49–56. DOI: <https://doi.org/10.1016/j.fshw.2016.04.001>
29. Xu DP, Li Y, Meng X, Zhou T, Zhou Y, Zheng J, et al. Natural antioxidants in foods and medicinal plants: extraction, assessment and resources. *Int J Mol Sci.* 2017;18(1):96. DOI: <https://doi.org/10.3390/ijms18010096>
30. Asmat U, Abad K, Ismail K. Diabetes mellitus and oxidative stress—a concise review. *Saudi Pharm J.* 2016;24(5):547–553. DOI: <https://doi.org/10.1016/j.jsps.2015.03.013>
31. Rehman K, Akash MSH. Mechanisms of inflammatory responses and development of insulin resistance: how are they interlinked? *J Biomed Sci.* 2016;23:87. DOI: <https://doi.org/10.1186/s12929-016-0303-y>
32. Newsholme P, Cruzat VF, Keane KN, Carlessi R, de Bittencourt PIH Jr. Molecular mechanisms of ROS production and oxidative stress in diabetes. *Biochem J.* 2016;473(24):4527–4550. DOI: <https://doi.org/10.1042/BCJ20160503C>
33. Birben E, Sahiner UM, Sackesen C, Erzurum S, Kalayci O. Oxidative stress and antioxidant defense. *World Allergy Organ J.* 2012;5(1):9–19. DOI: <https://doi.org/10.1097/WOX.0b013e3182439613>



COPYRIGHT & LICENSING

Copyright © 2026 Journal of Public Health and Pharmacy

This work is licensed under a [Creative Commons Attribution-ShareAlike 4.0 International License](https://creativecommons.org/licenses/by-sa/4.0/).