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RESEARCH ARTICLE

Kigelia africana (Lam.) Benth. fruit inhibits iron-induced lipid peroxidation and α-amylase enzyme activity

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Abstract

Insufficiencies in insulin secretion and/or action cause diabetes mellitus (DM), a complex condition characterized by abnormal blood glucose levels. Diabetes is often treated by modifying either glucose metabolism, lipids metabolism, or both. A direct correlation has been found between high levels of lipid peroxide in individuals with diabetes and lower intracellular antioxidant activity. Therefore, this study was designed to investigate the effect of the aqueous extract of *Kigelia africana* fruit on the carbohydrate hydrolyzing enzyme, α-amylase, and $FeSO_4$-induced lipid peroxidation in the rat pancreas. The *in vitro* antioxidant potential, including assays for (1,1 diphenyl-2-picryl hydrazyl (DPPH), ferric reducing antioxidant property (FRAP), nitric oxide (NO), hydroxyl (OH) scavenging, and Fe^{2+} chelating abilities, of the fruit extract was also evaluated. The effect of the fruit extract on the α-amylase enzyme, and $FeSO_4$-induced lipid peroxidation in the rat pancreas was also evaluated. *K. africana* at a concentration of 0.5 mg/mL and 1 mg/mL scavenged DPPH radicals, with the lower concentration showing significant differences compared to the control. The *K. africana* fruit extract reduced ferric compounds significantly compared to the standard. The OH* radical scavenging results revealed that all concentrations of *K. africana* fruit scavenged OH* radicals without significant differences compared to the control. *K. africana* fruit also chelated iron significantly compared to the control. The fruit extract inhibited iron-induced lipid peroxidation in the rat pancreas and α-amylase activity compared to the control. *K. africana* fruit displayed promising potential in inhibiting α-amylase activity and associated lipid peroxidation in diabetics. Therefore, it holds strong promise for use in diabetes treatment, validating its traditional use for managing the condition.

Keywords

Diabetes; Malondialdehyde; ferric reducing antioxidant property; Fe^{2+} chelating abilities; *Kigelia africana* fruit

Introduction

Insufficiencies in insulin secretion and/or action cause diabetes mellitus (DM), a complex condition characterized by abnormal blood glucose levels. Diabetes is often treated by modifying either glucose metabolism, lipids

metabolism, or both (1). Millions of people worldwide suffer from diabetic complications, with nearly 10% of the global population affected by this serious endocrine condition (2). By 2030, it is projected that there will be 439 million people with diabetes worldwide (3). Diabetes is associated with the growth of the contemporary lifestyle globally (4). Our society experiences substantial morbidity and mortality due to DM-related vascular impairment (5–7). Blood vessels and nerve tissues are predominantly damaged as a result of this metabolic imbalance, leading to significant cellular and organ damage (8).

Lipid peroxidation is regarded as the primary mechanism responsible for the toxic processes that lead to the oxidative destruction of cell components. Therefore, lipid peroxidation plays a significant role in human health and disease (9–12). Scientific evidence connects poor glycemic control, increased production of lipid oxidation products, and worsening metabolic health in diabetic individuals (13, 14). A direct correlation has been found between high levels of lipid peroxide in diabetes individuals and lower intracellular antioxidant activity (15). Therefore, the use of antioxidants may be useful in managing this condition (16–18). The importance of plant extracts in the management of diabetes is well known, and many medicinal plants have been identified for their usefulness in this regard (19). In hyperglycemic conditions, various factors, including impairment of the insulin mechanism, hyperlipidemia, and oxidative stress, contribute to secondary complications such as diabetic retinopathy, neuropathy, and cardiovascular diseases (20). Phenolic compounds such as flavonoids, phenolic acids, lignans, and stilbenes, found in plant-based foods, may be effective as nutraceuticals and supplemental treatments for diabetes (21) and its complications (22).

Kigelia africana (Lam.) Benth. is native to Africa and is most frequently found in the continent's southern, central, and western regions (23, 24). It is widely used to treat a variety of ailments and serves as an agroforestry tree. Due to its peculiar fruit and stunning deep red flowers, the plant was introduced to several countries in Southeast Asia, including India, Pakistan, China, the Philippines, and Iraq. Today, it is mainly grown as a decorative tree and is commonly found in gardens and parks (25). Traditional African healers have used formulations for various parts of *K. africana* to treat a variety of skin issues, as well as diarrhea, rheumatism, constipation, ulcers, wounds, gonorrhea, cancer, abscesses, and many other conditions (26). This plant is rich in terpenes, terpenoids, and flavonoids. According to research, *K. africana* and its contents have antioxidant potential, anti-inflammatory, anti-cancer, and antidiabetic properties (27). Therefore, it is imperative to investigate the α-amylase enzyme activity and lipid peroxidation in the pancreas to determine the mechanism of action of *K. africana* in the treatment of diabetes mellitus. Hence, the aim of this study was to determine the effect of *K. africana* fruit on the α-amylase enzyme and iron-induced lipid peroxidation in the rat pancreas.

Materials and Methods

Plant Collection, Identification and Authentication

The *Kigelia africana* fruits were purchased from the Oja Oba market in Osogbo, Osun state, Nigeria. They were identified at the Bowen University Herbarium, Iwo, Osun state, and authenticated at the Forest Herbarium in Ibadan (FHI number: 111350). The fresh fruit was cut into small pieces and pulverized using an electric grinder. 1 kg of pulverised paste was extracted with 800 mL of distilled water for 72 hrs. The filtrate was concentrated using a freeze-drier to yield the aqueous extract of the plant. The dark-brown residue was stored in the refrigerator for further analysis.

Antioxidant Assays

Ferric reducing power was determined using Oyaizu's method (28), while the DPPH free radical scavenging ability was evaluated according to standard procedure (29). The extracts' ability to chelate Fe^{2+} was assessed using a modified Minotti and Aust technique (30), with a minor modification made by Oboh *et al.* (31). The Halliwell and Gutteridge method (32) was used to test the extracts' capacity to inhibit the Fe^{2+}/H_2O_2-induced breakdown of deoxyribose.

α-amylase Inhibition Assay

To investigate the antidiabetic properties of *K. africana* fruit aqueous extract, we employed the α-amylase inhibitory protocol (33)**.** The extract dilution (0–200 µL) was combined with 500 µL of 0.02 M sodium phosphate buffer (pH 6.9 with 0.006 M NaCl) containing 0.5 mg/mL of porcine pancreatic amylase and incubated for 10 min at 25 °C. Each tube was then filled with 500 µL of a 1% starch solution in 0.02 M sodium phosphate buffer (pH 6.9 with 0.006 M NaCl). The reaction mixture was incubated for 10 min at 25 °C before being stopped with 1.0 mL of dinitrosalicylic acid (DNSA). Subsequently, the mixture was cooled to room temperature after 5 min of incubation in a hot water bath. After diluting the reaction mixture with 10 mL of distilled water, the absorbance was measured at 540 nm. The α-amylase inhibitory activity was expressed as percentage inhibition.

Lipid Peroxidation Assay

Animals

10 male albino rats, weighing between 150 and 200 g, were used. Commercial farmers' mash pellets were used to feed the rats. They were kept at room temperature and fed ad libitum, except for the final 12 to 15 hrs before the experiment's end. The animals were housed in plastic cages at room temperature with a 12-hr light/12-hr dark cycle. All relevant national, institutional, and international regulations for the handling and use of animals were adhered to. Additionally, the experiment was approved by the institutional animal ethics committee at Bowen University, Iwo (BUI/BCH/2023/0001).

Preparation of Pancreas Homogenate

The pancreases were quickly extracted after euthanizing the rats using moderate diethyl ether anesthesia. The tissue was then homogenized in cold saline (1/5 w/v) using

ten up-and-down strokes in a Teflon glass homogenizer at a speed of roughly 1200 rev/min. A low-speed supernatant (S1) was retained for the lipid peroxidation experiment after centrifuging the homogenate for 10 min at 3000 × g (34).

Lipid Peroxidation and Thiobarbibutric Acid Reactions

The modified protocol of Ohkawa *et al.* (35) was used for the lipid peroxidation assay. Briefly, 30 µL of 0.1 M pH 7.4 Tris-HCl buffer, 30 µL of freshly made 250 µM $FeSO_4$, and 100 µL of the S1 fraction were combined to form the reaction mixture (the operation was also carried out with 15 mM quercetin). After incubating the volume at 37 °C for 1 hr, 300 µL of water was added. Following the addition of 300 µL of 8.1% sodium dodecyl sulfate to the reaction mixture containing S1, 600 µL of acetic acid/HCl (pH 3.4) mixture, and 600 µL of 0.8% thiobarbituric acid were added to create the colour reaction. This mixture was then incubated at 100 °C for an hr. The absorbance was measured at 532 nm. The standard curve of MDA (Malondialdehyde) was used.

Statistical Analysis

Data (n=3) were presented as the mean ± standard deviation (SD) of three experiments. The data were analysed using One Way Analysis of Variance (ANOVA). A p-value less than 0.05 was considered statistically significant.

Results and Discussion

In vitro Antioxidant Activity

Free radical damage is etiologically connected to many chronic health problems. Antioxidants lessen the possibility of tissue damage brought on by free radicals by restricting the production of radicals, scavenging them, or encouraging their breakdown (36–40). Oxidative stress exacerbates a wide range of human disorders, such as diabetes, atherosclerosis, inflammatory arthritis, and cancer. The use of synthetic antioxidants has been limited due to their low solubility and possible health hazards (41–44). In the recent quest for novel antioxidants, many plant species have been investigated (41, 45, 46). Less hazardous phyto-antioxidants, which are important medicinal components of food, have successfully decreased the susceptibility to reactive oxygen species (ROS) (47). Fig. 1 displayed the result of the ferric reducing antioxidant property (FRAP) of *Kigelia africana* fruit, demonstrating that *K. africana* at both concentrations (0.5 and 1 mg/mL) significantly reduced ferric radicals compared to the standard. The results of the ability to scavenge DPPH free radicals are depicted in Fig. 2, with *K. africana* (0.5 and 1 mg/mL) exhibiting the highest DPPH radical scavenging ability, statistically different from the control. Fig. 3 illustrates the ability of *K. africana* to chelate iron. At both concentrations of 0.5 and 1 mg/mL, significant differences were observed compared to the control. Fig. 4 presents *K. africana*'s capacity to scavenge hydroxyl radicals (OH), showing no discernible difference between its capacity and that of the control. *K. africana* is a substantial source of compounds that may be useful in reducing oxidative stress (48). Therefore, consuming medicinal plants with antioxidant potential appears to be

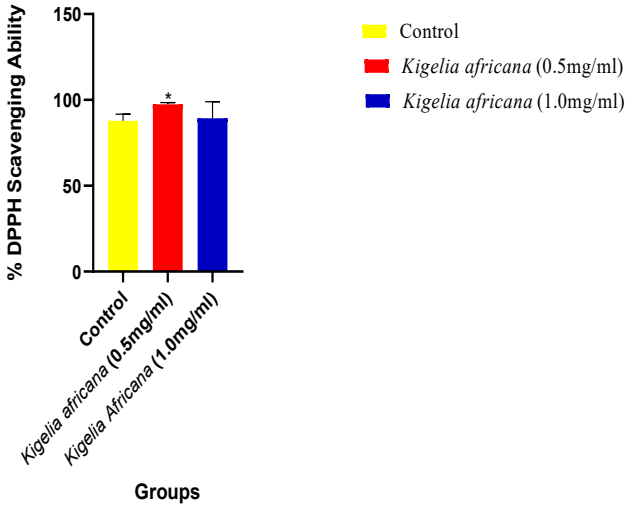

Fig. 2. DPPH scavenging ability of *Kigelia africana* fruit aqueous extract. Data are presented as mean ± SD (n=3). Values are statistically different at *p < 0.05 vs Control. Control = Quercetin.

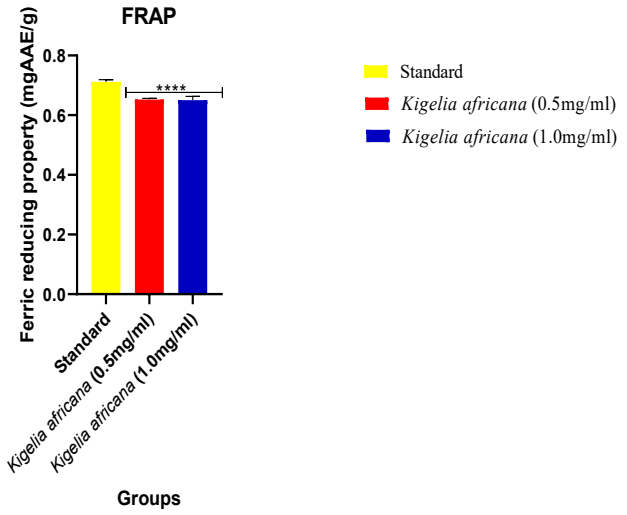

Fig. 1. Ferric reducing antioxidant property of aqueous extract of *Kigelia africana* fruit. Data are presented as mean ± SD (n=3). ****Values are statistically different at p < 0.0001 vs Standard. Standard = Ascorbic acid.

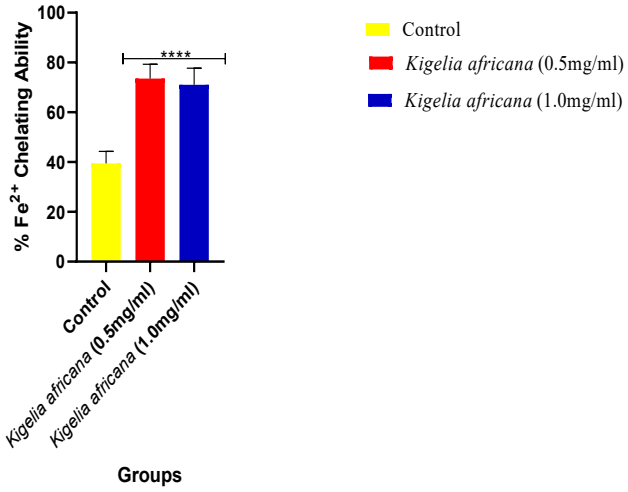

Fig. 3. Fe^{2+} chelating ability of *Kigelia africana* fruit aqueous extract. Data are presented as Mean ± SEM (n=3). Values are statistically different at ****p< 0.0001 vs Control. Control = Quercetin.

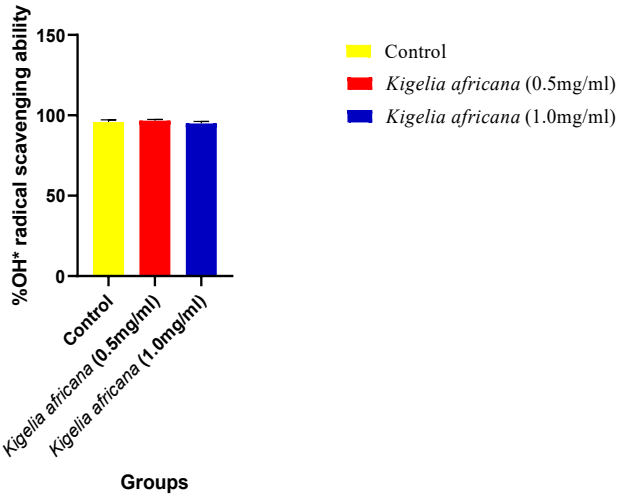

Fig. 4. OH* scavenging ability of *Kigelia africana* fruit aqueous extract. Data are presented as Mean ± SEM (n=3). Control = Quercetin.

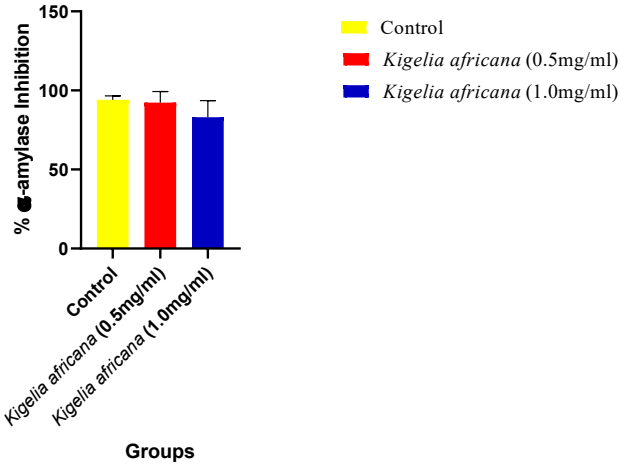

Fig. 5. α-amylase inhibitory effect of *Kigelia africana* fruit aqueous extract. Data are presented as Mean ± SEM (n=3). Control = Arcabose.

a workable substitute for natural antioxidant defense systems (49–51). Phenolics, which have a -OH functional group, are common components of medicinal plants and are used for several therapeutic applications, including the inhibition of free radicals. There is a comparable link between phenolics and antioxidant capacity (52–54). The high scavenging properties of the *K. africana* fruit aqueous extract may be due to the hydroxyl functional groups in the phenolic compound structure's skeleton.

α-amylase Inhibitory and Lipid Peroxidation Assays

While several chemicals with antioxidant activity have been identified in *K. africana* fruit (27, 49), little is known about how effectively these compounds function as antidiabetics (50, 51, 55–57). Fig. 5 presents the inhibition of α-amylase by *K. africana*, revealing that the concentrations of *K. africana* extract (0.5 and 1 mg/mL) did not significantly differ from the control in their ability to inhibit α-amylase activity. Fig. 6 depicts the inhibition of lipid peroxidation caused by iron sulfate ($FeSO_4$) in the rat pancreas by *K. africana* fruit aqueous extract. Both concentrations of *K. africana* extract (0.5 and 1 mg/mL) inhibited the production of MDA with no appreciable difference compared to the control. The Malondialdehyde (MDA) content significantly increased when 5 mM $FeSO_4$ was added to the rat pancreas homogenate (58). *K. africana* extract concentrations (0.5 and 1 mg/mL) reduced MDA generation more effectively than the control. The results of the α-amylase inhibition by *K. africana* fruit aqueous extract showed that *K. africana* concentrations (0.5 and 1 mg/mL) suppressed α-amylase activity more effectively than the control. Numerous compounds from botanicals are beneficial in the management of diabetes (59–61), with several medicinal plants possessing significant antioxidant activity also reported to have antidiabetic effects (54, 62). According to reports, one crucial component of treating type II diabetes is controlling human pancreatic α-amylase (54). Therefore, one of the primary strategies for managing diabetes is to delay the breakdown of starch by inhibiting α-amylase. Pancreatic α-amylase inhibitors slow down the digestion of carbohydrates, lowering the postprandial levels of blood glucose and slowing the rate of glucose absorption

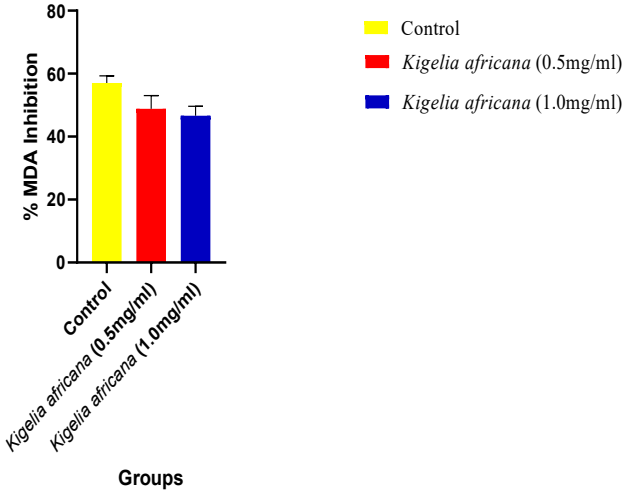

Fig. 6. Effect of *Kigelia africana* fruit aqueous extract on $FeSO_4$ induced lipid peroxidation in rat pancreas. Data are presented as Mean ± SEM (n=3). Control = Quercetin.

(63). The results of the current investigation also suggest one possible mechanism by which *K. africana* fruit might exhibit hypoglycemic effects: suppression of α-amylase activity, which would delay starch hydrolysis and subsequently lower postprandial hyperglycemia (PPHG) (64). The fruit of *K. africana* may possess anti-diabetic properties by preventing oxidation of pancreatic islet bio-membranes (65). However, the efficacy of *K. africana* fruit aqueous extract in alleviating diabetic conditions should not be solely based on α-amylase inhibitory activity. Therefore, *in vivo* assays and *in silico* studies need to be conducted to confirm this mechanism of action.

Conclusion

A *Kigelia africana* fruit exhibits promising potential to inhibit α-amylase activity and associated lipid peroxidation in diabetic individuals. Therefore, it holds strong promise for use in the treatment of diabetes, thereby validating its traditional medicinal use in managing the condition.

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Authors' contributions

EOF, ADO, and POA conceived the study and participated in its design and coordination. All authors carried out the study. POA performed the statistical analysis. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None.

References

1. Zhang BB, Moller DE. New approaches in the treatment of type 2 diabetes. Curr Opin Chem Biol. 2000;4:461-67. https://doi.org/10.1016/S1367-5931(00)00103-4
2. Burke JP, Williams K, Narayan KMV *et al*. A population perspective on diabetes prevention: whom should we target for preventing weight gain. Diabetes Care. 2003;26:1999-2004. https://doi.org/10.2337/diacare.26.7.1999
3. Wild S, Roglic G, Green A, Sicree R, King H. Global prevalence of diabetes: estimates for the year 2000 and projections for 2030. Diabetes Care. 2004;27:1047-53.
4. Vats RK, Kumar V, Kothari A *et al*. Emerging targets for diabetes. Curr Sci.2005;88:241-49.
5. Gokce N, Keaney JF Jr, Hunter LM, Watkins MT, Menzoian JO, Vita JA. Risk stratification for postoperative cardiovascular events via noninvasive assessment of endothelial function: A prospective study. Circulation. 2002;105:1567-72. https://doi.org/10.1161/01.CIR.0000012543.55874.47
6. Morrish NJ, Stevens LK, Head J, Fuller JH, Jarrett RJ, Keen H. A prospective study of mortality among middle-aged diabetic patients (the London cohort of the WHO multinational study of vascular disease in diabetics) I: Causes and death rates. Diabetologia. 1990;33:538-41. https://doi.org/10.1007/BF00404141
7. Morrish NJ, Wang SL, Stevens LK, Fuller JH, Keen H. Mortality and causes of death in the WHO multinational study of vascular disease in diabetes. Diabetologia. 2001;44:S14-S21. https://doi.org/10.1007/PL00002934
8. de Jager J, Dekker JM, Kooy A, Kostense PJ, Nijpels G, Heine RJ. *et al*. Endothelial dysfunction and low-grade inflammation explain much of the excess cardiovascular mortality in individuals with type 2 diabetes: The Hoorn Study. Arter Thromb Vasc Biol. 2006;26:1086-93. https://doi.org/10.1161/01.ATV.0000215951.36219.a4
9. Gianazza E, Brioschi M, Fernandez AM, Banfi C. Lipoxidation in cardiovascular diseases. Redox Biol. 2019;23:101119-40. https://doi.org/10.1016/j.redox.2019.101119
10. Ramana KV, Srivastava S, Singhal SS. Lipid peroxidation products in human health and disease. Oxidative Med Cell Longev.2019;7147235-37. https://doi.org/10.1155/2019/7147235
11. Njie-Mbye YF, Chitnis M, Opere C, Ohia S. Lipid peroxidation: Pathophysiological and pharmacological implications in the eye. Front Physiol. 2003;4:366-75. https://doi.org/10.3389/fphys.2013.00366
12. Fatani SH, Babakr AT, NourEldin EM, Almarzouki AA. Lipid peroxidation is associated with poor control of type-2 diabetes mellitus, diabetes and metabolic syndrome. Clin Res Rev. 2016;10:S64-S67. https://doi.org/10.1016/j.dsx.2016.01.028
13. Davì GA, Falco A, Patrono C. Lipid peroxidation in diabetes mellitus. Antioxid Redox Signal. 2005;7:256-68. https://doi.org/10.1089/ars.2005.7.256
14. Tangvarasittichai O, Tangvarasittichai S. Oxidative stress, ocular disease and diabetes retinopathy. Curr Pharm Des. 2018;24:4726-41. https://doi.org/10.2174/1381612825666190115121531
15. Kesavulu MM, Rao BK, Giri R, Vijaya J, Subramanyam G, Apparao C. Lipid peroxidation and antioxidant enzyme status in Type 2 diabetics with coronary heart disease. Diabetes Res Clin Pract. 2001;53:33-39. https://doi.org/10.1016/S0168-8227(01)00238-8
16. Abdollahi M, Farshchi A, Nikfar S, Seyedifar M. Effect of chromium on glucose and lipid profiles in patients with type 2 diabetes; a meta-analysis review of randomized trials. J Pharm Pharm Sci. 2013;16:99-114. https://doi.org/10.18433/J3G022
17. Rafieian-Kopaei M, Nasri H. Ginger and diabetic nephropathy. J Renal Inj Prev. 2013;2:9-10.
18. Nasri H, Rafieian-Kopaei M. Tubular kidney protection by antioxidants. Iran J Public Health. 2013;42:1194-96.
19. Pushparaj P, Tan CH, Tan BKH. Effects of *Averrhoa bilimbi* leaf extract on blood glucose and lipids in streptozocin-diabetic rats. J Ethnopharmacol. 2000;72:69-76. https://doi.org/10.1016/S0378-8741(00)00200-2
20. Tahrani AA, Piya MK, Kennedy A, Barnett AH. Glycaemic control in type 2 diabetes: targets and new therapies. Pharmacol Ther. 2010;125:328-61. https://doi.org/10.1016/j.pharmthera.2009.11.001
21. Lam KS. New aspects of natural products in drug discovery. Trends Microbiol. 2007;15:279-89. https://doi.org/10.1016/j.tim.2007.04.001
22. Dragan S, Andrica Maria F, Maria-Corina S, Timar R. Polyphenols -rich natural products for treatment of diabetes. Curr Med Chem. 2014;21:38. https://doi.org/10.2174/09298673216661408261154 22
23. Bello I, Shehu MW, Musa M, Asmawi MZ, Mahmud R. *Kigelia africana* (Lam.) Benth.(Sausage tree): Phytochemistry and pharmacological review of a quintessential African traditional medicinal plant. Journal of Ethnopharmacology. 2016 Aug 2;189:253-76. https://doi.org/10.1016/j.jep.2016.05.049
24. Guidigan ML, Azihou F, Idohou R, Okhimamhe AA, Fandohan AB, Sinsin B *et al*. Modelling the current and future distribution of *Kigelia africana* under climate change in Benin, West Africa. Modeling Earth Systems and Environment. 2018 Sep;4:1225-38. https://doi.org/10.1007/s40808-018-0491-4
25. Meminvegni Landry GG, Fortuné A, Appollonia Aimiosino O, Brice S, Brahim SU, Lucette A. Examining the effectiveness of a protected areas network in the conservation of *Kigelia africana* under climate change by 2050 in Benin.
26. Nabatanzi A, M Nkadimeng S, Lall N, Kabasa JD, J McGaw L. Ethnobotany, phytochemistry and pharmacological activity of *Kigelia africana* (Lam.) Benth.(Bignoniaceae). Plants. 2020 Jun 15;9(6):753. https://doi.org/10.3390/plants9060753
27. Ogunlakin AD, Sonibare MA, Yeye OE, Gyebi GA, Ayokunle DI, Arigbede OE *et al*. Isolation and characterization of novel hydroxyflavone from *Kigelia africana* (Lam.) Benth. fruit ethyl acetate fraction against CHO 1 and HeLa cancer cell lines: *In vitro* and *in silico* studies. Journal of Molecular Structure. 2023 Jun 15;1282:135180. https://doi.org/10.1016/j.molstruc.2023.135180

28. Oyaizu M. Studies on products of browning reactions: Antioxidative activities of products of browning reaction prepared from glucosamine. Jpn J Nutr. 1986;44:629-32. https://doi.org/10.5264/eiyogakuzashi.44.307

29. Gyamfi MA, Yonamine M, Aniya Y. Free-radical scavenging action of medicinal herbs from Ghana: *Thonningia sanguinea* on experimentally-induced liver injuries. General Pharmacology: The Vascular System. 1999 Jun 1;32(6):661-67. https://doi.org/10.1016/S0306-3623(98)00238-9

30. Minotti G, Aust SD. The requirement for iron (III) in the initiation of lipid peroxidation by iron (II) and hydrogen peroxide. Journal of Biological Chemistry. 1987 Jan 25;262(3):1098-104. https://doi.org/10.1016/S0021-9258(19)75755-X

31. Oboh G, Puntel RL, Rocha JB. Hot pepper (*Capsicum annuum*, Tepin and *Capsicum chinese*, Habanero) prevents Fe2+-induced lipid peroxidation in brain–*In vitro*. Food Chemistry. 2007 Jan 1;102(1):178-85.https://doi.org/10.1016/j.foodchem.2006.05.048

32. Halliwell B, Gutteridge JM. Formation of a thiobarbituric-acid-reactive substance from deoxyribose in the presence of iron salts: The role of superoxide and hydroxyl radicals. FEBS Letters. 1981 Jun 15;128(2):347-52. https://doi.org/10.1016/0014-5793(81)80114-7

33. Devi M, Kumar P, Singh R, Sindhu J, Kataria R. Design, synthesis, spectroscopic characterization, single crystal X-ray analysis, *In vitro* α-amylase inhibition assay, DPPH free radical evaluation and computational studies of naphtho [2, 3-d] imidazole-4, 9-dione appended 1, 2, 3-triazoles. European Journal of Medicinal Chemistry. 2023 Mar 15;250:115230. https://doi.org/10.1016/j.ejmech.2023.115230

34. Bellé NA, Dalmolin GD, Fonini G, Rubin MA, Rocha JB. Polyamines reduces lipid peroxidation induced by different pro-oxidant agents. Brain Research. 2004 May 22;1008(2):245-51. https://doi.org/10.1016/j.brainres.2004.02.036

35. Ohkawa H, Ohishi N, Yagi K. Assay for lipid peroxides in animal tissues by thiobarbituric acid reaction. Analytical Biochemistry. 1979 Jun 1;95(2):351-58. https://doi.org/10.1016/0003-2697(79)90738-3

36. Aziz MA, Diab AS, Mohammed AA. Antioxidant categories and mode of action. Antioxidants. 2019 Nov 6;2019:3-22.

37. Hussain T, Fatima I, Rafay M, Shabir S, Akram M, Bano S. Evaluation of antibacterial and antioxidant activity of leaves, fruit and bark of *Kigelia africana*. Pak J Bot. 2016;48(1):277-83.

38. Zhang C, Feng S, Wang Q, Wang P, Xu J, Chen T. Flavonoids and phenolic compounds from *Smilax scobinicaulis*. Chem Nat Compd. 2014;50(2):254-57. https://doi.org/10.1007/s10600-014-0925-9

39. Admassu S, Kebede M. Application of antioxidants in food processing industry: Options to improve the extraction yields and market value of natural products. Adv Food Technol Nutr Sci. 2019;5:38-49. https://doi.org/10.17140/AFTNSOJ-5-155

40. Gulcin İ. Antioxidants and antioxidant methods: An updated overview. Archives of toxicology. 2020 Mar;94(3):651-715. https://doi.org/10.1007/s00204-020-02689-3

41. Nieto G. How are medicinal plants useful when added to foods?. Medicines. 2020 Sep 14;7(9):58. https://doi.org/10.3390/medicines7090058

42. Sadiq IZ. Free radicals and oxidative stress: Signaling mechanisms, redox basis for human diseases and cell cycle regulation. Current Molecular Medicine. 2023 Jan 1;23(1):13-35. https://doi.org/10.2174/1566524022666211222161637

43. Stoia M, Oancea S. Low-molecular-weight synthetic antioxidants: Classification, pharmacological profile, effectiveness and trends. Antioxidants. 2022 Mar 26;11(4):638. https://doi.org/10.3390/antiox11040638

44. Girish YR, Sharath Kumar KS, Prashantha K, Rangappa S, Sudhanva MS. Significance of antioxidants and methods to evaluate their potency. Materials Chemistry Horizons. 2023 May 1;2(2):93-112.

45. Islam M, Prottay AA, Sultana I, Al Faruq A, Bappi MH, Akbor MS *et al*. Phytochemical screening and evaluation of antioxidant, anti-inflammatory, antimicrobial and membrane-stabilizing activities of different fractional extracts of *Grewia nervosa* (Lour.) Panigrahi. Food Bioscience. 2023 Aug 1;54:102933. https://doi.org/10.1016/j.fbio.2023.102933

46. Anusha Siddiqui S, Redha AA, Esmaeili Y, Mehdizadeh M. Novel insights on extraction and encapsulation techniques of elderberry bioactive compounds. Critical Reviews in Food Science and Nutrition. 2023 Aug 29;63(22):5937-52. https://doi.org/10.1080/10408398.2022.2026290

47. Jyotirmayee B, Mahalik G. A review on selected pharmacological activities of *Curcuma longa* L. International Journal of Food Properties. 2022 Dec 31;25(1):1377-98. https://doi.org/10.1080/10942912.2022.2082464

48. Akintunde JK, Akintunde DG, Irondi EA, Babaita K, Labaika R, Sunday O. Antioxidants from stem bark of *Kigelia africana* inhibits free radicals and membrane lipid damage in rat testes *in vitro*. Oxidants and Antioxidants in Medical Science. 2016;5(2):63. https://doi.org/10.5455/oams.240516.or.097

49. Alkhatib A. Antiviral functional foods and exercise lifestyle prevention of coronavirus. Nutrients. 2020 Aug 28;12(9):2633. https://doi.org/10.3390/nu12092633

50. Ogunlakin AD, Sonibare MA, Jabeen A, Shah SF, Shaheen F. Antioxidant and anti-proliferative studies on *Kigelia africana* (Lam.) Benth. and its constituents. Tropical Journal of Natural Product Research (TJNPR). 2021 Mar 1;5(3):570-75. doi.org/10.26538/tjnpr/v5i3. 25.

51. Fagbohun OF, Olawoye B, Ademakinwa AN, Jolayemi KA, Msagati TA. Metabolome modulatory effects of *Kigelia africana* (Lam.) Benth. fruit extracts on oxidative stress, hyperlipidaemic biomarkers in STZ-induced diabetic rats and antidiabetic effects in 3T3 L1 adipocytes. Journal of Pharmacy and Pharmacology. 2020 Dec;72(12):1798-811. https://doi.org/10.1111/jphp.13362

52. Ogunlakin AD, Ojo OA, Gyebi GA, Akinwumi IA, Adebodun GO, Ayokunle DI *et al*. Elemental evaluation, nutritional analysis, GC-MS analysis and ameliorative effects of *Artocarpus communis* JR Forst. & G. Forst. seeds' phytoconstituents on metabolic syndrome via *in silico* approach. Journal of Biomolecular Structure and Dynamics. 2023 Dec;11:1-21. https://doi.org/10.1080/07391102.2023.2293271

53. Ojo OA, Rotimi DE, Ojo AB, Ogunlakin AD, Ajiboye BO. Gallic acid abates cadmium chloride toxicity via alteration of neurotransmitters and modulation of inflammatory markers in Wistar rats. Scientific Reports. 2023 Jan 28;13(1):1577. https://doi.org/10.1038/s41598-023-28893-6

54. Ojo OA, Ogunlakin AD, Gyebi GA, Ayokunle DI, Odugbemi AI, Babatunde DE *et al*. Profiling the antidiabetic potential of GC–MS compounds identified from the methanolic extract of *Spilanthes filicaulis*: experimental and computational insight. Journal of Biomolecular Structure and Dynamics. 2023 Dec 6;1-22. https://doi.org/10.1080/07391102.2023.2291828

55. Fagbohun OF, Oriyomi OV, Adekola MB, Msagati TA. Biochemical applications of *Kigelia africana* (Lam.) Benth. fruit extracts in Diabetes mellitus. Comparative Clinical Pathology. 2020 Dec;29:1251-64. https://doi.org/10.1007/s00580-020-03179-9

56. Singh A, Kumari S, Singh AK, Singh NK. Ethnopharmacology and pharmacology of *Kigelia africana* (Lam.) Benth. Int J Green Pharm. 2018;11:S23-31.

57. Maritim A, Dene BA, Sanders RA, Watkins III JB. Effects of β-carotene on oxidative stress in normal and diabetic rats.

Journal of Biochemical and Molecular Toxicology. 2002;16 (4):203-08. https://doi.org/10.1002/jbt.10038

58. Ojo OA, Ogunlakin AD, Maimako RF, Gyebi GA, Olowosoke CB, Taiwo OA *et al*. Therapeutic study of cinnamic acid derivative for oxidative stress ablation: The computational and experimental answers. Molecules. 2023 Nov 4;28(21):7425. https://doi.org/10.3390/molecules28217425

59. Ezuruike UF, Prieto JM. The use of plants in the traditional management of diabetes in Nigeria: Pharmacological and toxicological considerations. Journal of Ethnopharmacology. 2014;155(2):857-924. https://doi.org/10.1016/j.jep.2014.05.055

60. Ogunlakin AD, Onifade TR, Ojo OA, Adesanya EO, Berena GA, Ayeni PO *et al*. Antidiabetic potential of *Carica papaya* L. and its constituents: From folkloric uses to products development. Bioactive Compounds in Health and Disease. 2023 Jun 30;6 (6):126-44. https://doi.org/10.31989/bchd.v6i6.1108

61. Ojo OA, Ogunlakin AD, Gyebi GA, Ayokunle DI, Odugbemi AI, Babatunde DE *et al*. GC-MS chemical profiling, antioxidant, anti-diabetic and anti-inflammatory activities of ethyl acetate fraction of *Spilanthes filicaulis* (Schumach. And Thonn.) CD Adams leaves: experimental and computational studies. Frontiers in Pharmacology. 2023;14. https://doi.org/10.3389/fphar.2023.1235810

62. Eichler HG, Korn A, Gasic S, Prison W, Businger J. The effect of new specific á amylase inhibitor on post-prandial glucose and insulin excursions in normal subjects and Type 2 (non insulin dependent) diabetic patients. Diabetologia. 1984;26(4):278-81. https://doi.org/10.1007/BF00283650

63. Tarling CA, Woods K, Zhang R, Brastianos HC, Brayer GD, Andersen RJ *et al*. The search for novel human pancreatic á-amylase inhibitors: High-throughput screening of terrestrial and marine natural product extracts. ChemBioChem. 2008;9:433 -38. https://doi.org/10.1002/cbic.200700470

64. Sonibare MA, Ogunlakin AD. Antidiabetic and antioxidant effects of methanol extract and fractions of *Glyphaea brevis* (Spreng.) Monachino in alloxan-induced diabetic rats. West African Journal of Pharmacy. 2016;27(1):42-53.

65. Kim YM, Jeong YK, Wang MH, Lee WY, Rhee HI. Inhibitory effect of Pine on hyperglycemia. Nutrition. 2005;21:756-61. https://doi.org/10.1016/j.nut.2004.10.014