

Regular Research Paper

Antioxidant properties of African mahogany (*Khaya senegalensis* (Desr.) A. Juss.) seed oil

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This study investigated the phytochemical constituents and antioxidant properties of *Khaya senegalensis* seed oil. Using standard analytical methods, the presence of saponins, steroids, terpenoids, cardiac glycosides, alkaloids, and proteins was confirmed, while flavonoids, tannins, reducing sugars, and anthraquinones were absent. Quantitative analysis showed high contents of flavonoids (106.38 ± 0.65), proanthocyanidins (103.74 ± 7.49), tannins (21.68 ± 0.81), and phenolics (17.60 ± 0.34). In vitro antioxidant assays demonstrated that *K. senegalensis* seed oil exhibited significant ferric reducing antioxidant power and strong nitric oxide scavenging activity, particularly at lower concentrations. However, its scavenging potential against DPPH radicals and lipid peroxidation was relatively lower compared to ascorbic acid. These findings underscore the potential of *K. senegalensis* seed oil as a valuable source of natural antioxidants, highlighting its possible application in dietary supplements and medicinal formulations. Rich in bioactive compounds, such as steroids, cardiac glycosides, and proteins, the seed oil holds promise for combating oxidative stress-related health issues. Further research exploring its precise antioxidant mechanisms and therapeutic efficacy is recommended, reinforcing its potential as a sustainable resource for enhancing human health and well-being.

Key words: *Khaya senegalensis*, phytochemistry, *in vitro* antioxidant activities, alkaloid, underutilized and neglected plant.

INTRODUCTION

In recent decades, there has been an increased interest in validating ethnomedicinal claims associated with various plant extracts, particularly focusing on oils derived from medicinal plants (Bolouri et al., 2022; Mohamed and Alotaibi, 2023; Nasim et al., 2022). This effort is deeply rooted in the historical utilization of herbs, which has been substantiated through scientific investigations revealing bioactive compounds, termed

phytochemicals, that exhibit significant physiological benefits for human health (Adamu et al., 2022). The intersection of ecological diversity and cultural heritage within a nation is also particularly noteworthy, as various plant species embody both biological richness and traditional knowledge (Olatunji et al., 2021; Ogwu et al., 2024; Ogwu et al., 2024). Among the plethora of medicinal plants, *Khaya senegalensis*

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(Desr.) A. Juss., commonly known as African mahogany, stands out due to its extensive applications in ethnopharmacology (Ogwu et al., 2017). The stem bark extract of *K. senegalensis* has been documented for an array of therapeutic properties, including antipyretic effects, treatment modalities for syphilis, and remedies for jaundice, allergies, infections, and more (Adamu et al., 2022; Olatunji et al., 2021). Furthermore, it has been shown to possess anti-inflammatory properties, rendering it a potential candidate for incorporation into anti-inflammatory formulations (Olatunji et al., 2021). This medicinal plant's root extracts have also been employed to address mental disorders and leprosy, while its seeds and leaves are used for alleviating fever and headaches, thereby reinforcing the therapeutic applications of this species across various health issues (Adji et al., 2023).

K. senegalensis thrives predominantly in sub-Saharan Africa's tropical rainforests and savannas (Rabadeaux et al., 2017; Allah et al., 2019; Baillères et al., 2019). This ecological preference for well-drained soils with adequate moisture aligns its growth with prominent tree species like *Milicia excelsa* and *Tectona grandis* (de Vries et al., 2001). Notably, the ecological contributions of African mahogany trees extend beyond mere biomass generation; they provide habitat and sustenance for diverse wildlife, regulate water, and stabilize soil (de Vries et al., 2001; Sa'adiya et al., 2023). Remarkably, these trees can attain heights of up to 50 meters, exhibit extensive spreading crowns, and develop complex leaf structures that enhance their adaptability to various environmental conditions (de Vries et al., 2001). Despite extensive documentation on the uses of *K. senegalensis*, its potential as a source of bioactive compounds remains inadequately explored (Oyekunle and Omode, 2008). As part of the Meliaceae family, it presents a reservoir of prospective medicinal applications, notably in treating malaria and exhibiting bactericidal properties (Touzout et al., 2023). Research has indicated that the stem bark extracts of *K. senegalensis* demonstrate activity against *Plasmodium falciparum*, possess anti-sickling properties, and demonstrate anti-hyperglycemic activity (Sa'adiya et al., 2023; Ugoh et al. 2014; Abdel-Wareth et al., 2014). The pharmacological capabilities of this plant encompass antifungal, antiprotozoal, anthelmintic, antimicrobial, anti-cancer, and free radical scavenging activities (Olatunji et al., 2021; Victor et al., 2021; Androulakis et al., 2006). Prior studies have reported hepatoprotective properties, underscoring its multifaceted biological activity (Olatunji et al., 2021; Victor et al., 2021). Nutritional analysis of *K. senegalensis* leaves revealed a composition of 12% crude protein and 43% neutral detergent fibers on a dry weight basis, indicating its potential dietary benefits (Adamu et al., 2022; Sharma et al., 2014).

This potential is particularly relevant in the context of rising reliance on herbal remedies among indigenous populations for managing various health conditions

(Olatunji et al., 2021; Abdel-Wareth et al., 2014). *K. senegalensis* has also gained recognition for its efficacy in traditional veterinary practices (Olatunji et al., 2021; Asigbaase et al., 2023; Onu et al., 2013). The increasing adoption of herbal treatments is largely fueled by their affordability and perceived safety, augmenting interest in the therapeutic potentials of this species (Ademola et al., 2004; Izah et al., 2024; Obahiagbon and Ogwu, 2023; Obahiagbon and Ogwu, 2023).

The implications of oxidative stress on human health are profound, as antioxidants play a critical role in mitigating such stress (Pizzino et al., 2017; Sharifi-Rad et al., 2020). It has been shown that chronic ailments such as cardiovascular diseases and endothelial cell dysfunction are closely linked to oxidative damage inflicted on essential biomolecules (Adamu et al., 2022; Ogwu et al., 2017; Scioli et al., 2020; Sun et al., 2020). This highlights the importance of antioxidants not only for prevention but also for treatment. Polyphenolic compounds, recognized for their potent antioxidant properties, positively influence endothelial functioning (Ogwu et al., 2017; Iqbal et al., 2023; Ziolkiewicz et al., 2023). Consequently, dietary regimes enriched with antioxidants are posited to alleviate obesity-related health issues while enhancing overall quality of life (Adamu et al., 2022). Antioxidants scavenge free radicals, combating lipid peroxidation and maintaining cellular integrity (Valgimigli, 2023; Kurutas, 2016). They act as vital reducing agents, preventing oxidative chain reactions and thereby promoting cellular health and warding off chronic diseases (Vwioko et al., 2018; Pham-Huy et al., 2008). This underscores the necessity of exploring the phytochemical profile of *K. senegalensis*, particularly its seed oil.

This study aims to investigate the secondary phytochemical profile, *in vitro* antioxidant capabilities, and potential health benefits associated with *K. senegalensis* seed oil. The methodology will encompass the collection and extraction of oil from *K. senegalensis* seeds, followed by a rigorous phytochemical assessment aimed at quantifying the antioxidant activity and nitric oxide scavenging potential of the oil extracts. This investigation seeks to elucidate the previously unexplored antioxidant properties of *K. senegalensis*, with aspirations for future applications in food and medicine. The study will contribute to understanding the phytochemical composition and potential health benefits of *K. senegalensis* seed oil. Through identifying and characterizing its secondary metabolites and antioxidant properties, the study provides scientific validation for its therapeutic potential. This is particularly valuable in the search for natural antioxidants that can combat oxidative stress-related diseases such as cancer, cardiovascular disorders, and neurodegenerative conditions. Furthermore, the study supports the sustainable use of indigenous plants in health and wellness applications, contributing to both local economic development and the



Figure 1. *K. senegalensis*.

global demand for plant-based functional compounds.

MATERIALS AND METHODS

Collection and identification of plant materials

The mature fruits of *K. senegalensis* were gathered from established trees in the Mandara hills of Adamawa State, Nigeria (24.84° N, 87.04° E) as shown in Figures 1 and 2 and were authenticated in the Plant Biology and Biotechnology Department at

the University of Benin, Edo State, Nigeria (6.40° N, 5.61° E). Subsequently, the mature fruits depicted in Figure 2 were left to dry in the open air for a period of two weeks under direct sunlight.

Extraction of *Khaya senegalensis* seed oil

This was done as described in Kandeda et al. [Kandeda et al., 2022], Rahim et al [2022] and Yang et al. [Yang et al., 2021]. The fruits were sliced open, and the seeds were extracted. The small outer covering was then removed to reveal the white seeds, which were sun-dried and roasted in a pot. They were subsequently



Figure 2. *K. senegalensis* fruit and leaves.

crushed to form a smooth paste. A kilogram of wood ash was soaked in 1.5 liters of water, filtered, and combined with 5.0 liters of water and 1.0 liter of the wood ash solution. This mixture was boiled with constant stirring for a period of 3 hours. Over time, the oil rose to the surface, was skimmed off, heated to eliminate any remaining water content, and stored in an airtight container.

Phytochemical screening

Flavonoid test

To screen for flavonoids, 1 ml of the extract was combined with 5 ml of diluted ammonia solution in a test tube. Subsequent to mixing, 1 ml of concentrated sulfuric acid (H_2SO_4) was added gradually to the solution (Sankhalkar and Vernekar, 2016). The appearance of a yellow coloration in the mixture was indicative of the presence of flavonoids, a class of compounds known for their antioxidant properties and cardiovascular benefits (Godlewska et al., 2023).

Tannin test

For the detection of tannins, approximately 1 ml of the extract, prepared as a filtrate, was subjected to heating in a test tube for five minutes until boiling. Following this, drops of 15% ferric chloride solution were introduced into the heated extract. The formation of a blue-black coloration provided confirmation of tannins, which are recognized for their astringent properties and health benefits, including potential anti-inflammatory and antimicrobial effects (Batool et al., 2019).

Cardiac glycosides test

To assess the presence of cardiac glycosides, Killiani's test was conducted (Bakir et al., 2022). About 1 ml of the extract was mixed with 2 ml of glacial acetic acid in a test tube. Following this, one drop of 15% ferric chloride and 1 ml of concentrated sulfuric acid

were added. The formation of a brown color at the interface of the layers signaled the presence of cardiac glycosides, compounds known for their significant cardiotonic effects (Calderón-Montaña, et al., 2014).

Saponin test

The frothing ability of saponins was utilized as a screening test (Chen et al., 2010). About 1 ml of the extract was vigorously mixed with 5 ml of distilled water. The observation of persistent frothing after shaking indicated the presence of saponins, which are noted for their potential immune-boosting and cholesterol-lowering properties (Mujeeb et al., 2014).

Steroid test

This was done using the Lieberman-Burchard test (Adu et al., 2019). To test for steroid compounds, 1 ml of the extract was combined with 2 ml of acetic acid, followed by the addition of 2 ml of concentrated sulfuric acid in a test tube. A notable color change from violet to blue-green indicated the presence of steroids, which are important for various biological functions and therapeutic applications (Auwal et al., 2014).

Terpenoids test

According to Salkowski's test, 1 ml of the extract was mixed with 2 ml of chloroform and 3 ml of concentrated sulfuric acid (Das et al., 2014). A reddish-brown coloration observed at the interface provided confirmation of terpenoids, a diverse class of organic compounds with potential pharmacological properties, including anti-inflammatory and anticancer effects (Antoniadou et al., 2023).

Alkaloids test

The alkaloid content was evaluated using Wagner's test (Alemu et al., 2024). 1 ml of the extract was treated with several drops of Wagner's reagent. The occurrence of a red-colored precipitate signified the presence of alkaloids, which are well-known for their effectiveness in pain relief, anti-inflammatory effects, and various other therapeutic uses (Dahanayake et al., 2019).

Reducing sugar test

To determine the presence of reducing sugars, 1 ml of the extract was mixed with boiling Fehling's solutions A and B in a test tube (Usman et al., 2009). A color change from blue to green indicated a positive result for reducing sugars, which are important for energy metabolism and exhibit antioxidant properties.

Anthraquinones test

For the detection of free anthraquinones, 5 ml of benzene was added to 1 ml of extract in a test tube (Owor et al., 2024). The mixture was vigorously shaken with 2.5 ml of ammonia. The formation of a pink-red coloration in the lower phase indicated the presence of free anthraquinones, known for their potential laxative effects and antimicrobial activity (Manosroi et al., 2020).

Proteins test

To check for protein content, the oil extract was treated with a few

drops of concentrated nitric acid (Gangwar et al., 2014). The development of a yellow color was indicative of the presence of proteins, confirming the positive outcome of this assay (Ali et al., 2018). Proteins play crucial roles in various biological processes and may also exhibit significant health benefits.

Quantification of phytochemicals

Estimation of total phenolic content

The total phenolic content in the seed oil extracts was determined by the Folin-Ciocalteu method as described in (Pérez et al., 2023). Various concentrations of gallic acid, ranging from 10 µg/mL to 120 µg/mL, were prepared in methanol to establish a standard curve. For the assay, 0.5 mL of the seed oil extract (at a concentration of 1 mg/mL) was mixed with 2.5 mL of a ten-fold diluted Folin-Ciocalteu reagent and 2 mL of 7% sodium carbonate (Na₂CO₃) solution (Srivastava et al., 2023; Mueed et al., 2023). The mixture was allowed to incubate at room temperature for 30 minutes to facilitate color development. Absorbance was subsequently measured at 760 nm using a spectrophotometer. All measurements were performed in triplicate, and the total phenolic content was expressed as Gallic Acid Equivalent (GAE), providing a quantifiable assessment of the phenolic compounds contributing to the antioxidant potential of the extracts (de Araújo et al., 2014).

Estimation of total flavonoid content

Flavonoid content is crucial for antioxidant activities, and it was quantified using the aluminum chloride colorimetric method according to Chandra et al. (Chandra et al., 2014). In this assay, a reaction mixture was prepared by combining 1.0 mL of the extract with 0.5 mL of 1.2% aluminum chloride solution in ethanol and 0.5 mL of 120 mM potassium acetate. After incubation at room temperature for 30 minutes, the absorbance of the mixture was measured at 415 nm. Quercetin, a well-known flavonoid, was used as the standard for comparison (Kumar and Jain, 2015). The different mechanisms of action attributable to flavonoids, such as metal ion chelation and scavenging of reactive oxygen species (ROS), emphasize their importance in health-related applications (Zahra et al., 2024; Speisky et al., 2022).

Determination of total tannin content

The total tannin content was determined through a modified Folin-Denis method as described by (Oikeh et al. 2020), which involves measuring the intensity of a blue color formed due to the reduction of phosphomolybdic acid by tannin compounds in an alkaline medium. Specifically, 0.5 mL of the seed oil extract (at a concentration of 1 mg/mL) and a standard solution of tannic acid (ranging from 10 to 150 µg/mL) were combined with 0.5 mL of Folin-Denis reagent and 1 mL of 7.5% Na₂CO₃ solution [Wiesneth and Jürgenliemk, 2017]. To dilute the final mixture, 3.4 mL of distilled water was added. Absorbance of the resulting solution was measured at 700 nm using a spectrophotometer. The total tannin content results were expressed in milligrams of tannic acid equivalent per gram of extract, reflecting the capacity of the extracts to scavenge free radicals and contribute to overall antioxidant activity [Ponticelli et al., 2024].

Determination of proanthocyanidin content

Proanthocyanidin content was quantified following the method outlined by Ngamsuk et al. (Ngamsuk et al., 2019), which relies on

the oxidative depolymerization of condensed tannins in the presence of a vanillin-methanol reagent. For this analysis, 0.5 mL of the 1.0 mg/ml seed oil extract was combined with 1 ml of a 4% vanillin-methanol solution and 0.75 ml of concentrated hydrochloric acid. The mixture was allowed to remain undisturbed for 15 minutes to ensure proper reaction. Absorbance was subsequently assessed at 500 nm. In this analysis, ascorbic acid was used as the standard for comparison (Nemes et al., 2018; Nitao et al., 2001). The quantification of proanthocyanidins, important for their health-promoting properties, underscores the significance of these compounds in the evaluation of the antioxidant capacity of *Khaya senegalensis* extracts.

In Vitro antioxidant activity

Determination of total antioxidant capacity

Total antioxidant activity was quantified using the phosphomolybdenum assay, as described by Prieto et al. [Prieto et al., 1999]. This assay measures the ability of the extract to reduce molybdenum (VI) ions to molybdenum (V) ions in an acidic medium, forming a green phosphomolybdic complex. For this assay, 1 ml of the seed oil extract diluted to a concentration of 1 mg/ml was combined with 3 ml of the molybdate reagent solution in a test tube. The mixture was subjected to incubation at a temperature of 95°C for a duration of 90 min to facilitate the reduction reaction. Following incubation, the tubes were allowed to cool to room temperature, typically for 20 to 30 min, to stabilize the reaction mixture. The absorbance of the resulting solution was subsequently measured at a wavelength of 695 nm using a spectrophotometer. The antioxidant capacity of the extracts was expressed as a percentage of inhibition, comparing the absorbance values to a standard curve created using ascorbic acid, a well-known potent antioxidant (Pisoschi et al., 2016).

Estimation of Diphenyl-2-Picryl-Hydrazyl (DPPH) radical scavenging activity

The scavenging potential of the *K. senegalensis* seed oil extracts against the stable free radical 1,1-diphenyl-2-picryl-hydrazyl (DPPH) was evaluated following a modified methodology based on Okawa et al (Okawa et al., 2001) and Chrzczanowicz et al. (Chrzczanowicz et al., 2008). The DPPH assay is predicated on the reduction of the purple-colored DPPH radical when it interacts with antioxidant compounds, resulting in a color change from deep violet to golden yellow. To conduct the assay, 0.5 milliliters (0.5 ml) of a 0.3 mM DPPH solution in methanol was combined with two milliliters (2 ml) of varying concentrations of the seed oil extracts, ranging from 0.2 mg/ml to 1.0 mg/ml. The reaction mixture was thoroughly shaken to ensure homogeneity and subsequently incubated for 15 min at room temperature in a dark environment to prevent light interference with the color change. The absorbance was then measured at a wavelength of 517 nm using a spectrophotometer. All assays were performed in triplicate to ensure reproducibility and statistical significance of results. As a control, ascorbic acid was used at comparable concentrations to the test samples. A blank control consisting of 0.5 ml of 0.3 mM DPPH solution and 2 ml of methanol was also prepared for baseline measurements. The radical scavenging activity (%) was calculated using the following formula:

$$\frac{A_0 - A_1}{A_0}$$

DPPH radical scavenging activity (%) = $\times 100$

Where A_0 was the absorbance of DPPH radical + methanol; A_1 was the absorbance of DPPH radical + sample extract or standard. The 50 % inhibitory concentration value (IC_{50}) was calculated as the effective concentration of the extract that is required to scavenge 50 % of the DPPH free radicals.

Ferric reducing antioxidant power (FRAP) assay

The Ferric Reducing Antioxidant Power (FRAP) assay was conducted employing a modified protocol based on the methodology established by Benzie and Strain [Benzie et al., 1996]. This assay evaluates the capacity of antioxidants to reduce ferric ions (Fe^{3+}) to ferrous ions (Fe^{2+}) in the presence of 2,4,6-tri(2-pyridyl)-s-triazine (TPTZ). The resulting blue Fe^{2+} -TPTZ complex exhibits a peak absorbance at 593 nm, which serves as an indicator of reducing power. To perform the assay, a freshly prepared FRAP solution was created by combining the following: 25 mL of 300 mM acetate buffer (adjusted to pH 3.6), 2.5 mL of a 10 mM TPTZ solution, and 2.5 mL of a 20 mM ferric chloride ($FeCl_3 \cdot 6H_2O$) solution. Subsequently, 1.5 mL of this FRAP solution was mixed with 1 mL of the *Khaya senegalensis* extracts at an approximate concentration of 1 mg/mL, as well as standard solutions of ferrous sulfate ($FeSO_4$) ranging in concentrations from 100 μ M to 600 μ M. The reaction mixtures were incubated at 37 °C for 30 minutes to allow complete reduction. After this incubation period, the absorbance of the solution was measured at 593 nm using a spectrophotometer. A calibration curve was constructed using the absorbance values from the standard $FeSO_4$ solutions, and the ferric reducing ability of the extracts was reported as micromoles of Fe (II) per gram of extract, allowing for a quantifiable assessment of antioxidant capacity.

Estimation of reducing power

The reducing power of the *K. senegalensis* seed oil extracts was determined using a method adapted from Ak and Gülçin [Ak and Gülçin, 2008], which leverages the reduction of ferric ions as a measure of electron-donating activity, a key indicator of antioxidant capability, particularly among phenolic compounds. For the assay, various concentrations of the seed oil extracts (ranging from 0.1 to 1.0 mg/ml) were combined with 2.5 ml of 0.2 M phosphate buffer at pH 6.6 and 2.5 ml of 1% potassium ferricyanide ($K_3Fe(CN)_6$). This reaction mixture was incubated at 50 °C for 20 min to facilitate the reduction process. To terminate the reaction, 2.5 ml of 10% trichloroacetic acid (TCA) was added. Following this, 2.5 mL of distilled water and 0.5 ml of 0.1% ferric chloride ($FeCl_3$) were introduced to the mixture. Absorbance was subsequently measured at 700 nm using a spectrophotometer, with higher absorbance values indicating greater reducing power of the extracts. Vitamin C functioned as the positive control for comparison, providing a benchmark for antioxidant activity.

Estimation of nitric oxide scavenging ability

The nitric oxide scavenging capability of the extracts was assessed using the method described by Green et al. (Green et al., 1982). In this assay, nitric oxide is generated from sodium nitroprusside when dissolved in an aqueous phosphate buffer saline (pH 7.4). Under these physiological conditions, nitric oxide reacts with oxygen to form nitrite ions, which are quantified using the Griess reaction. The ability of the extracts to scavenge nitric oxide competes with oxygen, thereby decreasing the nitrite production [Vikas et al., 2017]. To conduct the experiment, 2 mL of a 10 mM sodium nitroprusside solution was mixed with 0.5 mL of the seed oil extracts at variable concentrations ranging from 20 to 200 μ g/ml. In

Table 1. Phytochemical constituents of *K. senegalensis* oil.

Phytochemical	Presence
Saponins	+
Flavonoids	-
Steroids	+++
Tannins	-
Terpenoids	+
Cardiac glycosides	+++
Alkaloids	+
Reducing sugar	-
Anthraquinones	-
Proteins	+++

- = Absent, + = Present, +++ = Highly Present.

the assay as a standard for comparison within the same concentration range. The mixture was incubated at 25 °C for 150 min. Following incubation, 0.5 ml of the incubation solution was withdrawn and added to 0.5 mL of Griess reagent, which comprised 1.0 ml of sulfanilic acid reagent (0.33% in 20% glacial acetic acid) that had been prepared at room temperature for 5 minutes and 1.0 ml of naphthyl ethylene diamine dihydrochloride (0.1% w/v) (Amudha and Rani, 2016). The resulting mixture was then incubated at room temperature for an additional 30 min to allow color development. The absorbance of the solution was measured at 540 nm, with the resulting data utilized to assess the nitric oxide scavenging capacity of the extracts

RESULTS

The presence or absence of essential phytochemicals was determined using qualitative tests (Table 1) and quantitative analysis (Figure 3). The phytochemicals present include protein, flavonoids, terpenoids, tannins, phenolics, and cardiac glycosides. Quinones, coumarins, alkaloids, and saponins were absent. Some potential health benefits associated with these phytochemicals include antioxidant properties, anti-inflammatory effects, antimicrobial activity, and heart-protective effects. Flavonoids and phenolics have been linked to reducing the risk of chronic diseases such as cancer and cardiovascular diseases. Terpenoids have been studied for their potential anticancer and antimicrobial effects. Tannins have antioxidant and antimicrobial properties. Therefore, the presence of these phytochemicals in a plant can contribute to its health-promoting properties and make it beneficial for human consumption.

The quantitative studies of *K. senegalensis* oil, revealed total tannin content as 21.686 ± 0.81 , phenolic 17.603 ± 0.344 , flavonoid 106.383 ± 0.656 , and proanthocyanidin 103.746 ± 7.498 (Figure 3). These quantitative analyses provide valuable information about the phytochemical composition of *K. senegalensis* oil. The high levels of tannins, phenolics, flavonoids, and

proanthocyanidins indicate that this oil is rich in antioxidant compounds. Tannins are known for their antioxidant and antimicrobial properties, phenolics also have antioxidant and anti-inflammatory effects, flavonoids have been linked to various health benefits including heart health and anti-cancer properties, and proanthocyanidins are potent antioxidants that may help protect against oxidative stress and inflammation. These findings suggest that *Khaya senegalensis* oil may have potential health benefits due to its high levels of these beneficial phytochemicals.

Figure 4 suggests that the reducing power of the oil extracts of *K. senegalensis* is significantly higher than the standard ascorbic acid. More so, the ferric reducing antioxidant power of the *K. senegalensis* oil was significantly higher at higher doses. The results from Figure 4 indicate that the oil extracts of *K. senegalensis* have strong reducing power, even higher than the standard ascorbic acid, which is a well-known antioxidant. This suggests that the oil from *K. senegalensis* possesses potent antioxidant properties. Additionally, the ferric reducing antioxidant power of the *K. senegalensis* oil was observed to be significantly higher at higher doses. This means that at higher concentrations, the oil exhibited even greater antioxidant activity. This could be attributed to the presence of high levels of antioxidant compounds such as tannins, phenolics, flavonoids, and proanthocyanidins as previously mentioned. These results further support the potential health benefits of *Khaya senegalensis* oil due to its strong antioxidant capacity, which could help protect against oxidative stress, inflammation, and various diseases associated with free radical damage.

On the other hand, figure 5 shows the DPPH radical scavenging activity of the extracted oil. It was seen that *K. senegalensis* oil extracts have lower scavenging power when compared with the standard ascorbic acid. Figure 5 suggests that the DPPH radical scavenging activity of the extracted oil from *K. senegalensis* is lower compared to the standard ascorbic acid. DPPH is a stable free radical commonly used to evaluate the antioxidant activity of compounds, with higher scavenging power indicating stronger antioxidant properties. While the oil extracts from *Khaya senegalensis* may have demonstrated lower scavenging power compared to ascorbic acid in this specific assay, it is important to consider that different antioxidants may have varying mechanisms of action and target different types of free radicals.

Additionally, the overall antioxidant capacity of a compound or extract is often influenced by a combination of different antioxidant compounds present in the sample. Therefore, despite the lower scavenging power observed in the DPPH assay, the high levels of tannins, phenolics, flavonoids, and proanthocyanidins in *K. senegalensis* oil as indicated in the previous analyses suggest that it still possesses significant antioxidant potential and may

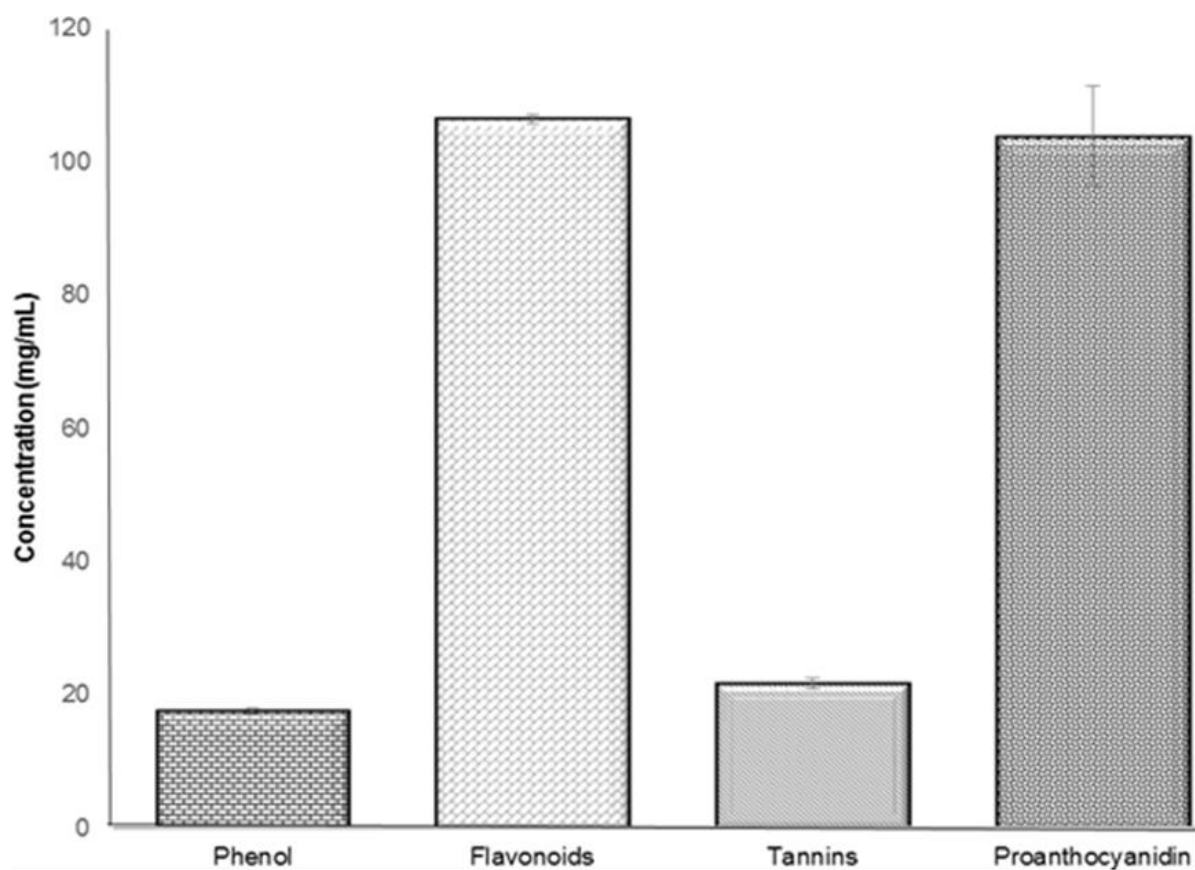


Figure 3. Qualitative assessment of the phytochemical constituents of *K. senegalensis* oil.

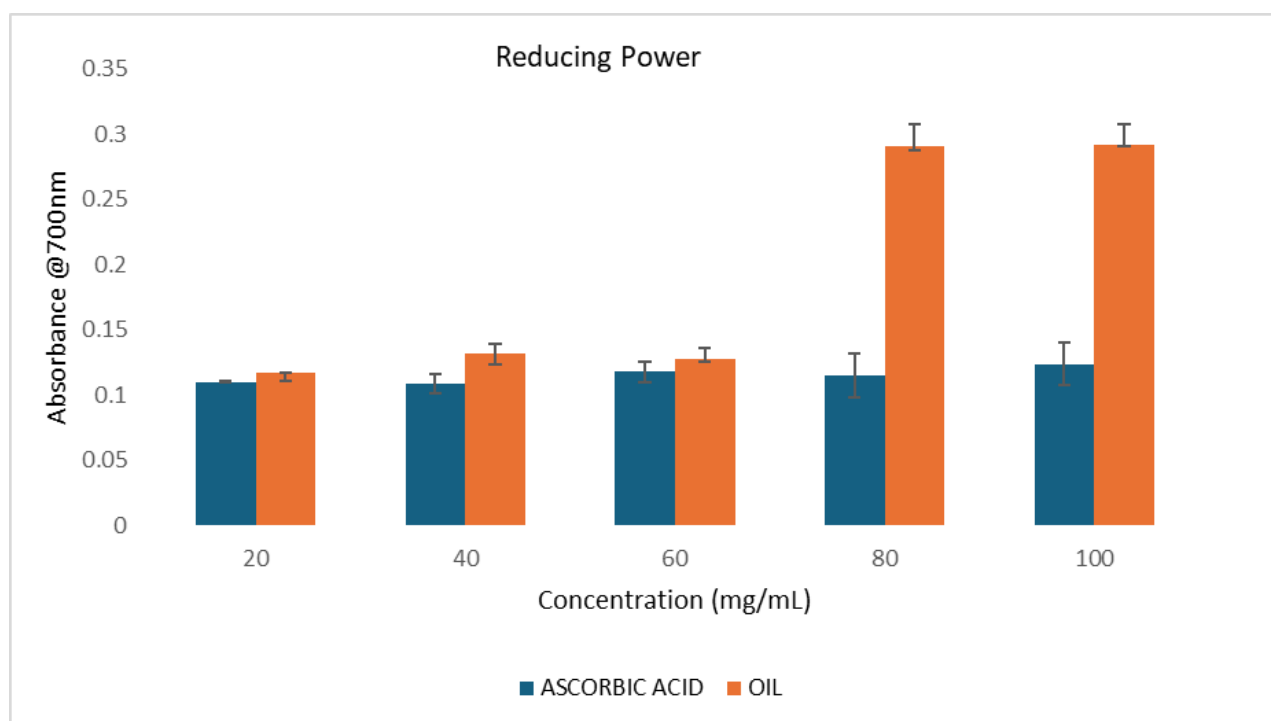


Figure 4. Reducing power of *K. senegalensis* seed oil in comparison with ascorbic acid.

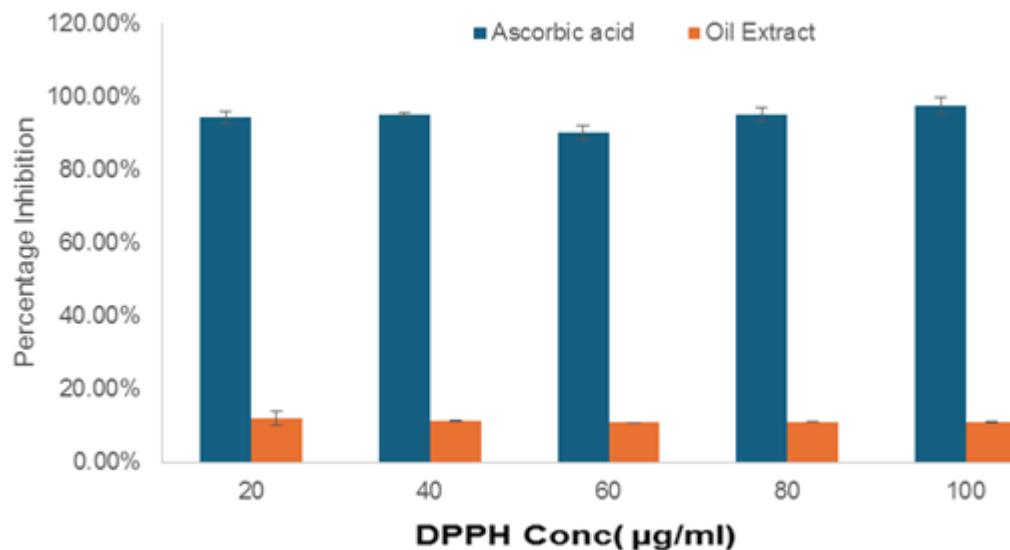


Figure 5. DPPH scavenging activity of *K. senegalensis* oil.

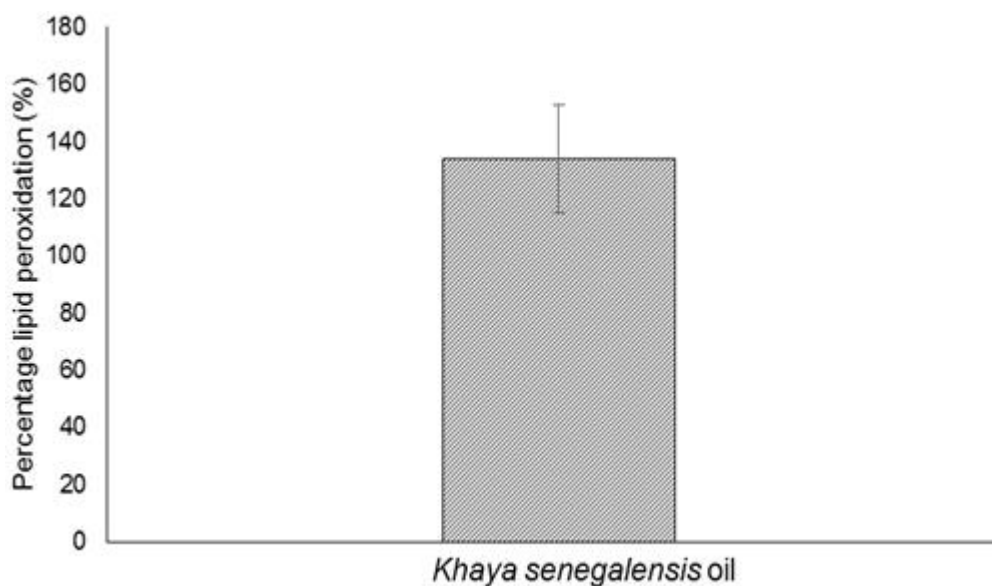


Figure 6. Percentage inhibition of lipid peroxidation of *K. senegalensis* oil.

provide health benefits through its antioxidant activity. Further studies are needed to fully understand the antioxidant mechanisms of *K. senegalensis* oil and its potential effects on health.

Whereas the inhibition of lipid peroxidation was shown to be lower in oil than the standard ascorbic acid (Figure 6). The results indicate that the oil extracts of *Khaya senegalensis* have lower inhibition of lipid peroxidation compared to the standard ascorbic acid. Lipid peroxidation is a chain reaction that can lead to cell damage and is often used as a marker for oxidative

stress and antioxidant activity. The lower inhibition of lipid peroxidation in the *K. senegalensis* oil compared to ascorbic acid in this assay suggests that the oil may be less effective in preventing the oxidative damage of lipids. This could be due to various factors such as the specific antioxidant compounds present in the oil, their concentrations, and their interactions with lipid peroxidation pathways.

The results in Figure 7 shows the nitric oxide scavenging ability of *K. senegalensis* oil extract. The results revealed that the *K. senegalensis* oil has higher

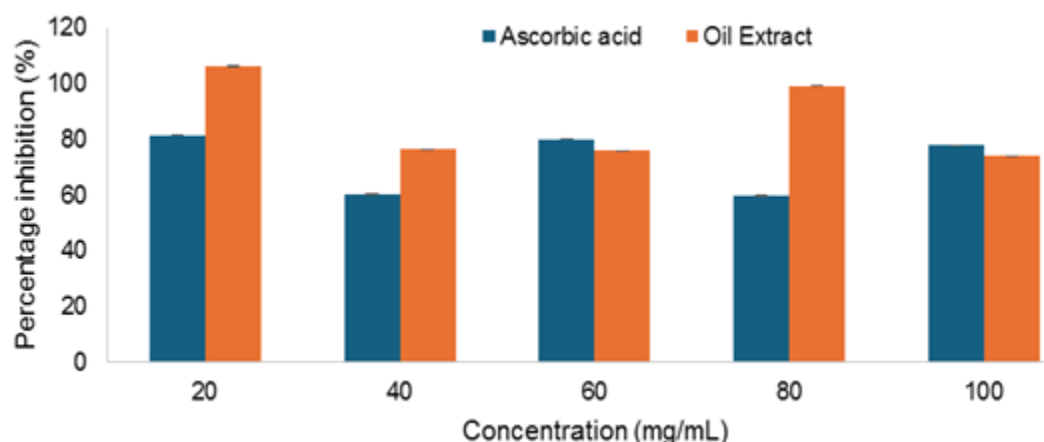


Figure 7. Nitric oxide Scavenging ability of *K. senegalensis* oil.

nitric oxide scavenging activity than the standard in a lower concentration. Nitric oxide (NO) is a signaling molecule that can act as a pro-oxidant in conditions of oxidative stress, leading to the formation of reactive nitrogen species and potential damage to cells and tissues. Scavenging of nitric oxide can help mitigate its harmful effects and protect against oxidative stress-related damage. The results showing that *K. senegalensis* oil exhibits higher nitric oxide scavenging activity compared to the standard at a lower concentration indicate that the oil may possess potent antioxidant properties specifically targeting nitric oxide-related oxidative stress. This suggests that the oil extract from *K. senegalensis* could potentially be beneficial in protecting against nitric oxide-induced damage and oxidative stress-related conditions.

It is important to note that different antioxidants may exhibit varying activities against specific free radicals or oxidative species, and the effectiveness of an antioxidant can depend on its specific interactions with the target molecule or pathway. Therefore, the observed higher nitric oxide scavenging activity of *K. senegalensis* oil compared to the standard at a lower concentration highlights its potential as a natural antioxidant source with specific benefits in mitigating nitric oxide-related oxidative stress.

Antioxidants, recognized as 'free radical scavengers', are compounds that can scavenge free radicals by interrupting the radical chain reactions or preventing the reactive oxidants from being formed and thereby inhibiting oxidation. The inhibition potential of *K. senegalensis* oil is presented in Figure 8.

DISCUSSION

The antioxidant properties of African Mahogany have been assessed to understand the ability of the plant to combat oxidative stress and neutralize harmful free

radicals in the body. Phytochemicals such as flavonoids, terpenoids, tannins, phenolics, proteins, cardiac glycosides, and steroids found in African Mahogany are believed to contribute to its antioxidant properties (Ugoh et al., 2014; Ishaq et al., 2014). These compounds have the ability to scavenge free radicals, prevent damage to cells and tissues, and protect against various oxidative stress-related conditions (Marino et al., 2022; Lobo et al., 2010). Studies have shown that African Mahogany oil extract exhibits high nitric oxide scavenging activity, indicating its potential as a potent antioxidant (Riyadi et al., 2023; Abba and Dogara, 2021). The presence of these antioxidants in African Mahogany suggests that it may have benefits for human health, including anti-inflammatory, anti-aging, and disease-preventive effects (Table 1; Figure 3). However, further research is needed to fully understand the mechanisms underlying the antioxidant properties of African Mahogany and to explore its potential applications in the development of natural antioxidant supplements or pharmaceuticals. The need to maintain a healthy lifestyle has become increasingly important due to human development and population growth (Obongodot et al., 2023). Plant-based foods offer a variety of essential nutrients that are crucial for human health and well-being. An analysis of the phytochemical composition of the seed oil from *K. senegalensis* indicates the presence of chemical components that have both physiological and medicinal benefits (Ugoh et al., 2014). These phytochemicals include flavonoids, terpenoids, tannins, phenolics, proteins, cardiac glycosides, and steroids, which are known to provide anti-inflammatory, antioxidant, and therapeutic benefits that support disease prevention and healing (Kumar et al., 2023). Notably, quinones, coumarins, alkaloids, and saponins were not found in *Khaya senegalensis* oil (Table 1; Figure 3).

Proteins, cardiac glycosides, and steroids are found to be present in exceptionally high amounts (Table 1). The high content of proteins, cardiac glycosides, and steroids

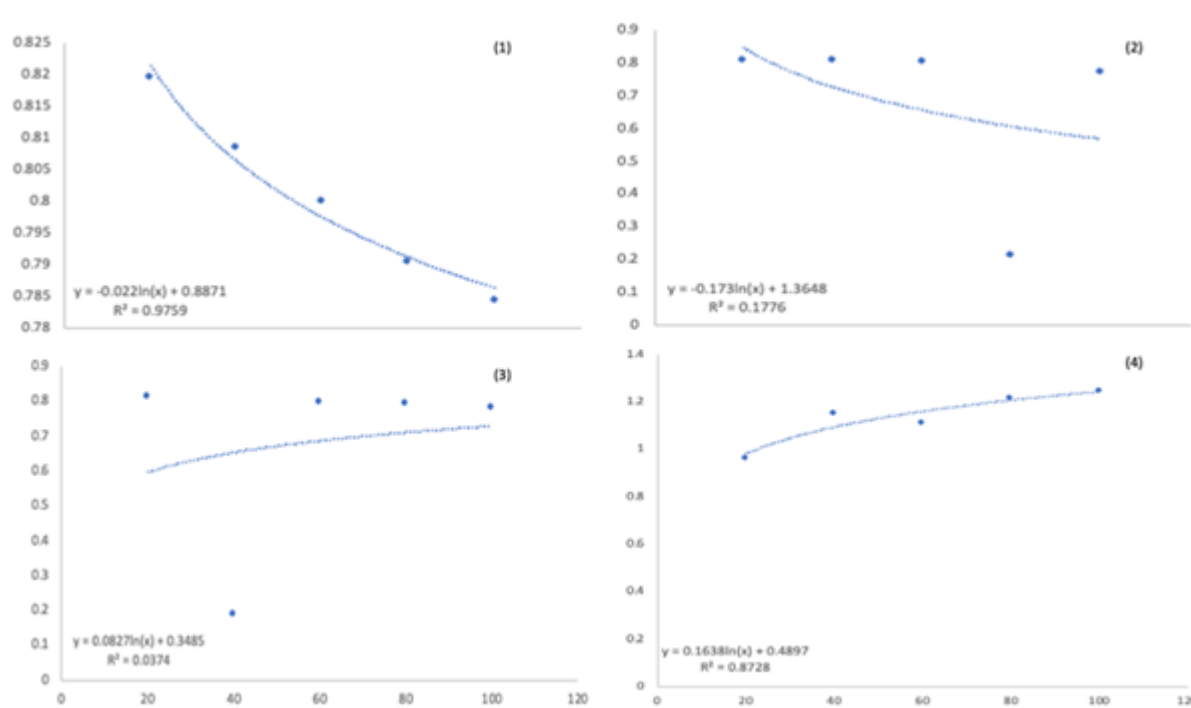


Figure 8. Percentage inhibition of *K. senegalensis* oil based on (1) total antioxidant capacity, (2) Diphenyl-2-Picryl-Hydrazyl (DPPH) Radical Scavenging Activity, (3) ferric reducing antioxidant power and (4) estimation of Reducing Power.

suggests that it could be a valuable source of dietary protein, which is essential for building and repairing tissues in the body, the treatment of heart conditions as well as an anti-inflammatory and cholesterol-lowering properties (Shaito et al., 2020; Zhang et al., 2020). Phenolic compounds offer health benefits and can be obtained through diet or applied topically to the skin to prevent skin conditions and alleviate symptoms (Działo et al., 2016). Due to their natural origin and minimal toxicity, phenolics have the potential to address the causes and effects of skin aging, skin diseases, and skin damage, including burns and wounds (Działo et al., 2016; Rahman et al., 2021). They also act protectively by slowing the progression of various skin disorders, from minor issues like acne and wrinkles to more serious and potentially life-threatening diseases such as cancer. Phenolics function through antioxidant mechanisms that help reduce lipid oxidation in tissues across various organisms (Rudrapal et al., 2022). Incorporating phenolics into the diet can help preserve food quality and reduce the risk of certain diseases. These compounds possess various biological properties, including anti-carcinogenic, anti-aging, anti-atherosclerotic, cardiovascular protective, endothelial function-enhancing, anti-apoptotic, cell proliferation-promoting, anti-inflammatory, and anti-angiogenic activities (Han et al., 2007). The antioxidant activity of the phenolic compound may be attributed to the capacity of scavenging radicals to donate hydrogen

atoms and electrons (Platzer et al., 2022; Hassanpour and Doroudi, 2023). Relatedly, tannins – which are water-soluble polyphenols, have been shown to decrease the mutagenic activity of mutagens (Makhafola et al., 2016; Dou, 2009; Dai and Mumper, 2010). The growth of many bacteria, viruses, fungi, and yeasts has been inhibited by tannins (Kaczmarek, 2020). Tannins could be applied to address physiological issues including lessening blood pressure, reducing the serum lipid level, accelerating blood clotting, producing liver necrosis, and modulating immune responses; although, the dosage is critical to this effect (Kaczmarek, 2020; Salehi et al., 2020). They also exhibit growth inhibition and cytotoxic effects, thus making them appropriate as tumour inhibiting agents (Maqsood et al., 2023; Kummar et al., 2006).

Terpenoids, or iso-terpenoids, are a significant category of phytochemicals known for their antioxidant properties and have long been utilized in traditional medicine. Some terpenoids exhibit biological activity and have been effective in combatting cancer, malaria, inflammation, and different infections (Kamran et al., 2022). They are also known for their protective effects on organs and possess antibacterial and antineoplastic properties (Masyita et al., 2022). Sterols, also known as steroid alcohols, are a crucial group of organic compounds that have been shown in clinical studies to inhibit the absorption of cholesterol in the human intestines, thereby reducing cholesterol uptake in the

body. Research suggests that phytosterols may have anticancer effects. Steroids have been revealed to have antibacterial properties and are significant compounds mainly due to their relationship with other compounds like sex hormones (Salehi et al., 2021; Bradford and Awad, 2007; Awad and Fink, 2000). The roles of these phytochemicals were reported as having anti-hypertensive, anti-inflammatory, analgesic, and anti-microbial activities (Sofowora, 1993). Our findings suggest that *K. senegalensis* oil contains considerable amounts of phenolic acids, tannin, and flavonoid content, signifying its importance to human health. The phenolic content of *K. senegalensis* oil was shown to be 17.60 ± 0.34 , the flavonoid (106.38 ± 0.65), tannin (21.68 ± 0.81) and proanthocyanidin 103.74 ± 7.49 .

Antioxidants are simply substances that have the potential to prevent or slow the detriment to cells induced by unstable molecules, and free radicals, which the body generates as a reaction to the environment and other pressures (Andrés et al., 2024; Lü et al., 2010). The antioxidant activities of plants are due to their phenolic compounds; they scavenge free radicals in biological organisms, thus aid in the prevention of diseases and strengthen the immune system. The antioxidant activity of *K. senegalensis* oil was determined using different assays such as; diphenyl-2-picryl-hydrazyl (DPPH) and ferric reducing antioxidant property (FRAP) and Reducing power (RO) Diphenyl-2-Picryl-Hydrazyl (DPPH) is a free radical scavenger like an anti-oxidant, which helps in protecting cells from the injury caused by free radicals. Free radicals are unstable molecules made during normal cell metabolism. The damage done may enhance the risk of cancer and several diseases. Therefore, DPPH acts as a scavenger to stabilise these molecules thereby preventing them from causing diseases in the body. DPPH of *K. senegalensis* oil revealed low scavenging power. Ferric reducing antioxidant potential (FRAP) assay is a fast, precise and simple assay. FRAP assay of the *K. senegalensis* oil showed significant reducing antioxidant potential. The inhibition of lipid peroxidation was low in oil. *K. senegalensis* oil also has high nitric oxide scavenging activity in a lower concentration.

Conclusions

K. senegalensis oil contains various phytochemicals such as saponins, steroids, terpenoids, cardiac glycosides, alkaloids, and proteins. The *in vitro* antioxidant activity reveal that the FRAP assay of the *K. senegalensis* oil possesses significant antioxidant reducing potentials. Moreover, *K. senegalensis* seed oil has high nitric oxide scavenging activity, especially in lower concentrations. These properties can be harnessed and used to manage physiological, biochemical, and metabolic issues pertaining to human health. High steroids, cardiac glycosides, and protein content characterize the seed oil of *K. senegalensis* as well as small amounts of

saponins, terpenoids, and alkaloids, which can be harvested for use in managing human health issues.

ABBREVIATIONS

The following abbreviations are used in this manuscript:

K. senegalensis: *Khaya senegalensis*, **CVD:** Cardiovascular diseases, **DNA:** Deoxyribonucleic acid, **DPPH:** 1,1-diphenylhydrazine-2-picrylhydrazyl (DPPH), **AAS:** Atomic Absorption Spectrophotometer, **H₂SO₄:** Sulphuric acid, **ml:** Milliliter, **%:** Percentage, **µg/mL:** micrograms per milliliter, **GAE:** Gallic Acid Equivalent, **ROS:** Reactive oxygen species, **mM:** millimoles, **mg/ml:** Milligrams/Millilitres, **HCl:** Hydrochloric acid, **nm:** Nanometer, **IC:** inhibitory concentration value, **FeCl₃:** Ferric chloride, **H₂O:** Water, **FRAP:** Ferric reducing antioxidant power, **Fe:** Iron, **µm:** Micrometer, **°C:** Degree Celsius, **TPTZ:** 2,4,6-tripyridyls-triazine, **pH:** Potential of hydrogen, **w/v:** weight per volume, **min:** minute, **M:** Mole of dissolved substance per liter of solution.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

- Abba A, Dogara AM (2021). Ethnomedicinal survey of plants used for management of inflammatory diseases in Ringim Local Government, Jigawa State, Nigeria. *Ethnobotany Research and Applications* 22:1-27.
- Abdel-Wareth AA, Hammad S, Ahmed H (2014). Effects of *Khaya senegalensis* Leaves on Performance, Carcass Traits, Hematological and Biochemical Parameters in Rabbits. *EXCLI Journal* 13:502-512.
- Abdel-Wareth AA, Hammad S, Ahmed H (2014). Effects of *Khaya senegalensis* leaves on performance, carcass traits, hemtological and biochemical parameters in rabbits. *EXCLI journal* 13:502-512.
- Adamu I, Majiyebo A., Alozieuwa U, Lawal A, Odey B, Alawode R, Berinyuy E (2022). Ethnopharmacology, Chemical Constituents, and Biological Activities of *Khaya senegalensis* (Desr.) A. Juss a Forest Plant with Multi-Purpose Applications. *AROC in Natural Products Research* 2:10-15.
- Ademola IO, Fagbemi BO, Idowu SO (2004). Evaluation of the Anthelmintic Activity of *Khaya senegalensis* Extract against Gastrointestinal Nematodes of Sheep: In Vitro and In Vivo Studies. *Veterinary Parasitology* 122:151-164.
- Adji B, Letort V, Wang X, Kang M, Reffye P, Jaeger M, Akaffou D (2023). Rethinking Iconic Species Reforestation in West Africa: Seed Shape Harnessing Is Strategic for Enhanced Germination and Vigorous Growth in *Khaya senegalensis* and *Parkia biglobosa*. *Forests* pp.14:1311.
- Adu JK Amengor CDK, Kabiri N, Orman E, Patamia SAG, Okrah BK (2019). Validation of a Simple and Robust Liebermann-Burchard Colorimetric Method for the Assay of Cholesterol in Selected Milk Products in Ghana. *International Journal of Food Science* 9045938 p.
- Ak T, Gülçin I (2008). Antioxidant and radical scavenging properties of curcumin. *Chemico-Biological Interactions* 174:27-37.
- Al-Amin BK, Russel MM, Kabir SM, Bhattacharjee S, Hannan RJM (2014). Phytochemical Screening and Evaluation of Analgesic Activity

- of *Oroxylum indicum*. Indian Journal of Pharmaceutical Sciences 76:571-575.
- Alemu M, Lulekal E, Asfaw Z, Warkineh B, Debella A, Abebe A, Degu S, Debebe E (2024). Antibacterial Activity and Phytochemical Screening of Traditional Medicinal Plants Most Preferred for Treating Infectious Diseases in Habru District, North Wollo Zone, Amhara Region, Ethiopia. PLoS One 19:e0300060.
- Ali S, Khan MR, Irfanulla SM, Zahra Z (2018). Phytochemical Investigation and Antimicrobial Appraisal of *Parrotiopsis jacquemontiana* (Decne) Rehder. BMC Complement. Alternative Medicine 18:43.
- Allah M, Alrasheid A, Elamin E (2019). In Vitro and In Vivo Studies of Anti Diabetic Effect of *Khaya senegalensis* Leaves and Bark Extracts. International journal of pharmacology and toxicology 7:12-16.
- Amudha M, Rani S (2016). Evaluation of In Vitro Antioxidant Potential of *Cordia retusa*. Indian Journal of Pharmaceutical Sciences 78:80-86.
- Andrés CMC, Pérez de la Lastra JM, Juan CA, Plou FJ, Pérez-Lebeña E (2024). Antioxidant Metabolism Pathways in Vitamins, Polyphenols, and Selenium: Parallels and Divergences. International Journal of Molecular Sciences 25(5):2600.
- Androulakis XM, Muga SJ, Chen F, Koita Y, Toure B, Wargovich MJ (2006). Chemopreventive Effects of *Khaya senegalensis* Bark Extract on Human Colorectal Cancer. Anticancer Research 26:2397-2405.
- Antoniadou M, Rozos G, Vaiou N, Zaralis K, Ersanli C, Alexopoulos A, Tzora A, Varzakas T, Voidarou CC (2023). The In Vitro Assessment of Antibacterial and Antioxidant Efficacy in *Rosa damascena* and *Hypericum perforatum* Extracts Against Pathogenic Strains in the Interplay of Dental Caries, Oral Health, and Food Microbiota. Microorganisms, pp. 12:60.
- Asigbaase M, Adusu D, Musah AA, Anaba L, Nsor CA, Abugre S, Derkyi M (2023). Ethnobotanical and Ethnopharmacological Survey of Medicinal Tree Species Used in the Treatment of Diseases by Forest-Fringe Communities of Southwestern Ghana. Heliyon 10:e23645.
- Auwal MS, Saka S, Mairiga IA, Sanda KA, Shuaibu A, Ibrahim A (2014). Preliminary Phytochemical and Elemental Analysis of Aqueous and Fractionated Pod Extracts of *Acacia nilotica* (Thorn Mimosa). Veterinary Research Forum 5:95-100.
- Awad AB, Fink CS (200). Phytosterols as anticancer dietary components: evidence and mechanism of action. Journal of Nutrition 130(9):2127-2130.
- Baillères H, Gril J, Koubaa A, Da Silva PD (2019). Wood Quality Variations within African Mahogany (*Khaya* spp.) Trees: A Review. International Wood Products Journal 10:95-111.
- Bakir Çilesioğlu N, Yalçın E, Çavuşoğlu K, Sipahi Kuloğlu, S (2022). Qualitative and Quantitative Phytochemical Screening of *Nerium oleander* L. Extracts Associated with Toxicity Profile. Scientific Reports 12:21421.
- Batool R, Khan MR, Sajid M, Ali S, Zahra Z (2019). Estimation of Phytochemical Constituents and In Vitro Antioxidant Potencies of *Brachychiton populneus*, pp. 13:32.
- Benzie IF, Strain JJ (1996). The Ferric Reducing Ability of Plasma (FRAP) as a Measure of "Antioxidant Power": The FRAP Assay. Analytical Biochemistry 239:70-76.
- Bolouri P, Salami R, Kouhi, S, Kordi M, Asgari LB, Hadian J, Astatkie T (2022). Applications of Essential Oils and Plant Extracts in Different Industries. Molecules pp. 27:8999.
- Bradford PG, Awad AB (2007). Phytosterols as anticancer compounds. Molecular Nutrition and Food Research 51(2):161-170.
- Calderón-Montaño JM, Burgos-Morón E, Orta ML, Maldonado-Navas D, García-Domínguez I, López-Lázaro M (2014). Evaluating the Cancer Therapeutic Potential of Cardiac Glycosides. BioMed Research International 794930 p.
- Chandra S, Khan S, Avula B, Lata H, Yang MH, Elsohly MA, Khan IA (2014). Assessment of Total Phenolic and Flavonoid Content, Antioxidant Properties, and Yield of Aeroponically and Conventionally Grown Leafy Vegetables and Fruit Crops: A Comparative Study. Evid. Based Complement. Alternative medicine 253875 p.
- Chen YF, Yang CH, Chang MS, Ciou YP, Huang YC (2010). Foam Properties and Detergent Abilities of the Saponins from *Camellia oleifera*. International Journal of Molecular Sciences 11:4417-4425.
- Chrzczanowicz J, Gawron A, Zwolinska A, de Graft-Johnson J, Krajewski W, Krol M, Markowski J, Kostka T, Nowak D (2008). Simple Method for Determining Human Serum 2,2-Diphenyl-1-picrylhydrazyl (DPPH) Radical Scavenging Activity-Possible Application in Clinical Studies on Dietary Antioxidants. Clinical Chemistry and Laboratory Medicine 46:342-349.
- Dahanayake JM, Perera K, Galappatty P, Perera HDSM, Arawwawala LDAM (2019). Comparative Phytochemical Analysis and Antioxidant Activities of Tamalakyadi Decoction with Its Modified Dosage Forms. Evidence-Based Complementary and Alternative Medicine, Pp. 6037137.
- Dai J, Mumper RJ (210). Plant phenolics: extraction, analysis and their antioxidant and anticancer properties. Molecules 15(10):7313-7352.
- de Araújo KM, de Lima A, Silva JN, Rodrigues LL, Amorim AG, Quelemes PV, Dos Santos RC, Rocha JA, de Andrade EO, Leite JR (2014). Identification of Phenolic Compounds and Evaluation of Antioxidant and Antimicrobial Properties of *Euphorbia tirucalli* L. Antioxidants 3:159-175.
- de Vries AMH, Hansen IEA, Shiemo PNM (2001). Distribution of African Mahogany (*Khaya* anthotheca, C. DC.) in Zambia and Potential for Sustainable Utilization. Forest Ecology and Management Journal 150:107-116.
- Dou QP (2009). Molecular mechanisms of green tea polyphenols. Nutrition and Cancer 61(6):827-835.
- Działo M, Mierziak J, Korzun U, Preisner M, Szopa J, Kulma A (2016). The Potential of Plant Phenolics in Prevention and Therapy of Skin Disorders. International Journal of Molecular Sciences 7(2):160.
- Gangwar M, Gautam MK, Sharma AK, Tripathi YB, Goel RK, Nat G (2014). Antioxidant Capacity and Radical Scavenging Effect of Polyphenol Rich *Mallotus philippensis* Fruit Extract on Human Erythrocytes: An In Vitro Study. Scientific World Journal 279451p.
- Godlewska K, Pacyga P, Najda A, Michalak I (2023). Investigation of Chemical Constituents and Antioxidant Activity of Biologically Active Plant-Derived Natural Products. Molecules, pp. 28:5572.
- Green LC, Wagner DA, Glogowski J (1982). Analysis of nitrate, nitrite and 15N in biological fluids. Analytical Biochemistry 126:131-136.
- Han X, Shen T, Lou H (2007). Dietary Polyphenols and Their Biological Significance. International Journal of Molecular Sciences 8(9):950-988.
- Hassanpour SH, Doroudi (2023). A Review of the antioxidant potential of flavonoids as a subgroup of polyphenols and partial substitute for synthetic antioxidants. Avicenna Journal of Phytomedicine 13(4):354-376.
- Iqbal I, Wilairatana P, Saqib F, Nasir B, Wahid M, Latif MF, Iqbal A, Naz R, Mubarak MS (2023). Plant Polyphenols and Their Potential Benefits on Cardiovascular Health: A Review. Molecules, pp. 28:6403.
- Ishaq FN, Zezi AU, Olurishe TO (2014). *Khaya senegalensis* inhibits piroxicam mediated gastro-toxicity in wistar rats. Avicenna Journal of Phytomedicine 4(6):377-384.
- Izah SC, Ogbu MC, Akram M (2024). Herbal Medicine Phytochemistry: Applications and Trends.
- Kaczmarek B (2020). Tannic Acid with Antiviral and Antibacterial Activity as A Promising Component of Biomaterials-A Minireview. Materials 13(14):3224.
- Kamran S, Sinniah A, Abdulghani MAM, Alshawsh MA (2022). Therapeutic Potential of Certain Terpenoids as Anticancer Agents: A Scoping Review. Cancers 14(5):1100.
- Kandeda AK, Lewale S, Djeuzong E, Kouamouo J, Dimo T (2022). An Aqueous Extract of *Khaya senegalensis* (Desv.) A. Juss. (Meliaceae) Prevents Seizures and Reduces Anxiety in Kainate-Treated Rats: Modulation of GABA Neurotransmission, Oxidative Stress, and Neuronal Loss in the Hippocampus. Heliyon, pp. 8:e09549.
- Kumar APN, Kumar M, Jose A, Tomer V, Oz E, Oz F (2023). Major phytochemicals: recent advances in health benefits and extraction method. Molecules, 28(2):87.
- Kumar T, Jain V (2015). Appraisal of Total Phenol, Flavonoid Contents, and Antioxidant Potential of Folkloric *Lannea coromandelica* Using In Vitro and In Vivo Assays. Scientifica 203679p.
- Kummar S, Gutierrez M, Doroshov JH, Murgu AJ (2006). Drug development in oncology: classical cytotoxics and molecularly targeted agents. British Journal of Clinical Pharmacology 62(1):15-26.

- Kurutas EB (2016). The Importance of Antioxidants Which Play the Role in Cellular Response Against Oxidative/Nitrosative Stress: Current State. *Nutrition Journal*, pp.15:71.
- Lobo V, Patil A, Phatak A, Chandra N (2010). Free radicals, antioxidants and functional foods: Impact on human health. *Pharmacognosy Reviews* 4(8):118-126.
- Lü JM, Lin PH, Yao Q, Chen C (2010) Chemical and molecular mechanisms of antioxidants: experimental approaches and model systems *Journal of Cellular and Molecular Medicine* 14(4):840-860.
- Makhafola TJ, Elgorashi EE, McGaw LJ, Verschaeve L, Eloff JN (2016). The correlation between antimutagenic activity and total phenolic content of extracts of 31 plant species with high antioxidant activity. *BMC Complement. Alternative medicine* 16(1):490.
- Manosroi A, Pattamapun K, Chankhampan C, Kietthanakorn BO, Kitdamrongtham W, Zhang J, Manosroi JA (2020). Biologically Active Artificial Saliva Formulation Containing Flower Mucilage from Ceylon Spinach (*Basella alba* Linn.). *Saudi Journal of Biological Sciences* 27:769-776.
- Maqsood R, Khan F, Ullah S, Khan A, Al-Jahdhami H, Hussain J, Weli AM, Maqsood D, Rahman SM, Hussain A (2023). Evaluation of Antiproliferative, Antimicrobial, Antioxidant, Antidiabetic and Phytochemical Analysis of *Anogeissus dhofarica* A.J. Scott. *Antibiotics* 12(2):354.
- Marino A, Battaglini M, Moles N, Ciofani G (2022). Natural Antioxidant Compounds as Potential Pharmaceutical Tools against Neurodegenerative Diseases. *ACS Omega* 7(30):25974-25990.
- Masyita A, Sari RM, Astuti AD, Yasir B, Rumata NR, Emran TB, Nainu F, Simal-Gandara J (2022). Terpenes and terpenoids as main bioactive compounds of essential oils, their roles in human health and potential application as natural food preservatives. *Food Chemistry* pp.13:100217.
- Mohamed AA, Alotaibi BM (2023). Essential Oils of Some Medicinal Plants and Their Biological Activities: A Mini Review. *Journal of Umm Al-Qura University for Applied Sciences* 9:40-49.
- Mueed A, Shibli S, Al-Quwaie DA, Ashkan MF, Alharbi M, Alanazi H, Binothman N, Aljadani M, Majrashi KA, Huwaikem M (2023). Extraction, Characterization of Polyphenols from Certain Medicinal Plants and Evaluation of Their Antioxidant, Antitumor, Antidiabetic, Antimicrobial Properties, and Potential Use in Human Nutrition. *Frontiers in Nutrition*, pp. 10:1125106.
- Mujeeb F, Bajpai P, Pathak N (2014). Phytochemical Evaluation, Antimicrobial Activity, and Determination of Bioactive Components from Leaves of *Aegle marmelos*. *BioMed Research International* 497606 p.
- Nasim N, Sandeep IS, Mohanty S (2022). Plant-Derived Natural Products for Drug Discovery: Current Approaches and Prospects. *Nucleus* 65:399-411.
- Nemes A, Szöllösi E, Stündl L, Biró A, Homoki JR, Szarvas MM, Balogh P, Cziáky Z, Remenyik J (2018). Determination of Flavonoid and Proanthocyanidin Profile of Hungarian Sour Cherry. *Molecules*, pp. 23: 3278.
- Ngamsuk S, Huang TC, Hsu JL (2019). Determination of Phenolic Compounds, Procyanidins, and Antioxidant Activity in Processed *Coffea arabica* L. Leaves. *Foods*, pp. 8:389.
- Nitao JK, Birr BA, Nair MG, Herms DA, Mattson WJ (2001). Rapid Quantification of Proanthocyanidins (Condensed Tannins) with a Continuous Flow Analyzer. *Journal of Agricultural and Food Chemistry* 49:2207-2214.
- Obahiagbon EG, Ogwu MC (2023). Sustainable Supply Chain Management in the Herbal Medicine Industry. In *Herbal Medicine Phytochemistry*; Izah SC, Ogwu MC, Akram M, Eds. https://doi.org/10.1007/978-3-031-21973-3_64-1
- Obahiagbon EG, Ogwu MC (2023). The nexus of business, sustainability, and herbal medicine. In *Herbal Medicine Phytochemistry: Applications and Trends* pp. 1-42.
- Obongodot NU, Ogwu MC (2023). Plant Food for Human Health: Case Study of Indigenous Vegetables in Akwa Ibom State, Nigeria. In *Herbal Medicine Phytochemistry* https://doi.org/10.1007/978-3-031-21973-3_2-1
- Ogwu MC, Ogwu HI, Kosoe EA (2024). Plants used in the management and treatment of cardiovascular diseases: case study of the Benin people of southern Nigeria. In *Herbal Medicine Phytochemistry: Applications and Trends* pp. 1-31.
- Ogwu MC, Ojo AO, Osawaru ME (2024). Quantitative Ethnobotany of Afenmai People of Southern Nigeria: An Assessment of Their Crop Utilization, and Preservation Methods. *Genetic Resources and Crop Evolution* 72(5):5807-5829. <https://doi.org/10.1007/s10722-024-02302-x>
- Ogwu MC, Osawaru ME, Obahiagbon GE (2017). Ethnobotanical Survey of Medicinal Plants Used for Traditional Reproductive Care by Usen People of Edo State, Nigeria. *Malaya Journal of Biosciences* 4:17-29.
- Oikeh EI, Ayevebuomwan, M.; Irabor, F.; Oikeh, A.O.; Oviasogie FE, Omoregie ES (2020). Evaluation of the Phenolic Content, Antioxidant and Antimicrobial Activities of Oil and Non-Oil Extracts of *Citrus sinensis* (L.) Osbeck Seeds. *Preventive Nutrition and Food Science* 25:280-285.
- Okawa M, Kinjo J, Nohara T, Ono M (2001). DPPH (1,1-diphenyl-2-picrylhydrazyl) Radical Scavenging Activity of Flavonoids Obtained from Some Medicinal Plants. *Biological and Pharmaceutical Bulletin* 24:1202-1205.
- Olatunji T, Odeunmi C, Adetunji A (2021). Biological Activities of Limonoids in the Genus *Khaya* (Meliaceae): A Review. *Future Journal of Pharmaceutical Sciences* 7:1-12.
- Onu A, Saidu Y, Ladan MJ, Bilbis LS, Aliero AA, Sahabi SM (2013). Effect of Aqueous Stem Bark Extract of *Khaya senegalensis* on Some Biochemical, Haematological, and Histopathological Parameters of Rats. *Journal of Toxicology* 803835 p.
- Orandi A (2020). Oxidative Stress and New Pathogenetic Mechanisms in Endothelial Dysfunction: Potential Diagnostic Biomarkers and Therapeutic Targets. *Journal of Clinical Medicine* pp.9:1995.
- Owor RO, Kawuma C, Nantale G, Kiyimba K, Obakiro SB, Ouma S, Lulenzi J, Gavamukulya Y, Chebijira M, Lukwago TW (2024). Ethnobotanical Survey and Phytochemistry of Medicinal Plants Used in the Management of HIV/AIDS in Eastern Uganda. *Heliyon*, pp. 10. e31908.
- Oyekunle J, Omode A (2008). Chemical Composition and Fatty Acid Profile of the Lipid Fractions of Selected Nigerian Indigenous Oilseeds. *International Journal of Food Properties* 11:273-281.
- Pérez M, Dominguez-López I, Lamuela-Raventós RM (2023). The Chemistry Behind the Folin-Ciocalteu Method for the Estimation of (Poly)phenol Content in Food: Total Phenolic Intake in a Mediterranean Dietary Pattern. *Journal of Agricultural and Food Chemistry* 71:17543-17553.
- Pham-Huy LA, He H, Pham-Huy C (2008). Free Radicals, Antioxidants in Disease and Health. *International Journal of Biomedical Science* 4:89-96.
- Pisoschi AM, Pop A, Cimpeanu C, Predoi G (2016). Antioxidant Capacity Determination in Plants and Plant-Derived Products: A Review. *Oxidative Medicine and Cellular Longevity*, 9130976p.
- Pizzino G, Irrera N, Cucinotta M, Pallio G, Mannino F, Arcoraci V, Squadrito F, Altavilla D, Bitto A (2017). Oxidative Stress: Harms and Benefits for Human Health. *Oxidative Medicine and Cellular Longevity* 8416763 p.
- Platze M, Kiese S, Tybussek T, Herfellner T, Schneider F, Schweiggert-Weisz U, Eisner P (2022). Radical Scavenging Mechanisms of Phenolic Compounds: A Quantitative Structure-Property Relationship (QSPR) Study. *Frontiers in Nutrition* pp. 9:882458.
- Ponticelli M, Carlucci V, Mecca M, Todaro L, Milella L, Russo D (2024). Extraction Optimization of *Quercus cerris* L. Wood Chips: A Comparative Study Between Full Factorial Design (FFD) and Artificial Neural Network (ANN). *Antioxidants*, pp. 13:1115.
- Prieto P, Pineda M, Aguilar M (1999). Spectrophotometric Quantitation of Antioxidant Capacity Through the Formation of a Phosphomolybdenum Complex: Specific Application to the Determination of Vitamin E. *Analytical Biochemistry* 269:337-341.
- Rabadeaux C, Vallette L, Sirdaarta J, Davis, C, Cock I (2017). An Examination of the Antimicrobial and Anticancer Properties of *Khaya senegalensis* (Desr.) A. Juss. Bark Extracts. *Pharmacognosy Journal* 9:504-518.
- Rahim MA, Shoukat A, Khalid W, Ejaz A, Itrat N, Majeed I, Koraqi H, Imran M, Nisa MU, Nazir A (2022). A Narrative Review on Various Oil Extraction Methods, Encapsulation Processes, Fatty Acid Profiles, Oxidative Stability, and Medicinal Properties of Black Seed (*Nigella*

- sativa). Foods, pp.11:2826.
- Rahman MM, Rahaman MS, Islam MR, Rahman F, Mithi FM, Alqahtani T, Almikhlaifi MA, Alghamdi SQ, Alruwaili AS, Hossain MS (2021). Role of Phenolic Compounds in Human Disease: Current Knowledge and Future Prospects. *Molecules* 27(1):233.
- Riyadi SA, Naini AA Supratman U (2023). Sesquiterpenoids from Meliaceae Family and Their Biological Activities. *Molecules* 28(12):4874.
- Rudrapal M, Khairnar SJ, Khan J, Dukhyil AB, Ansari MA, Alomary MN, Alshabmi FM Palai S, Deb PK, Devi R (2022). Dietary Polyphenols and Their Role in Oxidative Stress-Induced Human Diseases: Insights Into Protective Effects, Antioxidant Potentials and Mechanism(s) of Action. *Frontiers in Pharmacology* 13:806470.
- Sa'adiya M, Oyi R, Ibrahim Y (2023). Characterization of *Khaya senegalensis* Gum: Effects of Drying Methods on the Physicochemical Properties. *Journal of Pharmaceutical Research International* 22:142-151.
- Salehi B, Azzini E, Zucca P, Varoni EM, Anil KNV, Dini L, Panzarini E, Rajkovic J, Fokou PVT, Peluso I (2020). Plant-Derived Bioactives and Oxidative Stress-Related Disorders: A Key Trend towards Healthy Aging and Longevity Promotion. *Applied Sciences* 10(3):947.
- Salehi B, Quispe C, Sharifi-Rad J, Cruz-Martins N, Nigam M, Mishra AP, Konovalov DA, Orobinskaya V, Abu-Reidah IM, Zam W (2021). Phytosterols: From Preclinical Evidence to Potential Clinical Applications. *Frontiers in Pharmacology* 11:599959.
- Sankhalkar S, Vernekar V (2016). Quantitative and Qualitative Analysis of Phenolic and Flavonoid Content in *Moringa oleifera* Lam and *Ocimum tenuiflorum* L. *Pharmacognosy Research* 8:16-21.
- Scioli MG, Storti G, D'Amico F, Rodríguez GR, Centofanti F, Doldo E, Céspedes MEM,
- Shaito A, Thuan DTB, Phu HT, Nguyen THD Hasan, H, Halabi S, Abdelhady S, Nasrallah GK, Eid AH, Pintus G (2020). Herbal Medicine for Cardiovascular Diseases: Efficacy, Mechanisms, and Safety. *Frontiers in Pharmacology* 11:422.
- Sharifi-Rad M, Anil Kumar NV, Zucca P, Varoni EM, Dini L, Panzarini E, Rajkovic J, Tsouh FPV, Azzini E, Peluso I (2020). Lifestyle, Oxidative Stress, and Antioxidants: Back and Forth in the Pathophysiology of Chronic Diseases. *Frontiers in Physiology* 11:694.
- Sharma N, Samarakoon KW, Gyawali R, Park YH, Lee SJ, Oh SJ, Lee TH, Jeong DK (2014). Evaluation of the Antioxidant, Anti-Inflammatory, and Anticancer Activities of *Euphorbia hirta* Ethanolic Extract. *Molecules* 19:14567-14581.
- Sharma N, Samarakoon KW, Gyawali R, Park YH, Lee SJ, Oh SJ, Lee TH, Jeong DK (2014). Evaluation of the Antioxidant, Anti-Inflammatory, and Anticancer Activities of *Euphorbia hirta* Ethanolic Extract. *Molecules* 19:14567-14581.
- Sofowora, A. Recent trends in research into African medicinal plants. *Journal of Ethnopharmacology* 38(2-3):209-214.
- Speisky H, Shahidi F, Costa de Camargo, A, Fuentes J (2022). Revisiting the Oxidation of Flavonoids: Loss, Conservation or Enhancement of Their Antioxidant Properties. *Antioxidants* pp. 11:133.
- Srivastava RP, Kumar S, Singh L, Madhukar M, Singh N, Saxena G, Pandey S, Singh A, Devkota HP, Verma PC (2023). Major Phenolic Compounds, Antioxidant, Antimicrobial, and Cytotoxic Activities of *Selinum carvifolia* (L.) Collected from Different Altitudes in India. *Frontiers in Nutrition*, pp. 10:1180225.
- Sukardiman EM (2020). The recent use of *Swietenia mahagoni* (L.) Jacq. as antidiabetes type 2 phytomedicine: A systematic review. *Heliyon* pp. 6:e03536.
- Sun HJ, Wu ZY, Nie XW, Bian JS Role of Endothelial Dysfunction in Cardiovascular Diseases: The Link Between Inflammation and Hydrogen Sulfide. *Frontiers in Pharmacology*, pp. 10:1568.
- Touzout SN, Merghni A, Laouani A, Boukhibar H, Alenazy R, Alobaid A, Alenazy M, Ben-Attia M, Saguem K, El-Bok Sa (2023). Antibacterial Properties of Methanolic Leaf Extracts of *Melia azedarach* L. against Gram-Positive and Gram-Negative Pathogenic Bacteria. *Microorganisms* 11(8):2062. <https://doi.org/10.3390/microorganisms11082062>
- Turgut CD, Saydam F, Özbayer C, Doğaner F, Soyocak A Güneş HV, Değirmenci İ, Kurt H, Üstüner MC, Bal C (2015). Impact of tannic acid on blood pressure, oxidative stress and urinary parameters in L-NNA-induced hypertensive rats. *Cytotechnology* 67(1):97-105.
- Ugoh SC, Agarry OO, Garba SA (2014). Studies on the antibacterial activity of *Khaya senegalensis* [(Desr.) A. Juss] stem bark extract on *Salmonella enterica* subsp. *enterica* serovar Typhi [(ex Kauffmann and Edwards) Le Minor and Popoff]. *Asian Pacific Journal of Tropical Biomedicine* 4(Suppl 1):S279-S283.
- Ugoh SC, Agarry OO, Garba SA (2014). Studies on the antibacterial activity of *Khaya senegalensis* [(Desr.) A. Juss] stem bark extract on *Salmonella enterica* subsp. *enterica* serovar Typhi [(ex Kauffmann and Edwards) Le Minor and Popoff]. *Asian Pacific journal of tropical biomedicine*, 4(Suppl 1):S279-S283. <https://doi.org/10.12980/APJTB.4.2014C636>
- Usman H, Abdulrahman F, Usman A (2009). Qualitative Phytochemical Screening and In Vitro Antimicrobial Effects of Methanol Stem Bark Extract of *Ficus thonningii* (Moraceae). *African Journal of Traditional, Complementary and Alternative Medicines* 6:289-295.
- Valgimigli L (2023). Lipid Peroxidation and Antioxidant Protection. *Biomolecules*, pp. 13:1291.
- Victor A, Valery N, Chantal M, Zapfack L (2021). Floristic Composition, Diversity and Structure of *Khaya senegalensis* Stands in Benue Department, Cameroon. *Journal of Tropical Resources and Sustainable Science* 8:60-68.
- Vikas B, Akhil BSPR, Sujathan K (2017). Free Radical Scavenging Properties of *Annona squamosa*. *Asian Pacific Journal of Cancer Prevention* 18:2725-2731.
- Vwioko DE, Okoekhan I, Ogwu MC (2018). Stress Analysis of *Amaranthus hybridus* L. and *Lycopersicon esculentum* Mill. Exposed to Sulphur and Nitrogen Dioxide. *Pertanika Journal of Tropical Agricultural Science* 41:1169-1191.
- Wiesneth S, and Jürgenliemk G (2017). Total phenolic and tannins determination: A modification of Ph. Eur. 2.8. 14 for higher throughput. *Die Pharmazie-An International Journal of Pharmaceutical Sciences* 72(4): 195-196.
- Yang M, Zhu W, Cao H (2021). Biorefinery Methods for Extraction of Oil and Protein from Rubber Seed. *Bioresour. Bioprocess*, 8:45.
- Zahra M, Abrahamse H, George BP (2024). Flavonoids Antioxidant Powerhouses and Their Role in Nanomedicine. *Antioxidants* 13:922.
- Zhang X, Sergin I, Evans TD, Jeong SJ, Rodriguez-Velez A, Kapoor D, Che S, Song E, Holloway KB, Crowley JR (2020). High-protein diets increase cardiovascular risk by activating macrophage mTOR to suppress mitophagy. *Nature Metabolism* 2(1):110-125.
- Ziólkiewicz A, Kasprzak-Drozd K, Rusinek R, Markut-Miotła E, Oniszcuk A (2023). The Influence of Polyphenols on Atherosclerosis Development. *International Journal of Molecular Sciences*, pp. 24:7146.