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MODESTUM

Research Article

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Eco-friendly and facile production method, natural products chemistry, and pharmacological properties of silver nanoparticles using telfaria occidentalis leaf and stem extracts

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ABSTRACT

Using an extract from *telfairia occidentalis* leaves and stems, this work aims to provide an easy and environmentally friendly method to synthesize silver nanoparticles (AgNPs). Furthermore, the research will examine the extract's natural products chemistry and evaluate its possible anti-inflammatory, anti-diabetic, antioxidant, and antiglycation effects. The silver nanoparticles were characterized through ultraviolet-visible spectroscopy, Fourier transform infrared, and scanning electron microscopy (SEM). The antioxidant, anti-diabetic, and anti-inflammatory activities were conducted using various methods under standard conditions. The visual color change observed indicated the presence of synthesized AgNPs. The creation of silver nanoparticles was verified by surface plasmon resonance scan, which revealed that the nanoparticles had absorption peak at 400 nanometers. Additionally, SEM results provided insights into the size distribution of the AgNPs, ranging from 22 nm-68 nm, 43.66 nm mean. The study suggests that the extract from *telfairia occidentalis* leaf and stem has the potential to produce AgNPs with antioxidant, anti-inflammatory, anti-diabetic and anti-glycation uses. AgNPs may be valuable in the development of drugs for diabetes treatment and management.

Keywords: AgNPs, *telfairia occidentalis*, anti-inflammatory, antiglycation, eco-friendly production, antioxidant properties, hypoglycemic

INTRODUCTION

Research to gaining in-depth knowledge on the aetiologia, pathogenesis, prognosis, and potential therapeutic interventions for diabetes mellitus (DM) has gained a significant uptick lately (Hritcu et al., 2021). Orthodox medical practice has struggled to effectively manage diabetes without causing adverse effects. DM is associated with inflammation, glycation, and an increased need for antioxidants (Uuofin & Lebelo, 2020). Following the expert guidelines set by World Health Organization (2019) on DM, extensive research has

been conducted on medicinal plants known for their therapeutic benefits in the management of DM.

Telfairia occidentalis is a lush leafy plant commonly referred to as ugwu in the tropics of Southern Nigeria. It is a member of the curcurbitaceae family. *Telfairia occidentalis* is predominantly grown in Nigeria, particularly in the southeastern region (Igbo-speaking population), more precisely in Imo state. It is primarily utilized in broth and natural remedies (Akindele et al., 2013). The gourd's seeds are rich in protein and fat, making them a valuable addition to a nutritious diet. There has been a large-scale cultivation of this plant in many parts of Africa like Benin Republic, Cameroon, Sierra Leone, Angola, and Uganda (Eseyin et al., 2018).

Many derivatives of the active chemical compounds present in the leaves of *telfairia occidentalis* have been found to exhibit cancer fighting, antioxidant, anti-HIV reverse transcriptase, liver-protective, anti-inflammatory, anti-hepatitis, and sexual stimulating effects (Abubakar et al., 2020; Kalló et al., 2020). It has also been reported to be used in managing hypercholesterolemia, impaired immune system, reproductive and fertility issues, treating malaria, and replenishing lost blood due to its high iron content (Ojimelukwe, 2022; Osonuga et al., 2020). The traditional uses of natural substances to address this metabolic disorder and its implications, especially those originating from plants, and ethnobotany have garnered a lot of attention recently because of their few adverse effects as compared to many synthetic therapeutic agents (Asafo-Agyei et al., 2023).

This quest brought about the use of products from plants in DM therapy. According to Sukhikh et al. (2023) and Tastan (2023), research of plant-based remedies used to treat diabetes confirm the great diversity of antidiabetic plants found in Nigeria. More comprehensive scientific research requiring phytochemical, biological and structure-activity relationship studies of the chemical constituents of the plants need to be done together with their proper therapeutic applications. But pending more investigations, these compounds have undergone extensive testing to determine their effectiveness and are usually considered safe for human usage as a primary culprit in diabetes-related complications, triggering oxidative stress–a condition, where the body's antioxidant defenses struggle to neutralize excessive reactive oxygen species (ROS) production, resulting in cellular damage (González et al., 2023). The oxidative stress occurs due to increased glucose levels, leading to excess free radical production and a decrease in antioxidant activity via glycation and conformational alterations of antioxidant enzymes (Caturano et al., 2023). There is a close link between the production of advanced glycation end-products (AGEs) and oxidative stress since elevated levels of AGEs usually seen in diabetes contribute to oxidative stress and vice versa (Koska et al., 2018). Antioxidants are essential defense systems against free radicals. When glycation occurs in glutathione peroxidase (GPx), it causes denaturation and a reduction in enzymatic activity, resulting in increased oxidative stress (Pei et al., 2023). Inflammation is an important risk-factor in the development of diabetes-induced complications. Oxidative stress triggers the synthesis of inflammatory factors that bring about an increased production of ROS and AGEs. Hyperglycemia-induced oxidative stress and AGEs can also cause the production of inflammatory cytokines like tumor necrosis factor (TNF-α), interleukin-1 (IL-1), and interleukin-6 (IL-6) etc. (Oguntibeju, 2019). Controlling inflammation and oxidative stress is crucial for managing problems associated with diabetes. In individuals diagnosed with type 2 diabetes, glycemic control might be enhanced by using polyphenols, especially flavonoids and other nutritional antioxidants and certain medicines.

One important function antioxidants play is prevention of oxidation, which can lead to DNA damage, lipid peroxidation, compromised immune function, and even the development of cancerous cells. Phenolic compounds play a crucial role as bioactive phytochemicals, offering numerous health benefits to humans. The antioxidant potential of seeds, fruits, and leaves is strongly associated with the overall phenolic content. Leaves and fruits contain natural antioxidants like vitamins and polyphenols, which may help to reduce the risk of cancer, degenerative diseases such as cardiovascular diseases, Alzheimers diseases., etc.

In view of the above, this preliminary study is designed to determine the anti-diabetic, the antioxidant, the anti-glycation, and the anti-inflammatory potential of green synthesized nanoparticles using the extract from the emulsified leaf and stem of *telfairia occidentalis*, in addition to the determination of its phytochemistry.

MATERIALS & METHODS

Glassware & Equipment

Water bath, hot air oven, spectrophotometer, measuring cylinder, beakers, sample bottles, cuvette, whatmann filterpaper, and blender.

Reagents & Chemicals

Silver nitrate, deionized water, sodium carbonate, phosphate buffer, vitamin C, potassium persulfate, perchloric acid, boven serum albumin, distilled water, casein, phosphate buffer, tris buffer, and TCA.

Methodology

Plant collection and identification of *telfairia occidentalis* leaves was carried out in botany, Lagos State University (LASU) after initial procurement from LASU farm.

Preparation of plant extracts

Harvested plant leaves were carefully rinsed and air dried. They were then ground. The water-soluble sample (8.00% w/v) of *telfairia occidentalis* leaves was extracted by combining 8g of the powdered leaves, dissolved in 100 ml of deionized water in a 500ml beaker was used to prepare an aqueous extract (8.00%w/v) of *telfairia occidentalis*. The aqueous extract was subsequently heated for two hours using an oven at 70 °C. The water-soluble sample was first separated by centrifugation for five mins at 3,000 revolutions/min, then filtered. The filtered liquids was then stored in the fridge.

Synthesis of AgNPs

To synthesize AgNPs, a 20 ml of the decoction was transferred into a 250 ml beaker containing a 1millimolar, 180

ml of $AgNO_3$. The mixture was stirred for five minutes using a stirrer at ambient temperature. The transformation of silver nitrate into AgNPs was indicated by the color change of the solution after one week (Aisida et al., 2021). To monitor the progress of the reaction, two ml samples were collected every five hours for a total of 24 hours, and their absorbance in the wavelength range of 250-650 nm was determined spectrophotometrically and centrifuged at 5,000 revolutions/min. The resulting solid mass was separated and rinsed several times with deionized water and further centrifuged. Additionally, the final solid mass was oven-dried at 80 °C for 10 minutes.

Characterization of AgNPs

The AgNPs was characterized through scanning electron microscopy (SEM)–structure and size and Fourier transform infrared spectroscopy (FTIR) analysis–examine the materials surrounding the AgNP surfaces (Keshari et al., 2016).

1. UV–Visible absorbance spectroscopy

The reduction of silver ions in $AgNO_3$ was monitored using UV–Visible spectroscopy (Thermo Fisher Scientific, NanoDrop 2000/c) at concentrations of 250, 350, 450, 550, and 650 µL in a 10 mL solution. Subsequently, the UV–Vis absorption spectrum of AgNPs was recorded using the UV-2800 spectrophotometer across a range of 300-600 nanometers (Ashrafet al., 2016).

2. Fourier transform infrared spectroscopy

An analysis was conducted on the moieties responsible for reducing silver ions using FTIR. Analysis of materials' functional molecules, and physical bonds may be achieved via the use of FTIR. It achieves this by producing an infrared absorption spectrum, which provides insights into the molecular composition and structure (Bindhani & Panigrahi, 2015).

3. Scanning electron microscopy

Using energetic electrons, a SEM scans and records raster scan patterns of materials by interacting with the atoms in the compound being analyzed, generating valuable information about the sample's external structure, what it's made of and other characteristics. The silver colloid nanoparticles were synthesized through a chemical reduction process, while the selenium nanoparticles were produced by reducing sodium selenite with glutathione in its reduced state and then stabilized with Bovine serum albumin (BSA). Both nanoparticle samples underwent sterilization using UV radiation within a controlled airflow equipment (Hussain et al., 2016).

4. Antioxidants activities of AgNPs

a. DPPH radical scavenging assay

Exactly 2.4 mg of DPPH was dissolved in 100 ml of methanol to prepare a solution of the radical (DPPH). Then, about two milliliters of methanolic DPPH solution were enhanced with a fixed portion of various test materials. After thorough mixing, the solution was left to sit for 30 minutes at room temperature minutes in the dark. Following the incubation period, the absorbance of the reaction mixture was quantified spectrophotometrically at a wavelength of 515 nm, as per the method outlined by Owoade et al. (2016). Ascorbic acid was used as reference standard. The percentage of DPPH radical scavenging activity is given in Eq. (1).

$$\text{Percentage inhibition} = (\text{control} - \text{test})/(\text{control} \times 100) \quad (1)$$

b. Reducing power activity of AgNPs

In brief, 50 microliters of test solutions were mixed with 2.5 milliliters of phosphate buffered saline (200 millimolar, pH 6.6) and 2.5 milliliters of potassium ferricyanide (1.00%). This was then incubated at 50 °C for 20 minutes, followed by rapid cooling. Subsequently, 2.5 ml of 10.00% trichloroacetic acid (TCA) in water was added to the mixture and separated via spinning.

After centrifugation, one ml of a solution containing 0.10% ferric chloride was added to the supernatant. The absorbance of the resulting mixture was measured using spectrophotometry at a wavelength of 700 nm. BHT was used as reference standard, BHT (Shakibaie et al., 2021).

c. Total antioxidants capacity

The overall antioxidant potential of the extracts was evaluated following the methodology described by Ahmed et al. (2014). Precisely, four mM ammonium molybdate, 28 mM sodium phosphate, and 0.6 M sulfuric acid was mixed with a portion of the sample solution. In the absence of the sample, 0.5 mL of 45.00% ethanol was used instead. The tubes containing the mixtures were then placed in a water bath heated to 95 °C and maintained for 90 minutes. At room temperature, the absorbance at 695 nm was determined spectrophotometrically. As indicated by Agbaje and Charles (2022a), a higher absorbance value suggests greater antioxidant activity (**Appendix A**).

d. Nitric oxide inhibition

The production of nitric oxide (NO) in biological tissues is catalyzed by nitric oxide synthases, which produces citrulline from arginine through a five-electron oxidative process (Agbaje & Charles, (2022b). Sodium nitroprusside decomposes in water with a pH of 7.2, forming NO. Stable molecules including nitrate and nitrite are formed when NO is exposed to oxygen under aerobic circumstances.

These are monitored using Griess reagent, following the method. A solution containing 10 millimolar sodium nitroprusside is added to phosphate buffer saline (pH 7.4) and the sample at preparations ranging from 0.2 to 0.8 milligrams per milliliter. This mixture is then incubated at 25 degrees Celsius for 150 minutes. Afterward, a portion of the solution is extracted and combined with naphthylethylenediamine dichloride and Griess reagent. Following a 30-minute incubation at room temperature, the absorbance of the solution is measured at 546 nm using a cuvette (Naskar et al., 2010).

Eq. (2) calculates nitric oxide radical inhibition.

$$\%\ \text{inhibition of NO radical} = (A0 - A1)/A0 \times 100 \quad (2)$$

In the given context, A0 denotes the absorbance prior to the reaction, while A1 signifies the absorbance subsequent to the reaction involving griess reagent.

5. Anti-inflammatory properties of silver nanoparticles

a. Protein inhibitory action of silver nanoparticles

The inhibitory action of silver nanoparticles (AgNPs) on protein activity was investigated using a two ml reaction vessel. The reaction mixture consisted of 50 µl of test samples, one mL, 20 mM tris HCl (pH 7.4), and one mg trypsin. The mixture was heated to 37 °C for five minutes and addition of one milliliter of a 0.80% (w/v) casein solution. After a further incubation period of twenty minutes, the reaction was terminated by adding two milliliters of 70.00% perchloric acid. The turbid mixture was then centrifuged, and the spectrophotometry analysis of the supernatant was carried out at 210 nanometers, with buffer as a reference and water as a control (Abukabda, 2018).

b. Inhibition of albumin denaturation

We prepared a 1.00% solution of BSA by dissolving it in double-distilled water. Additionally, a solution containing 10 mg/ml concentration of nanoparticles derived from clove was prepared. Test samples consisted of 50 microliters of the reaction mixture combined with 0.5 ml of BSA. The final mixture was then incubated at 25 °C for 15 minutes, as described by Ryavanaki et al. (2020). Protein structure disruption was induced by heating for 10 minutes at 60 °C. Spectrophotometric analysis was carried out at 660 nanometers. BSA served as the negative control. % of denaturation inhibition is given in Eq. (3).

$$\frac{Negative\ control - test}{Negative\ control} \times 100 \quad (3)$$

6. Anti-diabetic activity of AgNps

a. α-Amylase inhibition

The α-amylase inhibition assay was carried out using DNSA (**Appendix B**). The reagent solution of 0.02 M sodium phosphate buffer (with six mM NaCl, pH 6.9, 500 mL), along with α-amylase solution (1U mL) and AgNPs preparations of 20-100 mg/mL was prepared (Simair et al., 2017). The mixture was incubated at 37 °C for 20 minutes. After incubation, 25 mL of 1.00% aqueous starch in the specified buffer was put in, followed by another incubation at 37 °C for 15 mins. The reaction was terminated by adding one mL DNSA and incubating the tubes in a vigorously boiling water bath for 10 minutes. After cooling, spectrophotometric analysis was done at 540 nm.

The α-amylase inhibitory activity was calculated using Eq. (4), as follows:

$$\%\ \alpha\ amylase\ inhibition\ = 100 \times \frac{Abs\ 100\%\ control - Abs\ sample}{Abs\ 100\%\ control} \quad (4)$$

b. α-Glucosidase inhibition activity

The inhibition of α-glucosidase was measured using an adjusted protocol based on the work of Chen et al. (2021). The test mixture comprised 150 mL of 0.1 M sodium phosphate buffer (pH 6.9) containing six mM sodium chloride, along with α-glucosidase and silver nanoparticles at concentrations ranging from 20-100 mg mL. This mixture was pre-incubated for 10 minutes at 37 °C. Following incubation, the mixture was combined with a solution containing 50 mL, two millimolar four-nitrophenol in PBS (0.1 M) and incubated at 37 °C for 20 minutes and terminated thereafter by adding 50 mL, 0.1 M sodium carbonate (Na_2CO_3) solution.

Table 1. Qualitative chemical study of natural products of plant

Phytochemicals	Aqueous extracts	
	Leaves	Stems
Phenol	Present	Not present
Flavonoid	Present	Present
Tannin	Present	Not present
Alkaloid	Present	Present
Saponin	Present	Present
Reducing sugar	Present	Present
Steroid	Not present	Present
Terpenoid	Not present	Present
Cardiac glycoside	Present	Present
Phlobatannin	Not present	Present

Absorbance was measured at 405 nm. The control tube, which contained α-glucosidase but lacked AgNPs, exhibited full enzyme activity (100%). The positive control used in the experiment described by Chen et al. (2021) was acarbose.

$$\%\alpha - Glucosidase\ inhibition\ activity\ = ¼\ Ai405\ Ae405/Ai405 \times 100 \quad (5)$$

where Ai405 ¼ is absorbance without nanoparticles; Ae405 ¼ absorbance with nanoparticles.

7. Anti-glycation activity of AgNps

Glycation, a non-enzymatic process accelerated in diabetes, can disrupt protein structure and speed up browning due to glucose presence. The degree of browning serves as a reliable glycation indicator. Measurement of absorbance at 420 nanometer using a one cm path length cell (Hrynets et al., 2013). Trials were conducted in duplicate. The percentage of protection from browning was calculated using Eq. (6):

$$Percentage\ protection = [(Abs\ control - Abs\ sample)/Abs\ control] \times 100 \quad (6)$$

where Abs cont is control solution and Abs sample is samples.

RESULTS

Qualitative Phytochemical Analysis *Telfairia Occidentalis*

Table 1 shows qualitative chemical study of the natural products of the plant. The stem extract shows more phytochemical profiles as compared to the leaves. Though there was a slight difference in the number of phytochemicals present in both extracts.

Quantitative Phytochemical Analysis *Telfairia Occidentalis*

Table 2 shows quantitative chemical study of the natural products of the sample. The analysis was carried out on fresh *telfairia occidentalis* both stem and leaves, while another analysis was done on both samples with the mixture of silver synthesized nanoparticles.

Table 2. Quantitative chemical study of natural products of sample

Samples	Tannin	Phenol	Saponin	Alkaloid	Reducing sugar	Cardiac glycoside	Flavonoid
Fresh ToLE	52.51	17.42	4.41	5.27	5.20	1.61	17.42
Fresh ToL-AgNPs	53.48	17.36	4.46	5.83	5.34	1.70	18.08
Fresh ToSE	0.00	0.00	3.56	3.16	4.74	0.85	8.82
Fresh ToS-AgNPs	3.60	1.00	3.66	3.47	4.40	1.03	16.24

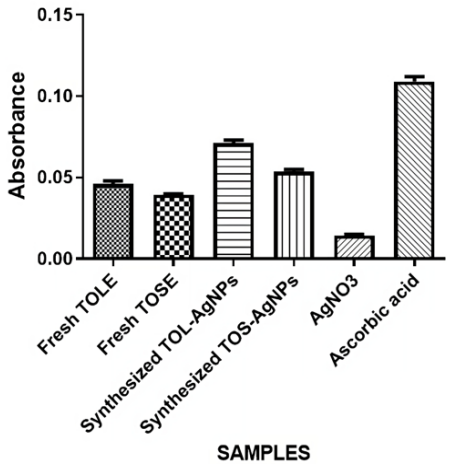

Figure 1. Reducing power of fresh extracts & synthesized AgNPs of *telfairia occidentalis* leaves, roots, flowers, & stems (Source: Authors' own elaboration)

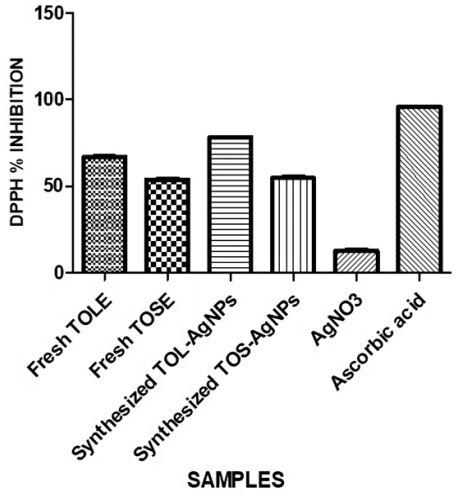

Figure 2. DPPH % inhibition of fresh extracts & synthesized AgNPs of *telfairia occidentalis* leaves, roots, flowers, & stems (Source: Authors' own elaboration)

Antioxidants Determination of Extracts & Synthesized AgNps of *Telfairia Occidentalis*

Reducing power of fresh extracts & synthesized AgNps of telfairia occidentalis

Figure 1 shows reducing power of fresh extracts and synthesized AgNPs of *telfairia occidentalis* leaves, roots, flowers and stems.

DPPH % inhibition of fresh extracts & synthesized AgNPs of telfairia occidentalis

Figure 2 shows DPPH % inhibition of fresh extracts and synthesized AgNPs of *telfairia occidentalis* leaves, roots, flowers and stems.

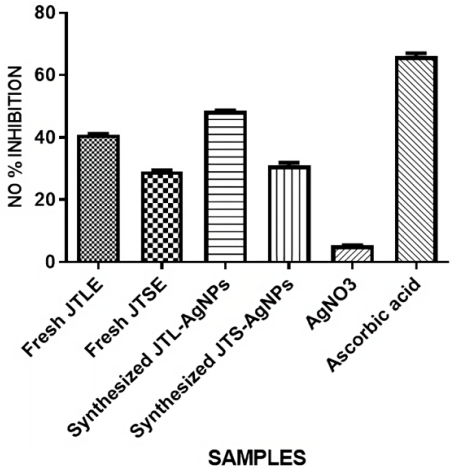

Figure 3. NO inhibition of fresh extracts & synthesized AgNPs of *telfairia occidentalis* leaves, roots, flowers, & stems (Source: Authors' own elaboration)

NO inhibition of fresh extracts & synthesized AgNPs of telfairia occidentalis

Figure 3 shows NO inhibition of fresh extracts and synthesized AgNPs of *telfairia occidentalis* leaves, roots, flowers and stems.

Antidiabetic Activity of Extracts & Synthesized AgNps of *Telfairia Occidentalis*

α-Glucosidase inhibition

Figure 4 shows *in vitro* suppression of (A) α-amylase and (B) α-glucosidase activity by fresh leaf, root, flower, and stem extracts and synthesised AgNPs of *telfairia occidentalis*.

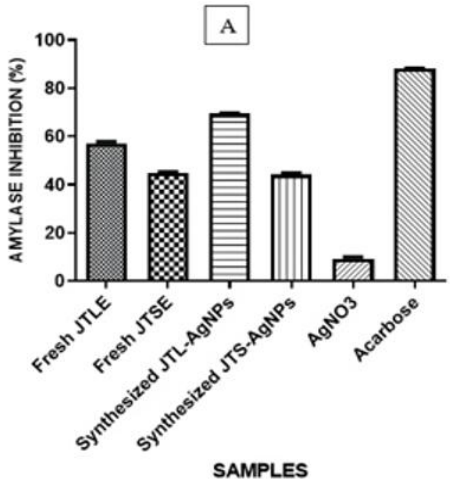

Figure 4. *In vitro* suppression of (a) α-amylase and (b) α-glucosidase activity by fresh leaf, root, flower, and stem extracts and synthesised AgNPs of *Telfairia occidentalis* (Source: Authors' own elaboration)

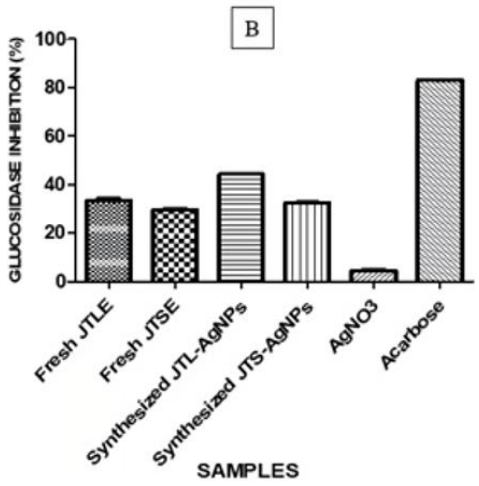

Figure 4 (continued). *In vitro* suppression of (a) α-amylase and (b) α-glucosidase activity by fresh leaf, root, flower, and stem extracts and synthesised AgNPs of *Telfairia occidentalis* (Source: Authors' own elaboration)

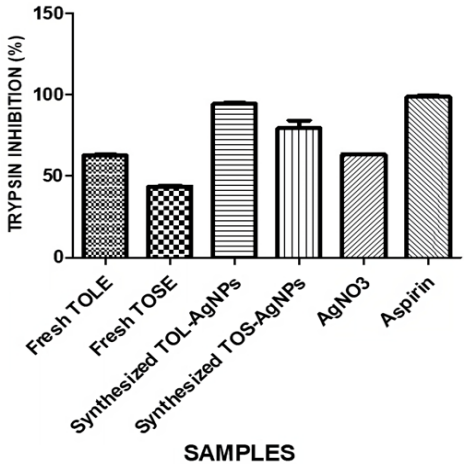

Figure 5. Trypsin inhibitory effects of fresh leaves, roots, flowers, & stems extracts & synthesized AgNPs of *telfairia occidentalis* (Source: Authors' own elaboration)

Anti-inflammatory Activities of Extracts & Synthesized AgNps of *Telfairia Occidentalis*

Protein inhibitory

Figure 5 shows trypsin inhibitory effects of fresh leaves, roots, flowers and stems extracts and synthesized AgNPs of *telfairia occidentalis*.

Albumin denaturation inhibition

Figure 6 shows albumin denaturation inhibitory effects of fresh leaves, roots, flowers and stems extracts and synthesized AgNPs of *telfairia occidentalis*.

Characterization of Generated Silver Nanoparticles

UV-Vis absorption spectra

Silver nanoparticles synthesized on leaf extract (TOL) and AgNPs produced on stem extract (TOS): **Figure 7** shows

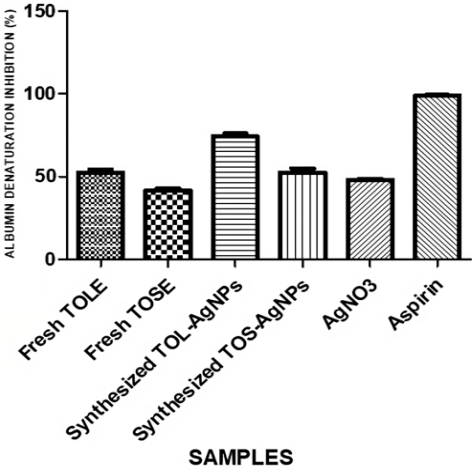

Figure 6. Albumin denaturation inhibitory effects of fresh leaves, roots, flowers, & stems extracts & synthesized AgNPs of Telfairia occidentalis (Source: Authors' own elaboration)

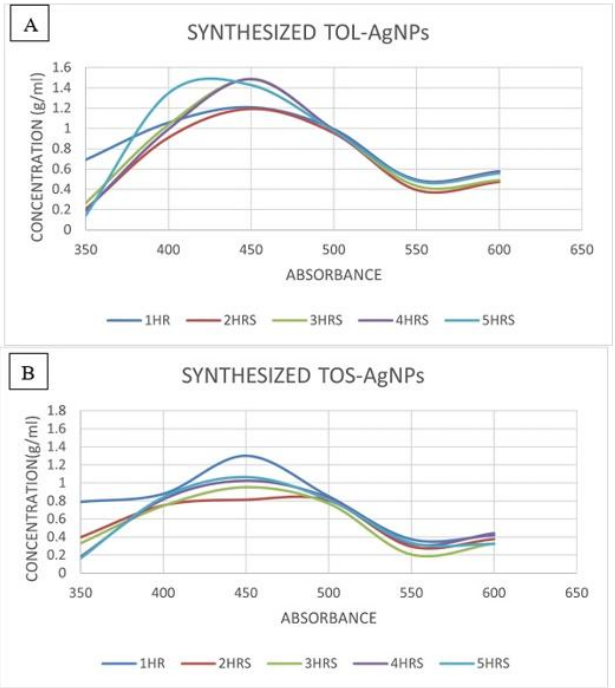

Figure 7. (A) Using aqueous *telfairia occidentalis* leaf extract, ultraviolet-visible spectrum of AgNPs were measured at various time intervals & (B) UV-Vis absorption spectra of obtained silver nanoparticles at different time intervals using aqueous stem extract of *telfairia occidentalis* (Source: Authors' own elaboration)

(A) using aqueous *telfairia occidentalis* leaf extract, the ultraviolet-visible spectrum of AgNPs were measured at various time intervals and (B) UV-Vis absorption spectra of obtained silver nanoparticles at different time intervals using aqueous stem extract of *telfairia occidentalis*.

AgNps ultraviolet-visible absorption spectra

Figure 8 shows, at different time intervals, an aqueous leaf extract of *telfairia occidentalis* was used as a reducing agent to evaluate ultraviolet-visible wavelengths of absorption of AgNPs.

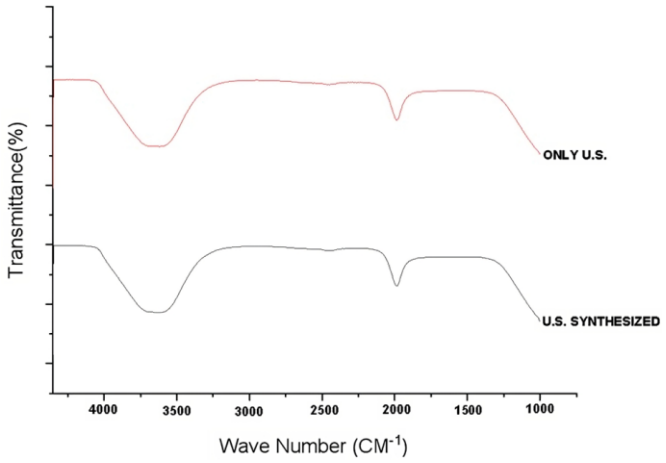

Figure 8. At different time intervals, an aqueous leaf extract of *telfairia occidentalis* was used as a reducing agent to evaluate ultraviolet-visible wavelengths of absorption of AgNPs (Source: Authors' own elaboration)

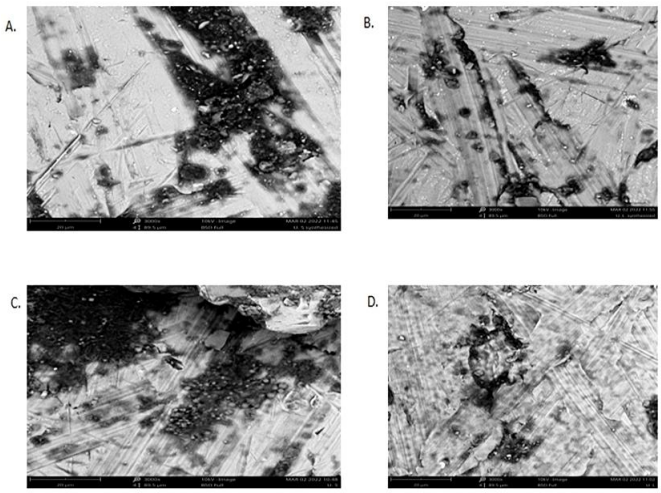

Figure 9. SEM shows that AgNPs of varying sizes have formed: (A) 20 nm silver nanoparticle synthesized from *telfairia occidentalis* stem, (B) 20 nm silver nanoparticle synthesized from *telfairia occidentalis* leaves, (C) 20 nm silver nanoparticle synthesized from *telfairia occidentalis* stem, & (D) 20 nm silver nanoparticle synthesized from *telfairia occidentalis* leaves (Source: Authors' own elaboration)

Scanning electron microscopy imaging

SEM image indicates the formation of variable size of silver nanoparticle: **Figure 9** shows the scanning electron micrograph shows that AgNPs of varying sizes have formed. (A) 20 nm silver nanoparticle synthesized from *telfairia occidentalis* stem (B) 20 nm silver nanoparticle synthesized from *telfairia occidentalis* leaves (C) 20 nm silver nanoparticle synthesized from *telfairia occidentalis* stem (D) 20 nm silver nanoparticle synthesized from *telfairia occidentalis* leaves.

SEM evaluation of average nanoparticle size: **Figure 10** shows SEM indicates the average size of silver nanoparticle (A) AgNps synthesized *telfairia occidentalis* stem (B) AgNps synthesized *telfairia occidentalis* leaves.

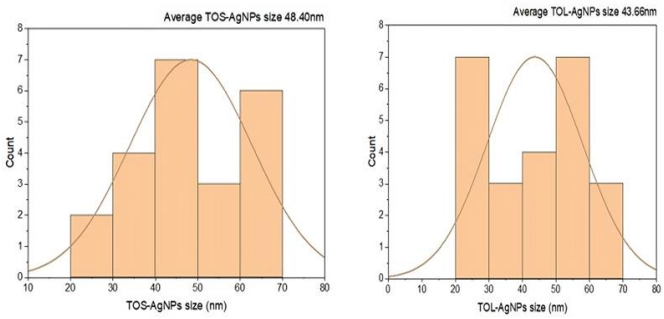

Figure 10. SEM indicates average size of silver nanoparticle: (A) AgNps synthesized *telfairia occidentalis* stem & (B) AgNps synthesized *telfairia occidentalis* leaves (Source: Authors' own elaboration)

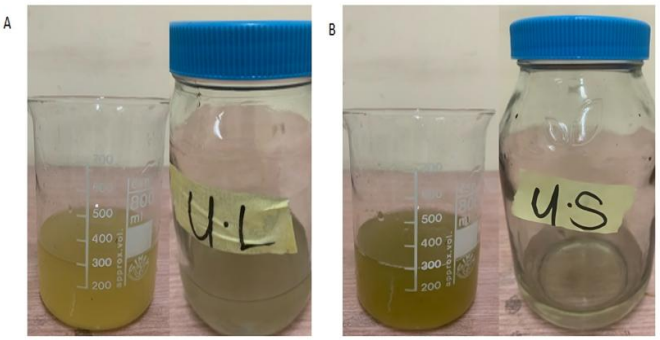

Figure 11. Reduction of Ag+ to AgNPs causes color changes from zero hour to 24 hour: (A) *telfairia occidentalis* leaves & (B) *telfairia occidentalis* stem (Source: Authors' own elaboration)

Visual observation of color of AG+ to AgNps

Figure 11 shows reduction of Ag+ to AgNPs causes color changes from zero hour to 24 hour: (A) *telfairia occidentalis* leaves (B) *telfairia occidentalis* stem.

DISCUSSION

Telfairia occidentalis leaf sample included a wide variety of chemical components, including coumarins, saponins, tannins, alkaloids, glycosides, phenols, and terpenoids. It was reported the identification of various chemical compounds in the foliage of *telfairia occidentalis*, such as triterpenes, flavonoids, saponins, alkaloids, tannins, glycosides, and saponins (Oladele et al., 2021). The color of the extracted substance underwent a transformation to brown as a result of the introduction of one mM $AgNO_3$ during a time frame of 30 minutes (**Figure 11**). Subsequently, no more alteration in color was detected within a period of 24 hours. Potentially due to an existence of potent flavonoids in the extract of *telfairia occidentalis*, silver metal was reduced to AgNPs. The reduction process is attributed to the stimulation of surface plasmon resonance of the produced AgNPs, as elucidated by Liao et al. (2022). Ultraviolet-vis spectroscopy was utilized to monitor the conversion of Ag+ ions into AgNPs within an $AgNO_3$ solution, facilitated by phytochemicals derived from *telfairia occidentalis*. The maximal absorbance of *telfairia occidentalis* was observed at 419 nm, confirming the presence of AgNPs.

The formed AgNPs (10-80 nm), were confirmed through SEM analysis (**Figure 10**). This finding aligns with the dimensions of the produced nanoparticles as documented by Aisida et al. (2021). The reduction capabilities of biosynthesized AgNPs were dose-dependent, derived from *telfairia occidentalis* leaves. These AgNPs exhibited significant effectiveness in reducing power activity compared to conventional BHT (**Figure 1**). Evaluating the obtained results in alignment with those reported by Eseyin et al. (2018) and Owoade et al. (2016) revealed notable outcomes. Unregulated accumulation of hydrogen peroxide leads to the generation of O_2 radicals (-H_2O_2 and -OH^-), which inflict considerable damage to organisms' cell membranes.

We revealed that hydrogen peroxide was inhibited by AgNPs at a percentage of 56.69%, whereas ascorbic acid exhibited a 92.19% inhibition. Concentrations of free radical H_2O_2 were diminished in comparison to the DPPH scavenging activity. AgNPs can generate higher levels of hydrogen peroxide and stimulate inflammasome formation due to their ability to leak cathepsins from damaged lysosomes. The silver nanoparticles exhibited comparable inhibition and enhanced efficacy against hydrogen peroxide and DPPH in comparison to *telfairia occidentalis* extract. *Telfairia occidentalis* extract showed an antioxidant activity lower than that of AgNPs, as evaluated by the ABTS and reducing power scavenging assay. The degradation of protein is a widely known factor that triggers inflammation in illnesses like rheumatoid arthritis (Ding et al., 2023). NSAIDs mechanism of action is by inhibiting the degradation of proteins (Duan et al., 2017). Therefore, ability of examined extract and environmentally friendly produced AgNPs to inhibit protein denaturation may contribute to their anti-inflammatory properties.

Telfairia occidentalis generated AgNPs has the capacity to hinder protein denaturation, (albumin) with an inhibition rate of 35.62% (**Figure 6**) However, this percentage inhibition is lower in comparison to the typical aspirin, which exhibits an inhibition rate of 53.25%. Nevertheless, the AgNPs exhibit a protein (trypsin) inhibitory effect of 76.54%, which is comparable to the control's effect of 85.29%. This similarity could be tied to the secondary metabolites in the extract utilized for AgNPs synthesis. Our findings are similar to reports by Ashraf et al. (2016), Bindhani and Panigrahi (2015), Eseyin et al. (2018), Keshari et al. (2020), and Owoade et al. (2016).

DM is a disease condition characterized by elevated amounts of glucose in the bloodstream (He et al., 2015). An effective approach is to inhibit the enzyme responsible for the breakdown of carbohydrates. Silver nanoparticles, derived from specific traditional medicinal plants, have been observed to possess anti-diabetic properties because of their ability to inhibit α-glucosidase activity (Khan et al., 2023). Nanoparticles derived from *telfairia occidentalis* exhibited significant inhibition of α-glucosidase activity, comparable to acarbose (**Figure 4**). The phenomenon is attributed to the adherence of phytochemicals from *telfairia occidentalis* to the surfaces of AgNPs. More significantly, the results of this research indicate that diabetes may be successfully treated by combining leaf extract from *telfairia occidentalis* with environmentally safe silver nanoparticles. This strategy seems to be a promising method for managing diabetes.

CONCLUSIONS

It is economically and environmentally safe to use a biological agent to produce nanoparticles, and it allows phytochemicals to serve as stabilizing and reducing agents. The surface plasmon resonance of silver nanoparticles synthesized using eco-friendly technology was investigated. FTIR spectra demonstrated that the phytochemicals were in charge of AgNPs' reduction and capping. SEM analysis revealed AgNPs' morphology and uniform dispersion. These AgNPs displayed notable attributes, including antioxidant, anti-diabetic, and anti-inflammatory properties. This study verifies previous findings that the AgNPs synthesis in *telfairia occidentalis* leaves is due to phytochemicals. The research also shows that these NPs have anti-inflammatory, anti-diabetic, and antioxidant capabilities.

Author contributions: DEO: software, investigation, data curation, conceptualization; **NMN:** writing - review & editing, methodology; **ARA:** writing - review & editing, writing - original draft, formal analysis; **AKA:** writing - original draft, data curation; **MCE:** writing - review & editing, methodology; **OMA:** writing original draft, conceptualization; **UUD:** writing - original draft, conceptualization; **VTO:** writing - original draft, resources; **JJO:** writing - original draft, resources; **TAA:** original draft, resources; **EEK:** writing - review & editing, resources; **SAA:** writing-original draft, investigation; **TOO:** writing-original draft, investigation, resources; **OCO:** writing-original draft, project administration. All co-authors agree with the results and conclusions.

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Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from corresponding author.

REFERENCES

Abubakar, I. B., Ukwuani-Kwaja, A. N., Olayiwola, F. S., Malami, I., Muhammad, A., Ahmed, S. J., Nurudeen, Q. O., & Falana, M. B. (2020). An inventory of medicinal plants used for treatment of cancer in Kwara and Lagos State, Nigeria. *European Journal of Integrative Medicine, 34*, Article 101062. https://doi.org/10.1016/j.eujim.2020.101062

Abukabda, A. B. (2018). *The microvascular and systemic effects of titanium dioxide nanoparticle exposure: A physiological perspective* [PhD thesis, West Virginia University].

Agbaje, E. O., & Charles, O. O. (2022a). Anti-inflammatory and cytokines modulatory activities of spondias mombin linn. (anacardiaceous) in wound healing: Roles of IL6. *The Journal of Phytopharmacology, 11*(4), 260-267. https://doi.org/10.31254/phyto.2022.11406

Agbaje, E. O., & Charles, O. O. (2022b). Spondias mombin linn. (anacardiaceous) essential oil ointment enhances healing of excision wounds in rats. *The Journal of Phytopharmacology, 11*(4), 224-232. https://doi.org/10.31254/phyto.2022.11401

Ahmed, D., Fatima, K., & Saeed, R. (2014). Analysis of phenolic and flavonoid contents, and the anti-oxidative potential and lipid peroxidation inhibitory activity of methanolic extract of carissa opaca roots and its fractions in different solvents. *Antioxidants, 3*(4), 671-683. https://doi.org/10.3390/antiox3040671

Aisida, S. O., Ugwu, K., Akpa, P. A., Nwanya, A. C., Nwankwo, U., Bashir, A. K. H., Madiba, I. G., Ahmed, I., & Ezema, F. I. (2021). Synthesis and characterization of iron oxide nanoparticles capped with moringa oleifera: The mechanisms of formation effects on the optical, structural, magnetic and morphological properties. *Materials Today: Proceedings, 36*, 214-218. https://doi.org/10.1016/j.matpr.2020.03.167

Akindele, A. J., Ajao, M. Y., Aigbe, F. R., & Enumah, U. S. (2013). Effects of telfairia occidentalis (fluted pumpkin; cucurbitaceae) in mouse models of convulsion, muscle relaxation, and depression. *Journal of Medicinal Food, 16*(9), 810-816. https://doi.org/10.1089/jmf.2012.0211

Asafo-Agyei, T., Appau, Y., Barimah, K. B., & Asase, A. (2023). Medicinal plants used for management of diabetes and hypertension in Ghana. *Heliyon, 9*(12). https://doi.org/10.1016/j.heliyon.2023.e22977

Ashraf, J. M., Ansari, M. A., Khan, H. M., Alzohairy, M. A., & Choi, I. (2016). Green synthesis of silver nanoparticles and characterization of their inhibitory effects on AGEs formation using biophysical techniques. *Scientific reports, 6*, Article 20414. https://doi.org/10.1038/srep20414

Bindhani, B. K., & Panigrahi, A. K. (2015). Biosynthesis and characterization of silver nanoparticles (SNPs) by using leaf extracts of ocimum sanctum L (tulsi) and study of its antibacterial activities. *Journal of Nanomedicine & Nanotechnology, 6*, Article 8. https://doi.org/10.4172/2157-7439.S6-008

Caturano, A., D'Angelo, M., Mormone, A., Russo, V., Mollica, M. P., Salvatore, T., Galiero, R., Rinaldi, L., Vetrano, E., Marfella, R., Monda, M., Giordano, A., & Sasso, F. C. (2023). Oxidative stress in type 2 diabetes: Impacts from pathogenesis to lifestyle modifications. *Current Issues in Molecular Biology, 45*(8), 6651-6666. https://doi.org/10.3390/cimb45080420

Chen, S., Dong, L., Quan, H., Zhou, X., Ma, J., Xia, W., Zhou, H., & Fu, X. (2021). A review of the ethnobotanical value, phytochemistry, pharmacology, toxicity and quality control of tussilago farfara L. (coltsfoot). *Journal of Ethnopharmacology, 267*, Article 113478. https://doi.org/10.1016/j.jep.2020.113478

Ding, Q., Hu, W., Wang, R., Yang, Q., Zhu, M., Li, M., Cai, J., Rose, P., Mao, J., & Zhu, Y. Z. (2023). Signaling pathways in rheumatoid arthritis: Implications for targeted therapy. *Signal Transduction and Targeted Therapy, 8*, Article 68. https://doi.org/10.1038/s41392-023-01331-9

Duan, P., Liu, Y., & Li, J. (2017). The comparative efficacy and safety of topical non-steroidal anti-inflammatory drugs for the treatment of anterior chamber inflammation after cataract surgery: A systematic review and network meta-analysis. *Graefe's Archive for Clinical and Experimental Ophthalmology, 255*, 639-649. https://doi.org/10.1007/s00417-017-3599-8

Eseyin, O. A., Benedict, U., Thomas, P. S., Etim, I., Essien, E., Johnson, E., Ebong, A., Munavvar, Z., Ahmad, A., Sheryar, A., & Akpan, U. (2018). Isolation and characterization of antioxidant constituents of the fruit of telfairia occidentalis hook F (cucurbitaceae). *Tropical Journal of Pharmaceutical Research, 17*(10), 1953-1960. https://doi.org/10.4314/tjpr.v17i10.9

González, P., Lozano, P., Ros, G., & Solano, F. (2023). Hyperglycemia and oxidative stress: An integral, updated and critical overview of their metabolic interconnections. *International Journal of Molecular Sciences, 24*(11), Article 9352. https://doi.org/10.3390/ijms24119352

He, C., Shan, Y., & Song, W. (2015). Targeting gut microbiota as a possible therapy for diabetes. *Nutrition Research, 35*(5), 361-367. https://doi.org/10.1016/j.nutres.2015.03.002

Hritcu, L. D., Borcea, D., Anton, E., Morosan, S., Pasca, S., Trinca, C., Spataru, M. C., Petrariu, F. D., Burtan, L. C., Ciobica, A., Curpan, A., & Timofte, D. (2021). Experimental induction of type 2 diabetes mellitus and the efficiency of bariatric surgery in its reversal in rats. *Acta Endocrinologica, 17*(2), 149-156. https://doi.org/10.4183/aeb.2021.149

Hrynets, Y., Ndagijimana, M., & Betti, M. (2013). Non-enzymatic glycation of natural actomyosin (NAM) with glucosamine in a liquid system at moderate temperatures. *Food Chemistry, 139*, 1062-1072. https://doi.org/10.1016/j.foodchem.2013.02.026

Hussain, I., Singh, N. B., Singh, A., Singh, H., & Singh, S. C. (2016). Green synthesis of nanoparticles and its potential application. *Biotechnology Letters, 38*, 545-560. https://doi.org/10.1007/s10529-015-2026-7

Kalló, G., Kunkli, B., Győri, Z., Szilvássy, Z., Csősz, É., & Tőzsér, J. (2020). Compounds with antiviral, anti-inflammatory and anticancer activity identified in wine from Hungary's Tokaj Region via high resolution mass spectrometry and bioinformatics analyses. *International Journal of Molecular Sciences, 21*(24), Article 9547. https://doi.org/10.3390/ijms21249547

Keshari, A. K., Srivastava, R., Singh, P., Yadav, V. B., & Nath, G. (2020). Antioxidant and antibacterial activity of silver nanoparticles synthesized by cestrum nocturnum. *Journal of Ayurveda and Integrative Medicine, 11*(1), 37-44. https://doi.org/10.1016/j.jaim.2017.11.003

Khan, H. A., Ghufran, M., Shams, S., Jamal, A., Khan, A., Abdullah, Awan, Z. A., & Khan, M. I. (2023). Green synthesis of silver nanoparticles from plant fagonia cretica and evaluating its anti-diabetic activity through indepth in-vitro and in-vivo analysis. *Frontiers in Pharmacology, 14*, Article 1194809. https://doi.org/10.3389/fphar.2023.1194809

Koska, J., Saremi, A., Howell, S., Bahn, G., De Courten, B., Ginsberg, H., Beisswenger, P. J., Reaven, P. D., & VADT Investigators. (2018). Advanced glycation end products, oxidation products, and incident cardiovascular events in patients with type 2 diabetes. *Diabetes Care, 41*(3), 570-576. https://doi.org/10.2337/dc17-1740

Liao, X., Liu, Y., Zheng, J., Zhao, X., Cui, L., Hu, S., Xia, T., & Si, S. (2022). Diverse pathways of engineered nanoparticle-induced NLRP3 inflammasome activation. *Nanomaterials, 12*(21), Article 3908. https://doi.org/10.3390/nano12213908

Naskar, S., Islam, A., Mazumder, U. K., Saha, P., Haldar, P. K., & Gupta, M. (2010). In vitro and in vivo antioxidant potential of hydromethanolic extract of Phoenix dactylifera fruits. *Journal of Scientific Research, 2*(1), 144-157. https://doi.org/10.3329/jsr.v2i1.2643

Oguntibeju O. O. (2019). Type 2 diabetes mellitus, oxidative stress and inflammation: Examining the links. *International Journal of Physiology, Pathophysiology and Pharmacology, 11*(3), 45-63.

Ojimelukwe, P. C. (2022) Telfairia occidentalis: A blood booster, an antioxidant and an antihyperglycaemic agent. *International Journal of Nutrition and Food Sciences, 7*(3), 1-19.

Oladele, J. O., Oyeleke, O. M., Awosanya, O. O., Olowookere, B. D., & Oladele, O. T. (2021). Fluted pumpkin (telfairia occidentalis) protects against phenyl hydrazine-induced anaemia and associated toxicities in rats. *Advances in Traditional Medicine, 21*, 739-745. https://doi.org/10.1007/s13596-020-00499-7

Osonuga, I. O., Faponle, A. S., Ezima, E. N., Adenowo, T. K., & Adelegan, A. A. (2020). Effects of aqueous leaf extract of Telfairia occidentalis on haematological parameters and liver enzymes in male wistar rats. *Annals of Health Research, 6*(1), 44-50. https://doi.org/10.30442/ahr.0601-05-65

Owoade, A. O., Aborisade, A. B., Adetutu, A., & Olorunnisola, O. S. (2016). Evaluation of the effectiveness of telfairia occidentalis leave extracts in the amelioration of carbon tetrachloride induced liver injuries and oxidative damage in rats. *Journal of Advances in Medical and Pharmaceutical Sciences, 10*(2), 1-11. https://doi.org/10.9734/JAMPS/2016/29199

Pei, J., Pan, X., Wei, G., & Hua, Y. (2023). Research progress of glutathione peroxidase family (GPX) in redoxidation. *Frontiers in Pharmacology, 14*, Article 1147414. https://doi.org/10.3389/fphar.2023.1147414

Ryavanaki, L., Tsai, H., & Fuh, C. B. (2020). Microwave synthesis of gold nanoclusters with garlic extract modifications for the simple and sensitive detection of lead ions. *Nanomaterials, 10*(1), Article 94. https://doi.org/10.3390/nano10010094

Shakibaie, M., Riahi-Madvar, S., Ameri, A., Amiri-Moghadam, P., Adeli-Sardou, M., & Forootanfar. (2021). Microwave assisted biosynthesis of cadmium nanoparticles: Characterization, antioxidant and cytotoxicity studies. *Journal of Cluster Science, 33*, 1877-1887. https://doi.org/10.1007/s10876-021-02107-3

Simair, A. A., Qureshi, A. S., Khushk, I., Ali, C. H., Lashari, S., Bhutto, M. A., Mangrio, G. S., & Lu, C. (2017). Production and partial characterization of α-amylase enzyme from bacillus sp. BCC 01-50 and potential applications. *BioMed Research International, 2017*, Article 9173040. https://doi.org/10.1155/2017/9173040

Sukhikh, S., Babich, O., Prosekov, A., Kalashnikova, O., Noskova, S., Bakhtiyarova, A., Krol, O., Tsvetkova, E., & Ivanova, S. (2023). Antidiabetic properties of plant secondary metabolites. *Metabolites, 13*(4), Article 513. https://doi.org/10.3390/metabo13040513

Tastan, P. (2023). Plants used in diabetes treatment. *International Journal of Nature and Life Sciences, 7*(2), 24-35. https://doi.org/10.47947/ijnls.1322105

Unuofin, J. O., & Lebelo, S. L. (2020). Antioxidant effects and mechanisms of medicinal plants and their bioactive compounds for the prevention and treatment of type 2 diabetes: An updated review. *Oxidative Medicine and Cellular Longevity, 2020*, Article 1356893. https://doi.org/10.1155/2020/1356893

World Health Organization. (2019). *Classification of diabetes mellitus*. https://iris.who.int/rest/bitstreams/1233344/retrieve

APPENDIX A: ANTIOXIDANT ACTIVITY OF AGNPS SYNTHESIZED USING AQUEOUS EXTRACT OF *TELFAIRIA OCCIDENTALIS*

Table A1. Antioxidant activity of AgNPs synthesized using aqueous extract of *telfairia occidentalis*

Samples	DPPH IC50 VALUES	NO IC50 values	TAC (mg/100g)
Fresh ToLE	42.47	207.93	5.86
Fresh ToL-AgNPs	22.29	188.17	8.55
Fresh ToSE	64.96	264.06	5.49
Fresh ToS-AgNPs	42.99	218.95	

Note. DPPH radical scavenging activity, NO, & TAC of fresh extract & AgNPs synthesized (leaf & stem) aqueous extract of *telfairia occidentalis* values was obtained

APPENDIX B: ANTI-DIABETIC ACTIVITY OF AgNps ON AQUEOUS EXTRACT OF *TELFAIRIA OCCIDENTALIS*

Table B1. Anti-diabetic activity of AgNPs on aqueous extract of *Telfairia occidentalis*

Samples	α- Amylase IC50 values	α- Glucosidase IC50 values
Fresh ToLE	110.22	174.93
Fresh ToL-AgNPs	100.74	161.75
Fresh ToSE	141.05	252.62
Fresh ToS-AgNPs	125.74	238.16

Note. α-Amylase inhibition & α- Glucosidase analysis was done on fresh *telfairia occidentalis* both stem & leaves, while another analysis was done on both samples with mixture of silver synthesized nanoparticles