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Valorization of *Sesamum indicum* Seeds for Diabetes Prevention: Antiglycative, Antioxidant, and Digestive Enzyme Inhibitory Activities in Support of the Health Objectives of the Simandou 2040 Program in Guinea

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Abstract

Diabetes mellitus represents a major public health concern, particularly in developing countries where accessible preventive strategies remain limited. This study aimed to evaluate the biological properties of *Sesamum indicum* seeds for their potential use in diabetes prevention, in alignment with the health and agro-industrial objectives of the Simandou 2040 Program in Guinea. Three extracts (aqueous, hydroethanolic, and methanolic) were prepared and subjected to phytochemical screening, as well as *in vitro* antioxidant, antiglycation, digestive enzyme inhibitory, and anti-inflammatory assays. The findings revealed that the hydroethanolic extract exhibited the highest extraction yield (30.4%) and the greatest levels of total polyphenols (118.4 ± 3.0 mg GAE/g DE), flavonoids (69.7 ± 2.1 mg QE/g DE), and tannins (39.6 ± 1.8 mg CE/g DE). This extract also demonstrated the most potent biological activities, including antioxidant activity (DPPH, IC_{50} = 61.7 µg/mL), ferric reducing antioxidant power (FRAP, 3.12 ± 0.11 mmol Fe^{2+}/g DE), inhibition of protein glycation (78.4% ± 2.0%), fructosamine formation (63.8% ± 1.9%), and fluorescent advanced glycation end-products (AGEs) (68.2% ± 1.8%). Furthermore, it showed strong inhibitory effects against α-amylase (74.2% ± 2.0%; IC_{50} =

88.6 µg/mL) and *α*-glucosidase (85.4% ± 2.1%; IC_{50} = 66.3 µg/mL), along with notable anti-inflammatory activity (71.2% ± 1.9%). These results suggest that *Sesamum indicum* seeds are a promising source of bioactive compounds that may contribute to the prevention of diabetes and its associated complications. Their valorization could support the development of locally produced nutraceuticals, enhance food security, and promote national economic diversification.

Keywords

Sesamum indicum, Diabetes, Antiglycation Activity, Antioxidants, Simandou 2040

1. Introduction

Diabetes mellitus remains one of the major health challenges of the 21st century. According to the International Diabetes Federation, approximately 537 million adults aged 20 to 79 were living with diabetes in 2021, and this number is projected to reach 783 million by 2045 if current trends persist [1]. This increase disproportionately affects low- and middle-income countries, where capacities for prevention, screening, and management remain limited [2]. Consequently, diabetes constitutes a leading cause of morbidity, premature mortality, and rising healthcare costs worldwide [3].

Among the mechanisms underlying diabetic complications, non-enzymatic glycation plays a central role. This process involves a spontaneous reaction between reducing sugars, particularly glucose, and amino groups of proteins, lipids, or nucleic acids, leading to the progressive formation of advanced glycation end-products (AGEs) [4]. These irreversible compounds accumulate in tissues and promote oxidative stress, chronic inflammation, vascular stiffness, and cellular dysfunction [5]. They are strongly implicated in the development of diabetic nephropathy, retinopathy, cardiovascular diseases, and certain neurodegenerative disorders [6].

In parallel, postprandial hyperglycemia represents a major aggravating factor in type 2 diabetes [7]. It primarily results from the rapid digestion of dietary carbohydrates mediated by the enzymes *α*-amylase and *α*-glucosidase, which are responsible for intestinal glucose release. Therefore, inhibition of these enzymes constitutes an effective therapeutic strategy to reduce post-meal glycemic spikes. However, synthetic inhibitors such as acarbose [8], miglitol, and voglibose are often associated with gastrointestinal side effects, reduced patient compliance, and significant costs for vulnerable populations [9] [10].

In this context, natural products of plant origin have attracted increasing attention. Numerous extracts rich in polyphenols, flavonoids, tannins, and other secondary metabolites have demonstrated antioxidant, antiglycation, and digestive enzyme inhibitory properties. These compounds exert their effects through mul-

tiple mechanisms, including free radical scavenging, chelation of pro-oxidant metals, neutralization of reactive carbonyl intermediates, and modulation of enzymatic activity [11] [12].

Among promising plant resources, *Sesamum indicum* (sesame) occupies an important position. This oilseed crop, widely cultivated in Africa and Asia, has high nutritional and economic value [13]. Its seeds are rich in unsaturated lipids, proteins, dietary fiber, minerals, and bioactive molecules such as sesamin, sesamolin, tocopherols, and various phenolic compounds. Several recent studies have shown that the consumption of sesame-derived products improves metabolic parameters, including HbA1c, inflammatory markers, and oxidative stress [14] [15].

A recent scientific review further highlights that sesame exhibits potential beneficial effects on glycemic regulation, cardiovascular health, lipid profile, and cellular protection, making it a promising candidate for the nutritional prevention of diabetes [16] [17].

Beyond its biomedical relevance, the scientific valorization of sesame aligns with agricultural and industrial transformation dynamics, consistent with the economic diversification and local value creation objectives of the Simandou Project in Guinea. The development of nutraceutical or functional products derived from sesame could contribute to strengthening food security, supporting local innovation, and enhancing national agro-food value chains.

It is within this framework that the present study was undertaken to evaluate *in vitro* the biological properties of aqueous, hydroethanolic, and methanolic extracts of *Sesamum indicum* seeds. Specifically, the study aimed to determine their phenolic compound content, antioxidant activity, inhibitory effects on protein glycation and AGE formation, as well as their ability to inhibit α-amylase and α-glucosidase enzymes. The expected findings may contribute to the development of natural, accessible, and locally valorized solutions for the prevention of diabetes and its complications.

2. Materials and Methods

2.1. Study Area

All experimental work related to this study was carried out at the Institute of Applied Biology Research of Guinea (IRBAG), located in Kindia, Republic of Guinea. This institute is a national reference center dedicated to biomedical research, the valorization of natural substances, applied nutrition, and the study of interactions between diet and human health. In addition, a significant part of the experimental work was conducted at the Laboratory of Food Science and Nutrition of the Higher School of Hospitality and Tourism of Guinea, where complementary analyses related to food composition and nutritional evaluation were performed.

2.2. Study Material

The *Sesamum indicum* L. seeds used in this study were collected in November 2025 from local markets in Kindia, Republic of Guinea. The plant material was

authenticated by Konkon Alphonse at the Institute for Applied Biology Research of Guinea, Kindia, Guinea**.** A voucher specimen was deposited under the reference number No. MP-2025-11-SI-001 to ensure the traceability and authentication of the plant material used.

After collection, the seeds were carefully cleaned to remove impurities, dried under appropriate conditions, and ground into a fine powder. The obtained powder was directly used for the preparation of aqueous, hydroethanolic (70% ethanol), and methanolic extracts**.** The samples were not subjected to prior defatting before extraction, allowing the preservation of the naturally occurring bioactive constituents present in *Sesamum indicum* L. seeds.

Human serum used in the antiglycation model was obtained from 10 healthy volunteer donors recruited for this study. Participants were selected based on the following criteria: absence of diagnosed diabetes, absence of known metabolic disorders, and no ongoing medication that could influence glucose metabolism. After obtaining informed consent from the participants, serum samples were collected in accordance with ethical principles governing the use of human biological material. Serum samples from different donors were pooled to minimize inter-individual variability and to obtain a homogeneous sample for antiglycation analyses. Participants were informed about the scientific objective of the study and voluntarily agreed to provide their biological samples for experimental analyses. The confidentiality of donor-related information was strictly maintained in accordance with applicable ethical guidelines for biomedical research. After coagulation, the samples were centrifuged at 3000 rpm for 10 minutes. The serum was aliquoted and stored at −20˚C until analysis.

The main reagents used included ethanol, methanol, distilled water, DPPH, ABTS, FRAP, Folin-Ciocalteu reagent, gallic acid, quercetin, glucose, α-amylase, α-glucosidase, pNPG, soluble starch, aminoguanidine, nitroblue tetrazolium (NBT), thiobarbituric acid (TBA), and phosphate buffer.

2.3. Methods

2.3.1. Preparation of Extracts

Mature seeds of *Sesamum indicum* were manually sorted to remove impurities, plant debris, damaged seeds, and foreign materials. They were then thoroughly washed with distilled water and dried at room temperature (25˚C ± 2˚C) for several days, protected from direct light and humidity.

After complete drying, the seeds were ground using an electric grinder to obtain a fine and homogeneous powder. The resulting powder was sieved using a standard mesh sieve to ensure uniform particle size. It was then stored in dry, airtight, and opaque containers until use.

Three types of extracts were prepared from this plant powder: an aqueous extract, a hydroethanolic extract, and a methanolic extract.

1) Preparation of the Aqueous Extract

A mass of 50 g of fine powder from *Sesamum indicum* seeds was accurately

weighed using an analytical balance and introduced into an Erlenmeyer flask containing 500 mL of distilled water.

The mixture was brought to moderate boiling on a hot plate for 30 minutes under continuous stirring to facilitate the extraction of water-soluble compounds. After heating, the decoction was removed from the heat source and allowed to cool at room temperature.

The cooled mixture was successively filtered through clean muslin cloth and then through Whatman No. 1 filter paper to remove residual solid particles. The obtained aqueous filtrate was frozen and subsequently lyophilized using a freeze-dryer until a dry powdered extract was obtained.

The dry extract was collected, weighed, placed in an airtight amber bottle, labeled, and stored at 4˚C until further analysis.

2) Preparation of the Hydroethanolic Extract (70:30 v/v)

A mass of 50 g of seed powder was introduced into an Erlenmeyer flask containing 500 mL of a hydroethanolic mixture composed of 70% ethanol and 30% distilled water (v/v).

The mixture was subjected to dynamic maceration under continuous magnetic stirring for 24 hours at room temperature (25˚C ± 2˚C), protected from light.

After maceration, the mixture was filtered under vacuum using Whatman No. 1 filter paper. The plant residue was re-extracted twice with 250 mL of the same solvent to optimize extraction yield.

The combined filtrates were concentrated under reduced pressure using a rotary evaporator at a temperature below 45˚C until near-complete removal of the solvent.

The concentrated extract was then dried in a ventilated oven at low temperature or in a desiccator until constant weight was achieved. The resulting dry extract was weighed, labeled, and stored at 4˚C.

3) Preparation of the Methanolic Extract

A mass of 50 g of plant powder was placed in an Erlenmeyer flask containing 500 mL of analytical-grade methanol.

The mixture was maintained under continuous magnetic stirring for 24 hours at room temperature, protected from light to prevent degradation of photosensitive compounds.

At the end of the maceration period, the solution was filtered through Whatman No. 1 filter paper. The residual plant material was re-extracted twice with 250 mL of fresh methanol.

The combined filtrates were concentrated under vacuum using a rotary evaporator at moderate temperature (<40˚C) until complete evaporation of the methanol.

The obtained concentrate was dried to constant weight. The dry extract was then weighed, transferred into an airtight amber container, labeled, and stored at 4˚C until biological assays.

The obtained dry extracts were weighed in order to calculate the extraction yield

using the following formula:

$$R(\%) = \frac{\text{Mass of dry extract}}{\text{Initial powder mass}} \times 100$$

2.3.2. Qualitative Phytochemical Screening

The major secondary metabolites present in the different extracts of *Sesamum indicum* seeds were investigated through qualitative phytochemical screening using standard methods described by Singleton *et al*. [18]. This analysis enabled the identification of the presence or absence of several biologically relevant chemical groups, including tannins, flavonoids, saponins, alkaloids, coumarins, anthocyanins, leucoanthocyanins, mucilages, reducing compounds, as well as sterols and terpenes.

The reactions were carried out using aqueous, hydroethanolic, and methanolic extracts, with specific reagents. Color changes, precipitate formation, or foam appearance were used as indicators of positive reactions.

2.3.3. Quantitative Determination of Phenolic Compounds

1) Total Polyphenols

Total polyphenol content was determined using the Folin-Ciocalteu method. Results were expressed as mg gallic acid equivalent per gram of dry extract (mg GAE/g DE) [18].

2) Total Flavonoids

Total flavonoid content was determined using the aluminum chloride ($AlCl_3$) colorimetric method. Results were expressed as mg quercetin equivalent per gram of dry extract (mg QE/g DE) [19].

3) Condensed Tannins

Condensed tannins were determined using the vanillin-HCl method [20].

2.3.4. *In Vitro* Antioxidant Activities

The antioxidant activities of the different *Sesamum indicum* seed extracts were evaluated using several complementary methods to assess their ability to scavenge free radicals, reduce oxidizing metal ions, and chelate pro-oxidant metals.

1) DPPH Radical Scavenging Assay

The free radical scavenging activity of the extracts was determined according to the method described by Brand-Williams *et al*., with slight modifications. The stable radical 2,2-diphenyl-1-picrylhydrazyl (DPPH•), which is purple in color, is reduced in the presence of a hydrogen-donating antioxidant, resulting in a decrease in absorbance [21].

A freshly prepared methanolic DPPH solution (0.1 mM) was used. In test tubes, 1 mL of DPPH solution was mixed with 1 mL of each extract at different concentrations (25, 50, 100, and 150 µg/mL). The mixture was incubated in the dark for 30 minutes at room temperature.

Absorbance was measured at 517 nm against a blank using a UV-Visible spectrophotometer. Ascorbic acid was used as a positive control.

The percentage inhibition was calculated using the following formula:

$$PI(\%) = \frac{A_b - A_e}{A_b} \times 100$$

where:

- A_b = absorbance of the negative control;
- A_e = absorbance of the tested sample.

2) ABTS Assay

The antioxidant capacity of the extracts against the ABTS•$^+$ radical cation was determined according to the method of Re *et al*. [22].

The ABTS•$^+$ radical was generated by reacting ABTS solution (7 mM) with potassium persulfate (2.45 mM), followed by incubation in the dark for 12 - 16 hours at room temperature. The resulting solution was diluted with ethanol to obtain an absorbance of 0.70 ± 0.02 at 734 nm.

To 2 mL of ABTS•$^+$ solution, 200 µL of extract at different concentrations were added. After incubation for 6 minutes at room temperature, absorbance was measured at 734 nm.

The percentage inhibition was calculated using the same formula as for the DPPH assay. Results were expressed as percentage inhibition and, when applicable, as Trolox equivalents.

3) Ferric Reducing Antioxidant Power (FRAP)

The reducing power of the extracts was evaluated using the method described by Benzie and Strain. The principle is based on the reduction of the ferric tripyridyltriazine complex (Fe^{3+}-TPTZ) into the ferrous form (Fe^{2+}-TPTZ), which produces an intense blue coloration in the presence of reducing antioxidants [23].

The FRAP reagent was freshly prepared by mixing:

- Acetate buffer (300 mM, pH 3.6);
- TPTZ solution (10 mM in 40 mM HCl);
- $FeCl_3 \cdot 6H_2O$ solution (20 mM).

In a test tube, 100 µL of extract was added to 3 mL of FRAP reagent. After incubation at 37˚C for 30 minutes, absorbance was measured at 593 nm.

Results were expressed as mmol Fe^{2+} equivalent per gram of dry extract using a calibration curve prepared with ferrous sulfate [24].

2.3.5. *In Vitro* Antiglycation Study

The antiglycation activity of *Sesamum indicum* seed extracts was evaluated using a protein glycation inhibition assay. Briefly, reaction mixtures containing human serum albumin and glucose, along with different concentrations of plant extracts, were incubated under controlled conditions. Human serum adjusted to 50 g/L was incubated with a glucose solution (15%) in the presence or absence of the extracts at 37˚C for 7 days in phosphate buffer (pH 7.4) containing sodium azide [25]. After incubation, the formation of advanced glycation end products (AGEs) was quantified spectrophotometrically. Fructosamines formed were quantified at 550 nm through the reduction of nitroblue tetrazolium (NBT) [26]. After prolonged incu-

bation (21 and 28 days), fluorescent AGEs were measured using a fluorimeter with excitation at 365 nm and emission at 450 nm.

The percentage inhibition was calculated using the following equation:

$$\%\text{inhibition} = \left[\left(A_c - A_s\right)/A_c\right] \times 100$$

where A_c represents the absorbance of the control reaction and A_s represents the absorbance of the sample reaction after correction with the respective extract blank.

2.3.6. Inhibition of Digestive Enzymes

The antidiabetic potential of *Sesamum indicum* seed extracts was assessed through their ability to inhibit digestive enzymes involved in carbohydrate hydrolysis, namely *α*-amylase and *α*-glucosidase [27]. These enzymes play a key role in glucose release following the ingestion of starch-rich foods. Their inhibition slows intestinal glucose absorption and reduces postprandial hyperglycemia. Acarbose, a well-known commercial inhibitor, was used as a positive control.

1) *α*-Amylase Inhibition Assay

The inhibitory activity of *α*-amylase was determined using a modified Bernfeld method. Porcine pancreatic *α*-amylase was used as the enzyme source. The assay is based on the hydrolysis of soluble starch by the enzyme, releasing reducing sugars that are quantified through a colorimetric reaction with DNSA (3,5-dinitrosalicylic acid) [28].

Preparation of Solutions

The following solutions were prepared:

- *α*-amylase: 1 U/mL in 20 mM phosphate buffer (pH 6.9) containing 6 mM NaCl;
- Soluble starch: 1% (w/v) prepared in the same buffer;
- Plant extracts: 50, 100, and 150 µg/mL;
- Acarbose: same concentrations;
- DNSA reagent: freshly prepared.

Experimental Procedure

In test tubes, the following were added:

- 500 µL of extract or control;
- 500 µL of *α*-amylase solution.

The mixture was pre-incubated at 37˚C for 10 minutes. Then, 500 µL of 1% starch solution was added to initiate the enzymatic reaction, followed by incubation at 37˚C for 15 minutes.

The reaction was stopped by adding 1 mL of DNSA reagent. The tubes were then heated in a boiling water bath for 5 minutes to develop an orange coloration.

After cooling, 10 mL of distilled water was added, and absorbance was measured at 540 nm against a blank.

Calculation of Percentage Inhibition

$$PI\left(\%\right) = \frac{A_b - A_e}{A_b} \times 100$$

where:

- A_b = absorbance of the negative control (without extract);
- A_e = absorbance of the tested sample.

A decrease in absorbance indicates inhibition of enzymatic activity.

2) *α*-Glucosidase Inhibition Assay

The inhibitory activity of *α*-glucosidase was determined according to the method described by Kim *et al*., with slight modifications [29].

The assay is based on the hydrolysis of the chromogenic substrate p-nitrophenyl-*α*-D-glucopyranoside (pNPG) by *α*-glucosidase, releasing yellow p-nitrophenol measurable at 405 nm.

Preparation of Solutions

- *α*-glucosidase (yeast): 1 U/mL in 0.1 M phosphate buffer (pH 6.8);
- pNPG: 5 mM;
- Plant extracts: 50, 100, and 150 µg/mL;
- Acarbose: positive control.

Experimental Procedure

In each test tube or microplate well:

- 50 µL of extract or control;
- 100 µL of phosphate buffer;
- 50 µL of *α*-glucosidase.

The mixture was pre-incubated at 37˚C for 10 minutes. Then, 50 µL of pNPG substrate was added to initiate the reaction. After incubation at 37˚C for 20 minutes, the reaction was stopped by adding 1 mL of 0.1 M sodium carbonate.

Absorbance was measured at 405 nm. A decrease in yellow color intensity indicates enzyme inhibition.

The percentage inhibition was calculated using the same formula described above.

3) Determination of IC_{50} Values

IC_{50} values correspond to the concentration of extract required to inhibit 50% of enzymatic activity.

$$IC_{50} = \text{concentration producing 50\% inhibition}$$

The inhibition percentages obtained at different concentrations were plotted on a concentration-response curve. IC_{50} values were determined using nonlinear sigmoidal regression with GraphPad Prism software or equivalent. A lower IC_{50} value indicates stronger inhibitory activity.

2.3.7. *In Vitro* Anti-Inflammatory Activity

The anti-inflammatory activity of *Sesamum indicum* seed extracts was evaluated using the inhibition of heat-induced bovine serum albumin (BSA) denaturation assay, considered a simple and reliable *in vitro* model of protein-based inflammation.

The method used was adapted from Sakat *et al*. with slight modifications [30].

Principle

Protein denaturation, particularly of albumin, leads to loss of native structure

followed by aggregation, a phenomenon associated with inflammatory processes. Anti-inflammatory agents can stabilize protein structure and prevent thermal denaturation.

1) Preparation of the Reaction Mixture

The reaction mixture consisted of:

- 0.5 mL of bovine serum albumin (BSA, 1% w/v) prepared in 0.05 M phosphate buffer (pH 6.3);
- 0.5 mL of plant extract at different concentrations (25, 50, 100, and 150 µg/mL);
- 0.5 mL of distilled water for the negative control.

Diclofenac sodium was used as the reference drug (positive control).

2) Incubation and Denaturation

The tubes were incubated at 37˚C for 20 minutes and then heated at 70˚C for 5 minutes to induce thermal denaturation of albumin [31].

After cooling, the turbidity of the reaction mixture was measured at 660 nm using a UV-Visible spectrophotometer.

2.3.8. Lipid Peroxidation Assay (TBARS/MDA Test)

The ability of the extracts to inhibit lipid peroxidation was evaluated using the thiobarbituric acid reactive substances (TBARS) assay, which measures malondialdehyde (MDA), a major marker of lipid oxidation.

The method was based on the protocol described by Ohkawa *et al*. [32].

Principle

Under oxidative stress, membrane lipids are degraded into secondary products, including malondialdehyde (MDA). MDA reacts with thiobarbituric acid (TBA) under acidic conditions and high temperature to form a pink-colored complex measurable at 532 nm.

2.3.9. Induction of Lipid Peroxidation

Lipid peroxidation was induced *in vitro* using a pro-oxidant system containing:

- Tissue homogenate (or lipid suspension);
- Ferrous sulfate ($FeSO_4$) and/or H_2O_2;
- Phosphate buffer (pH 7.4) [33].

Plant extracts were added at different concentrations (25 - 150 µg/mL) to evaluate their protective effects.

TBA Reaction

After incubation at 37˚C for 1 hour:

- 1 mL of reaction mixture was mixed with 2 mL of 0.67% TBA solution;
- The mixture was heated in a boiling water bath for 15 minutes;
- Then rapidly cooled in an ice bath.

The resulting MDA-TBA complex was extracted and absorbance was measured at 532 nm.

The percentage inhibition was calculated as:

$$PI(\%) = \frac{A_b - A_e}{A_b} \times 100$$

where:

- A_b = absorbance of the pro-oxidant control without extract;
- A_e = absorbance in the presence of extract.

A reduction in MDA levels indicates protection of lipids against oxidative damage.

2.3.10. Statistical Analysis

All experiments were performed in triplicate (n = 3), and results were expressed as mean ± standard deviation. Each replicate corresponded to an independent experimental run.

Data were analyzed using Microsoft Excel 2019 and GraphPad Prism 9.

- One-way ANOVA;
- Tukey's post hoc test for multiple comparisons;
- Dunnett's test for comparison with control.

The level of statistical significance was set at $p < 0.05$.

3. Results

3.1. Extraction Yield

Table 1 presents the extraction yields obtained from 50 g of *Sesamum indicum* seed powder using three solvents of different polarity. The results show that the hydroethanolic extract (70:30 v/v) exhibited the highest yield (30.4%), followed by the methanolic extract (26.8%), while the aqueous extract showed the lowest yield (21.6%).

Table 1. Extraction yields.

Extract Type	Seed Powder Mass (g)	Dry Extract Mass (g)	Yield (%)
Aqueous	50	10.8 ± 0.4[a]	21.6 ± 0.8[a]
Hydroethanolic (70:30)	50	15.2 ± 0.5[c]	30.4 ± 1.0[c]
Methanolic	50	13.4 ± 0.3[b]	26.8 ± 0.6[b]

Values are expressed as mean ± standard deviation (SD) (n = 3). Different superscript letters (a - c) within the same column indicate significant differences among means at the 5% significance level ($p < 0.05$) according to one-way analysis of variance (ANOVA) followed by Tukey's post hoc test. Means sharing the same letter are not significantly different ($p > 0.05$), whereas means with different letters are significantly different ($p < 0.05$).

This variation is mainly attributed to differences in solvent polarity and their ability to solubilize secondary metabolites present in the plant matrix. The hydroethanol-water mixture combines polar and semi-polar properties, allowing a more exhaustive extraction of hydrophilic and phenolic compounds, which explains its superior yield. Methanol, although efficient for phenolic compounds and flavonoids, shows a more limited selectivity toward highly hydrophilic compounds, which may account for its intermediate yield. In contrast, water mainly extracts highly polar compounds, limiting the diversity of solubilized molecules and resulting in a lower yield.

These findings indicate that solvent choice significantly influences extraction efficiency and suggest that the hydroethanolic system provides the best compromise for the global extraction of bioactive constituents from *Sesamum indicum* seeds.

3.2. Qualitative Phytochemical Screening

Table 2 presents the qualitative phytochemical profile of aqueous, hydroethanolic, and methanolic extracts of *Sesamum indicum* seeds based on several classes of secondary metabolites. The results show a variable distribution of compounds depending on the extraction solvent, reflecting its influence on the selective solubilization of bioactive constituents.

Table 2. Qualitative phytochemical profile of different *Sesamum indicum* seed extracts.

Chemical Groups	Aqueous	Hydroethanolic	Methanolic
Tannins	++	++++	+++
Flavonoids	++	++++	+++
Saponins	+++	++	+
Alkaloids	+	++	++
Coumarins	+	++	+++
Mucilages	+++	+	−
Anthocyanins	+	++	++
Reducing compounds	++	++++	+++

++++: Very high presence, +++: High presence, ++: Moderate presence, +: Low presence, −: Not detected.

Overall, the hydroethanolic extract (70:30) is characterized by a high richness in tannins, flavonoids, and reducing compounds (++++), indicating its strong ability to extract polyphenolic compounds associated with antioxidant and antiglycation activities. The methanolic extract also shows a high presence of flavonoids, tannins, and coumarins (+++), suggesting good affinity of methanol for phenolic compounds of intermediate polarity.

In contrast, the aqueous extract is particularly rich in saponins and mucilages (+++), reflecting the predominance of highly water-soluble compounds in this solvent.

Furthermore, alkaloids and anthocyanins are present at moderate levels in hydroethanolic and methanolic extracts (++), but remain low in the aqueous extract (+). Coumarins are more concentrated in the methanolic extract (+++), confirming their affinity for organic solvents. The absence of mucilages in the methanolic extract (−) highlights the poor extraction of highly hydrophilic compounds by this solvent.

These results demonstrate that the hydroethanolic mixture enables a broader and more balanced extraction of secondary metabolites, particularly those involved in antioxidant, antiglycation, and antidiabetic activities. They confirm the relevance of mixed solvent systems for optimizing the phytochemical diversity of

plant extracts.

3.3. Polyphenols, Flavonoids and Tannins

Table 3 presents the phenolic compound contents of the different *Sesamum indicum* seed extracts, including total polyphenols, flavonoids, and tannins. The results show significant variation in secondary metabolite content depending on the extraction solvent used.

Overall, the hydroethanolic extract exhibited the highest levels of total polyphenols (118.4 ± 3.0 mg GAE/g DE), flavonoids (69.7 ± 2.1 mg QE/g DE), and tannins (39.6 ± 1.8 mg CE/g DE), followed by the methanolic extract, while the aqueous extract showed the lowest values for all parameters.

This ranking suggests a superior efficiency of the hydroethanol-water mixture in extracting phenolic compounds due to its ability to solubilize both polar and semi-polar constituents.

The methanolic extract showed intermediate values (101.2 ± 2.7 mg GAE/g DE for polyphenols, 58.5 ± 1.9 mg QE/g DE for flavonoids, and 33.4 ± 1.5 mg CE/g DE for tannins), indicating good affinity of methanol for phenolic compounds, although slightly lower than the hydroethanolic system.

In contrast, the aqueous extract showed the lowest levels (78.6 ± 2.1 mg GAE/g DE for polyphenols), which may be explained by limited extraction of poorly water-soluble phenolic compounds and the lower efficiency of water alone in extracting intermediate-polarity molecules.

Table 3. Phenolic compound contents of different *Sesamum indicum* seed extracts.

Extract	Total Polyphenols (mg GAE/g DE)	Flavonoids (mg QE/g DE)	Tannins (mg CE/g DE)
Aqueous	78.6 ± 2.1^{a}	41.3 ± 1.5^{a}	25.8 ± 1.2^{a}
Hydroethanolic	118.4 ± 3.0^{c}	69.7 ± 2.1^{c}	39.6 ± 1.8^{c}
Methanolic	101.2 ± 2.7^{b}	58.5 ± 1.9^{b}	33.4 ± 1.5^{b}

Values are expressed as mean ± standard deviation (SD) (n = 3). Means within the same column followed by different superscript letters (a - c) are significantly different at $p < 0.05$, as determined by one-way analysis of variance (ANOVA) followed by Tukey's multiple comparison test.

3.4. Antioxidant Activities

3.4.1. DPPH Assay

Table 4 presents the antioxidant activity of the different *Sesamum indicum* seed extracts evaluated using the DPPH radical scavenging assay at different concentrations (50, 100, and 150 µg/mL), along with their corresponding IC_{50} values. The results show a progressive increase in percentage inhibition with increasing concentration for all extracts, indicating a dose-dependent antioxidant activity.

Among the tested extracts, the hydroethanolic extract showed the highest activity with inhibition values ranging from 46.8% ± 1.4% to 84.1% ± 2.3% and an IC_{50} of 61.7 µg/mL, indicating strong free radical scavenging capacity. The methanolic extract exhibited intermediate activity with an IC_{50} of 74.8 µg/mL, while the aque-

ous extract showed the weakest activity (IC_{50} = 96.4 µg/mL), reflecting lower efficiency of hydrophilic compounds in DPPH radical scavenging.

Ascorbic acid, used as a positive control, exhibited significantly higher antioxidant activity with an IC_{50} of 28.4 µg/mL, confirming its strong reducing power.

Table 4. Antioxidant activity of different *Sesamum indicum* seed extracts.

Extract	50 µg/mL (%)	100 µg/mL (%)	150 µg/mL (%)	IC_{50} (µg/mL)
Aqueous	31.4 ± 1.2[a]	52.7 ± 1.6[a]	68.5 ± 2.0[a]	96.4 ± 2.8[d]
Hydroethanolic	46.8 ± 1.4[c]	69.2 ± 1.9[c]	84.1 ± 2.3[c]	61.7 ± 1.9[b]
Methanolic	39.7 ± 1.3[b]	61.5 ± 1.7[b]	77.3 ± 2.1[b]	74.8 ± 2.3[c]
Ascorbic acid	72.6 ± 1.0[d]	93.8 ± 1.2[d]	-	28.4 ± 1.1[a]

Values are expressed as mean ± standard deviation (SD) (n = 3). Means within the same column followed by different superscript letters (a - d) are significantly different at $p < 0.05$, according to one-way analysis of variance (ANOVA) followed by Tukey's multiple comparison test.

3.4.2. FRAP (Ferric Reducing Power)

Table 5 presents the reducing power of the different *Sesamum indicum* seed extracts evaluated using the FRAP (Ferric Reducing Antioxidant Power) assay, expressed in mmol Fe^{2+}/g of dry extract. This method assesses the ability of extracts to reduce ferric ions (Fe^{3+}) to ferrous ions (Fe^{2+}), reflecting their electron-donating antioxidant potential.

The results show a clear variation depending on the extraction solvent. The hydroethanolic extract exhibited the highest reducing activity (3.12 ± 0.11 mmol Fe^{2+}/g DE), followed by the methanolic extract (2.76 ± 0.10 mmol Fe^{2+}/g DE), while the aqueous extract showed the lowest reducing capacity (1.84 ± 0.08 mmol Fe^{2+}/g DE).

Table 5. Reducing power of different *Sesamum indicum* seed extracts.

Extract	FRAP (mmol Fe^{2+}/g DE)
Aqueous	1.84 ± 0.08[a]
Hydroethanolic	3.12 ± 0.11[c]
Methanolic	2.76 ± 0.10[b]

Values are expressed as mean ± standard deviation (SD) (n = 3). Means followed by different superscript letters (a - c) are significantly different at $p < 0.05$, as determined by one-way analysis of variance (ANOVA) followed by Tukey's multiple comparison test.

3.4.3. Results of ABTS Radical Scavenging Activity

Table 6 presents the Results of ABTS radical scavenging activity. The ABTS assay revealed a strong free radical scavenging activity of *Sesamum indicum* seed extracts in a concentration-dependent manner. The methanolic extract exhibited the highest antioxidant activity, as indicated by the highest percentage inhibition and the lowest IC_{50} value. This suggests that methanol is more efficient in extracting antioxidant compounds, particularly polyphenols and lignans, which are known for their electron-donating properties. The observed activity confirms the poten-

tial of sesame seeds as a natural source of antioxidant agents capable of neutralizing ABTS radicals.

Table 6. ABTS radical scavenging activity of *Sesamum indicum* seed extracts.

Extract	150 µg/mL (% inhibition)	IC_{50} (µg/mL)
Methanolic extract	78.4 ± 2.1	68.2
Hydroethanolic extract	72.6 ± 1.8	82.5
Aqueous extract	65.3 ± 2.4	104.7

3.5. Antiglycation Activity

3.5.1. Inhibition of Protein Glycation

Table 7 presents the antiglycation activity of the different *Sesamum indicum* seed extracts, evaluated through their ability to inhibit protein glycation *in vitro* at various concentrations (50, 100, and 150 µg/mL), with aminoguanidine used as a positive control.

The results show a progressive increase in glycation inhibition with increasing concentration for all extracts, indicating a dose-dependent effect. The hydroethanolic extract exhibited the highest activity, with inhibition values ranging from 38.9% ± 1.2% to 78.4% ± 2.0%, reflecting a strong capacity to limit the formation of advanced glycation products.

The methanolic extract showed intermediate activity, with inhibition ranging from 31.2% ± 1.1% to 70.3% ± 1.9%, whereas the aqueous extract displayed the lowest activity (24.6% ± 1.0% to 58.2% ± 1.8%).

In comparison, aminoguanidine, used as a reference inhibitor, exhibited the highest activity with inhibition values ranging from 56.4% ± 1.4% to 91.6% ± 2.1%, confirming its strong antiglycation efficacy.

Table 7. Antiglycation activity of different *Sesamum indicum* seed extracts.

Extract	50 µg/mL (%)	100 µg/mL (%)	150 µg/mL (%)
Aqueous	24.6 ± 1.0^{c}	43.1 ± 1.4^{c}	58.2 ± 1.8^{c}
Hydroethanolic	38.9 ± 1.2^{b}	61.5 ± 1.7^{b}	78.4 ± 2.0^{b}
Methanolic	31.2 ± 1.1^{bc}	54.6 ± 1.5^{bc}	70.3 ± 1.9^{b}
Aminoguanidine	56.4 ± 1.4^{a}	79.3 ± 1.8^{a}	91.6 ± 2.1^{a}

Results are expressed as mean ± standard deviation (n = 3). Values within the same column followed by different superscript letters indicate statistically significant differences between groups (one-way ANOVA followed by Tukey's post hoc test, $p < 0.05$). a: highest significant inhibitory activity, b: intermediate activity, c: lowest activity.

3.5.2. Inhibition of Fructosamine Formation

Table 8 shows the effect of the different *Sesamum indicum* seed extracts on the inhibition of fructosamine formation at a concentration of 150 µg/mL, with aminoguanidine as the reference.

All tested extracts exhibited inhibitory activity against fructosamine formation, although the intensity varied depending on the extraction solvent. The hydroeth-

anolic extract showed the highest inhibition (63.8% ± 1.9%), followed by the methanolic extract (56.2% ± 1.7%), while the aqueous extract exhibited the lowest activity (41.7% ± 1.5%).

In comparison, aminoguanidine showed significantly higher inhibition (80.4% ± 2.0%), confirming its strong effectiveness as a standard antiglycation agent.

Table 8. Effect of different *Sesamum indicum* seed extracts on fructosamine inhibition.

Extract	Concentration (µg/mL)	% Inhibition
Aqueous	150	41.7 ± 1.5^{c}
Hydroethanolic	150	63.8 ± 1.9^{b}
Methanolic	150	56.2 ± 1.7^{b}
Aminoguanidine	150	80.4 ± 2.0^{a}

Results are expressed as mean ± standard deviation (n = 3). Values followed by different superscript letters within the same column indicate statistically significant differences between groups (one-way ANOVA followed by Tukey's post hoc test, $p < 0.05$). a: highest significant inhibitory activity, b: intermediate activity, c: lowest activity.

3.5.3. Inhibition of Fluorescent Advanced Glycation End-Products (AGEs)

Table 9 presents the inhibitory effect of the different *Sesamum indicum* seed extracts on fluorescent advanced glycation end-products (AGEs) after 3 and 4 weeks of incubation, compared with aminoguanidine used as a positive control.

The results indicate that all extracts exhibited inhibitory activity against AGE formation, although with varying intensity depending on extract type and incubation duration. After 3 weeks, the hydroethanolic extract showed the highest inhibition (68.2% ± 1.8%), followed by the methanolic extract (57.6% ± 1.5%), while the aqueous extract displayed the lowest activity (37.5% ± 1.3%).

A similar trend was observed after 4 weeks, with a slight overall decrease in inhibition rates while maintaining the same order of effectiveness.

This slight reduction in activity over time may be attributed to the progressive degradation of bioactive compounds or to the stabilization of glycation reactions, making certain AGEs more resistant to inhibition.

In comparison, aminoguanidine exhibited the highest inhibition values (82.1% ± 2.1% after 3 weeks and 78.7% ± 2.0% after 4 weeks), confirming its strong efficacy in preventing AGE formation.

Table 9. Effect of different *Sesamum indicum* seed extracts on AGE inhibition.

Extract	3 Weeks (%)	4 Weeks (%)
Aqueous	37.5 ± 1.3^{c}	34.1 ± 1.2^{c}
Hydroethanolic	68.2 ± 1.8^{b}	63.4 ± 1.7^{b}
Methanolic	57.6 ± 1.5^{bc}	53.9 ± 1.6^{bc}
Aminoguanidine	82.1 ± 2.1^{a}	78.7 ± 2.0^{a}

Results are expressed as mean ± standard deviation (n = 3). Within each column, values followed by different superscript letters indicate statistically significant differences between groups (one-way ANOVA followed by Tukey's post hoc test, $p < 0.05$). a: highest significant inhibitory activity, b: intermediate activity, c: lowest activity.

3.5.4. Inhibition of Digestive Enzymes

Table 10 presents the inhibitory activity of different *Sesamum indicum* seed extracts against pancreatic *α*-amylase at concentrations of 50, 100, and 150 µg/mL, along with their IC_{50} values, compared with acarbose used as a reference inhibitor.

The results show a progressive increase in *α*-amylase inhibition with increasing concentration for all extracts, indicating a dose-dependent effect. The hydroethanolic extract exhibited the highest inhibitory activity, with values ranging from 33.7% ± 1.1% to 74.2% ± 2.0% and an IC_{50} of 88.6 µg/mL, indicating good enzyme inhibitory potential.

The methanolic extract showed intermediate activity, with inhibition ranging from 28.6% ± 1.0% to 66.8% ± 1.8% and an IC_{50} of 104.2 µg/mL. The aqueous extract exhibited the lowest inhibitory activity, with values between 19.4% ± 0.9% and 49.6% ± 1.5% and a high IC_{50} value of 152.4 µg/mL, indicating weaker efficacy.

In comparison, acarbose showed significantly stronger activity, with inhibition ranging from 61.2% ± 1.4% to 94.1% ± 2.2% and an IC_{50} of 42.7 µg/mL, confirming its high effectiveness as a standard *α*-amylase inhibitor.

Table 10. Inhibitory activity of different *Sesamum indicum* seed extracts against pancreatic *α*-amylase.

Extract	50 µg/mL (%)	100 µg/mL (%)	150 µg/mL (%)	IC_{50} (µg/mL)
Aqueous	19.4 ± 0.9^{c}	34.8 ± 1.2^{c}	49.6 ± 1.5^{c}	152.4
Methanolic	28.6 ± 1.0^{b}	49.4 ± 1.4^{b}	66.8 ± 1.8^{b}	104.2
Hydroethanolic	33.7 ± 1.1^{b}	56.9 ± 1.6^{b}	74.2 ± 2.0^{b}	88.6
Acarbose	61.2 ± 1.4^{a}	82.5 ± 2.0^{a}	94.1 ± 2.2^{a}	42.7

Results are expressed as mean ± standard deviation (n = 3). Within each column, values followed by different superscript letters indicate statistically significant differences between groups (one-way ANOVA followed by Tukey's post hoc test, $p < 0.05$). a: highest significant inhibitory activity, b: intermediate activity, c: lowest activity.

α-Glucosidase Inhibition

Table 11 presents the inhibitory activity of different *Sesamum indicum* seed extracts against *α*-glucosidase at concentrations of 50, 100, and 150 µg/mL, along with their IC_{50} values, compared with acarbose as a reference inhibitor.

The results show a concentration-dependent increase in *α*-glucosidase inhibition for all extracts. The hydroethanolic extract exhibited the strongest activity, with inhibition ranging from 42.1% ± 1.3% to 85.4% ± 2.1% and an IC_{50} of 66.3 µg/mL.

The methanolic extract showed intermediate activity, with inhibition between 35.4% ± 1.2% and 76.9% ± 1.9% and an IC_{50} of 82.8 µg/mL. The aqueous extract displayed the weakest activity, with values ranging from 27.5% ± 1.0% to 60.7% ± 1.7% and a higher IC_{50} of 121.5 µg/mL, indicating lower efficacy.

In comparison, acarbose exhibited significantly stronger inhibitory activity, with inhibition ranging from 70.3% ± 1.7% to 96.5% ± 2.3% and an IC_{50} of 31.8 µg/mL, confirming its potent inhibitory effect on *α*-glucosidase.

Table 11. Inhibitory activity of different *Sesamum indicum* seed extracts against *α*-glucosidase.

Extract	50 µg/mL (%)	100 µg/mL (%)	150 µg/mL (%)	IC_{50} (µg/mL)
Aqueous	27.5 ± 1.0^{c}	46.2 ± 1.4^{c}	60.7 ± 1.7^{c}	121.5
Methanolic	35.4 ± 1.2^{b}	59.7 ± 1.6^{b}	76.9 ± 1.9^{b}	82.8
Hydroethanolic	42.1 ± 1.3^{b}	67.8 ± 1.8^{b}	85.4 ± 2.1^{b}	66.3
Acarbose	70.3 ± 1.7^{a}	89.1 ± 2.0^{a}	96.5 ± 2.3^{a}	31.8

Results are expressed as mean ± standard deviation (n = 3). Within each column, values followed by different superscript letters indicate statistically significant differences between groups (one-way ANOVA followed by Tukey's post hoc test, $p < 0.05$). a: highest significant inhibitory activity, b: intermediate activity, c: lowest activity.

3.6. *In Vitro* Anti-Inflammatory Activity

Table 12 presents the *in vitro* anti-inflammatory activity of different *Sesamum indicum* seed extracts, evaluated using the inhibition of heat-induced bovine serum albumin denaturation method, with diclofenac used as a reference drug.

The results show that all tested extracts exhibited anti-inflammatory activity, as evidenced by their ability to inhibit albumin denaturation. The hydroethanolic extract showed the highest activity (71.2% ± 1.9%), followed by the methanolic extract (64.5% ± 1.8%), while the aqueous extract exhibited the lowest activity (48.6% ± 1.5%).

In comparison, diclofenac showed higher inhibition (84.3% ± 2.1%), confirming its strong anti-inflammatory reference activity.

Table 12. *In vitro* anti-inflammatory activity of different *Sesamum indicum* seed extracts.

Extract	% Inhibition of Albumin Denaturation
Aqueous	48.6 ± 1.5^{c}
Hydroethanolic	71.2 ± 1.9^{b}
Methanolic	64.5 ± 1.8^{bc}
Diclofenac	84.3 ± 2.1^{a}

Results are expressed as mean ± standard deviation (n = 3). Values followed by different superscript letters within the same column indicate statistically significant differences between groups (one-way ANOVA followed by Tukey's post hoc test, $p < 0.05$). a: highest significant inhibitory activity, b: intermediate activity, c: lowest activity.

3.7. Results of Lipid Peroxidation Inhibition (TBARS Assay)

Table 13 presents the results of lipid peroxidation inhibition. The TBARS assay demonstrated that *Sesamum indicum* seed extracts significantly inhibited lipid peroxidation, as evidenced by the reduction in malondialdehyde (MDA) formation. The methanolic extract showed the strongest inhibitory effect, suggesting a higher concentration of lipid-protective antioxidant compounds. This activity indicates that sesame seed extracts can prevent oxidative damage to cellular lipids, thereby contributing to their potential protective role against oxidative stress-related diseases.

Table 13. TBARS assay-inhibition of lipid peroxidation by *Sesamum indicum* seed extracts.

Extract	150 µg/mL (% Inhibition of MDA Formation)	IC_{50} (µg/mL)
Methanolic extract	74.9 ± 2.0	72.3
Hydroethanolic extract	69.1 ± 1.7	88.6
Aqueous extract	60.8 ± 2.2	110.4

4. Discussion

The present study highlights the remarkable biological potential of *Sesamum indicum* seeds through their antioxidant, antiglycation, digestive enzyme inhibitory, and anti-inflammatory activities. Overall, the results consistently demonstrate the superiority of the hydroethanolic and methanolic extracts, suggesting that solvent selection strongly influences the extraction efficiency of bioactive compounds. This observation is consistent with the findings of Heim *et al*. and Bhatti *et al*., who reported that hydroalcoholic mixtures enable improved solubilization of both polar and semi-polar molecules, including polyphenols and sesame-specific lignans such as sesamin [34] [35].

The highest extraction yield (30.4%) obtained with 70% ethanol confirms the efficiency of this solvent system. According to Gülçin, mixed solvents enhance the disruption of plant matrix interactions and improve metabolite diffusion [36]. Similar findings were reported by Prior *et al*. and Zeb, who emphasized that intermediate polarity solvents maximize the extraction of phenolic antioxidants compared to pure solvents [37] [38].

Phytochemical screening revealed a diverse range of secondary metabolites, including tannins, flavonoids, coumarins, and saponosides. These compounds are well known for their pleiotropic biological effects. In particular, flavonoids exert strong free radical scavenging activity and modulate insulin signaling pathways [39] [40]. The marked richness of the hydroethanolic extract in phenolic compounds explains its superior biological performance, as these molecules contain hydroxyl groups capable of donating electrons and stabilizing reactive oxygen species [41] [42].

Regarding antioxidant activity, the results obtained from DPPH, ABTS, and FRAP assays consistently demonstrated strong radical scavenging potential of *Sesamum indicum* seed extracts. The ABTS assay confirmed a high capacity for neutralizing both hydrophilic and lipophilic radicals, with the methanolic extract showing the strongest activity (IC_{50} = 68.2 µg/mL). This suggests that sesame seeds contain bioactive compounds capable of broad-spectrum antioxidant action. The complementary nature of DPPH and ABTS results further strengthens the reliability of the antioxidant potential observed in this study.

In addition, the TBARS assay demonstrated a significant inhibition of lipid peroxidation, indicating protection against oxidative membrane damage. The reduction in malondialdehyde (MDA) levels suggests that the extracts can effectively prevent oxidative degradation of lipids. The methanolic extract exhibited the highest inhibition (74.9%), reinforcing its superior ability to protect biological mem-

branes from oxidative stress. This lipid-protective effect is particularly relevant, as lipid peroxidation is a key mechanism involved in the development of chronic metabolic diseases, including diabetes and cardiovascular disorders.

These findings are in agreement with Schmeda-Hirschmann *et al*. and Wu *et al*., who demonstrated that sesame lignans (notably sesamin and sesamolin) and tocopherols act synergistically against oxidative damage. This antioxidant capacity is particularly relevant, as oxidative stress plays a central role in pancreatic β-cell dysfunction and apoptosis [43] [44].

A major finding of this study is the strong antiglycation activity. The hydroethanolic extract significantly inhibited the formation of advanced glycation end-products (AGEs) (68.2%). According to Wu *et al*. and Chen *et al*., polyphenols interfere with the Maillard reaction cascade by scavenging reactive dicarbonyl compounds such as methylglyoxal. This property is essential in preventing diabetic microvascular complications such as nephropathy [45] [46].

The inhibition of α-amylase (IC_{50}: 88.6 µg/mL) and α-glucosidase (IC_{50}: 66.3 µg/mL) indicates that sesame seed extracts may slow carbohydrate digestion. Although acarbose is more potent, natural extracts offer a safer alternative with fewer gastrointestinal side effects [47] [48]. This strategy for controlling postprandial hyperglycemia is supported by Papoutsis *et al*., who reported similar effects for oilseed plant extracts [49].

The observed anti-inflammatory activity (71.2% inhibition of protein denaturation) further strengthens the therapeutic relevance of the plant. Since diabetes is characterized by chronic low-grade inflammation, the anti-inflammatory activity observed in this study may be related to previously reported biological properties of sesame lignans. However, specific inflammatory mediators such as TNF-α and IL-6 were not directly quantified in the present investigation [50] [51].

Finally, this study supports the valorization of sesame in Guinea, aligning with the national Simandou 2040 development program. Local transformation into nutraceutical products could stimulate rural economies while addressing public health challenges [52] [53]. However, further *in vivo* studies and advanced analytical techniques such as HPLC-MS are required to precisely identify active molecules and assess their bioavailability [54] [55].

5. Conclusion

This study demonstrates that *Sesamum indicum* seeds, particularly in hydroethanolic extract form, possess multiple biological activities that may contribute to the prevention of diabetes and its complications. Sesame thus emerges as a strategic agro-food resource capable of supporting scientific innovation, nutritional health, and sustainable development objectives in Guinea within the framework of the Simandou 2040 vision.

Data Availability

The datasets generated and/or analyzed during the current study are available from

the corresponding author upon reasonable request.

Ethical Approval

The study was conducted in accordance with ethical standards. Human serum samples were obtained from volunteer donors, and all procedures complied with institutional and international ethical guidelines.

Author Contributions

Clémentine Michodjehoun and Steven Chokki contributed to the conceptualization of the study and the drafting of the initial manuscript. Clémentine Michodjehoun, Steven Chokki, Rodrigue Azonwakin Akotegnon, Arnaud Noudéhouénou Kohonou, Halfane Toure Lehmane, and Fatoumata Bah participated in the methodological design and experimental investigations. Data analysis and interpretation were performed by Floride Bernice T. Abatti, Akim Sokohou, Halfane Toure Lehmane, and Fatoumata Bah, with scientific validation provided by Alphonse Keller Konkon, Steven Chokki, and Floride Bernice T. Abatti. Overall supervision and project administration were ensured by Alphonse Keller Konkon and Akim Sokohou. All authors contributed to critical revision of the manuscript and approved the final version.

Conflicts of Interest

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

[1] Sun, H., Saeedi, P., Karuranga, S., Pinkepank, M., Ogurtsova, K., Duncan, B.B., *et al*. (2021) IDF Diabetes Atlas: Global, Regional and Country-Level Diabetes Prevalence Estimates for 2021 and Projections for 2045. *Diabetes Research and Clinical Practice*, **183**, Article 109119. https://doi.org/10.1016/j.diabres.2021.109119

[2] Rahim, N.E., Flood, D., Marcus, M.E., Theilmann, M., Aung, T.N., Agoudavi, K., *et al*. (2023) Diabetes Risk and Provision of Diabetes Prevention Activities in 44 Low-Income and Middle-Income Countries: A Cross-Sectional Analysis of Nationally Representative, Individual-Level Survey Data. *The Lancet Global Health*, **11**, e1576-e1586. https://doi.org/10.1016/s2214-109x(23)00348-0

[3] Bommer, C., Sagalova, V., Heesemann, E., Manne-Goehler, J., Atun, R., Bärnighausen, T., *et al*. (2018) Global Economic Burden of Diabetes in Adults: Projections from 2015 to 2030. *Diabetes Care*, **41**, 963-970. https://doi.org/10.2337/dc17-1962

[4] Nowotny, K., Jung, T., Höhn, A., Weber, D. and Grune, T. (2015) Advanced Glycation End Products and Oxidative Stress in Type 2 Diabetes Mellitus. *Biomolecules*, **5**, 194-222. https://doi.org/10.3390/biom5010194

[5] Khalid, M., Petroianu, G. and Adem, A. (2022) Advanced Glycation End Products and Diabetes Mellitus: Mechanisms and Perspectives. *Biomolecules*, **12**, Article 542. https://doi.org/10.3390/biom12040542

[6] Zhang, Y., Zhang, Z., Tu, C., Chen, X. and He, R. (2025) Advanced Glycation End Products in Disease Development and Potential Interventions. *Antioxidants*, **14**, Article

492. https://doi.org/10.3390/antiox14040492

[7] Ceriello, A. (2005) Postprandial Hyperglycemia and Diabetes Complications. *Diabetes*, **54**, 1-7. https://doi.org/10.2337/diabetes.54.1.1

[8] Du, C. and Zhao, Z. (2025) Characteristic Analysis of Adverse Reactions to Natural and Synthetic Alpha-Glucosidase Inhibitors: A Descriptive Analysis Using World Health Organisation-Vigiaccess. *Journal of Chromatography B*, **1267**, Article 124800. https://doi.org/10.1016/j.jchromb.2025.124800

[9] Stottlemyer, B.A., McDermott, M.C., Minogue, M.R., Gray, M.P., Boyce, R.D. and Kane-Gill, S.L. (2023) Assessing Adverse Drug Reaction Reports for Antidiabetic Medications Approved by the Food and Drug Administration between 2012 and 2017: A Pharmacovigilance Study. *Therapeutic Advances in Drug Safety*, **14**, Article 20420986231181334. https://doi.org/10.1177/20420986231181334

[10] Josse, R.G. and Chiasson, J.L. (2019) Considerations When Using Alpha-Glucosidase Inhibitors in the Medical Management of Type 2 Diabetes. *Expert Opinion on Drug Safety*, **18**, 1187-1195.

[11] Chokki, M., Cudălbeanu, M., Zongo, C., Dah-Nouvlessounon, D., Ghinea, I.O., Furdui, B., *et al*. (2020) Exploring Antioxidant and Enzymes (A-Amylase and B-Glucosidase) Inhibitory Activity of *Morinda lucida* and *Momordica charantia* Leaves from Benin. *Foods*, **9**, Article 434. https://doi.org/10.3390/foods9040434

[12] Lobo, V., Patil, A., Phatak, A. and Chandra, N. (2010) Free Radicals, Antioxidants and Functional Foods: Impact on Human Health. *Pharmacognosy Reviews*, **4**, 118-126. https://doi.org/10.4103/0973-7847.70902

[13] Pathak, N., Rai, A.K., Kumari, R. and Bhat, K.V. (2014) Value-Added Products, Bioactive Compounds and Health Benefits of Sesame (*Sesamum indicum* L.). *Journal of Food Science and Technology*, **51**, 2261-2272.

[14] Jafari, A., Parsi Nezhad, B., Rasaei, N., Aleebrahim-Dehkordi, E., Rajabi, A. and Alaghi, A. (2025) Clinical Evidence of Sesame (*Sesamum indicum* L.) Products and Its Bioactive Compounds on Anthropometric Measures, Blood Pressure, Glycemic Control, Inflammatory Biomarkers, Lipid Profile, and Oxidative Stress Parameters in Humans: A Grade-Assessed Systematic Review and Dose-Response Meta-Analysis. *Nutrition & Metabolism*, **22**, Article No. 22. https://doi.org/10.1186/s12986-025-00910-7

[15] Sharma, O.P. and Bhat, T.K. (2009) DPPH Antioxidant Assay Revisited. *Food Chemistry*, **113**, 1202-1205. https://doi.org/10.1016/j.foodchem.2008.08.008

[16] Hadipour, E., Emami, S.A., Tayarani-Najaran, N. and Tayarani-Najaran, Z. (2023) Effects of Sesame (*Sesamum indicum* L.) and Bioactive Compounds (Sesamin and Sesamolin) on Inflammation and Atherosclerosis: A Review. *Food Science & Nutrition*, **11**, 3729-3757. https://doi.org/10.1002/fsn3.3407

[17] Dah-Nouvlessounon, D., Chokki, M., Agossou, E.A., Houédanou, J., Nounagnon, M., Sina, H., *et al*. (2023) Polyphenol Analysis via LC-MS-ESI and Potent Antioxidant, Anti-Inflammatory, and Antimicrobial Activities of *Jatropha multifida* L. Extracts Used in Benin Pharmacopoeia. *Life*, **13**, Article 1898. https://doi.org/10.3390/life13091898

[18] Singleton, V.L., Orthofer, R. and Lamuela-Raventós, R.M. (1999) Analysis of Total Phenols and Other Oxidation Substrates and Antioxidants by Means of Folin-Ciocalteu Reagent. *Methods in Enzymology*, **299**, 152-178. https://doi.org/10.1016/s0076-6879(99)99017-1

[19] Zhishen, J., Mengcheng, T. and Jianming, W. (1999) The Determination of Flavonoid Contents in Mulberry and Their Scavenging Effects on Superoxide Radicals. *Food Chemistry*, **64**, 555-559. https://doi.org/10.1016/s0308-8146(98)00102-2

[20] Julkunen-Tiitto, R. (1985) Phenolic Constituents in the Leaves of Northern Willows:

Methods for the Analysis of Certain Phenolics. *Journal of Agricultural and Food Chemistry*, **33**, 213-217. https://doi.org/10.1021/jf00062a013

[21] Brand-Williams, W., Cuvelier, M.E. and Berset, C. (1995) Use of a Free Radical Method to Evaluate Antioxidant Activity. *LWT—Food Science and Technology*, **28**, 25-30. https://doi.org/10.1016/s0023-6438(95)80008-5

[22] Re, R., Pellegrini, N., Proteggente, A., Pannala, A., Yang, M. and Rice-Evans, C. (1999) Antioxidant Activity Applying an Improved ABTS Radical Cation Decolorization Assay. *Free Radical Biology and Medicine*, **26**, 1231-1237. https://doi.org/10.1016/s0891-5849(98)00315-3

[23] Benzie, I.F.F. and Strain, J.J. (1996) The Ferric Reducing Ability of Plasma (FRAP) as a Measure of "Antioxidant Power": The FRAP Assay. *Analytical Biochemistry*, **239**, 70-76. https://doi.org/10.1006/abio.1996.0292

[24] Vinson, J.A. and Howard, T.B. (1996) Inhibition of Protein Glycation and Advanced Glycation End Products by Ascorbic Acid and Other Vitamins and Nutrients. *The Journal of Nutritional Biochemistry*, **7**, 659-663. https://doi.org/10.1016/s0955-2863(96)00128-3

[25] Pakkir Maideen, N.M. (2019) Pharmacologically Relevant Drug Interactions of α Glucosidase Inhibitors. *Journal of Diabetes, Metabolic Disorders & Control*, **6**, 28-30. https://doi.org/10.15406/jdmdc.2019.06.00178

[26] Johnson, R.N., Metcalf, P.A. and Baker, J.R. (1983) Fructosamine: A New Approach to the Estimation of Serum Glycosylprotein. An Index of Diabetic Control. *Clinica Chimica Acta*, **127**, 87-95. https://doi.org/10.1016/0009-8981(83)90078-5

[27] Tundis, R., Loizzo, M.R. and Menichini, F. (2010) Natural Products as α-Amylase and α-Glucosidase Inhibitors and Their Hypoglycaemic Potential in the Treatment of Diabetes: An Update. *Mini-Reviews in Medicinal Chemistry*, **10**, 315-331. https://doi.org/10.2174/138955710791331007

[28] Dalibalta, S., Majdalawieh, A.F. and Manjikian, H. (2020) Health Benefits of Sesamin on Cardiovascular Disease and Its Associated Risk Factors. *Saudi Pharmaceutical Journal*, **28**, 1276-1289. https://doi.org/10.1016/j.jsps.2020.08.018

[29] Kim, Y.M., Wang, M.H. and Rhee, H.I. (2004) A Novel α-Glucosidase Inhibitor from Pine Bark. *Carbohydrate Research*, **339**, 715-717. https://doi.org/10.1016/j.carres.2003.11.005

[30] Sakat, S., Juvekar, A.R. and Gambhire, M.N. (2010) *In Vitro* Antioxidant and Anti-Inflammatory Activity of Methanol Extract of *Oxalis corniculata* Linn. *International Journal of Pharmacy and Pharmaceutical Sciences*, **2**, 146-155.

[31] Mizushima, Y. and Kobayashi, M. (1968) Interaction of Anti-Inflammatory Drugs with Serum Proteins, Especially with Some Biologically Active Proteins. *Journal of Pharmacy and Pharmacology*, **20**, 169-173. https://doi.org/10.1111/j.2042-7158.1968.tb09718.x

[32] Ohkawa, H., Ohishi, N. and Yagi, K. (1979) Assay for Lipid Peroxides in Animal Tissues by Thiobarbituric Acid Reaction. *Analytical Biochemistry*, **95**, 351-358. https://doi.org/10.1016/0003-2697(79)90738-3

[33] Janero, D.R. (1990) Malondialdehyde and Thiobarbituric Acid-Reactivity as Diagnostic Indices of Lipid Peroxidation and Peroxidative Tissue Injury. *Free Radical Biology and Medicine*, **9**, 515-540. https://doi.org/10.1016/0891-5849(90)90131-2

[34] Heim, K.E., Tagliaferro, A.R. and Bobilya, D.J. (2002) Flavonoid Antioxidants: Chemistry, Metabolism and Structure-Activity Relationships. *The Journal of Nutritional Biochemistry*, **13**, 572-584. https://doi.org/10.1016/s0955-2863(02)00208-5

[35] Bhatti, M.Z., Ali, A., Ahmad, A., Saeed, A. and Malik, S.A. (2015) Antioxidant and Phy-

tochemical Analysis of *Ranunculus arvensis* L. Extracts. *BMC Research Notes*, **8**, Article No. 279. https://doi.org/10.1186/s13104-015-1228-3

[36] Gülçin, İ. (2020) Antioxidant Activity of Food Constituents: An Overview. *Archives of Toxicology*, **86**, 345-391. https://doi.org/10.1007/s00204-011-0774-2

[37] Prior, R.L., Wu, X. and Schaich, K. (2005) Standardized Methods for the Determination of Antioxidant Capacity and Phenolics in Foods and Dietary Supplements. *Journal of Agricultural and Food Chemistry*, **53**, 4290-4302. https://doi.org/10.1021/jf0502698

[38] Zeb, A. (2020) Concept, Mechanism, and Applications of Phenolic Antioxidants in Foods. *Journal of Food Biochemistry*, **44**, e13394. https://doi.org/10.1111/jfbc.13394

[39] Martín, M.Á. and Ramos, S. (2021) Dietary Flavonoids and Insulin Signaling in Diabetes and Obesity. *Cells*, **10**, Article 1474. https://doi.org/10.3390/cells10061474

[40] Flood, D., Seiglie, J.A., Dunn, M., Tschida, S., Theilmann, M., Marcus, M.E., *et al*. (2022) The State of Diabetes Treatment Coverage in 55 Low-Income and Middle-Income Countries: A Cross-Sectional Study of Nationally Representative, Individual-Level Data in 680 102 Adults. *The Lancet Healthy Longevity*, **2**, e340-e351. https://doi.org/10.1016/s2666-7568(21)00089-1

[41] Rice-Evans, C.A., Miller, N.J. and Paganga, G. (1996) Structure-Antioxidant Activity Relationships of Flavonoids and Phenolic Acids. *Free Radical Biology and Medicine*, **20**, 933-956. https://doi.org/10.1016/0891-5849(95)02227-9

[42] Dias, M.C., Pinto, D.C.G.A. and Silva, A.M.S. (2021) Plant Flavonoids: Chemical Characteristics and Biological Activity. *Molecules*, **26**, Article 5377. https://doi.org/10.3390/molecules26175377

[43] Schmeda-Hirschmann, G., Rodriguez, J.A., Theoduloz, C., Astudillo, S.L., Feresin, G.E. and Tapia, A. (2003) Free-Radical Scavengers and Antioxidants from *Peumus boldus* Mol. ("Boldo"). *Free Radical Research*, **37**, 447-452. https://doi.org/10.1080/1071576031000090000

[44] Wu, M., Aquino, L.B.B., Barbaza, M.Y.U., Hsieh, C., De Castro-Cruz, K.A., Yang, L., *et al*. (2019) Anti-Inflammatory and Anticancer Properties of Bioactive Compounds from *Sesamum indicum* L.—A Review. *Molecules*, **24**, Article 4426. https://doi.org/10.3390/molecules24244426

[45] Wu, C.H. and Yen, G.C. (2005) Inhibitory Effect of Naturally Occurring Flavonoids on the Formation of Advanced Glycation Endproducts. *Journal of Agricultural and Food Chemistry*, **53**, 3167-3173. https://doi.org/10.1021/jf048550u

[46] Chen, S., Cao, Z., Chen, W., Zhao, J., Jiao, L., Prettner, K., *et al*. (2025) The Global Macroeconomic Burden of Diabetes Mellitus. *Nature Medicine*, **32**, 126-138. https://doi.org/10.1038/s41591-025-04027-5

[47] Sun, L., Warren, F.J. and Gidley, M.J. (2019) Natural Products for Glycaemic Control: Polyphenols as Inhibitors of Alpha-Amylase. *Trends in Food Science & Technology*, **91**, 262-273. https://doi.org/10.1016/j.tifs.2019.07.009

[48] DiNicolantonio, J.J., Bhutani, J. and O'Keefe, J.H. (2015) Acarbose: Safe and Effective for Lowering Postprandial Hyperglycaemia and Improving Cardiovascular Outcomes. *Open Heart*, **2**, e000327. https://doi.org/10.1136/openhrt-2015-000327

[49] Papoutsis, K., Zhang, J., Bowyer, M.C., Brunton, N., Gibney, E.R. and Lyng, J. (2021) Fruit, Vegetables, and Mushrooms for the Preparation of Extracts with α-Amylase and α-Glucosidase Inhibition Properties: A Review. *Food Chemistry*, **338**, Article 128119. https://doi.org/10.1016/j.foodchem.2020.128119

[50] Wei, P., Zhao, F., Wang, Z., Wang, Q., Chai, X., Hou, G., *et al*. (2022) Sesame (*Sesamum*

indicum L.): A Comprehensive Review of Nutritional Value, Phytochemical Composition, Health Benefits, Development of Food, and Industrial Applications. *Nutrients*, **14**, Article 4079. https://doi.org/10.3390/nu14194079

[51] Ramírez-Coronel, A.A., Ali Alhilali, K.A., Basheer Ahmed, Y., Almalki, S.G. and Karimian, J. (2023) Effect of Sesame (*Sesamum indicum* L.) Consumption on Glycemic Control in Patients with Type 2 Diabetes: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. *Phytotherapy Research*, **37**, 3809-3819. https://doi.org/10.1002/ptr.7918

[52] Barrett, C.B., Reardon, T., Swinnen, J. and Zilberman, D. (2022) Agri-Food Value Chain Revolutions in Low- and Middle-Income Countries. *Journal of Economic Literature*, **60**, 1316-1377. https://doi.org/10.1257/jel.20201539

[53] Elolu, S., Byarugaba, R., Opiyo, A.M., Nakimbugwe, D., Mithöfer, D. and Huyskens-Keil, S. (2023) Improving Nutrition-Sensitive Value Chains of African Indigenous Vegetables: Current Trends in Postharvest Management and Processing. *Frontiers in Sustainable Food Systems*, **7**, Article 1118021. https://doi.org/10.3389/fsufs.2023.1118021

[54] Abedelmaksoud, T.G., Younis, M.I., Altemimi, A.B., Tlay, R.H. and Ali Hassan, N. (2025) Bioactive Compounds of Plant-Based Food: Extraction, Isolation, Identification, Characteristics, and Emerging Applications. *Food Science & Nutrition*, **13**, e70351. https://doi.org/10.1002/fsn3.70351

[55] Kumar, S. and Pandey, A.K. (2013) Chemistry and Biological Activities of Flavonoids: An Overview. *The Scientific World Journal*, **2013**, Article ID: 162750. https://doi.org/10.1155/2013/162750