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Phytochemical profiling of wastes from the processing of shea butter (*Vitellaria paradoxa*) and pharmacological potentials within the paradigm of circular bioeconomy: Emphasizing antioxidant and antidiabetic applications

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ABSTRACT

Shea butter is a natural fat that is extracted from the kernels of the shea butter tree, and it is widely used in food preparation, cosmetics, and therapeutic practices. Shea trees are prevalent across Africa, and the traditional extraction methods produce significant wastes. However, there is dearth of information on the phytochemical profiling of these wastes and their potential biomedical values. Thus, this study conducted a thorough phytochemical investigation of the shea butter wastes from different processing stages, including brown and black shea cakes (SNC1 and SNC2), shea nut shells (SNS), and shea nut wastewater (SNWW). By using gas chromatography-mass spectrometry (GC–MS), the bioactive chemicals in these wastes were identified and quantified. Furthermore, the antioxidant and antidiabetic activities of the wastes were investigated for their potential pharmacological applications. The maximum antioxidant activities obtained at 60 mg/ml revealed DPPH radical scavenging of 62.34 % for SNC1, ferric reducing power of 68.13 % for SNC2, H_2O_2 radical scavenging of 38.46 % for SNS, and nitric oxide scavenging of 35.13 % for SNWW indicating their potentials in combating oxidative stress. Additionally, the promising anti-diabetic activity, with alpha-amylase inhibition reaching 84.74 % for SNS at 60 mg/ml highlights their potential in diabetes management. This study provides a holistic understanding of shea butter wastes, unraveling their chemical complexity and exploring their pharmacological potentials. It not only expands our knowledge of shea butter wastes, but also unlocks new avenues for utilization of the wastes in various industries, thereby contributing to waste management and sustainable exploitation of shea resources.

Introduction

African culture and livelihoods rely heavily on shea butter, a natural fat made from the kernels of the shea fruit from the shea butter tree (*Vitellaria paradoxa*) (Fig. 1). Shea butter has many uses in cooking, cosmetics, medicine, and healing (Thioune et al., 2019; Kolo et al., 2022a; Koudoro et al., 2022; Ofoegbu-Chibuzo et al., 2022; Abdel-Razek et al., 2023). Shea trees, well-known for their versatility and widespread distribution in African nations like Nigeria, Ghana, Uganda, Congo, and Mali are important for economic, and medical needs of people (Kolo et al., 2022b; Nasare et al., 2022; Korese and Chikpah, 2023). The composition of shea butter reflects its resourcefulness and values across various industries (Goumbri et al., 2022; Koudoro et al., 2022).

Millions of women actively participate in the African shea belt economy, and the shea butter is a vital product in the world economy, as it provides direct or indirect sources of income along the value chain (Naah et al., 2021; Naangmenyele et al., 2023). Each year, more than 350,000 tons of shea butter from West Africa are exported to various regions and countries worldwide, substantially boosting their economies through export revenues (Iddrisu et al., 2019). Nigeria, one of the prominent producers of shea butter involves several key states in its production and processing. In the Northwest, Kaduna State is known for its abundant shea tree population, while Kano State is the major hub with the processing sites for shea nuts and butter. Central states like Kogi and Kwara also contribute significantly to the industry. Additionally, Oyo, Niger, and Nasarawa States play roles in processing and exporting

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shea butter products. These states collectively demonstrate Nigeria's diverse landscape in shea butter production to support local economies and livelihoods (Ayanfunke and Kabiru, 2020; Mégnanou and Niamké, 2021; Adesope et al., 2022; Mojisola et al., 2022).

In processing the shea nut, shea butter is extracted via mechanical, chemical, and traditional (manual or local) processes. However, compared to mechanical or chemical processes, the indigenous method of shea butter production produces more wastes (Goumbri et al., 2021; Sulaiman and Adeoye, 2021; Naangmenyele et al., 2023). The extraction of shea butter employs 100 % input of shea kernels, with an output of approximately 34.4 % shea butter, 54.3 % shea cakes, and 11.3 % wastewater (Naangmenyele et al., 2023). The presence of tannin, an environmental pollutant that is poisonous to soil microbes and makes the waste resistant to biodegradation and unsuitable for use as animal feed, makes the disposal of these wastes (shea cakes and wastewater) in the shea butter sector extremely difficult.

Shea butter wastes have detrimental consequences on the environment, such as clogging of drains, attraction of mosquitoes, promotion of water-borne illnesses, release of unpleasant aromas, and generally causing illnesses that are associated with smoking for those processors that use the local processing methods (Sulaiman and Adeoye, 2021). Shea butter wastes therefore present environmental problems because of their improper disposal into the environment (Sulaiman and Adeoye, 2021; Naangmenyele et al., 2023). However, a thorough examination of the chemical composition of the wastes could highlight potential advantages for waste reuse (Naangmenyele et al., 2023) within the paradigm of circular bioeconomy for carbon neutrality. The processing and management of the wastes from the production of shea butter are not well studied enough.

Shea solid wastes (SSWs) have emerged as vital resources with diverse potential applications, providing sustainable solutions for managing the wastes generated from shea butter production. For instance, some studies have investigated the incorporation of SSWs into clay bricks, revealing promising prospects for creating sustainable building materials (Adazabra et al., 2017; Doubi et al., 2017; Kouamé et al., 2020; Kouamé et al., 2021). This use helps promote ecological-friendly building techniques while also addressing waste management issues. Furthermore, studies have shown that shea waste slurry (SWS) is an efficient organic soil amendment as reported by Abagale et al. (2020). This application resulted in significant improvements in soil properties and nutrient levels. Utilizing SWS for soil amendment purposes is a sustainable approach to enhance the soil fertility, potentially contributing to improved agricultural practices. Moreover, some studies have been conducted on the use of shea nut shell (SNS) waste for the production of activated carbon (Adekola and Oba, 2017; N'goran et al., 2018). However, there is gap in knowledge in studying the phytochemical attributes of the different wastes that are obtained from the processing of the shea nut. Similarly, the investigation of the pharmacological potentials of some of the wastes is also limited. Therefore, this study was designed to expand the scope of utilization of shea butter wastes for circular economy by characterizing the bioactive compounds in the wastes and evaluating their antioxidant and antidiabetic activities.

Under the more general bioeconomy paradigm, circular bioeconomy offers a logical way to solve environmental issues while encouraging resource sustainability and economic expansion. Regenerative strategies like garbage reuse and recycling are highlighted as means of reducing resource depletion and mitigating environmental consequences while adding values (Kuisma and Kahiluoto, 2017; Stegmann et al., 2020; Muscat et al., 2021). The concept of circular bioeconomy is gaining momentum globally, with increasing efforts to manage agro-industrial by-products efficiently for conversion to useful bio-based products.

Several studies (Campos et al., 2020; Ferri et al., 2020; Rojas et al., 2022; Yaashikaa et al., 2022) have highlighted the importance of circular bioeconomy in minimizing waste generation and maximizing resource utilization. These works emphasized the transformative potential of circular bioeconomy practices in various sectors, including agriculture and food processing. Several agrowastes such as groundnut peel, melon shell, corncob, kolanut pod, kolanut seed shell, poultry feather, and locust bean wastewater among others have been valorized biotechnologically to produce series of bioproducts ranging from biogas, citric acid, fructooligosaccharides, enzymes to nanomaterials in our previous investigations (Lateef et al., 2015; Adelere and Lateef, 2016; Lateef et al., 2016a; Lateef et al., 2016b; Elegbede and Lateef, 2018; Elegbede and Lateef, 2019; Elegbede et al., 2020; Aguda and Lateef, 2021; Elegbede et al., 2021; Aguda and Lateef, 2022; Ajayi and Lateef, 2023; Lateef, 2023). Nevertheless, there are still gaps in the utilization of several agrowastes, particularly in tropical countries like Nigeria. One of

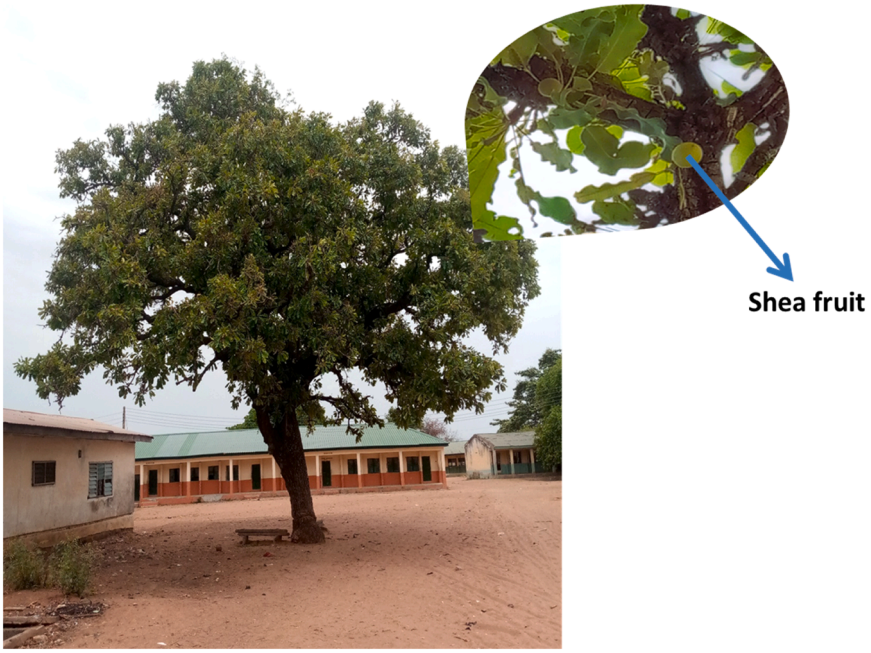


Fig. 1. Shea tree (*Vitellaria paradoxa*).

such priority wastes are those obtained from the processing of shea nut into shea butter.

Until now, limited information is available on the characterization of waste streams of shea butter; though Kouakou et al. (2021) reported the phytochemical analysis of shea by-products, specifically shea shells and press-cake among different types of waste generated during production of the shea butter. The study reported the presence of phenolic and flavonoid compounds in the wastes ranging from 16.962–21.395 mg GAE/100 g and 0.243–1.83 mg QE/100 g. The *in vitro* antioxidant activities of the wastes yielded IC_{50} of 0.398–0.235 mg/ml, 0.623–0.465 mg/ml and 0.137–0.154 mg/ml using DPPH, ABTS and FRAP assay, respectively.

However, the present study conducted a comprehensive phytochemical analysis of shea butter wastes at different processing stages: brown and black shea cakes, shea nut shells, and the wastewater, by employing GC–MS to identify and quantify the bioactive chemicals found in the wastes. This study sets itself apart by taking a comprehensive approach in phytochemical profiling of the wastes. By encompassing a broader range of waste materials, it provides a holistic understanding of shea butter wastes and adds novelty by conducting a thorough analysis across multiple waste streams, unraveling the chemical complexity of these wastes, and exploring their potential pharmacological applications. Furthermore, the antidiabetic activities of shea butter wastes are also reported herein for the first time. In essence, this study not only expands the knowledge of shea butter wastes, but also unlocks new avenues for their utilization across various industries through phytochemical profiling. By delving into the chemical intricacies of shea butter wastes and exploring the pharmacological potentials, this study contributes to sustainable practices in the shea butter production, while addressing the pressing environmental concerns that are raised in the processing of the industrial crop. The endeavor shall also promote the development of green economy (Batrancea et al., 2021a) and expand the opportunities available for SMEs (Batrancea et al., 2022) that are involved the shea butter value chain by supplying



Fig. 2. Schematic representation of production of shea butter showing the generation of the various wastes.

valuable raw materials and products (Batrancea et al., 2021b) at national, regional and international markets.

Materials and methods

Samples collection

Shea waste collection for this study was conducted at a regional processing facility located in Agbaku Eji, Kwara State, North-central Nigeria (8° 35′39″ N, 4°40′18″ E). About 100 g of the brown and black shea nut cakes (SNC1 and SNC2) and shea nut shell (SNS) and 500 ml of the wastewater (SNWW) were collected as produced by the processing facility. In the laboratory, SNC1, SNC2, and SNS were air dried at room temperature (30 ± 2 °C), while the wastewater was kept at 4 °C in the refrigerator until further use. The flow chart of the processing of shea butter showing the formation of wastes is presented as Fig. 2.

Phytochemical analysis of the samples

Phytochemical analyses of SNC1, SNC2, SNS, and SNWW were performed using GC–MS as follows:

Extraction of the phytochemicals

Ten gram of each sample was suspended in 10 ml of 70 % methanol (v/v) for the extraction process, which included maceration in a hydromethanolic solution. The samples were then homogenized using magnetic agitation for 48 h, after which Whatman filter paper No. 1 was used to filter the mixture. After that, a rotary evaporator was used to evaporate the solvent at 40 °C till a dry powder was produced. For further analysis, the resultant powder was kept in sterile vials at 4 °C (Nwachukwu et al., 2022).

GC–MS analyses of the samples

Helium gas was employed as the carrier gas in a gas chromatography system (Agilent, USA) that was coupled to a mass spectrometer (5975C) with a triple axis detector and an auto injector of 10 μl capacity. Every chromatographic separation was carried out using a capillary column that was treated with phenyl methyl siloxane and had the following specifications: length of 30 m, internal diameter of 0.2 μm, and thickness of 250 μm. Additional settings for GC–MS measurements include ion source temperature (EI) of 250 °C, interface temperature of 300 °C, pressure of 16.2 psi, out time of 1.8 min, and 1 μl injector in split mode with split ratio of 1:50 at injection temperature of 280 °C. After two min at 50 °C, the temperature in the column was increased to 100 °C at a rate of 20 °C per min. At a rate of 20 °C per min, the temperature was raised to 250 °C and maintained for 5 min. The system was operated and data was collected using MS Solution software, which was supplied by the supplier. The compounds were identified by contrasting the mass spectra that were acquired with those of the standard mass spectra from the NIST library (NISTII).

Evaluation of the antioxidant activities

The method of Olaitan et al. (2024) was used with slight modifications to assess the antioxidant activity of the shea waste samples using DPPH (2,2-diphenyl-1-picrylhydrazyl) assay, H_2O_2 (hydrogen peroxide) scavenging assay, FRAP (ferric reducing antioxidant power) assay and NO (nitric oxide) scavenging assay.

Nitric oxide scavenging assay

A solution of sodium nitroprusside (5 mM) in phosphate-buffered saline at pH 7.4 was prepared. Then, 1 ml of this solution was mixed with 1 ml of varying concentrations of shea wastes (6 to 60 mg/ml) and incubated at 25 °C for 30 min. A control sample was also prepared without the addition of the shea wastes. After the 30-min incubation period, the solution was extracted, and 2 ml of Griess reagent (consisting of 1 % sulphanilamide, 2 % phosphoric acid, and 0.1 % N-1-naphthyl ethylene diamine dihydrochloride) was added to dilute the mixture. The formation of the chromophore was measured by determining the absorbance at 546 nm using UV–vis spectrophotometer. The experiment was performed in triplicates. Nitric oxide scavenging activity was calculated by using the formula in Eq. (1):

$$\% \text{ scavenging of nitric oxide} = \frac{AC - AS}{AC} \times 100 \quad (1)$$

where: AC is the absorbance of control and AS is the absorbance of sample

Hydrogen peroxide scavenging assay

To evaluate the abilities of various shea wastes to scavenge hydrogen peroxide (H_2O_2), a 40 mM H_2O_2 solution was prepared using phosphate buffer at pH 7.4 and reacted with the wastes. Exactly 0.6 ml of the 40 mM H_2O_2 solution was mixed with 2 ml of various concentrations of shea wastes (6 to 60 mg/ml) in 4 ml distilled water. After 20 min of incubation at room temperature, the absorbance of H_2O_2 at 610 nm was measured using a spectrophotometer (Spectro UV-2505), and the readings was compared to a blank solution containing phosphate buffer with H_2O_2. The experiment was performed in triplicates and H_2O_2 scavenging assay was calculated as shown in Eq. (2)

$$\% \ H_2O_2 \text{ scavenging activity} = \frac{AC - AS}{AC} \times 100 \quad (2)$$

where AS is the absorbance of the negative control and AS is the absorbance of sample

Ferric reducing activity assay

Different concentrations of 6 to 60 mg/ml of the shea wastes and ascorbic acid (standard) were used in this assay. The test sample was mixed with 2.5 ml of 200 mM phosphate buffer (pH 6.6) and 2.5 ml of 1 % potassium ferricyanide. The resulting mixture was incubated at 50 °C for 20 min and cooled rapidly. Then, 2.5 ml of 10 % trichloroacetic acid was added and centrifuged at 3000 rpm for 10 min. The supernatant was mixed with 2.5 ml of deionised water and 1 ml of 0.1 % ferric chloride. Then, the absorbance was measured at 700 nm using UV–vis spectrophotometer. All the reagents were produced for a blank that was devoid of the shea wastes. The experiment was performed in triplicates and the reducing activity was determined using Eq. (3).

$$\% \text{ Ferric reducing activity} = \frac{A_{sample} - A_{blank}}{A_{blank}} \times 100 \quad (3)$$

where A_{blank} is the absorbance of the blank and A_{sample} is the absorbance of the sample.

DPPH (2,2-diphenyl-1-picrylhydrazyl) scavenging assay

Different concentrations of the shea wastes ranging from 6 to 60 mg/ml were tested in this assay. The procedure involved mixing 1 ml of the shea wastes with 4.0 ml of 1 mM DPPH solution. The mixture was then kept in a dark environment for 30 min to allow the shea wastes to scavenge the DPPH free radicals. After the incubation period, the absorbance of the solution was measured at 517 nm using a spectrophotometer (Spectro UV-2505). The experiment was performed in triplicates and DPPH scavenging activity was calculated following Eq. (4).

$$\%\ \text{DPPH scavenging activity} = \frac{AB - AS}{AB} \times 100 \quad (4)$$

where AB is the absorbance of the blank and AS is the absorbance of the sample

In vitro antidiabetic assay using inhibition of α-amylase

In vitro antidiabetic activity of the shea wastes at concentration of 10–100 μg/ml was investigated by the methods of Kazeem et al. (2013) for α-amylase inhibition with slight modifications. Acarbose at concentrations of 6–60 mg/ml was used as the reference standard, while the control was prepared without sample. Exactly 500 μL of sample was added in a test tube and 500 μL of 0.2 mM phosphate buffer (pH 6.9) containing α-amylase solution (0.5 mg/ml) was added to it. This mixture was incubated for 10 min at room temperature followed by the addition of 500 μL of 1 % starch solution in 0.02 M sodium phosphate buffer (pH 6.9). The reaction was carried out for 10 min. Thereafter, the addition of 1000 μL of 3,5- Dinitrosalicylic acid (DNS) was employed to stop the reaction. The reaction mixture was incubated for 5 min in a boiling water bath before cooling down to room temperature. Addition of 10 ml water was used to dilute the reaction mixture. Absorbance was measured at 540 nm. The experiment was performed in triplicates, and the percentage inhibition of α-amylase was calculated according to Eq. (5).

$$\%\ \alpha - \text{amylase inhibition} = \frac{AC - AS}{AC} \times 100 \quad (5)$$

where AC is the absorbance of control and AS is the absorbance of sample

Results and discussion

The bioactive compounds of shea wastes

The four shea wastes (SNC1, SNC2, SNS, and SNWW) were subjected

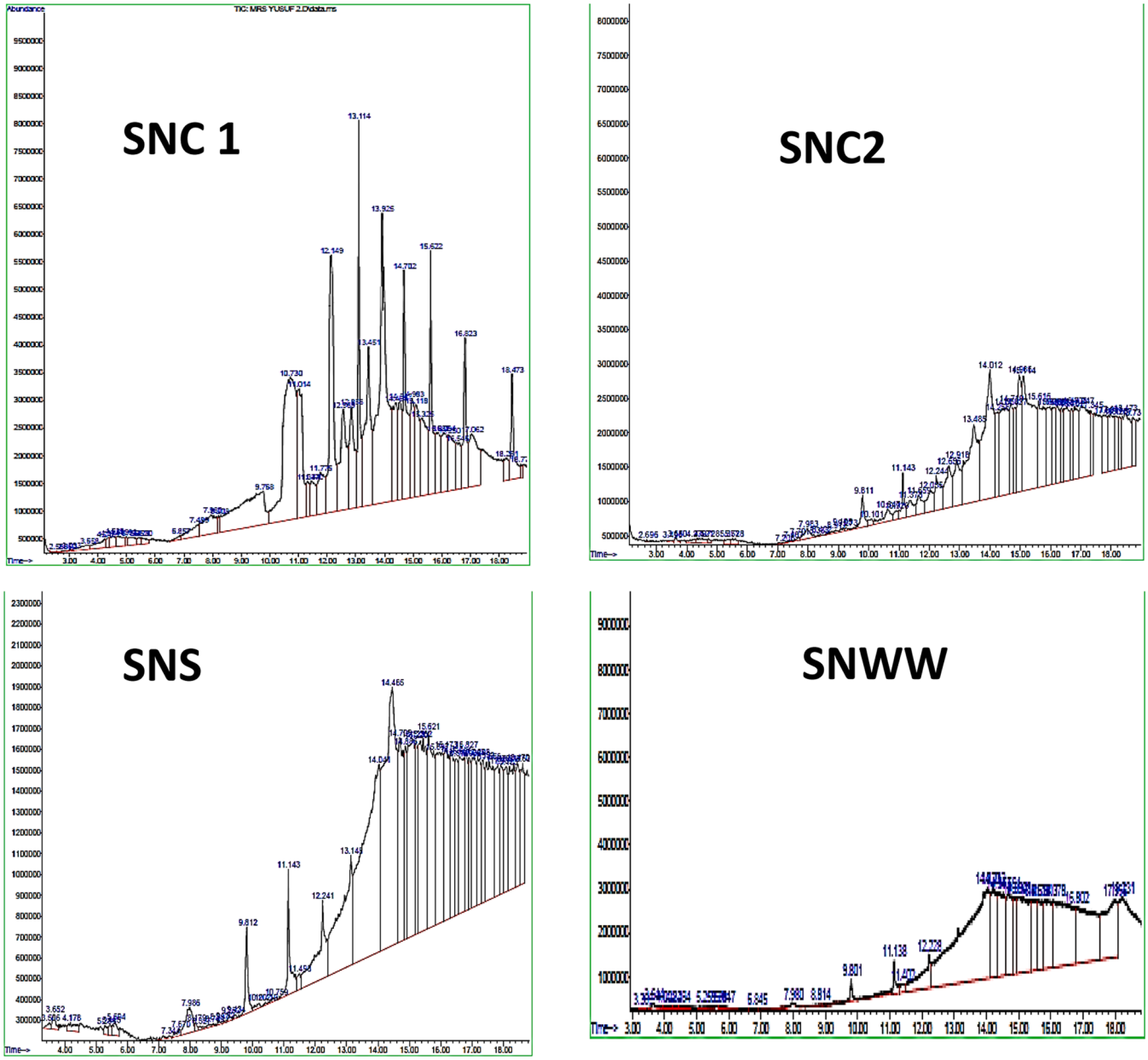


Fig. 3. GC–MS chromatograms of the shea butter wastes.

to phytochemical analysis, which produced a wide range of bioactive compounds. The chromatograms of the samples are as shown in Fig. 3. Each bioactive compound has a distinct chemical structure and has potential biological uses including antimicrobial, anticancer, antioxidant, anti-inflammatory, and insecticidal properties. Tables 1–4 display the 20 most abundant compounds together with their structure, retention time (RT), concentration (peak area %), previous occurrence in plants, and biomedical applications. A total of 44 compounds were identified in SNC1, 59 in SNC2, 49 in SNS, and 29 in SNWW. Of all the chemicals found in SNC1, cholestane had the greatest peak area percentage value at 12.24 %, while 2,4,6-cycloheptatrien-1-one and 3,5-bis-trimethylsilyl-pentanone had the lowest at 0.01 %. It has been reported that cholestane possesses antibacterial, anticancer, anti-inflammatory, and antioxidant activities (Bose et al., 2023; Credo et al., 2022; Susanto et al., 2019).

N-Methyl-1-adamantaneacetamide had the lowest peak area percentage value of 0.01 % for SNC2, while 9-Hexadecenoic acid, methyl ester, (Z)- had the greatest peak area percentage value of 9.97 %. The maximum peak area percentage value for SNS was 11.94 % for octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15-hexadecamethyl-, while the lowest peak area percentage values were 0.01 % for 9H-Fluorene-2-carboxylic acid, 9-oxo-, and (2-hydroxyethyl) (methyl) amide. In SNWW, 1H-Indole, 5-methyl-2-phenyl-had the lowest peak area percentage value of 0.02 %, while octadecanal had the greatest peak area percentage value of 22.79 %.

The compounds found in the shea wastes belong to different groups of bioactive molecules, each of which has distinct chemical properties and structure. Among these, terpenoids are represented by compounds such as cholestane, cycloheptasiloxane, and cyclohexasiloxane with a wide range of known biological activities, including antioxidant and antibacterial properties (Bose et al., 2023; Elbalola and Abbas, 2023). Another class found is phenolic compounds such as tetradecanal, which is known for its anti-inflammatory and antioxidant properties (Roncero et al., 2020; Mazurakova et al., 2022). Alkaloids, such as n-propyl 11-octadecenoate, constitute another class, often associated with antimicrobial activities (Mohanraj et al., 2018; Hu et al., 2022). Carotenoids, which include Z,E-2,13-Octadecadien-1-ol, are recognized for their potential health benefits and antioxidant properties (Gholizadeh-Moghadam et al., 2019; Koklesova et al., 2020).

Among the compounds detected in the four wastes, cyclohexasiloxane and dodecamethyl occurred across all the wastes. Cyclohexasiloxane and dodecamethyl which are known for their applications in skincare, cosmetics, breast implants, and as antibacterial agents have garnered attention for their potential biomedical applications. Studies have highlighted the diverse uses of these compounds, including their role as conditioning agents, emollients, lubricants, and defoaming agents in personal care products (Mohamed Iqbal et al., 2022). Furthermore, research has indicated that cyclohexasiloxane, and dodecamethyl possess bioactive properties, with report suggesting their involvement in hepatoprotective activities (Sathiyamurthy and Bavithra, 2019). Moreover, they have been shown to be important ingredients in several formulations, including varnishes, deodorants, moisturizers, cosmetics, silicone breast implants, and sanitation products (Mohamed Iqbal et al., 2022). In addition, these compounds have been previously reported to occur in plants such as *Pithecellobium dulce, Fagonia burguieri* DC, *Zygophyllum coccineum* L., and *Zygophyllum fabago* L. and exhibited antimicrobial activities (Bobade, 2019; Alarkwazi et al., 2021). Its ubiquity across different stages of shea wastes generation suggests its resistance to degradation.

Each waste exhibited a unique profile of compounds, suggesting variations in the processing conditions (such as temperature, pressure, or duration) or the extraction methods used at different stages of the shea butter manufacturing process, resulting in variations in the chemical composition of the wastes and distinctive profiles of the recognized compounds. For instance: Tetrasiloxane, decamethyl-, Pregnane-3,20-dione,17-[(trimethylsilyl)oxy]-, Morphinan,7,8-didehydro-4,5-epoxy-17-methyl-3,6-bis[(trimethylsilyl)oxy]-, 3-Trimethylsiloxy palmitic acid, trimethylsilyl ester, (Trimethylsilyl)methyl trifluoromethyl disulfide, Hexadecane, Benzoic acid, 1-Octadecene, Tetradecanal, Cholestane, Tetradecanal, Cyclotetradecane, 1,1,1,5,7,7,7-Heptamethyl-3,3-bis(trimethylsiloxy)tetrasiloxane, 17-Pentatriacontene, n-Propyl 11-octadecenoate, *cis*-7,*cis*-11-Hexadecadien-1-yl acetate, Hexadecanoic acid, and 2-hydroxy-, methyl ester are unique to SNC1.

N-Methyl-1-adamantaneacetamide, 8-Chloro-5H-indeno[1,2-b] quinoline-10,11-dione, Bicyclo[10.1.0]trideca-4,8-diene-13-carboxamide, N-(3-chlorophenyl)-, Methyl (5-hydroxy-1H-benzimidazol-2-yl) carbamate, Anthracene, 9,10-diethyl-9,10-dihydro-, Benzeneacetic acid, .alpha.-oxo-, trimethylsilyl ester, 2-Cyclohexenone, 4-acetamido-, 3,5-Dinitro-4-(3,4-xylidino)benzoic acid, Hexadecane, 1-(ethenyloxy)-, trans-2-Dodecen-1-ol, trifluoroacetate, 3-Isopropoxy-1,1,1,7,7,7-hexamethyl-3,5,5-tris(trimethylsiloxy)tetra siloxane, 7-Hexadecene, (Z)-, 11-Octadecenoic acid, methyl ester, 9-Tricosene, (Z)-, Z-10-Pentadecen-1-ol, 1,19-Eicosadiene, *cis*-11-Hexadecenal, 9-Octadecenoic acid (Z)-, 2,3-dihydroxypropyl ester, 9-Hexadecenoic acid, methyl ester, (Z)-, Butyl 9-octadecenoate or 9–18:1, n-Propyl 11-octadecenoate, 5-Octadecene, (E)-, Oleyl alcohol, and heptafluorobutyrate are unique to SNC2.

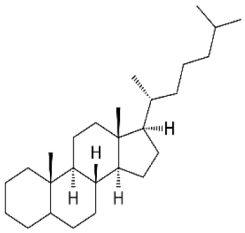
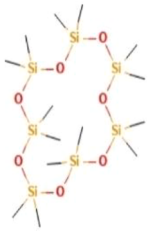
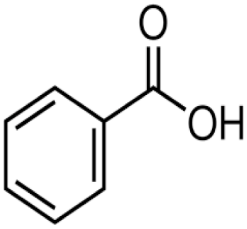
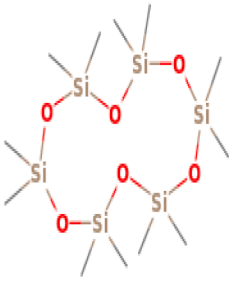
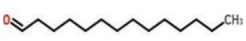
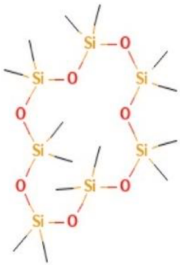
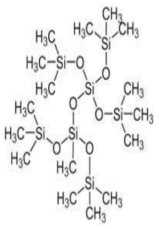
Tris(trimethylsilyl) ester, 2,4,6-Cycloheptatrien-1-one, 3,5-bis-trimethylsilyl-, 2,5-Dihydroxyacetophenone, bis (trimethylsilyl) ether, 2-Methyl-7-phenylindole, Thieno[2,3-c]furan-3-carbonitrile, 2-amino-4,6-dihydro-4,4,6,6-tetra methyl-, N-Methyladrenaline, tri-TMS, Silicic acid, diethyl bis(trimethylsilyl) ester, 9H-Fluorene-2-carboxylic acid, 9-o xo-, (2-hydroxyethyl) (methyl) amide, 5-Methyl-2-phenylindolizine, 2-(Acetoxymethyl)-3-(methoxycarbonyl)biphenylene, Octasiloxane, 1,1,3,3,5,5,7,7,9,9, 11,11,13,13,15,15-hexadecamethyl-, Pyridine, 1,2,3,6-tetrahydro-1-met hyl-4-[4-chlorophenyl]-, Benzenamine, 4-(2-phenylethenyl)-N-(3,5-dimethyl-1-pyrazolylmethyl)-, 9-Octadecenoic acid, (E)-, Octasiloxane, 1,1,3,3,5,5,7,7,9,9,11,11,13,13,15,15-hexadecamethyl-, Butyl 9-tetradecenoate, Z-8-Pentadecen-1-ol acetate, Methyl pentadecyl ether, Cyclobarbital, 2-Methyl-7-phenylindole, Z-8-Pentadecen-1-ol acetate+C42, Indole-2-one, 2,3-dihydro-N-hydroxy-4-methoxy-3,3-dimethyl-, Acetic acid, [4-(1,1-dimethylethyl) phenoxy]-, methyl ester, Fumaric acid, and pent-4-en-2-yl tridecyl ester are unique to SNS.

1-Benzenesulfonyl-1H-pyrrole, 1-(3-Hydroxy-4-methylphenyl)-1,3,3,6-tetramethylindan-5-ol, 2′,4′-Dihydroxyacetophenone, bis(trimethylsilyl) ether, Cyclopentasiloxane, decamethyl-, trans-3-Ethoxy-b-methyl-b-nitrostyrene, i-Propyl 9-tetradecenoate, 2-[(p-Trimethylsilyl oxy)phenyl]-2-[(p-trimethylsilyl oxyethylenoxy)phenyl]propane, Octadecanal, 13-Methyl-Z-14-nonacosene, Squalene, Trifluoroacetoxy hexadecane, 1-Hexacosene, 13-Methyl-Z-14-nonacosene, 13-Methyl-Z-14-nonacosene, 13-Octadecenal, (Z)-, Eicosane, and Tricosane are unique to SNWW.

The variety of substances found in the waste samples emphasizes how intricate the waste streams are and how useful bioactive molecules found in them might be. It is interesting to observe that the chemicals that have the largest %area in each waste type are unique to them, highlighting different chemical profiles.

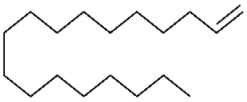
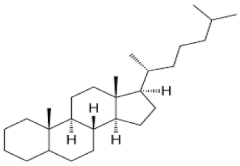
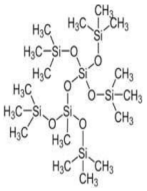
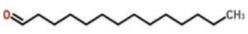
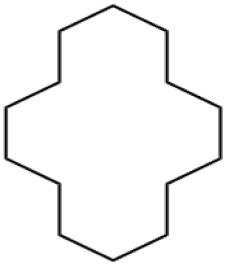
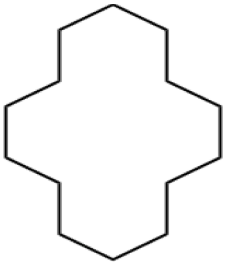
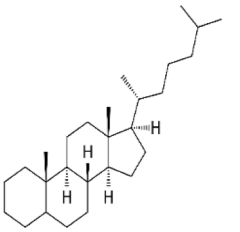
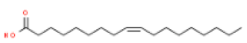
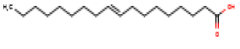
Some other compounds, namely 8-Chloro-5H-indeno[1,2-b]quinoline-10,11-dione, Methyl (5-hydroxy-1H-benzimidazol-2-yl)carbamate, 3,5-Dinitro-4-(3,4-xylidino)benzoic acid, 9H-Fluorene-2-carboxylic acid, 9-oxo-, (2-hydroxyethyl)(methyl)amide, Pyridine, 1,2,3,6-tetrahydro-1-methyl-4-[4-chlorophenyl]-, and 2′,4′-Dihydroxyacetophenone, bis(trimethylsilyl)ether are novel discoveries that warrant extensive research to clarify their possible biological activities and therapeutic uses. Their structural features, which include chemical properties, functional groups, and molecular patterns, point to the potential for a variety of biological functions. Nevertheless, in the absence of precise data from earlier investigations or literature references, their precise pharmacological relevance is uncertain. To clarify the biological activities and therapeutic potential of these compounds, more research is required.

Table 1
Bioactive compounds of SNC1.

S/N	Name	Chemical structure	RT	Area (%)	Previous reports of occurrence in plants	Potential applications	References
1.	Cholestane		13.919	12.24	*Calophyllum inophyllum*	Anticancer	(Susanto et al., 2019)
2.	Cycloheptasiloxane, tetradecamethyl		10.736	10.77	*Chlorella vulgaris*	Antimicrobial, antitumor, antifouling	(El-fayoumy et al., 2021)
3.	Benzoic acid		12.144	6.95	*Piper cumanense*	Antimicrobial, preservatives	(Amin et al., 2021)
4.	Cyclohexasiloxane, dodecamethyl		9.778	5.80	*Pithecellobium dulce*	Widely used in cosmetics	(Bobade, 2019)
5.	Tetradecanal		13.440	5.24	*Eryngium foetidum*	Antimicrobial, antioxidant, antidiabetic	(Paw et al., 2022)
6.	Cycloheptasiloxane, tetradecamethyl		11.018	4.43	*Chlorella vulgaris*	Antibacterial, antifungal, antitumor, antifouling	(El-fayoumy et al., 2021)
7.	1,1,1,5,7,7,7-Heptamethyl-3,3-bis (trimethylsiloxy)tetrasiloxane		14.708	4.21	*Berberis vulgaris*	Antibacterial	(Al Nuaimy and Hawar, 2024)

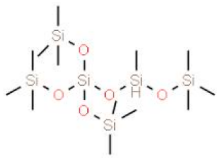
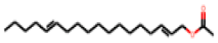
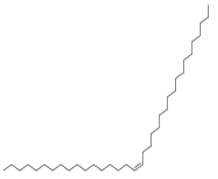
(*continued on next page*)

Table 1 (*continued*)

S/N	Name	Chemical structure	RT	Area (%)	Previous reports of occurrence in plants	Potential applications	References
8.	1-Octadecene		12.567	3.98	*Urena lobata* (Caesar weed)	Antibacterial, antioxidant, anticancer	(Keke et al., 2023)
9.	Cholestane		13.102	3.66	*Calophyllum inophyllum*	Anticancer	(Susanto et al., 2019)
10.	1,1,1,5,7,7,7-Heptamethyl-3,3-bis (trimethylsiloxy)tetrasiloxane		15.609	3.15	*Berberis vulgaris*	Antibacterial	(Al Nuaimy and Hawar, 2024)
11.	Tetradecanal		12.849	3.09	*Eryngium foetidum*	Antimicrobial, antioxidant, antidiabetic	(Paw et al., 2022)
12.	Cyclotetradecane		15.328	3.07	*Urena lobata* (Caesar weed)	Antimicrobial	(Keke et al., 2023)
13.	Cyclotetradecane		14.398	3.01	*Urena lobata* (Caesar weed)	Antimicrobial	(Keke et al., 2023)
14.	*cis*-7,*cis*-11-Hexadecadien-1-yl acetate		17.074	2.79	*Papaver somniferum*	No bioactivity reported	(Kumaravel et al., 2019)
15.	Cholestane		16.821	2.52	*Calophyllum inophyllum*	Anticancer	(Susanto et al., 2019)
16.	Oleic Acid		15.130	2.39	*Mimosa pudica* L.	Antibacterial, antioxidant	(Gandhi et al., 2023)
17.	Octadec-9-enoic acid		14.990	2.36	*Chenopodium quinoa* Wild	Antioxidant, anti-inflammatory	(Khan and Javaid, 2023)

(*continued on next page*)

Table 1 (*continued*)

S/N	Name	Chemical structure	RT	Area (%)	Previous reports of occurrence in plants	Potential applications	References
18.	n-Propyl 11-octadecenoate		16.257	2.33	*Musa paradisiaca* L. Musaceae	Anti-inflammatory	(Ekweogu et al., 2024)
19.	Z,E-2,13-Octadecadien-1-ol		14.539	2.24	*Solanum dasyphyllum*	Antimicrobial, antioxidant,	(Oyinloye et al., 2020)
20.	17-Pentatriacontene		15.891	1.84	*Allium cepa*	Anti-inflammatory, antibacterial	(G. O. Ajayi and Akinsanya, 2023)

Antioxidant activities of the shea butter wastes

Nitric acid scavenging activities

The shea wastes displayed moderate nitric oxide scavenging activities as presented in Fig. 4. The nitric acid scavenging activity of ascorbic acid increased consistently with concentration, starting from 33.24 % at 6 mg/ml and reaching 96.51 % at 60 mg/ml. For SNC1, the nitric acid scavenging activity started from 11.83 % at 6 mg/ml and reached 22.40 % at 60 mg/ml. Although the activity increased with concentration, it remained significantly lower than the standard, indicating moderate antioxidant properties. SNC2 exhibited the lowest initial activity at 6.36 % for the lowest concentration. However, its activity increased to 26.52 % at 60 mg/ml. This trend suggests that while SNC2 has weaker antioxidant properties at lower concentrations, it demonstrated a significant improvement at higher concentrations, potentially due to a higher density of active compounds becoming available. On the other hand, SNS showed a reassuringly steady increase in nitric acid scavenging activity, from 6.72 % at 6 mg/ml to 31.36 % at 60 mg/ml. The performance of SNS was better than SNC1 and SNC2 at higher concentrations, indicating a more substantial antioxidant potential and instilling confidence in its efficacy. SNWW showed the lowest activity at the initial concentration (0.090 % at 6 mg/ml), but notably increased to 35.13 % at 60 mg/ml. This indicates a modest concentration-dependent antioxidant activity, like the trend observed for the other samples.

All the four shea butter waste samples exhibited concentration-dependent nitric acid scavenging activities. However, none matched the efficacy of ascorbic acid at any concentration, highlighting the superior antioxidant capacity of the standard. Among the waste samples, SNWW displayed the most significant improvement from the lowest to the highest concentration, suggesting that it may contain a higher concentration of potent antioxidant compounds at higher doses. The concentration-dependent antioxidant activity of SNWW is particularly impressive, as it showed the lowest activity at the initial concentration (0.090 % at 6 mg/ml) but notably increased to 35.13 % at 60 mg/ml. This trend, observed for the other samples as well, underscores the inspiring potential of these waste samples for further exploration and utilization.

This report is similar to the study of Olaitan et al. (2024) on orange peel extract which also reported increased NO scavenging activity with increase in concentration highlighting robust NO scavenging activity, particularly at higher concentrations (up to 200 mg/ml). For shea waste extracts, the highest NO scavenging activity at 60 mg/ml was 35.13 %. Comparatively, orange peel extract showed a NO scavenging activity of 92.34 % at 100 mg/ml and 96.73 % at 200 mg/ml.

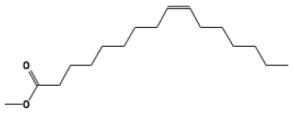
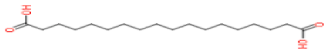
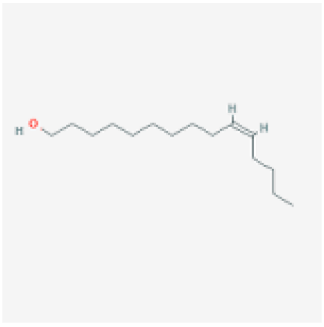
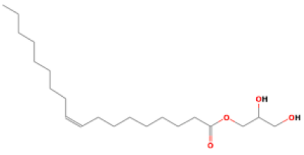
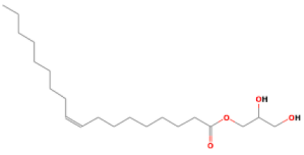
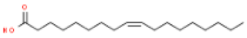
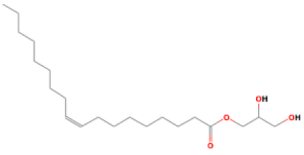
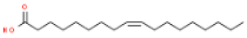
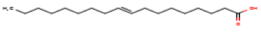
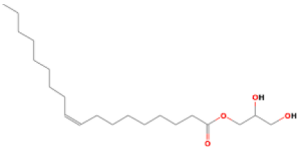
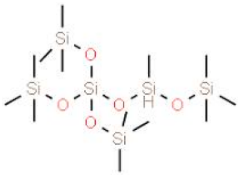
Nitric oxide (NO) has a vital role in multiple physiological processes, such as synaptic transmission, brain plasticity, and immunological responses (Turan et al., 2021; Imran et al., 2022; Lee, 2023). Excessive production of nitric oxide can result in oxidative stress, which is associated with negative consequences including poor synaptic plasticity, early neurodegeneration, and DNA damage (Amnan et al., 2021; Justo and Suemoto, 2022). The results of the nitric acid scavenging assay in this study provide valuable insights into the antioxidant properties of several samples of shea butter wastes.

H_2O_2 scavenging activities

Hydrogen peroxide scavenging activity is an important measure of antioxidant capacity, indicating how effectively a substance can neutralize reactive oxygen species (ROS). In this study, the H_2O_2 scavenging capacities of the wastes highlight their antioxidant potentials compared to the standard antioxidant, ascorbic acid, across multiple concentrations (Fig. 5). Ascorbic acid demonstrated a significant increase in H_2O_2 scavenging activity with rising concentrations. Starting at 19.86 % at 6 mg/ml, it reached 84.40 % at 60 mg/ml. Similarly, SNC1 showed a progressive increase in H_2O_2 scavenging activity from 3.30 % at 6 mg/ml to 36.81 % at 60 mg/ml. While the activity was significantly lower than the standard, the steady increase in concentration indicates moderate antioxidant properties. SNC2 exhibited the lowest initial scavenging activity at 2.75 % for 6 mg/ml, increasing to 15.38 % at 60 mg/ml. This sample displayed the weakest antioxidant activity across all concentrations, suggesting it has the least potent antioxidant compounds among the waste samples. SNS demonstrated a relatively moderate initial activity of 15.38 % at 6 mg/ml, rising to 38.46 % at 60 mg/ml. SNWW started with an activity of 8.79 % at 6 mg/ml, reaching 26.37 % at 60 mg/ml. Although lower than the standard and SNS, SNWW showed a consistent increase in antioxidant activity with concentration, indicating its moderate potential as an antioxidant. Across the shea butter waste samples, the H_2O_2 scavenging activity demonstrated a clear concentration-dependent pattern. However, none of the samples reached the efficacy level of ascorbic acid at any concentration. Among the waste samples, SNS exhibited the most potent antioxidant activity, particularly at higher concentrations.

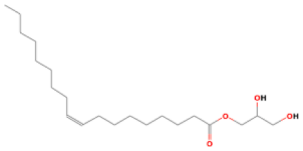
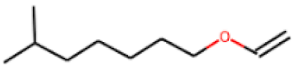
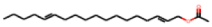
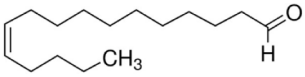
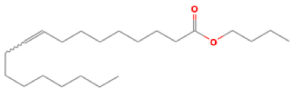
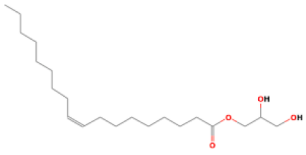
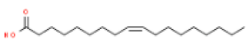
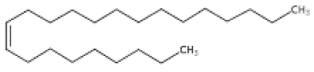
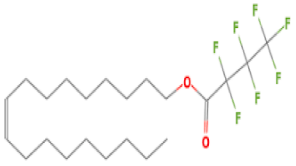
Similar studies have reported H_2O_2 activities in concentration-dependent manner (Revathi et al., 2023; Alemu et al., 2024; Olaitan et al., 2024). Revathi et al. (2023) investigated the H_2O_2 scavenging activity of *Anisomeles malabarica* and *Coldenia procumbens* extracts. *A. malabarica* demonstrated significant H_2O_2 scavenging potential, achieving up to 88.67 % inhibition at 90 mg/ml, while *C. procumbens* exhibited 73 % inhibition at the same concentration. Alemu et al. (2024) assessed the H_2O_2 scavenging activity of *Bersama abyssinica* F. seed extracts. The study demonstrated moderate scavenging activity, with a

Table 2
Bioactive compounds in SNC2.

S/N	Name	Chemical structure	RT	Area (%)	Previous reports of occurrence in plants	Potential applications	Reference
1.	9-Hexadecenoic acid, methyl ester, (Z)-		15.102	9.97	*Vernonia amygdalina* (Del.)	Antibacterial	(Onifade et al., 2023)
2.	1,19-Eicosadiene		14.004	9.79	*Lawsonia inermis*	Antibacterial	(Obuotor et al., 2021)
3.	Z-10-Pentadecen-1-ol		13.496	6.66	*Alchornea cordifolia*	Antimicrobial	(Enyiukwu et al., 2024)
4.	9-Octadecenoic acid (Z)-, 2,3-dihydroxypropyl ester		14.567	6.09	*Tinospora cordifolia*	Antimicrobial	(Akhilraj et al., 2024)
5.	9-Octadecenoic acid (Z)-, 2,3-dihydroxypropyl ester		17.046	5.41	*Tinospora cordifolia*	Antimicrobial	(Akhilraj et al., 2024)
6.	Oleic Acid		15.609	5.01	*Mimosa pudica* L.	Antibacterial, antioxidant	(Gandhi et al., 2023)
7.	9-Octadecenoic acid (Z)-, 2,3-dihydroxypropyl ester		14.990	4.25	*Tinospora cordifolia*	Antimicrobial	(Akhilraj et al., 2024)
8.	Oleic Acid		18.483	3.61	*Mimosa pudica* L.	Antibacterial, antioxidant	(Gandhi et al., 2023)
9.	Octadec-9-enoic acid		16.539	3.52	*Chenopodium quinoa* Wild	Antioxidant, anti-inflammatory	(Khan and Javaid, 2023)
10.	9-Octadecenoic acid (Z)-, 2,3-dihydroxypropyl ester		15.975	3.08	*Tinospora cordifolia*	Antimicrobial	(Akhilraj et al., 2024)
11.	n-Propyl 11-octadecenoate		16.821	2.88	*Musa paradisiaca* L. Musaceae	Anti-inflammatory	(Ekweogu et al., 2024)

(*continued on next page*)

Table 2 (*continued*)

S/N	Name	Chemical structure	RT	Area (%)	Previous reports of occurrence in plants	Potential applications	Reference
12.	9-Octadecenoic acid (Z)-, 2,3-dihydroxypropyl ester		18.004	2.86	*Tinospora cordifolia*	Antimicrobial	(Akhilraj et al., 2024)
13.	Octadecane, 1-(ethenyloxy)-		14.708	2.65	*Plumbago zeylanica* (Linn.)	Antimicrobial, antioxidant	(Gabriel et al., 2019)
14.	Z,E-2,13-Octadecadien-1-ol		12.905	2.51	*Solanum dasyphyllum*	Antimicrobial, antioxidant,	(Oyinloye et al., 2020)
15.	*cis*-11-Hexadecenal		14.257	2.47	*Sphenocentrum jollyanum*	Antimicrobial,	(Uka et al., 2022)
16.	Butyl 9-octadecenoate or 9-18:1		16.229	2.40	*Combretum platypetalum*	Antimicrobial	(Umoh et al., 2023)
17.	9-Octadecenoic acid (Z)-, 2,3-dihydroxypropyl ester		17.835	2.31	*Tinospora cordifolia*	Antimicrobial	(Akhilraj et al., 2024)
18.	Oleic Acid		16.088	2.29	*Mimosa pudica* L.	Antibacterial, antioxidant	(Gandhi et al., 2023)
19.	9-Tricosene, (Z)-		12.651	2.02	*Costus lucanusianus* J. Braun	Antimicrobial	(Onanuga and Oloyede, 2022)
20.	Oleyl alcohol, heptafluorobutyrate		18.736	1.84	*Moringa oleifera*	Antimicrobial	(Kumar and Sharma, 2023)

concentration-dependent increase. Although exact percentages are not specified, the implication of a concentration-dependent increase suggests a similarity in the trend observed with shea waste extracts. Olaitan et al. (2024) reported on the H_2O_2 scavenging activity of orange peel extracts. At 100 mg/ml, the extract showed an inhibition percentage of 72.75 %, compared to 86.27 % for ascorbic acid, a standard antioxidant.

Ferric-reducing activity power

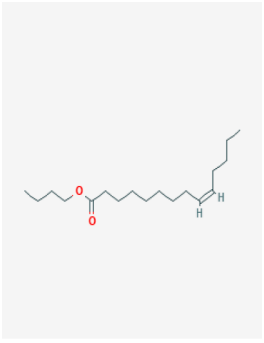
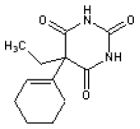
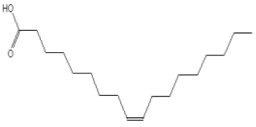
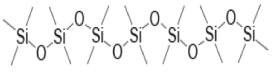
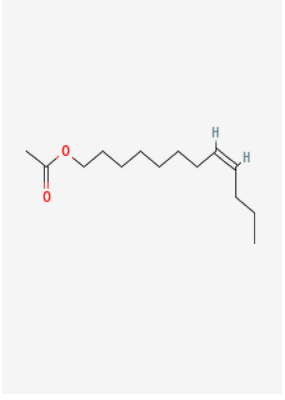
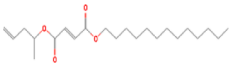
The Ferric Reducing Antioxidant Power (FRAP) assay is a commonly used method to assess the antioxidant potential of various substances by measuring their ability to reduce ferric ions (Fe^{3+}) to ferrous ions (Fe^{2+}) (Ghanimi et al., 2021; Malino, 2024). In this study, the antioxidant potential of various shea butter waste samples compared to the standard antioxidant, ascorbic acid was evaluated (Fig. 6). The standard, ascorbic acid demonstrated a strong and increasing ferric-reducing activity with rising concentrations, starting at 45.54 % at 6 mg/ml, to reach 80.56 % at 60 mg/ml. SNC1 exhibited the highest ferric-reducing activity among the waste samples. Starting at 55.28 % at 6 mg/ml, it increased steadily to 68.13 % at 60 mg/ml. Notably, SNC1 showed higher antioxidant activity than ascorbic acid at lower concentrations, indicating its strong potential as a natural antioxidant source. The SNC2 displayed relatively lower initial activity at 36.31 % for 6 mg/ml, increasing to 44.23 % at 60 mg/ml. Although SNC2 exhibited the weakest ferric-reducing activity among the waste samples, the consistent increase across concentrations suggests some antioxidant potential, albeit lower than other samples. SNS demonstrated moderate initial activity at 35.83 % at 6 mg/ml, rising significantly to 65.93 % at 60 mg/ml. This trend indicates that SNS possesses substantial antioxidant properties, particularly at higher concentrations. SNWW started with an activity of 26.09 % at 6 mg/ml, reaching 59.36 % at 60 mg/ml.

Comparing the ferric-reducing activities of shea waste extracts with those from other studies, particularly Revathi et al. (2023), Alemu et al. (2024), and Olaitan et al. (2024), shea wastes showed significant FRAP. For instance, Revathi et al. (2023) reported that the aqueous extract of *A. malabarica* displayed approximately 86 % ferric-reducing activity at a concentration of 90 mg/ml. In contrast, the *C. procumbens* extract exhibited only 25 % ferric-reducing activity at the same concentration. Comparing these results with the shea waste extracts, *A. malabarica* shows significantly higher ferric-reducing power. However, at 60 mg/ml, shea waste extracts, especially SNC1, exhibited higher activity than *C. procumbens* at 90 mg/ml. Alemu et al. (2024) reported that the ferric ion-reducing power of BASE increased in a concentration-dependent just as it is reported in this study. Moreover, Olaitan et al. (2024) reported the ferric-reducing antioxidant power of orange peel extract at different concentrations. The results showed that at 5 mg/ml, the orange peel extract exhibited 70.09 % inhibition, while at 100 mg/ml, the inhibition increased to 79.74 %.

DPPH (2,2-diphenyl-1-picrylhydrazyl) scavenging activities

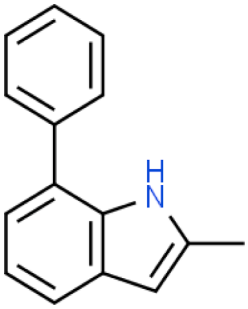
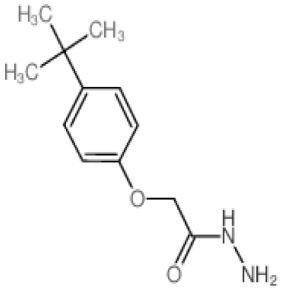
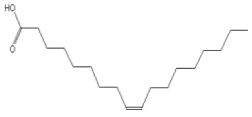
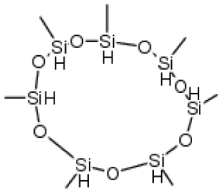
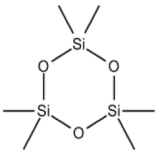
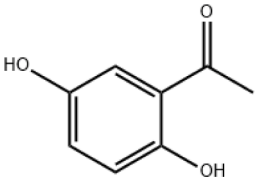
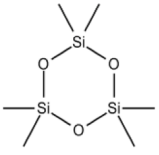
The DPPH scavenging capacities of the different shea butter waste

Table 3
Bioactive compounds in SNS.

S/N	Name	Chemical structure	RT	Area (%)	Previous reports of occurrence in plants	Potential applications	References
1.	9-Octadecenoic acid, (E)-		13.158	5.04	*Glinus lotoides* (Molluginaceae)	Antibacterial, antibiofilm	(Odewo et al., 2023)
2.	Butyl 9-tetradecenoate		15.891	4.52	*Acanthus polystachyus* Delile	Antioxidant, antibacterial	(Getahun et al., 2023)
3.	Cyclobarbital		17.553	4.16	*Acacia seyal*	Anesthetic, anti-convulsan, anti-proliferative	(Maher et al., 2021)
4.	Oleic Acid		16.173	3.54	*Mimosa pudica* L.	Antibacterial, antioxidant	(Gandhi et al., 2023)
5.	E-11-Tetradecenoic acid		16.623	3.00	*Senna occidentalis*	Antioxidant,	(Yakubu et al., 2021)
6.	Heptasiloxane, hexadecamethyl-		12.229	2.35	*Withania somnifera*	Antimicrobial, anticancer,	(Lingfa et al., 2024)
7.	Z-8-Pentadecen-1-ol acetate		17.215	2.15	*Berlinia grandiflora*	Not found	(Aboaba and Ibitoye, 2018)
8.	Fumaric acid, pent-4-en-2-yl tridecyl ester		18.623	2.10	*Azadirachta indica*	Antioxidant, antimicrobial	(Loganathan et al., 2021)

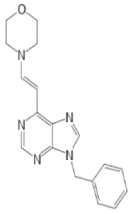
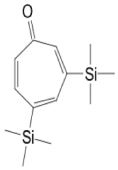
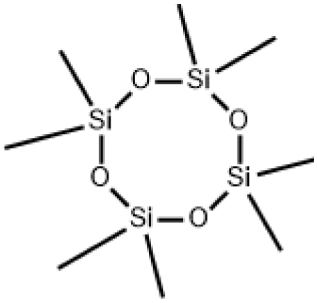
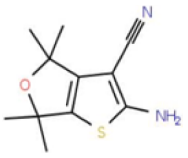
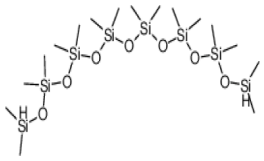
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Table 3 (*continued*)

S/N	Name	Chemical structure	RT	Area (%)	Previous reports of occurrence in plants	Potential applications	References
9.	2-Methyl-7-phenylindole		17.835	2.06	*Mangifera indica*	Antimicrobial, Anti-inflammatory, analgesic, antioxidant,	(Nwachukwu et al., 2022)
10.	Acetic acid, [4-(1,1-dimethylethyl) phenoxy]-, methyl ester		18.483	1.55	*Isolona campanulata*	Not found	(Adeniran et al., 2021)
11.	Oleic Acid		16.933	1.46	*Mimosa pudica* L.	Antibacterial, antioxidant	(Gandhi et al., 2023)
12.	Cycloheptasiloxane, tetradecamethyl-		11.130	1.11	*Chlorella vulgaris*	Antibacterial, antifungal, antitumor, antifouling	((El-fayoumy et al., 2021))
13.	Cyclotrisiloxane, hexamethyl-		4.172	0.25	*Breynia cernua*	Antibacterial, antioxidant	(Wiraswati et al., 2023)
14.	2,5-Dihydroxyacetophenone, bis (trimethylsilyl) ether		5.609	0.23	*Rumex crispus* L.	Antioxidant	(Saoudi et al., 2021)
15.	Cyclotrisiloxane, hexamethyl-		3.665	0.20	*Breynia cernua*	Antibacterial, antioxidant	(Wiraswati et al., 2023)

(*continued on next page*)

Table 3 (*continued*)

S/N	Name	Chemical structure	RT	Area (%)	Previous reports of occurrence in plants	Potential applications	References
16.	Benzenamine, 4-(2-phenylethenyl)-N-(3,5-dimethyl-1-pyrazolylmethyl)-		11.496	0.19	*Cyperus esculentus*	Antimicrobial	(Olukanni et al., 2022)
17	2,4,6-Cycloheptatrien-1-one, 3,5-bis-trimethylsilyl-		5.299	0.12	*Willughbeia edulis* Roxb.	Antibacterial, nematocidal, and used as a binder	(Sami, 2022)
18.	Cyclotetrasiloxane, octamethyl-		5.440	0.10	*Camellia sinensis*	Antibacterial,	(Hope et al., 2022)
19.	Thieno[2,3-c]furan-3-carbonitrile, 2-amino-4,6-dihydro-4,4,6,6-tetra methyl-		7.665	0.10	*Allium sativum* L., *Moringa oleifera* Lam.	Antioxidant, anticancer	(El-Fiki and Adly, 2020)
20.	Octasiloxane, 1,1,3,3,5,5,7,7,9,9, 11,11,13,13,15,15-hexadecamethyl-		10.201	0.10	*Linuim usitatissium*	Insecticidal	(Farag et al., 2021)

samples compared to ascorbic acid is as presented in Fig. 7. Ascorbic acid, displayed strong and increasing antioxidant activity across all concentrations, starting at 54.27 % at 6 mg/ml and reaching 88.83 % at 60 mg/ml. Among the waste samples, SNC1 exhibited the highest antioxidant activity. Starting at 39.32 % at 6 mg/ml, it increased consistently, reaching 62.34 % at 60 mg/ml. Despite not matching the efficacy of ascorbic acid, SNC1 showed substantial antioxidant properties, especially at higher concentrations. SNC2 displayed relatively stable antioxidant activity across all concentrations. Beginning at 47.40 % at 6 mg/ml, SNC2 slightly increased, reaching 49.56 % at 60 mg/ml. While SNC2 demonstrated moderate antioxidant activity, it did not show significant variation with increasing concentration. SNS showed moderate antioxidant activity, starting at 18.87 % at 6 mg/ml and increasing to 44.25 % at 60 mg/ml. SNWW exhibited the lowest antioxidant activity among the waste samples. Starting at 14.07 % at 6 mg/ml, its activity increased to 44.07 % at 60 mg/ml. While the antioxidant capacity of SNWW improved with concentration, it remained significantly lower compared to the other waste samples and the standard.

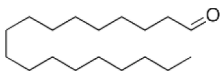
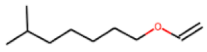
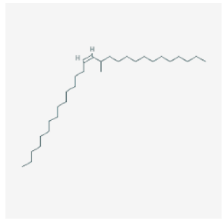
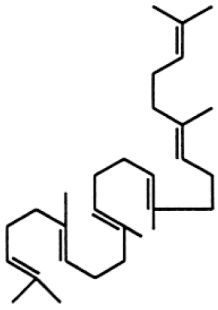
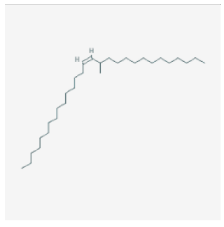
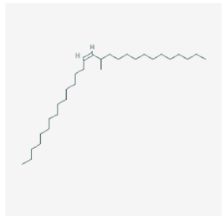
Comparatively, Olaitan et al. (2024), reported that the DPPH scavenging activity of orange peel extract was 35.77 % at 5 mg/ml and 54.494 % at 100 mg/ml. Although the concentrations differ, shea waste extracts like SNC1 (68.45 % at 60 mg/ml) demonstrate higher activity than orange peel extract at the highest concentration reported in their study. Similarly, Revathi et al. (2023) reported that *A. malabarica* displayed significant DPPH radical scavenging activity, with values ranging from 7.56 % at 15 mg/ml to 90.51 % at 90 mg/ml. In comparison, *C. procumbens* showed lower activity, with 69 % at 90 mg/ml. Shea waste extracts like SNC1 still exhibit notable activity, particularly at higher concentrations.

The antioxidant activity of shea wastes, assessed through various assays, demonstrated notable potential, with the highest activity observed in the SNC1 extract, showing 68.13 % FRAP at 60 mg/ml. The DPPH scavenging activities were also significant, particularly for SNC1. Compared to other studies, shea wastes generally exhibited moderate to high antioxidant activities, despite being tested at lower concentrations. These findings suggest that the shea wastes possess valuable antioxidant properties, highlighting their potential for further utilization in various applications.

Antidiabetic activities of the shea butter wastes

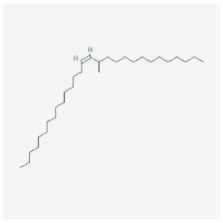
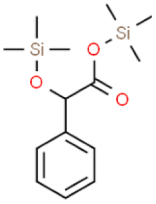
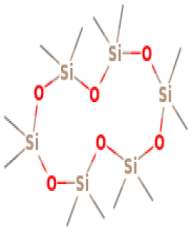
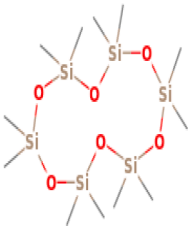
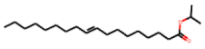
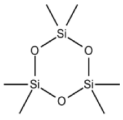
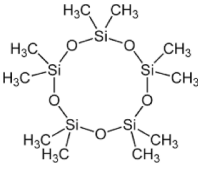
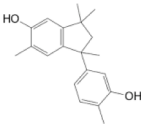
The antidiabetic activities of shea waste extracts were evaluated through their inhibition of alpha-amylase and compared to the standard antidiabetic drug, acarbose as shown in Fig. 8. Acarbose displayed vigorous and increasing α-amylase inhibitory activity with rising

Table 4
Bioactive compounds in SNWW.

S/N	Name	Chemical structure	RT	Area (%)	Previous reports of occurrence in plants	Potential applications	References
1.	Octadecanal		14.028	22.79	*Stachys betoniciflora*	Antioxidant	(Gad et al., 2022)
2.	13-Octadecenal, (Z)-		16.080	10.51	*Spilanthes filicaulis*	Antidiabetic	(Ojo et al., 2023)
3.	Octadecane, 1-(ethenyloxy)-		16.799	9.18	*Plumbago zeylanica* (Linn.)	Antimicrobial, antioxidant	(Gabriel et al., 2019)
4.	Tricosane		18.232	9.16	*Alkanna trichophila* var. *mardinensis*	Antimicrobial	(Kaplan and Çelikoğlu, 2020)
5.	13-Methyl-Z-14-nonacosene		15.004	7.80	*Ocimum basilicum*	Antioxidant	(Lawrence et al., 2023)
6.	Eicosane		17.994	6.83	*Marantodes pumilum*	Antioxidant	(Balachandran et al., 2023)
7.	Squalene		14.372	5.53	*Napoleonaea vogeli*	Antioxidant, antimicrobial,	(Oluseun et al., 2023)
8.	13-Methyl-Z-14-nonacosene		14.210	4.61	*Ocimum basilicum*	Antioxidant	(Lawrence et al., 2023)
9.	13-Methyl-Z-14-nonacosene		15.811	4.58	*Ocimum basilicum*	Antioxidant	(Lawrence et al., 2023)
10.	Trifluoroacetoxy hexadecane		14.691	4.35	*Cassia fistula* L.	Antimicrobial, anti-inflammatory	(Ferdosi et al., 2021)

(*continued on next page*)

Table 4 (*continued*)

S/N	Name	Chemical structure	RT	Area (%)	Previous reports of occurrence in plants	Potential applications	References
11.	1-Hexacosene		15.417	3.37	*Blighia sapida*	Antimicrobial, insecticidal, antioxidant	(Oloyede et al., 2023)
12.	13-Methyl-Z-14-nonacosene		15.611	3.29	*Ocimum basilicum*	Antioxidant	(Lawrence et al., 2023)
13.	2-[(p-Trimethylsilyl oxy)phenyl]-2-[(p-trimethylsilyl oxyethylenoxy)phenyl] propane		12.227	2.82	Cinnamon	Antimicrobial	(Ahuokpeme et al., 2020)
14.	1-Hexacosene		14.892	1.79	*Blighia sapida*	Antimicrobial, insecticidal, antioxidant	(Oloyede et al., 2023)
15.	Cycloheptasiloxane, tetradecamethyl-		11.138	1.05	*Chlorella vulgaris*	Antibacterial, antifungal, antitumor, antifouling	((El-fayoumy et al., 2021))
16.	Cyclohexasiloxane, dodecamethyl-		9.800	0.37	*Pithecellobium dulce*	Widely used in cosmetics	(Bobade, 2019)
17.	i-Propyl 9-tetradecenoate		11.401	0.36	Black Velvet Tamarind	antimicrobial	(Ololade et al., 2021)
18.	Cyclotrisiloxane, hexamethyl-		3.645	0.28	*Breynia cernua*	Antibacterial, antioxidant	(Wiraswati et al., 2023)
19.	Cyclopentasiloxane, decamethyl-		7.979	0.25	*Psidium guajava*	Antimicrobial	(Adetutu et al., 2021)
20.	1-(3-Hydroxy-4-methylphenyl)-1,3,3,6-tetramethylindan-5-ol		5.596	0.22	*Macrophomia phaseolus*	Antibacterial, antifungal	(Al-Rubaye et al., 2018)

concentrations. Starting at 44.12 % at 6 mg/ml, it reached 82.27 % at 60 mg/ml. This substantial increase highlights the potent antidiabetic activity of acarbose and serves as a benchmark for comparing the shea butter waste samples. SNC1 exhibited a significant increase in inhibitory activity from 9.072 % at 6 mg/ml to 84.54 % at 60 mg/ml. This steep rise, especially at higher concentrations, indicates strong antidiabetic properties, surpassing the standard at the highest concentration. SNC2 showed relatively lower initial activity at 5.98 % for 6 mg/ml, increasing

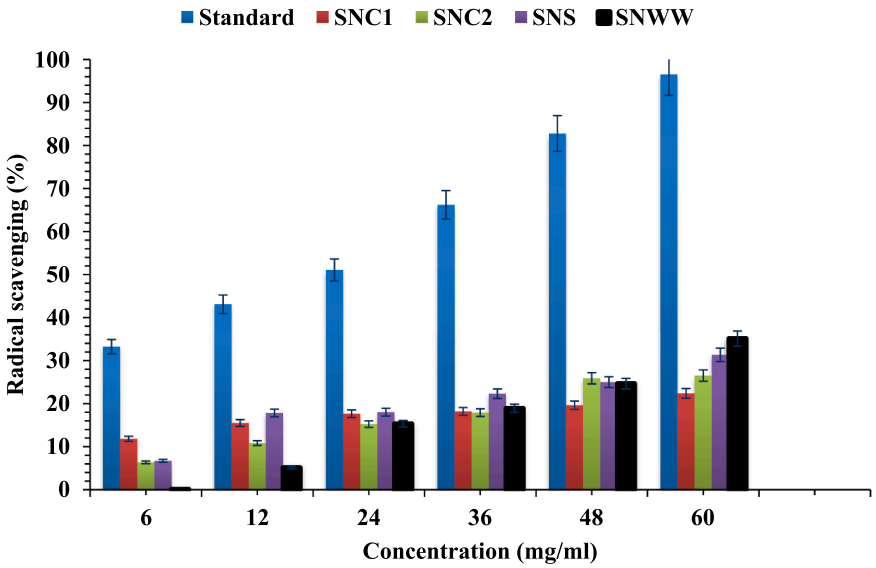


Fig. 4. Nitric oxide scavenging activities of the shea wastes.

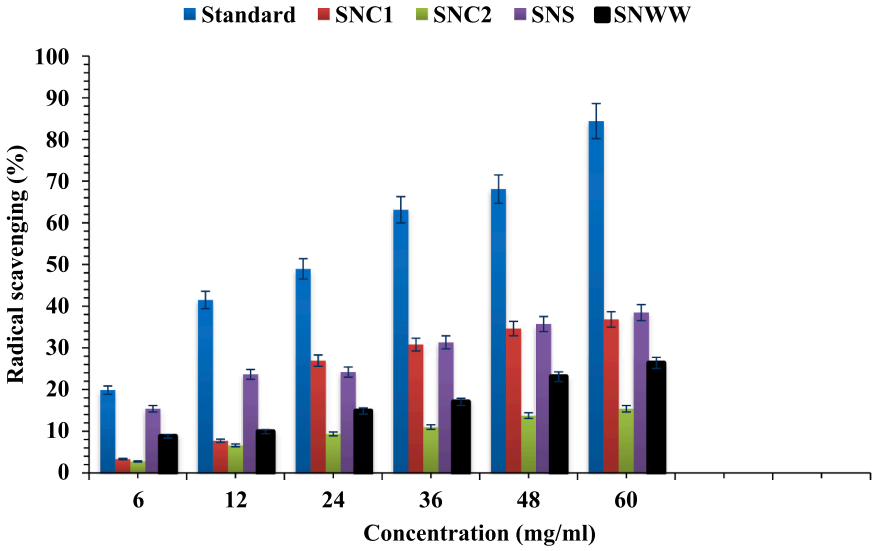


Fig. 5. H_2O_2 scavenging activities of the shea wastes.

to 20.41 % at 60 mg/ml. Although SNC2 exhibited the weakest antidiabetic activity among the waste samples, the consistent increase across concentrations suggests potential for further exploration and optimization. SNS demonstrated notable initial activity at 10.31 % at 6 mg/ml, rising significantly to 84.74 % at 60 mg/ml. This trend indicates that SNS possesses robust antidiabetic properties comparable to the standard at higher concentrations, making it a promising candidate for natural antidiabetic agent. SNWW had activity of 27.01 % at 6 mg/ml, reaching 68.45 % at 60 mg/ml. SNWW exhibited moderate antidiabetic activity, particularly at higher concentrations, indicating its potential as a natural antidiabetic source.

The results indicate that shea waste extracts, particularly SNC1 and SNS, exhibit strong α-amylase inhibition, comparable to or better than various medicinal plant extracts studied in the literature, despite being tested at lower concentrations. In a study by Ranjana and Jadhav (2019), the antidiabetic activity of *Aerva lanata* extracts was investigated, showing significant inhibition of up to 91 % at 100 mg/ml. Whereas, the antidiabetic activity of shea waste extracts concentration of 60 mg/ml showed a high activity of 84.54 %, suggesting that the antidiabetic potential of shea waste extracts, especially SNS is comparable to that of *Aerva lanata* extracts, even at lower concentrations. Similarly, Nisar et al. (2022) explored the antidiabetic effects of *Ficus carica* leaf extract, demonstrating inhibition rate of around 70 % at 50 mg/ml. Shea waste extracts, particularly SNS, SNC1, and SNWW exhibited higher activities at 60 mg/ml. The antidiabetic activities herein reported indicate the promising therapeutic potential of shea wastes in managing diabetes, as they could be formulated into functional supplements.

Shea butter wastes for circular bioeconomy

Many waste streams are produced throughout the shea butter production process, and these waste streams account for a sizable amount of the overall output. Together, the waste streams which include pulp, shell, and cake make up around 70 % of the weight of the wastes of shea butter (Mohammed et al., 2023). Notably, shea nut cake (SNC) makes up 40–55 % of the dry mass of mature shea tree fruits, and in mechanized processing facilities, where only roughly half of the product yield is processed, it frequently ends up as waste (Wei et al., 2019; Ibrahim et al., 2023). In view of the shea kernels input, the output includes approximately 34.4 % shea butter, 54.3 % shea cakes, and 11.3 % wastewater.

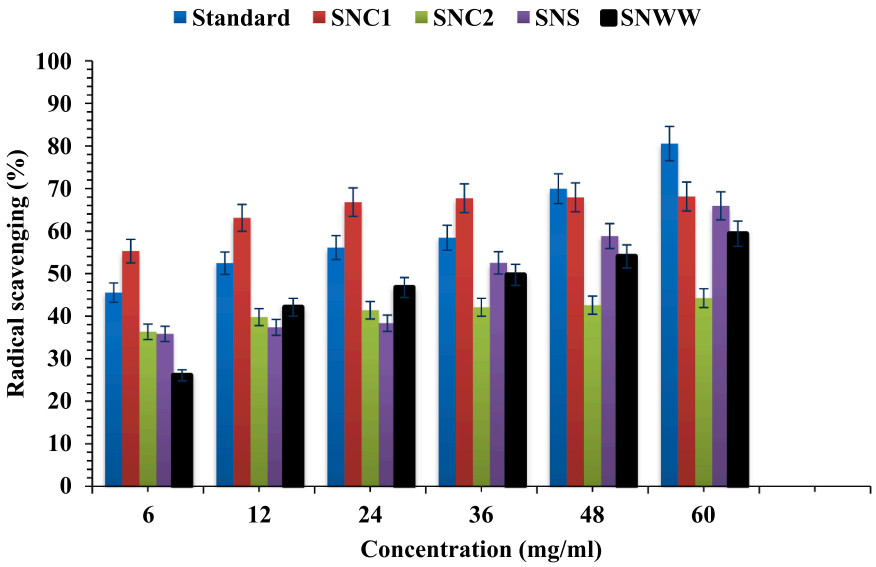


Fig. 6. FRAP activities of the shea wastes.

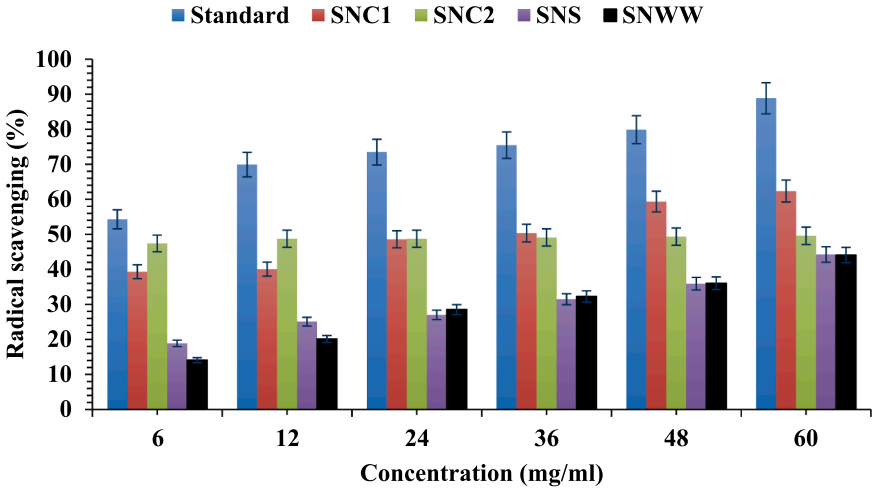


Fig. 7. DPPH scavenging activities of the shea wastes.

This breakdown highlights the significant proportions of shea cake and wastewater generated as wastes during the extraction process (Naangmenyele et al., 2023). Studies have also revealed the composition of shea butter waste, indicating that the amount of unsaponifiable matter ranges from 4 to 11 % by weight, with varying free fatty acid content up to 10.6 %, and an average moisture content ranging from 0.1 to 4.9 % (Bawah et al., 2019; Koudoro et al., 2022; Abdel-Razek et al., 2023).

Improper management of shea butter waste disposal can have negative impacts on the environment and nearby communities (Sulaiman and Adeoye, 2021; Ibrahim et al., 2023). Improper disposal methods, like burning or indiscriminate dumping of the wastes, can lead to air, soil, and water contamination, posing risks to ecosystems and human health (Sulaiman and Adeoye, 2021; Ibrahim et al., 2023). Burning of waste materials like shea nut cake can emit dangerous toxins into the environment, which can also exacerbates climate change and air pollution. Furthermore, inappropriate shea butter waste disposal can contaminate water and soil resources, affecting both human health and agricultural output (Sulaiman and Adeoye, 2021; Ibrahim et al., 2023). Moreover, the adverse effects of disposing of shea butter waste have far-reaching consequences for nearby populations and their means of living. Insufficient waste management techniques can lead to the depletion of precious resources and missed economic prospects. Improper disposal procedures of shea butter waste might worsen the detrimental effects of habitat degradation and biodiversity loss (Ibrahim et al., 2023). These consequences are illustrated in Fig. 9.

Owning to the chemical profiles and pharmacological properties of shea butter wastes, they represent precious resources that have great potential to contribute to circular bioeconomy. The circular bioeconomy concept emphasizes the sustainable management of resources, the reduction of wastes, and the addition of value through regenerative methods. It aligns with the principles of environmental conservation and economic viability (Capanoglu et al., 2022). The incorporation of shea butter wastes in this framework presents numerous attractive opportunities for circular bioeconomy practices. An important factor to consider is the composition of shea butter wastes, which consist of a range of organic components, fatty acids, and bioactive molecules that can be utilized for multiple purposes. This will help to reduce waste production and optimize the use of resources.

Research has shown that shea butter wastes have significant promise in a wide range of applications. For instance, the incorporation of Shea Solid Waste (SSW) into clay brick production showcases how the waste can be repurposed for sustainable construction materials (Adazabra et al., 2017; Doubi et al., 2017; Kouamé et al., 2020; Kouamé et al.,

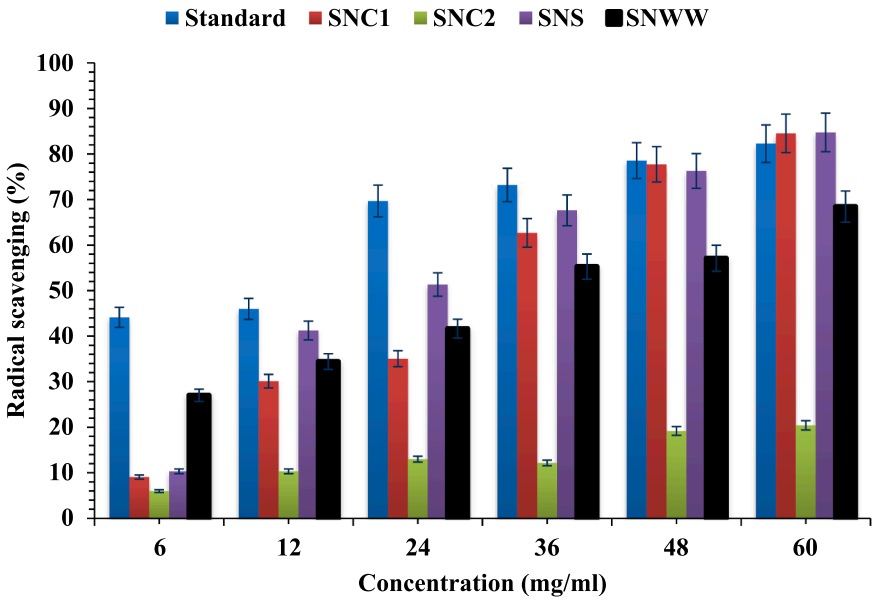


Fig. 8. Anti-diabetic activities of the shea wastes.

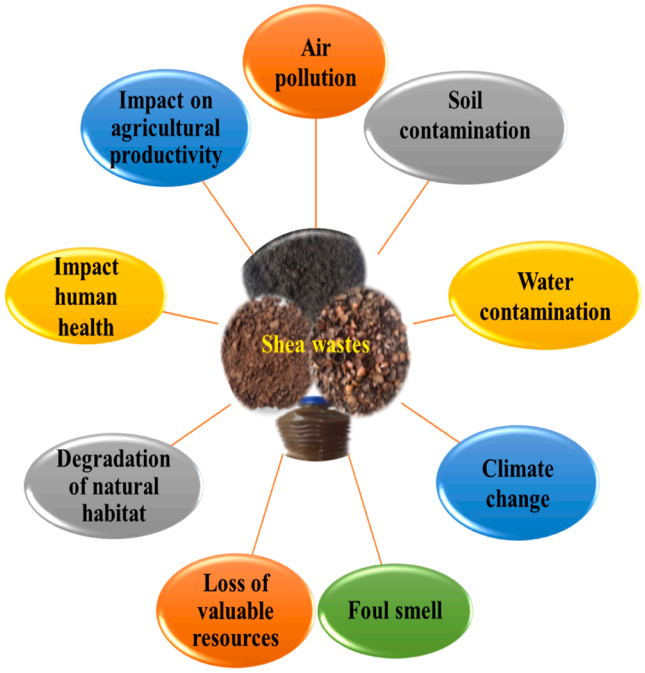


Fig. 9. Negative impact of wastes generated during the production of shea butter.

2021), addressing waste management concerns while promoting eco-friendly building practices. Additionally, Shea Waste Slurry (SWS) has been utilized as an organic soil amendment (Abagale et al., 2020), leading to improvements in soil fertility and agricultural productivity.

In addition, this work presents a thorough analysis of the chemical constituents present in shea butter wastes, indicating the existence of multiple untapped therapeutic potentials. The shea wastes have shown notable antioxidant activities, suggesting a considerable capacity to counteract oxidative stress. Furthermore, the noteworthy antidiabetic activity highlights the potential utilization of shea butter wastes in the management of diabetes. Although there is limited specific data on the pharmacological significance of certain compounds, their structural characteristics suggest possible biological activity that justifies further exploration. Through the application of nanotechnology and biotechnological methods, such as fermentation and bioconversion, it is feasible to transform wastes of shea butter into valuable bioproducts. These include additives found in cosmetics, nutritional supplements, biopesticides, biofuels, biopolymers, nutraceuticals, and substances that may have antioxidant and antidiabetic properties.

Shea butter wastes for the attainment of SDGs

The vast potential utilization of the shea butter wastes can be employed to advance the goals of the UN sustainable development agenda 2030. The incorporation of shea butter wastes into cosmetic additives is in line with Sustainable Development Goal 12 (SDG 12), which promotes responsible consumption and production practices in the beauty industry. This entails the reduction of waste production and the promotion of the utilization of natural, biodegradable components, thereby making a positive contribution to environmental sustainability. Supplements generated from the discarded shea butter can contribute to the advancement of Sustainable Development Goal 3 by providing possible health advantages through bioactive components, promoting overall well-being and nutritional health. Utilizing shea butter wastes to produce bioinsecticides and biopesticides supports SDG 15 by fostering sustainable agriculture methods, decreasing dependence on artificial pesticides, and mitigating damage to ecosystems and biodiversity.

Utilizing shea butter wastes for biofuel production aligns with SDG 7, providing an alternative, renewable energy source that mitigates greenhouse gas emissions and reduction of dependence on fossil fuels. The utilization of shea butter wastes to produce organic acids and biopolymers aligns with SDG 9 by promoting inventive approaches in the creation of sustainable materials and procedures, hence aiding the advancement of environmental-friendly industrial practices and infrastructure. Shea butter waste-derived nutraceuticals would support SDG 2 by offering nutrient-dense supplements and functional foods, which may help to combat hunger and enhance food security. The various uses of shea butter wastes demonstrate the potential in sustainable waste management and resource exploitation, providing economic opportunities and diversity within the shea butter sector. Thus, valorization of shea butter wastes has potential applications in different areas as advanced in Fig. 10.

Utilizing shea butter wastes offers multiple advantages in terms of environmental sustainability. It effectively manages wastes and reduces pollution by converting them into valuable bioproducts. This practice



Fig. 10. Valorization of shea wastes for different applications in agriculture, renewable energy, pharmaceutics and cosmetics.

also helps to maintain cleaner ecosystems and minimizes the negative impacts on soil, water, and air quality. Additionally, it aids in the preservation of natural resources by decreasing the need for fresh raw materials, so promoting resource conservation and sustainable resource management.

From an economic perspective, the utilization of shea butter wastes presents various prospects, including the establishment of new industries, job creation, and the diversification of revenue streams. These outcomes contribute to the development of resilience and economic advancement. Furthermore, by infusing shea butter wastes into various businesses, the total economic resilience is enhanced. The utilization of shea butter waste can promote the implementation of sustainable practices in diverse businesses. This is in line with global sustainability objectives and encourages responsible patterns of consumption and production. Through the implementation of waste reduction strategies and efficient resource management, we can actively contribute to the efforts aimed at reducing wastes and relieving the burden on waste disposal systems and landfills. Moreover, the economic endeavors linked to the utilization of shea butter wastes can bring advantages to the local communities. These encompass employment prospects, enhancement of skills, and enhanced quality of life, resulting in the advancement of communities and the empowerment of individuals.

Conclusion

The analysis of bioactive chemicals in the four shea butter wastes has yielded useful knowledge regarding the potential uses and advantages of these natural resources. This study emphasizes the considerable potential of shea butter wastes in promoting a circular bioeconomy and sustainable exploitation of resources. The wide range of chemicals discovered through phytochemical investigation highlights the unexplored medicinal possibilities of shea butter wastes. Notably, the antioxidant activities demonstrated by shea wastes indicate their potential in combating oxidative stress. Additionally, the promising antidiabetic activities underscore the potential use of shea butter wastes in managing diabetes. Biotechnological methods, such as fermentation and bioconversion, can be used to extract useful bioproducts from shea butter wastes. These bioproducts include additives for cosmetics, bioinsecticides, biopesticides, biofuels, organic acids, biopolymers, nutraceuticals, and potential antioxidant and anti-diabetic agents. These applications are in line with the Sustainable Development Goals (SDGs) and provide economic opportunities while advocating for ethical consumption and production practices. By making use of the shea butter wastes, the practice would not only be beneficial to the environment by reducing waste generation and pollution, but it can contribute to economic growth, community development, and improvements in health and well-being.

CRediT authorship contribution statement

B.O. Yusuf-Salihu: Writing – original draft, Visualization, Resources, Methodology, Investigation, Funding acquisition, Formal analysis. **A. Lateef:** Writing – review & editing, Validation, Supervision, Data curation, Conceptualization. **L. Azeez:** Writing – review & editing, Visualization, Software, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Data availability

Data will be made available on request.

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