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Comparative Phytochemical Profiling and FT-IR Analysis of *Artemisia annua* (L.) Varieties from Nigeria, China and Brazil: Insights into Bioactive Compounds and Functional Group Diversity

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Abstract

This study presents a comprehensive phytochemical screening of three varieties of *A. annua* sourced from Nigeria, China and Brazil. Utilizing GC-MS and FT-IR techniques, the phytochemical composition and functional groups of each variety were analyzed. GC-MS analysis identified 38, 31 and 48 compounds in the Nigerian, Brazilian and Chinese varieties, respectively, highlighting a diverse array of bioactive compounds. FT-IR analysis revealed complex phytochemical profiles for the Brazilian and Nigerian varieties, indicating the existence of aromatics, alkanes, hydroxyl groups', ketones, alkenes and esters. The FT-IR spectra for the Nigerian and Chinese varieties indicated additional functional groups, including nitro compounds and thiols, not observed in the Brazillian variety. Despite these differences, all varieties exhibited common functional groups' like C-O, C-H and C=O stretches, suggesting that hydrocarbons, oxygen containing compounds and carbonyl groups' were present. This comparative research offers significant understanding into the diversity of phytochemicals present in *A. annua* across different geographical locations, underpinning its potential pharmacological and medicinal applications.

Keywords: *A. annua,* Bioactive compounds, Functional groups, Pharmacological potential, Phytochemical screening

Introduction

A. annua (Linn), also called as 'sweet wormwood' and in Chinese known as 'qinghao', has attracted considerable interest because of its powerful bioactive compounds, particularly artemisinin, which is a cornerstone in malaria treatment (Das *et al.*, 2023). The plant is a member of the Asteraceae family and is widely distributed across the five continents namely; Asia, Europe, North America and Africa (Riggins and Seigler, 2012; Liu *et al.*, 2023). *A. Annua's* therapeutic potential extends beyond its antimalarial properties; it includes antiviral, antibacterial and anticancer activities, making it a subject of extensive phytochemical and pharmacological research (Sadiq *et al.*, 2014; Anibogwu *et al.*, 2021; Kumar *et al.*, 2024).

Anibogwu *et al.* (2021) reported that phytochemical composition of *A. annua* is known to vary significantly depending on its geographical origin, cultivation conditions and genetic factors, this variability can influence the concentration and efficacy of its bioactive compounds. In this study, we focus on comparing the phytochemical profiles of crude plant extracts of *A. annua* varieties from three distinct regions: Nigeria, China and Brazil. These countries were selected due to their diverse climatic conditions and their distinct traditional uses of the plant. Nigeria, with its tropical climate, provides a unique environment that could influence the phytochemical profile of the plant (Atawodi *et al.*, 2017; Ungogo *et al.*, 2020). China, with its long history of using *A. annua* in traditional medicine, provides a deep historical background for the plant's medicinal applications

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(Liu *et al.*, 2013; Ekiert *et al.*, 2021). Brazil, with its vast and varied ecosystems, presents another unique setting for the *A. annua* cultivation (Ferreira *et al.*, 2005; Wang *et al.*, 2022).

For a thorough comparative analysis, we utilize advanced analytical methods including Gas Chromatography-Mass Spectrometry (GC-MS) and Fourier Transform Infrared Spectroscopy (FTIR). GC-MS is effective in identifying and quantifying volatile and semi-volatile compounds by integrating gas-liquid chromatography with mass spectrometry, enabling the identification of different substances within a sample (Maji *et al.*, 2023). FTIR, on the other hand, captures the infrared spectrum of absorption or emission from solids, liquids, or gases to reveal molecular composition and structure, crucial for assessing the functional groups present in phytochemicals (Nsofor *et al.*, 2023).

Understanding the phytochemical diversity of *A. annua* from different regions can have significant implications for its use in traditional and modern medicine. A part from identifying the specific phytochemicals contents present in each variety that contributes to the plant's antimalarial activity, or aid in the development of more effective treatments. Moreover, recognizing the compounds responsible for other therapeutic effects can expand the medicinal uses of *A. annua*, likely paving the way for the identification of novel drugs.

This research aimed to ascertain, compare and assess the phytochemical profiles of *A. annua* from Nigeria, China and Brazil, to understand how geographical and environmental factors influence their composition and therapeutic potential. The findings of this research might contain considerable repercussion towards fields of pharmacology, agriculture and traditional medication, ultimately contributing to the improved use and conservation of *A. annua*. Furthermore, this study could contribute to the optimization of cultivation practices. By understanding how different environmental conditions affect the phytochemical profile of *A. annua*, farmers and researchers can develop strategies to cultivate the plant in a way that maximizes its therapeutic potential. This could involve selecting specific strains for cultivation in particular regions or adjusting farming practices to enhance the concentration of desired phytochemicals.

Materials and Methods

The Experimental Location

The research encompassed both field and laboratory work conducted between 2022 and 2023. Fieldwork involved the collection of *A. annua* samples, while laboratory activities were conducted at the Biological Sciences laboratories of Federal University Dutsinma and Umaru Musa Yar'adua University Central Laboratory, Katsina (UMYUK). Laboratory protocols included the preparation and phytochemical screening of the test plant, identification of functional groups and prediction of biological activity of plant extracts.

Collection and Identification of A. annua Varieties (Nigerian, Chinese and Brazilian)

In the collection and identification phase, three varieties of *A. annua* (Nigerian, Chinese and Brazilian) were collected from the Institute of Agricultural Research, ABU Zaria and Katsina State Afforestation Project Unit (KTAPU). They were subsequently deposited in the Herbarium, Biology Department, Umaru Musa Yar'adua University Katsina-Nigeria; where a taxonomist authenticated them with voucher No: BIO/UMYU/HBV/45321-3. In the lab, whole plants were air-dried and pulverised with a mortar and pestle to get its powder. The resulting powder was collected and kept in a dark container between 20-25 °C environments prior to use (Fayaz *et al.*, 2011).

Procedure for the Extraction of A. Annua Whole Plant

For each 100 g portion of *A. annua* powder, 500 ml of absolute Methanol was added and extraction was carried out using a Soxhlet extractor for six (6) hours (Fayaz *et al.*, 2011). The resultant extract underwent filtration utilising a filter paper (Whatman® No. 1) and the excess solvent was evaporated using an evaporating dish. A portion of filtrate was retained as crude extract. Subsequently, the crude extracts were dried at 40 °C using a water bath. The weight of the dried extracts were determined and stored at 4 °C prior to use (Kawo and Kwa, 2011).

Sterility Testing of the Extracts

The procedure outlined by Ekpiken *et al.* (2023) was followed. About 1 ml of each extract was added to a separate tube containing 5 ml of sterilised broth (nutrient), incubated at 37±1 °C for 24 hours. The extracts were confirmed to be sterile if the broth remained clear and showed no turbidity after the incubation.

GC-MS Analysis of Three Varieties of A. annua

GC-MS was engaged to define the phytochemical constituents of three distinct varieties of *A. annua*: Nigerian, Chinese and Brazilian. The GCMS-QP2010Plus Shimadzu Japan instrument was utilized under specified conditions as outlined by the manufacturer. The instrument underwent a rigorous cleaning protocol, including five rinses with pre-solvent, post-solvent and sample solvent respectively. The plunger speed during suction and injection was set to "High", with a viscosity compensation time of 0.2 sec. Injection was carried out in normal mode, with the injection temperature maintained at 250.00 °C. The column oven temperature was set to 60.00 °C, with a flow control mode of linear velocity and a pressure of 100.2 kPa. The GCMS operated in scan mode with a scan speed of 1428, scanning a mass range from 40.00 to 700 m/z. The phytochemical detection and relative percentage amounts of each component were automatically generated by the machine using its mass spectrophotometer and NIST Ver.6.0-Year 2019 library. Interpretation of the GC-MS results utilized the extensive NIST database containing over 62,000 patterns, enabling the identification of component names, molecular weights and structures within the test materials (Daskum *et al.*, 2020).

FT-IR Analysis of A. annua Extracts

FTIR analysis was conducted on extracts of Nigerian, Chinese and Brazilian *A. annua* using the Agilent Cary 630 FTIR spectrometer system. The system was interfaced with

an attenuated total reflection (ATR) and single reflection diamond (SRD) operated under specified conditions as outlined by its manufacturer.

The analysis utilized a library search method with the user-generated Phytochemical compounds library provided by Agilent. Spectra were recorded under the following conditions:

✓ Spectral range: 4,000 to 650 cm^{-1}

✓ Background scans: 32

✓ Spectral resolutions: 4 cm^{-1}

Background collection was performed in air and confidence levels for peak identification were color-coded as green (high confidence; >0.90), yellow (medium confidence; 0.80-0.90) and red (low confidence; <0.80). Characteristic peaks and functional groups present in the FTIR spectra were identified and interpreted according to established methodologies (Nandiyanto *et al.*, 2019).

Results and Discussion

The GC-MS Analysis of Three Varieties of A. Annua

The examination of compounds within the crude methanolic extracts of three *A. annua* varieties (whole plant) was performed by GC-MS, resulting in comprehensive findings outlined in table 1. The chromatograms of the GC-MS results illustrating distinct peaks of 38, 31 and 49 compounds for the Nigerian, Brazilian and Chinese varieties, respectively, are visually depicted in figure 1. The chromatographic profiles

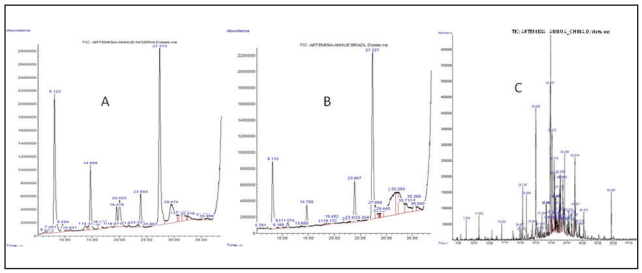

Figure 1: depicting the GC-MS chromatograms profiling methanolic extracts of three *A. Annua* varieties from (A) Nigeria, (B) Brazil and (C) China

revealed a multitude of phytochemical identified in the methanolic extracts of *A. annua*. Detailed characterization of the major peaks observed in the chromatograms facilitated the identification of individual components corresponding to each peak. The compounds, along with their respective components were carefully determined and documented in table 1.

The examination of *A. annua* methanolic extracts from Nigeria, Brazil and China using GC-MS identified various phytochemicals, as summarized in table 1. The compounds are characterized by their retention time (RT), area percentage, molecular formula and weight. The detailed interpretation of the significant findings of the major phytochemical compounds identified were categorised into high abundance, moderate and low abundance compounds.

The high abundance compounds are 2-Cyclohexen-1-one (RT = 8.1219, Area Pct = 20.8696%): This compound is the most abundant in the extract, indicating its significant presence and potential importance in the pharmacological activity of *Artemisia annua*. Its molecular formula is $C_{10}H_{16}O$ and has a molecular weight of 152.23 g mol^{-1}, 9,17-Octadecadienal (RT = 27.3733, Area Pct = 31.2904%). This compound has the highest area percentage, suggesting a prominent role. With a molecular formula of $C_{18}H_{32}O$ additionally molecular weight of 264.5 g mol^{-1}, it is likely a major contributor to the biological properties of the extract and 9,12-Octadecadienal (RT = 29.4744, Area Pct = 10.3117%): Another highly abundant compound, similar in structure to 9,17-Octadecadienal, sharing the same molecular formula and weight, indicating its significant presence. 2-Cyclohexen-1-one, 9,17-Octadecadienal, or linoleic aldehyde and 9,12-Octadecadienal all demonstrates antimicrobial, anti-inflammatory, antioxidant and potential anticancer activities. Its diverse bioactivities make them valuable in pharmaceutical, cosmetic and food industries and also in potential therapeutic uses (Fialová *et al.*, 2021; Michalak *et al.*, 2021).

The moderate abundance compounds identified are; Hexadecanoic acid (RT = 23.8928, Area Pct = 4.7565%), commonly known as palmitic acid, this saturated fatty acid ($C_{16}H_{32}O_2$, 256.42 g mol^{-1}) is prevalent in many natural sources and is identified for its ability to combat microbes (Michalak *et al.*, 2021). (S,E)-6-Hydroxy-6-methyl-2-((2S,5R)-5-methyl-5-vinyl tetrahydrofuran-2-yl)hept-4-en-3-one (RT = 20.0198, Area Pct = 5.5935%): A complex molecule ($C_{15}H_{24}O_3$, 252.34 g mol^{-1}) potentially contributing to the extract's bioactivity (Wan *et al.*, 2013) and Methyl tetradecanoate (RT = 19.4795, Area Pct = 2.6203%): This methyl ester ($C_{15}H_{30}O_2$, 242.39 g mol^{-1}) may have significant biological activities (Fialová *et al.*, 2021). The Deoxyartemisinin (RT = 23.697, Area Pct = 1.327%): This Deoxyartemisinin ($C_{15}H_{22}O_4$, 266.33 g mol^{-1}) has very significant antimalarial activities (Okhale *et al.*, 2022).

Accordingly, low abundance compounds are: 3-Octyne, 5-methyl- (RT = 6.5271, Area Pct = 0.5146%): An alkyne compound (C_9H_{16}, 124.22 g mol^{-1}) present in minor quantities, Cyclobutane acetonitrile (RT = 7.0891, Area Pct = 0.6908%): This nitrile compound ($C_{10}H_{15}N$, 149.23 g mol^{-1}) may have specific roles despite its low concentration, 1,3-Pentadiene (RT = 7.291, Area Pct = 0.5416%): A simple diene (C_5H_8, 68.12 g mol^{-1}), indicative of potential reactivity and interactions with other compounds, 3-Cyclopropenoic acid (RT = 14.3711, Area Pct = 0.4694%): having a molecular formula of $C_4H_4O_2$ and a weight of 84.07 g mol^{-1}, the substance is found in low amounts, but may be of interest due to its unique structure, Oleic acid: Detected at multiple retention times (RT = 21.6534, 30.6989, 31.5663) with varying area percentages (0.2823%, 1.0947%, 2.1599%), this monounsaturated fatty acid ($C_{18}H_{34}O_2$, 282.47 g mol^{-1}) and are well-known for their health benefits and potential biological activities (Sadiq *et al.*, 2014).

Also, various other compounds were detected in trace amounts, each contributing to the overall chemical profile of the methanolic extract. These include unique structures, such as 1H-3a,7-Methanoazulene (RT = 16.4332, Area Pct

= 1.4087%) and 2-Methyl-Z,Z-3,13-octadecadienol (RT = 18.2903, Area Pct = 0.0826%), which may have specific pharmacological or toxicological significance. Artennuic acid (RT = 13.795, Area Pct = 0.107%). Li *et al.* (2018) found that existence of these trace substances in *A. annua* extracts reduced parasitemia by about 93%, showing synergistic effects.

Table 1, lists the major phytochemicals identified in a crude *A. annua* methanolic extract from Brazil, identified by GC-MS. Each compound is characterized by its retention time (RT), percentage area and corresponding chemical identification along with its molecular formula and molecular weight.

Bicyclo[2.2.1]heptan-2-one ($C_{10}H_{16}O$): Detected with a low area percentage (0.1448%) and molecular weight of 152.23 g mol^{-1}. This compound, identified at a retention time of 5.448 minutes, contributes minimally to the overall composition of the extract. 2-(2-Methoxyethoxy) ethanol ($C_5H_{12}O_3$): With an area percentage of 0.0534% and a molecular weight of 120.15 g mol^{-1}, it was detected at a retention time of 5.7815 minutes, indicating a very minor presence. The Bicyclo[2.2.1] heptan-2-one has antimicrobial and insecticidal properties and potentially anti-inflammatory effects, contributing minimally to the overall composition of the extract but adding specific bioactivities (Batiha *et al.*, 2020; Zhang *et al.*, 2022). 2-(2-Methoxyethoxy)ethanol is primarily used for its solvent properties and its ability to enhance the permeability and delivery of other compounds, making it valuable in pharmaceutical and cosmetic applications despite its minor presence (Sabaghi *et al.*, 2022).

2-Cyclohexen-1-one (C_6H_8O): This compound, notable for its significant presence with an area percentage of 11.3446%, was identified at a retention time of 8.1146 minutes. With a molecular weight of 96.13 g mol^{-1}, it is a major component of the extract. Spiro[2.3]hexan-4-one (C_6H_8O): Also having a molecular weight of 96.13 g mol^{-1}, it was identified with a lower area percentage of 0.0852% at a retention time of 9.1685 minutes. Fatty acids and their derivatives: A variety of fatty acids, such as decanoic acid ($C_{10}H_{20}O_2$, 172.26 g mol^{-1}), dodecanoic acid ($C_{12}H_{24}O_2$, 200.32 g mol^{-1}), hexadecanoic acid ($C_{16}H_{32}O_2$, 256.42 g mol^{-1}) and were identified. These diverse compounds exhibit a variety of biological activities, such as antimicrobial, antioxidant, anticancer and anti inflammatory properties as well as neuroprotective effects (Namasudra *et al.*, 2021). These properties make tem valuable compounds for potential therapeutic applications in treating infections, cancers, inflammatory diseases and neurodegenerative conditions (Trivedi and Thumar, 2022).

Oleic acid ($C_{18}H_{34}O_2$, 282.47 g mol^{-1}), in particular, was found in substantial quantities with multiple entries across various retention times, it contributes to the plant's therapeutic properties through its antiparasitic, anti-inflammatory, immunomodulatory and synergistic effects (Virendra *et al.*, 2022). These activities enhance the plant's effectiveness in treating malaria and other related conditions, complementing the action of artemisinin and other active compounds (Ishaq *et al.*, 2023). 9,12-Octadecadienoic acid (Z,Z)- ($C_{18}H_{32}O_2$): With the highest area percentage of 29.2173%, this substance, commonly known as linoleic acid, is a major constituent, reflecting the potential nutritional and therapeutic value of the extract (Bauman *et al.*, 2020).

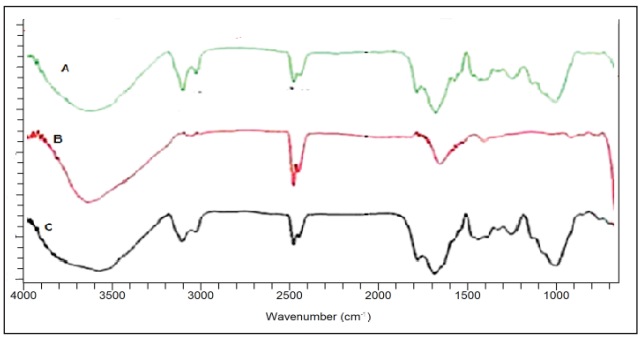

Figure 2: Illustrating the FT-IR Spectra of methanolic extracts of three varieties of *A. Annua* from (A) Nigeria, (B) Brazil and (C) China

Other notable compounds: Included are propanephosphonic acid ($C_3H_9O_3P$, 124.08 g mol^{-1}), 5-Bromo-3-nitro-1H-1,2,4-triazole ($C_2HBrN_3O_2$, 197.95 g mol^{-1}) and methyl tetradecanoate ($C_{15}H_{30}O_2$, 242.40 g mol^{-1}), among others. These compounds contribute to the chemical diversity of the extract (Anibogwu *et al.*, 2021).

The GC-MS investigation of the *A. annua* methanolic extract from China identified a various array of phytochemical compounds, each characterized by its retention time (RT), area percentage (Area Pct), molecular formula and molecular weight (Table 1). The detailed interpretations of the significant findings were presented as high, moderate, low and trace abundance compounds.

The high abundance compounds identified are; l-(+)-Ascorbic acid 2,6-dihexadecanoate (RT = 15.275, molecular formula: $C_{38}H_{68}O_8$, molecular weight: 652): This compound is a major constituent with significant area percentage, indicating its prominent presence. It is a derivative of ascorbic acid, renowned for its antioxidative capabilities (Sekar *et al.*, 2023; Mancuello *et al.*, 2024). Another highly abundant compound is Ingol-12-acetate (RT = 12.007, molecular formula: $C_{22}H_{32}O_7$, molecular weight: 408) which is likely contributing to the extract's bioactivity through its anti inflammatory and anticancer capabilities (Wang *et al.*, 2022).

Moderate abundance compounds found here are Cholestan-3-ol, 2-methylene-(3ß,5α) (RT = 3.739 and 11.670, molecular formula: $C_{28}H_{48}O$, molecular weight: 400): This sterol derivative appears twice in the analysis, suggesting a significant role in the extract's overall chemical profile (Fatima *et al.*, 2020). 9,12,15-Octadecatrienoic acid, 2,3-dihydroxypropyl ester (Z,Z,Z) (RT = 16.648, molecular formula: $C_{21}H_{36}O_4$, molecular weight: 352): An omega-3 fatty acid ester, which is known for its anti-inflammatory and cardio protective effects (Oppedisano *et al.*, 2020).

Low abundance compounds are 1,2-15,16-Diepoxyhexadecane (RT = 3.173, Area Pct = 0.1448%, molecular formula: $C_{16}H_{30}O_2$, molecular weight: 254): Present in minor quantities, but notable for its potential reactivity due to the epoxide groups and Cholestan-3-ol, 2-methylene-

(3ß,5α) (RT = 3.739, molecular formula: $C_{28}H_{48}O$, molecular weight: 400): This compound, detected in low amounts, could be critical in the sterol biosynthesis pathway (Bernardi *et al.*, 2021). The Cyclohexanone, 2,2-dimethyl-5-(3-methyloxiranyl)- (RT = 9.804, molecular formula: $C_{11}H_{18}O_2$, molecular weight: 182): An oxiranyl derivative present in low amounts, which may have unique biochemical properties (Ikhane *et al.*, 2024). Also, the detected compounds in trace quantities are Geranyl vinyl ether (RT = 9.621, molecular formula: $C_{12}H_{20}O$, molecular weight: 180): A trace compound with potential roles in plant defense mechanisms (Anibogwu *et al.*, 2021), Lupeol (RT = 20.327, molecular formula: $C_{30}H_{50}O$, molecular weight: 426): This triterpenoid is known for its anti-inflammatory and anti-cancer activities, albeit present in trace amounts and (+)-γ-Tocopherol, O-methyl (RT = 26.495, molecular formula: $C_{29}H_{50}O_2$, molecular weight: 430): A form of vitamin E, suggesting antioxidant properties (Anibogwu *et al.*, 2021; Liu *et al.*, 2023).

The comparative analysis of the methanolic extracts of *A. annua* from Nigeria, Brazil and China revealed significant phytochemical diversity. In Nigeria, high abundance compounds identified included 2-Cyclohexen-1-one, 9,17-Octadecadienal and Dodecanoic acid. Brazil's extract featured major compounds, such as Oleic acid, 2-Cyclohexen-1-one and 9,12-Octadecadienoic acid (Z,Z)-. Meanwhile, China's extract was notable for prominent constituents like l-(+)-Ascorbic acid 2,6-dihexadecanoate and Ingol-12-acetate. Each extract's unique chemical profile suggests distinct potential pharmacological activities (Fatima *et al.*, 2020; Azad *et al.*, 2023).

Oleic acid, Deoxyartemisinin and camphor were the common compound detected in all three extracts. Both Nigeria and Brazil shared compounds such as 2-Cyclohexen-1-one, Dodecanoic acid and Methyl tetradecanoate. Unique to Nigeria's extract were 9,17-Octadecadienal and 9,12-Octadecadienal and Arteannuic acid, both with high percentage yields except Arteannuic acid in a trace. Brazil's extract was characterized by a high percentage of 9,12-Octadecadienoic acid (Z,Z)- and Oleic Acid, while China's extract featured unique compounds like 1,2-15,16-Diepoxyhexadecane and (+)-γ-Tocopherol, O-methyl.

The major compounds by area percentage for Nigeria included 9,17-Octadecadienal (31.29%) and 9,12-Octadecadienal (10.31%). For Brazil, the dominant compounds were 9,12-Octadecadienoic acid (Z,Z)- (29.22%) and Oleic Acid (16.81%). China's extract was notable for its high percentage of (+)-γ-Tocopherol, O-methyl, highlighting the unique chemical contributions of each regional extract of *Artemisia annua* (Anibogwu *et al.*, 2021).

FT-IR Analysis of A. annua Extracts from Nigeria, Brazil and China

The FT-IR spectra of *A. annua* extracts from Nigeria, Brazil and China were analyzed to identify and compare the functional groups present in these samples. The comparative analysis is presented in figure 2 and table 2, highlighting the spectra, peak values, their corresponding intensities and the functional group assignments.

The Comparative FT-IR Analysis of Artemisia annua Varieties

The FT-IR analysis of methanolic extracts from *Artemisia annua* varieties cultivated in Nigeria, Brazil and China reveals significant insights into the phytochemical composition of these plants. The similarities and differences in functional group assignments and their concentrations among the three varieties are discussed below.

For similarities in functional group assignments; C-O stretch (ethers and alcohols) were found at peak 2 and 3. All three varieties show peaks in the C-O stretch region, indicative of the presence of ethers and alcohols. Specifically, the peaks at 1021.29 cm^{-1} (Nigeria and Brazil) and 1159.2 cm^{-1} (Nigeria and Brazil) fall within the expected range for these functional groups (1090-1020 cm^{-1} and 1190-1130 cm^{-1}, respectively). This suggests a shared chemical foundation in their composition, which includes compounds such as simple ethers and alcohols. These phytochemicals aid in the plant's antimicrobial and anti-inflammatory properties (Shinyuy *et al.*, 2023). C-H bend (alkanes) was detected at peak 5. The Nigerian and Brazilian varieties both exhibit a peak at 1367.93 cm^{-1}, corresponding to C-H bending vibrations in alkanes. The group frequency for these vibrations typically lies between 1370-1365 cm^{-1}. According to Nyalo (2022) reported that the presence of alkanes, which are hydrocarbon chains, indicates a common structural aspect in plants, contributing to the stability and integrity of their phytochemical profile.

The C=C stretch (alkenes and aromatic compounds) was presented at peak 7 and 8: Both Nigerian and Brazilian varieties show peaks around 1509.57 cm^{-1} and 1606.48 cm^{-1}, signifying the presence of alkenes and aromatic complex. The group frequencies for these stretches are within the spectrum of 1555-1485 cm^{-1} and 1650-1600 cm^{-1}, respectively. Alkenes and aromatic compounds are crucial for the plant's bioactivities, plus antioxidative and antimicrobial efficacies (Ailli *et al.*, 2023; Kumar *et al.*, 2024). This shared feature suggests similar potential therapeutic applications.

Also, C=O stretch (ketones and aldehydes) was spotted at peak 9: The Nigerian and Brazilian varieties both exhibit a peak at 1654.94 cm^{-1}, which is suggestive of C=O stretching ambiences found in ketones and aldehydes. These vibrations typically occur between 1760-1660 cm^{-1}. Ketones and aldehydes are often involved in metabolic processes and have roles in anti-oxidative mechanisms as describe by Ge *et al.* (2022), suggesting a common functional capacity in the Nigerian and Brazilian varieties. Accordingly, O-H stretch (alcohols and phenols) were found to be at peak 12. All three varieties show peaks indicating O-H stretching vibrations, with Nigeria at 3332.24 cm^{-1}, Brazil at 3306.15 cm^{-1} and China at 2848.86 cm^{-1}. The group frequencies for these stretches range from 3600-3200 cm^{-1}. The existence of phenols and alcohols is critical for the anti-oxidative properties of the plant (Hou *et al.*, 2022). This similarity underscores a shared capacity for scavenging free radicals and providing therapeutic benefits.

Table 1: Comparative analysis of major phytochemical compounds in methanolic extracts of three A. annua varieties from Nigeria, Brazil and China

A. annua (Nigeria)					
PK No.	RT	Area Pct	Phytochemical Compound	Mol. Wt.	Mol. Wt.
1	4.443	9.998	2(3H)-Furanone, 5-ethenyldihydro-5-methyl	$C_7H_{10}O_2$	126.15
2	5.45	1.151	Isophorone	$C_9H_{14}O$	138.21
3	6.5271	0.515	3-Octyne, 5-methyl-	C_9H_{16}	124.22
4	7.0891	0.691	Cyclobutane acetonitrile	$C_{10}H_{15}N$	149.23
5	7.291	0.542	1,3-Pentadiene	C_5H_8	68.12
6	8.1219	20.87	2-Cyclohexen-1-one	$C_{10}H_{16}O$	152.23
7	9.5938	1.722	Decanoic acid	$C_{10}H_{20}O_2$	172.27
8	10.297	12.88	Spiro[4.5]decan-7-one, 1,8-dimethyl-8,9-epoxy-4-isopropyl	$C_{15}H_{24}O_2$	236.35
9	10.407	0.265	Preg-4-en-3-one	$C_{20}H_{27}NO_2$	313.44
10	10.931	0.339	Sulfurous acid	$C_{17}H_{36}O_3S$	320.53
11	12.007	5.571	Ingol-12-acetate	$C_{22}H_{32}O_7$	408.5
12	13.795	0.107	Arteannuic acid	$C_{15}H_{22}O_2$	234.33
13	14.371	0.469	3-Cyclopropenoic acid	$C_4H_4O_2$	84.07
14	14.698	8.58	Dodecanoic acid	$C_{12}H_{24}O_2$	200.32
15	15.275	16.72	l-(+)-Ascorbic acid 2,6-dihexadecanoate	$C_{38}H_{68}O_8$	652.9
16	16.433	1.409	1H-3a, 7-Methanoazulene	$C_{15}H_{26}$	206.37
17	16.957	0.179	9,12-Octadecadienoic acid (Z,Z)-	$C_{18}H_{32}O_2$	280.45
18	17.822	0.114	(Z)6, (Z)9-Pentadecadien-1-ol	$C_{15}H_{28}O$	224.38
19	18.207	0.29	Bicyclo[4.1.0]heptane, -3-cyclopropyl	$C_{13}H_{20}O_2$	208.15
20	18.29	0.083	2-Methyl-Z, Z-3,13-octadecadienol	$C_{19}H_{36}O$	280.5
21	19.071	0.078	9,12-Octadecadienoic acid (Z,Z)-	$C_{18}H_{32}O_2$	280.45
22	19.48	2.62	Methyl tetradecanoate	$C_{15}H_{30}O_2$	242.39
23	20.02	5.594	(S, E)-6-Hydroxy-6-methyl-2-((2S,5R)-5-methyl-5-vinyl tetrahydrofuran-2-yl)hept-4-en-3-one	$C_{15}H_{24}O_3$	252.34
24	21.597	3.423	2,4,6-Decatrienoic acid, methyl ester, (2E,4E,6Z)	$C_{11}H_{16}O_2$	180.24
25	21.653	0.282	Oleic Acid	$C_{18}H_{34}O_2$	282.47
26	23.336	0.451	3,4-Octadiene	C_8H_{14}	110.2
27	23.697	1.327	Deoxyartemisinin	$C_{15}H_{22}O_4$	266.33
28	23.893	4.757	Hexadecanoic acid,	$C_{16}H_{32}O_2$	256.42
29	25.663	0.091	Methyl ester, (E,E)-	$C_{19}H_{34}O_2$	294.47
30	27.373	31.29	9,17-Octadecadienal	$C_{18}H_{32}O$	264.5
31	29.474	10.31	9,12-Octadecadienal	$C_{18}H_{32}O$	264.45
32	30.699	1.095	Oleic Acid	$C_{18}H_{34}O_2$	282.47
33	31.107	1.484	5-Dodecyne	$C_{12}H_{22}$	166.3
34	31.566	2.16	Oleic Acid	$C_{18}H_{34}O_2$	282.47
35	32.387	0.349	Cyclododecyne	$C_{12}H_{20}$	164.29
36	32.476	1.082	Cyclopentaneundecanoic acid	$C_{16}H_{30}O_2$	254.41
37	35.371	0.767	1,3-Oxathiane	C_4H_8OS	104.17

Table 1: Continue...

PK No.	RT	Area Pct	Phytochemical Compound	Mol. Wt.	Mol. Wt.
38	35.996	0.417	Cyclopentaneundecanoic acid	$C_{12}H_20$	164.29
39	-	-	-	-	-
40	-	-	-	-	-
41	-	-	-	-	-
42	-	-	-	-	-
43	-	-	-	-	-
44	-	-	-	-	-
45	-	-	-	-	-
46	-	-	-	-	-
47	-	-	-	-	-
48	-	-	-	-	-

Table 1: Continue...

A. annua (Brazil)

PK No.	RT	Area Pct	Phytochemical Compound	Mol. Formula	Mol. Wt.
1	5.448	0.1448	Bicyclo[2.2.1]-heptan-2-one	$C_8H_{12}O$	124.18
2	5.7815	0.0534	2-(2-Methoxyethoxy)-ethanol	$C_5H_{12}O_3$	120.15
3	8.1146	11.3446	2-Cyclohexen-1-one	C_6H_8O	96.13
4	9.1685	0.0852	Spiro[2.3]hexan-4-one	C_6H_8O	96.13
5	9.6406	1.0684	Decanoic acid	$C_{10}H_{20}O_2$	172.268
6	11.0738	0.9787	Propanoic acid	$C_3H_6O_2$	74.10
7	13.6795	0.2563	Propanephosphonic acid	$C_9H_{21}O_6P_3$	318.182
8	14.7002	3.0408	Dodecanoic acid	$C_{12}H_{24}O_2$	200.322
9	18.1862	0.2467	5-Bromo-3-nitro-1H-1,2,4-triazole	$C_2HBrN_4O_2$	192.96
10	18.6678	0.2141	9,17-Octadecadienal	$C_{18}H_{32}O_2$	264.5
11	19.0612	0.0732	Oleic Acid	$C_{18}H_{34}O_2$	282.47
12	19.1719	0.0238	9,17-Octadecadienal	$C_{18}H_{32}O_2$	264.5
13	19.4818	0.7032	Methyl tetradecanoate	$C_{15}H_{30}O_2$	242.40
14	22.7358	0.133	Oleic Acid	$C_{18}H_{34}O_2$	282.47
15	22.8327	0.111	9,17-Octadecadienal	$C_{18}H_{32}O_2$	264.5
16	23.407	0.4427	3,4-Octadiene	C_8H_{14}	110.19
17	23.9065	6.5977	Hexadecanoic acid	$C_{16}H_{32}O_2$	256.42
18	25.3544	0.0509	9,17-Octadecadienal	$C_{18}H_{32}O_2$	264.5
19	27.3271	29.2173	9,12-Octadecadienoic acid (Z,Z)-	$C_{18}H_{32}O_2$	280.45
20	27.8977	2.5733	Oleic Acid	$C_{18}H_{34}O_2$	282.47
21	28.5432	0.3548	Oleic Acid	$C_{18}H_{34}O_2$	282.47
22	28.6493	0.287	Oleic Acid	$C_{18}H_{34}O_2$	282.47
23	28.7726	0.1341	Oleic Acid	$C_{18}H_{34}O_2$	282.47
24	28.8871	0.2293	Methyl 9,12-heptadecadienoate	$C_{18}H_{32}O_2$	280.45
25	29.4396	1.4499	3-Octyne	C_8H_{14}	110.20
26	31.6773	16.8095	Oleic Acid	$C_{18}H_{34}O_2$	282.47
27	32.0912	5.0638	Oleic Acid	$C_{18}H_{34}O_2$	282.47

Table 1: Continue...

PK No.	RT	Area Pct	Phytochemical Compound	Mol. Formula	Mol. Wt.
28	32.2949	10.1235	Oleic Acid	$C_{18}H_{34}O_2$	282.47
29	33.7099	4.3556	Oleic Acid	$C_{18}H_{34}O_2$	282.47
30	35.3681	2.7179	1,E-11,Z-13-Octadecatriene	$C_{18}H_{32}$	284.44
31	36.0396	1.1157	Cyclopentaneundecanoic acid	$C_{16}H_{30}O_2$	254.41
32	-	-	-	-	-
33	-	-	-	-	-
34	-	-	-	-	-
35	-	-	-	-	-
36	-	-	-	-	-
37	-	-	-	-	-
38	-	-	-	-	-
39	-	-	-	-	-
40	-	-	-	-	-
41	-	-	-	-	-
42	-	-	-	-	-
43	-	-	-	-	-
44	-	-	-	-	-
45	-	-	-	-	-
46	-	-	-	-	-
47	-	-	-	-	-
48	-	-	-	-	-

Table 1: Continue...

A. annua (China)

PK No.	RT	Area Pct	Phytochemical Compound	Mol. Formula	Mol. Wt.
1	3.173	0.1448	0.1448	$C_{16}H_{30}O_2$	254.40
2	3.402	1.2354	1-Methyl-cycloheptanol	$C_8H_{16}O$	128.21
3	3.585	0.0089	3,5-Hexadien-2-ol2-methyl-	$C_7H_{12}O$	112.17
4	3.739	0.8679	Cholestan-3-ol, 2-methylene, (3ß,5α)-	$C_{28}H_{48}O$	400.68
5	3.871	0.1533	2,5-Octadecadiynoic acid, methyl ester	$C_{19}H_{30}O_2$	290.44
6	4.054	0.1539	Cyclohexene, 1-methyl-5-(1-methyl-ethenyl)	$C_{10}H_{16}$	136.23
7	4.180	0.3778	Cyclohexene, 4-isopropenyl-1-methoxymethoxy-methyl-	$C_{12}H_{20}O_2$	196.29
8	4.311	0.0526	Exo-2,7,7-trimethyl-bicyclo[2.2.1]heptan-2-ol	$C_{10}H_{18}O$	154.25
9	4.443	0.0075	2(3H)-Furanone, 5-ethenyl-dihydro-5-methyl	$C_7H_{10}O_2$	126.15
10	4.672	0.6203	2H-Benzo[f]oxireno[2,3-E]benzofuran-8(9H)-one, 9[[[2-(dimethylamin)	$C_{12}H_{20}O_2$	196.29
11	4.803	0.0852	2-Furanmethanol, 5-ethenyl tetrahydro-α,α, 5-trimethyl-, cis-	$C_{10}H_{18}O_2$	170.25
12	5.164	1.0684	5,8-Decadien-2-one, 5,9-dimethyl-, (E)-	$C_{12}H_{20}O$	180.29
13	5.376	0.7987	Methyl 6-oxoheptanoate	$C_8H_{14}O_3$	158.19
14	5.244	0.5263	Dodecanoic acid, 3-hydroxy-	$C_{12}H_{24}O_3$	216.32

Table 1: Continue...

PK No.	RT	Area Pct	Phytochemical Compound	Mol. Formula	Mol. Wt.
15	5.450	1.1508	Isophorone	$C_9H_{14}O$	138.21
16	5.708	0.2476	2H-Benzo[f]oxireno[2,3-E]benzofuran-8(9H)-one, 9-[[[2-(dimethylamin)	$C_{19}H_{32}N_2O_3$	336.5
17	5.994	0.2411	1,2-15,16-Diepoxyhexadecane	$C_9H_{14}O_2$	154.21
18	6.411	4.9757	10-Undecen-1-al, 2-methyl-	$C_{12}H_{22}O$	182.3
19	7.527	0.0509	1,4-Methanoazulen-7-ol, decahydro-1,5,5,8a-tetramethyl-, [1s-(1α,3a)	$C_{15}H_{24}O$	220.35
20	7.939	1.2173	3,5-Heptadienal, 2-ethylidene-6-methyl	$C_{10}H_{14}O$	150.22
21	8.094	0.5731	1,6-Dimethylhepta-1,3,5-triene	C_9H_{14}	122.21
22	8.563	0.3548	1(2H)-Naphthalenone, octahydro-4-hydroxy-, trans	$C_{10}H_{16}O_2$	168.24
23	9.026	0.287	Trans-Z-α-Bisabolene epoxide	$C_{15}H_{24}O$	220.35
24	9.312	9.0762	7-epi-cis-sesquisabinene hydrate	$C_{15}H_{26}O$	222.37
25	9.621	7.5734	Geranyl vinyl ether	$C_{12}H_{20}O$	180.29
26	9.804	22.3456	Cyclohexanone, 2,2-dimethyl-5-(3-methyloxiranyl)-, [2α(R*),3α]-(.+-.)-	$C_{11}H_{18}O_2$	182.26
27	10.297	15.0638	Spiro[4.5]decan-7-one, 1,8-dimethyl-8,9-epoxy-4-isopropyl	$C_{15}H_{24}O_2$	236.35
28	10.583	0.1234	6-epi-shyobunol	$C_{15}H_{26}O$	222.37
29	11.046	2.5555	3,6-Diazahomoadamantan-9-one Hydrazone	$C_9H_{16}N_4$	180.25
30	11.670	2.6541	Cholestan-3-ol, 2-methylene-, (3ß,5α)-	$C_{28}H_{48}O$	400.7
31	12.007	1.5711	Ingol-12-acetate	$C_{22}H_{32}O_7$	408.5
32	12.162	0.1636	Geranyl isovalerate	$C_{15}H_{26}O_2$	238.37
33	12.602	0.6325	1-Ethynyl-3,cis(1,1-dimethylethyl)-4, trans-methoxycyclohexan-1-ol	$C_{13}H_{22}O_2$	210.31
34	12.345	0.7978	1b,4a-Epoxy-2H-cyclopenta[3,4]-cyclopropa[8,9]-cycloundec[1,2-b]o	$C_{22}H_{32}O_8$	424.5
35	15.275	11.4118	l-(+)-Ascorbic acid 2,6-dihexadecanoate	$C_{38}H_{68}O_8$	652.9
36	16.648	6.2473	1,3-dihydroxypropan-2-yl (9Z,12Z,15Z)-octadeca-9,12,15-trienoate	$C_{21}H_{36}O_4$	352.5
37	17.266	0.1241	1-Heptatriacotanol	$C_{37}H_{76}O$	537.0
38	17.970	4.7727	Propanoic acid, 2-[5-(2-hydroxypropyl)tetrahydrofuran-2-yl]-, 1-[5-(1-m)	$C_{21}H_{36}O_7$	400.5
39	18.462	0.0838	10,13-Dioxatricyclo[7.3.1.0(4,9)]-tridecan-5-ol-2-carboxylic acid, 4-me	$C_{17}H_{26}O_5$	310.4
40	18.851	0.0732	9-Octadecenamide, (Z)-	$C_{18}H_{35}NO$	281.48
41	20.327	0.8133	Lupeol	$C_{30}H_{50}O$	426.73
42	20.791	0.0871	9-Desoxo-9-x-acetoxy-3,8,12-tri-O-acetylingol	$C_{28}H_{40}O_{10}$	536.0
43	21.363	0.6637	Olean-12-ene-3,15,16,21,22,28-hexol, (3ß,15α,16α,21ß,22α)-	$C_{30}H_{50}O_6$	506.7
44	21.597	3.4231	2,4,6-Decatrienoic acid, methyl ester, (2E,4E,6Z)	$C_{11}H_{16}O_2$	180.24
45	23.697	0.0897	Pregn-5-en-20-one	$C_{21}H_{32}O$	300.5
46	26.289	1.1243	Spirost-8-en-11-one, 3-hydroxy-(3ß,5α,14ß,20ß,22ß,25R)-	$C_{27}H_{40}O_4$	428.6
47	26.495	16.8976	(+)-y-Tocopherol, O-methyl	$C_{29}H_{50}O_2$	430.7
48	27.611	2.7098	1-Phenanthrene carboxylic acid, tetradecahydro-7-(2-methoxy-2-oxoe	$C_{22}H_{32}O_5$	376.5

Table 1: Continue...

Table 2: Comparative analysis for major FT-IR peak values of methanolic extracts of three *A. annua* varieties from Nigeria, Brazil and China

Peak No	Nigeria (cm^{-1})	Brazil (cm^{-1})	China (cm^{-1})	Intensity (Nigeria)	Intensity (Brazil)	Intensity (China)	Functional Group Assignment	Group Frequency (cm^{-1})
1	838.65	834.92	665.44	76.12	68.44	61.06	C-O-O-Stretch (Esthers, Peroxides)	890-820
2	1021.29	1021.29	777.31	55.29	42.13	64.62	C-O Stretch (Ethers, Alcohols)	1090-1020
3	1159.2	1159.2	894.97	71.43	61.65	74.4	C-O Stretch (Aromatic ethers, Alcohols)	1190-1130
4	1244.93	1244.93	1028.06	73.94	64.92	57.22	C-N Stretch (Amines)	1270-1230
5	1367.93	1367.93	1155.36	74.41	66.2	72.62	C-H Bend (Alkanes)	1370-1365
6	1438.75	1438.75	1242.16	79.4	72.15	72.14	C-H asym/sym. Bend (Alkenes)	1470-1430
7	1509.57	1513.3	1315.45	85.23	80.81	56.65	C=C Stretch (Alkenes, Aromatic)	1555-1485
8	1606.48	1606.48	1417.68	77.54	69.55	74.42	C=C Stretch (Aromatic)	1650-1600
9	1654.94	1654.94	1616.35	76.72	68.17	62.97	C=O Strecth (Ketones, Aldehydes)	1760-1660
10	1718.3	1733.21	1732.08	81.16	76.9	79.65	C=O Stretch (Esters)	1750-1725
11	2918.51	2918.51	2306.86	82.05	75.47	92.19	C-H Stretch (Alkanes)	3000-2850
12	3332.24	3306.15	2848.86	84.15	79.27	82.39	O-H Stretch (Alcohols, Phenols)	3600-3200
13	-	-	2918.3	-	-	77.95	C-H (Alkanes)	2850-2970
14	-	-	3064.89	-	-	85.717	H-O (H-bonded H-X group)	2500-3500
15	-	-	3273.2	-	-	79.265	O-H (Hydrogen bonded Alcohols, Phenols)	3200-3600
16	-	-	3361.93	-	-	79.184	O-H (Hydrogen bonded Alcohols, Phenols)	3200-3600

The differences in functional group concentrations and peak positions were found to be; C-O-O stretch (esters, peroxides) at peak 1. The Nigerian variety shows a higher peak at 838.65 cm^{-1} with an intensity of 76.12, while the Brazilian variety exhibits a peak at 834.92 cm^{-1} with an intensity of 68.44. The Chinese variety has a distinct peak at 665.44 cm^{-1} with a lower intensity of 61.06. Nurlybekova *et al.* (2022) reported that higher concentration of esters and peroxides in plants signifies a stronger anti-oxidative potential, also here the Nigerian variety is higher compared to the Brazilian and Chinese varieties. The different peak position in the Chinese variety indicates a different ester or peroxide profile, which may affect its bioactivity. C-O stretch (ethers, alcohols) at peak 2 and 3 were found in Nigeria and Brazil which shares the same peak positions at 1021.29 cm^{-1} and 1159.2 cm^{-1}, respectively, the Chinese variety exhibits peaks at 777.31 cm^{-1} and 894.97 cm^{-1} with higher intensities. This indicates that the Chinese variety contain different types or higher concentrations of ethers and alcohols, which are in concordance with the findings of Shinyuy *et al.* (2023) that potentially altering its antimicrobial efficacy and anti-inflammatory properties. When compared to the Nigerian and Brazilian varieties, China variety has the highest concentrations.

Peak 4 is having C-N stretch (amines). The Nigerian and Brazilian varieties show a peak at 1244.93 cm^{-1} with intensities of 73.94 and 64.92, respectively; whereas the Chinese variety has a peak at 1028.06 cm^{-1} with a lower intensity of 57.22. The presence of amines, which are less pronounced in the Chinese variety, suggests that the Nigerian and Brazilian varieties may have more significant pharmacological effects related to anti-inflammatory and analgesic activities (Zhang *et al.*, 2021). Then C-H Asym/Sym Bend (Alkenes) is identified at peak 6: The Nigerian and Brazilian varieties have similar peaks at 1438.75 cm^{-1}, with intensities of 79.4 and 72.15, respectively. The Chinese variety shows a different peak at 1242.16 cm^{-1} with a similar intensity of 72.14. The distinct peak position in the Chinese variety indicates variations in the alkene content, which could influence the plant's bioactivity, particularly its role in synthesizing other bioactive compounds (Zayed, 2022).

Peak 7 and 8 are presented with C=C stretch (alkenes, aromatic). The Nigerian variety shows a significantly higher intensity at 85.23 for the peak at 1509.57 cm^{-1}, compared to 80.81 for Brazil and 56.65 for China. Similarly, at 1606.48 cm^{-1}, Nigeria and Brazil show peaks with intensities of 77.54 and 69.55, respectively, while China shows a different peak at 1417.68 cm^{-1} with an intensity of 74.42. The higher intensity of these peaks in the Nigerian variety indicates a greater concentration of aromatic compounds and alkenes, which are essential for antioxidant and antimicrobial properties. The Chinese variety's different peak position suggests a

variation in these functional groups, potentially leading to different bioactivity profiles as expressed by Sadiq *et al.* (2014) and Fatima *et al.* (2020). At peak 10, C=O stretch (esters) was identified. The Nigerian variety shows a peak at 1718.3 cm^{-1} with an intensity of 81.16; whereas, the Brazilian and Chinese varieties have peaks at 1733.21 cm^{-1} and 1732.08 cm^{-1}, respectively, with slightly lower intensities of 76.9 and 79.65. The variations in peak positions and intensities suggest differences in the ester profiles among the varieties, which can affect their antimicrobial and anti-oxidative properties (Zayed, 2022; Wang *et al.*, 2022). Peak 11 has C-H stretch (alkanes). The Nigerian and Brazilian varieties exhibit peaks at 2918.51 cm^{-1} with intensities of 82.05 and 75.47, respectively, while the Chinese variety shows a different peak at 2306.86 cm^{-1} with a higher intensity of 92.19. This indicates that the Chinese variety has a different alkane profile, potentially contributing to differences in the structural stability and interaction of these compounds with other phytochemicals (Zhang *et al.*, 2021).

The additional peaks in Chinese variety; the Chinese variety uniquely exhibits peaks 13, 14, 15 and 16 at 2918.3 cm^{-1}, 3064.89 cm^{-1}, 3273.2 cm^{-1} and 3361.93 cm^{-1}, resultant to C-H, H-O and O-H stretching vibrations with significant intensities (77.95, 85.717, 79.265 and 79.184, respectively). Zhang *et al*. (2021) and Nedeljković *et al*. (2023) indicated that these additional peaks suggest a more complex profile of hydrogen-bonded groups and alcohols, which may enhance the anti-oxidative and anti-inflammatory properties of the Chinese variety.

Conclusion

The GC-MS analysis of *A. annua* from Nigeria, Brazil and China reveals a diverse array of phytochemical compounds, each contributing uniquely to the extract's pharmacological profile. The high abundance compounds such as 2-Cyclohexen-1-one, 9,17-Octadecadienal and l-(+)-Ascorbic acid 2,6-dihexadecanoate highlight the potential therapeutic significance of the extracts. Moderate and low abundance compounds add to the extract's chemical diversity, while trace compounds, although present in minimal quantities, may have specific biological activities.

The FT-IR analysis underscores that while the Nigerian, Brazilian and Chinese varieties of *Artemisia annua* share common functional groups such as esters, ethers and aromatic compounds, notable differences in peak positions and intensities reveal distinct phytochemical profiles. These differences are likely influenced by geographic and environmental factors, leading to variations in the concentration and type of bioactive compounds. Such variations could have considerable implications for the therapeutic efficacy and application of these plant extracts, highlighting the importance of region-specific cultivation and extraction practices to optimize their medicinal potential.

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References

Ailli, A., Handaq, N., Touijer, H., Gourich, A.A., Drioiche, A., Zibouh, K., Eddamsyry, B., El Makhoukhi, F., Mouradi, A., Jardan, Y.A.B., Bourhia, M., Elomri, A., Zair, T., 2023. Phytochemistry and biological activities of essential oils from six aromatic medicinal plants with cosmetic properties. *Antibiotics* 12(4), 721. DOI: https://doi.org/10.3390/antibiotics12040721.

Anibogwu, R., De Jesus, K., Pradhan, S., Pashikanti, S., Mateen, S., Sharma, K., 2021. Extraction, isolation and characterization of bioactive compounds from Artemisia and their biological significance: A review. *Molecules* 26(22), 6995. DOI: https://doi.org/10.3390/molecules26226995.

Atawodi, S.E., Adejo, G.O., Olowoniyi, O.D., Liman, M.L., 2017. Biological, pharmacognostic and phytochemical review of some cultivated medicinal plants of Nigeria. In: *Medicinal and Aromatic Plants of the World-Africa*, Volume 3. (Eds.) Neffati, M., Najjaa, H. and Máthé, Á. Springer, Dordrecht. pp. 311-344. DOI: https://doi.org/10.1007/978-94-024-1120-1_12.

Azad, A.K., Mohamed, F., 2023. Determination of total phenolic and flavonoid content and evaluation of antioxidant activities of *Cuscuta reflexa*. *Universal Journal of Pharmaceutical Research* 8(6), 8-13. DOI: http://doi.org/10.22270/ujpr.v8i6.1033.

Batiha, G.E.S., Olatunde, A., El-Mleeh, A., Hetta, H.F., Al-Rejaie, S., Alghamdi, S., Zahoor, M., Beshbishy, A.M., Murata, T., Zaragoza-Bastida, A., Rivero-Perez, N., 2020. Bioactive compounds, pharmacological actions and pharmacokinetics of wormwood (*Artemisia absinthium*). *Antibiotics* 9(6), 353. DOI: https://doi.org/10.3390/antibiotics9060353.

Bauman, D.E., Lock, A.L., Conboy Stephenson, R., Linehan, K., Ross, R.P., Stanton, C., 2020. Conjugated linoleic acid: Biosynthesis and nutritional significance. In: *Advanced Dairy Chemistry: Lipids*, Volume 2. (Eds.) McSweeney, P.L.H., Fox, P.F. and O'Mahony, J.A. Springer, Cham. pp. 67-106. DOI: https://doi.org/10.1007/978-3-030-48686-0_3.

Bernardi, D.M., Marchi, J.P., Araújo, C.S.A., do Nascimento, V.R., de Souza Lima, D., Wietzikoski, S., Ferro, M.M., Miyoshi, E., Lívero, F.A.R., Seixas, F.A.V., Lovato, E.C.W., 2021. Dopamine docking studies of biologically active metabolites from *Curcuma longa* L. *Research, Society and Development* 10(7), e59910716992-e59910716992. DOI: https://doi.org/10.33448/rsd-v10i7.16992.

Das, A., Pathak, K., Pathak, M.P., Saikia, R., Gogoi, U., Acharya, N.S., 2023. Potential of herbal drug delivery in treating malaria. In: *Malarial Drug Delivery Systems: Advances in Treatment of Infectious Diseases*. (Eds.) Shegokar, R. and Pathak, Y. Springer, Cham. pp. 333-357. DOI:

https://doi.org/10.1007/978-3-031-15848-3_15.

Daskum, A.M., Chessed, G., Qadeer, M.A., Ling, L.Y., 2020. Phytochemical screening, Gas Chromatography Mass Spectroscopy (GC-MS) and *in vitro* antiplasmodial analysis of *Senna siamea* leaves as antimalarial, Yobe State, Nigeria. *Nigerian Journal of Parasitology* 41(1), 60-67. DOI: https://doi.org/10.4314/njpar.v41i1.10.

Ekiert, H., Świątkowska, J., Klin, P., Rzepiela, A., Szopa, A., 2021. *Artemisia annua* - Importance in traditional medicine and current state of knowledge on the chemistry, biological activity and possible applications. *Planta Medica* 87(08), 584-599. DOI: https://doi.org/10.1055/a-1345-9528.

Ekpiken, E.S., Ekong, U.S., Upula, S.A., Oka, I.A., Ekong, M.O., 2023. Antibacterial activities of leaves extracts of *X. aethiopica* against some *Enterobacteriaceae* and GC-MS analysis of phytoconstituents. *World Journal of Pharmaceutical and Medical Research* 9(8), 10-18.

Fayaz, F., Roodsari, S.R., Gachkar, L., Pourkaveh, B., Safaei, H.G., 2011. The antimicrobial activity of Ferula gummosa on bacterial strains isolated from patients with gastroenteritis. *Iraninan Journal of Clinical Infectious Diseases* 6(Suppl.), 21-24.

Fatima, S., Gupta, P., Sharma, S., Sharma, A., Agarwal, S.M., 2020. ADMET profiling of geographically diverse phytochemical using chemoinformatic tools. *Future Medicinal Chemistry* 12(1), 69-87. DOI: https://doi.org/10.4155/fmc-2019-0206.

Ferreira, J.F.S., Laughlin, J.C., Delabays, N., de Magalhães, P.M., 2005. Cultivation and genetics of *Artemisia annua* L. for increased production of the antimalarial artemisinin. *Plant Genetic Resources* 3(2), 206-229. DOI: https://doi.org/10.1079/PGR200585.

Fialová, S.B., Rendeková, K., Mučaji, P., Nagy, M., Slobodníková, L., 2021. Antibacterial activity of medicinal plants and their constituents in the context of skin and wound infections, considering European legislation and folk medicine - A review. *International Journal of Molecular Sciences* 22(19), 10746. DOI: https://doi.org/10.3390/ijms221910746.

Ge, X., Liang, Q., Long, Y., Shen, H., Zhang, Q., Sun, Z., Li, W., 2022. Assessment of fresh *Alpinia galanga* (*A. galanga*) drying techniques for the chemical composition of essential oil and its antioxidant and biological activity. *Food Chemistry* 392, 133314. DOI: https://doi.org/10.1016/j.foodchem.2022.133314.

Hou, T., Sana, S.S., Li, H., Xing, Y., Nanda, A., Netala, V.R., Zhang, Z., 2022. Essential oils and its antibacterial, antifungal and anti-oxidant activity applications: A review. *Food Bioscience* 47, 101716. DOI: https://doi.org/10.1016/j.fbio.2022.101716.

Ikhane, A.O., Sithole, Z.S., Cele, N.D., Osunsanmi, F.O., Mosa, R.A., Opoku, A.R., 2024. *In vitro* antioxidant and *in silico* evaluation of the anti-β-lactamase potential of the extracts of *Cylindrospermum alatosporum* NR125682 and *Loriellopsis cavenicola* NR117881. *Antioxidants* 13(5), 608. DOI: https://doi.org/10.3390/antiox13050608.

Ishaq, K., Ahmad, T., Rajput, M., Maqbool, M., Gupta, A., Imran, M., Machtinger, E.T., 2023. Parasitic Control Strategies: Bioactive Crops and Nutrition. Chapter 9. In: *Parasitism and Parasitic Control in Animals: Strategies for the Developing World*. (Eds.) Rizwan, H.M. and Sajid, M.S. CAB International. pp. 136-150. DOI: https://doi.org/10.1079/9781800621893.0009.

Kawo, A.H., Kwa, A.M., 2011. Phytochemical screening and antibacterial activity of the aqueous extracts and fractions of ethanolic extracts of *Lawsonia inermis* leaf. *International Research Journal of Microbiology* 2(12), 510-516.

Kumar, N., Devi, R., Pratibha, Kumar, S., Saurav, Pathania, M.S., Kumari, A., 2024. A review on cytomorphological, medicinal, phytochemical and pharmacological potential of common weed of wheat crop of Himachal Pradesh: *Fumaria parviflora*. *Plant Health Archives* 2(1), 26-30. DOI: https://doi.org/10.54083/PHA/2.1.2024/26-30.

Li, J., Zhang, C., Gong, M., Wang, M., 2018. Combination of artemisinin-based natural compounds from *Artemisia annua* L. for the treatment of malaria: Pharmacodynamic and pharmacokinetic studies. *Phytotherapy Research* 32(7), 1415-1420. DOI: https://doi.org/10.1002/ptr.6077.

Liu, H., Tian, X., Zhang, Y., Wang, C., Jiang, H., 2013. The discovery of *A. annua* L. in the Shengjindian cemetery, Xinjiang, China and its implications for early uses of traditional Chinese herbal medicine *qinghao*. *Journal of Ethnopharmacology* 146(1), 278-286. DOI: https://doi.org/10.1016/j.jep.2012.12.044.

Liu, X., Renzengwangdui, Tang, S., Zhu, Y., Wang, M., Cao, B., Wang, J., Zhao, B., Lu, H., 2023. Metabolomic analysis and antibacterial and antioxidant activities of three species of *Artemisia* plants in Tibet. *BMC Plant Biology* 23, 208. DOI: https://doi.org/10.1186/s12870-023-04219-6.

Mancuello, C., Maubet, Y., Cristaldo, E., Veloso, B., Robledo, G., Traba, A., Marín, L., Gayoso, E., Campi, M., 2024. *Oudemansiella cubensis* an edible mushroom from the neotropics with biological and nutritional benefits. *Natural Resources for Human Health* 4(3), 257-268. DOI: https://doi.org/10.53365/nrfhh/189170.

Michalak, M., Pierzak, M., Kręcisz, B., Suliga, E., 2021. Bioactive compounds for skin health: A review. *Nutrients* 13(1), 203. DOI: https://doi.org/10.3390/nu13010203.

Namasudra, S., Phukan, P., Bawari, M., 2021. GC-MS analysis of bioactive compounds and safety assessment of the ethanol extract of the barks of *Holarrhena pubescens* Wall. ex.G.Don (family Apocynaceae): Sub-acute toxicity studies in Swiss albino mice. *Pharmacognosy Journal* 13(1), 162-171. DOI: https://doi.org/10.5530/pj.2021.13.23.

Nandiyanto, A.B.D., Oktiani, R., Ragadhita, R., 2019. How to read and interpret FTIR spectroscope of organic material. *Indonesian Journal of Science and Technology* 4(1), 97-118. DOI: https://doi.org/10.17509/ijost.v4i1.15806.

Nedeljković, N., Dobričić, V., Bošković, J., Vesović, M., Bradić, J., Anđić, M., Kočović, A., Jeremić, N., Novaković, J., Jakovljević, V., Vujić, Z., Nikolić, M., 2023. Synthesis and investigation of anti-inflammatory activity of new thiourea derivatives of naproxen. *Pharmaceuticals* 16(5), 666. DOI: https://doi.org/10.3390/ph16050666.

Nsofor, W.N., Nwaoguikpe, R.N., Ujowundu, F.N., Keke, C.O., Uba, M.T., Edom, C.V., 2023. Phytochemical, GC-MS, FTIR and amino acid profile of methanol extract of *Tetrapleura tetraptera* fruit. *Journal of Drug Delivery and Therapeutics* 13(2), 61-69. DOI: https://doi.org/10.22270/jddt.v13i2.5739.

Nurlybekova, A., Kudaibergen, A., Kazymbetova, A., Amangeldi, M., Baiseitova, A., Ospanov, M., Aisa, H.A., Ye, Y., Ibrahim, M.A., Jenis, J., 2022. Traditional use, phytochemical profiles and pharmacological properties of *Artemisia* genus from Central Asia. *Molecules* 27(16), 5128. DOI: https://doi.org/10.3390/molecules27165128.

Nyalo, P.O., 2022. *In vitro* antibacterial and antioxidant activities of ethyl acetate extracts of *Xerophyta spekei* (Baker), *Senna singueana* (Delile) and *Grewia tembensis* (Fresen). *M.Sc. Thesis* (Biotechnology), Kenyatta University, Nairobi, Kenya. p. 152. URL: http://ir-library.ku.ac.ke/handle/123456789/24859.

Okhale, S.E., Egharevba, H.O., Imoisi, C., Ibrahim, J.A., Jegede, I.A., 2022. Gas Chromatography-Mass Spectrometry (GC-MS) analysis of the essential oil from Nigerian *Artemisia annua* L. at different growth stages. *Nature and Science* 20(12), 49-54. DOI: https://doi.org/10.7537/marsnsj201222.07.

Oppedisano, F., Macrì, R., Gliozzi, M., Musolino, V., Carresi, C., Maiuolo, J., Bosco, F., Nucera, S., Zito, M.C., Guarnieri, L., Scarano, F., Nicita, C., Coppoletta, A.R., Ruga, S., Scicchitano, M., Mollace, R., Palma, E., Mollace, V., 2020. The anti-inflammatory and antioxidant properties of n-3 PUFAs: Their role in cardiovascular protection. *Biomedicines* 8(9), 306. DOI: https://doi.org/10.3390/biomedicines8090306.

Maji, S.R., Roy, C., Sinha, S.K., 2023. Gas chromatography-mass spectrometry (GC-MS): A comprehensive review of synergistic combinations and their applications in the past two decades. *Journal of Analytical Sciences and Applied Biotechnology* 5(2), 72-85. DOI: https://doi.org/10.48402/IMIST.PRSM/jasab-v5i2.40209.

Riggins, C.W., Seigler, D.S., 2012. The genus *Artemisia* (Asteraceae: Anthemideae) at a continental crossroads: Molecular insights into migrations, disjunctions and reticulations among Old and New World species from a Beringian perspective. *Molecular Phylogenetics and Evolution* 64(3), 471-490. DOI: https://doi.org/10.1016/j.ympev.2012.05.003.

Sabaghi, M., Tavasoli, S., Hoseyni, S.Z., Mozafari, M.R., Degraeve, P., Katouzian, I., 2022. A critical review on approaches to regulate the release rate of bioactive compounds from biopolymeric matrices. *Food Chemistry* 382, 132411. DOI: https://doi.org/10.1016/j.foodchem.2022.132411.

Sadiq, A., Hayat, M.Q., Ashraf, M., 2014. Ethnopharmacology of *Artemisia annua* L.: A Review. In: *Artemisia annua - Pharmacology and Biotechnology*. (Eds.) Aftab, T., Ferreira, J.F.S., Khan, M.M.A. and Naeem, M. Springer, Berlin, Heidelberg. pp. 9-25. DOI: https://doi.org/10.1007/978-3-642-41027-7_2.

Sekar, K., Hari, R., Moorthy, D., Hari, R., Sampath, S., Alagasen, S., 2023. GC-MS analysis and antioxidant evaluation of ativisa root extract. *Research Journal of Pharmacy and Technology* 16(2), 703-708. DOI: https://doi.org/10.52711/0974-360X.2023.00120.

Shinyuy, L.M., Loe, G.E., Jansen, O., Mamede, L., Ledoux, A., Noukimi, S.F., Abenwie, S.N., Ghogomu, S.M., Souopgui, J., Robert, A., Demeyer, K., Frederich, M., 2023. Secondary metabolites isolated from *Artemisia afra* and *Artemisia annua* and their anti-malarial, anti-inflammatory and immunomodulating properties - Pharmacokinetics and pharmacodynamics: A review. *Metabolites* 13(5), 613. DOI: https://doi.org/10.3390/metabo13050613.

Trivedi, N.S., Thumar, J.T., 2022. Mangrove endophytic fungi: A treasure of bioactive compounds against infectious disease. *Annals of Forest Research* 65(1), 10908-10937.

Ungogo, M.A., Ebiloma, G.U., Ichoron, N., Igoli, J.O., de Koning, H.P., Balogun, E.O., 2020. A review of the antimalarial, antitrypanosomal and antileishmanial activities of natural compounds isolated from Nigerian flora. *Frontiers in Chemistry* 8, 617448. DOI: https://doi.org/10.3389/fchem.2020.617448.

Virendra, S.A., Sahu, C., Kumar, A., Chawla, P.A., 2022. Natural antioxidants as additional weapons in the fight against malarial parasite. *Current Topics in Medicinal Chemistry* 22(24), 2045-2067. DOI: https://doi.org/10.2174/1568026622666220504172655.

Wan, K.K., Evans-Klock, C.D., Fielder, B.C., Vosburg, D.A., 2013. Synthesis of cis-and trans-davanoids: Artemone, hydroxydavanone, isodavanone and nordavanone. *Synthesis* 45(11), 1541-1545. DOI: https://doi.org/10.1055/s-0033-1338429.

Wang, D., Shi, C., Alamgir, K., Kwon, S., Pan, L., Zhu, Y., Yang, X., 2022. Global assessment of the distribution and conservation status of a key medicinal plant (*Artemisia annua* L.): The roles of climate and anthropogenic activities. *Science of the Total Environment* 821, 153378. DOI: https://doi.org/10.1016/j.scitotenv.2022.153378.

Zayed, M.F., 2022. Medicinal chemistry of quinazolines as analgesic and anti-inflammatory agents. *Chem Engineering* 6(6), 94. DOI: https://doi.org/10.3390/chemengineering6060094.

Zhang, S.S., Tan, Q.W., Guan, L.P., 2021. Antioxidant, anti-inflammatory, antibacterial and analgesic activities and mechanisms of quinolines, indoles and related derivatives. *Mini-Reviews in Medicinal Chemistry* 21(16), 2261-2275. DOI: https://doi.org/10.2174/1389557521666210111145011.

Zhang, M., Wang, Y., Wang, S., Wu, H., 2022. Synthesis and biological evaluation of novel pyrimidine amine derivatives bearing bicyclic monoterpene moieties. *Molecules* 27(22), 8104. DOI: https://doi.org/10.3390/molecules27228104.