Research Article

Bioassay-Guided Fractionation, ESI-MS Scan, Phytochemical Screening, and Antiplasmodial Activity of Afzelia africana

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Background. Afzelia africana is a plant species with reported numerous medicinal potentials and secondary metabolites. Various parts of the plant have been applied for the treatment of hernia, rheumatism, pain, lumbago, malaria, etc. The study seeks to evaluate the phytochemical constituents, antiplasmodial, and ESI-MS scan of bioassay-guided fractions from the methanol extract of the bark of the plant. Aims. The main aim of the study was to carry out bioassay-guided fractionation of the crude methanol extract of Afzelia africana in order to isolate fractions and to evaluate their antiplasmodial activities and ESI-MS fingerprints.

Methods. The methods employed include column chromatographic fractionation, phytochemical screening, antiplasmodial activity (malaria SYBER green assay (MSF)), and ESI-MS profile (full ESI-MS scan). Results. The column chromatographic fractionation and phytochemical screening of the plant led to the separation of the following four fractions: 1 (flavonoids, phenolics, glycosides, terpenoids, and steroids), 2 (alkaloids, anthraquinones, flavonoids, phenolics, glycosides, terpenoids, and steroids), 3 (anthraquinones, flavonoids, phenolics, glycosides, terpenoids, and steroids), and 4 (alkaloids, flavonoids, phenolics, glycosides, terpenoids, and steroids). The antiplasmodial activities of the fractions were tested against the 3D7 strain of Plasmodium falciparum with reported stronger activities for 1 (IC50: 0.097 ± 0.034 µg/mL) and 3 (IC50: 1.43 ± 0.072 µg/mL), and weaker activities for 2 (IC50 > 100 µg/mL) and 4 (IC50: 37.09 ± 6.14 µg/mL). The full ESI-MS fingerprint of fractions 1, 2, 3, and 4 revealed the presence of 14, 24, 34, and 37 major molecular ions or compounds in each fraction, respectively.

1. Introduction

Malaria is a parasitic disease transmitted by the female anophales mosquito through the injection of the Plasmodium falciparum into the bloodstream of the host organism [1–3]. Statistical data from the WHO indicated a total of 229 and 228 million cases for 2018 and 2019, respectively. The number of deaths recorded within the duration stood at 411,000 and 409,000, respectively [4, 5]. The infant-reported death cases accounted for about 67% (274,000) of the 2019 deaths. In view of the higher infant mortality, the WHO further recommended the use of the RTS, S/AS01 malaria vaccine for children [4, 5]. Previous intervention in the treatment of malaria involved single and combination therapy with known antiplasmodial compounds such as the derivatives of aminoquinoline and artesunate. However, antimalarial drug resistance has emerged as one of the challenges facing malaria treatment [4–6].

The biggest intervention in the chemical treatment regime for malaria has derived its source from herbal medicines [7]. The discovery of quinine and artesunate from natural sources rekindled giant steps into a rigorous search for secondary metabolites from plant sources. The utilization and derivation of treatment regimes from herbal medicines have gone through a two-way approach, that is, a rigorous approach through bioassay-guided fractionation to identify pure compounds and the evaluation of its antiplasmodial activity [8, 9]. The second approach has gone through the
formulation of herbal medicines directly from extracts from the plants after the evaluation of its biological activity. Furthermore, standard parameters are applied to standardize it for human patronage [10–12].

In the area of antimalarial drug discovery, where the contribution of ethnopharmacology has been well documented includes the discovery of quinine from the quincona plant, artemisinin from *Artemisinin annua*, and the isolation of cryptolestps from the West African plant, *Cryptolepis sanguinolenta* [13]. Over the last 20 years, 175 plant-derived antiplasmodial compounds have been published with several of them showing a nanomolar (nM) range of activity [14]. It is therefore evident that natural products from plants are endowed with thousands of secondary metabolites; however, the exact composition and the interactive effects of these secondary metabolites could be optimized to obtain them in different compositions [15]. Bioassay-guided isolation of bioactive compounds is a modern and efficient technique in metabolites screening. Through bioassay-guided fractionation studies, secondary metabolites have been obtained in fractions containing compounds existing in different compositions in several mixtures. Such processes have yielded fractions that have generated biological activities not originally present in the crude extracts [16]. Currently, advanced analytical tools and techniques have helped to further fractionate, isolate, and purify compounds from plants, and their biological activities are evaluated. Analytical techniques that have been employed include chromatographic techniques (LC, HPLC, and TLC) and spectra techniques (mass spectrometry, infrared, ultraviolet/visible, nuclear magnetic resonance, X-ray) [17, 18].

*Afzelia africana* is a plant species belonging to the Fabaceae family. The plant is commonly referred to as African mahogany and thrives well in the tropical regions of Africa. Various parts of the plant have been applied in traditional medicines such as analgesic, emetic, laxative, febrifuge, hemorrhagic, malaria, rheumatism, diuretic, paralytic, and lumbago. Furthermore, the pulverized mixture of the roots with millet beer is used to treat hernias and, whilst a decoction with pimento, is used as a remedy against gonorrhea and stomach ache. A leaf decoction, combined with *Syzygium guineensis* leaves and Xylopia fruit, forms a drink that is used to treat oedema [19–22]. The various reported ethnobotanical applications of the plant that have been authenticated by laboratory investigations include anthelmintic [23], antioxidant [24], anti-inflammatory/analgesic [25], and antitrypanosomal [26, 27]. Furthermore, the ethnobotanical utilization of the plant as antiplasmodial agent has been confirmed against the 3D7 strain of *Plasmodium falciparum* (IC$_{50}$: 2.97 μg/mL) [28]. The antimicrobial [29, 30], antidiabetic, liver, and kidney protective ability (against alanine transaminase (ALT) and aspartate aminotransferase (AST), bilirubin, urea, and creatinine) are further reported with significant outcomes [31, 32]. In view of the vast medicinal properties reported for the plant, further studies seek to carry out an extensive bioassay-guided fraction of the methanol extract and the evaluation of its phytochemical and antiplasmodial activities. In this study, the ESI scan of the various fractions will be investigated to give a fair insight into the phytochemical constituents, number of compounds, or molecular ions present in them.

2. Materials and Methods

2.1. Materials

2.1.1. Plant Materials. The Bark of *Afzelia africana* was obtained from the Sekyere Central District of the Ashanti Region. The plant material was further identified by Mr. Clifford Osafo Asare at the Department of Herbal Medicine, Faculty of Pharmacy and Pharmaceutical Sciences, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. A voucher specimen with voucher number [KNUST/HM1/2019/SB/008] was deposited in the Herbarium Unit for reference purposes.

2.1.2. Test Organism. The test organism (3D7 strain of *Plasmodium falciparum*) was obtained from the Department of Chemical Pathology, Noguchi Memorial Institute for Medical Research, University of Ghana, Legon.

2.1.3. Reagents. Artesunate (98%) was purchased from Sigma-Aldrich (St. Louis, MO, USA). Gentamicin was obtained from Invitrogen Life Technologies Inc. (Carlsbad, CA, USA). RPMI-1640 medium, streptomycin/penicillin, L-glutamine, and HEPES were obtained from Gibco BRL Life Technologies (Grand Island, NY, USA).

2.2. Extraction of Plant Material. A 500 g of the bark was dried under shade for three (3) weeks to reduce the moisture content. The dried plant material was further pulverized and then cold macerated in 90% methanol. The mixture was then stored for 72 hours with occasional swirling and shaking. The extract was then filtered by a vacuum pump to obtain the filtrate. The filtration procedure was repeated two more times with fresh 90% methanol solution until enough filtrate was obtained. The filtrate was further concentrated using the rotavap and then dried to obtain a solid residue. The percentage yield of the successive extractions was 16% (80) g. The solid crude extract was stored at 2°C until further use.

2.3. Column Chromatography and Bioassay-Guided Fractionation. Sixty grams (60 g) of the methanol extract was mixed with 100 g of silica gel 60 (0.05–0.2 mm (230–400 mesh)) in 100 mL methanol and then dried under reduced pressure. The adsorbed extract was then mounted on a column (open, 45 × 4.5 cm) containing 250 g silica gel (230–400 mesh size). The mounted column was eluted with the mobile phase solvent system comprising of petroleum ether, petroleum ether–ethyl acetate, and ethyl acetate through gradient elution. The procedure yielded 40 fractions based on TLC profiles using a solvent system of pet ether/ethyl acetate (1 : 1). Spots were visualized by using saturated iodine vapour and anisaldehyde solution. The fractions were further pooled into four fractions based on thin-layer...
chromatography (TLC) profile to give 1 (200 mg, pale yellow powder), 2 (brown precipitate, 342 mg), 3 (300 mg, yellow powder), and 4 (500 mg, brown precipitate).

2.4. Phytochemical Screening of Fractions. The phytochemical investigations of the fractions were achieved by adopting the procedure by Amir et al. [33] as described in the experimental procedures. The phytochemical classes that were tested for the fractions include alkaloids, flavonoids, sapo-

2.5. Antiplasmodial Screening of Fractions. Antimalarial activities of the fractions were investigated by adopting the malaria SYBER green fluorescence (MSF) assay method by Kwansa-Bentum et al. [34] with slight modification. A highly synchronous ring-stage parasite was used in the assay.

2.5.1. In-Vitro Cultivation of Malaria Parasite. Blood stages of the laboratory clones of chloroquine-sensitive 3D7 strain of P. falciparum were cultured in-vitro according to the method of Trager and Jensens. All culture steps were performed using the aseptic technique in the NuAire laminar flow class II safety cabinet. All glassware was autoclaved at 121°C (15 atmospheres) for at least 15 min. Malaria parasite was maintained in continuous culture with human packed red blood cells (blood group O+) in RPMI 1640 medium supplemented with 10% human AB+ serum, 25mM N-2-hydroxyethylpiperazine-N-2-ethanesulfonic acid (HEPES), 25 mM sodium bicarbonate, and gentamicin sulfate (60 μg/ml, pH 7.2). The culture was incubated at 37°C in an atmosphere consisting of 90% N2, 5% O2, and 5%. Parasite culture was synchronized to the ring stage by treatment with 5% (w/v) D-sorbitol.

2.5.2. Assessment of In Vitro Antimalarial Activity of Fractions. An aliquot of parasite inoculum (50 μL) with 0.5% parasitaemia and 2% haematocrit was added into each well of the microtiter plate. The fraction dissolved in DMSO and diluted with RPMI 1640 to a final concentration of 1% was added to the malaria culture at six final concentrations of 100, 25, 6.25, 1.56, 0.39, and 0.098 μg/mL with artemisin (ART) as a standard antimalarial drug. Wells without the fractions but the culture at the same parasitaemia and haematocrit in distilled water were included on the 96-well plate as control. Using the candle jar method, the plate was put into a humidified chamber in an incubator at 37°C for 72 hours. The antiplasmodial activities of the fractions were deduced by the malaria SYBR green fluorescence (MSF) assay. After 72 hours of incubation, 100 μL of the SYBR green 1 fluorescence lysis buffer containing 20 mM Tris-Cl (pH 7.5), 5 mM EDTA, 0.008% saponin, and 0.08% triton-X 100 and SBR green were added to each prepared well. The plate was further covered with aluminum foil and then incubated in the dark at room temperature for 3 hours. The fluorescence generated by each well was read on the multiwell plate reader (Tecan Infinite M200). The experiment was repeated two more times (triplicate each). The evaluation of the percentage inhibition was done by inputting the parasitaemia of control and the parasitaemia of serially diluted concentrations of test samples into the relation.

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\text{% Inhibition} = \frac{\text{Parasitaemia of control} - \text{Parasitaemia of test fraction}}{\text{Parasitaemia of control}} \times 100\%.
\]

The % inhibition versus the logarithm of the concentrations [LogC] of each fraction was plotted. The IC50 (μg/mL) of the fractions were further determined by employing the GraphPad Prism software package 6 (version 6.01) (San Diego, California USA). The data were further analyzed by the one-way ANOVA using GraphPad Prism 6 software with a significant difference at P < 0.01. The data from the experiment were reported as mean and SD values from triplicate measurements.

3. Results and Discussion

The principle of bioassay-guided fractionation has played a significant role in understanding the phytochemistry, pharmacognosy, and pharmacology of herbal medicines [15]. The principle has further led to the linkage of various fractions from plants to their biological activity and specific compounds directly linked to their biological activities [35]. In the current study, the principle of column chromatographic fractionation was employed to obtain fractions that were bulked together based on a similar retention factor (Rf). The crude methanol extract of the A. africana was obtained by employing the cold maceration technique with an overall yield of 16%. The crude extract was subsequently mounted...
on the column and eluted with a solvent system comprising petroleum ether and ethyl acetate. The procedure led to the isolation of four fractions. Fraction 1 (comprising three spots on TLC (Rf: 0.18, 0.36, 0.55)) was obtained as a yellow isolate with a solvent system of pet ether/ethyl acetate (85:15). Fractions 2, 3, and 4 were obtained with solvent systems of pet ether/ethyl acetate (75:25), pet ether/ethyl acetate (70:30), and pet ether/ethyl acetate (70:30), respectively. The fractions were bulked together based on the TLC profile (number of spots and their retentions times) and represented in Table 1.

The biological activity and, specifically, the antimalarial activity of plants have been linked to the presence of secondary metabolites and their synergistic effects [36, 37]. The existence of two or more secondary metabolites in their right compositions and permutations could be harnessed and optimized to yield resultant beneficial outcomes, notwithstanding, their associated toxic and adverse effects [36]. Phytochemical screening of secondary metabolites from plants is the first step in understanding the phytochemistry, pharmacognosy, and pharmacology of extracts from plants [15]. The phytochemical screening provides a rich source of information about the composition and structural varieties of compounds in extracts from plants [39]. Nevertheless, the test could further provide clues into biological activities, toxicities, and structures of active compounds for authenticating the ethnobotanical utilization of plant medicines [15]. As a result, well-standardized methods for screening alkaloids, terpenoids, steroids, flavonoids, phenolics, tannins, coumarins, anthraquinones are well documented [36]. The application of a standardized procedure for the screening of the phytochemical constituent of the plant is indicated in Table 2.

From Table 2, the isolated fractions indicated the presence of several secondary metabolites for 1 (flavonoids, phenolics, glycosides, terpenoids, and steroids), 2 (alkaloids, anthraquinones, flavonoids, phenolics, glycosides, terpenoids, and steroids), 3 (anthraquinones, flavonoids, phenolics, glycosides, terpenoids, and steroids), and 4 (alkaloids, flavonoids, phenolics, glycosides, terpenoids, and steroids). The phytochemical screening results have further revealed the presence of wide varieties of secondary metabolites present in the fractions from the bark of Afzelia africana. The presence of these secondary metabolites could account for the numerous medicinal properties reported for Afzelia africana. The phytochemical screening experiment indicating the presence of the phytochemicals in Afzelia africana further confirms similar results determined by other studies [31, 40, 41]. Further experimental procedures to justify the presence of the wide varieties of secondary metabolites in the four fractions were achieved by performing a full ESI-MS scan of the fractions. The single-stage full ESI-MS scanning of bioactive compounds in crude extracts from medicinal plants has attracted widespread interest and promoted a much better understanding of traditional herb medicines in recent years. Currently, liquid chromatography coupled with electrospray ionization (ESI) tandem mass spectrometry (LC-ESI-MS) has been widely used for the fast separation and structural identification of secondary metabolites without tedious isolation and purification of pure compounds from the complex sample matrix. Furthermore, several useful information is obtained from the MS experiment by MS full scan [39, 42]. The full ESI-MS scans of fractions 1, 2, 3, and 4 are displayed in Figures 1–4.

The ESI-MS scan figures revealed the identification of 14, 24, 34, and 37 major molecular ions in fractions 1 (225.2, 241.2, 263.8, 283.2, 295.8, 317.3, 331.1, 349.2, 365.2, 377.3, 397.2, 425.3, 431.5, 455.2), 2 (105.1, 181.1, 119.1, 125.1, 135.1, 161.0, 178.1, 179.1, 185.1, 193.1, 201.1, 209.1, 216.1, 219.2, 221.1, 233.2, 249.1, 279.3, 301.1, 335.3, 413.4, 439.5, 449.5, 495.5), 3 (97.1, 111.1, 114.1, 122.1, 131.1, 136.1, 139.1, 146.1, 153.1, 158.1, 169.1, 175.1, 177.1, 178.1, 187.2, 201.2, 215.1, 231.2, 239.1, 247.1, 249.3, 261.2, 271.2, 289.2, 301.2, 327.2, 341.4, 362.4, 385.4, 401.3, 431.5, 453.4, 461.3, 475.5), and 4 (120.8, 135.0, 149.0, 152.0, 163.1, 179.0, 193.1, 205.1, 210.1, 215.1, 220.1, 235.1, 239.1, 245.1, 249.1, 255.2, 271.1, 280.1, 289.1, 299.1, 301.2, 304.1, 319.3, 327.0, 341.3, 369.4, 385.4, 399.3, 413.3, 429.3, 439.5, 451.450.1, 458.5, 473.5, 485.2, 559.3), respectively. The results indicate the presence of wide varieties of molecular ion in the fractions and further confirming the phytochemical screening results (Table 3). In view of the presence of the wide varieties of secondary metabolites in the isolated fractions, they were submitted to in-vitro antimalarial testing against P. falciparum, 3D7 strain. A parasite culture was carried out as already described by Kwansa Bentum et al. [34]. The fractions were tested in triplicate, and the results are expressed as mean ± SD. The antimalarial activities of the isolated fractions were tested against 3D7 strain of Plasmodium falciparum through the malaria SYBER green fluorescence (MSF) assay method. The concentration range for the percentage inhibition assay was within the range of 100–0.098 μg/mL. The results for the plot of the percentage inhibition against the corresponding logarithm of the concentrations for the fractions and their IC50 (s) are shown in Figure 5 and Table 3.

The classification of the activity of the fractions was achieved by adopting the criteria, where IC50 < 5 μg/mL was classified as very active; promising activity between 5 and 15 μg/mL; moderate activity between 15 and 50 μg/mL; and inactive at IC50 > 50 μg/mL [43–45]. From the graph, the four fractions exhibited inhibitory activities for the various concentrations. For instance, fractions 1 and 3 exhibited stronger activity with percentage inhibitions within the range of (60–8)% and (65–8)% for the various concentrations. The fifty percentage inhibitory concentrations (IC50) for the fractions reported values of 0.097 ± 0.034 and 1.43 ± 0.072 μg/mL for 1 and 3, respectively. Preliminary phytochemical screening for 1 and 3 indicated the presence of phenolics, steroids, coumarins, alkaloids, and flavonoids, and these could account for the stronger activities. The observation further corroborates the antimalarial activity reported for the crude methanol extracts with an IC50 value of 2.97 μg/mL [28] and further supports the use of this plant in traditional medicine [46]. The fractions 2 and 4, however, respectively, recorded inactive and moderate inhibitory activities for the concentrations with inhibitory concentrations within the ranges of (up to 33) and (up to 47)%. The
IC\textsubscript{50} values for 2 and 4 were found to be greater than 100 μg/mL for fraction 2 and 37.09 ± 6.14 μg/mL for fraction 4. The negative inhibitory values of the percentage inhibitions for the fraction F4 could be due to the proliferation of the plasmodium species enhanced by the fractions. Several such observations are reported, and at specific concentrations, they achieve proliferation, and in other instances, they act as apoptosis [47]. In such instances, they significantly inhibit cell proliferation only at high concentrations but increase apoptosis at low concentrations. These data demonstrate that the effects of the fraction are concentration-dependent [47, 48]. Several classes of phytochemicals with such reported properties include resveratrol, epigallocatechin gallate, gingerol, phytosterol, and myricetin. They are known to directly influence various molecular signal transduction pathways such as inflammation cascade, cell proliferation/migration, oxidative stress, and metabolic disorders, which are involved in the development of several

### Table 1: TLC profile of fractions.

| Pooled fraction | Colour     | Solvent system | Method detection | No of spots | \(R_f\)  |
|-----------------|------------|----------------|-----------------|-------------|-----------|
| Fo (1–19)       | Pet ether  | —              | —               | —           | —         |
| 1 (20–21)       | Pale yellow| Pet ether/ethyl acetate (85:15) | Anisaldehyde | 3           | 0.18, 0.36, 0.55 |
| 2 (22–30)       | Brown      | Pet ether/ethyl acetate (75:25) | Iodine vapour  | 6           | 0.76, 0.78, 0.84, 0.89, 0.93, 0.98 |
| 3 (31–37)       | Brown      | Pet ether/ethyl acetate (70:30) | Iodine vapour  | 7           | 0.58, 0.67, 0.78, 0.84, 0.91, 0.96, 0.98 |
| 4 (38–40)       | Brown      | Pet ether/ethyl acetate (70:30) | Iodine vapour  | 8           | 0.25, 0.55, 0.64, 0.71, 0.82, 0.85, 0.91, 0.95 |

### Table 2: Phytochemical screening for fractions.

| Phytochemical test | Fraction 1 | Fraction 2 | Fraction 3 | Fraction 4 |
|--------------------|------------|------------|------------|------------|
| Alkaloids          | —          | +          | —          | +          |
| Anthraquinone      | —          | +          | +          | —          |
| Flavonoids         | +          | +          | +          | +          |
| Phenolics          | +          | +          | +          | +          |
| Coumarins          | —          | —          | —          | —          |
| Glycosides         | +          | +          | +          | +          |
| Terpenoids         | +          | +          | +          | +          |
| Steroids           | +          | +          | +          | +          |

+: positive, -: negative.

### Table 3: IC\textsubscript{50} values for fractions.

| Sample | IC\textsubscript{50} (μg/mL) | Comment |
|--------|-------------------------------|---------|
| 1      | 0.097 ± 0.034                 | Very active |
| 2      | > 100                         | Inactive |
| 3      | 1.43 ± 0.072                  | Very active |
| 4      | 37.09 ± 6.14                  | Moderate |
| ART    | 0.03 ± 0.01                   | Very active |

**Figure 1: ESI/MS full scan of fraction 1.**
Figure 2: ESI/MS full scan of fraction 2.

Figure 3: ESI/MS full scan of fraction 3.

Figure 4: ESI/MS full scan of fraction 4.
noncommunicable diseases [49]. Hence, the presence of a similar class of compounds in the fractions could contribute to the observation. The fractions could therefore be found to support accelerated cell divisions resulting in exponential cell proliferation faster than the positive control. For instance, several phytochemical classes such as triterpenoids, alkaloids, coumarins, flavonoids, steroids have been reported to contribute to the antimalarial activity of extracts [37, 50, 49]. Furthermore, *Afzelia africana* belongs to the Fabaceae family which has been known to exhibit promising antimalarial activities, with several active compounds isolated from them [52, 53].

Furthermore, the activities of the fractions (2 and 4) were relatively weaker, in spite of the rich phytochemical constituents detected in them. The observation could be due to the activity of constituents being masked by other compounds when in combination. Such phenomenon is reported, where the coexistence of two or more secondary metabolites could either produce competitive or noncompetitive antagonism [54]. Furthermore, secondary metabolites present in plants are classified into various phytochemical classes such as phenolic, flavonoid, and terpenoids. However, a particular phytochemical class has vast structural diversities with different physicochemical properties (hydrophilicity, lipophilicity, concentration, pH value, solubility, and bioavailability in critical biological targets) that could enhance or reduce their respective biological activities [55]. Therefore, the fact that the extracts have the same phytochemical composition or class does not mean they will register the same level of activity [55]. As a result, the current weaker activity cannot justify the rejection of the activities of the individual compounds in the fractions. It is therefore a good practice to carry out bioassay-guided fractionation in order to identify active fractions that could individually serve as drugs or lead agents for further studies. The myriad of chemical (phytochemical, ESI-MS) and biological (antimalarial) data reported for the plant could therefore account for the ethnomedicinal utilization of *A. africana* for the treatment of malaria. However, to account for the ethnomedicinal utilization of *A. africana* as an antimalarial remedy as well as the myriad of promising antimalarial activity reported, a review of the mechanism of action of the phytochemical classes identified in the plant could provide further insight. Several literature suggests that the mechanism of action of most phytochemicals is dependent largely on the site of action. Moreover, phytochemicals have been known to exhibit their mechanism of biological activity by interfering with a biosynthetic pathway, cell wall destruction, DNA intercalation, interference with DNA transcription, and protein synthesis [56, 57]. Furthermore, in order to account for the exact mechanism of action and the contribution of phytochemicals to the antimalarial activity of plants, the mechanism of action and drug-resistant activity of *P. falciparum* must be taken into account. Over the years, *P. falciparum* has developed several mechanisms for survival in the host organism as well as resisting drug activity, that is, drug resistance [58]. The parasite after infecting the host organism and degrading the RBC for its protein synthesis and other life processes (life stages: trophozoites, merozoites, and the schizonts) has been known to utilize the conversion of heme (Fe(II) protoporphyrin (IX): a hemoglobin metabolite) to hemozoin (a protective polymer) as a means of sequestering the toxic effect of the former (heme) [59]. Hence, targeting this mode of action involves the screening of compounds that could inhibit the synthesis of hemozoin in the parasite which subsequently leads to the accumulation of the toxic heme, leading to cytotoxicity and cell death. Phytochemicals with such inhibitory activity against heme-hemozoin conversion include alkaloids classes such as quinine, quinidine, cinchonine, and cinchonidine [60, 61]. Furthermore, the antimalarial activities of several anthraquinones, phenolics, and flavonoids could be linked to their ability to form
π-π stacking interaction with heme leading to binding and subsequent inhibition of hemozoin formation in the parasite [62–64]. The major pharmacophore responsible for the activity of these phytochemicals is due to the presence of multiple phenolic systems in their structures. Specific phytochemicals identified to follow this mechanism of action include rufigalol, exifone, agenpin, ellagic acid, and derivatives [65–67]. The existence of alkaloids, flavonoids, phenolics, anthraquinones as well as other phytochemicals in the fractions could therefore account for their antiplasmodial activities.

In other studies, *P. falciparum* have been discovered to utilize glutathione for its inhibitory effect against drug activity. The glutathione-s-transferase enzyme (GST) has been a key enzyme in the biosynthesis of glutathione. In fact, the enzyme represents 1–10% of the cellular proteins of *Plasmodium falciparum* [68]. The enzyme has been implicated in the antimalarial drug-resistant capacity of *P. falciparum*. Hence, phytochemicals with inhibitory activity against the enzyme could provide a route for addressing drug resistance. Several classes of flavonoids and polyphenolic compounds isolated from plants have been found to inhibit the action of glutathione-s-transferase such as derivatives of the compounds of ellagic acid, quercetin, rutin, kaempferol, purpurogallin due to the presence of phenolic groups [69–71]. It is experimentally documented that flavonoids or compounds with α-β unsaturated carbonyl groups and polyphenolic systems form monoadduct with L-cysteine of the enzyme (glutathione-s-transferase) through their α-β-unsaturated carbonyl moiety via the Michael addition mechanism [69–71]. The resultant effect could therefore lead to the inhibition of the protective capacity of the enzyme, leading to cytotoxicity and cell death [72]. As a result, the presence of flavonoids and phenolic compounds with similar structural motifs in fractions 1, 2, 3, and 4 (Table 2) could therefore account for their reported antiplasmodial activity.

Other mechanisms of antimalarial activity of phytochemicals have been linked to their ability to antagonize folic acid’s primary function. It is established that folic acid is involved in the biosynthesis of key biomolecules such as amino acids (e.g., serine, methionine) and DNA/RNA components (e.g., thymidine and purine bases) [73]. Antiplasmodial compounds with the antifolate mechanism inhibit folic acid synthesis by antagonizing the main enzyme, dihydrofolate reductase (DHFR), which is involved in the folic acid synthesis. The inhibition of the enzyme further produces a series of cascading effects such as the impairment of DNA, RNA, and protein synthesis in *P. falciparum leading to cell death* [74]. Several phytochemicals such as alkaloids (piperine, berberine, dictamnine reserpine), flavonoids (baicalin, biochanin, kaempferol, chalcone, catechin), coumarins, and terpenes have been found as potential folate synthesis inhibitors [56, 75, 76]. The phytochemical screening (Table 2) indicated the presence of a similar class of compounds in fractions 1, 2, 3, and 4 and could further account for the reported antiplasmodial and ethnobotanical application of *A. africana* as a malarial remedy.

4. Conclusion

The bioassay-guided fractionation of the bark of *Afzelia africana* led to the isolation of four distinct fractions with varying degrees of antiplasmodial activities against the 3D7 strain of *P. falciparum*. The study further reveals the presence of secondary metabolites such as alkaloids, anthraquinones, flavonoids, phenolic, glycosides, terpenoids, steroids, terpenoids, and steroids. The results of the study confirm the ethnobotanical utilization of *A. africana* as an herbal treatment for malaria and other diseases.

Data Availability

The TLC profile (Table 1) data, the phytochemical screening (Table 2) data, the ESI/MS (Figures 1–4) data, the antiplasmodial activity (Figure 5) data, and the antiplasmodial activity IC50 (Table 3) data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] S. Xin-zhuan, Z. Cui, and A. Joy Deirdre, “Host-malaria parasite interactions and impacts on mutual evolution,” *Frontiers in Cellular and Infection Microbiology*, vol. 10, p. 615, 2020.
[2] X.-z. Su, C. Zhang, and D. A. Joy, “Host-malaria parasite interactions and impacts on mutual evolution,” *Frontiers in Cellular and Infection Microbiology*, vol. 10, Article ID 587933, 2020.
[3] S. L. Hoffman, C. C. Campbell, and N. J. White, “Malaria,” *Tropical Infectious Diseases: Principles, Pathogens and Practice*, Elsevier, Amsterdam, Netherlands, pp. 646–675, 2011.
[4] World Health Organization, *World Malaria Report for 2019*, World Health Organization, Geneva, Switzerland, 2020.
[5] World Health Organization, *World Malaria Report for 2018*, World Health Organization, Geneva, Switzerland, 2019.
[6] T. M. Belete, "Recent progress in the development of new antimalarial drugs with novel targets," Drug Design, Development and Therapy, vol. 14, pp. 3875–3889, 2020.

[7] J. Achan, A. O. Talisuna, A. Erhart et al., "Quinine, an old antimalarial drug in a modern world: role in the treatment of malaria," Malaria Journal, vol. 10, no. 1, p. 144, 2011.

[8] E. P. A. K. Ameade, M. Ibrahim, H. S. Ibrahim, R. H. Habib, and S. Y. Gbedema, "Current use of herbal and orthodox medicines among residents of tamaile, northern Ghana, who patronize hospitals and herbal clinics," Evidence-based Complementary and Alternative Medicine, vol. 2018, Article ID 1289125, 8 pages, 2018.

[9] M. G. Weller, "A unifying review of bioassay-guided fractionation, effect-directed analysis and related techniques," Sensors, vol. 12, no. 7, pp. 9181–9209, 2012.

[10] M. Ekor, "The growing use of herbal medicines: issues relating to adverse reactions and challenges in monitoring safety," Frontiers in Pharmacology, vol. 4, p. 177, 2014.

[11] P. Yadav, K. Mahour, and A. Kumar, "Standardization and evaluation of herbal drug formulations," Journal of Advanced Laboratory Research in Biology, vol. 2, no. 4, pp. 161–166, 2011.

[12] M. Mensah, G. Komlaga, A. Forkuo, C. Firempong, A. Amning, and R. Dickson, "Toxicity and safety implications of herbal medicines used in africa," Herbal Medicine, IntechOpen, London, UK, 2019.

[13] M. Heinrich, "Ethnopharmacology and drug discovery," Comprehensive Natural Products II, vol. 3, pp. 351–381, 2010.

[14] W.-H. Pan, X.-Y. Xu, N. Shi, S. Tsang, and H.-J. Zhang, "Comparative studies of in vitro antimalarial activity of the ethanol extracts of Afzelia africana and Cassia alata commonly used as herbal medicines for malaria in Ghana," International Journal of Novel Research in Life Sciences, vol. 2, no. 6, pp. 10–16, 2015.

[15] G. A. Agbelusi, O. A. Ondukoya, and A. F. Otegbeye, "In vitro screening of chewing stick extracts and sap on oral pathogens: immune compromised infection," Biotechnology, vol. 6, no. 1, pp. 97–100, 2007.

[16] O. A. Aiyegoro, A. Adewusi, S. Oyedemi, D. Akinpelu, and A. Okoh, "Interactions of antibiotics and methanolic crude extracts of Afzelia africana (smith.) against drug resistance bacterial isolates," International Journal of Molecular Sciences, vol. 12, no. 7, pp. 4477–4487, 2011.

[17] R. I. Odo and C. N. Uchendu, "Phytochemical profile and ameliorative effect of fractions of methanol root bark extract of Afzelia africana (Smith) of family Fabaceae on libido, testosterone and sperm characteristics of diabetic male rats," Tropical Journal of Pharmaceutical Research, vol. 17, no. 8, pp. 1549–1555, 2019.

[18] R. I. Odo, I. U. Asuzu, and P. E. Aba, "The antidiabetic activities of the methanolic root bark extract of Afzelia africana in alloxan-induced diabetic mice," Journal of Complementary and Integrative Medicine, vol. 9, no. 1, 2012.

[19] H. Amir, Z. Akmal, and N. Khan, "The phytochemical screening and antioxidants potential of schoenoplectus alpinus (smith) on kidney, heart and liver of rats," Journal of Chemistry, vol. 2020, Article ID 3865139, 8 pages, 2020.

[20] B. Kwansa-Bentum, K. Agyeman, J. Larbi-Akor, C. Anyigba, H. Amir, Z. Akmal, and N. Khan, "The antiprotozoal activity of the Ethanolic extract of Afzelia africana (Smith.) against drug resistance Plasmodium falciparum strain NF54," Malaria Research and Treatment, vol. 2019, Article ID 6976298, 9 pages, 2019.

[21] J. Han, J. Zhang, W. He et al., "Bioassay-guided identification of bioactive molecules from traditional Chinese medicines," in Chemical Biology. Methods in Molecular Biology, J. Hempel, C. Williams, and C. Hong, p. 1263, Humana Press, New York, NY, USA, 2015.

[22] A. H. Rehab and A. A. El-Assnary, "Plants secondary metabolites: The key drivers of the Pharmacological actions of medicinal Plants," Herbal Medicine, Philip F. Builders, IntechOpen, London, UK, 2018.

[23] J. Čvorović, L. Ziberna, S. Fornasaro, F. Tramer, and S. Passamonti, R. R. Watson, V. R. Preedy, and S. Zibadi, Chapter bioavailability of flavonoids: the role of cell membrane transporters," Polyphenols: Mechanisms of Action in Human Health and Disease, pp. 295–320, Academic Press, Cambridge, MA, USA, Second, 2018.
A. H. Rehab and A. A. El-Anssary, "Plants Secondary Metabolites: The Key Drivers of the Pharmacological Actions of Medicinal Plants," in "Preparation of Phytopharmaceuticals for the Management of Disorders," C. Egbuna, A. P. Mishra, and M. R. Goyal, Academic Press, Cambridge, MA, USA, pp. 3–23, 2021.

S. A. Mina, F. R. Melek, R. M. Adeeb, and E. G. Hagag, "LC/ESI-MS/MS profiling of Ulmus parvifolia extracts and evaluation of its anti-inflammatory, cytotoxic, and antioxidant activities," Zeitschrift für Naturforschung C, vol. 71, no. 11-12, pp. 415–421, 2016.

D. A. Akinpelu, O. A. Aiyegoro, and A. I. Okoh, "In-vitro antibacterial and phytochemical properties of crude extract of stem bark of Afzelia africana (Smith)," African Journal of Biotechnology, vol. 7, pp. 3662–3667, 2008.

C. U. Friday, O. Akwada, and U. Igwe, "Phytochemical screening and antimicrobial studies of Afzelia africana and Detarium microcarpum seeds," Chemistry International, vol. 4, no. 3, pp. 170–176, 2018.

P. Truchado, P. Vit, T. A. Heard, F. A. Tomás-Barberán, and F. Ferreres, "Determination of interglycosidic linkages in O-glycosyl flavones by high-performance liquid chromatography/photodiode-array detection coupled to electrospray ionization ion trap mass spectrometry. Its application to Tetragonula carbonaria honey from Austr," Rapid Communications in Mass Spectrometry, vol. 29, no. 10, pp. 948–954, 2015.

R. Muganga, L. Angenot, M. Tits, and M. Frédérich, "In vitro and in vivo antiplasmodial activity of three Rwandan medicinal plants and identification of their active compounds," Planta Medica, vol. 80, no. 06, pp. 482–489, 2014.

R. Muganga, L. Angenot, M. Tits, and M. Frédérich, "Antiplasmodial and cytotoxic activities of Rwandan medicinal plants used in the treatment of malaria," Journal of Ethnopharmacology, vol. 128, no. 1, pp. 52–57, 2010.

M. M. Adia, S. N. Emami, R. Byamukama, I. Faye, and A.-K. Borg-Karlson, "Antiplasmodial activity and phytochemical analysis of extracts from selected Ugandan medicinal plants," Journal of Ethnopharmacology, vol. 186, pp. 14–19, 2016.

B. Y. Vigbedor, O. S. Acquah, and A. B. Gyan, "Ethnobotanical survey of plants used in the treatment of malaria in the Sekyere central district of the Ashanti region of Ghana," International Journal of Novelty Research in the Life Sciences, vol. 2, pp. 17–25, 2015.

V. M. Pushkarev, D. V. Starenki, V. A. Saenko et al., "Molecular mechanisms of the effects of low concentrations of taxol in anaplastic thyroid cancer cells," Endocrinology, vol. 145, no. 7, pp. 3143–3152, 2004.

N. J. Tsagarakis, I. Drygiannakis, A. G. Batistakis, G. Kolios, and E. A. Kouroumalis, "A concentration-dependent effect of ursodeoxycholate on apoptosis and caspases activities of HepG2 hepatocellular carcinoma cells," European Journal of Pharmacology, vol. 640, no. 1–3, pp. 1–7, 2010.

U. Swapna and D. Madhulika, "Role of polyphenols and other phytochemicals on molecular signaling," Oxidative Medicine and Cellular Longevity, vol. 2015, Article ID 504253, 15 pages, 2015.

A. H. Rehab and A. A. El-Anssary, "Plants Secondary Metabolites: The Key Drivers of the Pharmacological Actions of Medicinal Plants, Herbal Medicine," Philip F. Builders, IntechOpen, London, UK, 2018.

A. D. Kinghorn, "The discovery of drugs from higher plants," in Gullo, Discovery of Novel Natural Products with Therapeutic Potential, P. Vincent, Ed., Newnes, London, UK, pp. 81–108, 1994.

N. Tajudddeen and F. R. Van Heerden, "Antiplasmodial natural products: an update," Malaria Journal, vol. 18, no. 1, p. 404, 2019.

J. C. D. Tomani, O. Bonnet, A. Nyirimigabo et al., "In vitro antiplasmodial and cytotoxic activities of compounds from the roots of Eriosma montanum baker i. (fabaceae)," Molecules, vol. 26, no. 9, p. 2795, 2021.

C. K. Lindsay and C. B. Nadja, "Synergy and antagonism in natural product extracts: when 1 + 1 does not equal 2," Natural Product Reports, vol. 36, 2019.

S. Kirmusausk, “Synergistic activity of antibiotics and bioactive plant extracts: a study against gram-positive and gram-negative bacteria," Bacterial Pathogenesis and Antibacterial Control, Intechopen, London, UK, 2018.

B. Khameneh, M. Iranshahy, V. Soheili, and B. S. Fazly Bazzaz, “Review on plant antimicrobials: a mechanistic viewpoint," Antimicrobial Resistance & Infection Control, vol. 8, no. 1, p. 118, 2019.

B. Khameneh, N. A. M. Eskin, M. Iranshahy, and B. S. Fazly Bazzaz, "Phytochemicals: a promising weapon in the arsenal against antibiotic-resistant bacteria," Antibiotics, vol. 10, no. 9, p. 1044, 2021.

B. Blasco, D. Leroy, and D. A. Fidock, "Antimalarial drug resistance: linking Plasmodium falciparum parasite biology to the clinic," Nature Medicine, vol. 23, no. 8, pp. 917–928, 2017.

A. J. Rodriguez-Morales, "Current topics in malaria," Inactivation of Malaria Parasites in Blood: PDT vs Inhibition of Hemozoin Formation, Intech, London, UK, 2016.

P. P. Kushwaha, P. S. Vardhan, P. Kumari, A. G. Mtewa, and S. Kumar, "Bioactive lead compounds and targets for the development of antimalarial drugs," Phytochemicals as Lead Compounds for New Drug Discovery, vol. 157, pp. 305–316, 2020.

S. B. Christensen, "Drugs and drug leads based on natural products for treatment and prophylaxis of malaria," Evidence-Based Validation of Herbal Medicine, pp. 307–319, 2015.

A. J. Rodriguez-Morales, "Current topics in malaria," Inactivation of Malaria Parasites in Blood: PDT vs Inhibition of Hemozoin Formation, Intech, London, UK, 2016.

R. Vanderesse, L. Colombeau, C. Frochot, and S. Acherar, "Inactivation of malaria parasites in blood: PDT vs inhibition of hemozoin formation," Current Topics in Malaria, Intech, London, UK, pp. 217–218, 2016.

L. Mamede, A. Ledoux, O. Jansen, and M. Frédérich, "Natural phenolic compounds and derivatives as potential antimalarial agents," Planta Medica, vol. 86, no. 9, pp. 585–618, 2020.

M. Dell’Agli, S. Parapini, N. Basilio et al., "In-vitro studies of the mechanism of action of two compounds with antiplasmodial activity," Planta Medica, vol. 69, pp. 162–164, 2003.

P. Harwaldt, S. Rahlf, and K. Becker, "Glutathione s-transferase of the malarial parasite Plasmodium falciparum: characterization of a potential drug target," Biological Chemistry, vol. 383, no. 5, pp. 821–830, 2002.

L. Sánchez-del-Campo, M. Sáez-Ayala, S. Chazarra, J. Cabezas-Herrera, and J. N. Rodríguez-López, "Binding of natural and synthetic polyphenols to human dihydrofolate reductase," International Journal of Molecular Sciences, vol. 10, no. 12, pp. 5398–5410, 2009.

D. Ganesh, H.-P. Fuehrer, P. Starzengruber et al., "Antiplasmodial activity of flavonol quercetin and its analogues in Plasmodium falciparum: evidence from clinical isolates in" Biochemistry Research International
Bangladesh and standardized parasite clones,” *Parasitology Research*, vol. 110, no. 6, pp. 2289–2295, 2012.

[69] F. J. Barrios, “Chemistry of sesquiterpene lactones,” *Sesquiterpene lactones*, Springer, Berlin, Germany, pp. 93–117, 2018.

[70] A. K. Picman, E. Rodriguez, and G. H. N. Towers, “Formation of adducts of parthenin and related sesquiterpene lactones with cysteine and glutathione,” *Chemico-Biological Interactions*, vol. 28, no. 1, pp. 83–89, 1979.

[71] L. Masayoshi, K. Hiromi, S. Yumiko, O. Junko, and N. Hanako, “Effects of polyphenols, including flavonoids, on glutathione-S-transferase and glutathione reductase,” *Bioscience, Biotechnology, and Biochemistry*, vol. 57, no. 10, pp. 1678–1680, 1993.

[72] R. K. Haynes, H. H.-O. Pai, and A. Voerste, “Ring opening of artemisinin (qinghaosu) and dihydroartemisinin and interception of the open hydroperoxides with formation of N-oxides - a chemical model for antimalarial mode of action,” *Tetrahedron Letters*, vol. 40, no. 25, pp. 4715–4718, 1999.

[73] L. B. Bailey and M. A. Caudill, “Folate,” in *Present Knowledge in Nutrition*, J. W. Eardman Jr., I. A. MacDonald, and S. H. Zeisel, Eds., ILSI Press/Wiley-Blackwell, Ames, IA, USA, pp. 321–342, 10th, 2012.

[74] M. Visentin, R. Zhao, and I. D. Goldman, “The antifolates,” *Hematology-Oncology Clinics of North America*, vol. 26, no. 3, pp. 629–648, 2012.

[75] N. R. Kothapalli and R. V. Sekharipuram, “Dihydrofolate reductase and cell growth activity inhibition by the β-carboline-benzoquinolizidine plant alkaloid deoxytubulosine from *Alangium lamarckii*: its potential as an antimicrobial and anticancer agent,” *Bioorganic & Medicinal Chemistry*, vol. 7, no. 6, pp. 1105–1110, 1999.

[76] R. R. Narasimha and S. R. Venkatachalam, “Inhibition of dihydrofolate reductase and cell growth activity by the phenanthroindolizidine alkaloids pergularinine and tylophorinidine: the in-vitro cytotoxicity of these plant alkaloids and their potential as antimicrobial and anticancer agents,” *Toxicology In Vitro: An International Journal Published in Association with BIBRA*, vol. 14, no. 1, pp. 1–59, 2000.