

Original Research Article

IN VITRO ANTIPLASMODIAL ACTIVITIES OF CRUDE EXTRACTS AND COMPOUNDS DERIVED FROM SELECTED INDIGENOUS MEDICINAL PLANTS USED TRADITIONALLY TO TREAT MALARIA IN KENYA

ABSTRACT

Aims: To identify viable phytomedicines traditionally employed for the treatment of malaria in Kenya that could be developed into antimalarial agents.

Study design: Quantitative analysis of antiplasmodial activities and brine shrimp bioassays were carried out using standard procedures. The experiment was set in duplicate for each concentration of the drug and average IC₅₀ determined.

Place and Duration of Study: Seven indigenous plants: *Achyranthes aspera*, *Heinsiacrinita*, *Brideliacathartica*, *Citrus limon*, *Microglossa pyrifolia*, *Vernonia glabra* and *Carissa edulis* obtained from Kilifi and Homa-Bay counties in Kenya were evaluated for their anti-*Plasmodium falciparum* potential. Collection of samples and analysis took about three months.

Methodology: Both Chemical and aqueous crude extraction methods were carried out to identify the most active extracts against *P. falciparum* and then isolate pure reactive phytochemicals. Pure compounds were subjected to Nuclear Magnetic Resonance (NMR), Infra-Red (IR) and Mass Spectroscopy (MS) analyses for structure elucidation.

Results: Four extracts (hexane, dichloromethane (DCM), methanol and water) of seven different species of plants were analyzed for their anti-plasmodial activities. W2 and D6 strains of *Falciparum* were tested. However, the three most active extracts were from *Citrus lemon* roots (DCM) with IC₅₀ value of 7.017 µg/mL, *C. edulis* root (aqueous) with IC₅₀ value of 8.054 µg/mL and *B. Cathartica* leaves (methanol) with IC₅₀ value of 15.647 µg/mL. However, three pure compounds were obtained; suberosin IC₅₀ 26.7 (Strain W2), 53.1 (Strain D6) and xanthyletin IC₅₀ 1580 (Strain W2) from *C. Limon* (DCM) and spinasterol IC₅₀ 43.2 (Strain W2) from *M. pyrifolia* (hexane).

CONCLUSION: The three different species of plants with most active compounds have demonstrated their potentiality in treatment for *falciparum* malaria. Structures of the isolated three compounds can be modelled to synthesise anti-plasmodial drugs as they are active *in vitro*.

Key words: Phytomedicines, Antimalarials, chloroquine resistance, bioactivity-guided fractionation, coumarins.

1.0 INTRODUCTION

Malaria is present in more than 107 tropical countries with more than 3.2 billion people comprising, 40% of the world's population [26, 28]. In Africa including Kenya, malaria caused by *Plasmodium falciparum* is one of biggest obstacles to socio-economic development [15].

Malaria control and prevention is based on the use of prophylactic and treatment drugs, reduction of mosquito vector population via use of insecticides and prevention of mosquito bites in endemic areas [5]. The success of these initiatives has been prohibited by parasite and vector resistance to conventional drugs (CQ, Amodiaquine, Fansidar, Mefloquine, Primaquine, Quinine & Artemisinin, etc) and insecticides (DDT) respectively [29, 42, 47], hence the need for drugs.

Besides development of drug resistance, some of the antimalarial drugs are faced with challenges of toxicity that inhibit their use [29]. However, despite the use of ACT as the preferred first-line drug, there have been reports of *P. falciparum* resistance in various countries; [13, 14, 23]. The use of non-chloroquine drugs and insecticide treated nets is limited by their high cost. This have impoverish the local communities who are already experiencing high poverty levels causing them to turn to natural tradition remedies [18]), occasioning the need for research for new anti-malarial drugs [37].

The resistance of *P. falciparum* to antimalarials and mosquitoes to insecticides, has necessitated search for new compounds against malaria making use of leads from ethnopharmacology studies. To those populace relying on medicinal plants against malaria, it is vitally important that the safety and efficacy of such medicines be determined, reproducible dosage forms be developed and made available for use and their active components determined [40, 45]. It is against this strong back ground that this project was undertaken. The main objective of this study was to determine the antiplasmodial activity and safety of extracts and isolated compounds of *Achyranthesaspera*, *Heinsiacrinita*, *Brideliacathartica*, *Citrus limon*, *Microglossapyrifolia*, *Vernonia_glabra* and *Carissa edulis*.

2. MATERIAL AND METHODS

2.1 Preparation of collected plant samples

The collected plants samples were chopped, dried at room temperature at (about 30 °C) in the presence of air for two weeks for adequate drying of roots. The dried samples were then pulverized to powder thereafter stored at room temperature. Each sample pulverized of 3000 g, was divided into two portions, a small one of 100 g and a larger portion of 2900 g. The larger (2900 g) portion was used to prepare organic extracts by cold percolation sequentially using the following solvents: n-hexane, followed by dichloromethane and finally by methanol. The crude extracts from each plant sample and each extraction solvent were concentrated *in vacuo*. The smaller (100 g) portion of pulverized plant material was used to prepare an aqueous extract by boiling in water for 2 hours. The filtrate product from extraction by water was concentrated to powder and stored at 4 °C.

2.2 Preparation of the plant extracts for the tests

The stock solution of the drug containing 1 mg/20-50 μ l DMSO was further diluted ten folds to a concentration of 2 mg/ml with medium and was purified by filtering through a 0.22 μ m filter. Twenty five microlitres (25 μ l) of the working solution was dispensed in duplicates in row B of the test plate and diluted with an equal amount of CMS containing *P. falciparum* at 1% parasitaemia. A multitipped pipette was used to make two-fold dilutions from one row to the next such that the highest concentration of a drug in row B was $\times 64$ that in the last row H. The final concentration after adding 200 μ l of parasites into the wells was such that row B had a drug concentration of 111.1 μ g /ml while in row H it was 1.74 μ g /ml.

2.3 Preparation of *Plasmodium falciparum* test samples

All the strains of falciparum respond differently to variety of drugs. The laboratory-adapted multidrug resistant Southeast Asian, W2 strains, drug sensitive D6, CQ strains were used in the laboratory tests. The parasites obtained from the stabilate were assessed for viability via a microscopical examination under a light microscope followed by culture of viable parasites.

2.3.1 Preparation of parasite culture system

Antiplasmodial test was carried out as previously described [12] on 50% non-parasitized human O-positive red blood cells (RBC) were prepared as per the guidelines of previous work [46]. These O-positive RBCs aged 12-28 days old were infected with the Plasmodium species and then cultured. The O-positives in plasma was collected into 20 ml vacutainers containing citrate phosphate dextrose (CPD)-adenine buffer and was stored at 4 $^{\circ}$ C for 24 hours; in these conditions, they were active to a time limit of three weeks. Erythrocytes were prepared for use by washing three times in WM (RPMI 1640 containing HEPES (5.94g/L), and sodium bicarbonate (7.5%, 31ml/L)). The supernatant and the buffy coat containing WBC were removed after each wash. After the final wash the RBCs were suspended in WM 50% (v/v) which would also be used in parasite cultures. Parasites stored under liquid nitrogen were rapidly thawed at 37 $^{\circ}$ C and the isotonicity reconstituted as per previous work [46]. One ml of complete medium with serum (CMS) containing ten percent normal human serum which has been pooled and heat inactivated, Rhesus

+ve, (NHS) in RPMI 1640 containing HEPES buffer 25mmol/ μ l and sodium bicarbonate 25 mmol/l was added to the culture, homogenized spun and the supernatant removed.

Fifty percent erythrocytes and CMs were added to the cells and homogenised to produce 6 % haematocrit. A mixture of three percent carbon dioxide, five percent oxygen and ninety-five percent nitrogen gas were used to flush the parasites for 2 minutes which were then incubated at 37 $^{\circ}$ C. The supernatant in each flask was renewed after every 24 hours and the cultures mixed by gently rotating the flask on a level surface before re-gassing and re-incubating. Parasitaemia was assessed after every three days on Giemsa-stained thin films by counting the parasitised RBC among 10,000 RBC. When the parasitaemia exceeded 2% the culture was diluted to a desired level by adding fresh 50% RBC and CMS, but maintaining the 6 % haematocrit. The growth rate (GR) per 48 hours was calculated from the formula $GR = \frac{Pf}{Pi}^{2/n}$ where Pf = final

parasitaemia, and P_i = initial parasitaemia n = number of days in the culture [9]. The parasites were considered adapted to the *in vitro*

culture and ready for drug test when they achieved a growth rate of 3-fold or greater in 48 hours.

2.3.2 Harvesting the malaria parasites

The malaria parasite cultures were incubated for 24 hours and labelled by adding radiolabelled [^3H]-hypoxanthine solution per well and plates re-incubated further for 24 hours. The [^3H]-hypoxanthine incorporation was measured by liquid scintillation on a Beta counter after drying the filter papers at 60°C for 30 minutes. The set up was that each drug concentration was tested in duplicate. The parasites were harvested using a Mesh II harvester on mini mash glass filter (Wittaker M A products) with plenty of distilled water after the second

incubation period. The incorporation of [^3H]-hypoxanthine was determined by liquid scintillation counting on a scintillation counter. The % inhibition was calculated using the formula: % Inhibition = $[\text{mean NTPE} - \text{mean DTPE cpm} / \text{mean NTPE} - \text{mean NPE}] \times 100$. Where: cpm = count per minute. Mean NTPE = mean cpm for non-treated parasitized erythrocytes, mean NPE = mean cpm for non-parasitized erythrocytes and mean DTPE = mean cpm for drug treated parasitized erythrocytes.

2.4 Isolation and characterization of active chemicals/compounds from plants

2.4.1 Isolation of compounds

Slurry was prepared by mixing a known amount of silica gel with a solvent. The column (80 cm long & 5.5 cm diameter) was filled about half-full with solvent and the stopcock was opened to allow solvent to drain slowly into a large beaker. The column was packed with silica gel slurry 60 (0.063-0.2mm/70 - 230 mesh ASTM for column chromatography-Macherey Nagel-Germany) to a height of 70 cm. The void volume of the column was calculated as follows: the radius of the column (27.5 mm) squared multiplied by pi (3.1416) multiplied by the column length (800 mm), and the resulting volume was divided by 1000 [corrected formula for units]. This afforded the 1900.668 mL. The bed volume (L) was calculated as follows: bed height (70 cm) x column cross-sectional area ($\pi r^2 h$) (cm^2) / 1000 = $3.1416 \times 10^2 \times 700 / 1000 = 1663.0845 \text{ cm}^2$. Semi-purified biologically active

extracts, obtained from solvent fractionation were dissolved in a minimum solvent and added to the top of the column to form a layer on top of the adsorbent. Care was taken not to exceed the recommended solute loading capacity for silica gel. The sample was drained into the adsorbent until the top surface just begun to dry. Solvent elution was carried out starting with the solvent in which the sample was extracted until the first fractions were obtained then polarity of the solvent was increased with the addition of the more polar solvents. Different components of the sample charge passed through the column at different rates depending on their individual adsorption coefficients. These fractions eluted from the column were collected and concentrated.

Twenty grams of silica gel powder 60 PF₂₅₄ was transferred into 500 ml

conical flask and then thoroughly mixed with 50 ml distilled water to make homogeneous slurry. The slurry was carefully poured on a scrupulously clean 20x20cm glass plate and then spread evenly to cover the whole plate. The plate was left to dry at room temperature in a dust free environment overnight. The plate was then reactivated at 110°C for 45 minutes in an Oven. Twenty to 100 mg of sample dissolved in appropriate solvent was carefully streaked 1 cm from the end of the plate, it was left to dry and then visualized using ultraviolet (UV) light source 254nm and 366nm CAMAG limited. The plate was developed, dried and then viewed under UV light for UV active compounds. These were marked on the plate. The bands with codes such as A, B, C and D starting from the top of the plate were scrapped off and kept separately. The samples were separated from the gel using filter paper, Buchner funnel and solvent. Any pure compound which gave a weight of 5 mg and above was subjected to ¹H and ¹³C Nuclear Magnetic Resonance (NMR) and Mass Spectra (MS) structure elucidation (Tables 8 and9). Fractions from PTLC with the highest activity were subjected to NMR analysis.

2.4.2 Brine Shrimp Safety Screening Bioassay

Since most bioactive plant constituents are toxic at higher doses, a possible approach to developing a useful general bioassay is to screen for plant extracts that are toxic to zoologic systems. For this purpose, the brine shrimp (*Artemiasalina*) lethality test was originally proposed [31]. It represents an easy way to detect general bioactivity in plant

extracts and is again a handy procedure for tracking the isolation of bioactive constituents. A rectangular plastic double-chambered box with dividing wall and which had 2.3 mm holes (Encia-Italy) was used to hatch brine shrimp eggs from Lake Urmia-Iran. Artificial sea salt water made by dissolving 16g of sea salt in five hundred millilitre of distilled water was used to fill the chamber. Dry yeast (3mg) was added to serve as food for the larvae. The eggs were sprinkled carefully in the dark compartment while the other compartment was illuminated by natural light through a hole in the lid of the box. After 48 hours the larvae were collected by using a pipette from the illuminated side to which they moved on hatching due to their phototropism behaviour. They were separated from their shells by the divider wall [43]. Dimethylsulphoxide (DMSO) was used as a solvent to dissolve the plant extracts and the drug solution was then diluted with artificial sea salt water so that the DMSO content did not exceed 0.05%. Ten brine shrimps (Lake Urmia-Iran) were transferred to 1 ml of each plant sample vial containing 125, 250, 500, and 1000 µg/ml of plant extract using a Pasteur pipette. The experiment was set in duplicate for each concentration of the drug. The control tube had only sea water and DMSO. Brine shrimp survivors were enumerated after twenty four hours and the lethality fifties (LD₅₀ values) were determined by taking average of five assays using a Finney Probit analysis program on an IBM computer [30] or the ED₅₀ values (µg/ml) calculated using Probit, a computer program [43].

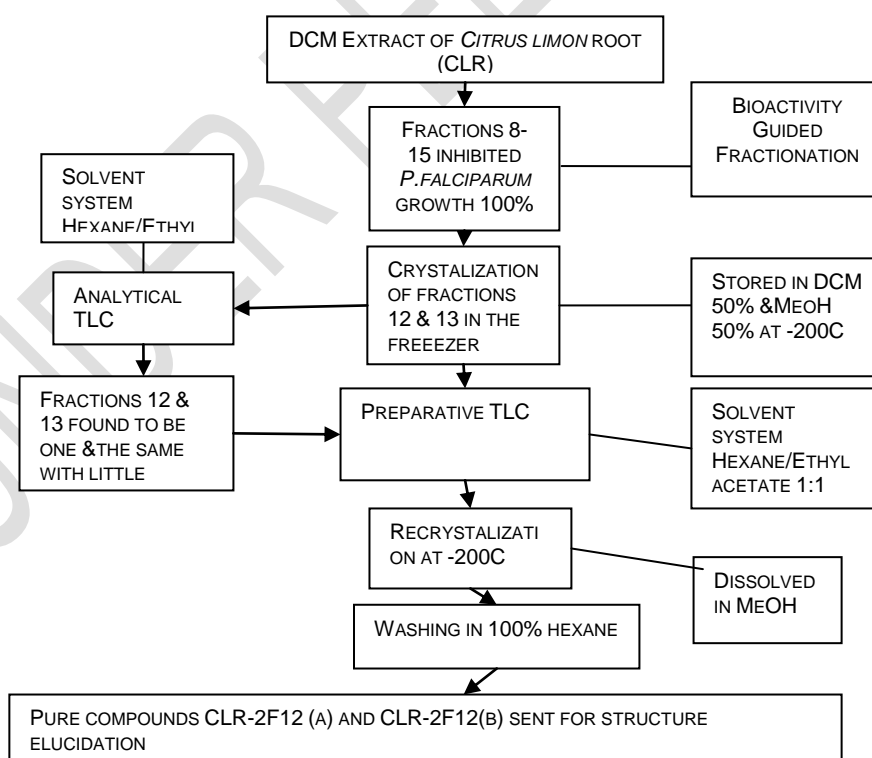
2.5 Bioactivity guided isolation of compounds from various plant extracts

2.5.1 Isolation of compounds from DCM root extract of *C. Limon* (CLR 2)

Crude DCM root extract of *Citrus Limon* (CLR-2) showed highest activity against both *P. falciparum* and brine shrimp and therefore was subjected to bioactivity-guided fractionation. The DCM extract (30 g) was packed in hexane, adsorbed on 25 g Silica gel using DCM and then extracted sequentially through a silica gel column with hexane, hexane/DCM mixtures, DCM, methanol, ethylacetate and finally acetic acid. Elution profile of plant *C. limon* root extract using hexane and DCM. The extract obtained from hexane/DCM mixtures yielded fractions 15 fractions from which fractions F8-15 were further purified as illustrated in scheme 3 below as up to 100 % inhibition of growth in *P. falciparum* was seen with these fractions. The column was eluted with increasing percentage of DCM in hexane and ethylacetate. Heavy crystals that settled without centrifugation were obtained from fractions 12 and 13 as these samples were stored at -20°C . The two fractions (12 & 13) after crystallizing out at -20°C therefore apart from being most active against *Plasmodium* and Brine Shrimp became easy targets for isolation of compounds on crystallizing out. They gave single spots on analytical TLCs after further purification. The fractions 12 and 13 were further purified according to scheme 2.

2.5.2 Further purification of CLR-2 fractions 12 and 13 on preparative TLC

i. **Figure 1:** Further purification of CLR-2 compounds on preparative TLC



Fractions F12 and F13 were the most active against *P. falciparum* and therefore preparative TLC was performed on them. Solvent and development system containing 50% Ethyl acetate in hexane gave the best separation of the two fractions on analytical TLC plates (Scheme 2). Sixty milligrams of fractions F12 and F13 were subjected to preparative TLC using hexane 1:1 ethylacetate as solvent system. Both F12 and F13 yielded two major compounds named CLR-2 F12 (a) and CLR-2 F12 (b) though with traces of contaminants. Both were recrystallised but now in methanol at -20 °C then washed several times with cold hexane in which the compound did not dissolve in except the contaminants. This resulted in two pure compounds as seen on analytical TLC plate. The structures of the compounds were determined using the following methods: ¹H, ¹³C NMR and MS and the respective spectra were compared with what were available in the literature

2.5.3 Isolation of compounds from *Brideliacathartica* methanolic leaf extract (BCL-3)

The methanolic crude leaf extract of *Brideliacathartica*, which displayed good *in vitro* antiplasmodial activity (15 µg/ml), was adsorbed on silica gel in methanol and eluted with increasing concentrations of DCM on a gel filtration column. The samples were pooled according to their analytical TLC profiles and then dried. Four major fractions were obtained which were screened for antiplasmodial activity. Individual fractions were subjected to antiplasmodial testing and the results are as shown in Table 7. BCL-3 F9 (IC₅₀ 13.474 µg/ml) was the most active fraction (Table 7) and therefore was subjected to further purification which did not give a pure compound.

2.5.4 Isolation of compounds from *M. pyrifolia* hexane extract using adsorption chromatography

Microglossapyrifolia's 1,1241g of dried leaves were crushed into powder and then extracted four times with pure hexane. The extract (MPL-1) was tested for *in vitro* antiplasmodial activity to give a mean IC₅₀ of 21.376 µg/ml. MPL-1 ranked 7th overall in terms of activity against *P. falciparum*. It was subjected to isolation of pure compounds as follows: the weight of the hexane extract was 23.0591g from which 20g was weighed out. This was dissolved in hexane, adsorbed onto 20g of silica and then dried. The sample was loaded on a gel filtration column (80 cm long, 5.5 cm diameter), packed with silica gel, eluted using hexane containing increasing amounts of DCM and 100ml fractions were collected (Table 7). Fractions 14 to 19 and 39 were oily. Clear white crystals were obtained as fraction 36 (solvent system: 10% MeOH in DCM) was being concentrated (BUCHI 110). Fraction 38 also gave white crystals which did not dissolve in methanol. Fraction 1 was the heaviest (2130.1mg) while fraction 40 was the lightest (10.4 mg) of them all. Fractions F28-F38 had similar analytical TLC profiles and therefore were pooled together and then coded MPL-1F37. This fraction had highest activity against falciparum. The tested combined column effluent coded MPL-1F37 was subjected to further isolation of compounds as shown in the next section.

2.5.5 Isolation of compound MPL-1F37 (a) (Spinasterol) from hexane leaf extract of *Microglossapyrifolia* by crystallization

MPL-1 F37 was then concentrated to 5ml and then kept at -20°C overnight for selective crystallization. White crystals formed at the bottom of the glass tube which was spun at 4400 rpm for 5 minutes. The crystals that formed were found to dissolve in DCM and methanol at room temperature. The crystals were dried at 50°C. This

sample was coded MPL-1F37 (a). Analytical TLC profile of MPL-1F37 (a) developed with 2.5% MeOH in DCM showed that it was a pure compound which gave a single band. This compound was later subjected to antiplasmodial activity and NMR analysis and was proposed to be spinasterol (Figure 6).

2.6 Characterization of isolated compounds

This was executed on a HP Model 6890A gas chromatograph provided with a Model 5973 mass selective detector, a split capillary inlet system (split ratio = 1/30), a Model 6890 auto-sampler. The injection (2 µl) was made at a temperature of 250°C. See Tables 2 and 3 for the compatibility models for compounds CLR 2F12 (a) and CLR 2F12 (b) as given by the MS machine.

Table 2: Compatibility model CLR 2F12 (a)

Header=	PK	RT	Area Pct	Library/ID	Ref	CAS	Qual
1=	1	9.4253	0.1429	2-Butenal, 3-methyl-	1388	000107-86-8	53
2=	2	20.9151	0.4953	36.12 Bisabolol<epi-alpha->	296	023178-88-3	93
3=	3	25.8648	1.0171	4-Nitro-1-naphthol	49193	000605-62-9	72
4=	4	26.3576	95.9367	2H-1-Benzopyran-2-one, 7-methoxy-6-(3-methyl-2-butenyl)-	87992	000581-31-7	94
5=	5	26.9175	0.2552	Benzoyl chloride, 4-hexyl-	74156	050606-95-6	59
6=	6	27.2086	2.1528	4,4'-Dimethoxy-2,2'-dimethylbiphenyl	86806	046873-19-2	58

Table 3: Compatibility model CLR 2F12 (b)

Header=	PK	RT	Area Pct	Library/ID	Ref	CAS	Qual
1=	1	20.915	0.7125	36.17 Bisabolol<alpha->	302	023089-26-1	91
2=	2	23.849	0.1816	Cyclodecasiloxane, eicosamethyl-	190220	018772-36-6	91
3=	3	25.1705	98.6696	47.27 Xanthyletin	1406	000523-59-1	50
4=	4	28.1269	0.4362	Benzonitrile, m-phenethyl-	62228	034176-91-5	25

2.6.1 Determination of melting points

Melting points were measured on a Gallen Kamp® SANYO MPD 350 BM3.5 UK capillary melting point apparatus at the Chemistry Department Kenyatta University.

3. RESULTS AND DISCUSSION

3.1 Yield of plant extracts

The seven plants in this study were extracted with aqueous and organic

solvents. Table 4 gives weights of ground material, weights of their

respective organic and aqueous extracts and the percentage yields per plant. Aqueous extracts had the highest percentage yield in each plant. The highest aqueous extracts percentage yield was obtained from the leaf of *M. pyrifolia* (39.74 g) followed by *V. glabra* (25.66 g). The least aqueous extracts percentage

yield was obtained from *C. edulis* root (8.175). Among the organic extracts the highest percentage yield was seen in the methanolic leaf extract of *V. glabra* (12.203 g) followed by another methanolic leaf extract of *M. pyrifolia* (10.43 g). Hexane extracts had the least percentage yields followed by DCM extracts (Table 4).

Table 4: Yield of the plants extracts

Plant material	Powder (g)	Solvent	Extract weight (g)	% yield
<i>Achyranthesaspera</i> leaves (AAL)	116	Hexane	0.3	0.259
		DCM	0.8	0.69
		Methanol	4.3	3.707
		Water	1.387	1.196
<i>Brideliacathartica</i> leaves (BCL)	152.3	Hexane	4.6	3.020
		DCM	2.7	1.773
		Methanol	10.7	7.026
		Water	0.89	0.584
<i>Hensiacrinita</i> Leaves (HCL)	92.2	Hexane	0.9	0.976
		DCM	0.7	0.759
		Methanol	2.7	2.928
		Water	1.119	1.214
<i>Citrus limon</i> roots (CLR)	31	Hexane	0.3	0.968
		DCM	0.9	2.903
		Methanol	1.0	3.225
		Water	0.764	2.465
<i>Microglossapyrifolia</i> leaves (MPL)	16.3	Hexane	23.059	2.089
		DCM	18.225	1.651
		Methanol	1.7	10.43
		Water	3.974	39.74
<i>Vernoniaglabra</i> leaves (VGL)	69	Hexane	0.6	0.870
		DCM	1.3	1.884
		Methanol	7.2	10.435
		Water	2.567	3.720
<i>Carrisa edulis</i> root (CER)	159.5	Hexane	1.1	0.690
		DCM	0.6	0.376
		Methanol	4.5	2.821
		Water	1.635	1.025

3.2 Results of the Brine shrimp lethality test

The results of the brine shrimp lethality test are displayed in Table 5. The DCM extract of *Achyranthesaspera* leaves was the most active against

brine shrimps with an LC₅₀ of 0.460 µg/ml. *Brideliacathartica* leaf DCM and methanolic extracts had LD_{50s} of 6.163 µg/mL and 6.197 µg/mL, respectively,

against the brine shrimps. Both *Citrus Limon* (CL) hexane (> 0.00) and DCM (> 0.00) root extracts were too active at the concentrations used against the brine shrimps and the two killed all the Shrimps depicted by the values. *Citrus limon* methanolic root extract had LC₅₀ of 2.195 µg/ml. *Microglossapyrifolia* (MP) hexane leaf extract had LC₅₀ of 3.389 µg/ml while its DCM leaf extract had LD₅₀ of 3.260 µg/ml. *Vernoniaglabra* (VG) hexane leaf extract had LC₅₀ of 6.087 µg/ml, while its DCM leaf extract was more active with an LC₅₀ of 2.449 µg/ml; its

methanolic leaf extract was the most active against brine shrimp in this plant with an LD₅₀ of 0.106 µg/ml second to *Citrus limon* root hexane and DCM extracts.

Achyranthesaspera(AA)hexane and methanolic leaf extracts were not active against brine shrimp larva. *Brideliacathartica* (BC) hexane leaf extract was inactive against the brine shrimps. Methanolic extracts of MPL did not show any activity against brine shrimps (Table 5).

Table 5: LC₅₀s (µg/ml) of crude plant extracts against brine shrimps calculated at 95% confidence interval using probit

Drug	Hexane (1)	DCM (2)	Methanol (3)
<i>Achyranthesaspera</i> ____leaves (AAL)	> 1000	0.460	> 500
<i>Brideliacathartica</i> leaves (BCL)	> 500	6.163	6.197
<i>Citrus limon</i> roots (CLR)	< 0.00	< 0.00	2.195
<i>Microglossa</i> __ <i>pyrifolia</i> leaves (MPL)	3.389	3.260	> 500
<i>Vernonia</i> _ <i>glabra</i> leaves (VGL)	6.087	2.449	0.106

Three plants including *B cathartica*, *C limon* and *M pyrifolia* were further processed using their DCM and methanolic extracts to obtain pure compounds.

3.3 In vitro antiplasmodial activity of the plant extracts

The *in-vitro* antiplasmodial activities of the extracts against V1/S, multidrug resistant strain of *P. falciparum* were as indicated in Table 9. Results indicate that the most active crude extract against *P. falciparum* was a DCM root extract of *C. limon* with an IC₅₀ of 7.017 µg/mL. The second crude extract in terms of antiplasmodial activity was an aqueous extract of *C. edulis* roots with an IC₅₀ of 8 µg/mL. The leaves of *B. cathartica* DCM extract was the third most active crude extract against *P. falciparum* with an IC₅₀ of 11.537 µg/mL. The statistical differences between mean IC₅₀ values were examined by the student's t-test (Table 6).

Table 6: *In vitro* antiplasmodial activity of plants extracts against V1/S Strain

Plant material	Solvent	IC ₅₀ s (µg/ml)
<i>Achyranthesaspera</i> leaves (AAL)	Hexane	18.087
	DCM	86.501
	Methanol	111.127
	Water	38.990

<i>Brideliacathartica</i> leaves (BCL)	Hexane	32.908
	DCM	11.537
	Methanol	15.647
	Water	25.985
<i>Hensiacrinita</i> Leaves (HCL)	Hexane	34.223
	DCM	13.336
	Methanol	24.805
	Water	47.203
<i>Citrus limon</i> roots (CLR)	Hexane	30.092
	DCM	7.017
	Methanol	916.997
	Water	96.860
<i>Microglossapyrifolia</i> leaves (MPL)	Hexane	21.376
	DCM	34.88
	Methanol	313.647
	Water	203.457
<i>Vernoniaglabra</i> leaves (VGL)	Hexane	427.40
	DCM	53.62
	Methanol	112.495
	Water	-
<i>Carrisa edulis</i> root (CER)	Hexane	193.599
	DCM	30.074
	Methanol	69.969
	Water	8.054
Chloroquine		49.915 ng/ml

Resistance to chloroquine is stated as an IC_{50} less than 100nM (approximately 0.052 $\mu\text{g}/\text{mL}$) [3]. However, K39 and V1 strains of *falciparum* fell far below this cut-off concentration in this study for reasons which could not be explained (IC_{50} of CQ was 0.040 $\mu\text{g}/\text{mL}$ for W2 & 0.011 $\mu\text{g}/\text{mL}$ for D6, IC_{50} of Mefloquine was 0.012 $\mu\text{g}/\text{mL}$ for W2 and 0.040 $\mu\text{g}/\text{mL}$ for D6 and IC_{50} of Quinine was 0.103 $\mu\text{g}/\text{mL}$ for W2 & 0.031 $\mu\text{g}/\text{mL}$ for D6). Most researchers consider IC_{50} values above 100 $\mu\text{g}/\text{mL}$ to be inactive and that values ranging between 20-100 $\mu\text{g}/\text{mL}$ as moderate activity [3]. Researchers have grouped plants with the following activities against malaria parasites as follows; Group A (greater than 1 $\mu\text{g}/\text{mL}$), B (1 to 5 $\mu\text{g}/\text{mL}$) and C (6 to 10 $\mu\text{g}/\text{mL}$) [3].

Most of the plant extracts in this study except DCM root extract of *C. limon*

with an IC_{50} of 7.017 $\mu\text{g}/\text{mL}$, aqueous extract of *C. edulis* with an IC_{50} of 8.054 $\mu\text{g}/\text{mL}$ and DCM and methanolic extract of *B. cathartica* with an IC_{50} of 11.537 $\mu\text{g}/\text{mL}$ and 15.647 $\mu\text{g}/\text{mL}$, respectively, DCM extract of *H. crinita* with an IC_{50} of 13.336 $\mu\text{g}/\text{mL}$ and hexane extract of *A. aspera* with an IC_{50} of 18.087 $\mu\text{g}/\text{mL}$ are considered to be within the mild or moderate activity range. Values less than 20 $\mu\text{g}/\text{mL}$ are considered to be in the high activity range for crude plants extracts.

Citrus aurantiifolia is frequently used against malaria in Brazil [33] and also *M. pyrifolia*, also studied here, has been used in Ghana against malaria. The present study also established the presence of some very popular herbal antimalarial plant species in Nyanza and the Coastal region that may not be very popular in other regions. However, though *B. carthatica* has

been used in Zimbabwe against malaria, its crude extracts did not exhibit significant antiparasitic activity in this study probably because of geographical varieties. The parts utilized by the traditional healers may also not necessarily contain the most active compounds for the choice may depend on the convenience of preparation. Most of the antimalarial concoctions are obtained from roots, leaves and at times the entire plant [35].

None of the crude extracts fell in the 1st or 2nd groups. The DCM extract of *C. limon* roots with an IC_{50} of 7.017 $\mu\text{g/mL}$, and an aqueous extract of *C. edulis* roots with an IC_{50} of 8.054 $\mu\text{g/mL}$ were the only crude extracts that fell within group C. The rest had lower activities with IC_{50} s greater than 11 $\mu\text{g/mL}$; for example, DCM extract of BCL had an IC_{50} of 11.537 $\mu\text{g/mL}$, DCM extract of HCL had an IC_{50} of 13.336 $\mu\text{g/mL}$, methanolic extract of BCL had an IC_{50} of 15.647 $\mu\text{g/mL}$ and hexane extract of AAL had an IC_{50} of 18.087 $\mu\text{g/mL}$. The remaining extracts had antimalarial activities above 20 $\mu\text{g/mL}$ and up to 916.997 $\mu\text{g/mL}$. Contrary to work by researchers [21] who demonstrated that unprocessed aqueous and ethanolic extracts of the root and the ethanolic stem extract of *B. cathartica* resulted in a 50% growth inhibition of *P. falciparum* when kept at 0.05 $\mu\text{g/mL}$, the present study showed that the extracts from this plant were generally active. The difference could have been due to the different localities and therefore different soil textures and climatic conditions. Out of the 28 crude extracts tested, only five

had IC_{50} s greater than 100 $\mu\text{g/mL}$ and thus 82% were active. This can reflect some accuracy in the part played by the herbalist and the authenticating authority at the University of Nairobi.

The following ranges of IC_{50} s were observed per plant regardless of the chemical used for extraction: AAL with an IC_{50} of 18.087-111.127 $\mu\text{g/mL}$, HCL with an IC_{50} of 13.336-47.203 $\mu\text{g/mL}$, CLR with an IC_{50} of 7.017-916.997 $\mu\text{g/mL}$, MPL with an IC_{50} of 21.376-313.647 $\mu\text{g/mL}$, VGL with an IC_{50} of 53.62-427.40 $\mu\text{g/mL}$, CER with an IC_{50} of 8.054-193.599 $\mu\text{g/mL}$ and BCL with an IC_{50} of 11.537-32.908 $\mu\text{g/mL}$. The same plants that showed high activities with IC_{50} s of 7.017-11.537 $\mu\text{g/mL}$ in category C against *P. falciparum*, had also significant bioactivity against brine shrimp, *Artemiasalina*. It therefore shows that these plant extracts were generally active. Some researchers [2] found a low antimalarial activity of an aqueous extract of *C. sinensis*. Various workers have claimed *C. limon* to have the following attributes: antiperiodic, astringent, antibacterial, antiscorbutic, carminative, refrigerant, stimulant, miscellany, rubifacient and stomachic. Lemons being the source of the most active crude extract with an IC_{50} of 7.017 $\mu\text{g/mL}$ is an extremely good prophylactic medicine for most ailments and has many uses at home. Vitamin C in which the fruit is rich in aids the body in the fight against infections and again protects or treats scurvy infections [8,16]; it has also been employed as a replacement for quinine against malaria and other fevers [16].

3.4 Results for isolation of compounds

3.4.1 Compounds isolated from active crude extracts

The most active fractions DCM root extract of *C. limon* (CLR-2), crude methanolic leaf extract of *Brideliacathartica* (BCL-3) and the mildly active hexane leaf extract *M. pyrifolia* (MPL-1) were subjected to fractionation on column chromatography using solvents of increasing polarity (hexane, hexane/DCM mixtures, DCM, DCM/methanol mixtures and methanol) on the plant extracts.

3.4.2 Isolation of compounds from the DCM root of *C.limon* (CLR 2)

Sixteen fractions were obtained and fractions 12 and 13 were active against *P. falciparum*. These fractions 12 & 13 were each subjected to preparative TLC using 50:50 hexane: ethylacetate developer.

The two fractions gave single spots on analytical TLCs after further purification by preparative TLC and recrystallization in methanol. This yielded two pure coumarin compounds; (Figures 3 and 5).

3.4.3 Compounds isolated from *Brideliacathartica* methanolic leaf extract (BCL-3)

The NMR spectra for compounds from this plant was not clear for structural elucidation. Fraction BCL-3F9 was the most active against falciparum (13.5µg/ml) (Table 7).

Table 7: Antimalarial test results for fractions of *Brideliacathartica* leaf methanolic extract

Fraction	IC₅₀µg/ml
BCL-3F7	29.1
BCL-3F8	19.4
BCL-3F9	13.5
BCL-3F11	29.9

3.4.4 Compounds isolated from *M. pyrifolia* hexane leaf extract: Adsorption chromatography

One hundred ml fractions were collected (Table 8) and 40 fractions were obtained. Fractions 14 to 19 and 39 were oily.

Clear white crystals were obtained as fraction 36 (solvent system: 10% MeOH in DCM) was being concentrated (Table 8).

Table 8: Weights of fractions of *Microglossa pyrifolia* hexane leaf extract

Fraction	W eight(mg)	Fraction	Weight(mg)
MPL-1F1	2130.1	MPL-1F21	288.2
MPL-1F2	1028.4	MPL-1F22	443.7
MPL-1F3	997.1	MPL-1F23	372.2

MPL-1F4	702.9	MPL-1F24	333.3
MPL-1F5	524.4	MPL-1F25	304.1
MPL-1F6	97.3	MPL-1F26	109.4
MPL-1F7	71.4	MPL-1F27	412.5
MPL-1F8	88.0	MPL-1F28	348.5
MPL-1F9	67.6	MPL-1F29	349.1
MPL-1F10	44.5	MPL-1F30	308.2
MPL-1F11	154.2	MPL-1F31	193.3
MPL-1F12	120.1	MPL-1F32	178.3
MPL-1F13	131.0	MPL-1F33	152.1
MPL-1F14	247.6	MPL-1F34	152.3
MPL-1F15	957.1	MPL-1F35	151.8
MPL-1F16	280.9	MPL-1F36	152.2
MPL-1F17	155.0	MPL-1F37	230.0
MPL-1F18	161.7	MPL-1F38	120.0
MPL-1F19	415.3	MPL-1F39	50.1
MPL-1F20		MPL-1F40	10.4

Fraction 1 was the heaviest (2130.1mg) while fraction 40 was the lightest (10.4 mg) of them all. Fractions F28- F38 had similar analytical TLC profiles and therefore were pooled together and then coded MPL-1F37. The combined column effluent coded MPL-1F37 was subjected to further isolation of compounds. Spinasterol was obtained (Table 8 and Figure 6).

3.5 Structures of isolated pure compounds

The pure compounds that were isolated from the plants were the following; (1) CLR-2 F12 (a), (2) CLR-2 F12 (b) from DCM root extract of *C. Limon* and (3) MPL -1F37 (a) from

hexane leaf extract of *M. pyrifolia* (Figures 3, 5 and 6). The first two compounds were very closely related as they were moving together as one and the same on analytical TLC with most solvent developers except when developed with hexane-ethylacetate 1:1 mixture which separated them as two distinct compounds. The structures of the compounds were arrived at after comparing their NMR, IR data with data available in literature and confirmed by MS analysis which gave their molecular weights (Figures 3 and 5) while structural elucidation for Figure 6 was proposed by NMR analysis only.

3.5.1 Suberosin

NMR, IR and MS Results for Compound CLR 2F12

The structure proposal of HSCCC peak fractions was carried out by ¹H-NMR and ¹³C-NMR (University of Nairobi, Department of Chemistry) and IR (Jomo Kenyatta University of Agriculture & Technology, Department of Chemistry). NMR spectra were run on RKCM.07.27.06 360 (¹H: 360 MHz;

¹³C: 212 MHz) spectrometer in CDCl₃ using TMS as internal standard or by reference to the solvent signal (CHCl₃ at δ_H 7.25). EIMS were obtained at 70 eV on a Shimadzu QP-2000 spectrometer. Its IR spectrum exhibited absorptions typical for 7-oxygenated coumarins. The ¹H NMR

spectrum showed a pair of doublets at δ 7.57 and 6.20 ($J \frac{1}{4} 9.5$ Hz), characteristic of H-4 and H-3 in a coumarin nucleus. The pair of doublets at δ 5.70 and 6.86 ($J \frac{1}{4} 10$ Hz), beside the singlet at δ 1.45 (6 H, s) are typical for the dimethylchromene ring. From the IR and UV it was deduced that 2 is a 7-oxygenated coumarin. The ^1H NMR spectrum showed two doublets at δ 6.20 and 7.59 ($J \frac{1}{4} 9.5$ Hz), and two singlets at δ 6.75 (H-8) and 7.15 (H-5) corresponding to 6,7-disubstituted coumarin. The presence of a doublet at δ 3.28 (2 H, d, $J \frac{1}{4} 7.5$, H-9) coupled with a multiplet at δ 5.26 (1 H, m, H-10) and two methyl signals at δ 1.68 and 1.74 indicated a prenyl function. The singlet at δ 3.87 was attributed to the methoxyl group. The MS showed [M⁺] at m/z 244, a base peak at 229 and a fragmentation pattern similar to that of suberosin. By comparison of

the obtained data with those reported for suberosin, compound 2 was identified as suberosin. The ^{13}C NMR spectral data showed 20 carbon signals confirming structure 2. Their assignments were addressed herein for the first time on the basis of several NMR experiments (DEPT, COSY and HETCOR). Compound 3 was identified as xanthyletin by comparison with an authentic sample (m.p., co-TLC and IR) and with literature data (m.p., IR, UV, MS, ^1H and ^{13}C NMR). The above data therefore prompted proposal of compound CLR 2F12 (a) to be suberosin. Compound CLR 2F12 (b) and xanthyletin had similar infrared spectra and therefore they were identical. For ^1H NMR, ^{13}C NMR (Table 8). The data in Table 8 prompted proposal of compound CLR 2F12 (a) to be suberosin as they compared well with literature information.

Physical and spectral data of compound CLR 2 F12

Compound CLR2F12 (a) was isolated as the major compound of DCM root extract of *C. limon* with dazzling bluish- violet-whitish appearance under UV light. The compound appeared as colourless crystals with a melting point of 119 °C and R_f equivalent to 0.8 (50 % hexane in ethyl acetate). ^1H NMR δ 7.61 (d, $j=9.5$ Hz, 1H, H-4), 7.58 (d, 1H, H-5), 6.25 (s, 1H, H-8), 6.16 (d, $j=9.5$ Hz, 1H, H-3), 6.76 (t, 1H, H-2'), 3.88 (s, 3H, OCH₃), 3.31 (m, 2H, H-1'), 1.76 (s, 3H, H-3'-CH₃), 1.69 (s, 3H, H-3'-CH₃). ^{13}C NMR (100MHz; CDCl₃; ppm) δ 161.39 (C-2), 160.57 (C-9), 154.40 (C-7), 143.50 (C-4), 133.53 (C-3'), 127.40 (C-10), 127.32 (C-5), 121.28 (C-2'), 112.68 (C-3), 111.82 (C-6), 98.42 (C-8), 55.76 (C-7 OCH₃), 27.69 (C-1'), 25.70 (C-3'-CH₃), 17.65 (C-3'-CH₃) (Table 9).

Table 9: ^{13}C (75 MHz) ^1H (360 MHz) data of Suberosin (CDCl₃, CD₃OD, δ in ppm) in Hz

Atom Number	Carbon -13	^1H
1	-	-
1'	27.69	3.31 (m, 2H)
2	161.39	-
2'	121.28	6.76.28 (t, 1H)
3	112.68	6.16 (d, 9.5Hz, 1H)
3'	133.53	-
4	143.50	7.61 (d, 9.5Hz, 1H)
5	127.32	7.58 (s, 1H)

6	111.82	-
7	154.40	-
8	98.42	6.25 (s, 1H)
9	160.57	-
10	127.40	-
C3'- CH3	17.65	1.76 (s, 3H)
C3' – CH3	25.70	1.69 (s, 3H)
C-7 – OCH3	55.76	3.88 (s, 3H)

IR spectra were recorded in KBr on a Shimadzu FTIR-8201PC IR spectrometer. The IR spectra of compound CLR 2F12 (a) corresponded to the IR spectra of suberosin, the IR spectrum of which had a frequency at KBr disk) $\nu = 1693$ (c = 0) cm^{-1} . These were consistent with what is reported in literature on suberosin.

MS retention time of compound CLR 2F12 (a) (Suberosin)

A single peak was obtained confirming the purity of the compound (Figure 2).

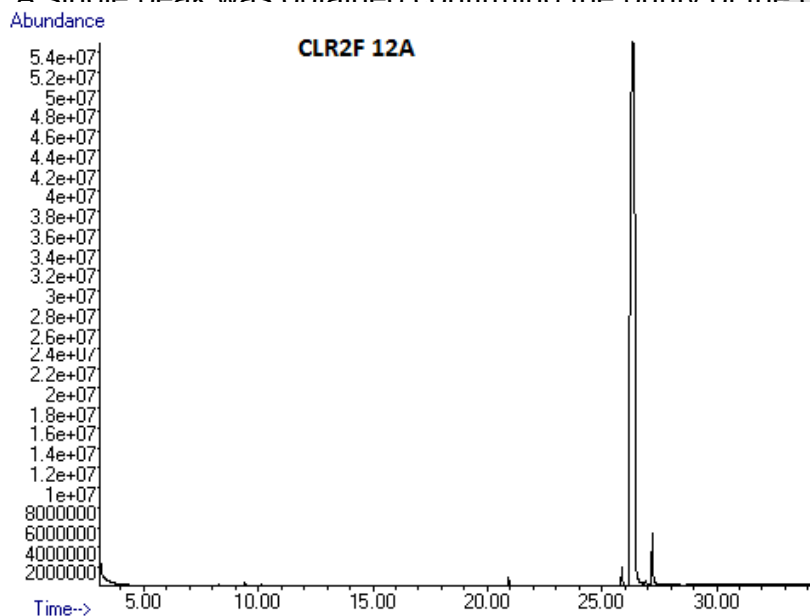


Figure 2: MS retention time of compound CLR- 2F12 (a) (Suberosin)

MS Spectra and structure of compound CLR 2F12

The above data were in agreement with those for suberosin (Figure 3). The molecular formula of compound CLR 2 F12 (a) was $\text{C}_{15}\text{H}_{16}\text{O}_3$ and therefore its molecular weight was 245. The NMR and IR data, the structure and the molecular weight (245.1) as given by the MS suited that of a coumarin known by the name suberosin. The purity of suberosin was estimated at 98 % with Gas Chromatography Analysis instrument.

Abundance

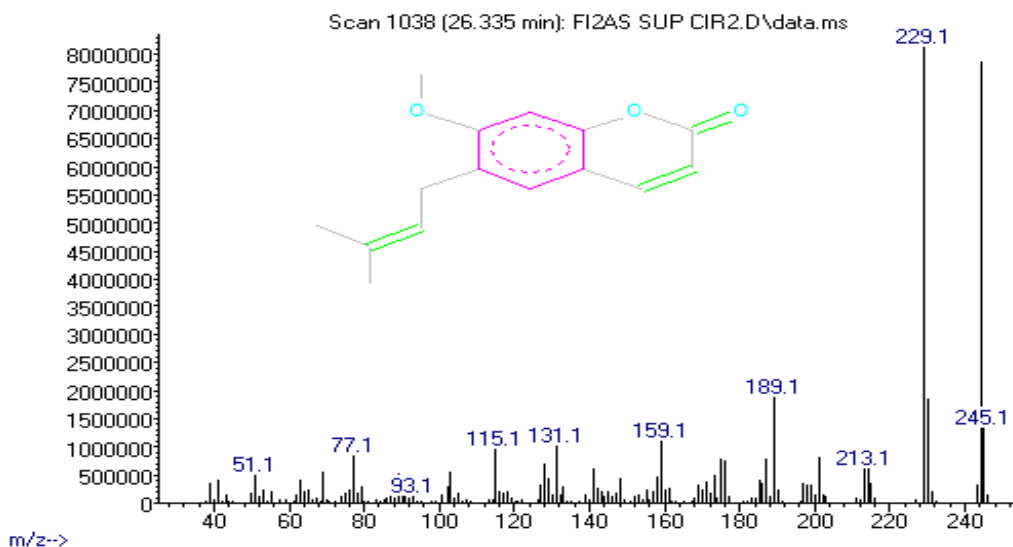


Figure 3: MS spectra, structure and molecular weight of compound CLR 2F12 (a) (Suberosin)

3.5.2 Xanthyletin

NMR, IR and MS results for compound CLR 2F12

Structural analysis was rooted on NMR data. The ^1H NMR spectrum demonstrated two doublet signals at δH 7.57 (1H; $J = 9.5$ Hz) and 6.20 (1H; $J = 9.5$ Hz). These signals were due to the presence of hydrogen atoms of conjugated double bond with carbonyl group. Two doublet signals at δH 6.33 (1H; $J = 9.9$ Hz) and 5.68 (1H; $J = 9.9$ Hz) were also due to alkenyl hydrogen atoms on vicinal carbon atoms. The singlet signals at δH 7.02 (1H) and 6.70 were assigned to aromatic hydrogen atoms distant from others. The singlet signal at δH 1.45 (6H) was assigned to hydrogen atoms of two methyl groups. ^{13}C NMR spectrum showed signals at δC 156.76, 155.38, 118.41, 112.95, and 77.63 which equated to non-hydrogenated carbon atoms. The signals at δC 143.19, 131.12, 124.65, 120.69, 113.41, and 104.31 equated to single-hydrogenated carbon atoms. The signal at δC 28.25 was assigned to two carbon atoms of the methyl groups. The 1D NMR spectra are typical of pyranocoumarin

construction. The two hydrogen signal at 7.02 (H-5) was linked to the carbon signals at δC 156.76 (C-7), 155.38 (C-9), 143.19 (C-4), and 120.69 (C-6). The hydrogen signal at δH 6.70 (H-8) was linked to the carbon signals at δC 156.76 (C-7), 155.38 (C-9), and 118.41 (C-6). The hydrogen signal at δH 6.34 (H-4') was linked to carbon signals at δC 156.76 (C-7), 124.66 (C-5), and 77.63 (C-2'). The hydrogen signal at δH 6.20 (H-3) was linked to the carbon signals at δC 161.2 (C-2) and 112.95 (C-10). The hydrogen signal at δH 5.68 (H-3') was linked to the carbon signals at δC 118.41 (C-6), 77.63 (C-2'), and 28.25 (C-1''/2''). The hydrogen signal at δH 1.45 (H-1''/2'') was linked to the carbon signals at δC 131.12 (C-3') and 77.63 (C-2'). These suited xanthyletin [25], a coumarin hitherto separated from *Brosimumgaudichaudii*[39]. The NMR spectrum of xanthyletin in CdCl_2 at 360 MHz. (CLR F12 (b) showed clearly the presence of two methyl groups at = 1.45 ppm(singlet), two signals corresponding to two protons which can be attributed to a double bond conjugated to a carbonyl group. Two further doublets ($j = 10$ Hz) as well as two singlets of one proton

each at 6,70 and 7,02 ppm suggested the presence of a dimethyl chromene unit on an aromatic ring possessing two protons in paraposition. The above data strongly favoured as structure coumarin with an annelated dimethyl chromene ring. NMR spectra were run on RKCM.07.26.06 360(1H: 360 MHz; 13C: 212 MHz) spectrometer in CDCl₃ employing TMS as internal standard or by remission to the solvent signal (CHCl₃ at δH 7.25 (Table 9). IR spectra were secured using KBr disks on a Shimadzu FTIR 8000, [default] FTIR 8400 Japan. The IR spectrum of 2 displayed peaks for an α, β-unsaturated carbonyl group that was reaffirmed and by comparing its physical properties with spectroscopic data (IR, 1H NMR), the substance xanthyletin is reported here. .

extract of *C. limon* with dazzling bluish- violet-whitish appearance under UV light. The compound was isolated as yellow white crystals, melting point: 122-124.0°C, R_f = 0.6 (hexane-ethyl acetate (1:1), 230R_f = 0.51 (hexane-ethyl acetate (2:1)). It was soluble in ethyl acetate, chloroform, ethanol, and methanol but not in water. ¹H NMR δH (7.57, d, J=9.5Hz, 1H), 7.02 (s, 1H, H-5), 6.72 (s, 1H, H-8), 6.70 (d, 9.9Hz, 2H-4'), 6.33 (d, J= 9.5Hz, 1H, H-3) 5.68 (d, J= 9.9Hz, 1H, H-3'), 1.45 (s, 6H, H-1'). ¹³C NMR (100MHz; CDCl₃; ppm), 156.76 (C-7), 155.38 2(C-9), 143.19 (C-4), 131.12 (C- 3'), 124.66 (C-5), 120.69 (C-4'), 118.41 (C-6), 112.95 (C-3), 112.64 (C-10), 104.31 (C-8), 77.28 (C-2), 28.25(C-3' -CH₃). Molecular Formula is C₁₄H₁₂O₃ and its chemical name is 8, 8 - dimethyl pyro (3, 2 - g) chromen-2-one.

Physical and spectral data of compound CLR 2 F12

Compound CLR2F12 (b) was isolated as the major compound of DCM root

Table 10: 1H (360 MHz) and 13C (360 MHz) data of Xanthyletin (CDCl₂, δ in ppm) in Hz. The structure of xanthyletin was ascertained by comparison of its physical data (mp, ¹H- and ¹³C- NMR) (Table 10) with reported values.

Atom Number	Carbon -13	1H
1	-	-
2	77.28	--
2'	77.63	-
3	112.95	6.33 (d, 9.5Hz, 1H)
3'	131.12	5.68 (d, 9.9Hz, 1H)
4	143.19	7.57 (d, 9.5Hz, 1H)
4'	120.69	6.70 (d, 9.9Hz, 1H)
5	124.66	7.02(s,1H)
6	118.41	-
7	156.76	-
8	104.31	6.72 (s, 1H)
9	155.38	-
10	112.64	-
CH ₃ /CH ₃	28.25	1.45 (s, 6H)

MS retention time of compound CLR 2F12 (b) (Xanthyletin)

Only one peak was obtained showing that the compound was pure (Figure 4).

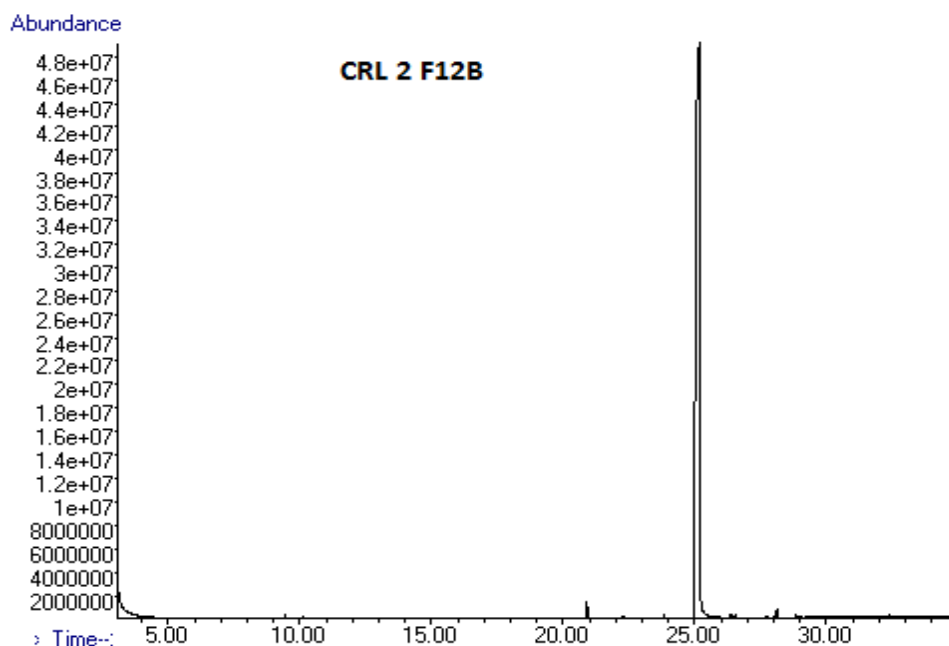
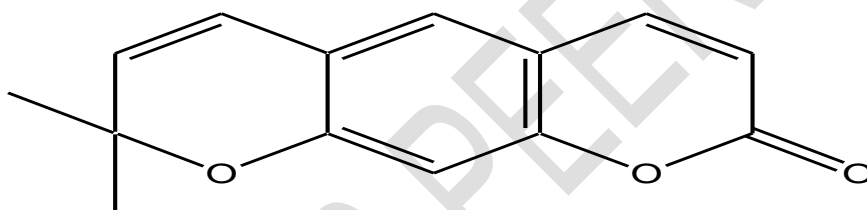


Figure 4: MS retention time of compound CLR 2F12 (b)

Chemical structure of compound CLR 2F12

The NMR and IR data, the structure and the molecular weight (228.1) suited that of a coumarin derivative known by the name xanthyletin. The molecular formula was found to be $C_{14}H_{12}O_3$ and therefore formula weight was 228.1 (Figure 5).



ii.

Figure 5: Chemical structure of compound CLR 2F12 (b) (xanthyletin)

3.5.3 Spinasterol

NMR data for compound MPL-1F37

The 1H -NMR spectrum of compound MPL-1F37 (a) specified vibrational harmony for free olefinic proton at α 5.16 (dd, $J=8, 8,$ 15.2 Hz), δ 5.15 (br s), and δ 5.02 (dd, $J=8.4, 15.2$ Hz); a carbonyl proton at δ 3.59; and six methyl protons at δ 1.03 (d, $J=6.8$ Hz), 0.85 (d, $J=6.4$ Hz), 0.84 (d, $J=6.0$ Hz), 0.81 (t, $J=7.2$ Hz), 0.80 (s), and 0.55 (s). The J-mod ^{13}C -NMR spectral data of MPL-1F37 (a) 9 indicated same vibrational quality for twenty-nine carbons with the following functionalities: four olefinic carbons, seven methane carbons, nine methylene carbons, a carbonyl carbon, two quaternary carbons, and six methyl carbons. These are characteristic resonances of a sterol with an alcohol and two olefinic bonds. NMR Spinasterol: Semisolid, Identity confirmed by 1H NMR, ^{13}C NMR and co-TLC. Spinasterol eluates when freed of the solvent provided 3, identified by co-TLC, 1H NMR (Figure 6).

Physical and spectral data of compound MPL-1F37

Compound MPL-1F37(a) had the following physical properties; white needle-like crystals. This pure compound was found to be a phytosteroid. ^1H NMR (CDCl_3 , (ppm), (400 MHz) δ 5.22 (1H, d, $j = 7.2$ Hz), δ 3.52 (m), δ 1.03 (3H, s), δ 0.94 (3H, d, $j = 8.4$ Hz), δ 0.86 (9H, m), δ 0.70 (3H, s); ^{13}C NMR (CDCl_3 , (ppm), 100 MHz). δ 11.8 (C-29), 12.0 (C-18), 18.7 (C-26), 19.0 (C-19), 19.4 (C-21), 19.7 (C-27), 21.1 (C-11), 23.1 (C-28), 24.3 (C-15), 26.1 (C-23), 28.2 (C-16), 29.2 (C-25), 31.7 (C-7), 31.9 (C-2), 31.9 (C-22), 34.0 (C-8), 36.1 (C-10), 36.5 (C-20), 37.3 (C-1), 39.8 (C-12), 42.3 (C-4), 42.3 (C-13), 45.8 (C-24), 50.1 (C-9), 56.1 (C-17), 56.8 (C-14), 71.8 (C-3), 121.7 (C-6), 140.8 (C-5) (Figure 6).

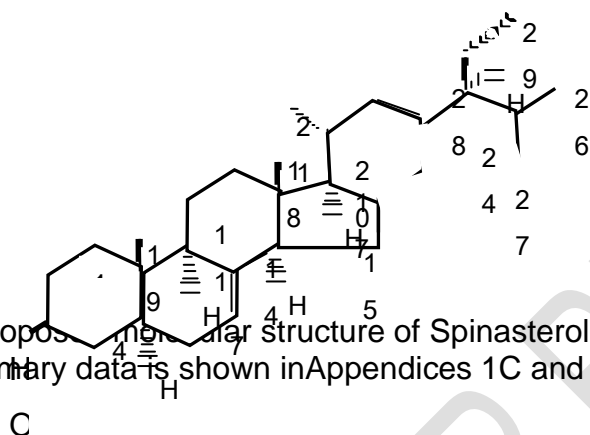


Figure 6: Proposed chemical structure of Spinasterol from NMR data (Detailed primary data is shown in Appendices 1C and 2I-L).

3.6 Antiplasmodial activity of the isolated compounds

Table 11 below summarises the IC_{50} s for the activity of the isolated compounds against falciparum strains. The standard drugs CQ, Mefloquine and Quinine were all more active than isolated compounds.

Table 11: Pharmacological and chemical data of pure compounds and reference drugs

Compound	Formula	IC_{50} $\mu\text{g/mL}$ against falciparum strain	
		W2	D6
1. CLR-2F12(a) Suberosin	$\text{C}_{15}\text{H}_{16}\text{O}_3$	26.7	53.1
2. CLR-2F12(b) Xanthyletin	$\text{C}_{14}\text{H}_{12}\text{O}_3$	1580.0	ND
3. MPL-1F37(a) Spinasterol		ND	43.2
4. STDS (a) CQ		0.040	0.011
	$\text{C}_{17}\text{H}_{16}\text{F}_6\text{N}_2\text{O}$		
b) Mefloquine	$\text{C}_{17}\text{H}_{16}\text{F}_6\text{N}_2\text{O}$	0.012	0.040
© Quinine	$\text{C}_{20}\text{H}_{24}\text{N}_2\text{O}_2$	0.103	0.031

Key: CQ-Chloroquine, ND-Not done, W2-multidrug resistant strain of *P. falciparum*; D6 was CQ sensitive strain of *P. falciparum*

This study has come up with two coumarins: suberosin with an IC_{50} of 26.7 $\mu\text{g/mL}$ for W2 and 53.1 $\mu\text{g/mL}$ for D6 strains as the most active compound and xanthyletin with an IC_{50} of 1580 $\mu\text{g/mL}$ for W2 strain both

from *C. limon* DCM root extract and spinasterol with an IC_{50} of 43.2 $\mu\text{g/mL}$ for D6 from *M. pyrifolia* leaves with a moderate activity. Work done previously [34]) showed that lemon flavonoids or eriocitrin and heparidin

taken in the diet are effective antioxidant *in-vivo*. Suberosin, a simple coumarin isolated from *C. limon* was the most active antiplasmodial (26.7 µg/ml α W2 and 53.1 µg/ml α D6 strains) whereas xanthyletin (1580 µg/ml α W2 strain) a pyranocoumarin also from the same plant had no activity. Spinasterol from *M. pyrifolia* leaves with a moderate activity (43.200 µg/ml α D6). A researcher [22] while working on *M. Pyrifolia* isolated sinapyldiangelate and acetyl-6-geranylgeraniol-19-oic acid as new compounds. The most active components in their test system were two diterpenes acetyl-6-geranylgeraniol-19-oic [IC₅₀, 12.9 µmol/L (PoW), 15.6 µmol/L (Dd2)] and E-phytol [IC₅₀ 8.5 µmol/L (PoW), 11.5 µmol/L (Dd2)]. Other compounds that have been isolated from *C. Limon* are bergapten, bergamottin, yakangelicin, citropten, imperatorin, isoimperatorin, isopimpinellin, phellopterin, prangol, scoparon, scopoletin, umbelliferone, umbelliprenin and xanthyletin [19]. Suberosin is structurally related to drugs such as propranolol, osthol, quinine, chloroquine and primaquine, and it inhibits anti-inflammatory activity and prevents growth of human peripheral blood mononuclear cells by means of modulating the transcription factors NF-Kb and NF-AT [6]. It is forms yellowish crystals with melting point of 88-89°C [36] as established in this present study. It has earlier been also isolated from the root bark of *C. nobilis* var. Sunki [44], the roots of *Citrus sinensis* (Rutaceae) [4], *Citropsis articulate* [24], *Citrus grandis* [7] and from the bark of *Xanthoxylum suberosum* [17]. Inhibition of aggregation and ATP release of rabbit platelets induced by arachidonic acid collagen, ADP, platelet activating factor (PAF) or U46619 (athromboxane A analog) was

characteristic of all the coumarins except xanthyletin [7].

Xanthyletin is structurally related to a drug named spectinomycin, and was also found to inhibit (100%) fungal growth and was isolated from the DCM extract of a plant known as *Pilocarpus riedelianus*, two shrubs found in North America, India and Bhutan; *Zanthoxylum alatum* and *Zanthoxylum americanum*, *Stauranthus perforatus* root, *S. perforatus* roots [32] and also from the bark of *Xanthoxylum americanum*, the roots of *X. ailanthoides*, the fruit of *Luvungascandens*, the wood of *Chloroxylon swietenia*, and *Citrus aurentifolia* (all Rutaceae). Also, it is found in the wood of *Brosimum* spp. (Moraceae). A closely related compound; xanthoxyletin with 100% inhibition on fungal growth has also been isolated from a methanolic extract of *C. limon*. It has antitumour and antibacterial activities and an efficient inhibitor of *Phytophthora citrooophthorain vitro* and also its synergistic effect was observed with other phenolics of Citrus [1]. As per work done before [38], existence of coumarins in the roots may protect the plant against microbial intrusion. Seselin, suberosin and xanthoxyletin have been characterized by ¹H NMR, ¹³C NMR, IR and UV spectra as standard methods [11].

Spinasterol, a phytosteroid, isolated from *Microglossa pyrifolia* leaves for the first time in this study, was the only active principle from this plant (MPL-1F37 (a) had an IC₅₀ of 43.169 µg/ml). It was found to structurally resemble adrenocortical antagonists; hydrocortisone, prenisolone, betamethasone, triamcinolone, 7-dehydrocholesterol and gonadal hormones. It has also been isolated from the stems of the

flowers of *Cucurbita maxima* Duch[10]. *Microglossapyrifolia* was documented for use as antiplasmodial remedy by Cameroon's traditional medicine users. A researcher [41] worked on *Microglossapyrifolia* and found new dihydrobenzofurans and triterpenoids from roots but not spinasterol. Work by a group [20] indicated that the content of *M. pyrifolia* leaf oil was predominantly gemacrene D (17.4%), careen (15.3%) or (E)-B-ocimene (13.4%), α -humulene (27.1-36.4%) and α -piniene

(18.7%) as opposed to the findings in this study.

Spinasterylglucoside and spinasterol have been separated as the main sterols from cell suspension cultures of *Saponaria officinalis* and determined by $^1\text{H-NMR}$, $^{13}\text{C-NMR}$, MS spectral data. Phytosterols are soluble in most organic solvents and contain alcohol functional groups but are insoluble in water.

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4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The conclusions associated with this study include:

(i) Hexane extracts of *Citrus limon* roots (CLR), *Microglossa pyrifolia* leaves (MPL), and *Vernonia glabra* leaves (VGL), dichloromethane (DCM) extracts of *Citrus limon* roots (CLR), *Achyranthesaspera* leaves (AAL), *Brideliacathartica* leaves (BCL), *Microglossapyrifolia* leaves (PML), and *Vernoniaglabra* leaves (VGL), and methanolic extracts of *Brideliacathartica* leaves (BCL), *Citrus limon* roots (CLR), and *Vernonia glabra* leaves (VGL) were active against the brine shrimp, *Artemiasalina*. Dichloromethane (DCM) root extract of *Citrus limon* roots (CLR) showed the highest activity *in vitro* against brine shrimp, *Artemiasalina* based on IC_{50} .

(ii) Dichloromethane (DCM) extract of *Citrus limon* roots (CLR) (7.017 $\mu\text{g/mL}$), aqueous extract of *Carrisa edulis* roots (CER) (8.054 $\mu\text{g/mL}$), DCM extract of *Brideliacathartica* leaves (BCL) (11.537 $\mu\text{g/mL}$), DCM extract of *Hensiacrinita* leaves (HCL) (13.336 $\mu\text{g/mL}$), methanolic extract of BCL (15.647 $\mu\text{g/mL}$), and hexane extract of *Achyranthesaspera* leaves (AAL) (18.087 $\mu\text{g/mL}$) demonstrated high antiplasmodial activity based on IC_{50} . Hexane extract of *Microglossapyrifolia* leaves (MPL) (21.376 $\mu\text{g/mL}$), methanolic extract of *Hensiacrinita* leaves (HCL) (24.805 $\mu\text{g/mL}$), aqueous extracts of *Brideliacathartica* leaves (BCL) (25.985 $\mu\text{g/mL}$), DCM extract of *Carrisa edulis* roots (CER) (30.074 $\mu\text{g/mL}$), hexane extract of *Citrus limon* roots (CLR) (30.092 $\mu\text{g/mL}$), hexane extract of *Brideliacathartica* leaves (BCL) (32.908 $\mu\text{g/mL}$), hexane extract

of *Hensiacrinita* leaves (HCL) (34.223 $\mu\text{g/mL}$), DCM extract of *Microglossapyrifolia* leaves (MPL) (34.88 $\mu\text{g/mL}$), aqueous extract of *Achyranthesaspera* leaves (AAL) (38.99 $\mu\text{g/mL}$), aqueous extract of *Hensiacrinita* leaves (HCL) (47.203 $\mu\text{g/mL}$), DCM extract of *Vernoniaglabra* leaves (VGL) (53.62 $\mu\text{g/mL}$), methanolic extract of *Carrisa edulis* roots (CER) (69.969 $\mu\text{g/mL}$), DCM extract of *Achyranthesaspera* leaves (AAL) (86.501 $\mu\text{g/mL}$), and aqueous extract of *Citrus limon* roots (CLR) (96.86 $\mu\text{g/mL}$) demonstrated moderate antiplasmodial activity based on IC_{50} . DCM extract of *Citrus limon* roots (CLR) (7.017 $\mu\text{g/mL}$) demonstrated the highest antiplasmodial activity based on IC_{50} .

(iii) Dichloromethane (DCM) extract of *Citrus limon* roots (CLR) owes its antiplasmodial activity to the presence of suberosin which together with other compounds synergistically works against *Plasmodium falciparum*. Further, Xanthyletin a compound without demonstrable antiplasmodial activity was also isolated from DCM extracts of *Citrus limon* roots. In addition, Spinasterol, a compound without demonstrable antiplasmodial activity was isolated from the *Microglossapyrifolia* leaves (MPL).

4.2 Recommendations

The observation that all the seven studied plants parts extracts including *Achyranthesaspera* leaves, *Brideliacathartica* leaves, *Microglossapyrifolia* leaves, *Vernonia glabra* leaves, *Hensiacrinita* leaves, *Carrisa edulis* roots, and *Citrus limon* roots demonstrated high to moderate antiplasmodial activity, supports their continued use as antimalarial drugs in Kilifi and Homa-bay.

Recommendations for further studies

Further, the compounds contributing to the antiplasmodial activity in these aqueous and organic extracts can be isolated, and characterized and identified using spectroscopic techniques based on bioassays.

(ii) Suberosin, the antiplasmodial compound isolated in DCM extracts of *Citrus limon* roots in this study should be subjected to *in vivo* antimalarial activity in rodent models such as infecting mice with *Plasmodium berghei* and treating the infected mice with varying doses of suberosin to confirm its antimalarial activity. If it has

moderate antimalarial activity, a drug that can cure malarial infection can be synthesized modeled upon its structure to confer it with a high *in vivo* antimalarial activity in addition to conferring it with a high *in vitro* activity against *P. falciparum*.

(iii) More work should be done on active antiplasmodial hexane, aqueous and methanolic extracts of *C. limon* roots in order to isolate, characterize and identify more compounds.

(iv) In addition, further work for example MS needs to be done on compound MPL-1 F37 (a) (Spinasterol) to confirm its identity.

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COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly used products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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