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RESEARCH ARTICLE

Spondias mombin: biosafety and GC–MS analysis of anti-viral compounds from crude leaf extracts

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Abstract

Essential oils are combinations of naturally occurring phytochemicals that, alone or in synergy with other compounds, can therapeutically attenuate disease-causing viral infections such as SARS-CoV-2, Ebola, and Marburg viruses. This study aimed to investigate the biosafety of and identification of antiviral phytochemicals of *Spondias mombin* (Linn) leaf crude extracts by GC–MS analysis. GC–MS analysis showed that the compound concentrations were dependent on the polarity of extracting solvent SMH (34), SMDCM (36), SMEA (12), SME (50) and SMM (36). Toluene (15.13%) and di-isooctyl phthalate (14.21%) were identified as the basic constituents of SMH. In SMDCM, n-nonadecanol-1 (19.64%) and eicosane (13.93%) were the main compounds, while in SMEA it was ethanol, 2-butoxy-(83.29%). Both SME and SMM showed the presence of Tetradecyl trifluoroacetate (15.43%). Pentadecanoic acid (12.18%), Propane, 2,2-diethoxy- (33.83%) and o-Xylene (15.87%). The identified antiviral compounds in the crude extracts, were D-Limonene (1.33%), p-Cymene (1.31%), Thymol (0.50%) and Carvacrol (0.87%) in SMM and SMH extracts, with Phytol, acetate being a common constituent in all the essential oils, except SMEA. In vitro cytotoxicity studies of crude *S. mombin* leaf extracts were performed using the MTT method in three cell lines: MCF-7, A-549 and HEK-293, with IC50 values between 15.91 and 178.5 µg/mL. Therefore, the results indicated that crude extracts from *S. mombin* leafs had low toxicity and could be used safely. Compared with hexane extracts (1), methanol extracts have more compounds with antiviral properties (3) and can be used as reusable therapeutic candidates, natural dietary supplements or in the fight against SARS-CoV-2, Ebola and Marburg viruses. This can be valuable in pharmaceutical preparations of drug candidates for the treatment of these viruses.

Keywords GC–MS · *Spondias mombin* · Plant extract · Essential Oils · Cytotoxicit

Introduction

Essential oils are naturally occurring mixtures of phytochemicals that, alone or in synergy with other compounds, therapeutically attenuate disease-causing viral infections such as SARS-CoV-2, Ebola, and Marburg viruses (Obi-Egbedi et al. 2012; Aromolaran and Badejo 2014). Natural products such as plant extracts, either as pure compounds or as standardized extracts, offer unlimited opportunities for new drug discovery due to the unparalleled availability of chemical diversity. According to the World Health Organization (WHO), more than 80% of the world's population relies on traditional medicine for their basic health needs (Santos Sampaio et al. 2018). Due to their natural properties, medicinal plants have been used to treat many diseases. Consequently, research has grown into the field of examining the potential properties and uses of terrestrial plant extracts to create potential nanomaterial-based drugs to treat diseases including cancer and viruses. Researchers have identified plant species with anticancer and antiviral properties, with a focus on plants used in herbal medicine in developing countries (Sabiu et al. 2015). However, there is a need to identify new drug candidates with chemotherapeutic, chemoprotective, and antiviral properties with little or no side effects on normal cells (Ishola et al. 2018).

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Despite the high availability of medicinal plant materials, relatively few have been thoroughly investigated, with reports on the detailed mechanisms of the adsorption process being limited (Obi-Egbedi et al. 2012).

Spondias mombin (S.M.), an essential oil-bearing plant, is a fructiferous tree that thrives in rainforests (Aromolaran and Badejo 2014) and coastal areas and is dispersed throughout the tropical regions of South America, Africa and Asia. *Spondias mombin* (*S. mombin*) has been used extensively in folk medicine and is known by various names (Aromolaran and Badejo 2014; Santos Sampaio et al. 2018). The *S. mombin* plan attains a height of 15–22 m and is commonly used to cure many diseases due to its potent bioactive principles, including tannins, saponins, flavonoids, phenolics and anthraquinone glycosides (Sabiu et al. 2015; Ishola et al. 2018).

This study aims to identify antiviral phytochemical compounds by using Gas Chromatography–Mass Spectrometry (GC–MS) in crude extracts of *S. mombin* (S.M.), serially and exhaustively extracted with increasing polarity.

The WHO has produced and licensed for use a variety of vaccinations as the number of infections rises (Li et al. 2021; Li and Lu 2020; Carvalho et al. 2021; Burgess et al. 2021; Mahase 2021). Notable vaccines (Connors et al. 2021) being provided in various regions of the world include; mRNA-1273 (Moderna) (World Health Organization 2021a), BNT162b2 (Pfizer/BioNTech) (World Health Organization 2021b; Liu et al. 2021), ChAdOx1 nCoV-19 (Astrazenac/Oxford) (Soto 2020; Voysey et al. 2021), (rAd26)/rAd5 (Sputnik V) (Soto 2020; Tulleken 2021; Jones and Roy 2021), and Janssen Ad26.COV2.S (Johnson and Johnson) (Douoguih 2021). Few medicines such as Chloroquine, Hydroxychloroquine, Remdesivir (GS-5734), Favipiravir, Ivermectin and Lopinavir/Ritonavir have also been extensively investigated and repurposed for the treatment of SARS-CoV-2 based on their previously reported potential as antiviral therapeutics (Savarino et al. 2003; Dan et al. 2020; Colson et al. 2020; Barlow et al. 2020; Dong et al. 2020; Wang et al. 2020; Awadasseid et al. 2021; Tu et al. 2020). The Food and Drug Administration subsequently approved Remdesivir, Ronapreve (Mahase 2021) to treat COVID-19 in hospitalized adults and pediatric patients (Goldman et al. 2021; Beigel et al. 2020).

To further investigate in vitro cytotoxic properties of these crude leaf extracts of S.M. using, (3-[4,5-dimethylthiazol-2-yl]-2,5 diphenyl tetrazolium bromide) (MTT) assay in three different cell lines: liver hepatocellular carcinoma cell lines, breast cancer (MCF-7), adenocarcinoma human alveolar basal epithelial cells (A-549) and human embryonic kidney cells (HEK-293).

Materials and methods

Collection of plant materials, reagents and instrumentations

The leaves of the medicinal plant *S. mombin* were collected from the Cape Coast (Coordinates: 5.114467, − 1.287032) Central Region of Ghana on 25/06/2019 at 11:30 am Central African Time with an average temperature of 25 °C, average humidity of 80% and an average pressure of 1009 bar. The plants were identified and authenticated at the Herbarium in the School of Life Sciences at the University of KwaZulu-Natal, Westville Campus. All chemicals and solvents used in this research work were of analytical reagent grade (A.R. grade) and purchased from Sigma Aldrich and Merck Millipore, South Africa. Hexane and ethyl acetate were purchased from Associated Chemical Enterprises, Dichloromethane, methanol, ethanol, 3-(4,5-Dimethyl-2-thiazolyl)-2,5-diphenyl-2H-tetrazolium bromide (MTT) salt Dulbecco's Modified Eagle Medium (DMEM), Eagle's Minimum Essential Medium (EMEM) and all other cell culture reagents, including Whatman filter paper were purchased from Sigma Aldrich, South Africa. Rotary evaporator and Soxhlet apparatus (Büchi-Germany) and Analytical balance (Lasec, South Africa) are some instrumentations used in the experiments.

Methodology

Various experimental procedures in this research were carried out after collecting the materials, such as the extractions using five different solvents of increasing polarity, preliminary phytochemical screening, Gas Chromatography–Mass Spectrometry (GC–MS) and in vitro cytotoxicity assay.

Study design

Preliminary phytochemical screening was carried out using the standard methods as reported (Dahiru et al. 2006; Kumar et al. 2007; Kwon et al. 2006; Parekh and Chanda 2007; Sengar et al. 2015; Wu et al. 2014; Iqbal et al. 2015). In brief, the leaves were air-dried at room temperature and pulverized to a fine powder. *S. mombin* leaf powder (20 g) was weighed using

an analytical balance and placed in the extractor of the Soxhlet apparatus with a total of 600 mL solvent measured into the distillation flask Serial exhaustive extraction method at a temperature of 70 °C, in triplicate, and involved successive extractions with bulk solvents of different polarities, namely hexane, dichloromethane, ethyl acetate, ethanol and methanol. The increasing solvent polarity was to ensure that a wide range of compounds with varying polarities was extracted (Nadembega et al. 2011). Each solvent extract was concentrated and dried using a rotary evaporator, and preserved in the refrigerator for future use in phytochemical screening and in vitro, isolation, purification and characterization (Rukshana et al. 2017). Interpretation of mass spectrum GC–MS was conducted using the National Institute Standard and Technology (NIST) database, having more than 62,000 patterns.

Specifications: Analysis by GC–MS using PerkinEmler Gas Chromatography (Clarus 580) equipped with MSD mass spectrometer (Clarus SQ8S) instrument with built-in autosampler. Column: Elite-5MS (30 m × 0.25 mm id × 0.25 µm). The oven temperature is programmed from 37 to 320 °C at a rate of 18–25 °C/min and held for 0.5 and 1.85 min at 18 and 320 °C, respectively. The injector temperature: 250 °C and MS Ion Source temperature: 280 °C with a full scan and solvent delay of 0–2.30 min. MS Scan Range was m/z 35–500 min 0.10 s. One microlitre of the samples was injected in He carrier gas at a 20 mL/min split flow.

The name of the compound, molecular weight (g/mol), molecular formula, retention time, percentage area (Area%), class of phytochemical, biological activity and reference (s) of the compounds were ascertained.

The MTT assay was performed using standard methods described by Hassan et al. (2019), with the crude extract (*S. mombin*) *in-vitro* cytotoxicity being evaluated in three different cell lines, the liver hepatocellular carcinoma cell lines-breast cancer (MCF-7), adenocarcinoma human alveolar basal epithelial cells (A-549) and human embryonic kidney cells (HEK-293) that were incubated. All three cells were sustained at 37 °C in a humidified atmosphere of 5% CO_2 in the air. The tested crude was dissolved in the cell culture media serving as a stock solution and diluted in the culture medium, resulting in 20, 40, 60, 80 and 100 µg/mL (Hassan et al. 2019). All three cell lines were transferred homogeneously (2.5×10^3) into a 96-well plate and incubated for 24 h to allow cell adherence. The ultimate treatment concentrations were reached by refilling the 96-well plate with a fresh culture medium (100 µL per well) that was composed of suitable concentrations of the studied solution crude extract. The culture medium alone was used for the control, while the blank contained only the culture medium in the 96-well plate with no cells. After 48 h of incubation, the culture medium and the studied samples in each well were withdrawn and substituted with fresh culture medium and MTT solution (5 mg/mL in PBS pH 7.4). The media and MTT solution were withdrawn after 4 h of incubation and immediately thereafter 100 µL of dimethyl sulfoxide was combined with each 96-well to solubilize the MTT formazan. The optical density of samples in the 96-well was measured on a microplate spectrophotometer (Spectrostar Nano, Germany) at a wavelength of 540 nm (Hassan et al. 2020), and the IC_{50} was calculated based on the previously reported method (Damiani et al. 2019). All experiments were completed in three replicates, the percentage (%) cell viability being calculated according to Eq. 1.

$$\% \text{ Cell Viability} = \frac{(\text{A540 nm treated cells})}{(\text{A540 nm untreated cells})} \times 100 \quad (1)$$

Results and discussions

Percentage yield and phytochemical screening

Table 1 presents the yield of *S. mombin* leaf extract obtained from hexane (SM-HEX), dichloromethane (SM-DCM), ethyl acetate (SM-EtOAc), ethanol (S.M.- EtOH) and methanol (S.M.- MeOH).

The result in Table 2 presents a preliminary phytochemical screening of *S. mombin* alcoholic crude leaf extracts. According to Nworu et al. (2007), the methanolic leaf extract of S.M. contained flavonoids, tannins, saponins, glycosides and triterpenes. Another author reported tannins, anthraquinones, flavonoids, cardiac glycosides and saponins being identified in SM-EtOH and SM-MeOH crude leaf extracts (Ayoka et al. 2005).

The experiments were done in triplicates and the preliminary phytochemical screening of the crude extract of *S.M* leaf indicated a positive test for anthraquinones derivatives, alkaloids, tannins, terpenoids, saponins and Cardiac glucoside, which are in line with reports by Ayoka et al.

Table 1 The amount of extract per solvent of extraction from 20 g S.M. dry powder

	SM-HEX extract	SM-DCM extract	SM-EtOAc extract	SM-EtOH extract	SM-MeOH extract	Total
Yield	2.072 g	0.1493 g	0.1802 g	0.1740 g	0.1801 g	2.7556 g
% Yield	10.36%	0.75%	0.90%	0.87%	0.90%	13.78%

Table 2 Preliminary phytochemical screening leaf extracts of *S. mombin*

Class of phytochemicals	Tests performed	*S. mombin* L. leaf extracts				
		SM-HEX	*SM-DCM*	*SM-EtOAc*	*SM-EtOH*	*SM-MeOH*
Alkaloids	Meyer	−	−	−	+	+
Anthraquinones derivatives	Borntrager's test	−	+	+	+	+
Steriods	Liebermann–Burchard test	+	+	+	−	−
Terpenoids	Liebermann–Burchard test	−	−	+	+	+
Saponins	Frothing	−	−	−	+	+
Flavonoids	Sulfuric acid test	+	−	−	−	−
Tannins	Ferric chloride test	+	+	+	+	+
Cardiac glucosides	Keller Killian	+	+	+	+	+

Legand: present (+), absent (−)

(2005) and Igwe et al. (2010). The absence of flavonoids and steroids was also reported by Igwe et al. (2010) and Maduka et al. (2014) in a study of anti-oxidant and microbial inhibitory effects of *S. mombin* leaf and stem bark extracts.

In vitro cytotoxicity of *S. mombin* in the different solvents of extraction

Biosafety is an essential criterion to establish the nontoxic dosages of any compound for biomedical applications. An MTT assay-based cytotoxicity study was employed to evaluate and quantify the cytotoxicity of newly extracted plant crude based on a previously used plant-reported method (Sonawane et al. 2015). The in vitro cell viability of the crude in Hex, DCM, EtOAc, EtOH and MeOH was studied in three different cell lines: liver hepatocellular carcinoma cell lines- breast cancer (MCF-7), adenocarcinoma human alveolar basal epithelial cells (A-549) and human embryonic kidney cells (HEK-293).

In vitro cytotoxicity of *S. mombin* in SM-EtOAc

Generally, the MTT assay demonstrated that the crude plant extract was safe in all three cell lines, as shown in Fig. 1A. The crude extracts demonstrated cell viability from 81.89 to 100% across all concentration from 20 to 100 µg/mL for A-549 cell line. In addition, the cell viability of the crude in HEK-293 was revealed to be from 78.43 to 100% viability in all crude extract concentrations, and for MCF-7, the cell viability was revealed to be from 73.47 to 100%. These results revealed that the crude leaf extract of SM-EtOAc shows that the cells were more viable in MCF-9 when compared to HEK-293 and A-549 cell lines. Therefore, these results suggested that cell viability was higher and more potent in MCF-7, and is greater than 75% viability, with ambiguous inhibitory concentration (IC_{50}) ranging from 41.78, 60.67 and 59.71 µg/mL in A-549, HEK-293 and MCF-7, which indicated that SM-EtOAc did not induce cytotoxicity on the cells.

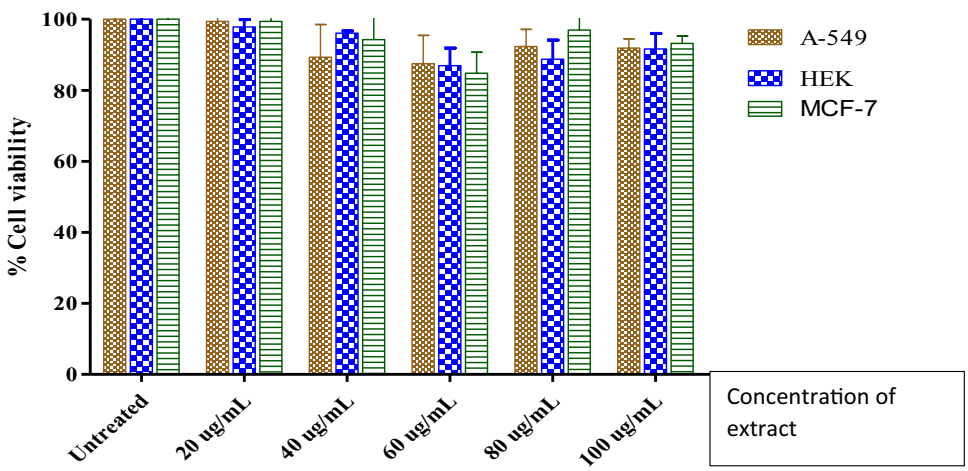


Fig. 1 Cell viability of S.M.-EtOAc leaf extract tested in three different cell lines: liver hepatocellular carcinoma cell lines—breast cancer (MCF-7), adenocarcinoma human alveolar basal epithelial cells (A-549) and human embryonic kidney cells (HEK-293)

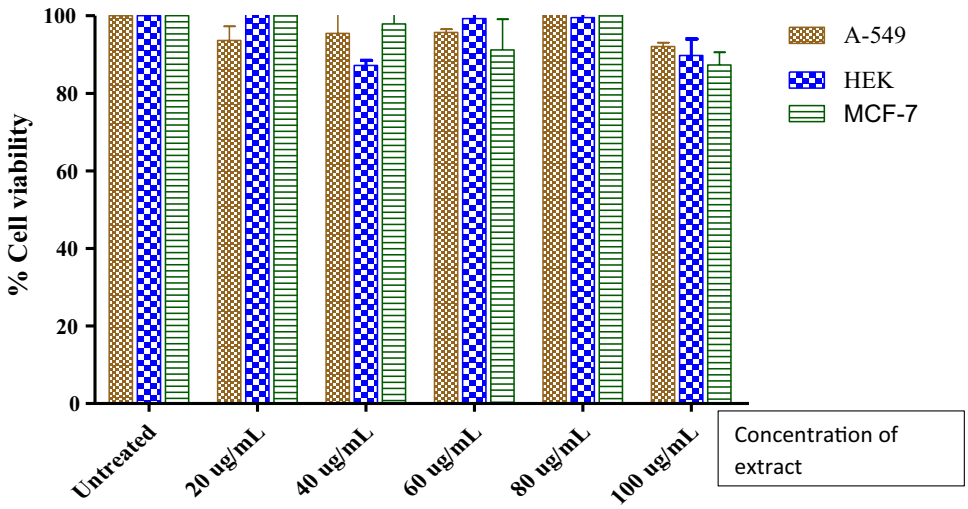


Fig. 2 Cell viability of SM-MeOH leaf extract tested in three cell lines: liver hepatocellular carcinoma cell lines—breast cancer (MCF-7), adenocarcinoma human alveolar basal epithelial cells (A-549) and human embryonic kidney cells (HEK-293)

In vitro cytotoxicity of *S. mombin* in SM-MeOH

As indicated in Fig. 2, the cell viability of the *S. mombin* methanolic (SM-MeOH) crude leaf extract was shown to be viable, with greater than 75% cell viability across all concentrations (20–100 µg/mL). The cell viability was shown to be from 82 to 100% in A-549, 86–100% in HEK-293 and 78% to 100% in MCF-7. These results demonstrated that the *S. mombin* crude extracted using methanol was more viable in MCF-7 than in A-549 and HEK-293 (MCF-7 > A-549 > HEK-293). The inhibitory concentration (IC_{50}) ranges from 36.42 to 15.91 and 178.5 µg/mL in A-549, HEK and MCF-7 respectively, which indicated that SM-MeOH did not induce cytotoxicity on the cells.

In vitro cytotoxicity of *S. mombin* in SM-EtOH

After exposure to the leaf extracted with ethanol (SM-EtOH), the viability of the cells was assessed by quantifying crystalline blue formazan formation (Abo et al. 1999). Figure 3 presented the breakdown of the cytotoxicity assay of the plant extract against the A549, HEK 293 and MCF-7 cells. The results indicate a high percentage of cell viability, from 83 to 100% for A549 cells, 93–100% for HEK-293, and 82–100% for MCF-7 cells for all concentrations of nanoplexes tested. The results confirm the biosafety of the plant extract, with greater than 75% cell viability indicating nontoxicity of the material to mammalian cells (Sikwal et al. 2016). The inhibitory concentration (IC_{50}) ranges from 19.59 to 15.81 and 51.55 µg/mL in A-549, HEK and MCF-7 respectively, which indicated that SM-EtOH did not induce cytotoxicity on the cells.

In vitro cytotoxicity of *S. mombin* in SM-HEX

The viability of cells after exposure to the SM-HEX was assessed by quantifying crystalline blue formazan formation (Abo et al. 1999). Figure 4 shows the breakdown of

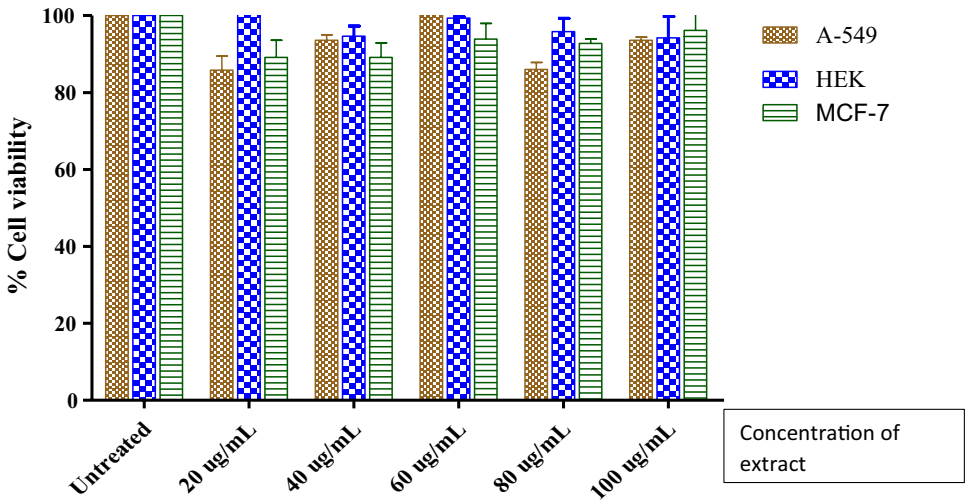


Fig. 3 Cell viability of plant (crude) extract in SM-EtOH tested in three cell lines: liver hepatocellular carcinoma cell lines—breast cancer (MCF-7), adenocarcinoma human alveolar basal epithelial cells (A-549) and human embryonic kidney cells (HEK-293)

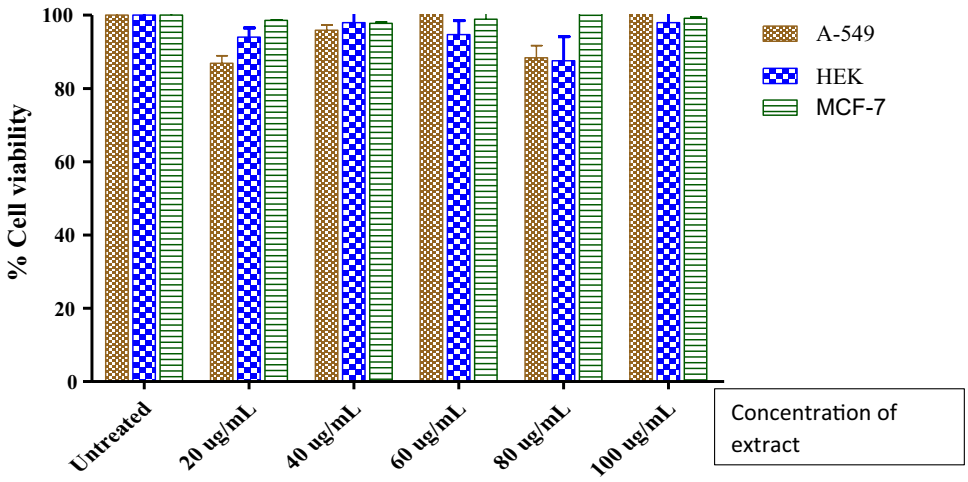


Fig. 4 Cell viability of SM-HEX leaf extract (crude) is tested in three cell lines: liver hepatocellular carcinoma cell lines—breast cancer (MCF-7), adenocarcinoma human alveolar basal epithelial cells (A-549) and human embryonic kidney cells (HEK-293)

the cytotoxicity assay of the plant extract against the A549, HEK-293 and MCF-7 cells. The results indicate a high percentage of cell viability, from 84 to 100% for the A549 cells, 8%–100% for the HEK-293, and 91–100% for the MCF-7 cells for all concentrations of nanoplexes tested. The results confirm the biosafety of the plant extract, with greater than 75% cell viability indicating the nontoxicity of the material to all the cell lines (Sikwal et al. 2016). The inhibitory concentration (IC_{50}) ranges from 38.55 to 35.56 and 60.52 µg/mL in A-549, HEK and MCF-7 respectively, which indicated that SM-HEX did not induce cytotoxicity on the cells.

In vitro cytotoxicity of *S. mombin* in DCM

Figure 5 shows the breakdown of the cytotoxicity assay of SM-DCM leaf extract against the A549, HEK 293 and MCF-7 cells. The results indicate a high percentage of cell viability, from 78 to 94% for A549 cells, 68–89% for HEK-293, and 86–100% for MCF-7 (MCF-7 > A-549 > HEK-293) for all concentrations of plant extract tested. The inhibitory concentration (IC_{50}) ranges from 113.2 to 56.48 and 16.39 µg/mL in A-549, HEK and MCF-7 respectively, which indicated that DCM did not induce cytotoxicity on the cells. The results confirm the biosafety of the plant extract, indicating the nontoxicity of the material to the mammalian cells (Sikwal et al. 2016). Based on these results, the plant extract can therefore be considered nontoxic and safe for cancer treatment.

GC–MS analysis of *S. mombin* L. crude leaf extracts

The suitability of the process for extracting phytochemicals from medicinal plants is an important step in determining the class of phytochemicals and their biological activities. The target compound can exist in different extraction solvents, ranging from polar to non-polar solvents. However, the choice of extraction solvent mainly depends on toxicity and availability (Zandoná et al. 2020). Therefore, the choice of five solvents with increasing polarity was made to be able to extract as many as possible phytochemicals that may possess antiviral properties.

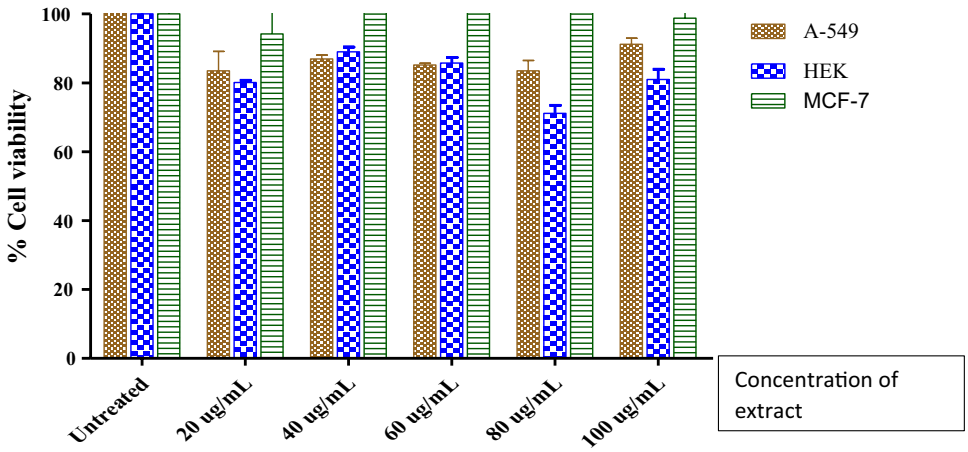


Fig. 5 Cell viability of S.M.-DCM crude extract tested in three cell lines: liver hepatocellular carcinoma cell lines—breast cancer (MCF-7), adenocarcinoma human alveolar basal epithelial cells (A-549) and human embryonic kidney cells (HEK-293)

The GC–MS analysis of *S. mombin* crude leaf extracts revealed various phytobioactive compounds as shown in the "Appendix" (Tables 3, 4, 5, 6, 7 and Figs. 6, 7, 8, 9, 10, 11, 12). Some of the common compounds found in all the extracts are Phytol, phytol acetate, Diisooctyl phthalate, Eicosane, Tetradecane, Ascorbic acid and Phthalic acid. Toluene (15.13%) and Diisooctyl phthalate (14.21%) were identified as the significant components of SMH. However a monoterpene, occurring in the Hexane crude extract of *S. mombin,* Carvacrol with molecular mass of 150.22 g/mol and a formula of $C_{10}H_{14}O$ was identified and has been reported by other authors to possess antiviral effect against herpes simplex virus types 1 (HSV-1), SARS-CoV-2, immunomodulatory and anti-inflammatory (Elbe et al. 2020; Javed et al. 2020). In addition to Carvacrol being identified as antiviral, other antiviral phytochemicals were also identified in polar crude extracts such as, methanol leaf extracts of *S. mombin* (SMM). These compounds with reported antiviral activities were D-Limonene has antiCoVID properties (Zahi et al. 2015; Panikar et al. 2021), p-Cymene, Thymol. This confirms the traditional use of leaf extracts of *S. mombin* in the treatment of viral diseases (Osuntokun 2019; Abubakar et al. 2022; Maria et al. 2022).

In SMDCM, n-Nonadecanol-1(19.64%) and Eicosane (13.93%) are the major compounds, while in SMEA, Ethanol, 2-butoxy- (83.29%). Both SME and SMM showed Tetradecyl trifluoroacetate (15.43%), Pentadecanoic acid (12.18%), Propane, 2,2-diethoxy- (33.83%) and o-Xylene (15.87%).

The SME extract chromatogram analysis revealed the highest number of compounds, i.e., 51, whereas the SMEA extract revealed the lowest number at 12, with almost all exhibiting various pharmacological activities. Phytol is an acyclic diterpene alcohol that shows anti-cancer, antimicrobial and anti-oxidant activities. Hexadecanoic acid, or palmitic acid, is known to possess anti-cancer, anti-inflammatory and anti-microbial activity. Eicosane, an alkane, is also known to exhibit anti-tumor and anti-cancer effects (Sivasubramanian and Brindha 2013). Tetradecane is an alkane that possesses anti-fungal, anti-tumor, anti-cancer and anti-proliferative activities (Guo et al. 2008; Erenler et al. 2016). While the majority of the compounds are yet to be illustrated in detail, more research attempts are needed to isolate, characterize and assess these compounds from *S.mombin* leaves to justify their various pharmacological relevance.

Conclusion

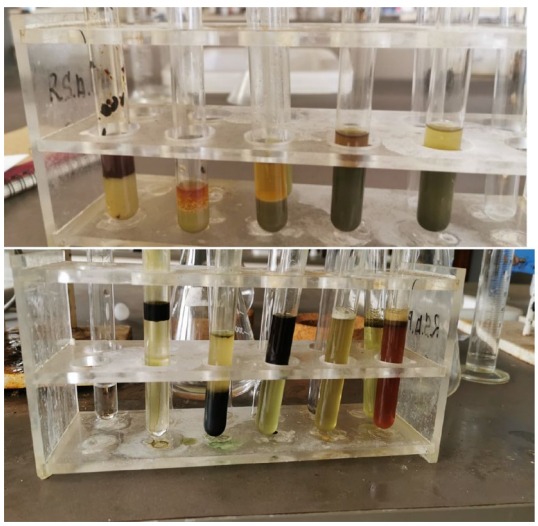
Results obtained from the phytochemical compounds of essential leaf oils (EO) from *S. mombin* (Linn) indicated that a total of 169 compounds was identified in SMH, SMDCM, SMEA SME, and SMM. Identified antiviral compounds in the EOs, were D-Limonene (1.33%), p-Cymene (1.31%), Thymol (0.50%) in SMM and Carvacrol (0.87%) in SMH extracts respectively. Phytol, acetate is a common constituent in all the essential oils except SMEA.

The in vitro cytotoxicity study of EOs of SM leaf extracts MCF-7, A-549 and HEK-293 indicate low toxicity. The *S. mombin* essential oils showed IC_{50} ranges between 15.91 and 178.5 µg/mL. The methanolic extract has the most compounds with antiviral properties that can be used as repurposing therapeutic candidates, natural supplements, or valuable for drug formulation in the fight against SARS-CoV-2, Ebola and Marburg viruses.

Further isolation of essential oil compounds, in silico and in vitro SARS-CoV-2 and Ebola or Marburg virus with A-549/HeLa infected cell lines from these essential oils is under process. Overall, this *S. mombin* leaf extract is an auspicious and treasured source of different bioactive compounds that could have tremendous health benefits.

To the best of our knowledge, Carvacrol and 11-Methyldodecanol have been identified for the first time in *S. mombin* leaf extract.

Appendix



Preliminary phytochemical screening of *S. mombin* leaf extracts.

Fractionated leaf extracts of *S. mombin.*

Spondias mombin dried leaf powder.
See Tables 3, 4, 5, 6 and 7.

Table 3 The GC–MS analysis data of SMH chromatogram with biological activity

Peak	Name	Molecular weight (g/mol)	Molecular formula	Retention time (min)	Area%	Class of phytochemical	Biological activity	References
1	Heptane, 2-methyl-	114.23	C_8H_{18}	3.569	3.06	Hydrocarbon	–	–
2	Toluene	92.14	C_7H_8	3.629	15.13	Hydrocarbon	Anxyolitic effect, depressant effect Induces locomotor hypersensitivity	Armenta-Reséndiz et al. (2019), Rangel-Sánchez et al. (2014)
3	Heptane, 2,4-dimethyl-	128.25	C_9H_{20}	3.960	2.63	Hydrocarbon	–	–
4	Tetrachloroethylene	165.8	C_2Cl_4	4.077	4.10	Chlorinated hydrocarbon	Anticonflict effect Anthelmintic activity in vivo in dogs	Umezu et al. (1997), Miller (1966)
5	2,4-Dimethyl-1-heptene	126.24	C_9H_{18}	4.463	0.43	Hydrocarbon	–	–
6	Ethylbenzene	106.16	C_8H_{10}	4.775	0.79	Aromatic	–	–
7	o-Xylene	106.16	C_8H_{10}	4.897	2.49	Aromatic	–	–
8	Cyclopropane, 2-chloro-1,1,3-trimethyl-	118.6	$C_6H_{11}Cl$	5.203	2.67	Chlorinated Alkane	–	–
9	Nonane	128.25	C_9H_{20}	5.240	0.30	Hydrocarbon	–	–
10	Benzene, 1-ethyl-3-methyl	162.27	$C_{12}H_{18}$	6.132	0.32	Aromatic	–	–
11	Undecane	156.31	$C_{11}H_{24}$	6.614	0.98	Hydrocarbon	–	–
12	Benzene, 1-methyl-3-propyl-	134.22	$C_{10}H_{14}$	7.370	0.31	Aromatic	–	–
13	Benzene, 1,4-diethyl-	134.22	$C_{10}H_{14}$	7.454	0.61	Aromatic	–	–
14	5-Chloropentanoic acid, 6-ethyl-3-octyl ester	276.84	$C_{15}H_{29}ClO_2$	7.713	0.40	Aromatic	–	–
15	Undecane, 4,7-dimethyl-	184.36	$C_{13}H_{28}$	7.970	0.38	Hydrocarbon	–	–
16	2-Isopropyl-5-methyl-1-heptanol	172.31	$C_{11}H_{24}O$	10.490	0.44	Primary alcohol	–	–
17	Carvacrol	150.22	$C_{10}H_{14}O$	10.537	0.87	monoterpene	Antiviral effect against herpes simplex virus types 1 (HSV-1), SARS-CoV-2, immunomodulatory, anti-inflammatory, and antiviral effects	Elbe et al. (2020), Javed et al. (2020)
18	11-Methyldodecanol	200.36	$C_{13}H_{28}O$	10.591	0.73	Alcohol	–	–
19	1-Tetradecene	196.37	$C_{14}H_{28}$	11.552	2.24	Hydrocarbon		–
20	Tetrapentacontane, 1,54-dibromo-	917.2	$C_{54}H_{108}Br_2$	13.266	0.37	Hydrocarbon	–	–
21	Dichloroacetic acid, 4-hexadecyl ester	353.4	$C_{18}H_{34}Cl_2O_2$	13.623	0.40	–	–	–
22	n-Nonadecanol-1	284.5	$C_{19}H_{40}O$	29.505	7.81	Primary alcohol	–	Ahmad et al. (2021)

Table 3 (continued)

Peak	Name	Molecular weight (g/mol)	Molecular formula	Retention time (min)	Area%	Class of phytochemical	Biological activity	References
23	Tetradecanoic acid	228.37	$C_{14}H_{28}O_2$	15.514	1.40	Carboxylic acid	Antimicrobial, antispasmodic and anti-inflammatory effects	Sosa et al. (2016)
24	Heneicosane	296.6	$C_{21}H_{44}$	15.898	0.35	Saturated hydrocarbon	Antimicrobial activity	Vanitha et al. (2020)
25	Phytol, acetate	338.6	$C_{22}H_{42}O_2$	16.394	0.55	Terpene Alcohol	Anti-oxidant and Antimicrobial	Syeda and Riazunnisa (2020)
26	2-Pentadecanone, 6,10,14-trimethyl-	268.5	$C_{18}H_{36}O$	16.489	0.55	Ketone	Has antibacterial effect in curing diarrhoea	Nayak et al. (2020)
27	l-(+)-Ascorbic acid 2,6-dihexadecanoate	652.9	$C_{38}H_{68}O_8$	18.813	8.70	Vitamin-C	Anticancer	Hase et al. (2017)
28	n-Tetracosanol-1	354.7	$C_{24}H_{50}O$	19.292	4.88	Alcohol	Antioxidant	Amudha et al. (2018)
29	Phytol	296.5	$C_{20}H_{40}O$	22.563	1.80	Diterpene alcohol	Antioxidant,anticonvulsant and antinociceptive effects	Silva et al. (2014), Santos et al. (2013), Costa et al. (2012), Shibula and Velavan (2015)
30	Linoleic Acid	280.4	$C_{18}H_{32}O_2$	23.658	3.34	fatty acids	Anti-bacteria action against the growth of Staphylococcus aureus NCTC 8325	Greenway and Dyke (1979)
31	cis-9-Hexadecenal	238.41	$C_{16}H_{30}O$	23.945	4.01	mono-unsaturated fatty-aldehyde	Antimelanogenic	Kumari and Shankar (2021)
32	Stearic Acid	284.5	$C_{18}H_{36}O_2$	24.88	2.58	Acid	Immunomodulatory effect	Bergamo et al. (2014)
33	1-Heptacosanol	396.7	$C_{27}H_{56}O$	25.953	3.59	Alcohol	Antibacterial, nematicidal and antioxidant effects	Murugan and Iyer (2014)
34	Diisooctyl phthalate	390.6	$C_{24}H_{38}O_4$	32.768	14.21	Plasticizer	Anti-microbial activity, and inhibited the growth of food-borne harmful bacteria	Naz et al. (2021), Yang et al. (2020)

Table 4 The GC–MS analysis data of SMDCM chromatogram with biological activity

Peak	Name	Molecular weight (g/mol)	Molecular formula	Retention time (min)	Area%	Class of phytochemical	Biological activity	References
1	Toluene	92.14	C_7H_8	3.631	9.80	Hydrocarbon	Anxyolitic effect, depressant effect and Induces locomotor hypersensitivity	Armenta-Reséndiz et al. (2019), Riegel and French (1999)
2	Cyclopropanecarboxylic acid, 2-pentyl ester	156.22	$C_9H_{16}O_2$	4.006	0.14	–	–	–
3	Ethanol, 2-butoxy-	118.17	$C_6H_{14}O_2$	5.350	1.23	Alcohol	–	–
4	Cyclobutane, 1,1-bis (1-methyl-ethenyl-, trans	136	$C_{10}H_{16}$	7.085	3.34	Hydrocarbon	–	–
5	Trans-p-Mentha-2,8-dienol	152.23	$C_{10}H_{16}O$	9.157	1.45	Monoterpene alcohol	Anti-proliferative and antioxidant	Alam et al. (2019), Brito et al. (2012), Bayala et al. (2018)
6	Cyclohexene,3-(3-methyl-1-butrnyl)-,(E)-	150	$C_{11}H_{18}$	9.732	0.19	Hydrocarbon	–	–
7	Cis-p-mentha-1(7),8-dien-2-ol	152.23	$C_{10}H_{16}O$	9.775	0.16	Monoterpene alcohol	Anti-proliferative and antioxidant	Brito et al. (2012), Bayala et al. (2018)
8	2-Hydroxy-iso-butyrophenone	164.2	$C_{10}H_{12}O_2$	10.416	0.56	Ketone	–	–
9	Tetradecene	196.37	$C_{14}H_{28}$	11.632	2.16	Hydrocarbon	–	–
10	Fermine	194.18	$C_{10}H_{10}O_4$	12.260	0.33	Plastersizer	–	–
11	Propiohydrazone, 3-benzoylamino-N2-(2-hydroximino-1-methylpropylideno)	290	$C_{14}H_{18}N_4O_3$	12.630	0.63	–	–	–
12	Pentadecane	212.41	$C_{15}H_{32}$	12.715	0.22	Hydrocarbon	Anti-microbial against Leishmania parasites	Bruno et al. (2015)
13	Phenol, 2,4-bis(1,1-dimethylethyl)-	206.32	$C_{14}H_{22}O$	12.903	0.15	Monoterpene	Antifungal activity	Rangel-Sánchez et al. 2014)
14	2(4H)-Benzofuranone, 5,6,7,7a-tetrahydro-4,4,7a-trimethyl-, (R)-	180	$C_{11}H_{16}O_2$	13.255	0.26	Furan	Antidiabetic and anti-obesity property	Carranza et al. (2020)
15	Hexamethylene diacrylate	226.27	$C_{12}H_{18}O_4$	13.598	3.91	–	–	–
16	n-Pentadecanol	228.41	$C_{15}H_{32}O$	13.673	2.83	Aliphatic alcohol	–	Naquvi et al. (2014)
17	Heptadecane	240.5	$C_{17}H_{36}$	12.742	0.46	Hydrocarbon	Antioxidant activity	Shyamala and Manikandan (2019)
18	Dihydrojasmone	166.26	$C_{11}H_{18}O$	13.912	0.27	Aromatic compound	–	–
19	3-Benzoyl-2-t-butyl-4-methyl-oxazolidin-5one	261	$C_{15}H_{19}NO_3$	14.175	0.60	–	–	–
20	Heptadecane,3-methyl-	254.5	$C_{18}H_{38}$	15.527	0.21	–	–	–
21	Tridecane,3-methylene	196.37	$C_{14}H_{28}$	15.721	6.52	Hydrocarbon	–	–
22	n-Nonadecanol-1	284.5	$C_{19}H_{40}O$	15.816	19.64	Primary alcohol	–	–
23	Phytol, acetate	338.6	$C_{22}H_{42}O_2$	16.393	1.06	Terpene Alcohol	Antioxidant and Antimicrobial	Syeda and Riazunnisa (2020)

Table 4 (continued)

Peak	Name	Molecular weight (g/mol)	Molecular formula	Retention time (min)	Area%	Class of phytochemical	Biological activity	References
24	2-Pentadecanone,6,10,14-trimethyl-	268.5	$C_{18}H_{36}O$	16.484	0.29	–	–	–
25	Octadecane,4-methyl-	268.5	$C_{19}H_{40}$	16.484	0.15	–	–	–
26	7-Octadecyne, 2-methyl-	264.5	$C_{19}H_{36}$	16.754	0.29		–	–
27	Phytol	296.5	$C_{20}H_{40}O$	17.052	0.49	Diterpene alcohol	cancer-preventive Antimicrobial, anti-inflammatory anti-diuretic Antioxidant	Silva et al. (2014), Santos et al. (2013), Costa et al. (2012), Shibula and Velavan (2015)
28	7,9-Di-tert-butyl-1-oxaspiro(4,5) deca-6,9-diene-2,8-dione	276.4	$C_{17}H_{24}O_3$	17.631	0.72	Flavonoid	Antibacterial activity	Monisha and Vimala (2018)
29	Hexadecanoic acid,methyl ester	270.5	$C_{17}H_{34}O_2$	17.834	1.56	Fatty acid methyl ester	Anti-oxidant, decrease blood cholesterol, anti-inflammatory	Belakhdar et al. (2015)
30	Phthalic acid,butyl hexyl ester	306.4	$C_{18}H_{26}O_4$	18.099	2.11	phthalate ester	–	–
31	1-(+)-Ascorbic acid 2,6-dihexadeconoate	652	$C_{38}H_{68}O_8$	18.505	0.25	Acid	Anti-oxidant and anti-inflammatory	Dulara et al. (2019)
32	Tridecane,3-methylene-	196.37	$C_{14}H_{28}$	18.699	5.99	Hydrocarbon	–	–
33	n-Tetracosanol-1	354.7	$C_{24}H_{50}O$	19.105	13.85	Alcohol	Anti-oxidant	Amudha et al. (2018)
34	Nonadecane, 2,3-dimethyl-	296.6	$C_{21}H_{44}$	20.873	0.39	Hydrocarbon	–	
35	1-Heptacosanol	396.7	$C_{27}H_{56}O$	25.934	4.02	Alcohol	Anti-bacterial, antioxidant and nematicidal effect	Naquvi et al. (2014), Sultana et al. (2010)
36	Eicosane	282.5	$C_{20}H_{42}$	26.230	13.93	Hydrocarbon	Anti-oxidant and anti-inflammatory effect	Dulara et al. (2019)

Table 5 The GC–MS analysis data of SMEA chromatogram with biological activity

Peak	Name	Molecular weight	Molecular formula	Retention time (min)	Area%	Class of phytochemical	Biological activity	References
1	Tetrachloroethylene	164	C_2C_{l4}	4.107	0.40	Chlorinated hydrocarbon	Anticonflict effect Anthelmintic activity in dogs	Umezu et al. (1997), Miller (1966)
2	Alpha-Hydroxyisocaproic acid	132	$C_6H_{12}O_3$	4.190	0.46	Acid	–	–
3	2-Hexanol, 2-methyl-	116	$C_7H_{16}O$	4.530	1.61	Primary alcohol	–	–
4	Ethanol, 2-butoxy-	118	$C_6H_{14}O_2$	5.453	83.29	Primary alcohol	Antibacterial effect	Elshafie et al. (2017)
5	(R)-(-)-2,2-Dimethyl-1,3-dioxolane-4-methanol	132	$C_6H_{12}O_3$	5.898	0.24	–	–	–
6	Ethane, pentachloro-	200	C_2HC_{l5}	6.442	0.32	Chlorinated hydrocarbon	Anti-parasitic effect on *F. hepatica*	Bartlet (1976)
7	Ethanol, 1-(2-butoxyethoxy)-	162	$C_8H_{18}O_3$	9.151	11.12		–	–
8	2(4H)-Benzofuranone, 5,6,7,7a-tetrahydro-4,4,7	180	$C_{11}H_{16}O_2$	13.249	0.37	Ketone	Antifungal, antioxidant and antibacterial effect	Anyasor et al. (2015)
9	Dihydrojasmone	166	$C_{11}H_{18}O$	13.905	0.23	Aromatic compound	–	–
10	4-[3,4-Dimethoxycyclohexyl]-n-butanol	216	$C_{12}H_{24}O_3$	14.087	0.41	Alcohol	–	–
11	1,9,12,15-Octadecatetraene, 1-methoxy-	276	$C_{19}H_{32}O$	14.169	0.29	–	–	–
12	Acetic acid, 2-(2,2,6-trimethyl-7-oxa-bicyclo[4.1	238	$C_{14}H_{22}O_3$	15.878	1.25	–	–	–

GC–MS chromatogram: crude leaf extracts *S. mombin* (Linn)

See Figs. 6, 7, 8, 9, 10, 11 and 12.

Table 6 The GC–MS analysis data of SME chromatogram with biological activity

Peak	Name	Molecular weight	Molecular formula	Retention time (min)	Area%	Class of phytochemical	Biological activity	References
1	Leucinic acid	132.16	$C_6H_{12}O_3$	4.185	1.41	Valeric acid	–	–
2	Cyclohexene, 3-(1-methyl-ethyl)-	124.22	C_9H_{16}	5.072	0.33		–	–
3	Ethanol, 2-butoxy-	118.17	$C_6H_{14}O_2$	5.397	0.68	Primary alcohol	–	–
4	Silane, [3-(2,3-epoxypropoxy) propyl]ethoxydimethyl-	218.36	$C_{10}H_{22}O_3Si$	6.505	1.40	–	–	–
5	tert-Butyldimethylsilyl 2-acetoxyacetate	232.35	$C_{10}H_{20}O_4Si$	9.089	0.53	–	–	–
6	Undecane, 6-ethyl-	184.36	$C_{13}H_{28}$	10.135	0.52	–	–	–
7	Nonane, 3-methyl-5-propyl-	184.36	$C_{13}H_{28}$	10.483	0.91	Hydrocarbon	Prevent osteoporosis	Diwan et al. (2011)
8	Phenol, 3-methyl-5-(1-methyl-ethyl)-, methylcarbamate	207.27	$C_{12}H_{17}NO_2$	10.601	0.45	Alkylbenzene	–	–
9	Dodecane, 2,6,11-trimethyl-	212.41	$C_{15}H_{32}$	11.345	0.39	Alkane	–	–
10	1-Tetradecene	196.37	$C_{14}H_{28}$	11.545	2.07	Hydrocarbon	–	–
11	Tetradecane	198.39	$C_{14}H_{30}$	11.627	1.64	Hydrocarbon	Antimicrobial, antipyretic, antihelmintic, and Tuberculosis effect	Diwan et al. (2011)
12	Dodecane, 2,6,11-trimethyl-	212.41	$C_{15}H_{32}$	12.711	1.15	Alkane	–	
13	Phenol, 2,4-bis(1,1-dimethyl-ethyl)-	206.32	$C_{14}H_{22}O$	12.929	0.60	Phenol	Antifungal activity	Diwan et al. (2011)
14	2(4H)-Benzofuranone, 5,6,7,7a-tetrahydro-4,4,7a-trimethyl-	180.24	$C_{11}H_{16}O_2$	13.250	0.92	Ketone	Antifungal, antioxidant and antibacterial effects	Anyasor et al. (2015)
15	Tetradecyl trifluoroacetate	310.39	$C_{16}H_{29}F_3O_2$	13.662	15.43	–	–	–
16	Heptadecane, 2,6,10,15-tetramethyl-	296.6	$C_{21}H_{44}$	13.730	2.23	Hydrocarbon	–	–
17	2-Undecenal	168.28	$C_{11}H_{20}O$	13.775	0.60	Hydrocarbon	Anti-leshmanial, Antibacterial and Anti-cancer activities	Diwan et al. (2011)
18	1,2-Oxathiane, 6-dodecyl-, 2,2-dioxide	304.5	$C_{16}H_{32}O_{3S}$	13.899	0.37	–	Antimicrobial activity	Anbukumaran et al. (2021)
19	Benzene, (1-pentylhexyl)-	232.4	$C_{17}H_{28}$	14.040	0.29	Alkylbenzene	–	Shoubaky and Salem (2014)
20	Benzene, (1-butylheptyl)-	232.4	$C_{17}H_{28}$	14.081	0.64	Alkylbenzene	–	Shoubaky and Salem (2014)
21	Benzene, (1-propyloctyl)-	232.4	$C_{17}H_{28}$	14.187	0.61	Alkylbenzene	–	Shoubaky and Salem (2014)
22	Benzene, (1-ethylnonyl)-	232.4	$C_{17}H_{28}$	14.416	0.38	Alkylbenzene	–	Shoubaky and Salem (2014)
23	Benzene, (1-methyldecyl)-	232.4	$C_{17}H_{28}$	14.812	0.46	Alkylbenzene	–	Shoubaky and Salem (2014)
24	Benzene, (1-pentylheptyl)-	232.4	$C_{17}H_{28}$	15.038	0.38	Alkylbenzene	–	Shoubaky and Salem (2014)
25	Benzene, (1-butyloctyl)-	232.4	$C_{17}H_{28}$	15.095	0.41	Alkylbenzene	–	Shoubaky and Salem (2014)

Table 6 (continued)

Peak	Name	Molecular weight	Molecular formula	Retention time (min)	Area%	Class of phytochemical	Biological activity	References
26	Benzene, (1-propylnonyl)-	232.4	$C_{17}H_{28}$	15.244	0.61	Alkylbenzene	–	Shoubaky and Salem (2014)
27	6,9,12-Octadecatrienoic acid, phenylmethyl ester, (Z,Z,Z)-	368.6	$C_{25}H_{36}O_2$	15.523	1.16	–	Antioxidant, anti-inflammatory, antimicrobial, pesticide and cancer-preventive activity	Al-Rubaye et al. (2017)
28	E-7-Octadecene	252.5	C18H36	15.730	0.69	Hydrocarbon	–	–
29	Heptadecane, 2,6,10,15-tetramethyl-	296.6	$C_{21}H_{44}$	15.876	4.42	Alkane	–	–
30	Benzene, (1-methylundecyl)-	246.4	$C_{18}H_{30}$	16.039	0.44	Alkylbenzene	–	Shoubaky and Salem (2014)
31	Benzene, (1-pentyloctyl)-	260.5	$C_{19}H_{32}$	16.253	0.50	Alkylbenzene	–	Shoubaky and Salem (2014)
32	Phytol, acetate	338.6	$C_{22}H_{42}O_2$	16.375	5.91	Terpene Alcohol	Antioxidant and Antimicrobial	Syeda and Riazunnisa (2020)
33	Phytone	268.5	$C_{18}H_{36}O$	16.465	3.55	Ketone	–	–
34	Benzene, (1-propyldecyl)-	260.5	$C_{19}H_{32}$	16.555	0.57	Alkylbenzene	–	–
35	Phytol	296.5	$C_{20}H_{40}O$	16.733	4.32	Diterpene Alcohol	Cancer-preventive Antimicrobial anti-inflammatory anti-diuretic Antioxidant	Silva et al. (2014), Santos et al. (2013), Costa et al. (2012), Shibula and Velavan (2015)
36	Geranyl benzoate	258.35	$C_{17}H_{22}O_2$	17.607	1.06	–	–	Figueiredo et al. (2018), Yan et al. (2020)
37	2-Piperidinone, N-[4-bromo-n-butyl]s-	234.13	$C_9H_{16}BrNO$	17.735	0.69	Amide/delta-lactams	Antimicrobial activity	Al-Salman (2019)
38	Pentadecanoic acid, 14-methyl-, methyl ester	270.5	$C_{17}H_{34}O_2$	17.810	1.90	–	Antioxidant, antimicrobial and fungal activity	Elaiyaraja and Chandramohan (2016)
39	Pentadecanoic acid	242.4	$C_{15}H_{30}O_2$	18.695	12.18	Fatty acid	–	
40	n-Tridecan-1-ol	200.36	$C_{13}H_{28}O$	19.130	0.36	Fatty Alcohol	Natural mosquito control agent	Arora and Kumar (2018)
41	n-Nonadecanol-1	284.5	$C_{19}H_{40}O$	19.233	7.16	Fatty Alcohol	–	
42	Eicosane	282.5	$C_{20}H_{42}$	19.366	1.66	Hydrocarbon	Anti-oxidant and antiinflamatory effect	Dulara et al. (2019)
43	Methyl 5,12-octadecadienoate	294.5	$C_{19}H_{34}O_2$	21.906	0.83	–	–	–
44	Dehydroelsholtzia ketone	164.2	$C_{10}H_{12}O_2$	22.100	0.40	–	–	–
45	Oxirane, hexadecyl-	268.5	$C_{18}H_{36}O$	22.140	1.28	Epoxide	Adhesive	Elangovan et al. (2015)
46	Heptadecanoic acid, 16-methyl-, methyl ester	298.5	$C_{19}H_{38}O_2$	23.059	1.03	–	Potent skin cancer activity	Kandasamy et al. (2012)
47	trans-Undec-4-enal	168.28	$C_{11}H_{20}O$	23.549	1.92	Hydrocarbon	–	–
48	7-Hexadecyn-1-ol	238.41	$C_{16}H_{30}O$	23.779	3.92	Alcohol	–	–
49	n-Tetracosanol-1	354.7	$C_{24}H_{50}O$	25.839	5.89	Alcohol	Anti-oxidant effect	Amudha et al. (2018)
50	2-Bromotetradecane	277.28	$C_{14}H_{29}Br$	26.103	1.31	–	–	–

Table 7 The GC–MS analysis data of SMM chromatogram with biological activity

Peak	Name	Molecular weight	Molecular formula	Retention time (min)	Area%	Class of phytochemical	Biological activity	References
1	Propane, 2,2-diethoxy-	132.2	$C_7H_{16}O_2$	3.622	33.83	–	–	–
2	Cyclotrisiloxane, hexamethyl-	222.46	$C_6H_{18}O_3Si_3$	4.182	0.52	–	Antimicrobial, antioxidant, antibacterial activity	Ismail et al. (2019)
3	2-Hexanol, 2-methyl-	116.2	$C_7H_{16}O$	4.646	0.84	Alcohol	–	–
4	Ethylbenzene	106.16	C_8H_{10}	4.790	2.92	Alkylbenzene	–	–
5	o-Xylene	106.16	C_8H_{10}	4.933	15.87	Alcohol	–	–
6	Ethanol, 2-butoxy-	118.17	$C_6H_{14}O_2$	5.460	0.48	–	–	–
7	Propanoic acid, 2,2-dimethyl-, 2-ethylhexyl ester	214.34	$C_{13}H_{26}O_2$	6.075	0.51	–	–	–
8	2-Hexyl-1-octanol	214.39	$C_{14}H_{30}O$	6.150	1.16	Alcohol	–	–
9	Benzene, 1-ethyl-3-methyl-	120.19	C_9H_{12}	6.190	1.14	–	–	–
10	Heptane, 5-ethyl-2-methyl-	142.28	$C_{10}H_{22}$	6.235	0.82	–	–	–
11	2',6'- 2',6'-Dihydroxyacetophenone, bis(trimethylsilyl) ether	296.51	$C_{14}H_{24}O_3Si_2$	6.306	0.76	–	Antimicrobial activity	Pradhan and Dubey (2021)
12	Decane	142.28	$C_{10}H_{22}$	6.645	6.75	Alkane	–	–
13	Benzene, (1-methylpropyl)-	134.22	$C_{10}H_{14}$	6.850	0.80	Alkylbenzene	–	–
14	Decane, 4-methyl-	156.31	$C_{11}H_{24}$	6.939	1.40	–	–	–
15	PseudoCumene	120.19	C_9H_{12}	7.024	2.16	–	–	–
16	D-Limonene	136.23	$C_{10}H_{16}$	7.114	1.33	–	AntiCoVID and Antimicrobial activity	Zahi et al. (2015), Panikar et al. (2021)
17	1-Decanol, 2-hexyl-	242.44	$C_{16}H_{34}O$	7.165	1.23	–	–	–
18	Indane	118.18	C_9H_{10}	7.225	0.23	–	–	–
19	Benzene, 1-methyl-3-propyl-	134.22	$C_{10}H_{14}$	7.396	1.01	–	–	–
20	Benzene, 1,4-diethyl-	134.22	$C_{10}H_{14}$	7.478	3.10	–	–	–
21	Benzene, (1,3,3-trimethylnonyl)-	246.4	$C_{18}H_{30}$	7.596	1.79	–	–	–
22	Benzene, 1-ethyl-2,3-dimethyl-	134.22	$C_{10}H_{14}$	7.731	0.68	–	–	–
23	Benzene, 1-methyl-3-(1-methylethyl)-	134.22	$C_{10}H_{14}$	7.773	0.89	–	–	–
24	p-Cymene	134.22	$C_{10}H_{14}$	7.854	1.31	Monoterpene	AntiCovid-19, antioxidant, anti-inflammatory, antiparasitic, antidiabetic, antifungal and antitumor activities	Panikar et al. (2021), Balahbib et al. (2021), Sharifi-Rad et al. (2018)
25	Undecane	156.31	$C_{11}H_{24}$	7.984	4.12	–	–	–
26	Benzenepropanal,.beta.-methyl-	148.2	$C_{10}H_{12}O$	8.056	0.56	–	–	–
27	Spiro[3.5]nona-5,7-dien-1-one, 5,9,9-trimethyl	176.25	$C_{12}H_{16}O$	8.124	1.18	–	–	–
28	Benzene, 2,4-diethyl-1-methyl-	148.24	$C_{11}H_{16}$	8.185	0.32	–	–	–

Table 7 (continued)

Peak	Name	Molecular weight	Molecular formula	Retention time (min)	Area%	Class of phytochemical	Biological activity	References
29	Benzene, 1,2,4,5-tetramethyl-	134.22	$C_{10}H_{14}$	8.335	0.48	–	–	–
30	10-Chloro-1-decanol, pentafluoropropionate	338.74	$C_{13}H_{20}ClF_5O_2$	8.505	0.47	–	–	–
31	Benzene, 1,3-diethyl-5-methyl-	148.24	$C_{11}H_{16}$	8.600	0.78	–	–	–
32	1,7,7-Trimethyl-2-vinylbicyclo[2.2.1]hept-2-ene	162.27	$C_{12}H_{18}$	8.815	0.32	–	–	–
33	Dodecane	170.33	$C_{12}H_{26}$	9.266	0.67	–	–	–
34	Pentadecane	212.41	$C_{15}H_{32}$	10.486	0.49	–	–	–
35	Thymol	150.22	$C_{10}H_{14}O$	10.595	0.50	Monoterpenoid	Antimicrobial, anti-inflammatory and antioxidant activity Antiviral SARS-CoV-2	Braga et al. (2006), Rolta et al. (2021), Abdelli et al. (2021), Kulkarni et al. (2020)
36	Phytol, acetate	338.6	$C_{22}H_{42}O_2$	16.375	0.29	Terpene Alcohol	Anti-oxidant and Anti-microbial	Syeda and Riazunnisa (2020)

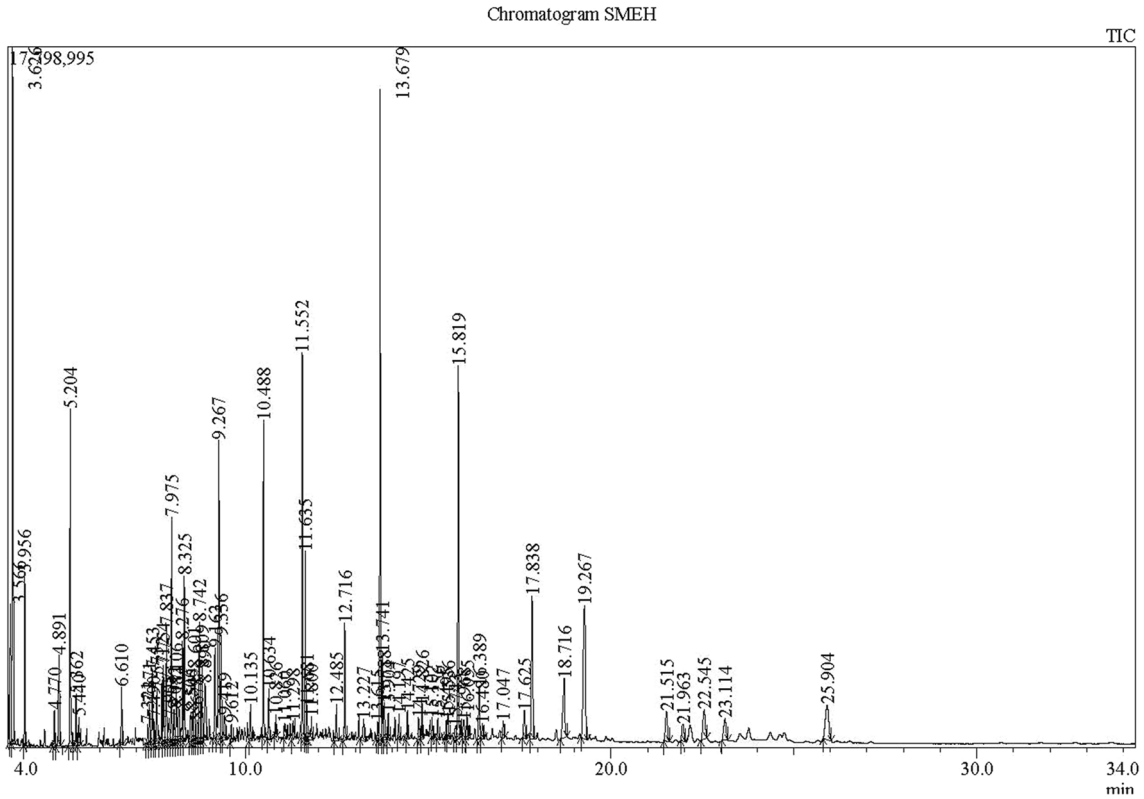


Fig. 6 GC–MS chromatogram for SMEH

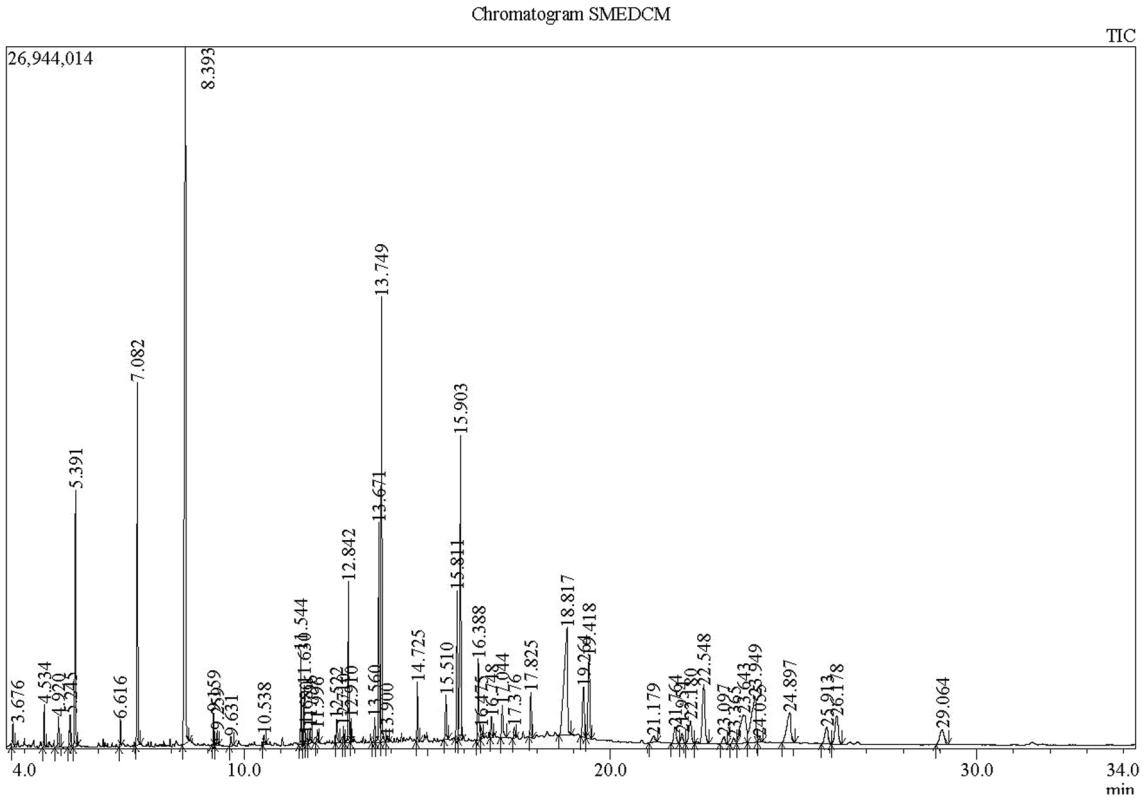


Fig. 7 GC–MS chromatogram for SMEDCM

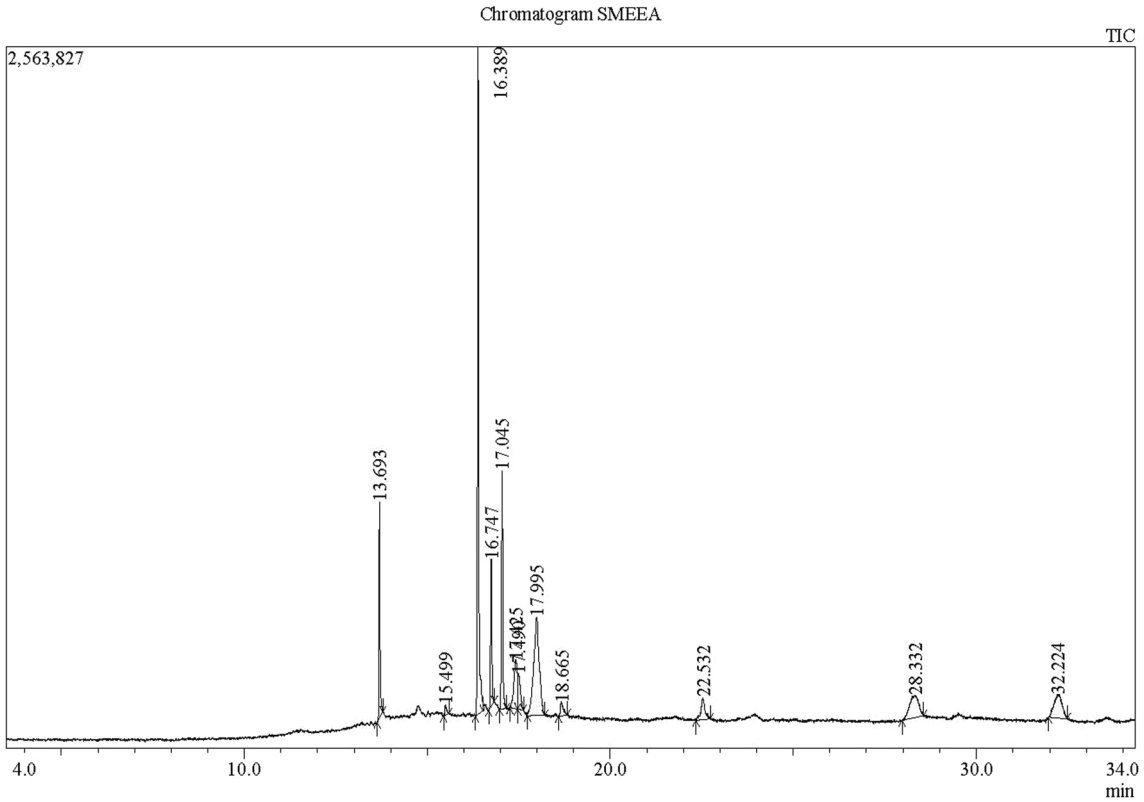


Fig. 8 GC–MS chromatogram for SMEEA

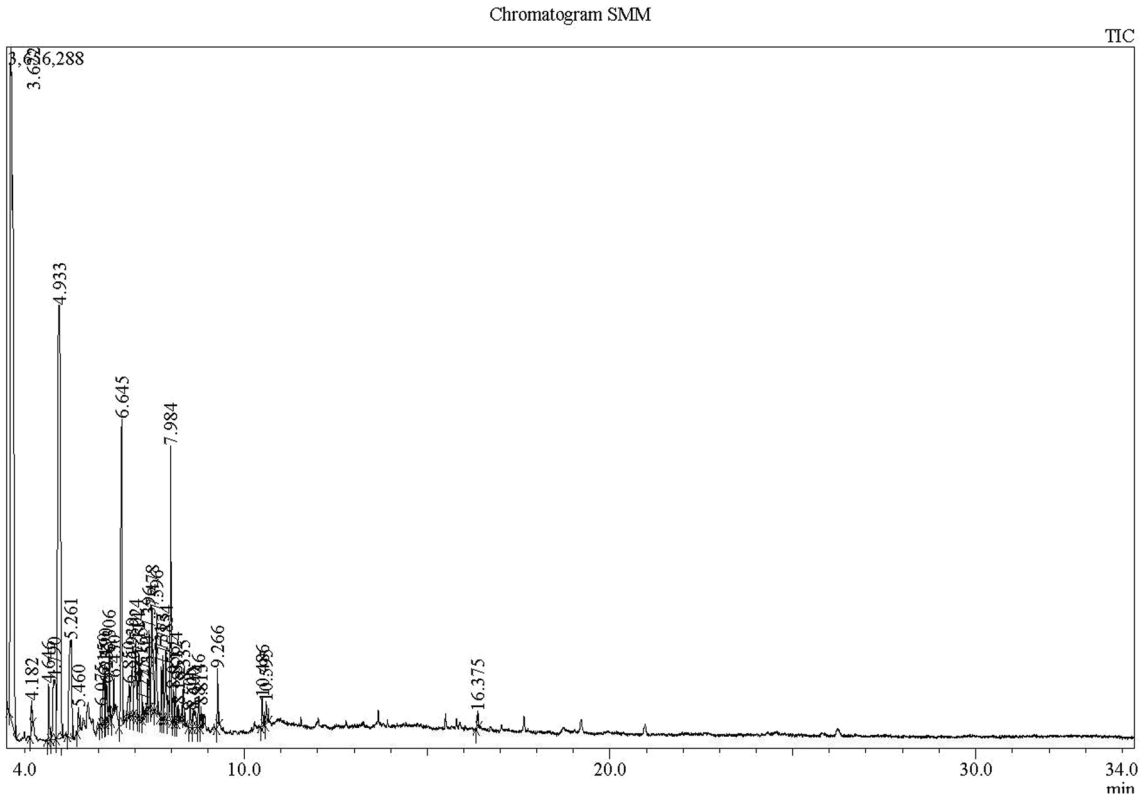


Fig. 9 GC–MS chromatogram for SMM

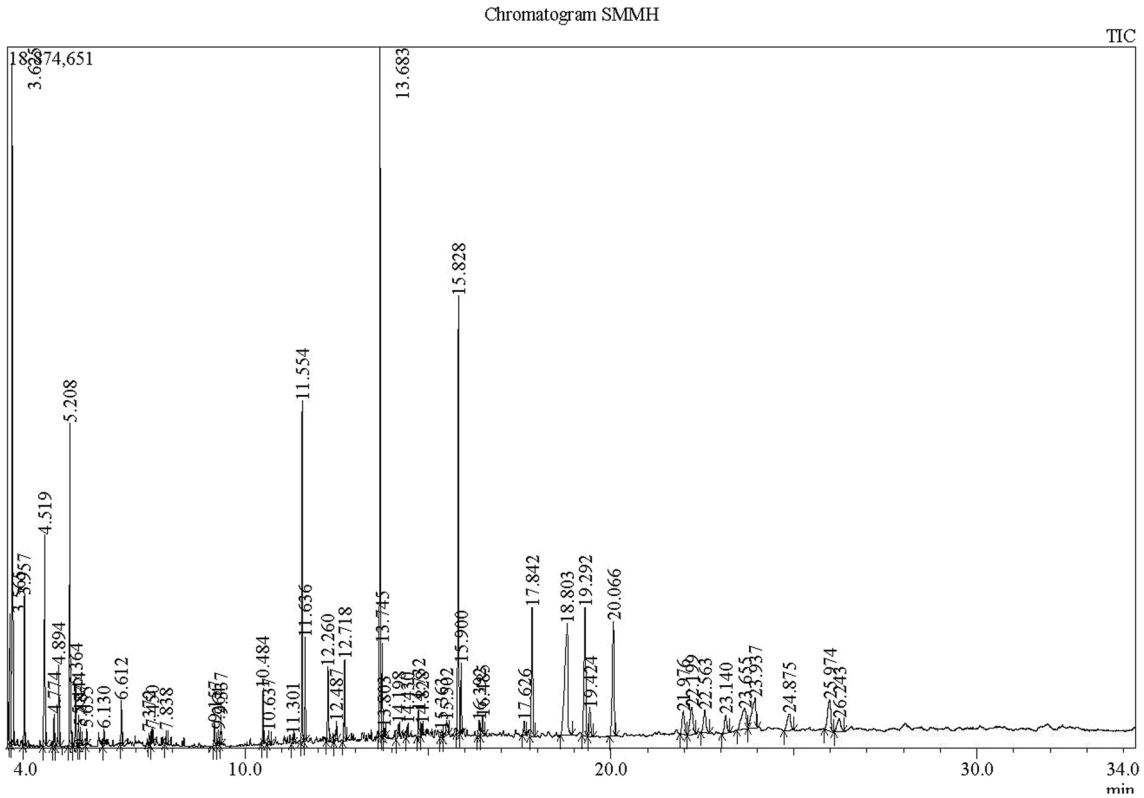


Fig. 10 GC–MS chromatogram for SMMH

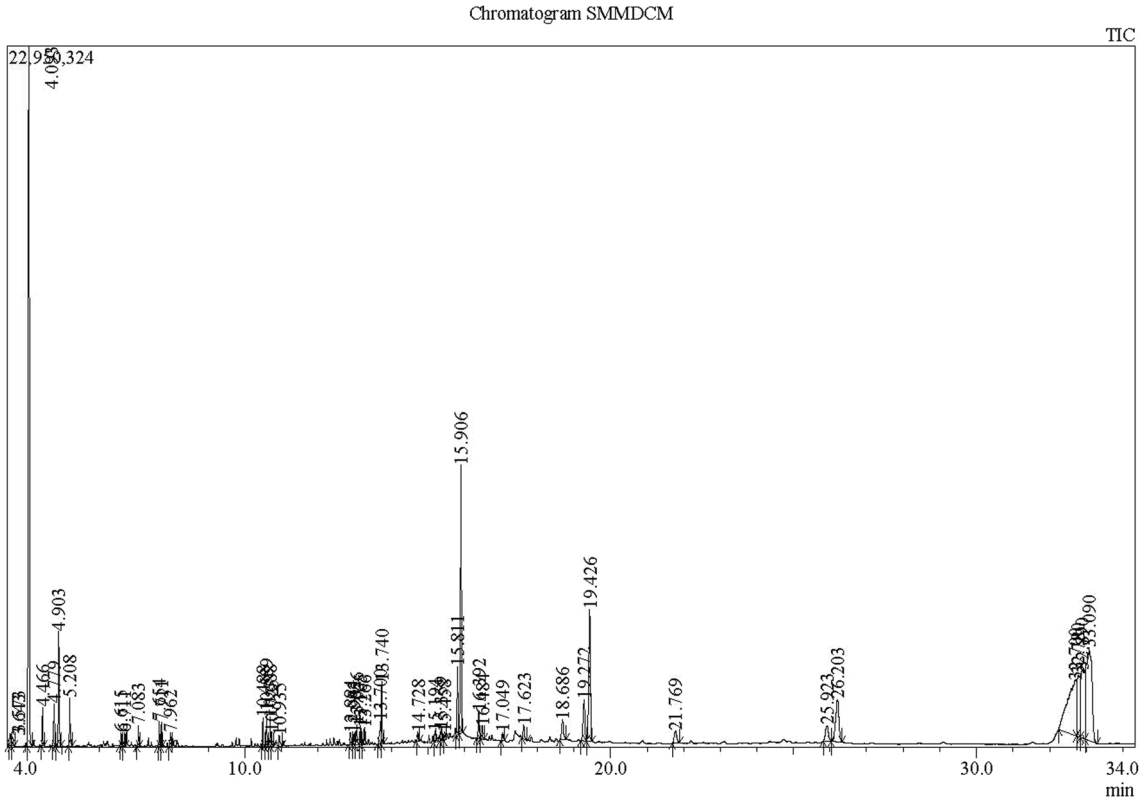


Fig. 11 GC–MS chromatogram for SMMDCM

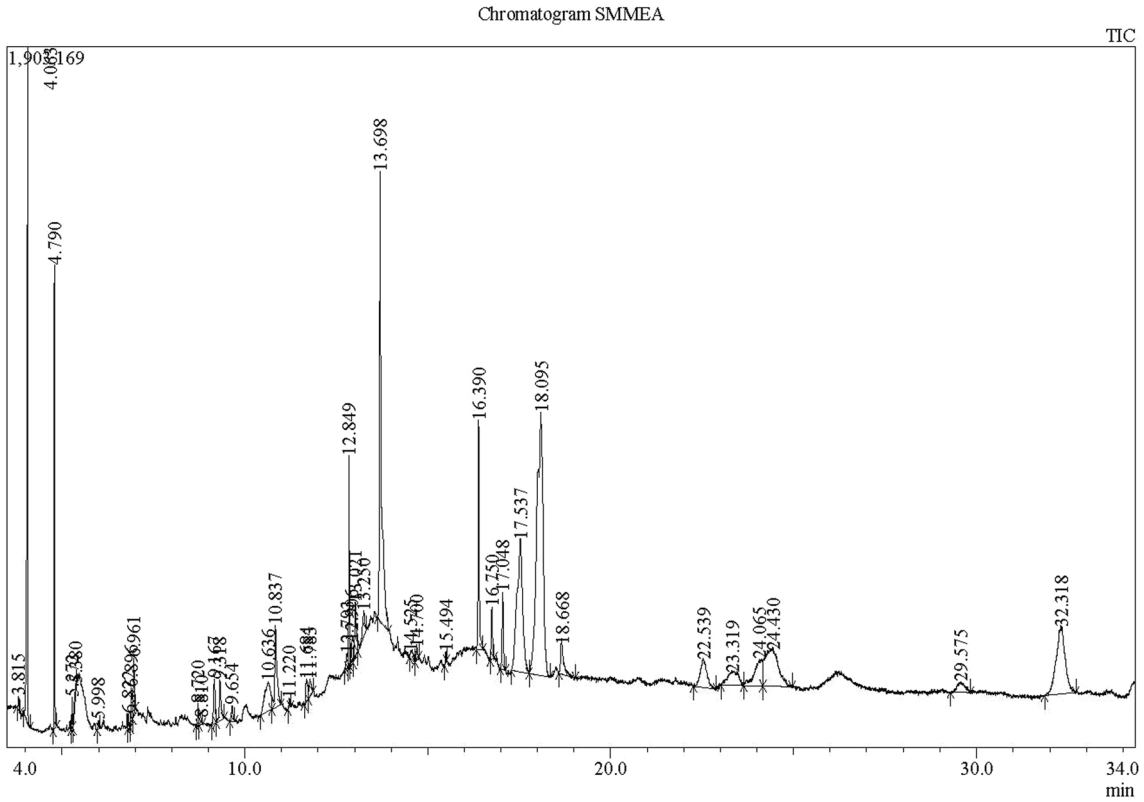


Fig. 12 GC–MS chromatogram for SMMEA

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Declarations

Ethical statement This article does not contain any studies involving animals and human participants performed by any of the authors.

Conflict of interest Akwasi Boadu has no conflict of interest. Rajshekhar Karpoormath has no conflict of interest. Manimbulu Nlooto has no conflict of interest.

References

Abdelli I et al (2021) In silico study the inhibition of angiotensin converting enzyme 2 receptor of COVID-19 by *Ammoides verticillata* components harvested from Western Algeria. J Biomol Struct Dyn 39(9):3263–3276

Abo K, Ogunleye V, Ashidi J (1999) Antimicrobial potential of *Spondias mombin*, *Croton zambesicus* and *Zygotritonia crocea*. Phytother Res Int J Devoted Pharmacol Toxicol Eval Nat Prod Deriv 13(6):494–497

Abubakar IB et al (2022) Traditional medicinal plants used for treating emerging and re-emerging viral diseases in northern Nigeria. Eur J Integr Med 49:102094

Ahmad MH et al (2021) Traditional uses, phytochemistry, and pharmacological activities of *Cochlospermum tinctorium* A. Rich (Cochlospermaceae): a review. Future J Pharm Sci 7(1):1–13

Alam P et al (2019) Chemical composition of fennel seed extract and determination of fenchone in commercial formulations by GC–MS method. J Food Sci Technol 56(5):2395–2403

Al-Rubaye AF, Kadhim MJ, Hameed IH (2017) Characterization of antifungal secondary metabolites produced by *Klebsiella pneumoniae* and screening of its chemical compounds using GC–MS. Int J Curr Pharm Rev Res 8(2):141–148

Al-Salman H (2019) Antimicrobial activity of the compound 2-piperidinone, N-[4-Bromo-n-butyl]-extracted from pomegranate peels. Asian J Pharm. https://doi.org/10.22377/ajp.v13i01.3008

Amudha P et al (2018) Identification of bioactive components in *Enhalus acoroides* seagrass extract by gas chromatography–mass spectrometry. Asian J Pharm Clin Res 11(10):131–137

Anbukumaran A et al (2021) Evaluation and characterization of phytocompounds from aerial parts of *Coldenia procumbens* Linn. Int J Bot Stud 6:486–492
Anyasor GN et al (2015) Evaluation of *Costus afer* Ker Gawl. in vitro anti-inflammatory activity and its chemical constituents identified using gas chromatography–mass spectrometry analysis. J Coast Life Med 3(2):132–138
Armenta-Reséndiz M et al (2019) Structure-activity study of acute neurobehavioral effects of cyclohexane, benzene, m-xylene, and toluene in rats. Toxicol Appl Pharmacol 376:38–45
Aromolaran O, Badejo OK (2014) Efficacy of fresh leaf extracts of *Spondias mombin* against some clinical bacterial isolates from typhoid patients. Asian Pac J Trop Dis 4(6):442–446
Arora S, Kumar G (2018) Phytochemical screening of root, stem and leaves of *Cenchrus biflorus* Roxb. J Pharmacogn Phytochem 7(1):1445–1450
Awadasseid A et al (2021) Effective drugs used to combat SARS-CoV-2 infection and the current status of vaccines. Biomed Pharmacother 137:111330
Ayoka A et al (2005) Studies on the anxiolytic effect of *Spondias mombin* L. (Anacardiaceae) extracts. Afr J Tradit Complement Altern Med 2(2):153–165
Balahbib A et al (2021) Health beneficial and pharmacological properties of p-cymene. Food Chem Toxicol 153:112259
Barlow A et al (2020) Review of emerging pharmacotherapy for the treatment of coronavirus disease 2019. Pharmacother J Hum Pharmacol Drug Ther 40(5):416–437
Bartlet A (1976) Actions of carbon tetrachloride, hexachlorotethane and the products of their metabolism in sheep on *Fasciola hepatica*. Br J Pharmacol 58(3):395
Bayala B et al (2018) *Cymbopogon citratus* and *Cymbopogon giganteus* essential oils have cytotoxic effects on tumor cell cultures. Identification of citral as a new putative anti-proliferative molecule. Biochimie 153:162–170
Beigel JH et al (2020) Remdesivir for the treatment of Covid-19. N Engl J Med 383(19):1813–1826
Belakhdar G, Benjouad A, Abdennebi E (2015) Determination of some bioactive chemical constituents from *Thesium humile* Vahl. J Mater Environ Sci 6(10):2778–2783
Bergamo P et al (2014) Immunomodulatory activity of a gut microbial metabolite of dietary linoleic acid, 10-hydroxy-cis-12-octadecenoic acid, associated with improved antioxidant/detoxifying defences. J Funct Foods 11:192–202
Braga PC et al (2006) Anti-inflammatory activity of thymol: inhibitory effect on the release of human neutrophil elastase. Pharmacology 77(3):130–136
Brito RG et al (2012) Citronellol, a monoterpene alcohol, reduces nociceptive and inflammatory activities in rodents. J Nat Med 66(4):637–644
Bruno F et al (2015) Cytotoxic screening and in vitro evaluation of pentadecane against *Leishmania infantum* promastigotes and amastigotes. J Parasitol 101(6):701–705
Burgess LH et al (2021) COVID-19: the vaccine race continues. HCA Healthc J Med 2(2):2
Carranza MSS et al (2020) The antioxidant and antiproliferative agents from the bark of Philippine *Alstonia scholaris* (L.) R. Br. (Apocynaceae). Jordan J Pharm Sci 13(2):207–224
Carvalho JC et al (2021) Hypersensitivity reactions to vaccines: current evidence and standards for SARS-CoV-2 vaccines. Acta Méd Port 34(13):541–547
Colson P, Rolain J-M, Raoult D (2020) Chloroquine for the 2019 novel coronavirus SARS-CoV-2. Int J Antimicrob Agents 55(3):105923
Connors M et al (2021) SARS-CoV-2 vaccines: much accomplished, much to learn. Ann Intern Med 174(5):687–690
Costa J et al (2012) Anticonvulsant effect of phytol in a pilocarpine model in mice. Neurosci Lett 523(2):115–118
Dahiru D, Onubiyi J, Umaru HA (2006) Phytochemical screening and antiulcerogenic effect of *Moringa oleifera* aqueous leaf extract. Af J Tradit Complement Altern Med 3(3):70–75
Damiani E et al (2019) How reliable are in vitro IC50 values? Values vary with cytotoxicity assays in human glioblastoma cells. Toxicol Lett 302:28–34
Dan Z, Sheng-Ming D, Qiang T (2020) COVID-19: a recommendation to examine the effect of hydroxychloroquine in preventing infection and progression. J Antimicrob Chemother 75:1667–1670
De Soto JA (2020) Evaluation of the Moderna, Pfizer/biontech, Astrazeneca/oxford and Sputnik V Vaccines for COVID-19
Diwan R, Malpathak N (2011) Ruta graveolens cultures as screening resources for phyto-pharmaceuticals: bio-prospecting, metabolic phenotyping and multivariate analysis. In: da Silva JAT (ed) Bioremediation, biodiversity and bioavailability, vol 5. Global Science Books, London, pp 1–9
Dong L, Hu S, Gao J (2020) Discovering drugs to treat coronavirus disease 2019 (COVID-19). Drug Discov Ther 14(1):58–60
dos Santos Sampaio TI et al (2018) Leaves of *Spondias mombin* L. a traditional anxiolytic and antidepressant: pharmacological evaluation on zebrafish (*Danio rerio*). J Ethnopharmacol 224:563–578
Douoguih M (2021) Overview of Janssen's single-dose COVID-19 vaccine, Ad26. COV2. S
Dulara BK, Godara P, Barwer N (2019) In-vivo and In-vitro phytochemical GC–MS analysis of volatile constituents of *Andrographis paniculata* (Burm. F.) Nees. Pharma Innov J 8:255–261
El Shoubaky GA, Salem EA (2014) Terpenes and sterols composition of marine brown algae *Padina pavonica* (Dictyotales) and *Hormophysa triquetra* (Fucales). Int J Pharmacogn Phytochem Res 6(4):894–900
Elaiyaraja A, Chandramohan G (2016) Comparative phytochemical profile of *Indoneesiella echioides* (L.) Nees leaves using GC–MS. J Pharmacogn Phytochem 5(6):158
Elangovan M et al (2015) Determination of bioactive compounds from the Petroleum ether leaf extract of *Moringa oleifera* and *Phyllanthus emblica* using GC–MS analysis. World J Pharm Res 4(3):1284–1298
Elbe H et al (2020) Comparison of ultrastructural changes and the anticarcinogenic effects of thymol and carvacrol on ovarian cancer cells: which is more effective? Ultrastruct Pathol 44(2):193–202
Elshafie HS et al (2017) In vitro study of biological activity of four strains of *Burkholderia gladioli* pv. agaricicola and identification of their bioactive metabolites using GC–MS. Saudi J Biol Sci 24(2):295–301
Erenler R et al (2016) Chemical constituents and antiproliferative effects of cultured *Mougeotia nummuloides* and Spirulina major against cancerous cell lines. Z Naturforschung C 71(3–4):87–92
Figueiredo PLB et al (2018) Chemical variability in the essential oil of leaves of Araçá (*Psidium guineense* Sw.), with occurrence in the Amazon. Chem Central J 12(1):1–11
Goldman DL et al (2021) Compassionate use of Remdesivir in children with severe COVID-19. Pediatrics. https://doi.org/10.1542/peds.2020-047803
Greenway D, Dyke K (1979) Mechanism of the inhibitory action of linoleic acid on the growth of *Staphylococcus aureus*. Microbiology 115(1):233–245
Guo L et al (2008) Chemical composition, antifungal and antitumor properties of ether extracts of *Scapania verrucosa* Heeg. and its endophytic fungus *Chaetomium fusiforme*. Molecules 13(9):2114–2125
Hase GJ et al (2017) Phytochemical studies on *Nerium oleander* L. using GC–MS. Int J Pharmacogn Phytochem Res 9(6):885–891

Hassan D et al (2019) Delivery of novel vancomycin nanoplexes for combating methicillin-resistant *Staphylococcus aureus* (MRSA) infections. Int J Pharm 558:143–156

Hassan D et al (2020) Novel chitosan-based pH-responsive lipid-polymer hybrid nanovesicles (OLA-LPHVs) for delivery of vancomycin against methicillin-resistant *Staphylococcus aureus* infections. Int J Biol Macromol 147:385–398

Igwe C et al (2010) Evaluation of the chemical compositions of the leaf of *Spondias mombin* Linn from Nigeria. Aust J Basic Appl Sci 4(5):706–710

Iqbal E, Salim KA, Lim LB (2015) Phytochemical screening, total phenolics and antioxidant activities of bark and leaf extracts of *Goniothalamus velutinus* (Airy Shaw) from Brunei Darussalam. J King Saud Univ Sci 27(3):224–232

Ishola IO, Ikuomola BO, Adeyemi OO (2018) Protective role of *Spondias mombin* leaf and *Cola acuminata* seed extracts against scopolamineinduced cognitive dysfunction. Alex J Med 54(1):27–39

Ismail GA et al (2019) In vitro potential activity of some seaweeds as antioxidants and inhibitors of diabetic enzymes. Food Sci Technol 40:681–691

Javed H et al (2020) Carvacrol, a plant metabolite targeting viral protease (Mpro) and ACE2 in host cells can be a possible candidate for COVID-19. Front Plant Sci 11:2237

Jones I, Roy P (2021) Sputnik V COVID-19 vaccine candidate appears safe and effective. The Lancet 397(10275):642–643

Kandasamy S, Sahu SK, Kandasamy K (2012) In silico studies on fungal metabolite against skin cancer protein (4, 5-diarylisoxazole HSP90 chaperone). Int Sch Res Not 2012:626214

Kulkarni SA et al (2020) Computational evaluation of major components from plant essential oils as potent inhibitors of SARS-CoV-2 spike protein. J Mol Struct 1221:128823

Kumar G et al (2007) Antimicrobial effects of Indian medicinal plants against acne-inducing bacteria. Trop J Pharm Res 6(2):717–723

Kumari S, Shankar J (2021) Exploration of mycelial proteins and shikonin mediated growth inhibition of *Aspergillus terreus* using proteomics approach

Kwon Y-II, Vattem DA, Shetty K (2006) Evaluation of clonal herbs of Lamiaceae species for management of diabetes and hypertension. Asia Pac J Clin Nutr 15(1):107–118

Li Q, Lu H (2020) Latest updates on COVID-19 vaccines. BioSci Trends 14:463–466

Li Y et al (2021) A comprehensive review of the global efforts on COVID-19 vaccine development. ACS Cent Sci 7(4):512–533

Liu Y et al (2021) BNT162b2-elicited neutralization against new SARS-CoV-2 spike variants. N Engl J Med 385:472–474

Maduka H et al (2014) Phytochemical, antioxidant and microbial inhibitory effects of *Spondias mombin* leaf and stem bark extracts. J Pharm Biol Sci 9(2):14–17

Mahase E (2021) Covid-19: UK approves first monoclonal antibody treatment. BMJ 374:n2083

Maria ACB et al (2022) *Spondias mombin* L.: an updated monograph. Pharmacogn Rev 16:45–61

Miller T (1966) Anthelmintic activity of tetrachloroethylene against various stages of *Ancylostoma caninum* in young dogs. Am J Vet Res 27(119):1037–1040

Monisha SI, Vimala JR (2018) Extraction, identification and pharmacological evaluation of phyto-active compound in Manilkara Hexandra (Roxb.) Dubard Stem Bark. Biosci Biotechnol Res Asia 15(3):687–698

Murugan K, Iyer VV (2014) Antioxidant activity and gas chromatographic-mass spectrometric analysis of extracts of the marine algae, *Caulerpa peltata* and *Padina gymnospora*. Indian J Pharm Sci 76(6):548

Nadembega P et al (2011) Medicinal plants in Baskoure, Kourittenga Province, Burkina Faso: an ethnobotanical study. J Ethnopharmacol 133(2):378–395

Naquvi KJ et al (2014) Volatile oil composition of *Rosa damascena* Mill. (Rosaceae). J Pharmacogn Phytochem 2(5):177–181

Nayak S et al (2020) *Eclipta alba* L. derived phytochemicals against campylobacter causing Diarrhea. J Pharm Res Int 32:108–111

Naz F et al (2021) In vivo hepatoprotective and in vitro antimicrobial potential of *Ceasalpinia bonduc* (Linn): pharmacological correlation with identified phytochemicals. Pak J Pharm Sci 34(2):809–817

Nworu C et al (2007) Oxytocic activity of leaf extract of *Spondias mombin*. Pharm Biol 45(5):366–371

Obi-Egbedi N, Obot I, Umoren S (2012) *Spondias mombin* L. as a green corrosion inhibitor for aluminium in sulphuric acid: Correlation between inhibitive effect and electronic properties of extracts major constituents using density functional theory. Arab J Chem 5(3):361–373

Osuntokun O (2019) Exploring the medicinal efficacy, properties and therapeutic uses of *Spondias mombin* (Linn.). Int J Appl Res Med Plants 2:115

Panikar S et al (2021) Essential oils as an effective alternative for the treatment of COVID-19: molecular interaction analysis of protease (Mpro) with pharmacokinetics and toxicological properties. J Infect Public Health 14(5):601–610

Parekh J, Chanda S (2007) In vitro antimicrobial activity and phytochemical analysis of some Indian medicinal plants. Turk J Biol 31(1):53–58

Pradhan S, Dubey R (2021) GC–MS analysis and molecular docking of bioactive compounds of *Camellia sinensis* and *Camellia assamica*. Arch Microbiol 203:2501–2510

Rangel-Sánchez G, Castro-Mercado E, García-Pineda E (2014) Avocado roots treated with salicylic acid produce phenol-2, 4-bis (1, 1-dimethylethyl), a compound with antifungal activity. J Plant Physiol 171(3–4):189–198

Riegel AC, French ED (1999) Acute toluene induces biphasic changes in rat spontaneous locomotor activity which are blocked by remoxipride. Pharmacol Biochem Behav 62(3):399–402

Rolta R et al (2021) Phytocompounds of *Rheum emodi*, *Thymus serpyllum*, and *Artemisia annua* inhibit spike protein of SARS-CoV-2 binding to ACE2 receptor: in silico approach. Curr Pharmacol Rep 7:135–149

Rukshana M, Doss A, Kumari P (2017) Phytochemical screening and GC–MS ANALYSIS of leaf extract of *Pergularia daemia* (Forssk) Chiov. Asian J Plant Sci Res 7:9–15

Sabiu S et al (2015) Indomethacin-induced gastric ulceration in rats: protective roles of *Spondias mombin* and *Ficus exasperata*. Toxicol Rep 2:261–267

Santos CCMP et al (2013) Antinociceptive and antioxidant activities of phytol in vivo and in vitro models. Neurosci J 2013:949452

Savarino A et al (2003) Effects of chloroquine on viral infections: an old drug against today's diseases. Lancet Infect Dis 3(11):722–727

Sengar N et al (2015) Anti-inflammatory, analgesic and anti-pyretic activities of standardized root extract of *Jasminum sambac*. J Ethnopharmacol 160:140–148

Sharifi-Rad J et al (2018) Antiviral activity of monoterpenes thymol, carvacrol and p-cymene against herpes simplex virus in vitro. Int Pharm Acta 1(1):73–73

Shibula K, Velavan S (2015) Determination of phytocomponents in methanolic extract of *Annona muricata* leaf using GC–MS technique. Int J Pharmacogn Phytochem Res 7(6):1251–1255

Shyamala R, Manikandan R (2019) Determination of bioactive compounds in *Ziziphus oenoplia* leaves extract using gas chromatography and mass spectroscopic technique. J Pharmacogn Phytochem 8(5):157–160

Sikwal DR et al (2016) Polyelectrolyte complex of vancomycin as a nanoantibiotic: preparation, in vitro and in silico studies. Mater Sci Eng C 63:489–498

Silva RO et al (2014) Phytol, a diterpene alcohol, inhibits the inflammatory response by reducing cytokine production and oxidative stress. Fundam Clin Pharmacol 28(4):455–464

Sivasubramanian R, Brindha P (2013) In-vitro cytotoxic, antioxidant and GC–MS studies on *Centratherum punctatum* Cass. Int J Pharm Pharm Sci 4:e8

Sonawane SJ et al (2015) Transforming linoleic acid into a nanoemulsion for enhanced activity against methicillin susceptible and resistant *Staphylococcus aureus*. RSC Adv 5(110):90482–90492

Sosa AA, Bagi SH, Hameed IH (2016) Analysis of bioactive chemical compounds of *Euphorbia lathyrus* using gas chromatography–mass spectrometry and Fourier-transform infrared spectroscopy. J Pharmacogn Phytother 8(5):109–126

Sultana N et al (2010) Nematicidal natural products from the aerial parts of *Buddleja crispa*. Nat Prod Res 24(9):783–788

Syeda AM, Riazunnisa K (2020) Data on GC–MS analysis, in vitro anti-oxidant and anti-microbial activity of the *Catharanthus roseus* and *Moringa oleifera* leaf extracts. Data Brief 29:105258

Tu Y-F et al (2020) A review of SARS-CoV-2 and the ongoing clinical trials. Int J Mol Sci 21(7):2657

Umezu T et al (1997) Behavioral effects of trichloroethylene and tetrachloroethylene in mice. Pharmacol Biochem Behav 58(3):665–671

van Tulleken C (2021) Covid-19: sputnik vaccine rockets, thanks to Lancet boost. BMJ 373:n1108

Vanitha V et al (2020) Heneicosane: a novel microbicidal bioactive alkane identified from *Plumbago zeylanica* L. Ind Crops Prod 154:112748

Voysey M et al (2021) Safety and efficacy of the ChAdOx1 nCoV-19 vaccine (AZD1222) against SARS-CoV-2: an interim analysis of four randomised controlled trials in Brazil, South Africa, and the UK. The Lancet 397(10269):99–111

Wang M et al (2020) Remdesivir and chloroquine effectively inhibit the recently emerged novel coronavirus (2019-nCoV) in vitro. Cell Res 30(3):269–271

World Health Organization (2021a) mRNA-1273 vaccine (Moderna) against COVID-19 background document: draft prepared by the Strategic Advisory Group of Experts (SAGE) on Immunization Working Group on COVID-19 vaccines, 19 Jan 2021a. World Health Organization

World Health Organization (2021b) Background document on the mRNA vaccine BNT162b2 (Pfizer-BioNTech) against COVID-19: background document to the WHO interim recommendations for use of the Pfizer–BioNTech COVID-19 vaccine, BNT162b2, under emergency use listing, 14 Jan 2021b. World Health Organization

Wu B et al (2014) Simultaneous determination of eight active components in the traditional Chinese Medicine Dan Deng Tong Nao capsules by HPLC-MS/MS. Planta Med 80(06):517–522

Yan X et al (2020) Functional characterization and catalytic activity improvement of BAHD acyltransferase from *Celastrus angulatus* Maxim. Planta 252(1):1–12

Yang M-T et al (2020) Authentication, phytochemical characterization and anti-bacterial activity of two Artemisia species. Food Chem 333:127458

Zahi MR, Liang H, Yuan Q (2015) Improving the antimicrobial activity of D-limonene using a novel organogel-based nanoemulsion. Food Control 50:554–559

Zandoná GP et al (2020) Extraction and characterization of phytochemical compounds from araçazeiro (*Psidium cattleianum*) leaf: putative antioxidant and antimicrobial properties. Food Res Int 137:109573