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Identification and quantitative composition of nematicidal ingredients in leaves of some *Aloe* species

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Abstract

Phytochemical and infrared analyses were carried out for eight *Aloe* species: *Aloe schweinfurthii* (ASF), *Aloe succrotina* (AST), *Aloe vera* (AVR), *Aloe chinensis* (ACS), *Aloe arborescens* (AAR), *Aloe keayi* (AKY), *Aloe macrocarpa* (AMC) and *Aloe schweinfurthii* x *Aloe vera* (ASV) that showed nematicidal activity in *in vitro* on *Meloidogyne incognita*. The phytochemical analyses revealed that the *Aloe* species had similar phytochemicals: tannins, saponins, flavonoids, cardenolides, phenols, alkaloids and anthraquinones. However, total phenol (14.3 mg/g), tannins (14.5 mg/g) and saponins (59.8 mg/g) were highest in AKY than in other aloes. Flavonoid content (3.7 mg/g) was highest in AAR while alkaloid content was highest in AST. The infrared analyses revealed that the *Aloe* species had similar functional groups; amines, hydroxyl, unsaturated aromatic compounds, ketone, aldehyde and phenol. The nematicidal potentials of these *Aloe* species might be due to the type and quantity presence in these phytochemicals. The presence of the nematicidal principles identified in *Aloe* species used in the management of *M. incognita*.

Keywords: *Aloe* species, phytochemicals, *Meloidogyne incognita*, infrared analysis, plant extracts

Over the period of evolution, plants have acquired mechanisms to ensure their survival either morphological or based on their chemical constituents (Dutta, 1995). Some of the plants already explored and known to produce economically important organic compounds, pharmaceuticals and pesticides; but many species of higher plants never surveyed (Satish *et al*., 2007). Natural potentials in plants presented new pesticides for pest control (Parmar & Devakumar, 1993; Chitwood, 2003).

Plants produced secondary metabolites and their functions were not known in photosynthesis, growth, development and other aspects of plant physiology (Adedire *et al*., 2003). Pesticidal activity attributed to plants linked to the presence of these metabolites or chemical substances known as "phytochemicals" (Chitwood, 2002; Adedire *et al*., 2003; Ajayi *et al*., 2012). These metabolites belonging to groups such as alkaloids, phenolics, terpenoids, flavonoids, hydrocarbons, chromones, esters, lactones and others (Golob *et al*., 1999; Adedire *et al*., 2003; Adekunle & Fawole, 2003). Phytochemicals were the basis of therapeutic abilities of most plants, against diseases and pests of humans, plants and animals (Edeoga *et al*., 2005; Koroma & Basil, 2009; Akinkurolere *et al*., 2011). Many plants reported to exhibit nematicidal activity linked to their constituent phytochemicals (Hassan, 1992; Fatoki & Fawole, 1999; Adekunle & Fawole, 2003). Many plants were not properly screened for their phytochemicals against many pests and pathogens (Ofuya, 2009).

Over 450 aloes species are in family Asphodelaceae worldwide and predominantly found in Africa (Dagne *et al*., 2000; Adodo, 2004; Omino, 2010). Centres of richness for aloes were Southern and Eastern Africa with a

rich heritage of over 120 species in South Africa (Dagne *et al*., 2000; Adodo, 2004; Omino, 2010). However, many aloes were naturally rare and confined to specific habitats with many African countries harbouring endemic *Aloe* spp., (Omino, 2010). Aloes possessing medicinal properties are frequently cultivated as ornamental plants in gardens and in pots (Tucker *et al*., 1989; Barcroft, 1996; Adodo, 2004). *Aloe* pulp used into refreshment drinks in parts of Asia, specially in Korea and nutritive ingredients in the food and beverage industry (Brown, 1995; Omino, 2010). Other aloes, such as *A. arborescens* and *A. secundiflora* are used as live fence and some are consumed as vegetable using their leaves, seeds and flowers e.g., *A. arborescens* and *A. greatheadii* (Omino, 2010).

Aloe species has pesticidal potentials on insects, pathogenic fungi, bacteria and nematodes (Hussain & Mosood, 1975; Pandey & Hasseb, 1988; Omotoso & Oso, 2005; Ukoima & Okah, 2006) but failed to identify active principles. In Nigeria, there was paucity of information on the nematicidal potentials and active ingredients of the *Aloe* species found within the country. Recently, Tanimola & Fawole (2012) reported the nematicidal activity of some *Aloe* species found within Nigeria on root-knot nematode (*Meloidogyne incognita*), but did not give information on the active principles in these aloes. Omino (2010) reported that research into chemical composition and affinities of *Aloe* species was well underway, specially in Southern and Eastern Africa; whereas, the West African aloes needed further chemical studies. Thus, to fill the gap on chemical composition of West African aloes, this research was carried out to characterize some *Aloe* species in Nigeria with the view to identifying the active ingredients in relevance to nematode management.

Materials and Methods

Sources of *Aloe* species: Eight *Aloe* species were collected within Nigeria: *Aloe chinensis* and *A. vera* from the Forestry Research Institute of Nigeria (FRIN), Ibadan; *Aloe succrotina* and *A. keayi* from the Department of Forest Resources Management, University of Ibadan, Ibadan; *A. macrocarpa* from the Federal College of Forestry, *A. vera* x *A. schweinfurthii* from the Mayflower Collections, Ugbowo, Benin-City; *A. arborescens* and *A. schweinfurthii* from the Sealand Gardens, Port Harcourt, Rivers State. *Aloe* plants collected were properly identified by botanists and curators from Departments of Botany, Forest Resources Management of University of Ibadan; Forestry Research Institute of Nigeria, Ibadan and Department of Crop, Soil and Pest Management, Federal University of Technology, Akure. Suckers of each *Aloe* species were later transferred into five-litre pots (20 cm diam., and depth of 18 cm) in six replicates per species and grown for a minimum of three years.

Phytochemical characterization of *Aloe* leaves: The leaves of the *Aloe* species were selected based on their *in vitro* nematicidal activity in terms of egg-hatching inhibition and mortality of *M. incognita* second-stage juveniles (Tanimola & Fawole, 2012). The leaves were collected from four year old *Aloe* plants. Leaves of each *Aloe* species were air-dried for eight weeks in the laboratory and later pulverized using Kenwood electric blender. Air-dried and milled leaves of each *Aloe* species were phytochemically screened to determine the types of phytochemicals present and quantity of each phytochemical. The air-dried milled leaves of the *Aloe* species were also subjected to Infrared analyses using standard procedures.

Phytochemical characterisation of milled *Aloe* leaves: Qualitative analysis to test for the presence of tannins, flavonoids, saponins, anthraquinones, cardenolides and alkaloids was carried out using the methods of Trease & Evans (1989). This experiment was done in the Department of Pharmacognosy, University of Ibadan.

Test for tannins: Each powdered leaf material (0.5 g) was weighed on Mettler balance (Model P1210) into test tubes and shaken in 5 ml of distilled water. The test tube was heated in water

bath to 100 °C after which it was left to cool and then filtered with Whatmann No.1 filter paper. Ferric chloride was added to the filtrate as a reagent. Presence of tannins was confirmed when the solution turned dark blue (Trease & Evans, 1989).

Test for flavonoids: The presence of flavonoids was determined by weighing 0.5 g of the leaf powders from each of the selected *Aloe* species into a test tube; 10 ml of distilled water was added. The set-up was warmed over bath of 100 °C for two minutes. 1 ml of the extract dissolved in dilute sodium hydroxide solution. Flavonoids were confirmed when the solution from yellow turned colourless on addition of hydrochloric acid (Trease & Evans, 1989).

Test for saponins: Saponins test was carried out by weighing 0.5 g of powdered leaves of the *Aloe* species into test tubes. The material was shaken together with 5 ml distilled water and heated over a bath at 100 °C. Saponins presence was confirmed by the evidence of frothing (Trease & Evans, 1989).

Test for alkaloids: Alkaloids test was carried out by weighing 0.5 g powder of leaves of *Aloe* species in 10 ml of distilled water. The set-up was heated at 70 °C for two minutes and filtered. Aqueous extracts of filtrate was spotted as Thin Layer Chromatography (TLC) plates and later sprayed with Dragendorff's reagent. The presence of alkaloids was confirmed when there was orange-red colour (Trease & Evans, 1989).

Test for anthraquinones: The Borntrager test was used in which 2 ml of the test sample was shaken with 4 ml of hexane. The upper lipophilic layer was separated and treated with 4 ml dilute ammonia. If the lower layer changed from violet to pink it indicated the presence of anthraquinones (Chhabra *et al*., 1984; Orech *et al*., 2005).

Test for cardenolides: The milled leaves were thoroughly mixed with 20 ml distilled water and kept at room temperature for 2 hrs. The suspension was filtered and divided into two separate test tubes (A and B). To test tube A, 4 drops of Kedde's reagent was added. The appearance of a blue violet colour indicated the presence of cardenolides. Test tube B was used to monitor and compare colour changes (Harbourne, 1984; Chhabra *et al*., 1984).

Quantitative estimation of phytochemicals present in *Aloe* species: Leaves of the eight *Aloe* species were also used for this experiment and these aloes had been in cultivation for over a period of four years. The experiment was carried out in Emma Laboratory Ibadan in June, 2011.

Preparation of extracts: Methanolic extracts of the samples were prepared following the method of Chan *et al*., (2006). Methanol (25 ml) was added to 0.5 g of sample contained in a covered 50 ml centrifuge tube and shaken continuously for one hour at room temperature. The mixture was centrifuged at 3,000 rpm for 10 minutes and then the supernatant was collected and stored at -20^{o} C until analysis.

Determination of total phenolic content (TPC): The total phenolic content of each extract was determined according to the Folin-Ciocalteu method used by Chan *et al*., (2006). Some 300 µl of extract was dispensed into test tube (in triplicates). To this was added 1.5 ml of Folin-Ciocalteu reagent (diluted 10 times with distilled water) followed by 1.2 ml of Na_2CO_3 solution (7.5 w/v). The reaction mixture was mixed, allowed to stand for 30 minutes at room temperature before the absorbance was measured at 765 nm (using a spectrophotometer) against a blank prepared by dispensing 300 µL of distilled water instead of sample extract. TPC was expressed as gallic acid equivalent (GAE) in mg/g material. The calibration equation for gallic acid was $Y = 0.0645x - 0.0034$ ($R^2 = 0.9997$).

Determination of total flavonoid content (TFC): TFC was determined using aluminium chloride method as reported by Kale *et al*., (2010). Extract (0.5 ml) was dispensed into test tube, followed by 1.5 ml of methanol, 0.1 ml of aluminum chloride (10%), 0.1 ml of 1M potassium acetate and 2.8 ml of distilled water. The reaction mixture was mixed, allowed to stand at room temperature for 30 minutes, before absorbance read at 514 nm using a spectrophotometer. TFC was expressed as quercetin equivalent (QE) in mg/g material. The calibration equation for quercetin was $Y = 0.0395x - 0.0055$ ($R^2 = 0.9988$).

Determination of tannin content: Tannin content of samples was determined according to the method of Padmaja (1989). Sample (0.1g) was extracted with 5 ml of acidified methanol (1% HCl in methanol) at room temperature for 15 minutes. The mixture was centrifuged at 3,000 rpm for 20 minutes. 0.1 ml of the supernatant added with 7.5 ml of distilled water, 0.5 ml of Folin-Denis reagent, 1 ml of 35% sodium carbonate solution and diluted to 10 ml with distilled water. The mixture was shaken well, kept at room temperature for 30 minutes and absorbance was measured at 760 nm using a spectrophotometer. Blank was prepared with distilled water instead of the sample. Tannin content was expressed as tannic acid equivalent (TAE) in mg/g material. The calibration equation for tannic acid was $Y = 0.0695x + 0.0175$ ($R^2 = 0.9978$).

Determination of total saponins (TSP): Total saponins were determined by the method of Hiai *et al*., (1976) as described by Makkar *et al*., (2007). 0.5 g of sample was extracted with 25 ml of 80% aqueous methanol by shaking on a mechanical shaker for 2 hrs, after which contents of the tubes were centrifuged for 10 min at 3,000 rpm. In a test tube, an aliquot (0.25 ml) of the supernatant was taken to which 0.25 ml vanillin reagent (8% vanillin in ethanol) and 2.5 ml of 72% aqueous H_2SO_4 were added. The reaction mixtures in the tubes were heated in a water bath at 60 °C for 10 minutes. Then tubes were cooled in ice for four minutes and then allowed to acclimatize to room temperature. Subsequently, the absorbance was measured in a UV/Visible spectrophotometer at 544 nm. Diosgenin was used as a standard and the results obtained were expressed as mg diosgenin equivalent per g of sample dry matter.

Total alkaloid determination: The total alkaloid content in the samples was measured using 1, 10-phenanthroline method described by Singh *et al*., (2004). 100 mg sample powder was extracted in 10 ml 80% ethanol. This was centrifuged at 5000 rpm for 10 minutes. Supernatant obtained was used for the further estimation of total alkaloids. The reaction mixture contained 1 ml plant extract, 1 ml of 0.025 M $FeCl_3$ in 0.5 M HCl and 1 ml of 0.05 M of 1, 10-phenanthroline in ethanol. The mixture was incubated for 30 minutes in hot water bath with the temperature maintained at 70 ± 2 °C. The absorbance of red coloured complex was measured at 510 nm against reagent blank using a spectrophotometer. Alkaloid contents were estimated and it was calculated with the help of standard curve of quinine (0.1 mg/ml, 10 mg dissolved in 10 ml ethanol and diluted to 100 ml with distilled water).

Infra-red analysis (IR) of air-dried milled of *Aloe* leaves: The leaves of the eight *Aloe* species were air-dried and milled into powder with potassium bromide (KBr). Leaf powder (0.8 mg) form each species mixed properly with 80 mg of KBr. The mixture was later compressed into a transparent disc using a compressor. The disc was scanned in a Fourier Infrared Transform (FITR) spectrometer (Perkin Elmer spectrum BXII) in the Multidisciplinary Central Research Laboratory, University of Ibadan. The IR spectra were printed out with the aid of the machine printer. The spectra produced were later interpreted so as to identify the functional groups present in each leaf by the identification of wavelengths (cm^{-1}) corresponding to functional groups (Williams, 1987).

Results

Phytochemicals present in the leaves of the eight *Aloe* species were presented in Table 1. The analyses revealed the presence of tannins, saponins, flavonoids, anthraquinones, cardenolides, alkaloids and these phytochemicals were also the same sets present in the eight *Aloe* species (*Aloe macrocarpa*, *A. succotrina*, *A. arborescens*, *A. keayi*, *A. vera*, *A. chinensis* and *A. vera* x *A. schweinfurthii* (Table 1).

Table 1. Phytochemicals present in the leaves of eight *Aloe* species.

S. No.	Aloe species	Tannins	Saponins	Flavonoids	Cardenolides	Alkaloids	Anthraquinones
1.	*Aloe schweinfurthii*	+	+	+	+	+	+
2.	*Aloe succotrina*	+	+	+	+	+	+
3.	*Aloe vera*	+	+	+	+	+	+
4.	*Aloe arborescens*	+	+	+	+	+	+
5.	*Aloe keayi*	+	+	+	+	+	+
6.	*Aloe macrocarpa*	+	+	+	+	+	+
7.	*Aloe vera* x *A Schweinfurthii*	+	+	+	+	+	+
8.	*Aloe chinensis*	+	+	+	+	+	+

+ = present; - = absent.

Quantitative composition of phytochemicals in *Aloe* leaves: The quantities of phenols, flavonoids, tannins, alkaloids and saponins present in the leaves of eight *Aloe* species were presented in Table 2.

Total phenols: *A. keayi* had the highest total phenol (14.3 mg/g) among all the *Aloe* species screened and this value significantly higher than the mean phenols in the leaves of the other species. *A. succrotina* had 13.1 mg/g and *A. vera* with 11.5 mg/g. The least quantity of phenol was obtained in *A. schweinfurthii* x *A. vera* (4.1 mg/g).

Total flavonoids: The highest quantity of flavonoids was observed in *A. arborescens* (3.7 mg/g) which significantly higher when compared with the flavonoids in the other *Aloe* species. *A. vera* had the next high quantity of flavonoids (2.8 mg/g) which significantly higher than *A. keayi* (2.6 mg/g). The least quantity of flavonoids was found in *A. schweinfurthii x A. vera* (0.5 mg/g).

Total tannins: *A. keayi* had the highest quantity of tannin (14.5 mg/g) but not significantly higher than the tannin content in *A. macrocarpa* (14.4 mg/g). The tannin in both *A. macrocarpa* and *A. keayi* were significantly higher than those found in the other *Aloe* species. *A. succrotina* had tannin content of 12.4 mg/g which was not significantly different from the tannin content in *A. vera* (12.3 mg/g). The least of tannin was found in *A. schweinfurthii* (5.2 mg/g).

Total alkaloids: The highest quantity of alkaloids was found in *A. succotrina* and *A. macrocarpa* (11.6 mg/g) but not significantly higher in *A. vera* and *A. keayi* (11.5 mg/g). The least quantity of alkaloids was found in *A. chinensis* (10.3 mg/g) and significantly lower when compared with the alkaloids content in the other leaves of seven *Aloe* species screened.

Total saponins: *Aloe keayi* leaves contained more saponins (59.8 mg/g) as compared with other seven *Aloe* species. *A. vera* had saponin content of 42.0 mg/g greater than *A. succrotina* (39.6 mg/g). The least saponins

content was found in *A. chinensis* (31.4 mg/g) which not significantly different from saponins content in *A. arborescens* (31.6 mg/g).

Table 2. Quantitative composition of phytochemicals in leaves of eight *Aloe species*.

Aloe species	Total Phenol (mg/g)	Flavonoids (mg/g)	Tannins (mg/g)	Alkaloids (mg/g)	Saponins (mg/g)
A. schweinfurthii	4.8	1.5	5.2	10.7	36.1
A. succotrina	13.2	2.4	12.4	11.6	39.6
A. vera	11.5	2.8	12.3	11.5	42.3
A. arborescens	8.2	3.7	8.4	11.4	31.6
A. keayi	14.3	2.6	14.5	11.5	59.8
A. macrocarpa	11.2	1.5	14.4	11.6	35.3
A. schweinfurthii x *A. vera*	4.1	0.5	4.5	11.4	24.7
A. chinensis	5.6	1.6	5.5	10.3	31.4
LSD ($P \leq 0.05$)	0.1	0.1	0.2	0.1	0.9

Infra-red analysis (IR) of extracts from selected *Aloe* leaves: Infrared spectra emphasizing the functional groups present in the leaves of the eight *Aloe* species (Fig. 1-8). The analyses revealed that *Aloe schweinfurthii* consists of hydroxyl, amine, C-H, unsaturated aromatic compounds, carbonyl, double bond, carboxylic acid and phenol groups. The functional groups identified from all the *Aloe* species were similar to those observed in *A. schweinfurthii*. The major functional groups common to these *Aloe* species were amine, phenols, carboxylic acid, double bond, carbonyl and hydroxyl.

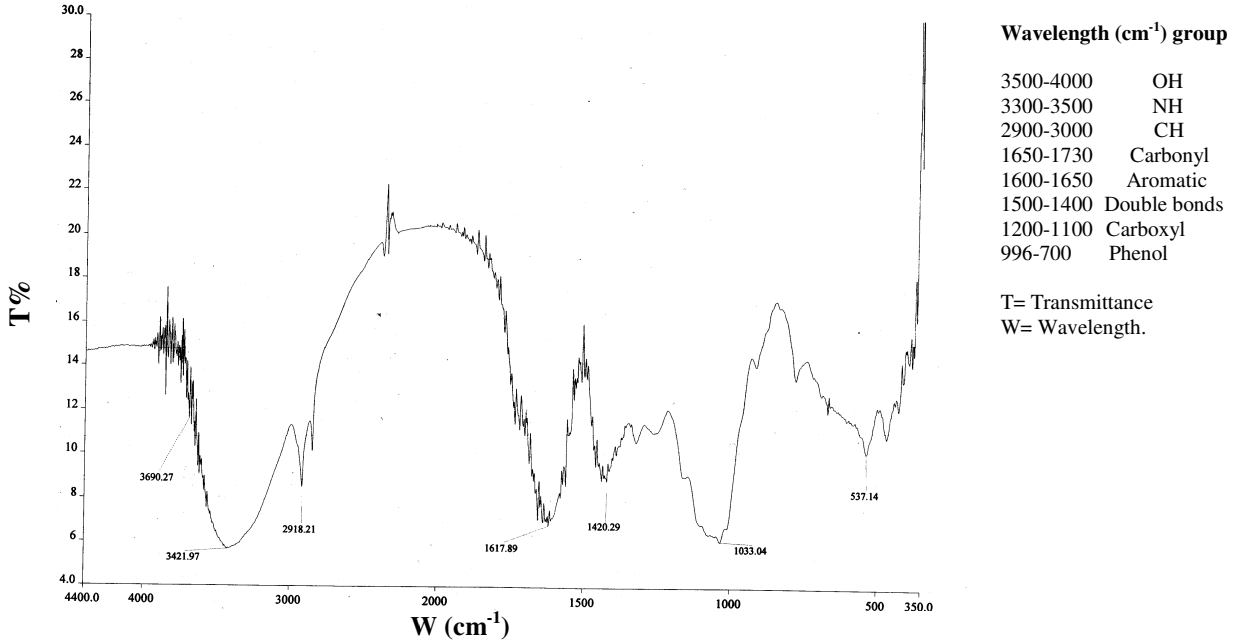
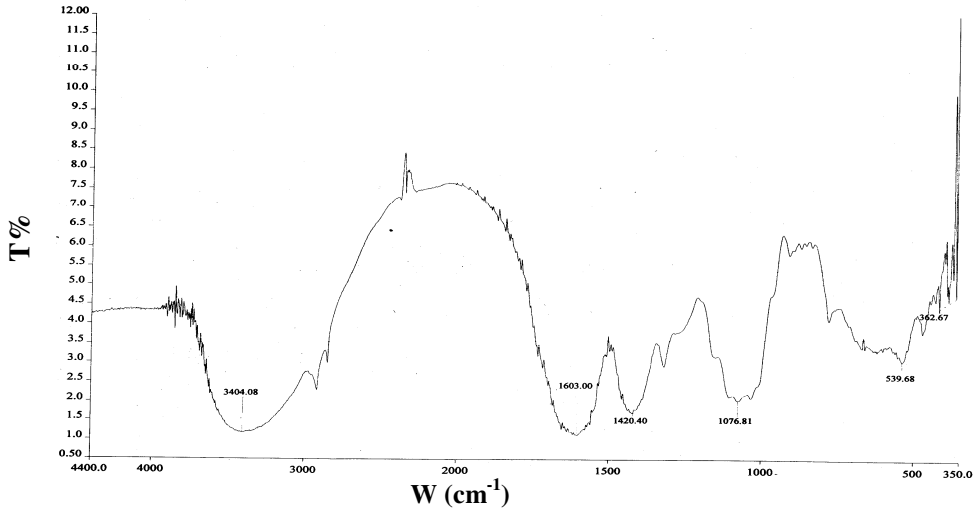


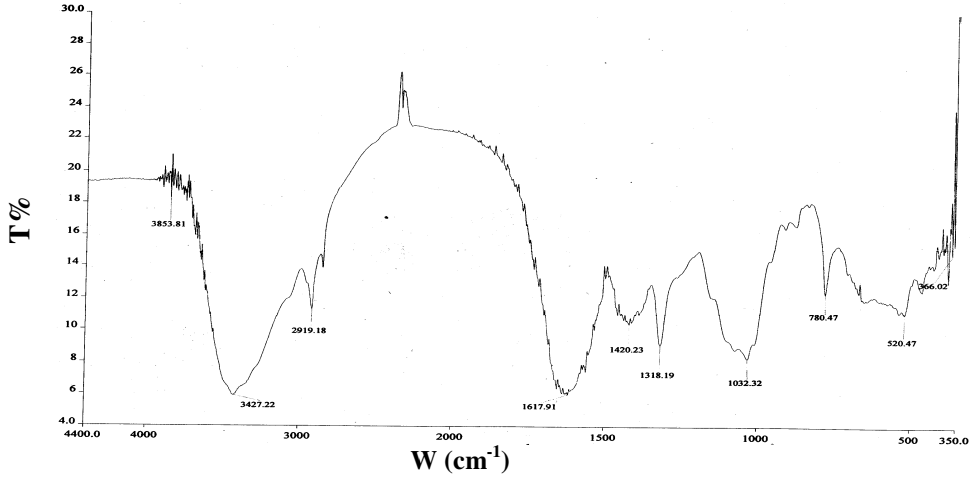
Fig. 1. Infrared spectrum showing functional groups in the leaves of *Aloe schweinfurthii*.



Wavelength (cm^{-1})	group
3500-4001	OH
3300-3501	NH
2900-3001	CH
1650-1730	Carbonyl
1600-1651	Aromatic
1500-1401	Double bonds
1200-1101	Carboxyl
996-700	Phenol

T= Transmittance
W= Wavelength.

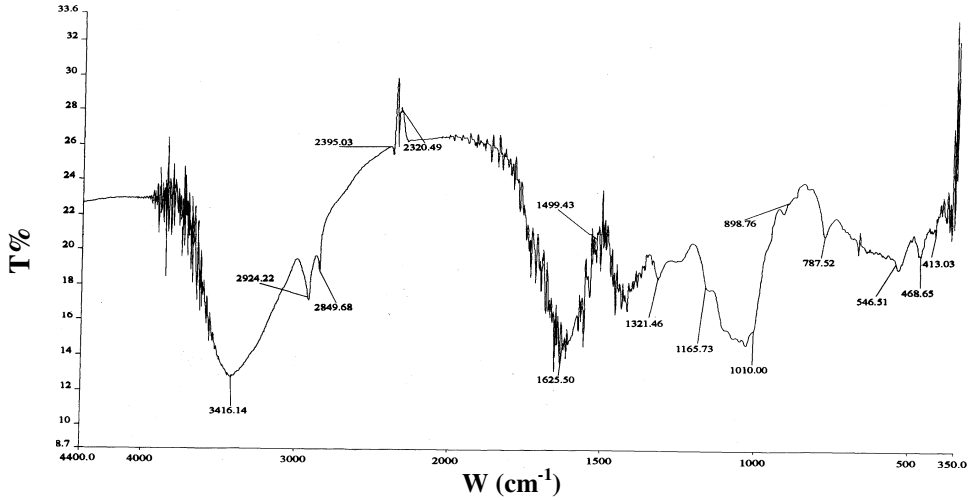
Fig. 2. Infrared spectrum showing functional groups in the leaves of *Aloe succrotina.*



Wavelength (cm^{-1})	group
3500-4002	OH
3300-3502	NH
2900-3002	CH
1650-1730	Carbonyl
1600-1652	Aromatic
1500-1402	Double bonds
1200-1102	Carboxyl
996-700	Phenol

T= Transmittance
W= Wavelength.

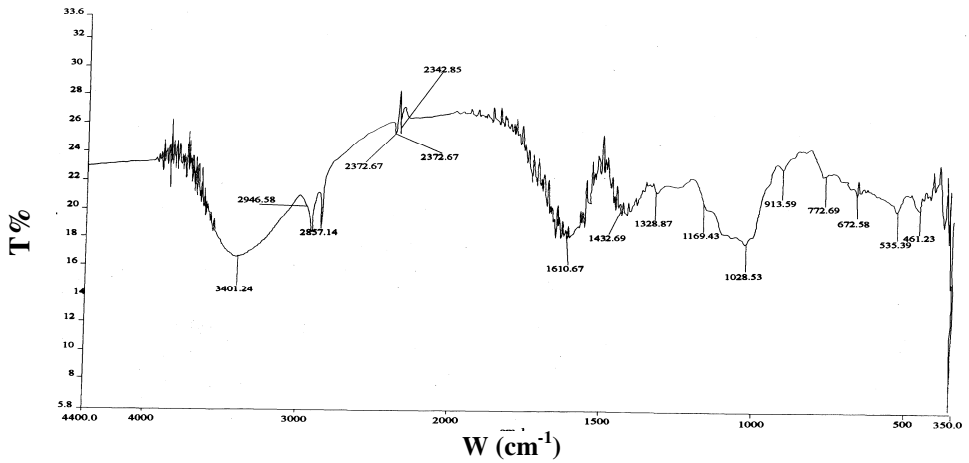
Fig. 3. Infrared spectrum showing functional groups in the leaves of *Aloe vera*.



Wavelength (cm^{-1})	group
3500-4003	OH
3300-3503	NH
2900-3003	CH
1650-1730	Carbonyl
1600-1653	Aromatic
1500-1403	Double bonds
1200-1103	Carboxyl
996-700	Phenol

T= Transmittance
W= Wavelength.

Fig. 4. Infrared spectrum showing functional groups in the leaves of *Aloe arborescens*.

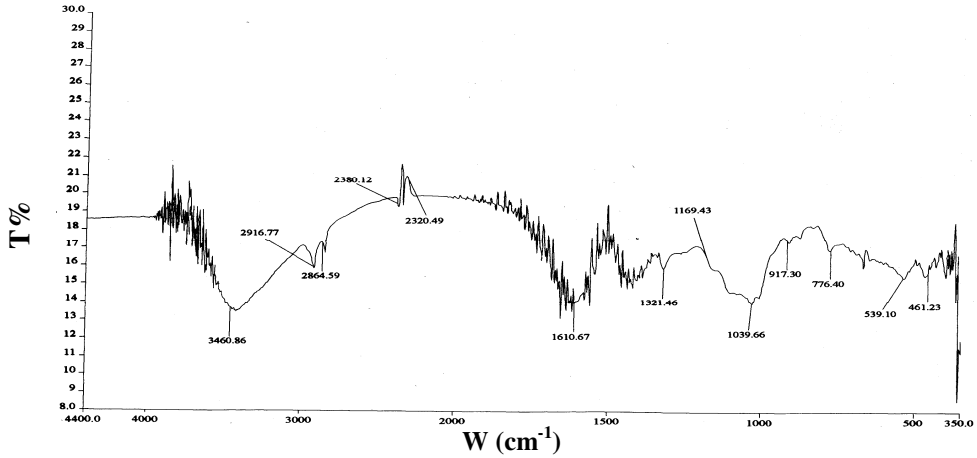


Wavelength (cm^{-1}) group

3500-4004	OH
3300-3504	NH
2900-3004	CH
1650-1730	Carbonyl
1600-1654	Aromatic
1500-1404	Double bonds
1200-1104	Carboxyl
996-700	Phenol

T= Transmittance
W= Wavelength.

Fig. 5. Infrared spectrum showing functional groups in the leaves of *Aloe keayi*.

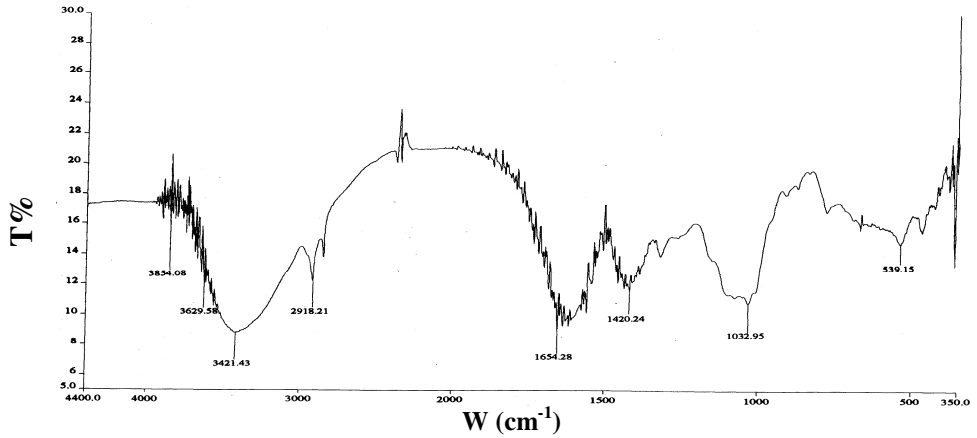


Wavelength (cm^{-1}) group

3500-4005	OH
3300-3505	NH
2900-3005	CH
1650-1730	Carbonyl
1600-1655	Aromatic
1500-1405	Double bonds
1200-1105	Carboxyl
996-700	P

T= Transmittance
W= Wavelength.

Fig. 6. Infrared spectrum showing functional groups in the leaves of *A. macrocarpa*.



Wavelength (cm^{-1}) group

3500-4006	OH
3300-3506	NH
2900-3006	CH
1650-1730	Carbonyl
1600-1656	Aromatic
1500-1406	Double bonds
1200-1106	Carboxyl
996-700	Phenol

T= Transmittance
W= Wavelength.

Fig. 7. Infrared spectrum showing functional groups in the leaves of *Aloe schweinfurthii* x *A. vera*.

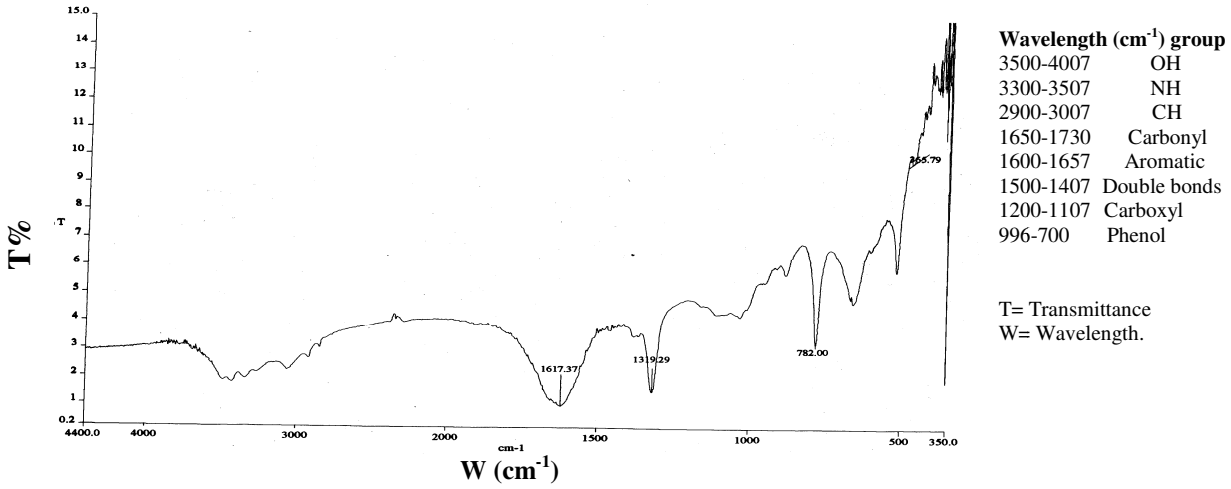


Fig. 8. Infrared spectrum showing functional groups in the leaves of *Aloe chinensis*.

Discussion

The results of the phytochemical screening in terms of identification of phytochemicals present in the leaves of the eight *Aloe* species showed that similar phytochemicals were present in these aloes. *Aloe* species screened contained basic phytochemicals such as tannins, saponins, flavonoids, cardenolides, anthraquinones and alkaloids. Phytochemicals identified in *Aloe* species in this study were similar in some constituents to those reported by Arunkumar & Muthuselvam (2009) but this research reported the presence of more phytochemicals such as alkaloids, cardenolides and anthraquinones and variation in the phytochemical (Bassetti & Sala, 2005; Tiwari *et al*., 2011). Arunkumar & Muthuselvam (2009) analysed phytochemical constituents and antimicrobial activities of *A. vera* against clinical pathogens reported the presence of tannins, saponins, flavonoids when the plant was qualitatively analyzed. In the GC-MS analysis, 26 bioactive phytochemcial compounds were identified in the ethanolic extract of *A. vera*. They linked the antifungal bioactivity of *A. vera* against human clinical pathogens of *Aspergillus flavus* and *Aspergillus niger* to the phytochemicals.

The phytochemicals identified in these *Aloe* species have been reported to confer pesticidal abilities in plants (Chitwood, 2002; Adekunle & Fawole, 2003; Adeniyi *et al*., 2010). Some of these phytochemicals such as tannins, saponins, amongst others were reported to have nematicidal properties and linked to disruption of membranes in organisms thereby facilitating penetration of toxic principles to the detriment of such organisms (Agrios, 2005; D'Addabbo *et al*., 2011). Saponins also called saponocydes reported to possess cell membrane-breaking property. In particular, saponins bind with the lipid membrane of cells, making the cells more permeable and at the same time more fragile, enabling a loss of cell contents through leakage (Bassetti & Sala, 2005). In *Aloe* species saponins have a purifying, antiseptic and antimicrobial action (Basseti & Sala, 2005). Also, alkaloids in plants have been reported to exhibit nematicidal activity on root-knot nematodes decreasing galling in roots (Chitwood, 2003). Phenolics reported toxic to insects, fungi, bacteria, nematodes and weeds (Koul, 2008).

The interpretation of spectra from infrared analyses of the *Aloe* species revealed that various functional groups which were indicators of compound that might have conferred same nematicidal efficacy. *Aloe* species were made up of similar chemical constituents (Dagne *et al*., 2000; Arunkumar & Muthuselvam, 2009; Mbagwu *et al*., 2010).

The results quantified phytochemicals in *A. chinensis* and *A. barbadensis* (*A. vera*) showed that phytochemicals (tannins, flavonoids, saponins and alkaloids) were found in larger quantities (Mbagwu *et al*., 2010). The differences observed due to the age of the plants when plants sampled, methods and solvents of extraction amongst other plants (Qasem, 1996; Mondale *et al*., 2009; Tiwari *et al*., 2011). The supposition of older the plants contained higher amounts of phytochemicals (Tiwari *et al*., 2011). Bassetti & Sala (2005) reported that aloes reached maturity at three to four years of cultivation and most of the phytochemicals in significant quantities to exert potency. Also, different solvents of extraction have different abilities in the extraction of active principles (Lale & Ajayi, 1996; Mondale *et al*., 2009; Tiwari *et al*., 2011).

Some of the phytochemicals identified in the *Aloe* species screened have already reported for medicinal or pesticidal (Golob *et al*., 1999; Chitwood, 2002; Adedire *et al*., 2003; Adekunle & Akinlua, 2007; Thoden *et al*., 2009). Tannins inhibit pathogenic fungi and possessed anthelminthic properties (Gills, 1992; Chitwood, 2002; Tiwari *et al*., 2011). Flavonoids were also present in the *Aloe* species which prevented oxidative cell damages, strong anti-cancer activity and protected against all stages of carcinogenesis medically (Del-Rio *et al*., 1997) and equally have antimicrobial abilities (Tiwari *et al*., 2011). Tannins had anthelmintic, antimicrobial; whereas alkaloids had antimicrobial, anthelmintic and antidiarrhoeal abilities (Tiwari *et al*., 2011). Saponins prevented disease invasion of plants by pathogenic parasitic fungi and equally pesticidal in action and noted for disruption of cell membranes (Ibe, 2007; Tiwari *et al*., 2011).

Conclusion

Active principles were identified from leaves of the *Aloe* species using both phytochemical and infrared analyses and these principles conferred nematicidal properties. The phytochemicals identified and quantified as saponins, alkaloids, tannins, phenols, flavonoids, anthraquinones and cardenolides. The basic functional groups present in these *Aloe* species were hydroxyl, amine, carboxylic acid, phenols and unsaturated aromatic compound. All the *Aloe* species screened contain similar active principles in them, but these phytochemicals varied quantitatively. *A. keayi* had highest amounts of these phytochemicals than the other *Aloe* species screened, followed by *A. vera*, *A. succrotina* and *A. macrocarpa*.

The study showed that the nematicidal activity in the *Aloe* species screened linked to phytochemicals and functional groups. Also the variation in the nematicidal activity on *M. incognita* across the *Aloe* species linked to the types and quantities of phytochemicals. Thus, the outstanding nematicidal activity in *A. keayi* might be due to the higher concentration of phytochemicals than other *Aloe* species. *Aloe* species based on their nematicidal activity due to the identified nematicidal principles used in the management of *M. incognita*.

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