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Response of *Alectra vogelii* Benth to Different Crop Root Exudates

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Authors' contributions

This work was carried out in collaboration between all authors. Authors CN and JM designed the study and wrote the protocol. Author JM wrote the first draft of the manuscript. Author CN managed the literature searches, analyses of the study and performed the spectroscopy analysis. Author BN managed the experimental process. Author TM identified the species of plants. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The aim of the study was to evaluate the effect of root exudates from cowpea, groundnut, maize, sorghum and pearl millet genotypes on the germination and attachment of *Alectra vogelii*. It also aimed to identify functional groups in the powdered root samples that stimulate *A. vogelli* germination.
Study Design: In the laboratory, a Complete Randomised Design (CRD) replicated six times with six treatments; cowpea (IT18, CBC2 and CBC3); groundnuts (Nyanda), maize (PAN 413), sorghum (Landrace) pearl millet (Landrace) and a negative control (distilled water) were used.
Place and Duration of Study: Department of Agronomy Laboratory, Midlands State University Gweru, Zimbabwe (19°25'S and 29°50'E), between March 2014 to May 2014.
Methodology: To assess the germination and attachment of *A. vogelii* seeds, three seeds from each genotype were placed on a moistened filter paper in a petri dish with 0,01 g of preconditioned *A. vogelii* seeds. Identification of functional groups from the powdered root samples of all the crop genotypes using the FT-IR spectroscopy was also done.
Results: Significant differences (P<.05) in the germination of *A. vogelii* were observed among the

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crop genotypes. All Cowpea genotypes and groundnut showed no statistical differences and had the highest germination percentages ranging between 72%-80%. The pearl millet landrace (62%) and groundnut (72%) also showed no statistical differences. Sorghum and maize allowed for low germination percentages (29.6% and 24.5%, respectively) Significant differences were noted among attachment counts (P<.05), however, with no statistical differences noted among the three cowpea varieties, which had the highest counts recorded on attachments (123-139 attachments). Significantly low counts on attachment were recorded in groundnut and all the cereals, ranging between 9-15 counts. The FT-IR spectra obtained from the root samples showed differences and similarities as revealed by the peaks (groundnut, CBC2 and PAN 413 - 8 peaks; IT 18, CBC3 and sorghum – 7 peaks; pearl Millet – 5 peaks).

Conclusion: Groundnut and pearl millet genotypes caused effective suicidal germination of *A. vogelii* seeds and therefore can be used as trap crops in Integrated Weed Management Program. Maize and sorghum did not effectively support germination or attachment. Use of High Performance Liquid Chromatography (HPLC) and mass spectrometry to identify and quantify the strigolactones in each genotype is highly recommended.

Keywords: Alectra vogelii Benth; integrated weed management program; weeds; FT-IT spectroscopy; germination; attachment.

1. INTRODUCTION

Parasitic weeds such as *Alectra vogelli* Benth and *Striga gesnerioides* are seen as the most common reasons for the low yields in pulses [1,2] and have been reported to have devastating effects on food security of small holder famers in Zimbabwe [3,4]. The situation has been worsened due to the increase in population leading to limited land, shift in cropping systems, poor rotation practices, lack of fertilisers and other farming resources causing the small holder farmers to be the most affected by parasitic weeds. *A. vogelii*, the predominant parasitic weed species of legumes, is an obligate hemi-parasite of the Scrophulariaceae family and also placed in the Orobanchaceae family which derives water and nutrients from roots of the host plant after forming an attachment with the host [5]. *A. vogelii* has been shown to cause extensive damage in groundnuts (*Arachis hypogaea*), cowpea (*Vigna anguiculata*) and soybean (*Glycine max*) among other legumes with yield losses on cowpea reaching up to 70% and even 100% under severe infestation [6,7,8].

Despite some considerable work having been done on various control methods for parasitic weeds, the control of *A. vogelii* in cowpeas and groundnuts has received relatively little attention in Zimbabwe. According to Rugare et al. [7], using resistant varieties to control *Striga asiatica* and *S. hermonthica* has been done extensively but such work on *A. vogelii* resistance has been limited.

Strigolactones (SLs) also identified as a group of plant hormones, is the collective name given to root stimulants produced by different plants that induce germination of parasitic witch weeds [9,10,11]. The germination and severity of *A. vogelii* attachment is determined by the amount of germination stimulants produced by different hosts or non-hosts as well as the spatial relationship between the host roots and *Striga* seed [10,12,13]. The chemical elicitors of haustorial formation are different from those stimulants that initiate germination in the first instance [14]. This would also possibly bring about a control strategy where these elicitors of haustorial formation are suppressed through breeding for such mechanism in either host or non-host plants. Organic acids, amino acids and oligosaccharides are the major ingredients in root exudates [15]. The presence of phenyl group at different positions of the cyclohexanone ring has shown to have a considerable influence on the induction of germination of *Orobanche* seeds and ketones and enol ethers have been shown to cause germination of parasitic weeds [11]. The FT-IR Spectroscopy is a quick, non-invasive and high resolution analytical tool for the identification of different types of chemical bonds in a molecule by producing the infrared absorption spectrum. It is one of the most widely used techniques to identify the chemical components and elucidate the structural compounds [16].

The study was undertaken to determine the response of *A. vogelii* to stimulants of different crop root exudates (cowpea – IT 18, CBC2 and CBC3, groundnuts- Nyanda, maize- PAN 413, sorghum- Landrace and pearl millet- Landrace) with the aim of determining crop genotypes with the capacity to reduce witch weed seed banks in arable areas of Zimbabwe.

The specific objectives of the study were to (a) determine the effect of root exudates from cowpea, groundnut, maize, sorghum and pearl millet varieties on germination of *A. vogelii*, (b) evaluate the extent of attachment of *A. vogelii* on the roots of cowpea, groundnut, maize, sorghum and millet varieties and (c) identify the functional groups in root samples of cowpea, groundnut, maize, sorghum and pearl millet varieties that stimulate *A. vogelli* germination.

2. MATERIALS AND METHODS

The experiment was carried out in the laboratory at Midlands State University in Gweru, Zimbabwe. The grid for the site is 19°25'S and 29°50'E and it is in the Natural Region III (NRIII) of Zimbabwe. It is elevated 1 425 m above sea level.

The experiment was laid out in a Complete Randomised Design (CRD) replicated six times. Six treatments which included the following crops; cowpea (IT18, CBC2 and CBC3); groundnuts (Nyanda), maize (PAN 413), sorghum (Landrace) and pearl millet (Landrace) and a negative control (distilled water) (Table 1) were screened for their capacity to germinate *A. vogelii* seeds and ability to form any attachments. Furthermore, root exudates extracted from these different crops were screened so as to identify the compounds present. CBC2 and CBC3 varieties were obtained from DR&SS, Nyanda and IT18 from SeedCo and PAN 413 from Pannar whilst the Landraces were purchased from a local market.

Table 1. Table of treatments

Treatment number	Treatment description (Crop/Cultivar)
1	Cowpea-IT18
2	Cowpea- CBC2
3	Cowpea- CBC3
4	Groundnut- Nyanda
5	Maize- PAN413
6	Sorghum- landrace
7	Distilled water (negative control)

Prior to the experiment, *A. vogelii* seeds obtained from the University of Zimbabwe from a seed stock collected from the Weed Research Department at Henderson Research Station were conditioned first. A filter paper was placed at the base of a large petri dish and the petri dish was moistened with 25 ml of distilled water. *A. vogelii* seeds were then put in the petri dish. The petri dish was wrapped with aluminum foil paper to exclude light. Preconditioning was completed by incubating the petri dish at 30°C for 10 days.

For the germination assay, two filter papers were placed at the base of all petri dishes. Uniform quantities (0,01 g) of preconditioned *A. vogelii* seeds were then sprinkled on the base of the each petri dish using a spatula. Three seeds (sterillised by immensing in NaOCl for 5 minutes and thoroughly rinsing with distilled water afterwards) per each of the crop varieties were placed at the centre of each petri dish. Each treatment was replicated six times. 5 ml of distilled water were pipetted into the petri-dishes to provide moisture with a further application of moisture applied when necessary. In the control, distilled water was pipetted into a petri dish, with *A. vogelii* seeds. All petri dishes were then sealed and covered with aluminum foil paper and placed in an incubator at 30°C for almost ten days. Viewing was done using a stereo microscope where monitoring was done on a daily basis. The number of germinated *A. vogelii* seeds were counted in all the petri- dishes at every 24 hour interval and expressed as a germination percentage. Germination was regarded to have occurred when the radical was visible. The number of successful attachments formed from each treatment were also counted at 24-hour interval and recorded.

Prior to the identification of functional groups in the roots of the crops, seedlings were raised in the greenhouse for three weeks in pots filled with fine textured sandy soil. Seven pots measuring 20 cmx 20 cm were labeled and sown with twenty seeds from each of the varieties. The pots were watered everyday using tap water and after three weeks the seedlings were uprooted and carefully washed off excess soil using running tap water before being rinsed using distilled water.

Root parts were cut using a surgical blade from the seedlings collected from the greenhouse and sun dried for 3 days. The dried roots were then cut into small pieces using a surgical blade, ground into very fine powder and weighed (0.01 g). Pure Potassium Bromide (KBr) (0.1 g) was crushed using an agate pestle and motor and weighed. The solid sample was mixed with KBr at a ratio of 1 (powdered sample): 10 (KBr). The sample mixture was then ground together for about 3 minutes after which it was compressed in a barrel tightened with nuts at both ends to make pellets or discs. The pellets were then, one at a

time, put into the FT-IR sample holder and absorption and percentage transmission were recorded.

The FT-IR spectra of the functional groups for all the seven root powder samples were obtained and the effective peaks were compared with the IR frequency absorptions from literature. The peak value in the region of infrared radiation was used to identify the functional groups of the active components. The specific wave numbers lengths and intensities were considered.

Data on germination percentage were arcsine transformed before a one way analysis of variance was performed using Genstat version 14. Significantly different treatment means were separated using LSD at 5% significance.

3. RESULTS AND DISCUSSION

Significant differences (P< .05) were observed among the crop genotypes tested on their ability to stimulate germination of *A. vogelii.* The leguminous crops (cowpea and groundnuts) showed no statistical differences and had the highest germination percentages ranging between (72 -80%). The pearl millet landrace and Nyanda groundnut also showed no statistical differences, with germination percentages of 62% and 72%, respectively. *Alectra vogelii* did not germinate in the treatment without any crop. Sorghum landrace and maize (PAN 413) allowed for low germination percentages (29.6% and 24.5% respectively) (Fig. 1).

Significant differences were noted among attachment counts (P < .05) of the different crop genotypes as shown in Fig. 2. No statistical differences were noted among the three cowpea varieties, which had the highest counts recorded on attachments (ranging between 123-139 attachments). Significantly low counts on attachment were recorded in Nyanda and all the cereals, ranging between 9-15 counts.

The amount of germination stimulants exuded by different crops determines the germination and severity of *A. vogelii* attachment [13]. The crop genotypes (cowpeas CBC2 and 3, groundnut Nyanda as shown in Fig 3(a) and pearl millet Landrace) induced the highest rates of germination and this could be as a result of high production of strigolactones from these crop genotypes. Low production of SLs leads to poor and low germination and such case of lower production of germination stimulants was noted in sorghum landrace (29%) and maize PAN 413 (24%) [17].

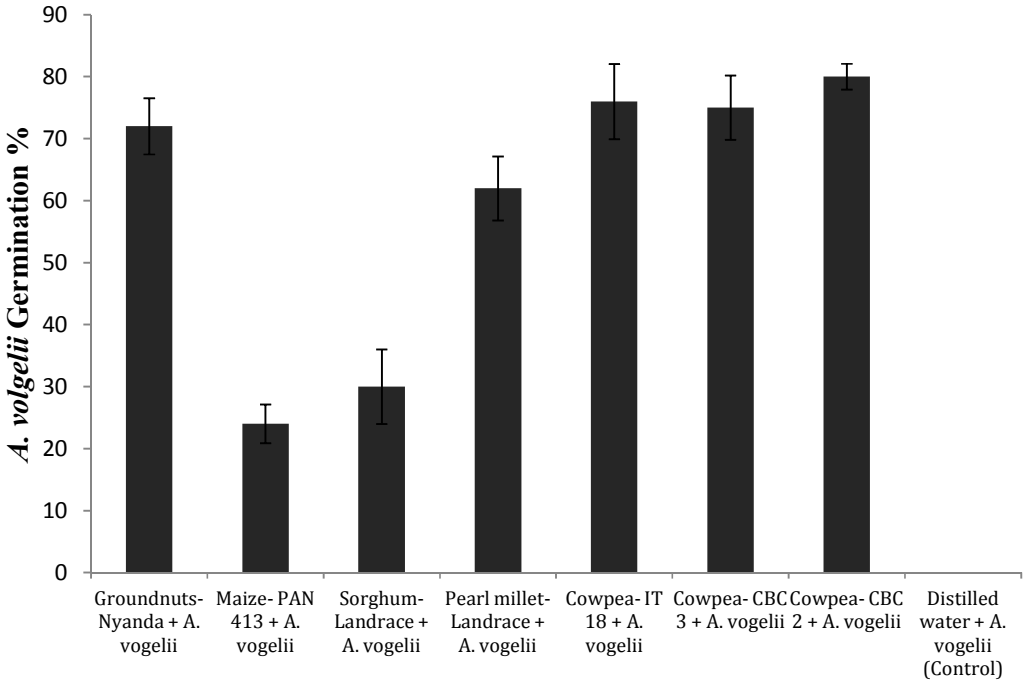


Fig. 1. Germination percentage of *A. vogelii* as induced by different crop root exudates

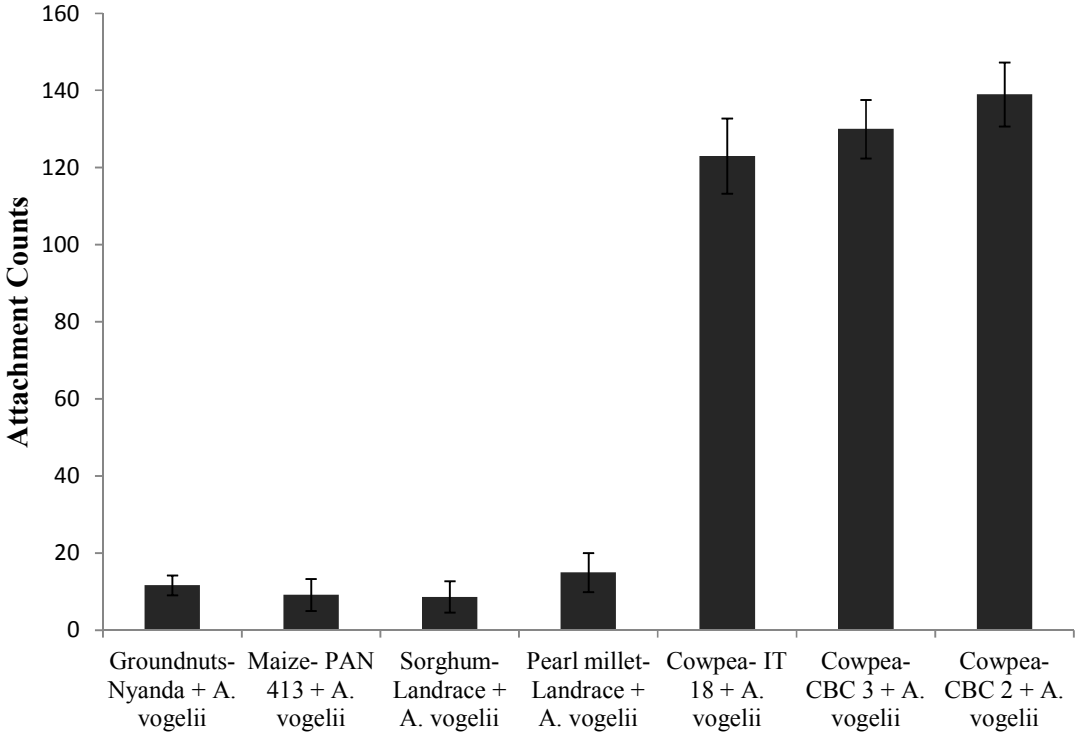


Fig. 2. Attachments counts obtained from the crop genotypes

The FT-IR analysis confirmed the presence of ketones, ethers and aldehydes in all the legume crop varieties and confirmed them absent in all the cereal crop varieties used in this study. These compounds could have been responsible for the high germination induced in all the cowpea and groundnut varieties. This is in line with work done by Mwakabobo and Zwanenburg [11] who showed that ketones and enol ethers induced high germination of parasitic weeds. Moreover all the crop varieties under study had phenols or phenolic compounds in their roots and this could be the reason why all the crop varieties under study managed to induce germination despite being low and high among the varieties. The variation in the germination percentages however could be attributed to the presence of phenyl group at different positions of the cyclohexanone ring. Previous studies have shown that the presence of phenyl group at different positions of the cyclohexanone has a considerable influence on the germination of *Orobanche* seeds [11]. This could strongly be the case with pearl millet. However, the chemical composition of the SLs could also have resulted in such differences for example its known that Alectrol is the main SLs found in cowpea and is also mainly responsible for the germination of *Alectra* whilst Strigol the main SL found in maize is mainly responsible for the germination of *Striga* species.

As was expected, the negative control (distilled water) did not induce any germination of *A. vogelii* as shown in Fig 3(b) and this concurs with results from previous work on *Striga* where no germination was observed from the negative controls [18,19,20]. Since no germination was observed from distilled water with the opposite being true where there were germination stimulants, this shows that the germination of *A. vogelii* is a response after exposure to some stimulants as revealed in this study.

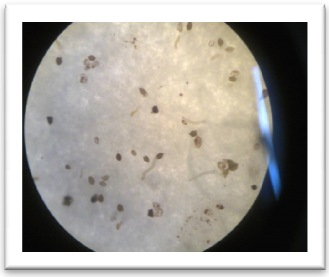
Attachment numbers varied among the crop genotypes. Cowpea genotypes had higher numbers of attachments formed whilst very low attachments occurred in pearl millet, maize and sorghum just as anticipated however unexpectedly groundnuts as shown in Fig 3(c) had very low number of attachments. This is because the cereal crop genotypes used in this study are known to be non-hosts of *A. vogelii* (instead they host *Striga*) whilst cowpea [3] and groundnut are hosts to *A. vogelii* [6,20,21].

Also it was in cowpea genotypes where successful formation of the haustorium and penetration of the weed seed radicle into the host roots was observed. The variation in attachment could be due to differences in SLs secretions into the rhizosphere. Furthermore, some previous work have reported that the haustorial formation is dependent on haustorium initiating substances or factors 2,6-dimethoxy-p-benzoquinone (2.6 DMBQ) and kinctin which are different from those that stimulate germination (SLs) in the first place [14], hence the very low attachment counts observed in groundnuts, millet, maize and sorghum could be attributed to the absence or very low production of the haustorium initiating substances. According to Jamil et al. [17] the low production of the haustorial initiation factor means no attachment.

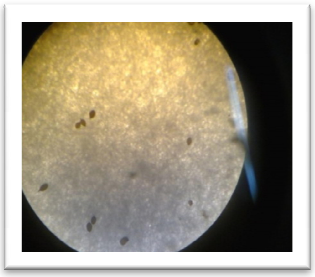
It has also been reported that certain flavonoids and phenolics such as p-hydroxy acids, quinones and cytokinins from the host can induce haustorium formation [22,23]. However the exact structural requirements of the secreted compounds for haustorium induction is not fully understood [22] and therefore it cannot be ruled out that other mechanisms of resistance might have come into play thereby not favouring attachment formation, such as failure of the xylem connection [17] and compatible interaction or connection between the parasite and host root and avoidance through root architecture as shown in a previous study where a maize variety expressed resistance to *Striga* [19].

Furthermore *A vogelii* seeds contain only small or very limited food reserves such that they only survive for a few days after their germination unless they reach host root and xylem [24] hence maybe the low attachments levels observed in Nyanda, pearl millet, sorghum and maize could be due to the fact the germinated *A. vogelii* seeds quickly ran out of food reserves before reaching the host root.

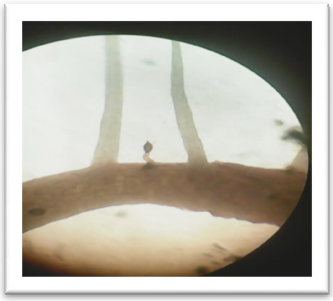
The low attachment counts observed in some of the varieties could also be due to the failure of radicles to respond to chemotropism and also due to host root tissue which may stagger the penetration process of *A. vogelii* haustorial cell till it fails to establish through mechanical barrier. This is because varieties differ in their morphological characteristics such as wall thickness and therefore screening of host varieties with regard to their resistance to penetration via the various root tissues maybe useful [25].



(a)



(b)



(c)

Fig. 3. Images showing; (a) germination induced by groundnut (Nyanda) (b) no germination induced by distilled water and (c) attachment formed in Nyanda

The variation in the germination and attachments of *Alectra* could have also been due to the quality and quantity of root exudates. According to Li et al. [26], the quantity, quality and composition of SLs depend on the plant species, cultivar, growth stage and environmental factors and could also explain the significant differences in *A. vogelii* germination [26]. In previous studies,it was discovered that in some groundnut varieties benzoic acid was the highest among the phenolics accountings for 60% of the total phenolic content [6] highlighted that parasitic root meristem need exposure to 10^{-6} m 2,6- DMBQ for 6 hours to initiate germination.

The high or low rates of germinations and low attachment counts attained in groundnuts, pearl millet, sorghum and maize means that these crops can be used as trap/catch crops or in rotation by the farmers. In case of groundnut (Nyanda) some degree of resistance has been exhibited and local farmers in *Alectra* hot spots should not be worried. This concurs with previous studies [27] where examples of trap crops is seen in Botswana where certain varieties of bambara and pearl millet were potent stimulators of *A. vogelii* germination without being susceptible and these can be used in rotation to cause suicidal germination. This will provide a cheap way especially for the poor resourced farmers not only in some instances to save their current crop but also reduce the soil seed weed bank.

The identification of functional groups was based on the FT-IR peaks attributed to stretching and bending vibrations.

As shown in Table 2 the FT-IR Spectra for groundnut variety Nyanda had 8 peaks with value of 3418.19, 2927.64, 1640.60, 1420.84, 1256.31, 1057.02, 536.10, 468.27 cm^{-1} and of all these peaks, the peak 468.28 cm^{-1} could not be identified or accounted for. All the FT-IR Spectra peaks for Cowpea IT18 root powder sample had the functional groups they represent identified and the peaks were a total of 7 lying between 3557.60 and 617.85 cm^{-1}respectively as shown in Table 3.

The FT-IR Spectra for Cowpea CBC2 had 8 peaks recorded at values of 3416.26, 2928.41, 1619.32, 1421.16, 1250.00, 1037.62, 619.30, 472.55 cm^{-1} of which the peak with the wavelength 472.55 cm^{-1} was unknown as represented in Table 4, whilst 7 absorption peaks of the FT-IR Spectrum at the value of 3935.01, 3409.81, 2933.37, 1630.11, 1406.85, 1047.62, 617.96 cm^{-1} for Cowpea variety CBC3 root extract were identified, except for the peak 3935.01 cm^{-1} which was unknown. The results are shown in Table 5.

Sorghum had 7 absorption peaks which all had their possible peak assignments, assigned to as ranging 3407.66, 2924.16, 1638.21, 1618, 1382.47, 1074.67, 619.99 cm^{-1}as shown in Table 6. Maize absorption peaks (3413.84, 2925.38, 1638.87, 1379.78, 1253.16, 1042.58, 613.31, 469.98 cm^{-1}) were shown to be 8 of which one (peak 469.98 cm^{-1}) was not known and no functional group could be assigned to this peak, Table 7.

Table 2. Absorption peak areas of FT-IR spectra recorded for groundnut root extract

Source of root extract	Experimental frequency (cm^{-1})	Functional class	Possible peak assignments and intensity
Groundnut (Nyanda)	3418.19	Amines, Alcohols and Phenols	N-H stretching, O-H (H-bonded), stretching(str.)
	2927.64	Alkanes	CH_3, CH_2 & CH (2 or 3 bands), stretching (str.)
	1640.60	Carboxylic groups Amines	C=O stretching (str.), NH_2 (1^0-amines) (str.)
	1420.84	Alkanes, Alcohols, Phenols, Ketones & Aldehydes	-CH bending, CH_2& CH_3deformation, O-H bending (in plane)(med.), α-CH_2 bending (str.)
	1256.31	Ethers, Carboxylic Acids& derivatives, Alkanes	-OH alcohols (primary &secondary) and aliphathic ethers, O-C (2bands), CH_2 & CH_3 deformation.
	1057.02	Alcohols, Phenols, Sulfoxide	C-O stretching of COOH, S=O
	536.10	Disulfide weak	S-S
	468.27	Unknown	Unknown

Table 3. Absorption peak areas of FT-IR spectra recorded for cowpea IT 18 root extract

Source of root extract	Experimental frequency (cm^{-1})	Functional class	Possible peak assignments and intensity
Cowpea (1T 18)	3557.60	Oxidised Nitrogen Functions	O-H stretching, (str.)
	2933.28	Alkanes	-CH , CH_3, CH_2& CH 2 OR 3 bands stretching
	2043.84	Unknown	Unknown
	1631.20	Amines, Carboxylic group, Alkenes	NH_2 scissoring (1^0 amines) (med-str.), C=O (amide 1 band), N-H (amide 2 band) (med.), C=C (symmetry reduces intensity)
	1404.94	Carboxylic groups, Aldehydes, Ketones, Alkanes, Alcohols and Phenols	- CH bending vibrations, C-O-H bending (med.), α-CH_2 bending (str.), CH_2 & CH_3 deformation (med.), O-H bending (in plane) (med.)
	1022.91	Alcohol, Phenols, Amines, Carboxylic groups	C-O stretching of COOH, C-N (med.), O-C (2 bands) (str.), stretching
	617.85	Alkynes	C-H deformation bending,(str.)

Furthermore, the functional group analysis (from the peaks) of Nyanda root extract confirmed the presence of amines, alcohols, phenols, carboxylic groups, alkanes, ketones, aldehydes, ethers, sulfoxide and disulfides (Table 2) while those for Cowpea IT 18 revealed the presence of oxidised nitrogen functions, alkanes, amines, carboxylic group, aldehydes, ketones, alcohols, phenols and alkynes (Table 3). That of CBC2 gave evidence to the presence of amines, alcohols, phenols, alkanes, carboxylic groups, ketones, aldehydes, ethers, sulfoxide and alkynes (Table 3) whereas that of CBC3 showed the presence of amines, alcohols, phenols, alkanes, carboxylic groups, aldehydes, ketones, sulfoxide and alkynes (Table 5). The FT-IR analysis results of Sorghum root extract confirmed the presence of amines, alcohols, phenols, alkanes, carboxylic groups and alkynes (Table 6) with that of PAN 413 revealing the

Table 4. Absorption peak areas of FT-IR spectra recorded for cowpea variety CBC2 root extract

Source of root extract	Experimental frequency (cm^{-1})	Functional Class	Possible peak assignments and intensity
Cowpea (CBC2)	3416.26	Amines, Alcohols and Phenols	N-H stretching, O-H (H-bonded), stretching (str.)
	2928.41	Alkanes	CH_3, CH_2 & CH (2 or 3 bands), -CH stretching (str.)
	1619.32	Carboxylic groups, Amines	N-H (1_i-amide)11 band bending, NH_2scissoring(1^0- amines) bending, (str.)
	1421.16	Alkanes, Alcohols, Phenols, Ketones & Aldehydes	-CH bending, CH_2& CH_3 deformation, O-H bending (in plane) (med.), α-CH_2 bending (str.)
	1250.00	Ethers, Carboxylic Acids & derivatives, Alkanes	-OH alcohols (primary & secondary) and aliphathic ethers, O-C (2bands), CH_2 & CH_3 deformation.
	1037.62	Alcohols, Phenols, Sulfoxide, Carboxylic group	C-O stretching of COOH, S=O, O-C (2 bands) (str.)
	619.30	Alkynes	C-H deformation bending, (str.)
	472.55	Unknown	Unknown

Table 5. Absorption peak areas of FT-IR spectra recorded for cowpea variety CBC3 root extract

Source of root extract	Experimental frequency (cm^{-1})	Functional class	Possible peak assignments and intensity
Cowpea (CBC3)	3935.01	Unknown	Unknown
	3409.81	Amines, Alcohols & Phenols	N-H stretching, O-H (H-bonded), stretching (str.)
	2933.37	Alkanes	CH_3, CH_2 & CH (2 or 3 bands), -CH stretching (str.)
	1630.11	Carboxylic groups, Amines	NH_2 scissoring (1^0 amines) (med-str.), C=O (amide 1 band), N-H (amide 2 band) med, C=C (symmetry reduces intensity)
	1406.85	Carboxylic groups, Aldehydes, Ketones, Alkanes, Alcohols and Phenols	- CH bending vibrations, C-O-H bending (med.), α-CH_2 bending (str.), CH_2 & CH_3 deformation (med.), O-H bending (in plane) (med.)
	1047.62	Alcohol, Phenols, Amines, Carboxylic groups, Sulfoxide	C-O stretching of COOH, C-N (med.), O-C (2 bands) (str.), stretching, S=O (str.)
	617.96	Alkynes	C-H deformation bending, (str.)

Table 6. Absorption peak areas of FT-IR spectra recorded for sorghum root extract

Source of root extract	Experimental frequency (cm^{-1})	Functional class	Possible peak assignments and intensity
Sorghum (Landrace)	3407.66	Amines, Alcohols & Phenols	N-H stretching, O-H (H-bonded), stretching (str.)
	2924.16	Alkanes	CH_3, CH_2 & CH (2 or 3 bands), -CH stretching (str.)
	1638.21	Carboxylic groups, Alkenes	C=O (amide 1 band) (str.), C=C (symmetry reduces intensity) stretching
	1618	Carboxylic groups	N-H (1_i- amide) 11 band, bending, (med.)
	1382.47	Alkanes	- CH bending vibrations, CH_3 deformation bending (med.)
	1074.67	Alcohol, Phenols, Amines, Carboxylic groups	C-O stretching of COOH, C-N (med.), O-C (2 bands) (str.), stretching
	619.99	Alkynes	C-H deformation bending, (str.)

presence of amines, alcohols, phenols, alkanes, carboxylic groups, aliphatic groups, sulfoxide and alkynes (Table 7).

Pearl Millet root extract confirmed the presence of amines, alcohols, phenols, carboxylic groups, alkenes and alkynes (Table 8).

As presented in Table 8, Pearl Millet had the lowest number of peaks recorded (5) at wavelength values of 3934.30, 3403.02, 1628.96, 1069.06, 618.30 cm^{-1} compared to all the other varieties. The peak 3934.30 cm^{-1} was however, unknown.

The results presented from the FT-IR analysis highlighted the similarities as well as the differences among the various root powder samples from different crop varieties in terms of functional groups. Nyanda, CBC2 and PAN 413 had the highest same number of peaks (8) whilst IT 18, CBC3 and Sorghum had the same number of peaks (7). Pearl Millet had the lowest number of peaks (5) which was different from all the other crop varieties. This is in line with results that Mariswamy [16] got which also showed similarities and variations among the peaks that represented functional groups in the crude powder of *Aerva lanata* (L) Juss. stems, leaves

Table 7. Absorption peak areas of FT-IR spectra recorded for maize variety PAN 413 root extract

Source of root extract	Experimental frequency (cm^{-1})	Functional class	Possible peak assignments and intensity
Maize (PAN 413)	3413.84	Amines, Alcohols & Phenols	N-H stretching, O-H (H-bonded), stretching (str.)
	2925.38	Alkanes	CH_3, CH_2 & CH (2 or 3 bands), -CH stretching (str.)
	1638.87	Carboxylic groups, Alkenes	C=O (amide 1 band) (str.), C=C (symmetry reduces intensity) stretching
	1379.78	Alkanes	- CH bending vibrations, CH_3 deformation bending (med.)
	1253.16	Aliphatic groups, Carboxylic groups	O-C (med.) stretching, O-H alcohols
	1042.58	Alcohols, Phenols, Amines, Sulfoxide, Carboxylic groups	C-O stretching of COOH, C-N stretching (med.), S=O str., O-C (2 bands) (str.)
	613.31	Alkynes	C-H deformation bending, (str.)
	469.98	Unknown	Unknown

Table 8. Absorption peak areas of FT-IR spectra recorded for pearl millet root extract

Source of root extract	Experimental Frequency (cm^{-1})	Functional class	Possible peak assignments and intensity
Pearl millet (Landrace)	3934.30	Unknown	Unknown
	3403.02	Amines, Alcohols & Phenols	N-H stretching, O-H (H-bonded), stretching (str.)
	1628.96	Carboxylic groups, Alkenes	C=O (amide 1 band) str.), C=C (symmetry reduces intensity) stretching
	1069.06	Alcohol, Phenols, Amines, Carboxylic groups	C-O stretching of COOH, C-N med., O-C (2 bands) (str.), stretching
	618.30	Alkynes	C-H deformation bending, (str.)

**Standard abbreviations (str = strong, med = medium; wk = weak) were used to describe the absorption bands.*

and flower, thus their FT-IR analysis showed the presence of different functional groups.

The spectral differences are the objective reflection of componential differences. The fact that there was variation among the number of peaks from the results of this study ultimately meant variation within the functional groups also existed.

The major similarity and difference among the functional groups identified from the crop root samples could be the presence of alcohols, phenols, carboxylic acids which were confirmed in all the crop varieties under study whereas ketones and aldehydes were only present in the legumes only with none confirmed in the cereal varieties. To date, Alectrol has not been identified in any of the cereal varieties under study and it has been highlighted that it is mostly unlikely that Alectrol is an alcohol because their study showed that the infrared spectrum does not reveal the typical OH absorption at 3600 cm^{-1} [11]. Perhaps then Alectrol could be a ketone or aldehyde which from this study was only confirmed in the legume varieties. However the work of Zwanenburg and Pospisil [11] disputed the claims made earlier on by Muller et al. [28], in line with Matsuura et al. [29].

According to Mariswamy [16] knowing the functional groups presented in a sample is very useful for the proper identification of the active compounds and therefore the identified functional groups for the different crop root powder samples used in this study can be used to identify and characterize the strigolactones, germination stimulants and haustorium initiating factors that the analysed crops produce. However the researcher had some limitations

and challenges in properly identifying the active compounds represented by the various functional groups which could have been easily linked to the germination and attachment trend showed from the results of this study. Some of the limitations and challenges include lack of standards, limited literature and other resources, therefore the identification of the functional groups serves more like a preliminary study which needs to be pursued.

In light of the results obtained in this study, there is an imperative need to carefully pay attention to the link between SLs, *A. vogelii* germination and the colonization by AMF. It might be of interest to test whether *A. vogelii* and AMF are triggered by exactly the same type of SL and then see if it can be an option to identify crop genotypes that produce the types of SLs that produce AMF without triggering *A. vogelii* germination. Akiyama et al. [30] confirmed that SLs such as 5-deoxystrigol and orobanchol are more active in inducing AMF hyphal branching than others, such as Strigol and sorgomol. Hence with the use of this knowledge, plant breeders could select cultivars that produce only the desired types of SL that cause maximum AMF hyphal branching without triggering *A. vogelii* germination [17].

4. CONCLUSION

Groundnut and pearl millet genotypes caused effective suicidal germination of *A. vogelii* seeds as they did not further effectively support attachment. Therefore they can be used as trap crops in Integrated Weed Management Program in *A. vogelii* endemic areas. Maize and sorghum did not effectively support germination or attachment. Use of High Performance Liquid Chromatography (HPLC) and mass spectrometry to identify and quantify the strigolactones in each genotype is highly recommended.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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