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Research Article

Nematicidal Activity of Pyrolisate of *Bambusa vulgaris* on Root-Knot *Nematode; Meloidogyne incognita* of Lettuce

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Abstract | Pyroligneous Liquors are obtained from diverse biomasses and have been found to contain important biologically active components with high phenolic, carbonyl and organic acid contents which have several pest control properties. Bamboo Pyroligneous Liquor (BPL) has proved effective in controlling several insect pests of many crops but its nematicidal potential is yet to be fully determined. We, therefore, investigated the nematicidal activities of Bamboo Pyroligneous Liquor in managing root-knot nematodes of *Lactuca sativa* in greenhouse trials. *Bambusa vulgaris* biomass was carbonised at 500 °C in a locally fabricated pyrolizer with automatic temperature control to obtain the Bamboo Pyroligneous Liquor (BPL). Two weeks old lettuce plants were inoculated with 1,000 juveniles of *Meloidogyne incognita*. BPL was applied at three concentrations of 100, 200 and 400 mg/ml. Results revealed that nematode infected lettuce plants treated with BPL recorded significantly higher ($P< 0.05$) mean number of leaves, plant height and yield compared to the untreated control. In addition, BPL at 400 mg/ml had substantially higher nematicidal effects on both the soil and root population of nematodes of *L. sativa* and compared favourably with the carbofuran treatments. We concluded that BPL could serve as a very potent eco-friendly alternative to synthetic nematicides in managing *M. incognita* of lettuce.

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Introduction

Pyroligneous acids or liquors which are generally light red or reddish brown in colour have been produced from diverse biomasses ranging from forest, agricultural and household wastes. Pyrolysis is a thermo-chemical process of decomposition of lignocellulosic materials into smaller molecules by thermal energy (Demirbas, 2007). The yields of Pyroligneous liquor (PL) depend on the pyrolysis procedures, moisture contents of feeding materials (Antal and Gronli, 2003), type of feeding materials (Fapetu, 1994; Oladeji, 2013); heating rate (Putun *et al*., 2007); and temperature (Oladeji, 2012; Yaman, 2004; Weerachanchai *et al*., 2011).

The bioactivities and possible applications of Pyroligneous liquor (PL) have been extensively explored (Souza *et al*., 2012; Ma *et al*., 2013, 2014; Wu *et al*., 2015). PL has been reported to contain various types of important biologically active components such as; organic acids, phenolic, alkane, furan derivatives, esters, alcohol, sugar derivatives, and nitrogen compounds (Wei *et al*., 2010; Pimenta *et al*., 2018). The diversity of functions of PL has attracted attention due to its environmental friendliness. PL has been widely used in medicine, food and agriculture (Cai *et al*., 2012; Dissatian *et al*., 2018). In agriculture, PL specifically from bamboo has been used in controlling insects pests such as termites, flies, ticks and fleas (Yatagai, 2004; Hagner *et al*., 2018); ameliorate soil, aids crop germination, used as fertilizer (Mohan *et al*., 2006; Jung, 2007; Wei *et al*., 2009, 2010); feed additive to improve animal performance (Samanya and Yamauchi, 2001; Yoo *et al*., 2007; Watarai and Koiwa, 2008; Choi *et al*., 2009; Wang *et al*., 2012); antibacterial, antifungal and antivirus for eliminating non-beneficial soil microbes (Mu *et al*., 2004, 2006), Herbicide (Tworkoski, 2002; Salonen *et al*., 2008; Ruuttunen, 2007); simulate plant growth (Mu *et al*., 2004, 2006); mushroom fruit-body formation stimulant (Yoshimura *et al*., 1995) and many more. Bamboo has been one of the popular sources of PL, however, there are still limited studies available on the bioactivities of PL obtained from bamboo against nematode pests.

Plant parasitic nematodes (PPNs) are regarded as a major threat to agricultural crop production causing extensive significant yield losses to farmers worldwide (Javad *et al*., 2006; Fabiyi, 2022a). *Meloidogyne* species also called the root-knot nematodes (RKN) are described as the most devastating due to their wide host range (Bello *et al*., 2020; Fabiyi, 2021a) and being responsible for yearly crop loss reaching approximately hundred million US dollars worldwide (Chitwood, 2003). Characteristic symptoms of RKN infection include visible galling of the roots, stunting, wilting and nitrogen deficiency signs (Siddiqui *et al*., 2001; Fabiyi, 2021b). Control of RKN is made difficult due to their wide host range, high rate of reproduction and short lifecycle (Natarajan *et al*., 2006).

Lettuce (*Lactuca sativa* L.) is an important crop that is widely grown in many home gardens and almost sometimes cooked, it is exclusively eaten as a fresh vegetable in salads (Lebeda *et al*., 2007). Lettuce is also produced on a commercial scale in different countries worldwide (Lebeda *et al*., 2007; Mou, 2008). In Nigeria, Lettuce is generally considered an important exotic vegetable crop and its increased production was attributed to the increasing awareness about its health and nutritional benefits (Ogbodo *et al*., 2010; Shuaibu and Mohammed, 2018). Lettuce like many other vegetable crops is susceptible and severely affected by the root-knot nematodes causing substantial yield losses thereby posing a significant threat to its production worldwide (Raid, 2004; Fabiyi, 2022). Growers most times resort to the use of synthetic chemical nematicides in managing this economically important pest (Fabiyi and Bello, 2023). Chemical control, aside being expensive, poses a potential hazard to the environment, crops and human health (Tsay *et al*., 2004; Fabiyi and Olatunji, 2021; Fabiyi *et al*., 2023). Due to the health and environmental hazards posed by continuous use of these synthetic nematicides, the search for other eco-friendly alternatives has been on the increase. The antibacterial properties and the effects of PL specifically bamboo PL as bacterial growth suppressors have been investigated by various researchers (Kim *et al*., 2005; Jankowsky *et al*., 2018). Pyroligneous liquid from different species of wood has been used to control birds (Strong, 1973) and insect pests (Pangnakorn, 2009; Regnault-Roger, 1997). They have also exhibited high insecticidal activities against termites (Yatagai *et al*., 2002), aphids (*Myzus persicae*) and psyllids (*Trioza apicalis*) (Lindqvist *et al*., 2010). Hagner *et al*. (2010) reported positive results on harmful soil microbes but no significant effects on nematodes when used at concentrations between 500-1360 Lha. Of all these reports, there is an inadequacy of scientific evidence to prove the efficacy of bamboo pyroligneous liquor in eradicating root-knot nematodes. In this study, we investigated the nematicidal activity of Bamboo Pyroligneous Liquor (BPL) against *Meloidogyne incognita* parasitizing lettuce plants.

Materials and Methods

Sample preparation and pyrolysis of the bamboo sample

Three to four-years old culm of *Bambusa vulgaris* were collected from Forestry Research Institute of Nigeria, Ibadan, Oyo state. The air-dried bamboo sample used was 1 kg which was 1.219 kg when collected fresh. The samples were cut into smaller sizes of about

4cm by 2cm and were air dried to constant weight. Slow pyrolysis was performed using an electric tube furnace. One kg of the dried bamboo biomass was fed into a locally fabricated laboratory scale pyroliser and was pyrolysed at a controlled temperature of 500 °C. The heating chamber was heated to 500 °C at a rate of 20 °C/min and then maintained for 150 min. The pyroligneous liquor was obtained by condensation of the volatile gases within 2 hours of reaching the desired pyrolytic temperature. Bio-oil was collected from the reactor outlet. The obtained BPL was analysed with Perkin–Elmer SPECTRUM-2000 spectrometer.

Oil property determination

The oil property of the liquor was determined using pH value, colour, odour, density, dissolved tar content, percentage ignition residue, yield and transparency through visual examination and the use of formulae.

Yield

$$\text{Yield (\%)} = \frac{\text{Air dry mass of the biomass}}{\text{Mass of product}} \times 100$$

Density

This was determined using the formula:

$$\text{Density} = \frac{\text{Mass of oil (g)}}{\text{Volume (ml)}}$$

Percentage ignition residue

This was known using the formula:

$$\text{\% ignition residue} = \frac{(A - B)}{C} \times 100$$

Where A is the weight of crucible and residue after heating; B is the weight of empty crucible; C is the weight of sample (crude bio-oil).

Dissolved tar content

This was determined by oven drying already weighed crucible and sample (crude bio-oil) at 60°C for 24 hrs. The black residue was then regarded as the dissolved tar content and the dissolved tar content was determined by subtracting the weight of crucible with oil after oven drying from the weight of crucible and oil before oven drying.

Fourier transform infra-red spectroscopy (FTIR)

The functional groups of BPL constituents were analysed using FTIR.

Nematode inoculum collection

Galled roots of *Celosia argentea* plants containing a pure culture of *M. incognita* eggs were collected from the International Institute of Tropical Agriculture, IITA, Ibadan, Nigeria and multiplied on a susceptible tomato cultivar (Tropimech) using the protocol of Hussey and Baker (1973) so as to obtain the required quantity of nematode inoculum for the experiment. This was done by washing the galled roots thoroughly under running tap water to release the debris and sand attached to the roots. They were then cut into small bits between 1-1.5 cm lengths and poured into a litre glass jar containing a solution of 0.05% sodium hypochlorite. The jar was mixed thoroughly for four minutes after which the content was poured out and passed through stack of sieves: 75 μm, 55 μm, and 25 μm aperture, respectively. The eggs were retained inside the 25 μm sieve and were collected by using water to rinse the sieve off into a beaker and left in the laboratory at ambient temperature.

Bioactivity of the bamboo pyroligneous liquor on Meloidogyne incognita

The nematicidal effect of BPL on *M. incognita* infected lettuce plants was conducted at the screen-house of the Department of Crop Protection, University of Ilorin, Nigeria. Thirty-five 10-litre plastic buckets were filled with steam-sterilized loamy soil. Three weeks old lettuce plants were transplanted from nursery into each bucket. Each lettuce plant was inoculated with 1,000 active second stage juveniles (J2s) of *M. incognita* after a week of transplanting. The juveniles were introduced using a syringe to inject four 3 cm deep holes encircling each lettuce plant per container. The lettuce plants were treated two weeks after nematode inoculation with 100, 200 and 400 mg/ml of BPL and also, carbofuran at 1.0, 1.5 and 2.0 kg/a-i/ha. Lettuce growth was monitored for 5 weeks after treatment and at harvest.

Data collection and analysis

Data were taken on yield, nematode count in root, nematode count in 200 cc soil, number of leaves, and plant height. Additionally, 200 cc of soil was taken around each lettuce plant in the experimental pot and nematodes (J2s) were extracted using the modified Baermann tray (pie-pan) process (Coyne *et al*., 2007). Data were subjected to a factorial analysis of variance (ANOVA) using R software version, significant means were separated with Tukey's HSD at $P < 0.05$.

Result and Discussion

Physical properties of the pyroligneous liquor

Liquor yield: The product of pyrolysis is three; the solid (char), the liquid (pyroligneous liquor) and the gas. Although, in this study, emphasis was placed on the liquid part of the products. Bamboo presents a very different product yield from agricultural waste and forestry residue that has been used for oil production. The results showed that the yield of non-condensable gases out of the three bamboo products (solid, liquid, gas) has the highest percentage of (89%), followed by that of char (7.5%) while the yield of the liquid (BPL) was lowest with (3.5%) Table 1. These results are contrary to earlier findings on wood pyrolysis. Dobele *et al*. (2007) reported 63% liquid product when dried mixture of hardwood was pyrolysed at 550°C. Şensoz *et al*. (2000) reported 46% bio-oil weight pyrolysis of *Brassica napus* conducted at 500°C running at 40°C/min. Pütün *et al*. (1999) reported 23.1% for hazelnut shells pyrolysed in a fixed-bed tubular reactor under nitrogen at 500 °C and a heating rate of 7K/min. Pyrolysed sugarcane bagasse involving a laboratory scale vacuum condition produced more oil; 34.4% vs 30.1% and less charcoal 19.4 wt% vs 25.7 wt% compared to pilot scale runs (Garcia-Perez *et al*., 2002). According to Mohan *et al*. (2006) paper, wood and other biomass depending on the composition of the feedstock, yielded bio-oil within the range of 60-99%. The researchers concluded that high lignin contents have a tendency to give lower liquid yields. Likewise, Sarkar and Wang (2010) recorded 48.7% yield at 600°C indicating that temperature played a vital role in the product yield, as well as having a vital effect on the characteristics of the PL.

Table 1: *Yield of pyroligneous liquor.*

Products	Yield (g)
Char	7.5
Bio oil	3.5
Gas	89

Bamboo pyroligneous liquor characteristics

The main physical properties of bio-oil include heating value, water content, density, flash point, and so on. Table 2 shows the properties of the BPL based on some selected criteria such as pH value, moisture content, density, colour, odour, etc. It was discovered that bamboo has lower moisture content (18%) compared to between 15-35% reported by Bridgwater *et al*. (2001) and 48-56wt% by Weerachanchai *et al*. (2011).

Table 2: *The physical properties of the liquor.*

Physical properties	Results
pH	2.39
Density	1.04g/ml
colour	Dark brown
odour	smoky
Dissolve tar content	0.03
Transparency	Not transparent has no suspended matter
% Moisture	18

The moisture content is usually derived from both the original moisture in the feedstock and from dehydration reactions that occur during biomass pyrolysis and bio-oil storage (Lu *et al*., 2009). The pH value was 2.39 which corroborated Mohan *et al*. (2006) that the pH of bio-oil can be as low as 2 or 3 as well as Weerachanchai *et al*. (2011) who recorded 2.98 and 2.95 for palm shell and cassava pulp residue. However, this was extremely low to 5.62 recorded for palm kernel oil (Weerachanchai *et al*., 2011). The pyrolysis liquid products consisted of the water content, this pointed to the acidic content of the BPL. The majority of acidic compounds in bio-oil are carboxylic acids, acetic acid and formic acid which according to Piskorz *et al*. (1988) represent around 5 wt% and 3 wt% of bio-oil. This may account for the acidic pH of 2.39 that is exhibited by the BPL and the acidity may be a factor of antimicrobial activities.

The density of the BPL was 1.04 g/cm^3. This is in line with the range of 1.1-1.3 g/cm^3 reported in literatures (Xu *et al*., 2011; Weerachanchai *et al*., 2011). The bulk density of the BPL in this study falls in the range recorded by Weerachanchai *et al*. (2011) for palm kernel (1.01g/cm^3), palm shell (1.11g/cm^3) and cassava pulp residues (1.10g/cm^3) and higher than 0.78g/cm^3 and 0.94g/cm^3 recorded for fast diesel oil (Islam *et al*., 1999) and heavy fuel oil (Zhang *et al*., 2007), respectively. The density of BPL may be attributed to the high content of cellulose, hemicellulose and other macromolecules like phenolic and oligomeric compounds (Oasmaa and Czernik, 1999) in the bamboo raw material.

According to Weerachanchai *et al*. (2011), the types of biomass have an influence on the bio-oil appearances depending on the biomass sources. Transparent, dark red-brown colour was recorded for pyrolysis liquids from cassava pulp residue while palm kernel oil had opaque dark colour but with separation of oil phase and

Table 3: *Band position (cm^{-1}), peak assignment and structural polymer present in Bamboo Pyroligneous liquor as determined by FT-IR analysis.*

S. No	Band (cm^{-1})	Functional group	
1.	3395.26	O-H stretching from cellulose	Phenols and Alcohols
2.	2955.15	C-H	Alkanes
3.	1732.98	C=O Stretch	Ester, six member lactone (ketone)
4.	1593.67	Aromatic skeletal vibration (C=C)	Olefinic compounds
5.	1511.35	Aromatic skeletal vibration (C=C), guaiacyl > 5	Phenolic compounds
6.	1460.69	CH deformation, asymmetry in CH_3 and CH_2	Olefinic compounds
7.	1362.53	CH_2 and CH_3 bending	Aldehyde and Ketones
8.	1223.22	C–O of guaiacyl ring	Phenolic
9.	1099.74	O–H deformation vibration	Alcohols and Phenolics
10.	1045.91	C–O stretch	Alcohols

aqueous phase (Weerachanchai *et al*., 2011). However, BPL obtained had a distinct dark-black viscous appearance with no suspended matter in it. This is similar to those reported in the literatures for bio-oil (Bridgwater *et al*., 2001; Bridgwater, 2004; Pollard *et al*., 2012). Aside black viscous appearance, Pollard *et al*. (2012) observed different colours ranging from extremely viscous black which on cooling turned to resinous solids at room temperature; honey-like flow characteristics; watery, red-tinted liquid similar to the characteristic of the BPL obtained in this study.

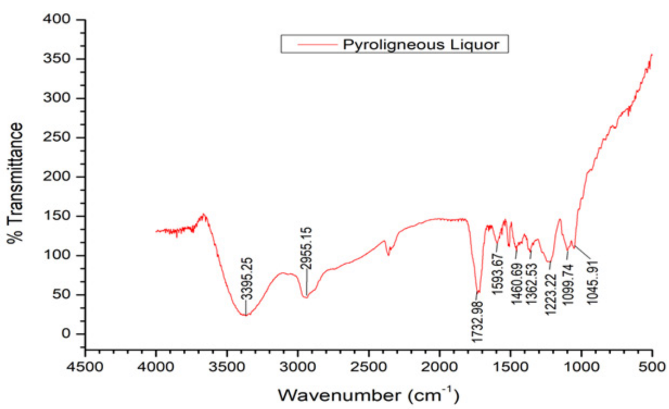

Figure 1: *FTIR spectra showing the active groups of the compound present in the Bamboo PL.*

Fourier-transform infrared spectroscopy (FTIR) analysis

Infrared spectrum of the liquor obtained from pyrolysis of *Bambusa vulgaris* is presented in Figure 1. The characteristic peaks are presented in Table 3. The BPL contained diverse functional groups which were revealed at different wave numbers (Table 1). There were seven classes of compounds which are; alcohols, alkanes, esters, ketone, olefine, phenol and aldehyde. The BPL has O-H stretching vibration at 3395.26 cm^{-1} indicating the presence of polymeric O-H group that exists in water, phenol, alcohol, and/or carboxylic acids in the liquor. This indicates the presence of water/hydroxyl group, impurities and other polymeric O-H in the BPL (Lee *et al*., 2010; Islam *et al*., 2003). BPL is associated with highly oxygenated peak assignments with pronounced functional groups and aromatic compounds which makes them highly acidic (pH = 2.39). This result is in accordance with study conducted by Didem and Filiz (2004) and Natarajan and Ganapathy (2009) that the liquid composition from biomass of rice husk and rape cake, respectively are dominated by oxygenated compounds coupled with the C-O and aromatic compounds which showed the potential as a chemical feedstock.

The propensity of BPL to be utilised as fuel is largely due to the presence of alcohol and hydrocarbon (C-H; C-C) groups (Islam *et al*., 2012). The C=O stretching vibration at 1732.98cm^{-1} displayed aldehydes, carboxylic acids and ketonic compounds (Islam *et al*., 2012). The band of C-H stretching at 2955.15 cm^{-1} wave number shows the presence of alkanes in the BPL (Islam *et al*., 2003; Tsai *et al*., 2007). The C=C aromatic skeletal vibration, guaiacyl > 5 at 1511.35 cm^{-1} and C–O of guaiacyl ring at 1223.22 signifies the presence of phenolic compounds C=C aromatic skeletal vibration at 1593.67 cm^{-1} and the CH deformation, asymmetry in CH_3 and CH_2 vibration at 1460.69 cm^{-1} explains the presence of alcohol and olefinic (alkenes) compounds in the liquor. C-H deformation also occurred at 1362.53 cm^{-1}. The Absorption bands of 1045.91 and 1099.74 cm^{-1} were due to the presence of primary, secondary and tertiary alcohols, ethers and esters due to the C–O stretching and O–H deformation vibration of these functional groups (Qian *et al*., 2007).

FTIR analysis of the BPL showed the presence of characteristic functional groups of alcohol, phenol, alkane, aldehyde and ester compound derivatives which were responsible for the nematicidal properties of the BPL. The obtained Pyroligneous liquor from *B. vulgaris* had typical infrared spectra that are comparable with Pyroligneous liquor from different lignocellulosic biomass from previous studies (Fuwape *et al*., 2011; Şensöz, *et al*., 2006). Phenolic compounds were identified as the main organic components in the BPL followed by alcohols, olefins and ketonic compounds. Other components are esters, alkanes and aldehydes. The presence of phenol and ketone groups is attributed to its nematicidal activity. Most phenolic compounds have disinfectant properties. Several reports from literature suggested that high levels of organic and phenol contents in pyroligneous liquids had a positive correlation with bacterial growth inhibition (Ma *et al*., 2011; Wei *et al*., 2010a).

Table 4: *Variations in the weekly height of L. sativa after the application of BPL and carbofuran treatments.*

Treatment concentration	Mean plant height				
	1 WAT	2 WAT	3 WAT	4 WAT	5 WAT
$CBFN_0$	11.03^d	12.13^d	12.93^e	15.00^{de}	16.33^e
$BMBO_0$	9.93^d	10.60^d	12.43^e	13.67^e	17.00^e
$CBFN_1$	14.43^b	13.57^{cd}	15.17^d	17.00^d	21.67^d
$CBFN_2$	16.97^b	16.93^c	18.53^{cd}	20.33^c	26.67^c
$CBFN_3$	21.63^{ab}	22.17^b	23.70^b	26.33^b	32.00^b
$BMBO_1$	13.97^{bc}	15.43^c	18.50^{cd}	20.53^c	26.17^c
$BMBO_2$	15.17^b	16.77^c	20.27^c	21.93^c	31.67^b
$BMBO_3$	23.23^a	24.73^a	27.73^a	29.33^a	42.33^a

WAT = weeks after treatment was added; $BMBO_0$ = PL 0% (control); $BMBO_1$ = PL 100mg/ml; $BMBO_2$ = PL 200mg/ml); $BMBO_3$ = PL 400mg/ml; $CBFN_0$ = Carbofuran 0g (control); $CBFN_1$ = Carbofuran 5g; $CBFN_2$ = Carbofuran 10g; $CBFN_3$ = Carbofuran 15g. Means in the same column with same alphabets are not significantly different at P≤ 0.05.

Effect on L. sativa agronomic parameters

Tables 4 and 5 show the plant height and number of leaves of *L. sativa* across the growing weeks after transplanting (WAT). There were significant differences observed in the mean heights and mean number of leaves of *L. sativa* (Tables 4 and 5). Likewise, at different concentrations of BPL and carbofuran, the height of *L. sativa* at week 1 was statistically similar for both BPL and carbofuran at highest treatment concentrations of 400 mg/ml and 15 g respectively even though 400 mg/ml BPL gave the highest plant height (23.23 cm) compared to that of carbofuran (21.63 cm). However, at 2, 3, 4 and 5 WAT; BPL at 400 mg/ml gave the highest plant height and number of leaves which were followed by carbofuran treatment at 15 g concentration. However, the control treatments for BPL and carbofuran both showed decreased plant height and number of leaves (Tables 4 and 5). The results showed that the higher the concentration of BPL and carbofuran, the higher the number of leaves and plant height. However, BPL treated plants perform best even compared to the conventional nematicide (carbofuran). Although, it has been discovered that conventional carbofuran promotes plant growth (Adegbite and Agbaje, 2007; Tanimola, 2008). However, in this study, treating root-knot nematode (*M. incognita*) in lettuce with BPL was more effective than carbofuran, although, the increase in the yield (Figure 2C) was immediately followed by that of lettuce treated with carbofuran compared to the control proving that BPL displayed higher nematicidal potential than carbofuran.

Table 5: *Variations in the number of leaves of L. sativa after the application of BPL and Carbofuran treatment.*

Treatment concentrations	Mean number of leaves				
	1 WAT	2 WAT	3 WAT	4 WAT	5 WAT
$CBFN_0$	5.00^c	5.67^d	6.33^e	5.33^f	6.00^f
$BMBO_0$	5.33^c	9.00^c	7.33^e	4.33^f	5.67^f
$CBFN_1$	7.00^b	7.67^{cd}	8.00^d	9.00^e	8.67^e
$CBFN_2$	7.67^b	8.00^c	11.00^c	13.00^{cd}	14.00^c
$CBFN_3$	12.67^a	11.67^b	13.67b^c	15.67^c	18.00^b
$BMBO_1$	7.00^b	8.33^c	11.33^c	12.00^d	12.33^d
$BMBO_2$	8.67^b	10.00^b	14.67^b	17.00^b	18.67^b
$BMBO_3$	13.67^a	15.67^a	18.67^a	23.33^a	24.67^a

WAT = weeks after treatment was added; $BMBO_0$ = PL 0% (control); $BMBO_1$ = PL 100mg/ml; $BMBO_2$ = PL 200mg/ml); $BMBO_3$ = PL 400mg/ml; $CBFN_0$ = Carbofuran 0g (control); $CBFN_1$ = Carbofuran 5g; $CBFN_2$ = Carbofuran 10g; $CBFN_3$ = Carbofuran 15g. Means in the same column with same alphabets are not significantly different at P≤ 0.05

The increase in *L. sativa* height and number of leaves due to the addition of BPL may be a result of high organic acid content which is an essential component in the different compounds of BPL (Mungkunkamchao *et al*., 2013). Furthermore, the presence of some alcohols, aldehydes and acids has made BPL a viable energy and carbon substrate for some soil microbial agents that help to promote crop growth (Yang *et al*., 2014). Our findings agree with the previous reports of Mahmud *et al*. (2016) where 2% (v/v) pyroligneous acid used to fertilize okra

(*Abelmuscus esculentus*) resulted in the highest mean number of fruits and leaves as well as studies of Mu *et al*. (2004, 2006), where bamboo vinegar showed an increase in vegetative growth, germination and radicle growth for several seeds. Thus, this study successfully demonstrated that BPL has great potential as an organic plant growth promoter with no detrimental effect on the environment.

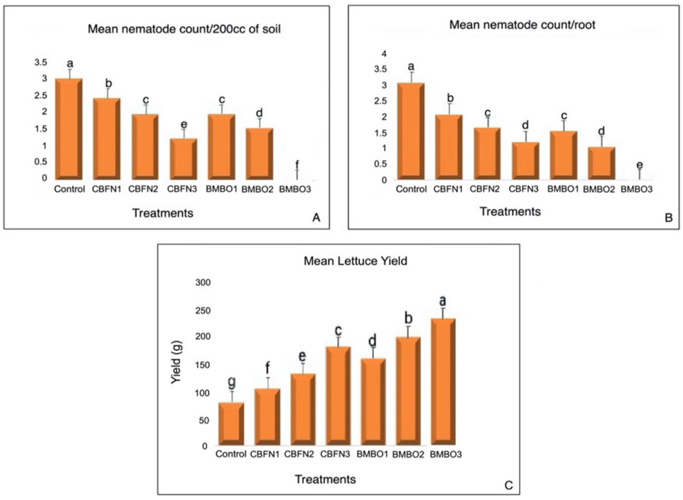

Figure 2: *Log transformed mean values of (A) soil nematode (J2s), (B) root nematode (J2s and eggs) population and (C) yield of lettuce plants treated with BPL. Bars having same case letters are not significantly different at P≤ 0.05. Control= inoculated untreated lettuce plants; CBFN1 = Carbofuran 5g; CBFN2 = Carbofuran 10g; CBFN3 = Carbofuran 15g; BMBO1 = PL 100mg/ml; BMBO2 = PL 200mg/ml); BMBO3 = PL 400mg/m.*

Nematicidal effect of BPL on yield and nematode population in root and soil of lettuce plants

The results for nematode populations at harvest and yield of lettuce are presented in Figure 2A, B and C, respectively. There were significant variations in the root and soil nematode population across the BPL and carbofuran treatments applied (Figure 2). The nematode population in the root of *L. sativa* was highest for the control treatments which contained no BPL or carbofuran (Figure 2B). Generally, BPL had marked killing effect on both the soil and root nematodes compared to the carbofuran treatments and invariably an increase in yield of treated plants. The highest nematode population in the roots was 36 in BPL treatment as against 122 in carbofuran at 200 mg/ml and 5 g/ml, respectively. 11 nematodes were counted in 300 mg/ml of BPL as against 46.67 nematodes in 10 g/ml carbofuran. While no nematode was recorded at 400 mg/ml BPL treatments whereas, 16.33 were recorded for 15 g/ml carbofuran (Figure 2). The results of root nematode population follow a similar pattern to that of soil nematode population. These results showed that BPL was very effective in the control of *M. incognita*. Over the years, PL has shown interesting antimicrobial and disinfectant properties. PL has been used to control diversities of crop insect pests and diseases. For root-knot nematodes, Hagner *et al*. (2010) reported no significant effect on root-knot nematodes when used at concentrations between 500-1360 Lha^{-1}. However, this study showed the killing effects of BPL on *M. incognita* even at low concentrations with complete eradication at higher dosage of 400 mg/ml. Whereas, carbofuran was able to lower the population of both the root and soil nematodes without complete killing. The action of BPL is attributed to the presence of compounds such as phenolic, carbonyls and organic acids (Lee at al., 2010; Loo *et al*., 2008).

Conclusions and Recommendations

Our findings have proved the efficacy of Bamboo Pyroligneous liquid both as a promising growth promoter and a potent nematicidal agent against root-knot nematode: *M. incognita*. This interesting nematicidal effect could be attributed to the presence of several compounds in the Pyroligneous liquor. BPL compared favourably to carbofuran (conventional nematicide) and the fact that it is an organic material makes it a viable alternative to the use of chemical nematicides in managing root-knot nematode pests of lettuce.

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Novelty Statement

This study has proved the efficacy of Bamboo Pyroligneous liquid as a potent nematicidal material which could serve as a substitute to chemical nematicides in managing *M. incognita*.

Author's Contribution

Sadiku, N.A. and Fabiyi A.O. Designed the study.
Bello T.T. Analysed data.
Sadiku, N.A. Wrote the first draft of the manuscript.
Fabiyi A.O. and Bello T.T. Edited the final draft of

the manuscript.
All authors approved the final manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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