

Farmers' Knowledge and Perceptions of Banana Borer Weevil and Insecticidal Potential of Neem and Wood Ash for Its Management in Fako Division, Cameroon

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Abstract: Banana borer weevil is a major insect pest of banana and plantain in Cameroon. The undesirable effects of synthetic insecticides have attracted global attention and there is urgent need for alternative measures. This study consisted of a survey and five laboratory experiments, to investigate farmers' perceptions of the weevil in Fako Division of Cameroon, and the insecticidal potential of the aqueous extract of neem and wood ash as alternative sources for its management. A structured questionnaire was administered in several villages in the study area. For the laboratory experiments, the treatments were the aqueous extract of neem (25, 50, 75 and 100%), wood ash (20%), mocap® (positive control) and water (negative control). Majority of the farmers (49.6%) used mocap® to control the weevil; 29.2% used at least one cultural practice, 11.2% applied wood ash while 10% employed other methods. At 14 days after exposure (DAE), the aqueous extract of neem at 75 and 100% resulted in 79% mortality of the adult weevil; 50% of the extract caused 68% mortality similar to wood ash; 25% of the extract killed 42% of them. Corms treated with water had 0% mortality throughout while those with mocap® had 100% mortality 1 DAE. The number of weevils that settled on corms treated with the extract at 50 and 75% (<1.5) and wood ash (≤ 1.9) was less than that on the control corms with water (≥ 6.2). The extract at 50 and 75% and wood ash inhibited weevil oviposition (<2 eggs laid/corm) and larva emergence (zero larva) significantly. These treatments also significantly increased the average time each larva spent locating a feeding site, initiating feeding and boring into discs compared to control discs with water. The potency of these treatments on the mortality of the weevil lasted for three to four weeks. Therefore, the aqueous extract of neem and wood ash offer a promising, affordable, environmentally friendly and cost-effective option which could be incorporated into an integrated package for sustainable management of the banana borer weevil.

Keywords: Aqueous Extract, Banana, Banana Borer Weevil, Farmers' Perceptions, Neem, Wood Ash

1. Introduction

Banana (*Musa* spp) is a major food crop which is grown and consumed in more than 100 countries throughout the tropics and subtropics [1]. The all year-round fruiting habit of the crop makes it superior in bridging the 'hunger gap' between crop harvests. It provides more than 25% of carbohydrate requirements for over 70 million people [2]. Cameroon is the fifth largest producer of banana in sub-Saharan Africa after Uganda, Rwanda, Ghana and Nigeria

[3]. In terms of the amount exported to the European Union, Cameroon is among the major exporters (about 300,000 tons annually), followed by Ivory Coast (about 202,000 tons) [4].

Despite the significance of banana to the economy of Cameroon, its production is declining due to pest infestation. The banana borer weevil (*Cosmopolites sordidus*) is a major pest of the crop throughout the tropics [5]. Larvae of the insect have strong mandibles which they use to excavate and create galleries in corms thereby destroying the root system of the plant, causing 40–100% yield losses [6]. Yield loss can

also occur through toppling of damaged plants [5]. The feeding habits of the larvae cause weak growth, poor anchorage and toppling of the plants especially when the weather is windy [7]. The affected plants manifest symptoms such as reduced vigor, leaf chlorosis and chocking of the bunch in the pseudostem.

Subsistence and large-scale farmers rely on cultural and chemical methods for the management of this weevil. Cultural methods such as farm sanitation, use of clean planting material, splitting and drying of harvested pseudostems [8] and use of pseudostem traps [9] contribute to its management. However, high labour demand and material requirement are sources of concern for their adoption [5]. Rather, farmers and banana corporations mostly use synthetic pesticides such as Mocap 10G® and Dursban® [10]. This is because the chemicals act fast and are easy to apply. However the weevil has developed resistance to a wide range of conventional pesticides [11]. In addition, concerns about the use of pesticides in banana production have been raised; these include effects on public health, environment and wild life [12]. They are expensive to subsistence farmers and are also toxic to humans.

A reduction in environmental contamination is a major challenge in the world. The development of cost-effective pest management technologies which are affordable, environmentally friendly and readily available will significantly contribute to a reduction in environmental degradation. The use of botanicals in the development of insecticides could also serve as appropriate alternatives that would lead to a safe environment [13]. Neem (*Azadirachta indica*) is a botanical which has been widely reported as an outstanding natural insecticide against insect pests especially in storage. It was reported that, several compounds have been isolated from various parts of the neem tree [14]. These compounds are effective against a wide range of insects. However, there is limited information on the insecticidal potential of neem for management of the banana borer weevil. It is hoped that this study will provide information on suitable indigenous methods as well as the botanical neem, which can be used as components for a suitable integrated management package. The objectives of this study were to investigate farmers' knowledge and perceptions of the banana borer weevil, document plant species and indigenous methods used for its management, and determine the insecticidal potential of the aqueous extract of neem and wood ash (an indigenous method) for its management.

2. Materials and Methods

2.1. Study Area

This study was carried out from 2012 to 2015 in Fako Division of the South West Region of Cameroon and it comprised a field survey and laboratory experiments. The survey was conducted in several villages in Buea (Bova, Bonakanda, Bokova, Muea, Molyko, Mile 14 and Mile 16), Ekona (Ekona Mbenge and Ekona Yard) and Tiko

(Mutengene, Likomba and Tiko town) subdivisions. The laboratory experiments were carried out in the Life Sciences Laboratories of the University of Buea. Fako Division has a humid tropical climate and the soil type is typically volcanic. There are two major seasons: the rainy and dry seasons.

2.2. Survey

A structured questionnaire was administered to 250 farmers in the study area. They were selected based on their involvement in the production of banana and the interviews were conducted in their farms or around their homes. The farmers were interviewed in English Language or Pidgin and in situations where they could not write, the researchers filled the questionnaire. Attention was paid on the socio-cultural status of the farmers such as sex and occupation. Each farmer was asked which varieties s/he cultivated, the purpose for which the crop was cultivated and the main pests that affect its production. Information was also sought on the farmers' knowledge of banana borer weevil and the different parts of the crop damaged by the pest. Emphasis was laid on the different methods used to manage the weevil: indigenous methods, plant products and synthetic insecticides with the associated constraints.

2.3. Laboratory Experiments

Insect culture

Banana borer weevils were trapped in farmers' farms in Buea and its environs, using 25cm split longitudinal pieces of banana pseudo stem traps. The insects were taken to the Life Sciences Laboratories of the University of Buea and reared in 10 L plastic buckets (24 cm diameter and 26 cm depth) with pieces of banana corms as food. The buckets were covered with mosquito nets to prevent the weevils from escaping. The corms were moistened with water when necessary. The sexes of the weevils were determined based on the distribution of punctuation on the rostrum [15]) and by observing the angle of inclination of the ninth abdominal segment [16]. In males, the distal end of the last abdomen truncates sharply, whereas in females, the ovipositor truncates gently. Female weevils were first kept for three days in all cases on a non-laying substrate to deter them from early oviposition in order to reserve the eggs for the tests [17]. Each weevil was used only once during the experiment.

Sources of neem, wood ash and Insecticide

Leaves of neem were obtained from the Botanical Garden in Limbe, Fako Division. Wood ash was obtained from local residents in Ekona. Mocap® is a conventional pesticide which was bought from an agro-chemical shop in Buea. The neem leaves were thoroughly washed with sterile water and air-dried in the Life Sciences Laboratories.

Preparation of the aqueous extract of neem

The dried neem leaves were ground using an electric blender and the aqueous extract (100%w/v) was prepared in a 1000 ml flask. Powder soap was added to the mixture; it was stirred and kept overnight. The purpose of the powder soap was to enhance the adhesion of the botanical on the surface

of the treated corms. The mixture was kept for 24 hours and during this period, it was shaken periodically using a shaker vibrating at 250 revolutions per minute. The solution was filtered using a 250 mm filter paper and centrifuged at 500 revolutions per minute for 7 minutes. The residual stock solution was put in a 100 ml flask and stored in the laboratory at room temperature until it was used [18–20]. Five concentrations (0, 25, 50, 75 and 100%w/v) of the botanical were tested.

Effect of the aqueous extract of neem and wood ash on the mortality of adult banana borer weevil

The effect of the treatments on the mortality of the adult weevil was tested in a no-choice experiment. Treatments consisted of the aqueous extract of neem at 0 (negative control), 25, 50, 75 and 100%w/v, wood ash (20%w/v) and mocap® (positive control). Fresh banana corms (5×5×5cm) were dipped in the different treatments for 15 minutes. After this, the corms were removed, properly drained and placed in 5L plastic buckets (15 cm in diameter and 20 cm in depth). Thirty adult weevils starved for 24 hours were introduced on each treated corm at 1800 hours. The treatments were arranged in a completely randomized design and replicated 10 times. In each treatment, weevils were monitored after every 24 hours for fourteen days and dead weevils were counted and removed.

Persistency of the aqueous extract of neem and wood ash for the management of banana borer weevil

The persistency of the treatments was assessed in a no choice experiment. Fresh banana corms (5×5×5cm) were dipped in the aqueous extract of neem at 0, 50 and 75%w/v as well as in wood ash (20%w/v) and mocap® for 15 minutes. The corms were removed, properly drained and placed in different 5L plastic buckets (15 cm in diameter and 20 cm in depth). Once every week, 20 adult weevils were collected from the stock culture, starved for 24 hours and introduced on each treated corm at 1800 hours. The treatments were laid out in a completely randomized design and replicated 10 times. In each treatment the number of weevils that died after five days were counted and removed. The introduction of weevils continued weekly and the experiment was terminated when subsequent weevils introduced did not die.

Effect of the aqueous extract of neem and wood ash on weevil settling response

The effect of the treatments on weevil settling response was investigated in a choice experiment. Treatments consisted of the aqueous extract of neem at 0 (negative control), 75 and 100%w/v, and wood ash (20%w/v). Freshly cut pieces of banana corms weighing 400g were dipped in each treatment for 15 minutes; control corms were dipped in water. After 15 minutes, the treated corms were removed, properly drained and placed equidistant from each other in a 30L basin. Twenty adult weevils (10 males and 10 females) starved for 24 hours were introduced at the centre of the basin at 1800 hours. The basins were covered with perforated black polythene sheets to provide adequate ventilation, reduce light and prevent weevils from escaping. The

experiment was set up as a completely randomized design and the treatments were replicated 10 times. The number of male and female weevils found settling on corms after 1, 2, 4, 24, 48 and 72 hours was counted and recorded.

The percentages of male and female weevils that settled on treated and control corms after 48 and 72 hours were calculated as $100T/(T+C)$; where T and C were the number of weevils that settled on treated and control corms, respectively [21].

Effect of the aqueous extract of neem and wood ash on banana borer weevil oviposition

The effect of the treatments was investigated using no-choice tests. Fresh banana corms free from weevil attack were pared to a depth of 3–5 cm to remove any eggs previously laid on them. Clean 500g pared banana corms were dipped in the aqueous extract of neem at 0, 75 and 100%w/v, wood ash (20%w/v) and mocap® for 15 minutes. After draining properly, the treated corms were placed in separate 5L buckets. Ten male and ten female adult weevils were introduced into each bucket. The buckets were covered with a mosquito net. The experiment was set up as a completely randomized design and each treatment was replicated 10 times. The corms were removed after seven days and dissected by peeling off thin layers of the tissue to expose eggs. The number of eggs laid on each corm was counted and the buckets were covered. At 13, 14 and 15 days after treatment, the number of larvae emerging from each corm was counted.

Effect of the aqueous extract of neem and wood ash on larva feeding response

The effect of the treatments on the feeding response of the weevil larva was investigated in a no choice experiment. Banana pseudostem discs 8 cm in diameter were dipped in the aqueous extract of the botanical at 0, 25, 50, 75 and 100%w/v, wood ash (20%w/v) and mocap®. After 5 minutes, pseudostem discs were removed, properly drained and each placed in 9 cm-diameter Petri-dishes. Laboratory-reared larvae were each weighed using a Mettler balance and released on each pseudostem disc. The treatments were placed in a completely randomized design on a laboratory table and replicated ten times. The time each larva spent searching for a feeding site, initiating feeding and penetrating the disc was recorded. The larval feeding-damage was assessed based on percentage coefficient of infestation (PCI) during a 72-hour-period of confinement of the larva on treated or control discs and it was scored on a scale of 0–100; where 0 = no galleries, 5 = traces of galleries, 20 = galleries on an area of 1/4 of the corm, 40 = galleries on an area of 1/2 of the corm, 60 = galleries on an area of 3/4 of the corm and 100 = galleries on the entire corm [22]. The larva that survived in each treatment was weighed using a Mettler balance.

2.4. Data Analyses

Data obtained were subjected to Analysis of Variance (ANOVA), using the Statistical Package for Social Sciences Version 17.0. The treatment means were compared using

Tukey's test at $P = 0.05$. The mortality of the adult weevil on corms with the different treatments was calculated as percent mortality of weevils on daily bases for two weeks.

3. Results

3.1. Survey

Out of the 250 banana farmers interviewed, 200 were males and 50 were females. Most of them (76.4%) were involved only in farming, 22% were engaged in both farming and trading while only 0.8% were involved in activities other

than farming. The farm sizes ranged from approximately 0.5 to 2.0 ha. Most of the farmers (50%) had a farm size of approximately 1.0 ha, 22.4% had approximately 0.5 ha, 14.8% had approximately 1.5 ha and only 12.8% had ≥ 2.0 ha. Majority of the farmers (58.8%) produced banana for home consumption only, 29.6% produced the crop for both home consumption and sale while 11.6% produced it only for sale. Most of the farmers (69.6%) produced the variety Gros Michel, 21.6% cultivated Cavendish while 8.8% produced banana from other sub-groups (Figure 1).

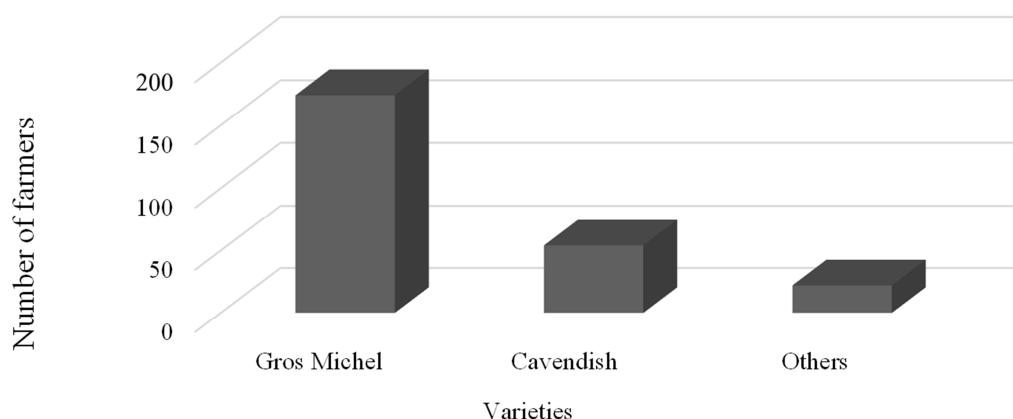


Figure 1. Varieties of banana produced by farmers in Fako Division, Cameroon.

The farmers revealed that the major challenges to banana production were insects, weeds and diseases. They also stated that sigatoka (75.2%), Panama (22.4%) and other diseases (2.4%) were constraints to banana production in the study site. According to 80% of them, banana borer weevil commonly called "Tumbu" was the most damaging insect pest; 18% indicated that banana mealybug damages the fruit

and reduces its market value while only 2% mentioned that other insects were a problem (Figure 2). They were also aware of the parts of banana damaged by the weevil. Majority of them (82.8%) indicated that the weevil bores only the corm while 17.2% indicated that the weevil bores both the corm and pseudostem.

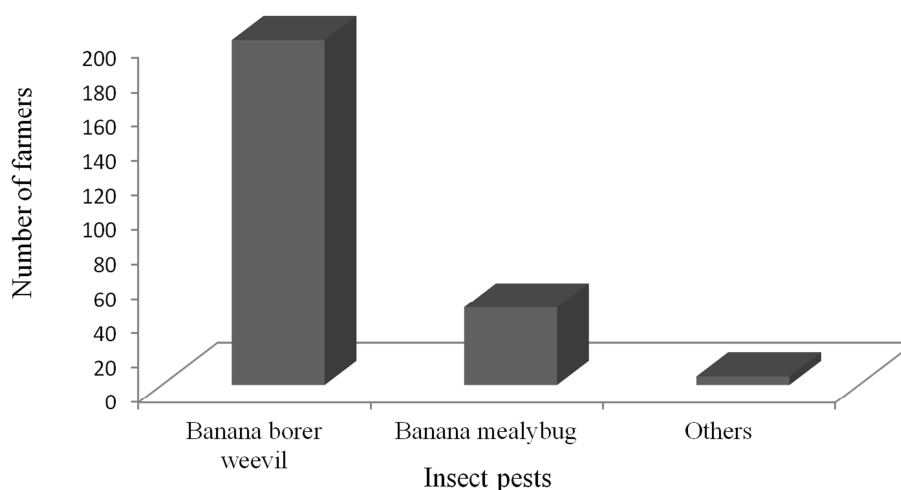


Figure 2. Insect pests of banana in Fako Division, Cameroon.

The farmers used several methods to control the weevil: application of mocap® around the plant, application of only wood ash and application of mocap® mixed with wood ash (Figure 3). Common cultural methods such as the use of clean planting material, weeding, mulching, "desuckering"

and slashing were also practiced. Majority of the farmers (47.6%) used at least one of the cultural practices to reduce damage caused by the weevil; 29.2% applied only wood ash; 11.2% applied a mixture of mocap® and wood ash while 9.7% used only mocap®. None of the farmers mentioned the

use of pesticidal plants or botanicals to control the weevil although a few were familiar with the use of some plants as

post-harvest protectants against insect pests in storage.

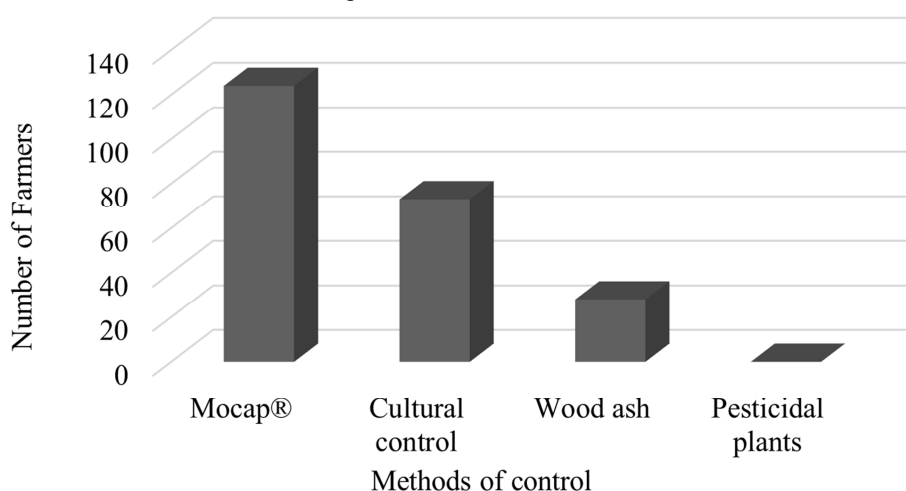


Figure 3. Methods used by farmers to control banana borer weevil in Fako Division, Cameroon.

3.2. Laboratory Experiments

Effect of the aqueous extract of neem and wood ash on the mortality of adult banana borer weevil

The effect of the aqueous extract of neem and wood ash on the mortality of the adult weevil up to 14 days after exposure (DAE) is presented in Figure 4. The treatments had significant effect ($P < 0.05$) on the mortality of the adult weevil at the different dates of sampling. In general, the aqueous extract of neem at 25–100%, wood ash and mocap® significantly killed more weevils than the negative control;

the highest mortality was recorded for mocap® (100%) throughout. In general, among the concentrations of the neem extract tested, 25% caused the least mortality throughout; 50% resulted in mean mortality similar to that caused by woodash; 75 and 100% caused the highest mortality. At 4 DAE, the aqueous extract of neem at 25–100% and wood ash resulted in <50% mortality of the adult weevil. The mean mortality of the weevil in treatments with wood ash and the extract at 50–100% was similar.

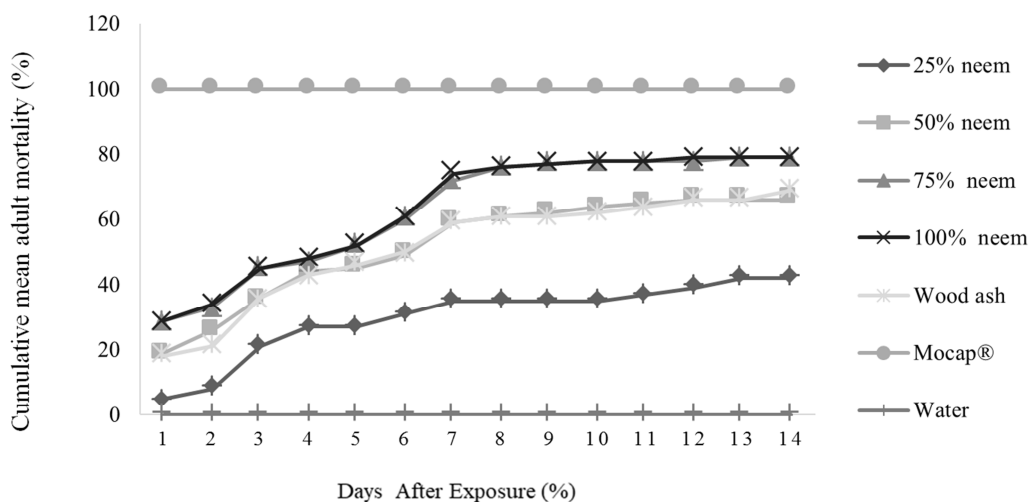


Figure 4. Mortality of the borer weevil on banana corms treated with the aqueous extract of neem at various concentrations (25, 75, 50 and 100%) and wood ash.

At 7 DAE, the mortality of the adult weevil caused by neem at various concentrations (25, 50, 75 and 100%) of the aqueous extract was between 35 and 76%. Concentrations of 75 and 100% of the extract resulted in 76% mortality which was higher than that caused by the lower concentrations and wood ash. The mean mortality caused by wood ash and 50% of the extract was 59%. At 14 DAE, the aqueous extract of neem at 75 and 100% resulted in 79% mortality of the

weevil; the extract at 50% and wood ash caused 68% mortality while the extract at 25% killed 42% of the insects. The corms treated with water registered 0% mortality throughout.

Persistency of the aqueous extract of neem and wood ash on banana borer weevil

The persistency of the treatments on the adult weevil decreased with time (Figure 5). The aqueous extract of neem

at 50 and 75% and wood ash were significantly ($P<0.05$) more persistent in killing the weevils than the negative

control throughout the sampling period. However, the effect of neem varied with the concentration of the extract.

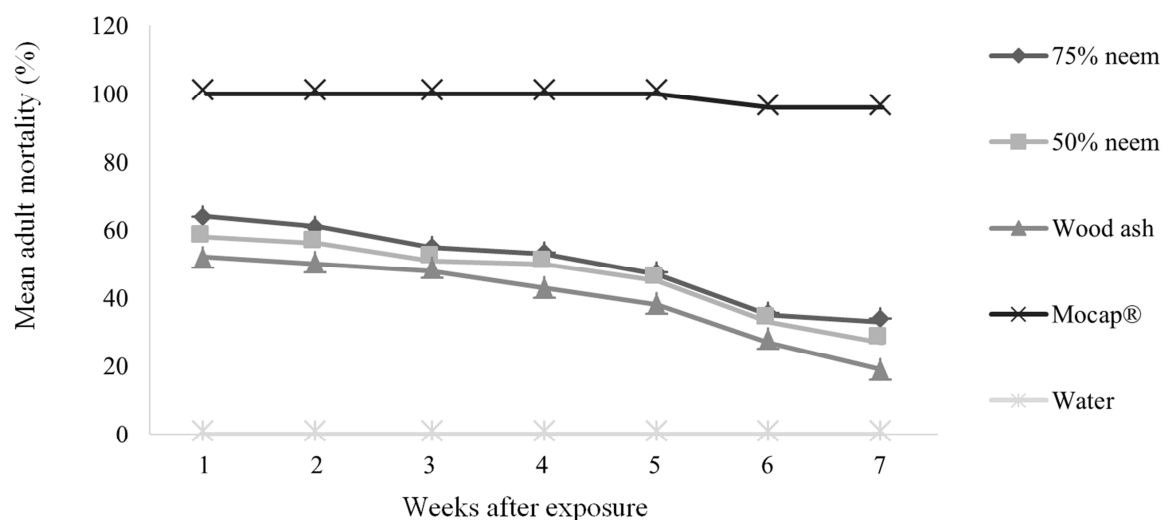


Figure 5. Persistency of the aqueous extract of neem at 50 and 75% concentrations and wood ash for the management of banana borer weevil.

During the first week, weevils introduced on corms treated with the aqueous extract of neem resulted in $\leq 64\%$ mortality. A total of 52% of the weevils were killed on corms treated with wood ash, mocap® caused 100% mortality while the water treated corms did not cause any mortality. During the second week, the mean mortality of adult weevils introduced on corms treated with 50 and 75% of the extract of neem decreased by 2 and 3% respectively. The values for mortality further reduced in a similar trend at 3, 4 and 5 weeks after treatment (WAT). From 6 WAT, the potency of the extract at both concentrations and wood ash significantly reduced, resulting in $<36\%$ weevil mortality. However, corms treated with mocap® still caused $>95\%$ mortality at 6 and 7 WAT. The aqueous extract of neem at 50 and 75% offered significantly ($P<0.05$) longer residual effect on the weevils than wood ash, although the potency of these treatments reduced at 6 and 7 WAT.

Effect of the aqueous extract of neem and wood ash on banana borer weevil settling response

The repellent effect of the treatments was not dependent on

the sex of the weevil therefore the data for males and females were combined (Table 1). The mean number of weevils which settled on corms treated with the aqueous extract of neem at 50 and 75% as well as wood ash was significantly ($P<0.05$) lower than that on corms with the control treatment (0% neem) throughout the sampling period. The mean number of weevils that settled on corms treated with 50 and 75% of the aqueous extract of neem and wood ash was between 0.0 and 1.9. No weevil settled on corms treated with both concentrations of the extract at 1 and 2 hours after exposure. However, 2 hours after exposure, 1.5 weevils settled on corms treated with wood ash. The extract at 50 and 75% exerted the strongest deterrent effect, resulting in ≤ 1.3 weevils on the corms after 72 hours of exposure. Corms treated with wood ash registered 3.4 weevils, 72 hours after exposure. The repellent effect of the aqueous extract of neem was similar at 50 and 75%, and better than that of wood ash. In all the treatments, the mean number of weevils which settled on treated corms increased with the time of exposure.

Table 1. Mean number of banana borer weevils on corms treated with the aqueous extract of neem and wood ash at different periods of exposure.

Periods of exposure (hours)						
Treatments	1	2	4	24	48	72
Water	2.85±0.9b	3.0±0.9c	3.5±1.2c	3.7±1.2c	5.2±2.1c	6.2±2.1b
75% Neem	0.0±0.0a	0.0±0.0a	0.4±0.2a	0.7±0.2a	0.8±0.2a	1.1±0.4a
50% Neem	0.0±0.0a	0.0±0.0a	0.4±0.2a	0.8±0.2a	0.8±0.2a	1.3±0.4a
Wood ash	0.2±0.1a	0.8±0.2b	0.9±0.4b	1.5±0.7b	1.5±0.7b	1.7±0.7a
Mocap®	NA	NA	NA	NA	NA	NA

Within columns, means followed by the same alphabet are not significantly different ($P<0.05$) from each other by Tukey's test. NA=Not applicable.

Effect of the aqueous extract of neem and wood ash on banana borer weevil oviposition

The aqueous extract of neem at 50 and 75%, wood ash and mocap® significantly ($P<0.05$) reduced the number of eggs laid by the weevil compared to the negative control. The mean number of eggs laid on corms treated with neem varied

with the concentration. At 7 DAE, the mean number of eggs laid on corms treated with the extract at 75% was significantly lower (0.4) than that on treatments with 50% of the extract (1). The mean number of eggs laid on corms with wood ash was similar to that on corms with 50% of the extract. The aqueous extract of neem at 75% was very

effective in inhibiting weevil oviposition to the same extent as the synthetic pesticide mocap® (0). There were significantly ($P<0.05$) more larvae (5.4) on control corms with water than all other treatments. No larva emerged on corms treated with 50 and 75% of the extract, wood ash and mocap®.

Effect of the aqueous extract of neem and wood ash on larva feeding response

Effects of the aqueous extract of neem at 50 and 75% and wood ash on larva feeding response of the weevil are presented in Table 2. The results revealed that the larvae were

significantly ($P<0.05$) repelled by the treatments. Neem and wood ash deterred the larvae significantly ($P<0.05$) and increased the time each spent to locate a feeding site, initiate feeding and bore into the discs compared to water (negative control). The average time taken by the larvae to locate feeding sites, initiate feeding and bore into discs treated with the aqueous extract of neem at both concentrations and wood ash was similar (mean=49.2±3.7, 21.1±2.1 and 15.9±2.7 minutes respectively). The larvae introduced on pseudostem discs treated with mocap® died immediately.

Table 2. Feeding response of banana borer weevil larvae on pseudostem discs treated with the aqueous extract of neem and wood ash.

Treatments	Time spent in minutes			Corm damage (PCI,%)
	Locate feeding site	Initiate feeding	Bore into disc	
50% neem	47.5±3.7b	21.0±2.0b	15.8±2.7b	1.5±1.0a
75% neem	52.3±3.7b	23.5±2.0b	18.8±2.7b	2.5±1.7a
Wood ash	47.8±3.7b	18.8±2.1b	13.0±2.7b	18.3±1.7b
Water	3.4±2.1a	0.9±0.1a	0.5±0.2a	84.3±1.7c
Mocap®	NA	NA	NA	NA

Within each column, means with the same alphabet are not significantly ($P<0.05$) different from each other by Tukey's test. PCI=Percentage coefficient infestation; NA=Not applicable.

The larva feeding damage on pseudostem discs treated with the aqueous extract of neem at 50 and 75% was similar (<3%) and less than that on discs containing wood ash and the control with water after 72 hours of confinement. The highest damage was caused by larvae on control discs treated with water. Larvae that survived on discs treated with neem and wood ash after 72 hours of confinement were smaller in size and weighed significantly ($P<0.05$) less than those that fed on discs treated with water (Table 3). In general, larvae

that survived on discs treated with the aqueous extract of neem at 50 and 75%, and wood ash had similar weight loss. Those which recovered from discs treated with water had a mean weight gain of 0.4±0.1 g. When the larvae that survived on discs with the different treatments were later confined for 2 weeks, some reddish brown pupae were recovered from those treated with water; all larvae on discs treated with neem and wood ash died.

Table 3. Effect of the aqueous extract of neem and wood ash on the weight of larvae.

Treatments	Weight of larvae (g)			
	Weight before exposure	Weight 72 h after exposure	Weight loss 72 h after exposure	Weight gain 72 h after exposure
75% neem	0.6±0.1a	0.3±0.1a	0.3±0.1b	0.0±0.0a
50% neem	0.7±0.1a	0.3±0.1a	0.4±0.1b	0.0±0.0a
Wood ash	0.6±0.1a	0.3±0.2a	0.4±0.1b	0.0±0.0a
Water	0.6±0.1a	1.0±0.1b	0.0±0.0a	0.4±0.1b
Mocap®	0.6±0.1a	NA	NA	NA

Within columns, means followed by the same alphabet are not significantly different ($P<0.05$) by Tukey's test. NA=Not Applicable.

4. Discussion

The survey revealed that more males were involved in banana production than females. Probably, the females preferred the cultivation of short cycle field crops such as vegetables and maize while the males with more energy were engaged in banana production. Although, some of the respondents were involved in trading and other activities besides farming, majority of them were strictly farmers.

Majority of the farmers had relatively small farm sizes. Therefore, they were resource-poor farmers who constituted a sample that is representative of the general population in the study area. Among the varieties of banana produced in the study site, most of them were from the Gros Michel sub-group while 21.6% were from the Cavendish sub-group. This could be because of farmers' slow rate of acceptance to adapt

and become involved in the production of improved and high yielding varieties.

Most of the respondents (80%) indicated that the weevil was a major constraint to banana production. The mealybug is another insect pest that was reported (18%) to affect banana production though not as severely as the weevil. Chemical and cultural control practices dominated methods used by the farmers to manage the weevil. Although these resource-poor farmers used pesticides, they lacked adequate knowledge about their proper use. They complained that the pesticides were expensive and caused adverse effects on human health. In general, the farmers do not put on protective clothing during the application of pesticides and the rates used are estimates. The results of this study revealed that the insecticide commonly used by the farmers in the study area was Mocap®, an organophosphate. This

insecticide could be very hazardous to humans when not protected adequately during application. Cultural control practices such as de-suckering, de-leaving, use of clean planting material, weeding and mulching were some of the common methods available to farmers but they are labour intensive. The main indigenous method used was application of wood ash around the base of the banana stands. This ash is obtained from wood burnt in the farmers' kitchens when they are preparing food. None of the farmers indicated the use of pesticidal plants in managing the weevil.

The results of this study also indicated that the aqueous extract of neem had insecticidal effects against the weevil. The extract especially at 75 and 100% was very persistent and caused significant mortality of the adult weevil up to 14 DAE better than wood ash. The phytochemical active compounds of this botanical could be responsible for its insecticidal potential against the weevil. The findings are in line with those of a previous study in which the authors reported that neem contains the bioactive constituents called 'azadirachtins', known to interfere with the neuro-endocrine regulation of juvenile and molting hormone during insect development [23]. Researchers have also reported that neem adversely affects the behaviour and physiology of the banana borer weevil [21].

Wood ash also demonstrated insecticidal effect on the weevil although this was not as effective as the aqueous extract of neem at concentrations $\geq 50\%$. Wood ash was able to repel the weevil, cause mortality, and reduce the number that settled on the corms. These results strengthen farmers' perceptions about wood ash as a potential insecticide against the weevil. It is possible that wood ash also contains bioactive compounds which could be toxic to the weevil. In another study, a mixture of *C. ambrosioides* and wood ash (50:50%) killed 85% of *S. zeamais* adults at 3 days after infestation and by 5 days, it registered 100% mortality [24].

Banana borer weevils were repelled from corms treated with the aqueous extract of neem at 50 and 75% as well as wood ash. It is possible that these treatments could have produced an undesirable smell which repelled the weevils. Neem has been reported to possess complex insecticidal phytochemical compounds that are effective against more than 200 pests of agricultural crops and the household [25].

Neem and wood ash were very effective in reducing weevil oviposition. Studies have indicated that eggs are laid by the weevil within 3 to 4 days of their adult life [17]. A reduction in the number of eggs laid on corms may be attributed more to reduced free mobility and mating caused by the repellent properties of these treatments, their undesirable nature or a reduction in the survival of weevils than their ovicidal properties. In another study, it was reported that neem seed derivatives reduced oviposition and hatching of eggs for the banana borer weevil because the treated corms were unfavourable for laying eggs [21]. Wood ash may have rendered the corms undesirable for hatching eggs also.

No larva emerged on corms treated with wood ash and the aqueous extract of neem at 50 and 75%, similar to those with

mocap®. This could be attributed to anti-oviposition or ovicidal effects of neem and wood ash. Also, the bioactive chemical constituents of neem and wood ash could have rendered the few eggs that were laid unproductive and unable to be hatched. This agrees with the findings of previous researchers who observed that corms treated with neem reduced weevil oviposition and hatching of eggs [21]. Research has also shown that extracts of neem inhibit the hatching of eggs and juvenile activity of several insect pests on a wide range of crops [26].

The aqueous extract of neem at 50 and 75% and wood ash, significantly deterred the larvae from feeding. These treatments increased the average time each larva spent to locate a feeding site, initiate feeding and bore into the discs. When the larvae were confined for 72 hours, the feeding damage was reduced to $<19\%$ while control discs treated with water had 84.3% damage. At two weeks after exposure, larvae on discs treated with neem and wood ash died while some pupae with visible adult symptoms were found on treatments with water. The weight gained by larvae on discs treated with water could be due to the ability of the larvae to feed freely. These findings are similar to those of another study, in which the authors found that various concentrations of neem seed extract significantly reduced the weight of the African Bollworm larvae, *Helicoverpa armigera* (Hubner) (Lepidoptera) six days after treatment [27].

The potency of the various treatments on the weevil decreased with time. After one and two weeks, the mortality of weevils introduced on corms treated with neem at 50 and 75% and wood ash was above 55%. During the third and fourth weeks, the insecticidal strength of the treatments reduced significantly and after this period, mortality was less than 50%. The potency of neem and wood ash lasted for three to four weeks because the introduction of adult weevils beyond this period caused a reduction in mortality. It is possible that the active ingredients of neem and wood ash could have been biodegraded after four weeks. Also, opening the containers at weekly intervals to re-introduce weevils could have led to the evaporation of some bioactive constituents of neem and wood ash which were toxic to the weevil. These results suggest that the treatments needed to be re-applied within 3–4 weeks intervals for appropriate management of the weevil. These findings agree with those of another study which indicated that the potency of wood ash and *Chenopodium ambrosioides* (another botanical) reduced with the duration of exposure [24]. The insecticide Mocap® was more effective than neem and wood ash in causing mortality and deterrence of the weevil, as well as in reducing oviposition. However, the synthetic insecticides cause many adverse problems [28].

5. Conclusion

The results of this study revealed that farmers in the study area mostly rely on the use of synthetic pesticides for the management of the banana borer weevil. They have limited knowledge of indigenous and plant based methods for the

management of the weevil. The aqueous extract of neem and wood ash demonstrated insecticidal effect on the weevil through adult mortality, repulsion, inhibition of egg laying, feeding deterrence and reduction of larva damage. The extract of neem at 75 and 100% was very persistent and caused higher mortality of the weevil than wood ash. The extract at 50% and above was more potent and effective in repelling the insects than woodash. The aqueous extract of neem at a concentration of 75% is recommended for the management of the weevil. Based on these promising results, neem, wood ash and other plant derivatives could be exploited further, and incorporated into an integrated management programme for the weevil.

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