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INTEGRATING *TITHONIA DIVERSIFOLIA*, *PIPER GUINEENSE* AND OIL PALM BUNCH RESIDUE ASH FOR THE MANAGEMENT OF SWEET POTATO WEEVIL (*CYLAS PUNCTICOLLIS* BOH.) AND ON YIELD OF SWEET POTATO IN FAKO DIVISION OF CAMEROON

Justin N. Okolle[1+]
Mbei N. Abuno[2]
Ekwa Y. Monono[3]
Nanganoa L. Tatanah[4]
George B. Chuyong[5]

[1]*Institute of Agricultural Research for Development, Barombi Kang-Kumba, South West Region, Cameroon.*
[1]*Department of Agronomic & Applied Molecular Science, University of Buea, Buea, South West Region, Cameroon.*
[1]*Email: okollejustin@yahoo.com Tel: +237674534786*
[2,3,5]*Department of Plant Science, University of Buea, Buea, South West Region, Cameroon.*
[2]*Email: abunombi@yahoo.com Tell: +2347063694213*
[5]*Email: chuyong99@yahoo.com Tell: +237677623216*
[3,4]*Institute of Agricultural Research for Development, Ekona, Buea, South West Region, Cameroon.*
[3]*Email: ymekwado@yahoo.com Tell: +237675595865*
[4]*Email: tatanah2002@yahoo.fr Tell: +23767550830*


(+ Corresponding author)

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ABSTRACT

This research was to evaluate the effects of integrating *T. diversifolia*, *P. guineense* and OPBRA to manage *Cylas puncticollis* infestation and on the yield of sweet potatoes. Bioassay 1, 5g *T. diversifolia* + 5g *P guineense* /100mL and 10g *P guineense* /100mL showed significant low ($P < 0.05$) in mortality, number of eggs laid, percentage repellence and progeny emergence of *C. puncticollis*. Bioassay 2: 20 g OPBRA /100mL, 5g OPBRA + 5g *P guineense* /100mL, and 10g *P guineense* /100mL. The lowest progeny emergence was 5g OPBRA + 5g *P guineense* /100mL. 5g OPBRA + 5g *P guineense* /100mL, and 10g *P guineense* /100mL showed significant difference ($P < 0.05$) in mortality, mean number of eggs laid of *C. puncticollis* with the control. Bioassay 3 and 4: showed significant effect ($P < 0.05$) of *T. diversifolia*, OPBRA and *P. guineense* pastes on weight loss due and root sizes to *C. puncticollis* damage of sweet potato. On the field, sweet potatoes that were treated with 2 ton/ha T. diversifolia + 2 ton/ha OPBRA + 0.33 ton/ha *P. guineense* and 0.67 ton/ha *P. guineense* showed significantly ($P < 0.05$) less infestation than the other treatments. Plants treated with 2 tons/ha *T. diversifolia* +2 tons/ha OPBRA + 0.33 tons/ha *P. guineense* had the highest yield. The combination of *T. diversifolia*, OPBRA and small proportion of *P guineense* could serve as an alternative of source of synthetic pesticides managing *C. puncticolis* infestation as well as source of organic matter improve soil fertility.

Contribution/Originality: This research primary contribution is finding that toxic of *T. diversifolia*, *P. guineense* and Oil Palm Bunch Residue Ash (OPBRA) on *C. puncticollis* infesting sweat potatoe (*Ipomoea batatas*) at storage and on the field.

1. INTRODUCTION

Sweet potato (*Ipomoea batatas* Lam), is a dicotyledonous plant belonging to the family Convolvulaceae, a small herbaceous, annual or perennial, trailing root crop [1]. This crop is propagated vegetatively and has a growth

duration that varies four to six months depending on variety, soil conditions and place of cultivation [2]. The crop significantly contributes to food security, nutrition, and income generation [3]. Globally the crop is ranked as the seventh most important staple crop in the world and the fifth in developing countries after rice, wheat, maize, and cassava [4]. Asia and the Pacific island produce about 92% of sweet potato, with 89% of this cultivated and utilized in China Meadows [5]. FAOSTAT [6] reported that sweat potatoes cultivation surface area in Cameroon has been on an increase from 81822 to 85953 ha giving an increase in production from 466449 to 495177 tons in 2018 and 2019 respectively.

Sweet potato is considered as the future food crop which can be used to alleviate food shortage and to overcome hunger [7]. This is because of its low labour, low cost and low risk [8], as well as its potential of high yield year-round harvest [9]. Sweet potato plays an essential dietary role in many parts of tropical Africa, and also as an efficient producer of edible biological material for humans and animals [10]. The green leaves of the plant contain essential minerals and vitamins such as pro-vitamin A, vitamin B, vitamin C, calcium, potassium, iron and sodium [11]. The root is termed a 'three in one' commodity, blending the characters of cereals which contain increased levels of starch, fruits with high amounts of vitamins and pectin and vegetables which also contain vitamins and minerals [11]. With this rich minerals and vitamins, this crop is consumed raw, boiled, fried, dried, and processed into flour for bread and pastries [12]. Sweet potato has many uses in addition to that of a food crop. It is also an important industrial raw material for producing starch, sugar and alcohol [13]. In Cameroon, it is an important subsistence food crop grown in almost all agro-ecological zones for its storage roots, which are used for human consumption and to a lesser extent its vines used as animal feed [4].

In spite of the nutritient-rich potential as well as its adaptation to different climatic factors, far less attention is given to sweet potato compared to other root and tuber crops. In addition, the few farmers that cultivate the crop face threats from a series of abiotic and biotic stresses such as soil nutrient depletion, drought, pests and disease and crop management factors. A major challenge faced by many smallholder farmers is in managing *C. puncticollis*, a major biotic stress on sweet potato [14]. The damage caused by this weevil considerably affects the growth and yield of sweet potato in Fako Division, Cameroon. The pest attacks both vines and roots, causing an unacceptable odour and bitter taste, rendering the roots unfit for human and animal consumption Uritani, et al. [15]. Nottingham and Kays [16] reported that *C. puncticollis* can cause yield losses ranging up to 98% in Africa. They have been very difficult to eradicate and remain a major problem in sweet potato production. These problems may be persisting because current control methods for sweet potato weevils are either inadequate, or are slow to produce rapid results, or because conventional pesticides are expensive and not always available at critical periods.

Insects may also evolve a resistance to conventional insecticides and become even harder to kill. Farmers are therefore on a kind of treadmill, trying out one chemical after another. The increasingly stringent national and international legislations in the agri-foodstuffs sector is bringing in increasingly rigorous quality control and monitoring procedures which are phasing out highly hazardous chemicals like Mocap® (Terbufos) commonly used by sweet potato farmers in Cameroon. Although synthetic insecticides are currently used in the control of pests, their adoption and use by resource-poor farmers in rural areas is limited by high cost, unavailability at critical periods, low level of application skills, health concerns and perhaps, most importantly, product adulteration [17].

These chemical pesticides are known to have effective and rapid reduction of pest populations on crops, but because of their toxic effects on the environment and non- target organisms [18], there is currently a preference for integrated pest management (IPM), and a decline in absolute dependence on chemical pesticides. One approach being explored vigorously is the use of available plant materials as biopesticides for pest control [19]. Many plant substances in the form of powders, pellets, extracts could be channeled as possible entomotoxicants, deterrents, anti-feedants and anti-reproductive agents for the control of pests in crops [19]. Local farmers do not have enough information on the use of locally available plant-derived substances in pest control, and do not take the advantage of using them to boost their production. *Tithonia diversifolia* known as wild sunflower or tree marigold is a well-

known herb used traditionally in developing countries with agricultural benefits due to insecticidal properties [20]. In Cameroon, it is common in field boundaries, grasslands, disturbed lands and major roads. This plant is in abundance and its adaptation to various environments coupled with its rapid growth rate and very high vegetative matter turnover makes it ideal for soil rejuvenation [21]. The bioactive constituents of *T. diversifolia* were identified as the sesquiterpene lactones, named tagitinins [22, 23]. These plant secondary metabolites are effective and cheap bioresource for the development of oviposition inhibitors against mites [24].

Tithonia diversifolia has been recognized to be a great source of nutrients in improving soil fertility as green manure [25, 26]. The application of organic matters improves the physical, chemical and biological properties of soil [27, 28]. *Tithonia diversifolia* has been used as mulch, biomass transfer and improved fallows in soil fertility management. It has also increase on the yield of crops but the mechanisms by which tithonia impacted positively on the yields were often not studied or properly understood [21]. Published works on effect of oil palm bunch residue ash (OPBRA) on yield and as pesticide used on sweat potatoes are limited. OPBRA is a waste product of oil palm fruit processing which results from incineration of palm bunch residues after fruit extraction. In Fako Division there are so many oil palm (*Elaeis guineensis*) plantations, which are involved in processing of oil palms. These generate bunch residue which are consider as waste by the owners and farmers. The bunch residues contain substantial nitrogen and potassium which are essential for the optimal tuber yield of crops and Ojeniyi, et al. [29] reported that oil bunch ash (OBA) at 4 t/ha increased significantly yield of maize and its leaf nutrient content sure as N, P, K, Ca and Mg. Lim and Zaharah [30] reported that 1 ton of oil palm fresh fruit bunches when processed produces about 220 kg of empty fruit bunch which contains about 0.8% nitrogen (N), 0.1% phosphorus (P), 2.5% potassium (K) and 0.2% magnesium (Mg) on dry weight basis. Palm bunch ash was also found to increase nutrient supply to crops and increased the yield of crops significantly Ezekiel, et al. [31]; Ogbuehi [32]. Ogbuehi [32] reported that palm bunch ash can be used to amend pH of highly acidic soils as well as a nutrient supplement in soils with leached nutrients. Wahedi, et al. [33]; Ogbedeh and Ani [34] in their studies concluded that palm bunch ash and neem leaf powder each consistently suppressed insects' incidence and severity. But the suppressive ability of palm bunch ash to insect incidence and severity increased with increase in rate of application [34, 35], and the insecticidal properties of ashes vary according to the plant species [36]. The testing of ash from different plant species may lead to the identification of more active ash, which may be more practical for the protection of crops [35]. *Piper guineense*, is in the family *Piperaceae*, is an important plant that has culinary, medicinal, cosmetic and insecticidal uses [37, 38]. The most widely recognized species are black pepper, *Piper nigrum* L., and African Guinea pepper but many other species in the family are also insecticidal [39]. This pepper is an important source of various nutrients and produce phytochemicals with insecticidal activity [38, 39]. They contains a range of natural products including alkaloids, flavonoids, polyphenols, amides, oils, lignins, and volatiles Juliani, et al. [37]; Ukpai, et al. [40]. Mobolade, et al. [41], repoted that *P. guineense* exhibited moderate level of insecticidal activity in effectively reducing *Podagrica* spp population in okra. Adedotun, et al. [42] had also noted that the efficacy of contact toxicity of different levels of *P. guineense* powder in controlling *Callosobruchus maculatus*. Ojiako, et al. [43] reported that insecticidal ability of *P. guineense* might be as a result of isobutyl amides, a compound that acts as neurotoxins in insects. Extracts prepared from plants have a variety of properties including insecticidal activity, repellence to pests, anti-feedant effects, insect growth regulation, toxicity to nematodes, mites and other agricultural pests. Some also have antifungal, antiviral and antibacterial properties against pathogens. The purpose of this research therefore was to evaluate the effects of integrating *T. diversifolia*, *P. guineense* and OPBRA to manage *Cylas puncticollis* infestation and on the yield of sweet potatoes in Fako Division.

2. MATERIALS AND METHODS

2.1. Experimental Site

The experiment was carried out at the Institute of Agricultural Research for Development (IRAD) Ekona

(4°16′44″ N and 9°17′50″ E) in the South West Region of Cameroon at an altitude of about 450 m above sea level. It has a humid tropical climate characterized by mean temperatures ranging from 23.7° C in the rainy season to 24.4 ° C in the dry season, and rainfall of approximately 2,500 mm per year. The rainy season is usually from March to September and dry season from October to February.

2.2. Experimental Design and Layout

2.2.1. Powder Preparation

2.2.1.1. Tithonia Diversifolia Powder

Leaves and non-woody soft stems of pre-flowered *T. diversifolia* were harvested from the Ebenezer Baptist Church Compound Great Soppo, Small Soppo, Tole and Muea all in the Buea Sub Division Cameroon. They were plucked as reported in Kaho, et al. [26], chopped and then air-dried in a well-ventilated room. They were then stored in nylon bags for three months prior to the commencement of the experiments. The powder needed for the experiments was obtained by grinding the dried leaves using mechanical hand-grinder (Victoria® 24, made in China). It was then sieved with a 1 mm pore size mesh to obtain a fine powder which was stored in a tightly closed plastic container and kept away from direct sunlight.

2.2.1.2. Oil Palm Bunch Residue Ash (OPBRA)

Oil Palm Bunch Residue Ash was obtained from Cameroon Development Corporation (CDC), Mondoni Oil Palm mill. The oil palm bunch residues were sun-dried and then burnt in air to obtain OPBRA. The ash were grind using an electric grinder. The ash was sieved using a 1mm sieve and then stored in a tightly closed plastic container.

2.2.1.3. Piper Guineense Powder

Piper guineense seeds (3 kg) were purchased from the local market in Muea (South West Region, Cameroon). They were cleaned by winnowing to remove lighter materials like leaf debris, and then hand-picked to remove heavier debris like stones. These seeds were then oven-dried for 24 hours at 80°C as obtained in Oparaeke and Bunmi [17] before grinding to powder using Victoria® (Type 24) manual grinding machine, made in China. It was then sieved using a 0.5mm pore size mesh and kept in a tightly closed plastic container.

2.2.2. Preparation of Aqueous Extracts

2.2.2.1. Extract of T. Diversifolia

The procedures involved in this preparation were same as in Moyin-Jesu [44], where 0 g/100mL, 10g/100mL, 15g/100mL and 20g/100mL aqueous filtrates of the *T. diversifolia* as treatments Table 1. Masses of 100g, 150g, 200g, and combination of 50g of the *T. diversifolia* and 50 g *P. guineense* were weighed out of the plastic container using an electronic scale (OBH NORDICA® 9832, made in Sweden). Each of these masses was separately added into a 5L plastic bucket containing 1000mL of water. This mixture was stirred and kept in the laboratory for 24 hours for proper extraction of the water-soluble components of the *T. diversifolia.*

Table 1. Treatment of aqueous extract *T. diversifolia* per 100mL used.

Treatment	*T. diversifolia* (g/100mL)	*P guineense* (g/100mL)
B_1T_1(negative control)	0	0
B_1T_2	10	0
B_1T_3	15	0
B_1T_4	20	0
B_1T_5	5	5
B_1T_6(positive control)	0	10

2.2.2.2. Extract of OPBRA

The same measurement for Bioassay 1 were used for the OPBRA treatments: 0g, 10g, 15g and 20g per 100 mL aqueous filtration Table 2. Masses of 100g, 150g, 200g, and combination of 50g of the OPBRA and 50 g *Piper guineense* of were weighed out of the plastic container using an electronic scale. Each of these masses was separately added into a 5L plastic bucket containing 1000 mL of water. This mixture was stirred and kept in the laboratory for 24 hours for proper extraction of the water-soluble components of the OPBRA.

Table 2. Treatment of aqueous extract OPBRA per 100mL used.

Treatment	OPBRA (g/100mL)	*P. guineense* (g/100mL)
B_2T_1(negative control)	0	0
B_2T_2	10	0
B_2T_3	15	0
B_2T_4	20	0
B_2T_5	5	5
B_2T_6(positive control)	0	10

2.2.3. Rearing of C. Puncticollis

Sweet potato weevils were collected from abandoned infested farms in Ekona Mbenge, Mile16 (Bolifamba) and Muea. These weevils were cultured at the Entomology Laboratory of the Institute of Agricultural Research for Development (IRAD) Ekona. Clean sweat potato tubers bought from Muea market was added to the infested roots with weevils in a 70L bucket and three 12L transparent plastic buckets. These buckets were sealed with a 0.5 mm nylon mesh, held in place by extensible rubber bands to prevent weevils from straying. Freshly infested tubers were transferred to new rearing buckets to ensure the use of freshly emerged weevils or to minimize the use of ageing weevils in the experiments.

The identification and separation of the males from the females was done for the newly emerged adults (< 1 month old) to be for use in the bioassays. The sex differentiation was done according to Malgwi and Onu [45] using the curvature of the antennae, where males have straight antennae, and females have club-shaped antennae.

2.2.4. Laboratory Experiment

2.2.4.1. Bioassays 1 and 2: Biocidal Effects of Aqueous T. Diversifolia and OPBRA Extracts on C. Puncticollis

In these bioassays, seventy-two completely intact sweet potato storage roots (approximately 70g each) were washed with running tap water while avoiding any abrasion. They were rinsed with 10% w/v salt and water solution, then air dried for 5 minutes. They were then soaked in the treatments of aqueous extracts of the *T. diversifolia* and OPBRA Tables 1 and 2 for 2 minutes and then air- dried for 10 minutes. The two bioassays had six treatments each with each treatment replicated three times in transparent plastic boxes in a completely randomized design with two storage roots and ten weevils (5 males and 5 females) in each box serving as an experimental unit.

Biocidal effects were assessed by the cumulative daily counts of the number of dead weevils from the different treatments. A weevil was declared dead, and not pretending, if after stretching its antennae and/or limbs or wings, it fails to return to the position from which they were disturbed. It was done for 14 days and recorded as the number of dead males and the number of dead females distinguishable by the curvature of their antennae. The percentage mortality was calculated as the number of dead weevils divided by the total number of weevils multiplied by 100.

The non-mortality effects were assessed within 14 days as; anti-feedant effect was obtained by counting the number of feeding punctures created by the weevils every seventh day. The mean number of feeding punctures per weevil per day was recorded. The oviposition deterrence was obtained by counting the number of oviposition punctures created by the weevils every seventh day. The oviposition punctures differ from the feeding punctures in that they have easily observable necrotic cells around the punctures, and have brown frass produced by the female

weevils to close the opening of the oviposition puncture. The number of oviposition punctures per female per day was recorded. Repulsion (recorded in percentages) was assessed by the daily counts of the number of weevils found away from the treated sweet potato storage roots. Larval emergence was assessed by a count of the number of larvae and pupae that emerged from the eggs in the storage root from the commencement of the experiment. This was made possible after the dissection of all sections of the storage roots in the various treatments after fourteen days.

2.2.4.2. Bioassay 3: Effect of T. Diversifolia and OPBRA Pastes on Weight Loss of Sweet Potato Roots

Each experimental unit was a sweet potato root held at a temperature of about 29°C and a relative humidity of 85 to 90% with proper ventilation for three to five days immediately after harvest [46]. In an attempt to improve on this technique, pastes of *T. diversifolia* and OPBRA were added to the curing regime of simple moisture and raised temperatures (and referred to as modified curing) to represent different treatments. These pastes were prepared by adding 500cL of water to each of 500g powder *T. diversifolia* and 500g OPBRA Table 3 to obtain a thick mass that could adhere to the storage root surface. Six treatments of pastes combinations were applied in a completely randomized design. Five sweet potato storage roots representing a replicate were exposed to 30 weevils (15 males + 15 females). There were three replicates per treatment Table 3.

Table 3. Mass of botanical used with 0.5L water in paste composition.

Treatment (paste)	*T. diversifolia* (g)	OPBRA (g)	*P. guineense(g)*
B3T1(negative control)	0	0	0
B3T2	500	0	0
B3T3	0	500	0
B3T4	250	250	0
B3T5	250	250	25
B3T6(positive control)	0	0	50

2.2.4.3. Bioassay 4: The Effect of Sweet Potato Storage Root Size on Susceptibility and Weight Loss due to C. Puncticollis Infestation

This experiment consisted of five treatments of sweet potato roots with five different size ranges (48.17 g to 634.27 g), exposed to the same degree of *C. puncticollis* infestation in an insect cage. Each treatment had five sweet potato roots each serving as a replicate (R) Table 4. To minimize pressure and simulate infestation during storage, the roots in all the treatments were weighed, labeled and randomly mixed with *Cylas* infested sweet potatoes in the insect cage, from which emerging sweet potato weevils would infest the different treatments according to their preference. The weight losses due to weevil damage were recorded every seventh day for 28 days. The experiment was a complete randomized designed.

Table 4. Sizes in grams of sweet potato storage roots representing treatments and replicates.

Treatment	Replicates (g)					Treatment total (g)	Treatment average (g)
	R1	R2	R3	R4	R5		
T_1	38.30	55.81	46.20	43.22	57.32	240.85	48.17
T_2	72.55	80.60	76.81	79.45	84.47	393.39	78.78
T_3	101.58	112.06	125.44	112.51	137.01	112.51	117.72
T_4	170.55	203.53	198.67	160.81	218.04	951.60	190.32
T_5	360.10	753.25	764.81	522.21	770.98	3171.35	634.27

2.2.5. Field Experiment

An experimental plot of 20 × 25 m was allocated for this study. The experimental site was divided into 3 replicate of 6 beds of 4 × 1.5 m each. The replicate were 2 m apart give experimental design of completely

randomize design (CRD). The beds were covered with green manure as it is practiced by farmers in Fako Division. Fresh *T. diversifolia* leaves was chopped while OPBRA and *P. guineense* were used as powdered for the formulation of the treatment used for the experiment making the total application range from 0 to 12 tons/ha Table 5. The treatments were applied during planting of the vines. Each vine was 40 cm long, which was obtained from local farmers in Muea. The planting spacing was 75 × 50 cm, giving a planting density of approximately 2.5 stands/m².

Planting and the inoculation was carried out 90 days after planting (DAP) by releasing 30 weevils (15 males and 15 females) per replicate. The application of the treatment was done in three slip, which was done during planting, 45 DAP and 90 DAS.

Table 5. Treatment for the application *T. diversifolia* and OPBRA on sweet potato on the field.

Treatment	*T. diversifolia*		OPBRA		*P. guineense*	
	Kg/6m²	*Ton/Ha*	Kg/6m²	*Ton/Ha*	Kg/6m²	*Ton/Ha*
T_1	0.0	0.0	0.0	0.0	0.0	0.0
T_2	2.4	4.0	0.0	0.0	0.0	0.0
T_3	0.0	0.0	2.4	4.0	0.0	0.0
T_4	1.2	2.0	1.2	2.0	0.0	0.0
T_5	1.2	2.0	1.2	2.0	0.2	0.33
T_6	0.0	0.0	0.0	0.0	0.4	0.67

2.2.5.1. Harvesting

Harvesting was done 120 DAP by carefully digging out all the storage roots without wounding them. The storage roots were weighed using a scale, then tied in bags and stored in the laboratory for one week to enable the development of feeding and oviposition punctures from infestation. Infested roots were carefully selected from uninfested roots. The different fractions were counted and weighed for infested and uninfested roots. Percentage of infested roots was calculated as the total number of infested roots divided by the total number of roots stored multiplied by 100.

2.3. Data Analysis

Data was analyzed using a one-way analysis of variance (ANOVA) at $P = 0.05$ in Stat Disk statistical software package Version 9.1. The treatment means were compared and separated using Tukey's method at 5% probability level.

3. RESULTS

3.1. Laboratory Experiments

3.1.1. Bioassay 1: Effects of Aqueous T. Diversifolia Extracts on C. Puncticollis.

3.1.1.1. The Effect on Mortality

The percentage mortality of *C. puncticollis* treated with the plant extracts is shown on Figure 1. All the *C. puncticollis* treated with aqueous *T. diversifolia* extract experienced some death after 7 and 14 days of application. The mortality on the *C. puncticollis* was not significantly ($P > 0.05$) different from the negative control (B_1T_1), but was significantly ($P < 0.05$) different from the positive control (B_1T_6). The treatment B_1T_5 extract caused 10.0, 66.7 and 73.3% mortality after 1, 7 and 14 days of application respectively. *Cylas puncticollis* were not killed by aqueous extract of B_1T_1 (negative control), B_1T_2, B_1T_3 and B_1T_4 at all after the first day of exposure.

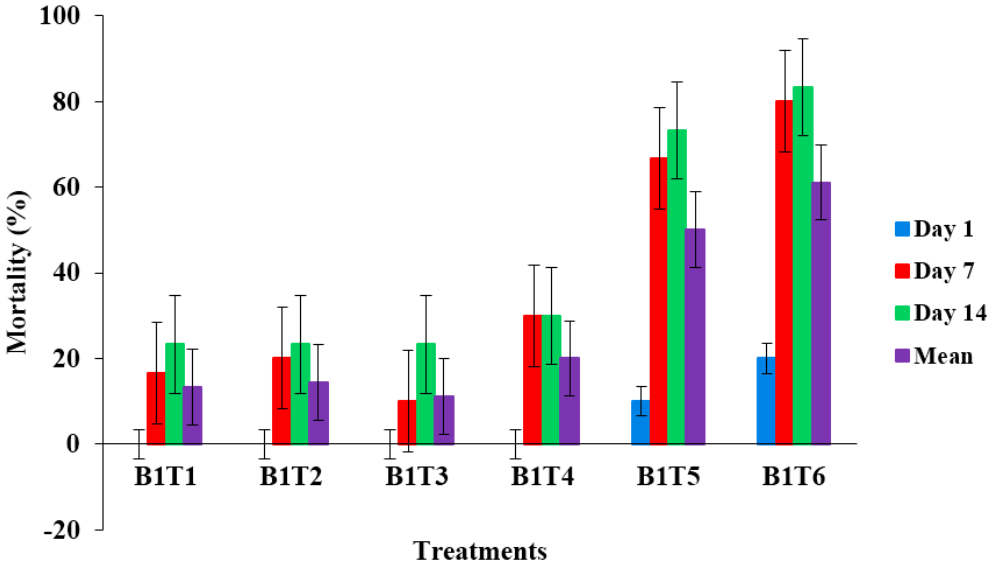

Figure 1. Effects of aqueous *T. diversifolia* extract on the percentage mortality of *C. puncticollis.*
Note: B_1T_1 (negative control) = 0 g *T. diversifolia*/100mL, B_1T_2 = 10 g *T. diversifolia* /100mL, B_1T_3 =15 g *T. diversifolia*/100mL, B_1T_4 =20 g *T. diversifolia*/100mL, B_1T_5 =5 g *T. diversifolia* + 5 g *P guineense* /100mL, and B_1T_6 (positive control) =10 g *P guineense* /100mL.

3.1.1.2. The Effect on Oviposition Deterrence

The number of eggs laid by adult *C. puncticollis* varied with aqueous *T. diversifolia* extract concentrations Figure 2. In the negative control (B_1T_1) the mean number of eggs (0.91 ± 0.09) laid was not significantly higher ($P > 0.05$) than any other treatment of B_1T_2 (0.91 ± 0.09), B_1T_3 (0.86 ± 0.04) and B_1T_4 (0.58 ± 0.01). The mean number of eggs laid decreased with *T. diversifolia* extract concentration. There was reduction in the mean number of eggs laid as the concentration of the plant extract increased as well as significant reduction ($P < 0.05$) in the mean number of eggs laid by *C. puncticollis* when treated with positive control (B_1T_6) (0.12 ±0.03) and B_1T_5 (0.03 ± 0.00) compared with the other treatment.

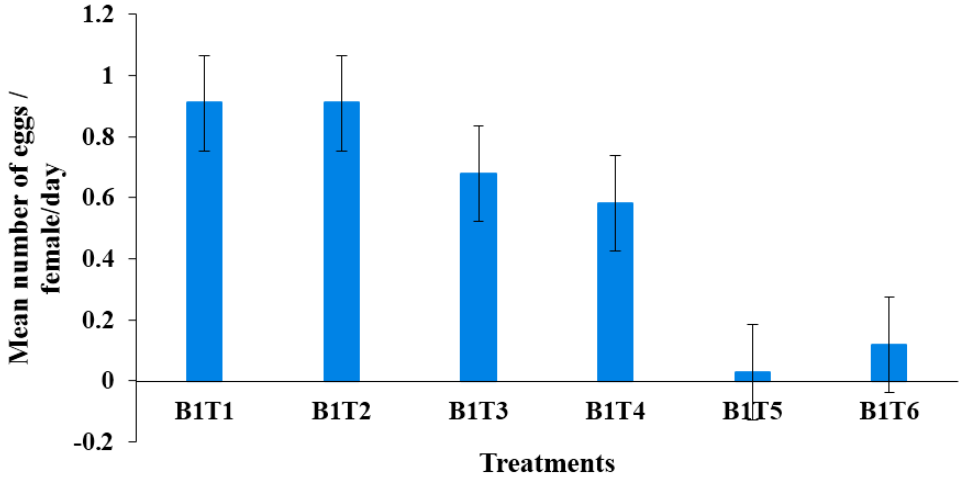

Figure 2. The effect of aqueous *T. diversifolia* extract on oviposition deterrence of *C. puncticollis.*
Note: B_1T_1 (negative control) = 0 g *T. diversifolia*/100mL, B_1T_2 = 10 g *T. diversifolia* /100mL, B_1T_3 =15 g *T. diversifolia*/100mL, B_1T_4 =20 g *T. diversifolia*/100mL, B_1T_5 =5 g *T. diversifolia* + 5 g *P guineense* /100mL, and B_1T_6 (positive control) =10 g *P guineense* /100mL.

3.1.1.3. The Effect on the Feeding Deterrence

There was no significant reduction ($P > 0.05$) in the mean number of feeding punctures per weevil per day when treated with aqueous *T. diversifolia* extracts of B_1T_2 (1.88 ±0.19), B_1T_3 (1.66 ± 0.05) and B_1T_4 (1.44 ± 0.06) compared to the negative control (B_1T_1) (1.83 ±0.11) from the 8thto the 14th day Figure 3. There was a slight

reduction in the mean number of feeding punctures per weevil per day from the 8th to the 14th day in all treatment except for B_1T_3, which showed slight increase from 1.61 to 1.71 feeding punctures per weevil per day from the 8th to the 14th day respectively. There was a significant reduction ($P < 0.05$) in the mean number of feeding punctures per weevil per day with B_1T_5 (0.65 ± 0.14), B_1T_6 (0.32 ± 0.09) as compared with the other treatments Figure 3.

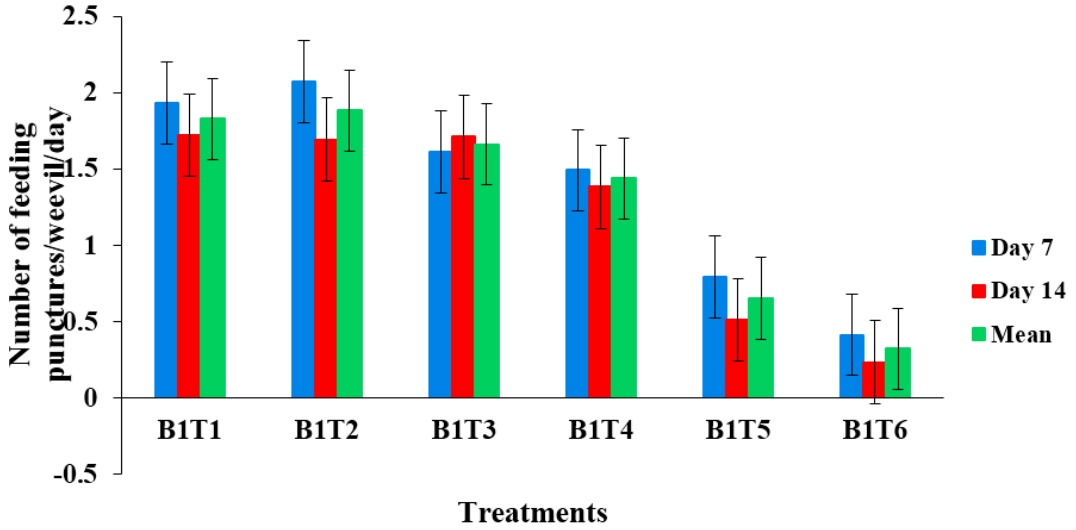

Figure- 3. The effect of aqueous *T. diversifolia* extract on the feeding deterrence on *C. puncticollis*.

Note: B_1T_1 (negative control) = 0 g *T. diversifolia*/100mL, B_1T_2 = 10 g *T. diversifolia* /100mL, B_1T_3 =15 g *T. diversifolia*/100mL, B_1T_4 =20 g *T. diversifolia*/100mL, B_1T_5 =5 g *T. diversifolia* + 5 g *P guineense* /100mL, and B_1T_6 (positive control) =10 g *P guineense* /100mL.

3.1.1.4. Effects of on the Repellence

The mean repellence of *C. puncticollis* by aqueous extract of *T. diversifolia* varied between 23.33% and 87.77% and they were significantly ($P < 0.05$) different for B_1T_5 (65.53 ± 11.28%) and B_1T_6 (positive control) (77.77 ± 9.09%) from B_1T_1 (negative control), B_1T_2, B_1T_3 and B_1T_4 Figure 4. But the percentage repellence for B_1T_2, B_1T_3 and B_1T_4 was not significantly ($P>0.05$) different from the repellence of the negative control (30.00 ± 15.74%). The repellence was also seen to increase from the first to the fourteenth day of the experiment, from 0 to 83.30% within 14 days. The negative control (B_1T_1) and B_1T_2 showed no repellence effects with the first 6 days Figure 4.

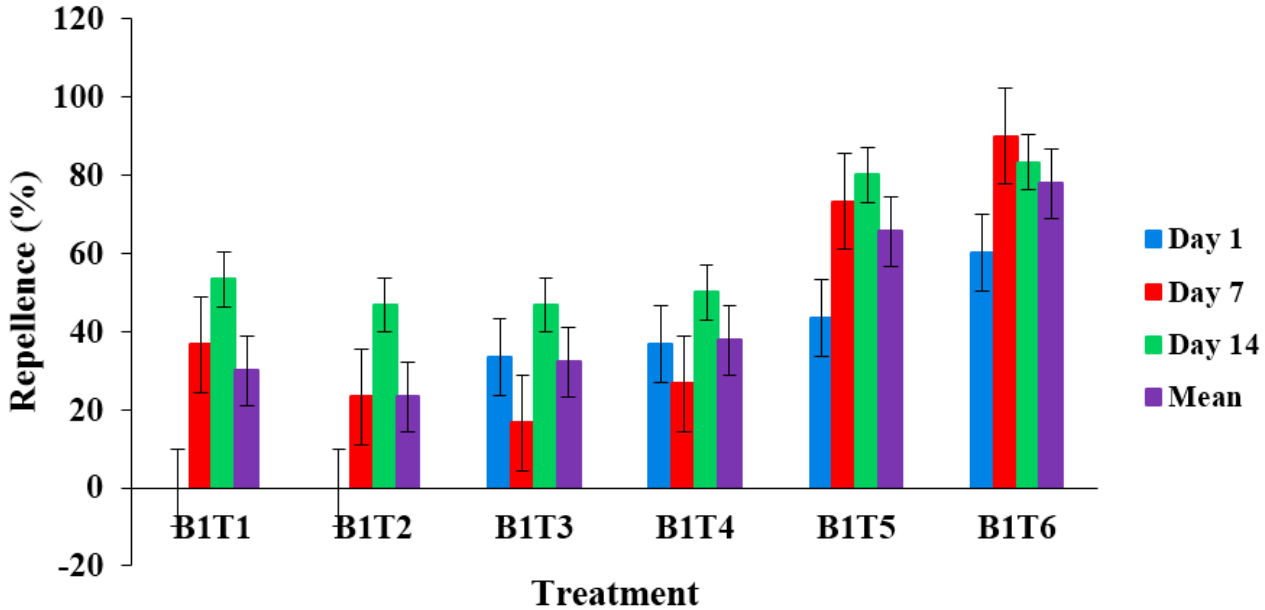

Figure 4. Effects of aqueous *T. diversifolia* extract on the percentage repellence of *C. puncticollis*.

Note: B_1T_1 (negative control) = 0 g *T. diversifolia*/100mL, B_1T_2 = 10 g *T. diversifolia* /100mL, B_1T_3 =15 g *T. diversifolia*/100mL, B_1T_4 =20 g *T. diversifolia*/100mL, B_1T_5 =5 g *T. diversifolia* + 5 g *P guineense* /100mL, and B_1T_6 (positive control) =10 g *P guineense* /100mL.

3.1.1.5. Effects the Larval and Pupae Emergence

The treatments B_1T_4 (33.70 ± 2.60), B_1T_5 (1.00 ± 0.58%) and B_1T_6 (0.33 ± 0.33%) showed a significant effect ($P < 0.05$) on progeny emergence when compared with the other treatments Figure 5. In the negative control (B_1T_1), it was observed that the highest cumulative percentage of emerged progeny of *C. punticollis* (55.00 ± 1.14) was not significantly higher ($P > 0.05$) than emerged progeny in B_1T_2 (48.00 ± 6.09) and B_1T_3 (49.00 ± 6.66).

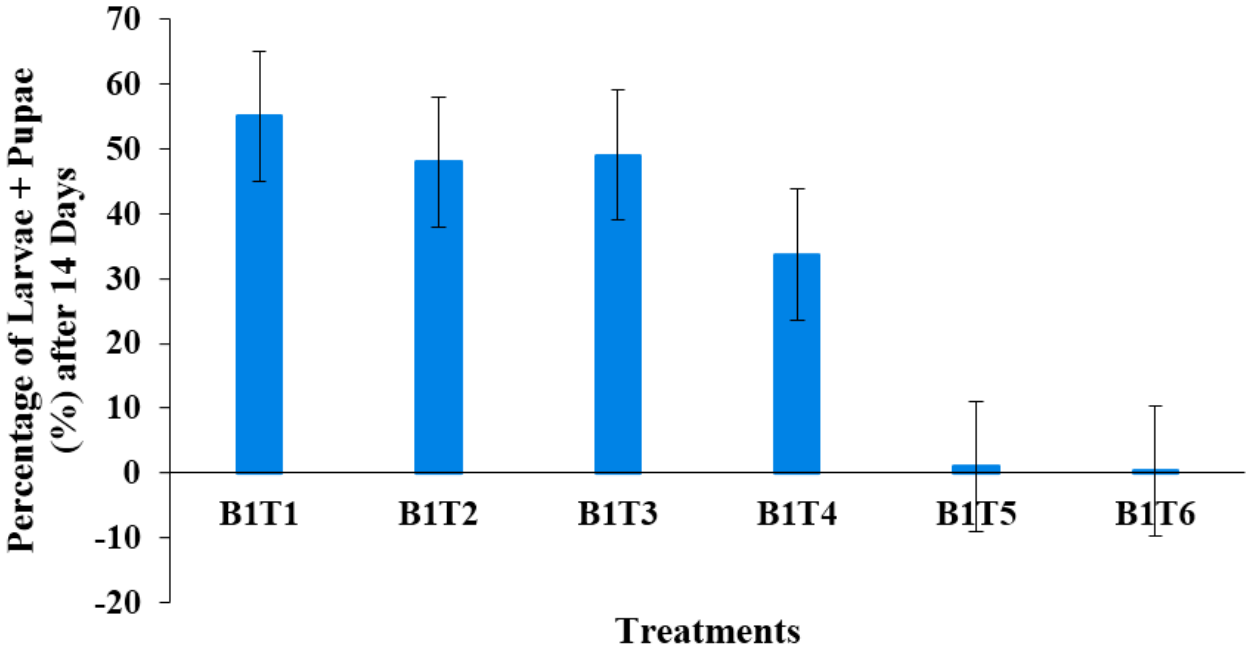

Figure 5. Effect of aqueous *T. diversifolia* extract on larval emergence and pupae of *C. puncticollis*.
Note: B_1T_1 (negative control) = 0 g *T. diversifolia*/100mL, B_1T_2 = 10 g *T. diversifolia* /100mL, B_1T_3 =15 g *T. diversifolia*/100mL, B_1T_4 =20 g *T. diversifolia*/100mL, B_1T_5 =5 g *T. diversifolia* + 5 g *P guineense* /100mL, and B_1T_6 (positive control) =10 g *P guineense* /100mL.

3.1.2. Bioassay 2: Effects of Aqueous OPBRA Extracts on C. Puncticollis

3.1.2.1. The Effect on Mortality

Treatment, significant differences ($P < 0.05$) were observed among the aqueous OPBRA extracts of B_2T_5, B_2T_6 (positive control) and control on cumulative mean mortality (%) of adult *C. puncticollis*. All the *C. puncticollis* treated with aqueous OPBRA extracts showed some mortality after 7 and 14 days of application Figure 6. The negative control (B_2T_1) showed mortality of 16.7 and 23.3% after the first and seventh day application respectively.

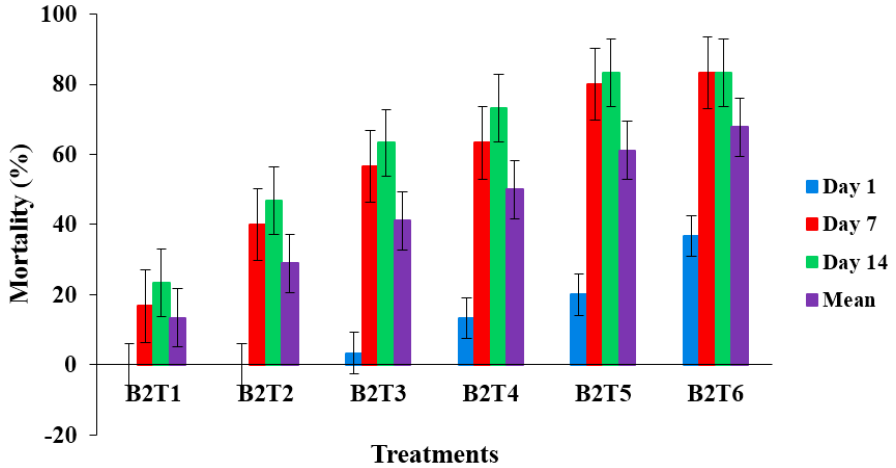

Figure 6. Effect of aqueous OPBRA extracts on the mortality of *C. puncticollis*.
Note: B_2T_1 (negative control) = 0 g OPBRA /100mL, B_2T_2 = 10 g OPBRA /100mL, B_2T_3 =15 g OPBRA /100mL, B_2T_4 =20 g OPBRA /100mL, B_2T_5 =5 g OPBRA + 5 g *P guineense* /100mL, and B_2T_6 (positive control) =10 g *P guineense* /100mL.

3.1.2.2. The Effect on Oviposition Deterrence

The mean number of eggs laid by adult *C. puncticollis* varied with aqueous OPBRA extract concentrations Figure 7. All the concentrations showed a significant effect ($P < 0.05$) on mean number of eggs laid per day when compared to the control. There was reduction in the mean number of eggs laid as the concentration of plant extract increased. The mean number of eggs laid in B_2T_3 (0.24 ± 0.03) was lower than B_2T_4 (0.28 ± 0.06), although B_2T_4 aqueous concentration is higher Figure 7.

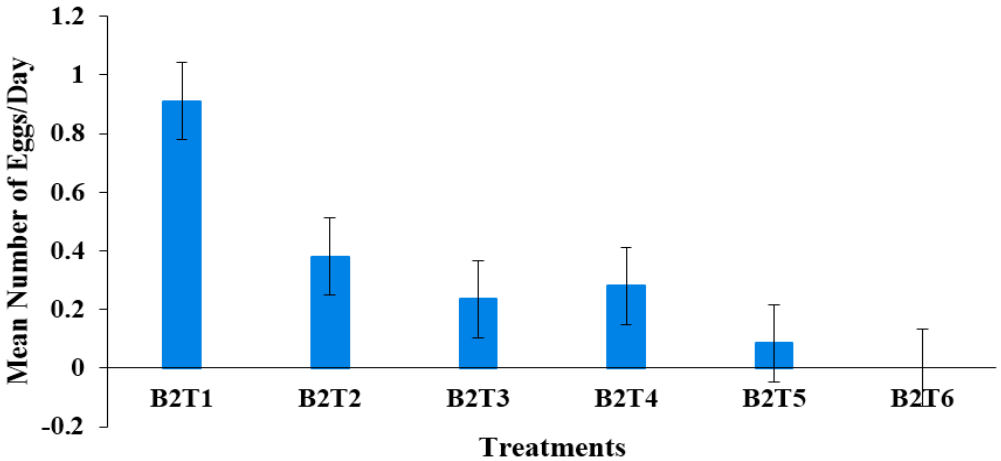

Figure 7. Effect of aqueous OPBRA extract on oviposition deterrence of *C. puncticollis*.
Note: B_2T_1 (negative control) = 0 g OPBRA /100mL, B_2T_2 = 10 g OPBRA /100mL, B_2T_3 =15 g OPBRA /100mL, B_2T_4 =20 g OPBRA /100mL, B_2T_5 =5 g OPBRA + 5 g *P guineense* /100mL, and B_2T_6 (positive control) =10 g *P guineense* /100mL.

3.1.2.3. The Effect on Feeding Deterrence

Cylas puncticollis feeding on sweet potatoes treated with B_2T_5 (0.52 ± 0.09) and B_2T_6 (positive control) (0.11± 0.03) made significantly ($P < 0.05$) more feeding holes than those treated with B_2T_1 (negative control), B_2T_2, B_2T_3, and B_2T_4 Figure 8. The number of feeding holes also did not differ significantly ($P > 0.05$) among B_2T_2 (1.66 ± 0.08), B_2T_3 (1.28 ± 0.04), and B_2T_4 (1.22 ± 0.04), with the negative control (1.84 ± 0.10). The mean numbers of feeding holes increased with sweet potatoes treated with B_2T_3 and B_2T_4 after 7 days from 1.24 to 1.31 and 1.19 to 1.25 holes respectively while all the other treatment experience a drop of numbers of holes Figure 8.

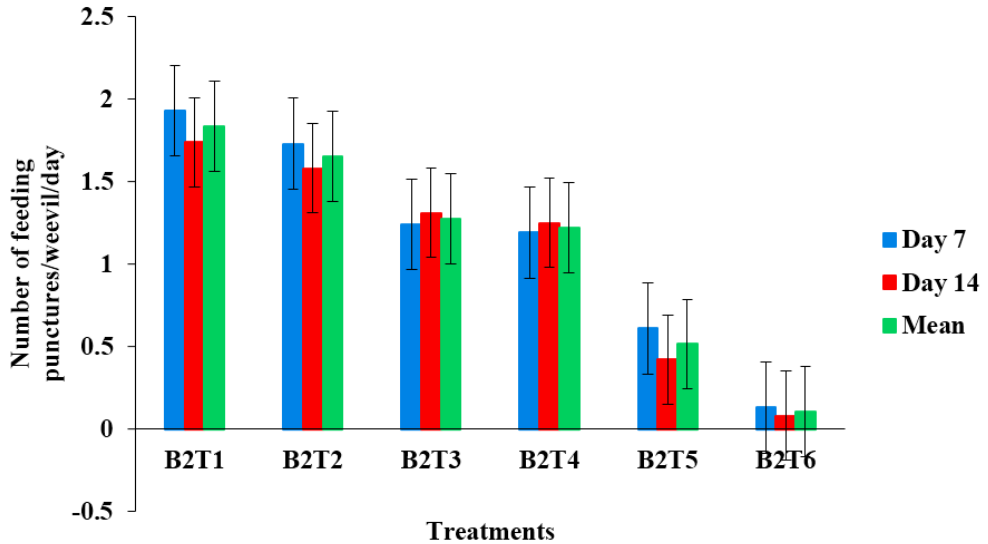

Figure 8. Effect of aqueous OPBRA extract on feeding deterrence of *C. puncticollis*.
Note: B_2T_1 (negative control) = 0 g OPBRA /100mL, B_2T_2 = 10 g OPBRA /100mL, B_2T_3 =15 g OPBRA /100mL, B_2T_4 =20 g OPBRA /100mL, B_2T_5 =5 g OPBRA + 5 g *P guineense* /100mL, and B_2T_6 (positive control) =10 g *P guineense* /100mL.

3.1.2.4. The Effect on Repellence

There was a significant ($P < 0.05$) different in repellence percentage of *C. puncticollis* with aqueous OPBRA extract concentration. The repellence was however, not significantly ($P > 0.05$) higher than the repellence 62.20 ± 10.60, and 80.00 ± 5.09% caused by B_2T_4, and B_2T_5, respectively Figure 9. *Cylas puncticollis* indicate higher percentage repellence treated with B_2T_5 (80.00 ± 5.09%) aqueous OPBRA extract as compared to the positive control (B_2T_6) (79.97 ± 3.33%). Repellence percentage of 28.90 ± 14.57 and 54.46 ± 15.43% of *C. puncticollis* when treated with B_2T_2 and B_2T_3 respectively were not significantly ($P > 0.05$) different from repellence percentage of negative control (20.00 ± 10.18%) Figure 9.

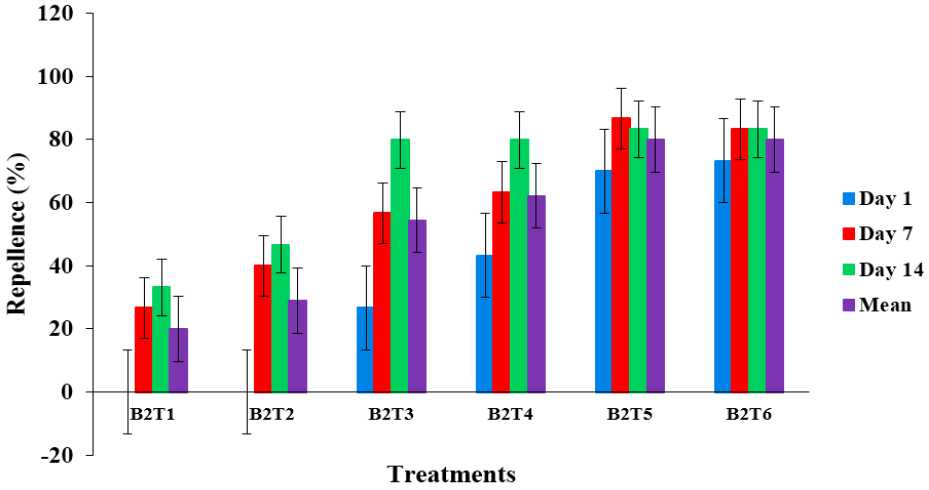

Figure 9. Effect of aqueous OPBRA extract on percentage repellence of *C. puncticollis*.
Note: B_2T_1 (negative control) = 0 g OPBRA /100mL, B_2T_2 = 10 g OPBRA /100mL, B_2T_3 =15 g OPBRA /100mL, B_2T_4 =20 g OPBRA /100mL, B_2T_5 =5 g OPBRA + 5 g *P guineense* /100mL, and B_2T_6 (positive control) =10 g *P guineense* /100mL.

3.1.2.5. The Effect on Larval and Pupae Emergence

Oil palm bunch residue ash (OPBRA) aqueous extracts concentration were significant ($P < 0.05$) effects on reducing the number of offspring produced by *C. puncticollis* compared to the negative control (55.00 ± 3.39%) Figure 10. The lowest percentage larvae produced was B_2T_5 (2.70 ± 0.66%) followed by B_2T_4 (9.70 ± 1.77%) and B_2T_3 (10.00 ± 1.15%) respectively. But the positive control (B_2T_6) did not support the production of any larvae Figure 10.

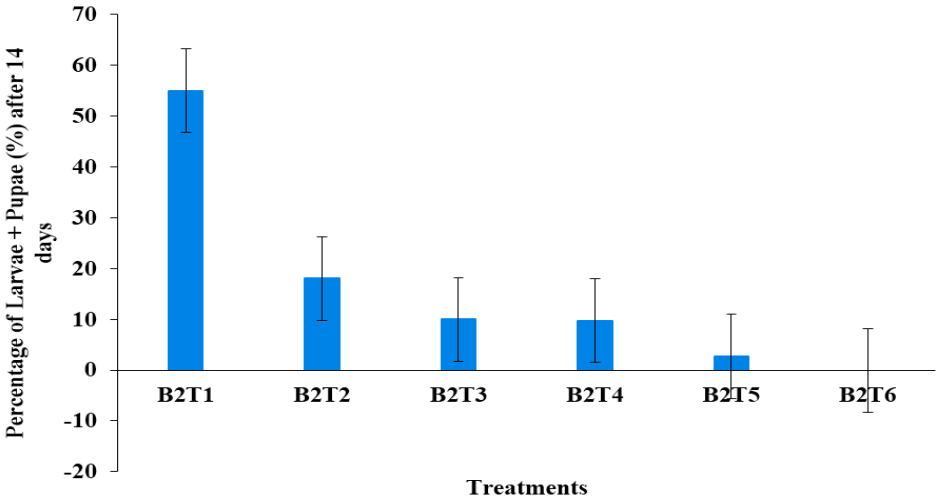

Figure 10. Effect of aqueous OPBRA extract on percentage larval + pupae emergence of *C. puncticollis*.
Note: B_2T_1 (negative control) = 0 g OPBRA /100mL, B_2T_2 = 10 g OPBRA /100mL, B_2T_3 =15 g OPBRA /100mL, B_2T_4 =20 g OPBRA /100mL, B_2T_5 =5 g OPBRA + 5 g *P guineense* /100mL, and B_2T_6 (positive control) =10 g *P guineense* /100mL.

3.1.3. Bioassay 3: Effect of T. Diversifolia and Oil Palm Bunch Residue Pastes on Sweet Potato Root Weight Loss from C. Puncticollis Damage

There was significant effect ($P < 0.05$) of *T. diversifolia* and OPBRA pastes on weight loss due to *C. puncticollis* damage of sweet potato Figure 11. The application of *T. diversifolia* and OPBRA pastes on sweet potato reduces sweet potato weight loss due to *C. puncticollis* damage. The mean percentage weight loss on sweet potato treated with B_2T_2 (4.65 ± 0.74%) and B_3T_4 (4.00 ± 0.55%) showed not significant different ($P > 0.05$) with the negative control (4.35 ± 0.74%). The results of sweet potato treated with B_3T_3 (3.02 ± 0.49%), and B_3T_5 (1.87 ± 0.41%) were not significantly different from the positive control (1.53 ± 0.12%) (Fig. 11). The percentage weight loss for sweet potato treated with B_3T_2 (6.73%), B_3T_3 (4.33%) and B_3T_4 (5.57%) were higher on the 15 to 21 days as compared to the first 14 days of the application of the paste Figure 11.

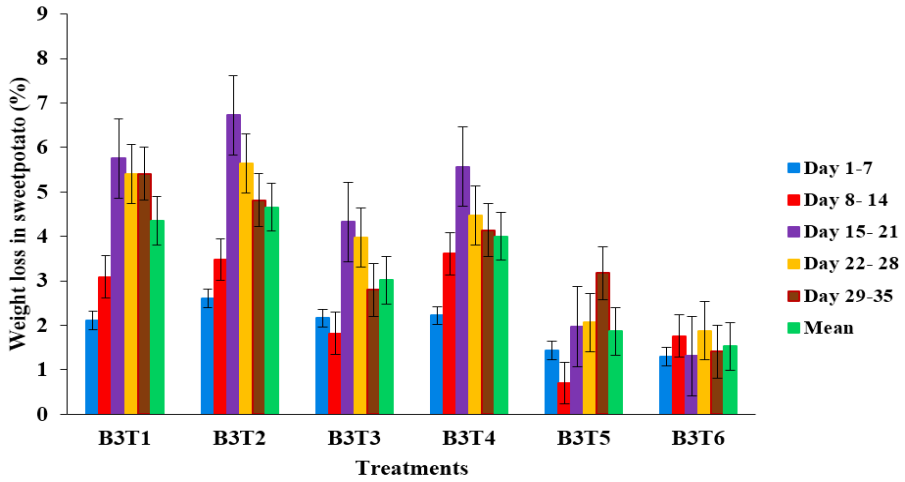

Figure 11. Effect of *T. diversifolia* and OPBRA pastes on weight loss due to *C. puncticollis* damage.
Note: B_3T_1 (negative control) = 0 g/0.5 L, B_3T_2 = 500 g *T. diversifolia* /0.5 L, B_3T_3 = 500 g OPBRA /0.5 L, B_3T_4 = 250 g *T. diversifolia* + 250 g OPBRA /0.5 L, B_3T_5 = 250 g *T. diversifolia* + 250 g OPBRA +25 g *P. guineense*/0.5 L, B_3T_6 (positive control) = 25g *P. guineense* /0.5 L.

3.1.4. Bioassay 4: Effect of Root Size on Susceptibility and Weight Loss in Sweet Potato from C. Puncticollis Damage

The root sizes had significant differences ($P < 0.05$) on percentage weight loss in sweet potatoes due to *C. puncticollis* damage after 35 days Figure 12. The sizes of the storage roots were directly proportional to damage caused by *C. puncticollis* thus the bigger the root, the less infested the *C. puncticollis* Figure 12.

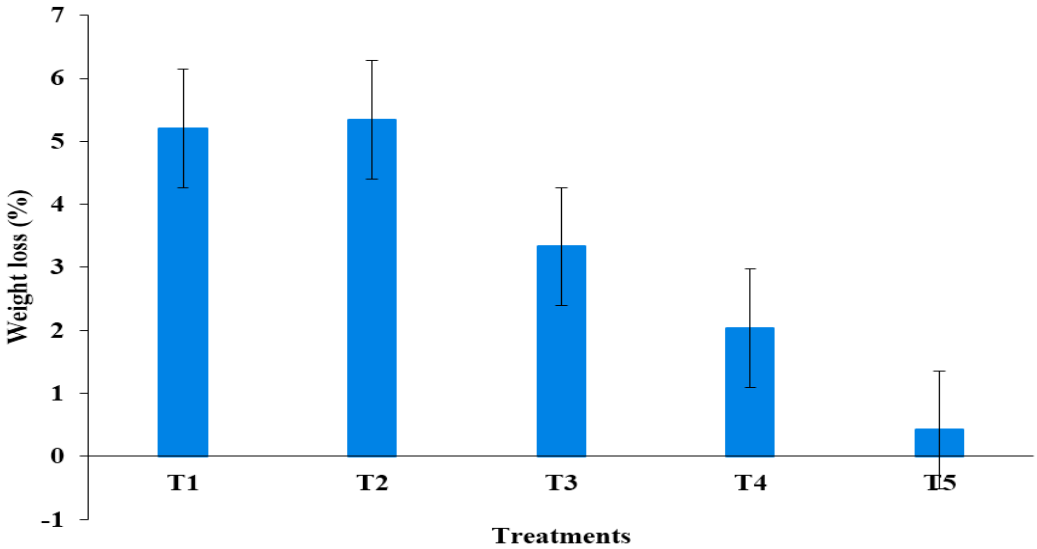

Figure 12. Effect of root size on susceptibility and weight loss in sweet potato from *C. puncticollis.*
Note: T_1 = 48.17g sweet potato, T_2 = 78.78g sweet potato, T_3 = 117.72g sweet potato, T_4 = 190.32g sweet potato, T_5 = 634.27 potato.

3.2. Field Experiment: The effects of Combining T. Diversifolia Leaves, OPBRA and P. Guineense on Sweet Potato Infestation and Yield

The infestation sweet potato showed a significant effects ($P < 0.05$) with the application of T. diversifolia leaves, OPBRA and P. guineense Figure 13. The sweet potatoes treated with T. diversifolia alone (T2) (25.59 ± 0.88%), OPBRA only (T3) (22.66 ± 0.67%), and the combination of T. diversifolia and OPBRA (T4) (28.6 ± 1.89%) did not show any significant difference ($P > 0.05$) with the control (24.76 ± 2.85%). But the sweet potatoes that where treated with the combination of P. guineense, T. Diversifolia and OPBRA (T5) (12.38 ± 1.38) and T6 (8.10 ± 1.83) showed significantly less infestation than the other treatments Figure 13.

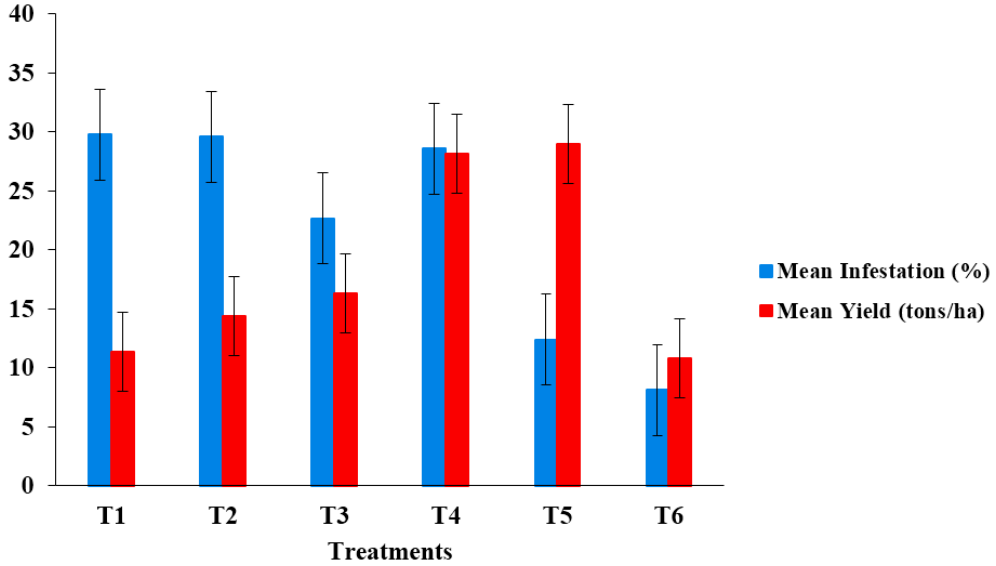

Figure 13. The effects of *T. diversifolia* leaves and OPBRA on sweet potato yield and storage.
Note : T_1 = Control (No application), T_2 = 4 ton/ha *T. diversifolia*, T_3 = 4 ton/ha OPBRA, T_4 = 2 ton/ha *T. diversifolia* + 2 ton/ha OPBRA, T_5 = 2 ton/ha *T. diversifolia* + 2 ton/ha OPBRA + 0.33 ton/ha *P. guineense* and T_6 = 0.67 ton/ha *P. guineense*.

Sweet potatoes plants treated with 2 tons/ha *T. diversifolia* +2 tons/ha OPBRA + O.33 tons/ha *P. guineense* (T_5) had the highest yield (29.00 ± 1.22 tons/ha) and the lowest yield (11.33 ± 0.92 tons/ha) produced by the control Figure 13. Sweet potato plants treated with T_2 (14.40 ± 0.73 tons/ha), T_3 (16.26 ± 1.61 tons/ha) and T_6 (10.76 ± 1.18 tons/ha) were not significantly different from the control.

4. DISCUSSION

The results obtained from this study suggested that biocidal effects (mortality, oviposition deterrence, feeding deterrence, repellence, and larval emergence/pupae) of aqueous extract *T. diversifolia* combined with aqueous extract of *P guineense* was effective against *C. puncticollis* than aqueous extracts of *T. diversifolia* alone. This result was not in line with the results of Anjarwalla, et al. [47]; Kerebba, et al. [48] who reported that *T. diversifolia* is very effective on whiteflies, aphids, and weevils when leaves or seeds are used as insecticide. The no effectiveness of *T. diversifolia* alone might be as a results of the dosage and the period of exposure. This is with conformity with Ileke [49] who reported that *T. diversifolia* powder depends on high dosages and exposure time to be toxic. The higher the concentration, the higher the mortality rate. The concentration of aqueous extracts of *T. diversifolia* used for the study might be too low for the active compounds in extracts that function as stomach poisons for insects was not active to increase the mortality of *C. puncticollis*. Alkan, et al. [50]; Himawan, et al. [51] report that *T. diversifolia* causes stomach poisons on insects that causes them to die immediately or slowly when they feed on *T. diversifolia* extracts. From the results it was observed that 20 g of *T. diversifolia*/100mL (33.70 ± 2.60) had a slight reduced significant larvae/pupae emergence as compared to the control. This indicates that if the exposure time and dosages might have been increase the result might be better. The genus *Tithonia* contain biologically active

molecules characterized by sesquiterpene lactones tagitinins which showed antifeedant activities on several arthropod pests Stevenson, et al. [22]; Green, et al. [23]; Pavela, et al. [24]. Ambrósio, et al. [52] reported that *Tithonia* sp, exhibited pronounced antifeedant activity on the caterpillar *Chlosyne lacinia* (Lepidoptera) but, when tagitinin decreases in the plant, infestation by caterpillar increases. However, this result indicates that aqueous extract of *T. diversifolia* may be improved by adding *P. guineense* to increase the effectiveness. Paul and Sohkhlet [53] used *rotenone* and *azadirachtin* with the addition of butoxide as a synergist to improve on their killing of insects.

The biocidal effects (mortality, oviposition deterrence, feeding deterrence, repellence, and larval emergence/pupae) of aqueous extract OPBRA was effective against *C. puncticollis* as well as it's combined with aqueous extract of *P guineense*. From the result we can see that aqueous extract OPBRA effectiveness was dependent on dosage and exposure time [34, 35]. All the concentrations of the aqueous extract OPBRA showed significant effects on oviposition, larval emergence, and repelled weevils. Higher aqueous extract concentrations of 15g/100mL OPBRA and 20g/100mL OPBRA had a significant deterrence on feeding. This effective result might be the presence of active compounds in the ash which might be toxic to the *C. puncticollis*. These findings are similar to those of Moyin-Jesu [44]; Paul and Sohkhlet [53] who studied the repellent and anti-feedant effects of wood ash, *Nicotiana tobaccum* and *Zanthoxylum alatum* on *Pieris brassiceae*. Wood ash has insecticidal properties which may result from starvation of weevils due to repulsion. The protectant effect might be as the consequence of the presence of potash which contains potassium [31, 32]. The protectant effect shown by OPBRA in the study also agrees with the study of Wini, et al. [35] who reported that wood ash successfully controlled *Sitophilus zeamais* in stored maize. The positive effect of *P guineense* might be the presence of some secondary metabolites which will suppress the activities of *C. puncticollis*. This was similar with the work of Ukpai, et al. [40]; Ojiako, et al. [43] reported that high content of flavonoid in *P. guineense* seed extract. Ukpai, et al. [40] further suggested that the presence of alkaloids, flavonoids and phenols may be responsible for the bioactivity and consequent mortality of Sitophilus zeamais Motschulsky in maize stored with the botanical.

The use of *T. diversifolia* and oil palm bunch residue pastes on sweet potato weevil is called curing. Curing increases the shelf life of root and tuber crops, and improves on the post-harvest handling of such produce. Proper curing is an indispensable first step in a process that increases the shelf- life and quality of sweet potatoes [46]. According to Fawole [12], efforts to improve current production and allied activities must involve the control of pests and diseases and an improvement in the shelf life of the crop. The positive results from OPBRA paste indicate that the action of paste on the insect could be as result of stomach poisoning or unable to feed on through picking lethal doses of the active compounds while feeding or cause the roots sweet potato to be less palatable to herbivores. The results is with conformity with Wahedi, et al. [33]; Ogbedeh and Ani [34] who reported that wood ash protects garden plants more than neem leaf powder, although all confirmed their efficacy.

There was a trend which shows that the larger the storage root the smaller the percentage weight loss. There was a higher percentage weight loss in smaller sweet potato storage roots than the larger onces. This to an extent can be attributed to the thick skin of the larger sweet potatoes which have a store of latex which oozes and hardens once the cambium of the skin is broken, preventing further damage before the weevil reaches the sweet potato flesh. Another argument can be that storage roots have lower surface area per volume ratios, giving a smaller surface area for weevils to get into the roots for every unit mass of the flesh.

The field experiment was conducted to assess if *T. diversifolia* leaves and OPBRA on sweet potato yield and storage (infestation of *C. puncticollis*). The chopped leaves of *T. diversifolia* showed high infestation of *C. puncticollis* as compared to the negative control. The infestation was low only in the combination of *T. diversifolia*, OPBRA and *P. guineense*. This indicate that the *P. guineense* may contain active compound such as alkaloids, tannins, flavonoids, saponins, terpenoids, and phenols. This results was agreement with the study of Ehisianya, et al. [54] who reported the application of neem seed oil and diazinon combine lowered *C. puncticollis* infestation and damage of sweetpotato

roots in delayed production and thus, provided adequate protection of roots.

The effect of *T. diversifolia* leaves and OPBRA on sweet potato yield did not showed any significant with the control but the combination of *T. diversifolia* leaves and OPBRA produced high yield. This can be explained by the interaction of these nutrients (N P K) supplied by the botanicals. Ojeniyi, et al. [55] conducted an analysis oil palm bunch ash and reported that they contain a considerable percentage of N, P, K, Ca and Mg. They further explained that the nutrient release from oil palm bunch ash contribute in improving nutrients soil fertility Opala [21]. Lele, et al. [56] reported that green biomass of *T. diversifolia* contain a reasonable percentage of N, P, K, Ca and Mg. These chemical properties improves biological properties of soil and contribute the crop productivity Rusaati, et al. [28]. Bilong, et al. [57]; Moe, et al. [58] reported that despite the benefits, organic fertilizers alone are insufficient to compensate for the low level of nutrients in tropical soils. That is why combination of *T. diversifolia* and OPBRA gave the best yield in our study. This results is in conformity with Rusaati, et al. [28] reported that green leaves of *Tithonia* in combination with phosphate rock significantly enhanced the growth and yield of rice. Hafifah, et al. [59] reported that the combined application of *T. diversifolia* green manure and cow manure improved the soil physical and chemical properties as well as increased yield of cauliflower. They later explained that the combination reduces the soil bulk density, increased soil organic carbon, the increased total N soil, increased total porosity, increased the soil P availability and increased K exchangeable.

5. CONCLUSION

The results of this study clearly revealed that the aqueous extract of *T. diversifolia* had little or no biocidal effects (mortality, oviposition deterrence, feeding deterrence, repellence, and larval emergence/pupae) on *C. puncticollis* (sweet potato weevil) while aqueous extract of *T. diversifolia* in combination with aqueous extract of *P. guineense* has a great potency in controlling *C. puncticollis*. The biocidal effects (mortality, oviposition deterrence, feeding deterrence, repellence, and larval emergence/pupae) of aqueous extract of OPBRA was effective against *C. puncticollis* as well as its combination with aqueous extract of *P guineense*. Therefore, the combination of *T. diversifolia*, OPBRA and small proportion of *P. guineense* could serve as an alternative source of synthetic pesticides for managing *C. puncticolis* infestation, source of organic matter improve soil fertility and therefore significantly increasing yield of sweet potato.

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