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Efficacy of selected botanical extracts against *Tuta absoluta* Meyrick (*Lepidoptera: Gelechiidae*) on tomato

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Summary: *Tuta absoluta* Meyrick, also known as the tomato leaf miner, is a destructive pest that feeds on tomato plants, causing significant economic losses to tomato farmers globally. Traditional methods of controlling *Tuta absoluta* involve the use of synthetic pesticides, but these methods have drawbacks such as environmental pollution, development of resistance by the pest, and negative effects on non-target organisms. As a result, there is a growing interest in the use of botanical extracts as alternative and safer pest control options. Three bioassay experiments were conducted to test the insecticidal, antifeedant and repellency effects of botanical extracts on *Tuta absoluta*. The experiments were conducted as completely randomized design (CRD) with three (3) replicates. There were eleven treatments; pyrethrum, neem, warbugia, each at different concentration levels of (8%, 10%, 12%) and controls positive (Indoxacarb 150g/L) and negative (distilled water). In all the bioassay conducted, the effects of all treatments increased over time, except for distilled water control. Synthetic chemical Indoxacarb exhibited significantly stronger insecticidal properties compared to neem, warburgia and pyrethrum extracts. Application of neem at 8%, 10% and 12% and pyrethrum at 12% had higher antifeeding effect on *Tuta absoluta* compared to the other treatments while warburgia at 8% concentration and indoxacarb had the lowest repellency effect compared to the other plant extracts.

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Key words: plant extracts, antifeedant, insecticidal, repellancy

Introduction

Tomato production is a significant agricultural activity in Kenya and plays an essential role in the country's economy (FAO, 2022). The country has ideal agro-climatic conditions that allow for the production of high-quality tomatoes, making it one of the largest producers of the crop in Africa. Tomato farming is widespread across the country, with most production concentrated in the Central, Rift Valley, and Eastern regions (HCD, 2014). Smallholder farmers dominate tomato production in Kenya, with the majority of farmers operating on less than two acres of land (Ochilo et al., 2019). The farmers use traditional farming methods, which are often inefficient and result in low yields. As a result, tomato farmers in Kenya face several challenges that hinder their productivity and profitability.

One of the significant challenges facing tomato farmers in Kenya is pests and diseases. *Tuta absoluta*, a pest that feeds on tomato leaves and fruits, has become a significant threat to tomato production in the country (Kinyanjui et al., 2021). Other pests such as aphids, whiteflies, and thrips, and diseases such as bacterial wilt, powdery mildew, and leaf spot, also affect tomato production in Kenya. These pests and diseases can cause significant crop losses, leading to reduced yields and lower income for farmers. Another challenge facing tomato farmers in Kenya is access to quality inputs such as seeds, fertilizers, and pesticides (Gatahi, 2020). Most smallholder farmers use low-quality seeds and fertilizers, leading to low yields and poor crop quality. The cost of high-quality inputs is often prohibitive, making it challenging for farmers to access them. Additionally, the lack of knowledge on the appropriate use of pesticides results in improper use, leading to environmental pollution and health hazards (Kinuthia, 2019).

Tuta absoluta commonly known as tomato leafminer, is a devastating pest of tomato crops. *Tuta absoluta* larvae significantly damage to the leaves, stems, and fruits causing yield losses of up to 100% (Illakwahhi & Srivastava, 2017). The use of chemical pesticides has been the primary method for controlling *Tuta absoluta*, but the overuse of pesticides has led to the development of resistance in the pest (Roditakis et al., 2019) and environmental concerns. In recent years, botanical extracts have emerged as a potential alternative to chemical pesticides for controlling *Tuta absoluta*. Some of the botanical extracts include neem, pyrethrum, and warbugia.

Botanical extracts, such as neem, pyrethrum, and warbugia, have been used for centuries to control a wide range of agricultural pests including potato aphid (*Macrosiphum euphorbiae* Thomas), thrips (*Thrips tabaci* Lindemanla; *Frankliniella occidentalis* Pergande), greenhouse whitefly (*Trialeurodes vaporariorum* Westwood), cotton bollworm (*Helicoverpa armigera* Hübner), and two-spotted spider mite (*Tetranychus urticae* Koch) (Mineva et al., 2022) and have shown promise as natural control options for *Tuta absoluta*, a devastating pest of tomato plants. These extracts contain compounds that are toxic to insects and can disrupt their hormonal systems, leading to reduced feeding and growth and eventually death (Opender & Suresh, 2009). They also have repellent properties that can prevent adult moths from laying their eggs on tomato plants. Neem, or *Azadirachta indica*, and pyrethrum or *Tanacetum cinerariifolium*, known for their traditional use as natural insecticides, have been widely studied for their effectiveness against various pests, including *Tuta absoluta* (Mafara & Bakura, 2021; Jeran et al., 2021). Warbugia, or *Warbugia ugandensis*, is a tree native to East Africa that produces a group of compounds called warburganal, which have insecticidal properties (Inocente et al., 2019). Warburganal has been shown to be effective against a wide range of insect pests (Inocente et al., 2019). However, warbugia extracts are not as commonly used as neem or pyrethrum extracts in pest control, but they have shown promise as a natural control option for *Tuta absoluta*.

In Kenya, there is less information on the current status of *Tuta absoluta* in fields and its alternative control measures despite many farmers' complaints about the increasing severity of *Tuta absoluta* and decline in efficacy of some pesticides used for its control (Chepchirchir et al., 2021.). Consequently, Pesticide Regulatory agencies and distributors often attribute the low pesticide efficacy to misuse by farmers, while scientists speculate resistance development. Therefore, these botanical extracts are easily available, less expensive and ease to use by smallholder farmers. The objective of this study therefore, was to evaluate the efficacy of neem, phyrethrum and warbugia extracts in controlling the *Tuta absoluta* in Kenya.

Materials and methods

Experimental site

The study entailed two parts; laboratory and greenhouse experiment conducted at the Horticulture Research and Teaching Field, Egerton University, Njoro, Kenya. The field is located on longitude 35º35′E latitude 0º23′S, in the lower highland III (LH3) agro ecological zone at an altitude of 2238 m above sea level. The site receives a mean rainfall of 1012 mm with a maximum and minimum temperature of 22 ºC and 8 ºC, respectively, (Jaetzold et al., 2012).

Collection and Preparation of Plant Extracts

Fresh neem leaves, pyrethrum flowers and the bark of warbugia plant were collected in Egerton University botanical garden and its environs, washed to remove dirt then dried under shade and stored in a well-ventilated room at ambient temperatures (18 ºC - 28 ºC) for 2 weeks (Asawalam et al., 2006). The dried samples were ground into fine powder using pestle and motor, then sieved through a 25µm-mesh diameter sieve to obtain fine and uniform powder. The samples were then packaged in biodegradable plastic bags. Crude extracts of test plants were prepared according to Narayan (2012) with some slight modifications. Extraction of the botanicals was done using warm water (40 ºC - 50 ºC) (Mohammed et al., 2016). Two hundred grams (200g) each of the powdered neem leaves, pyrethrum flowers and warbugia bark were separately soaked in 2 litres warm water at 40 ºC - 50 ºC (Azwanida, 2015) for 24h with frequent agitation and later filtered through Whatman no.1 filter paper. The extracts obtained were weighed and redissolved (1g/10ml) to give 10% weight/volume (w/v). The same was done to the other concentrations (8% and 12%). The extracts were then stored in the refrigerator at 4 °C and used within 2 weeks to prevent degradation of active compounds.

Mass rearing of T. absoluta

Tomato plants were grown in plastic pots filled with peat moss and soil (2:1) and maintained in cages (60x50x60 cm), covered with transparent insect netting leaving a small sleeve opening measuring 15 cm to allow access. This was set in the laboratory. A local strain of *T. absoluta* was introduced to the plants 3-4 weeks after transplanting using infested leaves. Individual *T. absoluta* larvae were collected from infested tomato leaves and transferred to the tomato plants in the cage using a fine hair brush.

Laboratory experiments

This part of the study addressed the first two (2) objectives of the study; it was to evaluate (i) insecticidal and (ii) anti-feedant and repellant effects of pyrethrum, neem and warbugia, crude extracts at different concentration on *T. absoluta* in tomato.

Insecticidal toxicity bioassay on Tuta absoluta

Insecticidal toxicity of neem, pyrethrum and warbugia extracts were tested in glass petri dishes using the leaf dipping method with modifications from insecticide resistance action committee (IRAC) 2013. The experiment was arranged in a completely randomized design (CRD) with three (3) replications as shown in ***Table 1.*** There were eleven treatments; pyrethrum, neem, warbugia, each at different concentration levels of (8%, 10%, 12%) and controls positive (Indoxacarb 150g/L) and negative (distilled water). Third and fourth leaves of tomato plant was collected and placed in a moist paper towel to avoid wilting. Two leaves were dipped for 15 seconds in specific treatment according to the procedure described by Erdogan et al. (2012). The leaves were left to dry at room temperature for one hour and later transferred to petri dishes. Each experimental unit consisted a glass petri dish (9.5 cm x 2.0 cm) containing moistened filter paper and two treated leaves. The second (2^{nd}) or third (3^{rd}) instar larvae stages were used for toxicity bioassays (Wang et al., 2009). By using a fine brush, 6 larvae were placed on each treated leaf in a petri dish. Monitoring for dead larvae started after 24 hrs of exposure. Larvae was considered dead if they didn't move when prodded with a fine paint brush and if they moved or moribund, they were alive. The observed mortality was computed after 72hrs.

$$\text{Observed mortality} = \frac{\text{Number of dead larvae per treatment}}{\text{Total number of larvae per treatment}} \text{x100}$$

The observed mortality was subjected to correction using Abbott's formula (1925):

$$\text{C.M.}(\%) = \frac{\text{O.Mortality in treatment}(\%) - \text{O.Mortality in control}(\%)}{100 - \%\text{Control mortality}} \text{x100}$$

Where;
CM (%) – Corrected mortality percentage
O – Observed mortality

Antifeedant bioassay of T. absoluta

A specific bioassay method for evaluating the antifeedant activity of extracts from the plants was used against *T. absoluta* larvae and feeding mark responses were analyzed after a period of 96h. In this method, bioassay was done using tomato leaves detached from the 4th plant node from the stem apex. Leaves were dipped in each treatment for 10 seconds and then air dried. There were eleven treatments similar to those described for insect toxicity bioassay experiment. After air drying, two (2) treated leaves were placed in each glass petri dish (9.5 cm x 2.0 cm) containing wet filter paper. Six (6) Larvae at 2nd instar were released into each petri dish to feed on the leaves. The experiment was conducted in a completely randomized design with 3 replications (***Figure 6***). Observations on feeding was taken after 24h. All feeding marks were analyzed using leaf area meter (Delta-T Devices, Serial No. 15736 F 96, UK). The leaf area consumed was corrected from the control.

The percentage of antifeedant index (AFI) was calculated using the formula of Ben-Jannet et al. (2000).

$$AFI\% = [(C-T) / (C+T)] \times 100$$

Where;

C= is the leaf area consumed in control

T = is the leaf area consumed in treated conditions

Table 1: Treatments description.

Treatment	Description
T_1	Warbugia 8%
T_2	Warbugia 10%
T_3	Warbugia 12%
T_4	Neem 8%
T_5	Neem 10%
T_6	Neem 12%
T_7	Pyrethrum 8%
T_8	Pyrethrum 10%
T_9	Pyrethrum 12%
T_{10}	Indoxacarb 150g/L
T_{11}	Distilled Water

Repellency bioassay of T. absoluta pest

A repellence test was performed according to El-sharabasy (2010) with modifications. Tomato leaf detached from the 4th plant node from the stem apex was dipped in each treatment for 10 seconds. The treated leaves were left to dry at room temperature for 30 seconds and then put in petri dishes (9.5 cm x 2.0 cm) containing wet filter paper. Two leaves in a petri dish used for each treatment. Six (6) larvae at 2nd instar were introduced in each petri dish containing the treated leaves and were left to move freely for 24h. The experiment was conducted in a completely randomized design (CRD) with 3 replications (***Table 2***).

Table 2. Experimental layout for the lab experiment.

T_2R_1	T_9R_2	T_1R_3	T_5R_2	T_3R_1	T_8R_2	$T_{10}R_3$	T_1R_2	T_6R_3	$T_{11}R_1$	T_7R_1
T_3R_3	T_6R_1	T_8R_3	T_2R_3	T_7R_2	T_5R_3	$T_{10}R_2$	T_3R_2	$T_{11}R_2$	T_4R_1	T_9R_1
T_8R_1	T_2R_2	T_6R_2	$T_{10}R_1$	T_4R_2	$T_{11}R_3$	T_1R_1	T_9R_3	T_4R_3	T_7R_3	T_5R_1

Key:

T_1= 8% W, T_2= 10% W, T_3= 12% W, T_4= 8% N,
T_5= 10% N, T_6= 12% N, T_7= 8% P,
T_8= 10% P, T_9= 12% P, T_{10}= I,
T_{11}= Distilled water, R= Replications

Repellency index (RI) was calculated according to Pascual-Villalobos and Robledo, (1999) as;

$$RI = [(C-T) / (C+T)] \times 100$$

Where;

C=is the number of larvae on control diet

T=is the number of larvae on treated diet

RI varying from -100 (Total attractancy) to +100 (Total repellence) with zero mean has no effect.

Data analysis

Data collected was subjected to analysis of variance (ANOVA) and significant means separated using Tukey's Honestly Significant Difference (Tukey's HST) test at $P \leq 0.05$. Data analysis was done using SAS (version 9.0).

The statistical model for this experiment is $Y_{ij} = \mu + t_i + \varepsilon ij$.

i=1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 (treatments);

j=1, 2, 3 (replication)

Where;

Y_{ij} – larvae mortality

μ – Overall mean

t_i- The effect of the ith treatment

ε_{ij}– Random error component

Results

Insecticidal toxicity bioassay on Tuta absoluta

At 24 hours post application of treatments, the number of dead larva was significantly ($P \leq 0.05$) greater in the indoxacarb treatment than distilled water treatment and the botanical extracts at all the concentration levels in both trials (***Table 3***). In trial one, no significant difference was recorded between the control (water) treatment and treatment with botanical extracts at all concentration levels tested. More dead larvae were recorded at 48hrs of post treatment application where indoxacarb treatment registered the highest numbers of dead larvae as compared to the other treatments. No dead larva was recorded in the control treatment as well as treatments with neem extracts at the time of data collection while warbugia and pyrethrum registered few dead larvae at 10% and 12% concentrations each. This was not the case in trial two where indoxacarb treatment registered significantly higher no of dead larvae than the other treatments that do not differ significantly. The numbers of dead larvae increased in most of the treatments in both trials at 72 hour post application of the treatments. However indoxacarb still registered the highest number of dead larvae but was not significantly different to treatments with warbugia at 12% in trial one and pyrethrum at 12% and neem at 10% and 8% concentrations in trial two. The control treatment (distilled water) registered no dead larvae at all sampling dates in both trials.

Corrected mortality percentage

Tuta absoluta mortality was influenced ($P \leq 0.05$) by different insecticides used in the experiment (***Table 4***). Indoxacarb treatment recorded the highest mortality of 100% at the end of 72 hours period of the pest exposure in both trials while the distilled water treatment recorded no pest mortality in both trials. Although, the botanical extracts showed some level of mortality that also varied in each trials, the treatments showed no consistency in their mode of action however there was no significant difference in most of the treatments.

Table 3: Dead larvae (insecticidal).

Treatment	Hours after treatment application		
	24	48	72
TRIAL 1			
Indoxacarb 150g/L	3.33a*	5.67a	6.00a
Pyrethrum 8%	0.00b	0.00c	0.33bc
Pyrethrum 12%	0.67b	0.67bc	1.33bc
Warbugia 8%	0.33b	0.00c	0.00c
Neem 10%	0.00b	0.00c	0.67bc
Distilled water	0.00b	0.00c	0.00c
Warbugia 10%	0.00b	1.00b	0.33bc
Warbugia 12%	0.33b	0.33bc	2.67ab
Neem 12%	0.00b	0.00c	0.00c
Neem 8%	0.00b	0.00c	0.00c
Pyrethrum 10%	0.00b	0.67bc	0.67bc
TRIAL 2			
Indoxacarb 150g/L	5.00a	6.00a	6.00a
Pyrethrum 8%	0.00b	1.00b	1.00bc
Pyrethrum 12%	0.00b	0.67b	2.00ab
Warbugia 8%	0.00b	0.00b	0.00c
Neem 10%	0.67b	1.33b	1.67abc
Distilled water	0.00b	0.00b	0.00c
Warbugia 10%	0.00b	0.00b	0.00c
Warbugia 12%	0.00b	0.00b	0.33bc
Neem 12%	0.67b	0.67b	0.67bc
Neem 8%	0.00b	0.33b	1.33abc
Pyrethrum 10%	0.00b	0.33b	0.67bc

*Means followed by the same letters within a trial column are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$. Data were subjected to square root transformation before analysis but values presented are original means.

Table 4: Corrected mortality percentage.

Treatment	C.M. (%)
TRIAL 1	
Indoxacarb 150g/L	100.00a
Pyrethrum 8%	5.56bc
Pyrethrum 12%	22.22bc
Warbugia 8%	0.00c
Neem 10%	11.11bc
Distilled water	0.00c
Warbugia 10%	22.22bc
Warbugia 12%	44.44b
Neem 12%	0.00c
Neem 8%	0.00c
Pyrethrum 10%	11.11bc
TRIAL 2	
Indoxacarb 150g/L	100.00a
Pyrethrum 8%	16.67bc
Pyrethrum 12%	33.33b
Warbugia 8%	0.00c
Neem 10%	27.78bc
Distilled water	0.00c
Warbugia 10%	0.00c
Warbugia 12%	5.56bc
Neem 12%	11.11bc
Neem 8%	0.00c
Pyrethrum 10%	11.11bc

*Means followed by the same letters within a trial are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$. Data were subjected to square root transformation before analysis but values presented are original means.

Antifeedant bioassay of T. absoluta

Generally, the level of feeding increased with increase in time for all the treatments however, the rate of feeding varied for each treatment at the end of the experiment. More feeding was observed on distilled water treatment compared to the other treatments in both trials while least feeding was observed on pyrethrum treatment at 12% concentration in the first trial and indoxacarb treatment in the second trial (***Table 5***). Although distilled water treatment recorded the highest feeding in both trials, there was no significant difference between all the treatments in the first trial. In the second trial, warbugia treatments showed no significant difference to the control treatment (distilled water) in most of the sampling dates, pyrethrum at 8% and 10% concentrations had no significant difference compared to the distilled water treatment while neem treatments at all the concentration level significantly differed from the control (distilled water) in all of the sampling dates except for 24 hours of treatment application.

Table 5: Antifeedant bioassay.

Treatment	Hours after treatment application		
	24	48	72
TRIAL 1			
Indoxacarb 150g/L	4.33*	4.33	4.33
Pyrethrum 8%	9.00	12.67	14.00
Pyrethrum 12%	1.67	4.00	4.00
Warbugia 8%	9.33	11.67	12.33
Neem 10%	8.00	11.67	12.33
Distilled water	10.67	16.67	22.00
Warbugia 10%	7.33	11.67	11.67
Warbugia 12%	8.33	14.00	16.00
Neem 12%	7.33	8.33	8.67
Neem 8%	9.00	12.33	13.00
Pyrethrum 10%	4.67	5.33	5.67
TRIAL 2			
Indoxacarb 150g/L	3.00b	3.67d	3.67d
Pyrethrum 8%	7.33ab	11.67ab	16.33ab
Pyrethrum 12%	2.67b	5.67bcd	7.33bcd
Warbugia 8%	5.33ab	10.33abc	12.67abc
Neem 10%	5.33ab	7.00bcd	8.67bcd
Distilled water	11.67a	16.67a	21.00a
Warbugia 10%	4.33ab	6.67bcd	11.33abc
Warbugia 12%	5.00ab	7.33bcd	11.67abc
Neem 12%	2.33b	4.33cd	6.33cd
Neem 8%	3.67b	5.33bcd	6.67cd
Pyrethrum 10%	5.00ab	9.33abcd	12.33abc

*Means followed by the same or no letters within a trial column are not significantly different according to Tukey's Honestly Significant Difference Test at $P \leq 0.05$. Data were subjected to arcsine transformation before analysis but values presented are original means.

Repellency bioassay of T. absoluta pest

Different treatments influenced the level of pest repellency in this bioassay (***Table 6***). Although, the lowest number of repelled pests were obtained on the control treatments (distilled water and indoxacarb). There was no significant difference in the numbers of repelled *Tuta absoluta* during the entire experiment except for trial two where the differences in the level of repellency varied with treatments after 72 hours of treatment application. At that time of data collection, pyrethrum treatment at 12% concentration recorded the highest repellency. However, there was no significant difference with other treatments except for indoxacarb and warbugia at 8%.

***Table 6*:** Repellency bioassay.

Treatment	**Hours after treatment application**		
	24	**48**	**72**
	TRIAL 1		
Indoxacarb 150g/L	0.67*	0.67	0.67
Pyrethrum 8%	2.67	2.33	2.33
Pyrethrum 12%	2.67	3.33	3.67
Warbugia 8%	1.33	1.67	1.67
Neem 10%	1.33	1.33	1.33
Distilled water	0.67	0.67	0.67
Warbugia 10%	2.00	2.00	1.67
Warbugia 12%	1.00	1.67	2.00
Neem 12%	1.67	2.00	2.00
Neem 8%	1.67	2.33	2.00
Pyrethrum 10%	3.33	2.33	2.67
	TRIAL 2		
Indoxacarb 150g/L	1.00	2.00	0.00c
Pyrethrum 8%	1.00	1.33	1.00ab
Pyrethrum 12%	2.00	2.00	2.00a
Warbugia 8%	1.00	1.00	0.33bc
Neem 10%	1.33	1.67	1.33ab
Distilled water	0.67	1.00	1.00ab
Warbugia 10%	1.67	2.00	1.67a
Warbugia 12%	2.00	1.67	1.33ab
Neem 12%	2.33	2.00	1.67a
Neem 8%	2.33	1.67	1.33ab
Pyrethrum 10%	1.67	1.33	1.67a

*Means followed by the same or no letters within a trial column are not significantly different according to Tukey's Honestly Significant Difference Test at P≤0.05. Data were subjected to square root transformation before analysis but values presented are original means.

Discussion

The use of synthetic chemical Indoxacarb has demonstrated to be more beneficial as it has more insecticidal properties on *Tuta absoluta* compared to neem, warburgia and pyrethrum extracts. These insecticides differ in chemical composition, mode of action, and persistence, which makes them suitable for various situations in controlling pest. Indoxacarb is a synthetic insecticide that belongs to the oxadiazine chemical class. It works by targeting the sodium channels in the nervous system of insects (McCann et al., 2001). They bind to the sodium channels and prevent them from functioning correctly, leading to paralysis and death of the insect (Wing et al., 2010). This mode of action is unique compared to other insecticides, making oxadiazines effective against resistant insect pests. Reports from various authors present the effectiveness of Indoxacarb in controlling *Tuta absoluta*. Derbalah et al. (2012) and Shahini et al. (2021) reported that Indoxacarb had higher efficacy than Bt, at reducing the infestation in tomato leaves and fruits. Although Indoxacarb has good efficacy, it is an insecticide; therefore, its application is recommended for high population densities. Moreover, like all insecticides, the prolonged and frequent use of oxadiazine pesticides can lead to the development of resistance in target pests. Therefore, resistance of these chemicals to control *T. absoluta* has opened a new window for development of other methods including biopesticides, pheromone traps, and parasitoids (Cherif et al., 2013; Zappala et al., 2013).

The efficacy of botanical extracts can be affected by several factors, including time (Gonzalez et al., 2006). The potency and effectiveness of botanical extracts can decline over time due to various factors such as exposure to air, light, heat, and moisture, as well as the breakdown of active compounds (De Freitas Araújo & Bauab, 2012). Apart from indoxacarb, Neem and Pyrethrum extracts caused significantly low feeding compared to the distilled water treatment. After 24 hours of application, both neem and pyrethrum extracts reduced the population of *Tuta absoluta* to some extent. However, neem extract could have taken longer to show its full effect due to its mode of action. Neem contains disulphide which contributes to its bioactivity and a dozen azadirachtin analogs which are the major ingredient to its insecticidal activity while the remaining triterpenoids including nimbin, salannin, and their derivatives have little efficacy (Isman, 2006). Therefore, Azadirachtin interferes with the growth and moulting process of insects and ingestion leading to abnormal moults, growth reduction and increased mortalities (Flavia et al., 2004). This means that it may take some time for the full effect to be observed. Pyrethrum, on the other hand, works rapidly and can provide a quick knockdown effect as demonstrated from the current experiment However, the residual effects of pyrethrum were shorter in duration compared to neem, meaning that its effectiveness may diminish after a few hours.

After 48 hours of application, the differences between neem and pyrethrum became more pronounced although with no significant difference. According to Ukoroije & Otayor (2020), neem extract may continue to reduce the population of *Tuta absoluta* as its antifeedant and growth inhibitory effects persist longer. Pyrethrum, on the other hand, may have a reduced effect after 48 hours due to its shorter residual activity. However, if a higher concentration of pyrethrum is used, its effect may still be noticeable for a longer duration. After 72 hours of application, the residual effect of neem extract started to decline, leading to a reduction in its effectiveness. However, if the application is repeated regularly, neem extract would continue to provide long-term control of *Tuta absoluta*. As observed from the experiment, pyrethrum may have a shorter residual effect, meaning that its effectiveness may have diminished significantly after 72 hours.

From the study, high concentration of warburgia showed a higher repellency, antifeeding and insecticidal effect on *Tuta absoluta* compared to most of the treatments although the effect was not consistent in both trials. This might probably mean that a higher concentration of warburgia would have increased its effect in controlling *Tuta absoluta*. This is evident from the current experiment where lower concentrations of warburgia 8% and 10% showed no significant difference compared to the distilled water treatment while 12% concentration of warburgia significantly differed from the distilled water treatment.

Conclusions

Synthetic chemical Indoxacarb which has 100% mortality is more beneficial as it has more insecticidal properties on *Tuta absoluta* compared to neem, warburgia and pyrethrum extracts. The application of neem at 8%, 10% and 12% and pyrethrum at 12% had the highest antifeeding effect on *Tuta absoluta* compared to the other treatments. Distilled water treatment had the highest feeding in both trials. Warburgia at 8% concentration and indoxacarb treatment had the lowest repellency effect compared to the other plant extracts in 72 hours of trials. At that time, pyrethrum treatment at 12% concentration recorded the highest repellency. In all the bioassay, the effect of all the treatments increased with time except for distilled water treatment.

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