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Research article

Insecticidal Efficacy of *Syzygium aromaticum*, *Tephrosia vogelii* and *Croton dichogamus* Extracts against *Plutella xylostella* and *Trichoplusia ni* on *Brassica oleracea* crop in Northern Tanzania

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Abstract: The insecticidal efficacy of 10%, 5% and 1% w/v of *Tephrosia vogelii*, *Croton dichogamus* and *Syzygium aromaticum* aqueous plant extracts were assessed against larvae of *Plutella xylostella* and *Trichoplusia ni* on *Brassica oleracea* var. capitata crop field. Synthetic organophosphate pesticide (Chlorpyrifos) was used as a positive control and the negative controls were water and water plus soap. It was revealed that, aqueous plant extracts significantly ($P \leq 0.05$) controlled the number of *P. xylostella* and *T. ni* larvae compared to negative controls. The 10% concentration of aqueous plant extracts showed significant higher efficacy in terms of reducing the insect population and their damage than 1% and 5 % concentration. The population of *P. xylostella* larvae per *B. oleracea* in five weeks of treatment applications at 10% w/v of *T. vogelii*, *C. dichogamus* and *S. aromaticum* aqueous plant extracts were 0.08, 0.15, 0.13, 0.05 and 0.08; 0.08, 0.20, 0.15, 0.13 and 0.18; 0.03, 0.05, 0.15, 0.18 and 0.13, respectively which was significantly ($P \leq 0.05$) lower than in water (1.13, 1.68, 2.28, 2.20 and 3.28) and water plus soap (0.75, 1.60, 2.58, 1.83 and 3.30) negative controls respectively. The number of *T. ni* larvae per *B. oleracea* in five weeks of treatment applications at 10% w/v of *T. vogelii*, *C. dichogamus* and *S. aromaticum* of aqueous plant extracts were 0.00, 0.03, 0.05, 0.03 and 0.00; 0.03, 0.08, 0.05, 0.08 and 0.08; 0.05, 0.03, 0.00, 0.05 and 0.03, respectively which was significantly ($P \leq 0.05$) lower than in water (0.50, 0.63, 0.60, 0.48 and 0.78) and water plus soap (0.30, 0.48, 68, 0.65 and 0.80) negative controls. The percentage damage of *B. oleracea* in five weeks of treatment applications at 10% w/v of *T. vogelii*, *C. dichogamus* and *S. aromaticum* aqueous plant extracts were 10.0, 6.3, 7.5, 7.5 and 5.6; 11.3, 11.3,

11.3, 11.3 and 12.5; 8.8, 8.1, 6.9, 8.1 and 9.4, respectively compared with water (33.8, 33.1, 38.8, 45.0 and 70.6) and water plus soap (30.0, 31.9, 41.3, 41.3 and 56.3). These pesticidal plants can be recommended for smallholder farmers to significantly control *P. xylostella* and *T. ni* larvae in *B. oleracea* crop.

Keywords: cabbage insect pests; phytochemicals; rotenone; terpenoids and alkaloids

1. Introduction

Cabbage, *Brassica oleracea* var. capitata, is vital vegetable crop grown as an annual plant worldwide [1]. Cabbage is a leafy vegetable of *Brassica* family and is round, oblate and pointed shapes [2]. Cabbage is intensively grown by poor smallholder farmers of African countries for subsistence and a source of income [3]. The cabbage plant grows well on a well-drained soil, ranging from lighter sand and heavier clay preferring fertile soils and has soft, light green and whitish inner leaves covered with harder and dark green outer leaves [1]. Cabbage is the source of vitamins K and C, the dietary fibers and nutritional elements mainly potassium and Manganese [4].

Despite the nutritional and economical importance, the gardening of *B. oleracea* by smallholder farmers in Africa is constrained by several insect pest infestations. The high nutritional content contained in *B. oleracea* makes it attractive to various phytophagous insect pests which feed and cause severe damages and economic losses to it [5]. Specifically, Diamondback moth (*Plutella xylostella* L. Lepidoptera: Plutellidae) and the cabbage looper (*Trichoplusia ni* (Hübner) Lepidoptera: Noctuidae) infest severely the *B. oleracea* on the field and reduces the quality and marketability of the crop [1,6].

Diamondback moth (*P. xylostella*) is the most severely destructive insect pests of *B. oleracea* in many parts of Africa and are particularly damaging in the tropics and subtropics [7,8]. *P. xylostella* larvae feed on the leaves between the large veins and midribs of cruciferous crops and the plants which produce glucosinolates [2]. The *P. xylostella* larvae prefer to feed on the lower surface of the leaf which as a result leave a "window-paning" effect [9]. The severe feeding result into stunts and destroys the heads of *B. oleracea* and can cause abortion of the heads resulting into huge yield loss [10]. The *T. ni* larvae create irregular holes of different shapes when feeding on the leaves [11]. The created holes inhibit the growth and marketability of *B. oleracea*. *T. ni* is difficult to control and manage due to its broad distribution and resistance to many insecticides [11,12].

The management of *P. xylostella* and *T. ni* is inefficient in most African smallholder farmers [3]. Most of African *B. oleracea* gardeners in which the use of modern technology is limited prefer cultural practices such as site selection, crop rotation and seed selection, sowing date, row spacing, plant density and weed control to reduce insect infestation in *B. oleracea* [6,13]. For example, *T. ni* can be controlled by crop rotation when lettuce is introduced into the garden after *B. oleracea* [2]. Also, using clean planting materials and transplanting only healthy and vigorous insect-free seedlings, reduce the infestation of *B. oleracea* insect pests in the field [2]. However, those cultural practices are less effective to protect *B. oleracea* from *P. xylostella* and *T. ni* infestations although, they are cheap and safe to the environment. Natural enemies of insects like predators, parasitoids and pathogens support to reduce *B. oleracea* insect pest infestations [8]. But the natural enemies are also insufficiently effective to control *P. xylostella* and *T. ni* in the fields [2]. Therefore, the smallholder

famers in African countries prefer intensively on the application of broad-spectrum synthetic pesticides to control the *B. oleracea* insect pest in the field [14]. The unselective and arduous use of broad-spectrum insecticides affect the ecosystems of useful natural enemies like bees, butterflies [1] and lady bird beetles [15,16]. Moreover, the massive application of synthetic pesticides contributes to a serious environmental pollution especially water and soil pollution [17]. The surface and ground water pollution due to synthetic pesticides, results into destruction of aquatic ecosystems [18].

However, botanical pesticides like *T. vogelii* and *Azadirachta indica, Annona squamosa, Cupscum frutensces, Allium sativa* are the encouraging alternatives and have been used to control insect pests in cereal crops successfully [16,19]. Botanical pesticides have been used broadly in the protection of crops like beans, cowpeas and maize from insect pest infestations in the field and during storage [13]. Botanical pesticides contain groups of active compounds of diverse chemical nature and have an average residual life of 2-5 days [3]. Botanical pesticides are affordable [20], easy to prepare and use [19], environmentally friendly [21], degraded rapidly in sunlight, air, and moisture and are readily broken down by detoxification enzymes and have reduced risks of toxicity to human and to non-target organisms [19,22].

In the present study, the efficacy of phytochemicals from *T. vogelii, C. dichogamus* and *S. aromaticum* were assessed to control *P. xylostella* and *T. ni* in *B. oleracea* crop on the field. Normally, *T. vogelii* is known as the "fish bean", "fish-poison bean", or "vogel's tephrosia" [23]. Smallholder farmers in many countries in Africa use *T. vogelii* as an organic pesticide to control pests on livestock, in cultivated fields and as medicine for skin diseases [24]. Apart from that, *S. aromaticum* contains a chemical known as eugenol [25]. This chemical compound in *S. aromaticum* is used as an insect repellent. This property of insect repellent has been reported to be potential in agriculture to protect foods from micro-organisms during storage [26]. Moreover, *S. aromaticum* has a variety of pharmacological activities including antimicrobial, anti-inflammatory, analgesic, anti-oxidant and anticancer activities [27]. Also, globally, *Croton species* are usually used as folk medicines for the treatment of various health problems such as cancer, constipation and diabetes [28]. The phytochemical investigations of the *Croton species* revealed the presence of various secondary metabolites including alkaloids, phenolics and terpenoids in all plant's parts [29]. However, there is limited information on the applications of *S. aromaticum, T. vogelii, C. dichogamus* aqueous extracts to control *P. xylostella* and *T. ni* of *B. oleracea* crop in the field. Therefore, this study focused on assessment of insecticidal efficacy of phytochemicals extracted from *T. vogelii, C. dichogamus* and *S. aromaticum* to control *P. xylostella* and *T. ni* of *B. oleracea* in northern part of Tanzania.

2. Materials and methods

2.1. Study location

The study was conducted in Northern part of Tanzania. The sites of the study were located in Arusha region and in Kilimanjaro region in Tanzania. In Kilimanjaro region, the experiment was set in Boro site located at Latitude 3°17′31.5″S and Longitude 37°17′49.1″E and an elevation of 1078 m above sea level. In Arusha region, the experiment was set in Tengeru site located at latitude 3°23′4.5″S and longitude 36°48′26.7″E at an elevation of 1262 m above sea level. The meteorological data of rainfall and temperature was also observed from the experimental locations.

2.2. Land and plant materials preparation

2.2.1. Plant materials collection, drying and grinding

The fresh plant materials were collected from different locations in Manyara, Arusha, Tanga and Kilimanjaro regions in Tanzania. Leaves of *C. dichogamus* and *T. vogelii* was collected from Manyara, Arusha and Kilimajaro regions of Tanzania. Flower buds was collected from *S. aromaticum* plant in Tanga Region. The leaves of plants were separately washed thoroughly with water and air dried under shade and at room temperature for seven days. The dried leaves of *C. dichogamus* and *T. vogelii,* and flower buds of *S. aromaticum* was pulverized into fine particles (powder) using electric blender. The fine powder was extracted separately using water and soap to get the aqueous plant extracts for field experiments. Soap was used during extraction experimental procedure because firstly, it helps to extract compounds which are not water soluble from plant materials and secondly, it helps to spread the extract onto the plant leaves more effectively during applications.

2.2.2. Land preparation and transplanting

The land was cleared and prepared prior to transplanting of seedlings. Ploughing and harrowing was performed on the land before transplanting of the seedlings at both sites using a plough. The Cabbage (*B. oleracea*) seeds were sown near the experimental plots on March 2019, then after 5 weeks, were transferred and transplanted into the experimental plots from the mid of April to August 2019 at both study sites. The cabbage was planted at spacing of 50 cm between the rows and 50 cm in the rows in the plots that is measured 2.0 m × 2.5 m at both experimental sites. Watering was done twice a day in the morning and in the evening.

2.3. Experimental design and treatments preparations

The experiment was designed in a Randomized Complete Block Design (RCBD) with 12 treatments replicated four times. The treatments consisted aqueous plant extracts of three pesticidal plants (*T. vogelii, C. dichogamus* and *S. aromaticum*), two negative control (water only and water plus soap) and one positive insecticide control (chlorpyrifos) was also included in the treatments. From each individual plant, three concentrations 1%, 5% and 10% w/v of aqueous plant extracts were prepared to spray on the *B. oleracea* crop field. The concentrations of aqueous plant extracts were prepared in water containing 0.1% soap from dry powder of *T. vogelii, C. dichogamus* and *S. aromaticum.* Thus, 1%, 5% and 10% of aqueous plant extracts was prepared by dissolving 10 g, 50 g and 100 g of powder into one litre of water respectively. The extraction experiment was left to stand for 24 hours at room temperature [15]. There were 12 treatments in each experimental site with 4 plot replicates making a total of 48 plots.

2.4. Treatments applications

The treatments were sprayed into the *B. oleracea* crops in the field at the interval of 7 days [16,19] throughout the growing of the *B. oleracea* crop. The concentration of synthetic insecticide (Chlorpyrifos)

was applied as per manufacturers' recommendations. The treatments were sprayed, on top and under the leaves of *B. oleracea* crop by using a 2 L sprayer in the evening during the growing of the crop. The spraying was done during the evening hours in order to avoid direct sun light which may cause the decomposition of bioactive compounds of the botanicals. Each plot required approximately 250 mL of the aqueous plant extracts at both sites [30]. The sprayer was thoroughly cleaned with water and soap before re-filling it again with another formulation for application.

2.5. Insect and Brassica oleracea crops' damage assessment

Insect pests and damage evaluation was done one day before spraying of treatments by randomly selecting 5 inner *B. oleracea* crops inside the plots each week. The larval population of diamondback moth larvae (*P. xylostella*) and cabbage looper (*T. ni*) larvae were counted. Damage of the crops was done by counting the number of damaged leaves and head on weekly basis. Then, the damaged parts (leaves and heads) were differentiated into four scale; 0% damage, up to 25% damage, up to 50% damage, up to 75% damage and up to 100% depending onto the number of damaged leaves and heads [15].

2.6. Data analysis

The collected data were analyzed using Statistica 8.0 software package version 7 program. Two-way ANOVA statistical analyses were performed to split plots locations and the treatments. The Fisher's Least Significance Difference (LSD) was used to compare the treatment means at P = 0.05 level of significance.

3. Results

3.1. Temperatures and rain precipitations of the study sites

Figure 1A and 1B shows the temperatures and precipitations of the two experimental study sites. It was observed that, the temperatures of Boro study site were lower than that of Tengeru study site (Figure 1A) during the experimental period (2019 season) (Figure 1B). Therefore, Boro study site was cooler than Tengeru study site. Figure 1B showed the rainfall precipitations of the two study sites. It was observed that, the rainfall precipitations of Boro study site were higher than that of Tengeru study site and the high difference in rain precipitations was observed during April-June at the two experimental study sites. Those weather conditions have affected either by lowering or by increasing the population abundance of *P. xylostella* and *T. ni*. The mean maximum and minimum temperatures of Boro experimental site were 25.16 and 16.11 ℃, respectively while the mean maximum and minimum temperatures of Tengeru experimental site were 29.54 and 16.91 ℃. The mean maximum rainfall precipitations of Boro and Tengeru experimental sites were 148.05 and 70.81 mm respectively.

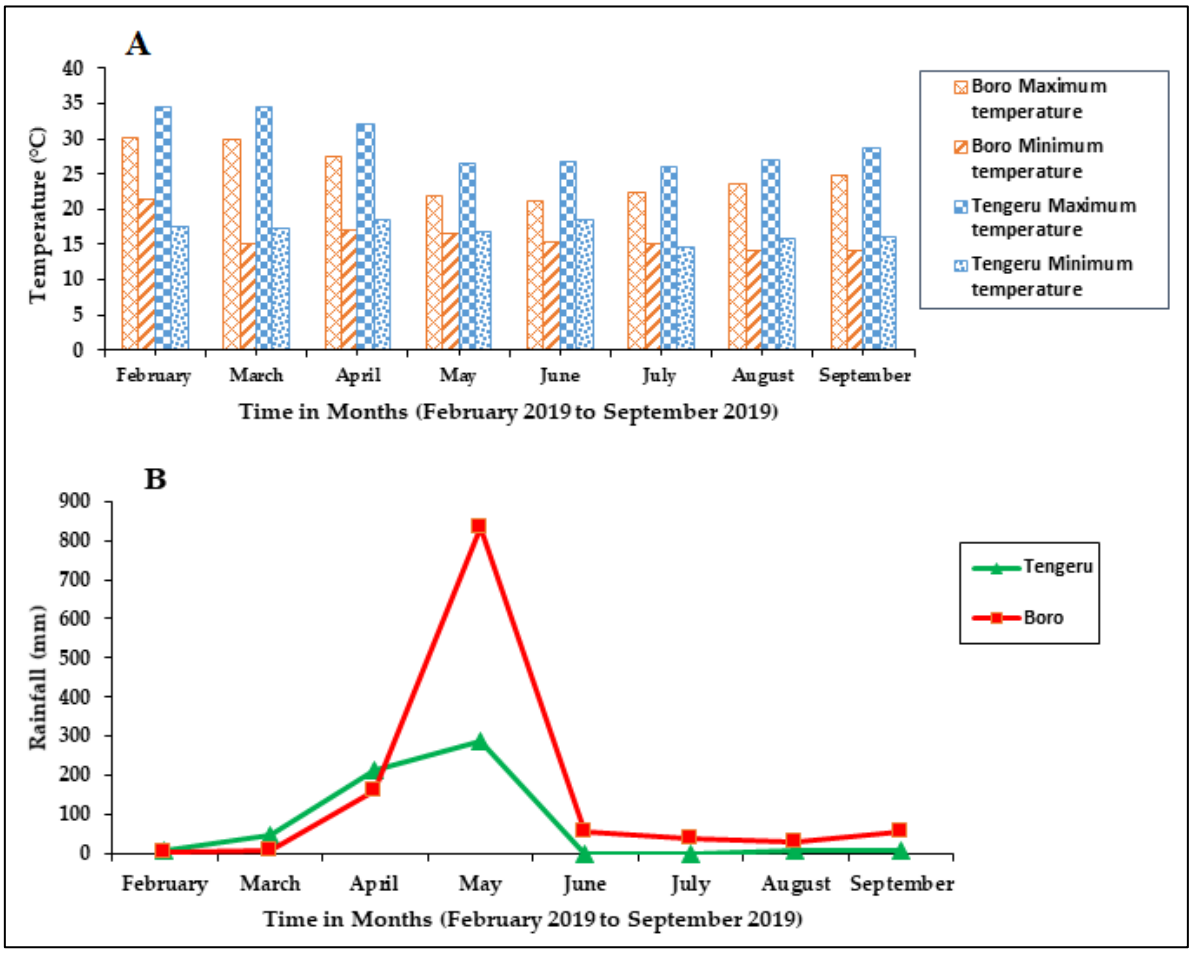


Figure 1. Temperatures (A) and Rainfall precipitation (B) of Boro study site and Tengeru study site during the field experiments 2019.

3.2. Population dynamics of larvae of diamondback (P. xylostella)

The larval population of diamondback moth (*P. xylostella*) were observed on *B. oleracea* crop 4 weeks after transplanting and their larvae were recorded each week of the assessment in the field plots until the *B. oleracea* crops were harvested. The larvae were mostly found in the underside of the leaves of the *B. oleracea* crops. It was observed that, at 1st, 2nd, 3rd, 4th and 5th week after the application of treatments, the population of *P. xylostella* larvae were significantly ($P \leq 0.001$) higher (0.41, 0.56, 0.87, 0.71 and 0.96) at Boro site than the population (0.09, 0.23, 0.30, 0.23 and 0.44) at Tengeru site (Table 1). A gradual increase in population of insect pests was noticed over weekly interval throughout the growing season at both experimental sites (Table 1).

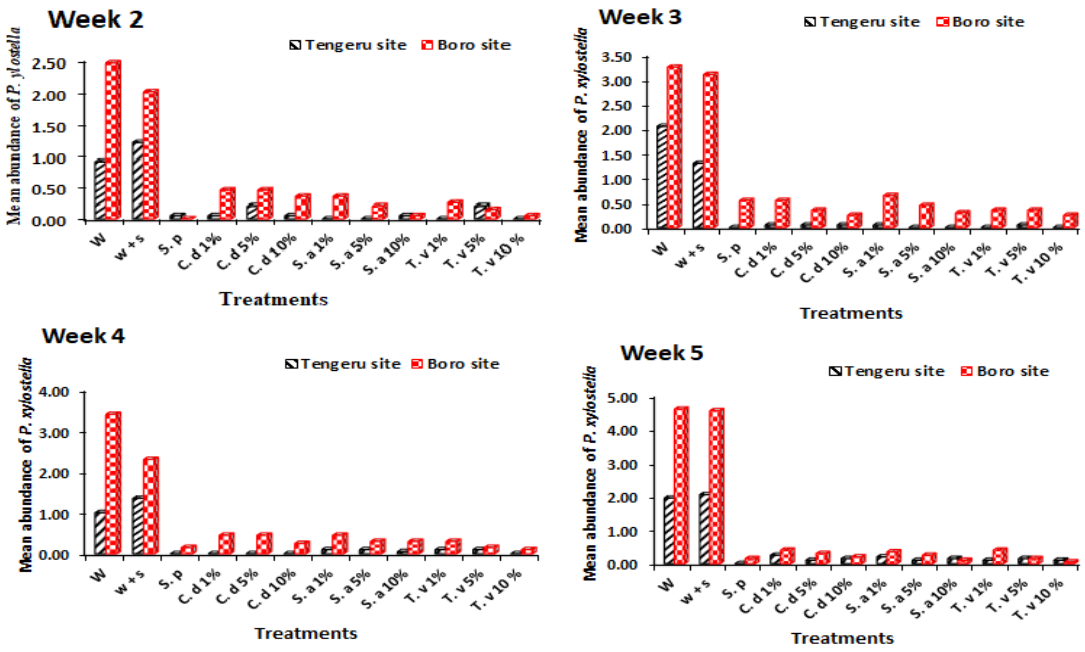
Three (1%, 5% and 10%) concentrations of *T. vogelii, C. dichogamus* and *S. aromaticum* aqueous plant extracts were used to control *P. xylostella* larvae in the *B. oleracea* crop field at both study sites (Table 1). The results showed that, the aqueous plant extracts and chlorpyrifos treated plots hosted fewer *P. xylostella* larvae (Table 1) when compared with negative controls (water and water plus soap) ($P \leq 0.001$). In negative controls treated plots, the population of *P. xylostella* larvae were highest throughout the experimental duration as compared to aqueous plant extract treated plots with maximum population of 3.28 and 3.30 during the 5th week for water and water plus soap treated

plots, respectively (Table 1). Statistically, aqueous plant extracts were significantly ($P \leq 0.001$) as effective as chlorpyrifos in controlling the *P. xylostella* larvae (Table 1). It was observed that, *P. xylostella* persisted from week 1 before and from the 1st to the 5th week of the treatments (Table 1) in water and water plus soap and the population of larvae grew progressively in control plots. The interactions (Figure 2) of the weather conditions (rainfall and temperatures) of the study sites and treatments were observed from the 1st week of treatments to the 5th week (Table 1). It was observed that, the combination of rainfall and warm conditions (Figure 2) of the experimental sites and the treatments together significantly ($P \leq 0.01$) inhibited the growth and development of *P. xylostella* in the field (Figure 2).

Table 1. Mean number of *P. xylostella* per *B. oleracea* in response to weekly application of pesticides.

Location and treatments	Week 1 before Treatment	Weeks after treatments 1	2	3	4	5
Location						
Tenger	0.08 ±0.02a	0.09 ±0.03b	0.23 ±0.08b	0.30 ±0.10b	0.23 ±0.08b	0.44 ±0.11b
Boro	0.07 ±0.02a	0.41 ±0.11a	0.56 ±0.12a	0.87 ±0.16a	0.71 ±0.15a	0.96 ±0.24a
Treatments						
Water (−ve control)	0.13 ±0.05a	1.13 ±0.53a	1.68 ±0.41a	2.28 ±0.44a	2.20 ±0.53a	3.28 ±0.60a
Water + soap (−ve control)	0.10 ±0.04a	0.75 ±0.15ab	1.60 ±0.31a	2.58 ±0.36a	1.83 ±0.35a	3.30 ±0.49a
Synthetic pesticide (+ve control)	0.00 ±0.00a	0.05 ±0.10c	0.03 ±0.03b	0.28 ±0.15b	0.08 ±0.04b	0.08 ±0.04b
C. dichogamus (1%)	0.13 ±0.05a	0.28 ±0.12bc	0.25 ±0.09b	0.30 ±0.10b	0.23 ±0.10b	0.33 ±0.08b
C. dichogamus (5%)	0.08 ±0.04a	0.15 ±0.10c	0.33 ±0.06b	0.20 ±0.08b	0.23 ±0.10b	0.20 ±0.07b
C. dichogamus (10%)	0.03 ±0.03a	0.08 ±0.04c	0.20 ±0.08b	0.15 ±0.05b	0.13 ±0.08b	0.18 ±0.06b
S. aromaticum (1%)	0.18 ±0.05a	0.13 ±0.05c	0.18 ±0.10b	0.35 ±0.12b	0.23 ±0.09b	0.28 ±0.04b
S. aromaticum (5%)	0.03 ±0.03a	0.15 ±0.07c	0.10 ±0.05b	0.23 ±0.09b	0.23 ±0.08b	0.18 ±0.06b
S. aromaticum (10%)	0.03 ±0.03a	0.03 ±0.03c	0.05 ±0.05b	0.15 ±0.08b	0.18 ±0.06b	0.13 ±0.04b
T. vogelii (1%)	0.00 ±0.00a	0.10 ±0.05c	0.15 ±0.05b	0.18 ±0.07b	0.20 ±0.07b	0.25 ±0.07b
T. vogelii (5%)	0.08 ±0.05a	0.08 ±0.05c	0.18 ±0.10b	0.20 ±0.08b	0.13 ±0.04b	0.15 ±0.03b
T. vogelii (10%)	0.05 ±0.05a	0.08 ±0.04c	0.15 ±0.05b	0.13 ±0.08b	0.05 ±0.03b	0.08 ±0.04b
2-way ANOVA	(F-Statistics)					
Location	0.42ns	15.11***	19.55***	58.04***	38.06***	59.75***
Treatments	2.04ns	5.52***	20.22***	45.09***	28.14***	109.40***
Location*treatments	1.95ns	2.84***	3.00***	3.64***	5.63***	17.46***

Note: Each value is a mean ± standard error of eight replicates, *, **, and *** significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively and ns means not significant. Means within the same column followed by the same letter(s) are not significantly different at ($P = 0.05$) from each other using Fishers Least significant Difference (LSD) test.



Note: W—water, w + s—Water plus soap, S. p—Synthetic pesticide, *C. d—Croton dichogamus, S. a—Syzygium aromaticum, T. v—Tephrosia vogelii*.

Figure 2. The interactive effectiveness of weather conditions of the experimental sites and the treatments on the reduction of population abundance of *P. xylostella* larva (Week 2, 3, 4 and 5).

3.2. Population dynamics of cabbage looper (Trichoplusia ni)

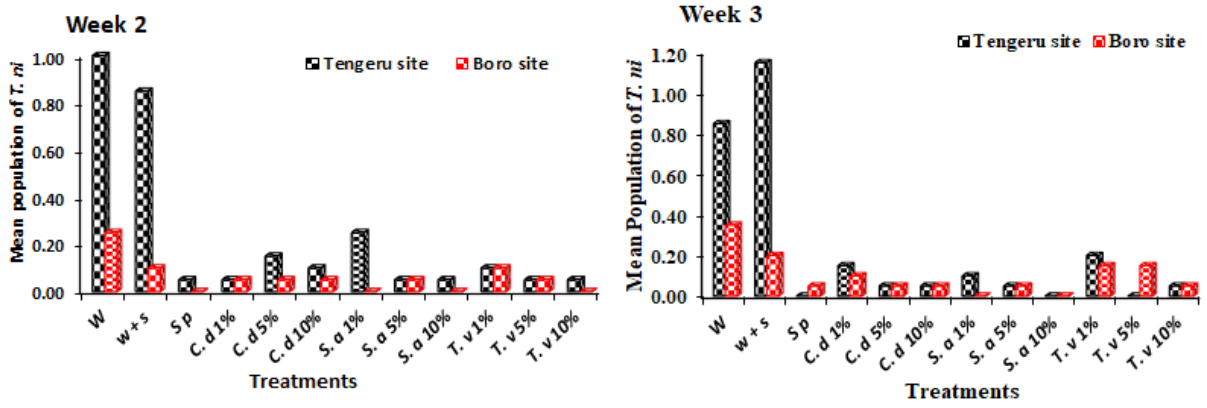
T. ni larvae were observed on the field 3 weeks after transplanting. Generally, the *T. ni* larvae were lower in population abundance at both study sites compared to *P. xylostella* larvae per *B. oleracea* crop. In the first week before spraying of the treatments, there were very few *T. ni* larvae in all plots and did not differed significantly ($P > 0.05$). The number of *T. ni* larvae per *B. oleracea* plant over five weeks of spray were shown in Table 2. It was observed that, the population of *T. ni* larvae were significantly ($P \leq 0.05$) higher (0.18, 0.18, 0.23, 0.22) at Tengeru site (Table 3) than (0.09, 0.06, 0.06 and 0.10) at Boro site (Table 2) from the week before application of the treatments to the third week after application of the treatments. It was observed that, at the 1st, 2nd and the 3rd week of the treatments, the population of the *T. ni* larvae were significantly ($P \leq 0.001$) lower at Boro study site compared with Tengeru site (Table 2).

The result showed that, the aqueous plant extracts and chlorpyrifos treated plots hosted fewer *T. ni* larvae compared with the negative controls (water and water plus soap) (Table 2). In the negative control plots, *T. ni* larvae were highest of all the treated plots (Table 2). The aqueous plant extracts from *T. vogelii, C. dichogamus* and *S. aromaticum* were significantly ($P \leq 0.05$) effective as synthetic pesticide (Chlorpyrifos) in controlling the cabbage looper (*T. ni*) larvae (Table 2). Also, there was interactions of the weather conditions of the experimental sites and treatments which was observed at the 2nd and 3rd week of application of treatments (Figure 3). It was revealed that, the combination of the weather conditions of the experimental sites and the treatments together significantly ($P \leq 0.01$) reduced the population of *T. ni* in the field.

Table 2. Mean number of *T. ni* per *B. oleracea* plant in response to weekly application of pesticides.

Location and treatments	Week 1 before Treatment	Weeks after treatments 1	2	3	4	5
Location						
Tengeru	0.18 ±0.02a	0.18 ±0.03a	0.23 ±0.0a	0.22 ±0.07a	0.17 ±0.05a	0.20 ±0.05a
Boro	0.09 ±0.02b	0.06 ±0.03b	0.06 ±0.02b	0.10 ±0.02b	0.15 ±0.04a	0.14 ±0.04a
Treatments						
Water (−ve control)	0.18 ±0.07a	0.50 ±0.09a	0.63 ±0.30a	0.60 ±0.24a	0.48 ±0.15a	0.78 ±0.16a
water + soap (−ve control)	0.10 ±0.05a	0.30 ±0.08b	0.48 ±0.20a	0.68 ±0.26a	0.65 ±0.20a	0.80 ±0.18a
Synthetic pesticide (+ve control)	0.13 ±0.05a	0.05 ±0.03c	0.03 ±0.03b	0.03 ±0.03b	0.03 ±0.03bc	0.00 ±0.00b
C. dichogamus (1%)	0.15 ±0.05a	0.08 ±0.04c	0.05 ±0.03b	0.13 ±0.05b	0.23 ±0.10b	0.08 ±0.04b
C. dichogamus (5%)	0.08 ±0.04a	0.10 ±0.04c	0.10 ±0.05b	0.05 ±0.03b	0.13 ±0.04bc	0.08 ±0.04b
C. dichogamus (10%)	0.15 ±0.05a	0.03 ±0.03c	0.08 ±0.04b	0.05 ±0.03b	0.08 ±0.05bc	0.08 ±0.04b
S. aromaticum (1%)	0.10 ±0.04a	0.13 ±0.05c	0.13 ±0.08b	0.05 ±0.03b	0.08 ±0.04bc	0.08 ±0.04b
S. aromaticum (5%)	0.18 ±0.03a	0.05 ±0.03c	0.05 ±0.03b	0.05 ±0.03b	0.00 ±0.00c	0.03 ±0.03b
S. aromaticum (10%)	0.10 ±0.01a	0.05 ±0.03c	0.03 ±0.03b	0.00 ±0.00b	0.05 ±0.05bc	0.03 ±0.03b
T. vogelii (1%)	0.13 ±0.05a	0.10 ±0.04c	0.10 ±0.05b	0.18 ±0.06b	0.15 ±0.03bc	0.10 ±0.04b
T. vogelii (5%)	0.20 ±0.04a	0.05 ±0.03c	0.05 ±0.03b	0.08 ±0.04b	0.03 ±0.03bc	0.00 ±0.00b
T. vogelii (10%)	0.13 ±0.04a	0.00 ±0.00c	0.03 ±0.03b	0.05 ±0.03b	0.03 ±0.03bc	0.00 ±0.00b
2-way ANOVA	(F-Statistics)					
Location	12.10***	20.44***	8.80**	4.66*	0.24ns	2.21ns
Treatments	0.67ns	10.90***	3.83***	5.53***	5.42***	16.01***
Location*treatments	0.26ns	1.05ns	1.96*	2.46**	0.37ns	1.16ns

Note: Each value is a mean ± standard error of eight replicates, *, **, and *** significant at P ≤ 0.05, P ≤ 0.01 and P ≤ 0.001 respectively and ns means not significant. Means within the same column followed by the same letter(s) are not significantly different at (P = 0.05) from each other using Fishers Least significant Difference (LSD) test.



Note: W—water, w + s—Water plus soap, S. p—Synthetic pesticide, *C. d—Croton dichogamus, S. a—Syzygium aromaticum, T. v—Tephrosia vogelii.*

Figure 3. The interactive effectiveness of weather conditions of the experimental sites and the treatments on the reduction of population abundance of *T. ni* (Week 2 and 3).

3.3. The percent damage caused by P. xylostella and T. ni larvae

Generally, the damage to *B. oleracea* caused by *P. xylostella* and *T. ni* larvae were significant ($P \leq 0.001$) at the two study sites (Boro and Tengeru) (Table 3). At the 1st week before application of the treatments and the 1st and the 2nd weeks after application of treatments the damage percentage of *B. oleracea* was significantly ($P \leq 0.001$) lower (10.1, 10.3 and 11.8) at Boro site than (19.7, 19.1, 18.0) at Tengeru site respectively (Table 3). At the 3rd, 4th and the 5th weeks of the treatments, the percentages of *B. oleracea* damage was significantly ($P \leq 0.001$) the same at both study sites.

Before treatments, there was non-significant different ($P > 0.05$) of *B. oleracea* percentage damage caused by *P. xylostella* and *T. ni* larvae in all treatments in different plots (Table 3). After the treatments, the aqueous plant extracts of *S. aromaticum* and *T. vogelii* at 10% concentration each, exhibited significantly ($P \leq 0.05$) the lowest (8.8, 8.1, 6.9, 8.1 and 9.4) and (10.0, 6.3, 7.5, 7.5 and 5.6), percentage damage of *B. oleracea* at the 1st, 2nd, 3rd, 4th and the 5th of application of the treatments respectively. Moreover, the percentage of *B. oleracea* damage in the water (33.8, 33.1, 38.8, 45.0 and 70.6) and water plus soap (30.0, 31.9, 41.3, 41.3 and 56.3) was higher than in the *T. vogelii, C. dichogamus* and *S. aromaticum* aqueous plant extracts and chlorpyrifos pesticide treated plots (Table 3) from the first week to the 5th week of the treatments.

For the three concentrations (1%, 5% and 10%), the 10% of *T. voelii* and *S. aromaticum* aqueous plant extracts showed the least percentage damage (6.3%, 7.5%, 7.5% and 5.6%) and (8.1%, 6.9%, 8.1% and 9.4%) of the *B. oleracea* respectively compared with the 5 % and 1 % concentrations (Table 3). The 10% of the *T. voelii* and *S. aromaticum* aqueous plant extracts were as effective as synthetic pesticide (6.3, 6.9, 7.5 and 5.0) in reduction of the percentage damage of *B. oleracea.* The other concentrations (1% and 5%) of the aqueous plant extracts reduced the damage of *B. oleracea* compared with negative controls (Table 3).

3.4. The relationship between the population of insect pests and the damage (%) of (B. oleracea) crop

Figure 4 indicates the relationship between the population of *P. xlostella* and *T. ni* and the percentage damage incurred in the negative controls and the treatments. It was revealed that, the percentage damage was highest in the negative controls (water and water plus soap) because the populations of *P. xlostella* and *T. ni* were higher compared with the pesticide and plant extract treatments. Also, it was found that, the percentage damage was lowest in the synthetic pesticide used (chlorpyrifos) followed by *T. vogelli* (10%) and *S. aromaticum* (10%). Moreover, *C. dichogamus* (10%), *T. vogelii* (5%), *S. aromaticum* (5%) *and C. dichogamus* (5%) aqueous plant extracts lowered the percentage damage of *B. oleracea* plant compared with 1% of extracts from each pesticidal plant (Figure 4).

Further correlation analysis (Table 4), clearly showed that, the population of *P. xylostella* and *T. ni* have positive and significantly ($P < 0.001$) very strong relationship with the damage score of the *B. oleracea*. From this study, the population of *P. xylostella* larvae has positive ($R = 0.976$) and significantly ($P < 0.001$) very strong correlation with the percentage damage of *B. oleracea*. Moreover, population of *T. ni* has positive ($R = 0.990$) and significantly ($P < 0.001$) very strong correlation with the percentage damage of *B. oleracea* crop. Therefore, due to strong infestation and damage caused by *P. xylostella* and *T. ni*, the smallholder farmers are convinced to increase the rate

and the dose of synthetic pesticides to the field during the control and management of those insect pests.

Table 3. Percent damage per plant of *B. oleracea.*

Location and treatments	Week 1 before Treatment	Weeks after treatments 1	2	3	4	5
Location						
Tengeru	19.7 ±1.1a	19.1 ±1.8a	18.0 ±2.0a	16.3 ±2.1a	15.3 ±1.9a	19.9 ±2.8a
Boro	10.1 ±0.5b	10.3 ±1.0b	11.8 ±1.1b	15.5 ±1.4a	18.3 ±2.0a	21.8 ±3.2a
Treatments						
Water (−ve control)	18.8 ±3.1a	33.8 ±5.6a	33.1 ±4.5a	38.8 ±2.3a	45.0 ±4.3a	70.6 ±3.1a
water + soap (−ve control)	15.6 ±4.4a	30.0 ±5.7a	31.9 ±3.7a	41.3 ±3.1a	41.3 ±3.0a	56.3 ±2.3b
Synthetic pesticide (+ve control)	16.3 ±2.6a	8.1 ±1.6c	6.3 ±1.6e	6.9 ±1.9e	7.5 ±1.6d	5.0 ±1.3g
C. dichogamus (1%)	16.9 ±2.8a	16.3 ±3.2b	17.5 ±3.0b	17.5 ±1.9b	18.1 ±1.9b	18.8 ±1.8c
C. dichogamus (5%)	15.0 ±2.7a	10.0 ±1.3bc	13.8 ±3.5bcde	15.0 ±2.7bc	15.0 ±2.1bc	18.8 ±1.8c
C. dichogamus (10%)	13.8 ±1.8a	11.3 ±1.6bc	11.3 ±1.6bcde	11.3 ±0.8cde	11.3 ±2.1cd	12.5 ±2.8de
S. aromaticum (1%)	14.4 ±2.4a	13.8 ±2.5bc	15.6 ±2.4bcd	15.0 ±1.3bc	17.5 ±1.9b	18.1 ±1.6c
S. aromaticum (5%)	12.5 ±1.3a	10.6 ±1.1bc	10.0 ±0.0bcde	8.1 ±1.3e	8.8 ±1.3d	10.6 ±1.5ef
S. aromaticum (10%)	14.4 ±2.2a	8.8 ±1.8bc	8.1 ±0.9de	6.9 ±1.3e	8.1 ±1.6d	9.4 ±1.5efg
T. vogelii (1%)	11.9 ±3.3a	12.5 ±1.9bc	16.3 ±4.6bc	13.8 ±2.3bcd	15.0 ±0.9bc	17.5 ±1.3cd
T. vogelii (5%)	16.3 ±3.0a	11.3 ±1.6bc	8.8 ±1.8cde	8.8 ±0.8de	6.9 ±1.6d	6.9 ±1.6fg
T. vogelii (10%)	11.9 ±1.6a	10.0 ±1.9bc	6.3 ±1.6e	7.5 ±1.3e	7.5 ±1.3d	5.6 ±1.1fg
2-way ANOVA						
Location	77.06***	45.03***	18.56***	0.51ns	6.05**	2.89ns
Treatments	1.19ns	13.70***	12.98***	44.96***	37.05***	117.55***
Location*treatments	1.53ns	1.94ns	1.28ns	1.90ns	0.57ns	0.77ns

Note: Each value is a mean ± standard error of eight replicates, *, **, and *** significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively and ns means not significant. Means within the same column followed by the same letter(s) are not significantly different at (P = 0.05) from each other using Fishers Least significant Difference (LSD) test.

Table 4. Correlation matrix between *P. xylostella*, *T. ni* and damage (%) of *B. oleracea.*

	P. xylostella	*T. ni*	Damage (%)
P. xylostella	1.000		
T. ni	0.993 (<0.001)	1.000	
Damage (%)	0.976 (<0.001)	0.99 (<0.001)	1.000

Keys: In brackets are the P—values of significant correlations of measured variables.

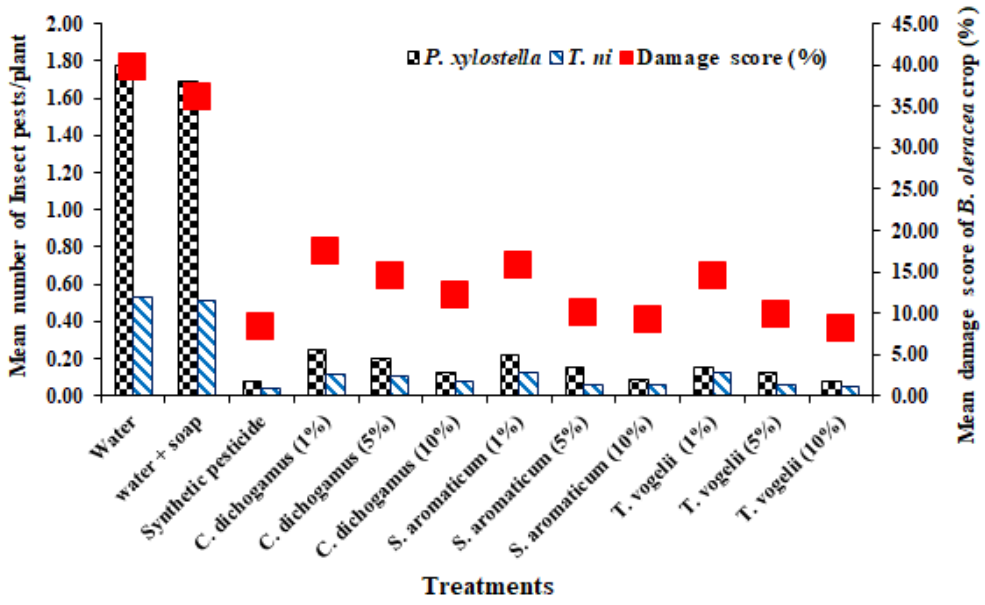


Figure 4. The relationship of the population of *P. xlostella* and *T. ni* larvae and damage (%) of *B. oleracea.*

4. Discussion

4.1. Effect of rainfall and temperature on Population dynamics of P. xylostella and T. ni larvae

Generally, the population of *P. xylostella* and *T. ni* larvae from this study differed significantly from one study site to another. The population of *T. ni* larvae were significantly higher at Tengeru site than at Boro site. The population of *P. xylostella* larvae were significantly ($P \leq 0.01$) higher at Boro site than at Tengeru site. These results could be contributed by variations of weather conditions of the two experimental sites and the building up of *P. xylostella* and *T. ni* larvae. Moreover, the building up of the two larvae could be contributed by the species diversity and present of natural enemies. For instance, the building up of *P. xylostella* at Boro site could have contributed the high damaging effect of the *B. oleracea* at Boro site at 3rd, 4th and 5th of the application of the treatments. Extreme weather conditions like heavy rainfall, either high or low temperatures and high humidity have strong influences on the population abundance of the insects in their ecosystem [31]. At Boro site the rainfall ranged from 5 mm to about 883 mm and the temperature ranged from 22 to 30.2 ℃ during the study period march to August 2019 which mighty have enhanced the growth and development of *P. xylostella*. However, at Tengeru experimental site, the rainfall precipitations and temperatures were lower which ranged from 0 mm to 287 mm and 25.9 to 34.5 ℃, respectively. These variations in rainfall and temperatures could have affected significantly ($P \leq 0.05$) the population abundance of the *P. xylostella* and *T. ni* larvae in the two experimental sites. As results, the population abundance of the *T. ni* larvae were significantly ($P \leq 0.05$) higher at Tengeru study site than at Boro site while, the population abundance of *P. xylostella* was higher at Boro study site than at Tengeru study site.

The higher rainfall precipitations and lower temperatures of the Boro site might have had contributed the higher populations of *P. xylostella* larvae compared with Tengeru study site whereby

the population was low. The results concur with Tanyi *et al*. [32] and Patra [31] who reported that, *P. xylostella* is favoured by warm conditions and rain precipitations. Moreover, Ayalew *et al.* [33] showed that, rain precipitation and temperatures ranging from 25 to 33 ℃ have significant influences on the population of *P. xylostella*. According to them the increase of population of *P. xylostella* was reported to be positively correlated with high rain precipitations and the temperatures which ranges from 25 to 33 ℃. It was clear from this study that, the population abundance of *P. xylostella* and *T. ni* larvae varies from one location to another location due weather conditions variability, species diversity and distribution of natural enemies. Those results concur with Ayalew and Ogol [33] who indicated that, the importance of a particular insect pest varies from location to location due to differences in rainfall precipitations and temperatures.

4.2. Effect of treatments on population dynamics of P. xylostella and T. ni larvae

The distribution of *P. xylostella* larvae and *T. ni* larvae in the 1st week before application of the aqueous plant extracts and the chlorpyrifos was low and was not significantly different and the infestation was less intense because the *B. oleracea* plants were still young. In the negative controls (water and water plus soap) plots the population of *P. xylostella* larvae persisted from week 1 up to week 6 and the infestation of the *B. oleracea* crops increased progressively week after week. After application of the treatments, it was observed that, the aqueous plant extracts from *T. vogelii, C. dichogamus* and *S. aromaticum* significantly lowered ($P \leq 0.05$) the population of *T. ni* and *P. xylostella* larvae on *B. oleracea* crops and reduced the damage of *B. oleracea*. However, on the negative control plots, the infestations and damage increased progressively. It was found that, the aqueous plant extracts were as effective as synthetic pesticide (Chlorpyrifos) for controlling *P. xylostella* and *T. ni* larvae in the *B. oleracea* crop in the field. The effectiveness of botanical pesticides used for controlling *P. xylostella* larva and *T. ni* larvae in the field could be contributed by the presence of active chemical compounds in the studied pesticidal plants [34].

The 10% concentration of the aqueous plant extracts was more effective in reduction of the population of *T. ni* and *P. xylostella* larvae and the damage of *B. oleracea* compared with the other tested concentrations (1% and 5%). In general, the botanicals used were effective as chlorpyrifos in reducing the population of *T. ni* and *P. xylostella* larvae and the damage of *B. oleracea* crop in the field. The results obtained agree with the previous studies [16,35–42]. Kamanula *et al*. [40] and Grzywacz *et al*. [38] reported that, the control of insect pests using pesticidal plant extracts could be contributed by the presence of insecticidal bioactive compounds in those pesticidal plants. Belmain *et al*. [30] reported the present of rotenone in *T. vogelii*, which could be responsible for *T. ni* and *P. xylostella* larvae control efficacy. Khater [43] indicated that, rotenone is a contact and stomach poison which limits the electron transport chain in the Mitochondria.

Apart from that, this study revealed that, all concentrations of the aqueous extracts used from *S. aromaticum* significantly ($P \leq 0.05$) reduced the population of *T. ni* and *P. xylostella* larvae when compared with negative controls (water and water plus soap). These results agree with Kamatou *et al*. [25], Araujo *et al*. [27] and Tian *et al*. [26]. Kamatou *et al.* [25] and Araujo *et al*. [27] reported that, *S. aromaticum* contains eugenol, β-caryophyllene, α-humulene and eugenol acetate and eugenol being the most active compound responsible for imparting the taste of the *S. aromaticum* (Figure 5). Because of that, eugenol is the bioactive chemical compound of *S. aromaticum* which can be used as repellent. Tian *et al.* [26] revealed that, *S. aromaticum* has a range of pharmacological activities

which includes antimicrobial, anti-inflammatory, analgesic, anti-oxidant and anticancer activities, amongst others and therefore can be used in agricultural to protect crops and foods from micro-organisms during storage. In addition, *S. aromaticum* might have an effect on insect as a pesticide and fumigant [25,26]. Araujo *et al.* [27] showed that, the essential oils from *S. aromaticum* exhibited larvicidal activity against resistant populations of *Aedes aegypti*.

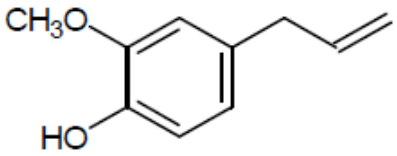


Figure 5. Chemical structure of Eugenol $C_{10}H_{12}O_2$. Source: [25].

Also, this study reported that, all concentrations (1%, 5% and 10%) of the extracts used from *C. dichogamus* significant ($P \leq 0.05$) reduced the *T. ni* and *P. xylostella* larvae when compared with negative controls. These results agree with Aldhaher *et al*. [29] and Silva *et al*. [28] who reported that, the *Croton species* possesse alkaloids, phenolics, terpenoids including monoterpenes, sesquiterpenes and diterpenes in all plant parts. Those compounds could be responsible for the insecticidal, repellents and deterrent effects to *T. ni* and *P. xylostella* larva in this study. In Africa, America and Asia croton species are commonly used as folk medicines in the treatment of cancer, constipation, diabetes, digestive problems, dysentery, external wounds, fever, hypercholesterolemia, hypertension, inflammation, intestinal worms, malaria, pain, ulcers and weight-loss [28] due to the present of those chemicals. These results agree with Aldhaher *et al.* [29] who reported that *Croton* species contain chemicals which are responsible for insecticidal activity.

4.3. Effect of interactions of rainfall and temperatures with the treatments on Population dynamics of P. xylostella and T. ni larvae

The interactions of the site's weather condition (Temperatures and rainfall) and treatments was observed in some weeks during the application of aqueous plant extracts and organophosphate pesticide for reduction of the *P. xylostella* and *T. ni* larvae. The interactions of weather conditions (temperatures and rainfall precipitations) and treatments have significant ($P \leq 0.05$) effect on the population abundance of *P. xylostella* and *T. ni* larvae. It was revealed that, the variations in weather conditions caused *P. xylostella* and *T. ni* larvae to be reduced more in the treatment plots compared with negative controls at both experimental sites. The vegetation density of a particular environment, predation exposure, and proliferation of natural enemies together with the treatments mighty have affected the reproduction capacity, growth and development of *P. xylostella* and *T. ni* larvae in the field. It is important to note that, the low and high temperatures have effect on the survival and development of *P. xylostella* larvae. High temperatures (above 30 ℃) for instance can reduce the reproduction capacity, growth and development of *P. xylostella* whereas low temperatures can favour the *P. xylostella* larvae survivorship [44]. *P. xylostella* larvae survive well in the regions in which the temperature is not more than 30 ℃ [44]. The combinations of fluctuations of rainfall precipitations and the treatments reduced the population of the *P. xylostella* at the experimental sites.

Similarly, those results agree with Tanyi *et al*. [32], Patra [31], Kobori and Amano [45] who reported that, population abundance of *P. xylostella* is affected by rainfall precipitations. Moreover, most of *T. ni* larvae lay many eggs on the upper leaf surface of the host plants and few are laid on the lower surface. In heavy rainfall precipitations, the eggs of *T. ni* on the upper surface of the leaf are washed away and few eggs remain which hatch into few larvae and inhibit the reproduction capacity of *T. ni* larvae. Therefore, the combinations of temperatures and rainfall precipitations and treatments reduced the reproduction capacity of *T. ni* hence inhibited the population of the insect pest at both experimental sites. Therefore, smallholder farmers can manage the larvae of *P. xylostella* and *T. ni* by considering the weather conditions of a particular location and the botanicals in case synthetic pesticides are not affordable.

5. Conclusion

The three concentrations (1%, 5% and 10%) of the plant extracts used in this study were able to reduce the population of *T. ni* and *P. xylostella* larvae and the damage of *B. oleracea* crop in the field. Therefore, *T. vogelii, C. dichogamus* and *S. aromaticum* are at 10% w/v aqueous extracts is potential for African smallholder farmers for controlling *T. ni,* and *P. xylostella* larvae infestation and to increase their crop yield. Due to the efficacy of aqueous plant extracts against *T. ni* and *P. xylostella* larvae, these plants can be used as alternatives to synthetic pesticides.

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Conflicts of interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

1. Baidoo P, Mochiah M (2016) Comparing the effectiveness of garlic (*Allium sativum* L.) and hot pepper (*Capsicum frutescens* L.) in the management of the major pests of cabbage Brassica oleracea (L.). *Sustainable Agric Res* 5: 83–91.

2. Mpumi N, Machunda RS, Mtei KM, et al. (2020) Selected insect pests of economic importance to *Brassica oleracea*, their control strategies and the potential threat to environmental pollution in Africa. *Sustainability* 12: 1–22.
3. Mudzingwa S, Muzemu S, Chitamba J (2013) Pesticidal efficacy of crude aqueous extracts of *Tephrosia vogelii* L., *Allium sativum* L. and *Solanum incanum* L. in controlling aphids (*Brevicoryne brassicae* L.) in rape (*Brassica napus* L.). *J Agric Res* 2: 157–163.
4. Norman C, Shealy M (2007) *Illustrated Encyclopedia of Healing Remedies.* Toledo, OH, USA: Elements Book Inc.
5. Gibson A (2012) *Colewart and the cole crops*. Los Angeles: University of California Los Angeles.
6. Baidoo P, Adam J (2012) The Effects of Extracts of *Lantana camara* (L.) and *Azadirachta indica* (A. Juss) on the Population Dynamics of *Plutella xylostella*, *Brevicoryne brassicae* and *Hellula undalis* on Cabbage. *Sustainable Agric Res* 1: 229–234.
7. Furlong MJ, Wright DJ, Dosdall LM (2013) Diamondback moth ecology and management: problems, progress, and prospects. *Annu Rev Entomol* 58: 517–541.
8. Labou B, Brévault T, Sylla S, et al. (2017) Spatial and temporal incidence of insect pests in farmers' cabbage fields in Senegal. *Int J Trop Insect Sci* 37: 225–233.
9. Begna F, Damtew T (2015) Evaluation of four botanical insecticides against Diamondback Moth, *Plutella Xylostella* L.(Lepidoptera: Plutellidae) on head cabbage in the central rift valley of Ethiopia. *Sky J Agric Res* 4: 97–105.
10. Timbilla J, Nyarko K (2004) A survey of cabbage production and constraints in Ghana. *Ghana J Agric Sci* 37: 93–101.
11. Fening K, Amoabeng B, Adama I, et al. (2013) Sustainable management of two key pests of cabbage, *Brassica oleracea* var. capitata L.(*Brassicaceae*), using homemade extracts from garlic and hot pepper. *Org Agric* 3: 163–173.
12. Capinera J (2001) *Handbook of vegetable pests*. Eds, editor: Cambridge, MA, USA: Academic Press.
13. Mpumi N, Mtei K, Machunda R, et al. (2016) The toxicity, persistence and mode of actions of selected botanical pesticides in Africa against insect pests in common beans, *P. vulgaris*: a review. *Am J Plant Sci* 7: 138–151.
14. Labou B, Brévault T, Bordat D, et al. (2016) Determinants of parasitoid assemblages of the diamondback moth, *Plutella xylostella*, in cabbage farmer fields in Senegal. *Crop Prot* 89: 6–11.
15. Mkenda P, Mwanauta R, Stevenson PC, et al. (2015) Extracts from field margin weeds provide economically viable and environmentally benign pest control compared to synthetic pesticides. *PLoS ONE* 10: 1–14.
16. Mkindi A, Mpumi N, Tembo Y, et al. (2017) Invasive weeds with pesticidal properties as potential new crops. *Ind Crops Prod* 110: 113–122.
17. Ondieki JJ (1996) The current state of pesticide management in Sub-Saharan Africa. *Sci Total Environ* 188: 30–34.
18. Weinberger K, Srinivasan R (2009) Farmers' management of cabbage and cauliflower pests in India and their approaches to crop protection. *J Asia-Pac Entomol* 12: 253–259.
19. Amoabeng BW, Gurr GM, Gitau CW, et al. (2014) Cost: Benefit analysis of botanical insecticide use in cabbage: Implications for smallholder farmers in developing countries. *Crop Prot* 57: 71–76.

20. de Cássia Seffrin R, Shikano I, Akhtar Y, et al. (2010) Effects of crude seed extracts of *Annona atemoya* and *Annona squamosa* L. against the cabbage looper, *Trichoplusia ni* in the laboratory and greenhouse. *Crop Prot* 29: 20–24.
21. Mochiah M, Banful B, Fening K, et al. (2011) Botanicals for the management of insect pests in organic vegetable production. *J Entomol Nematol* 3: 85–97.
22. Isman MB (2006) Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world. *Annu Rev Entomol* 51: 45–66.
23. Orwa C, Mutua A, Kindt R, et al. (2009) Agroforestree database: a tree species reference and selection guide version 4.0. World Agroforestry Centre ICRAF, Nairobi, KE.
24. Munthali MG, Gachene CK, Sileshi GW, et al. (2014) Amendment of *Tephrosia* Improved Fallows with Inorganic Fertilizers Improves Soil Chemical Properties, N Uptake, and Maize Yield in Malawi. *Int J Agron* 2014: 1–9.
25. Kamatou GP, Vermaak I, Viljoen AM (2012) Eugenol from the remote Maluku Islands to the international market place: A review of a remarkable and versatile molecule. *Molecules* 17: 6953–6981.
26. Tian BL, Liu QZ, Liu ZL, et al. (2015) Insecticidal potential of clove essential oil and its constituents on *Cacopsylla chinensis* (Hemiptera: Psyllidae) in laboratory and field. *J Econ Entomol* 108: 957–961.
27. Araujo AFdO, Ribeiro-Paes JT, Deus JTd, et al. (2016) Larvicidal activity of Syzygium aromaticum (L.) Merr and *Citrus sinensis* (L.) Osbeck essential oils and their antagonistic effects with temephos in resistant populations of *Aedes aegypti*. *Memórias do Instituto Oswaldo Cruz* 111: 443–449.
28. Silva CG, Oliveira J, da Camara CA (2018) Insecticidal activity of the ethanolic extract from *Croton species* against *Plutella xylostella* L.(Lepidoptera: Plutellidae). *Revista Facultad Nacional de Agronomía Medellín* 71: 8543–8551.
29. Aldhaher A, Langat M, Ndunda B, et al. (2017) Diterpenoids from the roots of *Croton dichogamus* Pax. *Phytochemistry* 144: 1–8.
30. Belmain SR, Amoah BA, Nyirenda SP, et al. (2012) Highly variable insect control efficacy of Tephrosia vogelii chemotypes. *J Agric Food Chem* 60: 10055–10063.
31. Patra S, Dhote V, Alam S, et al. (2013) Population dynamics of major insect pests and their natural enemies on cabbage under new alluvial zone of West Bengal. *J Plant Prot Sci* 5: 42–49.
32. Tanyi CB, Ngosong C, Ntonifor NN (2018) Effects of climate variability on insect pests of cabbage: adapting alternative planting dates and cropping pattern as control measures. *Chem Biol Technol Agric* 5: 1–11.
33. Ayalew G, Ogol C (2006) Occurrence of the diamondback moth (*Plutella xylostella* L.) and its parasitoids in Ethiopia: influence of geographical region and agronomic traits. *J Appl Entomol* 130: 343–348.
34. Grzywacz D, Rossbach A, Rauf A, et al. (2010) Current control methods for diamondback moth and other brassica insect pests and the prospects for improved management with lepidopteran-resistant Bt vegetable brassicas in Asia and Africa. *Crop Prot* 29: 68–79.
35. Belmain S, Haggar J, Holt J, et al. (2013) Managing legume pests in sub-Saharan Africa: Challenges and prospects for improving food security and nutrition through agro-ecological intensification. Chatham Maritime (United Kingdom): Natural Resources Institute, University of Greenwich, 34.

36. Belmain S, Stevenson P (2001) Ethnobotanicals in Ghana: Reviving and modernising age-old farmer practice. *Pestic Outlook* 12: 233–238.
37. Do Ngoc Dai TDT, Ogunmoye A, Eresanya OI, et al. (2015) Chemical constituents of essential oils from the leaves of *Tithonia diversifolia*, *Houttuynia cordata* and *Asarum glabrum* grown in Vietnam. *Am J Essent Oils Nat Prod* 2: 17–21.
38. Grzywacz D, Stevenson P, Mushobozi WL, et al. (2014) The use of indigenous ecological resources for pest control in Africa. *Food Secur* 6: 71–86.
39. Ileke K, Oni M (2011) Toxicity of some plant powders to maize weevil, *Sitophilus zeamais* (motschulsky)[Coleoptera: Curculiondae] on stored wheat grains (*Triticum aestivum*). *Afr J Biotechnol* 6: 3043–3048.
40. Kamanula J, Sileshi GW, Belmain SR, et al. (2010) Farmers' insect pest management practices and pesticidal plant use in the protection of stored maize and beans in Southern Africa. *Int J Pest Manag* 57: 41–49.
41. Mkenda PA, Mtei K, Ndakidemi PA (2014) Pesticidal efficacy of *Tephrosia vogelii* and *Tithonia diversifolia* against field insect pests of common beans [*Phaseolus vulgaris* L.]. within African farming communities. *Afr J Appl Agric Sci Technol* 2: 9–26.
42. Mwanauta RW, Mtei K, Ndakidemi PA (2014) Prospective Bioactive Compounds from *Vernonia amygdalina*, *Lippia javanica*, *Dysphania ambrosioides* and *Tithonia diversifolia* in Controlling Legume Insect Pests. *Agric Sci* 5: 1129–1139.
43. Khater HF (2012) Prospects of botanical biopesticides in insect pest management. *Pharmacologia* 3: 641–656.
44. Marchioro C, Foerster L (2011) Development and survival of the diamondback moth, *Plutella xylostella* (L.)(Lepidoptera: Yponomeutidae) as a function of temperature: effect on the number of generations in tropical and subtropical regions. *Neotrop Entomol* 40: 533–541.
45. Kobori Y, Amano H (2003) Effect of rainfall on a population of the diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). *Appl Entomol Zool* 38: 249–253.

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