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Aqueous extracts from *Syzygium aromaticum*, *Tephrosia vogelii* and *Croton dichogamus* provide environmentally benign control of *Crocidolomia binotalis* on *Brassica oleracea* crop in the fields in Northern Tanzania

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Abstract

The aqueous extracts from *Tephrosia vogelii, Syzygium aromaticum* and *Croton dichogamus* were assessed for the control of *Crocidolomia binotalis* in the *Brassica oleracea* field. Synthetic pesticide, water and water plus soap were used as positive and negative controls, respectively. Results show that the aqueous extracts from *S. aromaticum, C. dichogamus* and *T. vogelii* were significantly ($P \leq 0.05$) as effective as synthetic pesticide in controlling *C. binotalis* in weeks 1 and 2 after treatments. On weeks 3, 4 and 5, the population of *C. binotalis* was significantly ($P \leq 0.05$) lower in 5% concentration of aqueous extract of the mixed plants compared with aqueous extracts from the individual plants. However, the aqueous extracts from individual plant at 1, 5 and 10% concentrations possessed significantly ($P \leq 0.05$) lower number of *C. binotalis* compared with negative controls. Also, the 5% of extracts of the mixed plants had significantly ($P \leq 0.05$) lower percentage damage of *B. oleracea* comparable to synthetic pesticide in weeks 1 to 5 after treatment applications, respectively. The aqueous extracts of each individual plant at 10% exhibited less percentage damage of *B. oleracea* compared with the 5 and 1% concentrations of the extracts. However, 1 and 5% of the extracts of the individual plant reduced the percentage damage of *B. oleracea* crops compared with negative controls. Therefore, the aqueous extracts of mixed plants at 5% concentration and individual plant at 10% concentration can be used by smallholder cabbage growers to control *C. binotalis* larvae in the field.

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Introduction

The cabbage head caterpillar *Crocidolomia binotalis* Zeller (Lepidoptera: Pyralidae) is an increasingly devastating pest on white cabbage (*Brassica oleracea* var. capitata) (Karungi *et al.*, 2010). The larvae are severely destructive insect pests in the Tropic and subtropics of *Brassica species* in the cruciferous gardens (Astuti *et al.*, 2018; Mpumi *et al.*, 2021a). It is harmful and economically important caterpillars on cabbage crop which seriously injure the *Brassica species* by eating into their hearts (Usui *et al.*, 1987). The severe infestation of the larvae is contributed by the reproductive capacity of the females whereby a single adult female can lay as many as an average of 350 eggs at once (Schellhorn, 1995). The larvae feed under a web of silk on young leaves, petioles, soft tissues and growing points of the *B. oleracea* crop destroying it entirely and causing death (Murthy *et al.*, 2005). A single larva causes a serious severe damage to the leaves and the hearts of *B. oleracea* in the field (Astuti *et al.*, 2018; Usui *et al.*, 1987). A low population of larvae can cause a very huge damage up to 100% to the *B. oleracea* crops (Badjo *et al.*, 2015). When the shoots of *Brassica species* crops are seriously affected, the young plant can either die or results into formation of unmarketable multiple heads on relatively older plants (Mpumi *et al.*, 2020). The *C. binotalis* larvae infest crucifer crops like white cabbage, broccoli, cauliflower, radish and mustard severely causing a huge yield loss (Badjo *et al.*, 2015). Larvae can travel simply two and above meters in search of a suitable host plant (Murthy *et al.*, 2005). The distribution area of the insect pest is reported in South Africa, Australia, South and Southeast Asia and the Pacific Islands (Kalshoven, 1981).

Although *C. binotalis* pest can be controlled by cultural and biological methods but these methods are insufficient to effectively control of the pest. In Africa, smallholder vegetable growers often intensively apply synthetic pesticides to improve and increase the crop yield, together with increasing the economic benefits (Bolor *et al.*, 2018). Synthetic pesticides are highly effective to control *Crocidolomia species* when is applied twice a week and when two or more insecticides are mixed together, but unwise use have been associated with contaminations of foods, water and soil (Koul *et al.*, 2004; Ntow *et al.*, 2006). Also, synthetic pesticides have been linked with insect pests' resistance development (Kalshoven, 1981). For instance, Koul (2004) reported that, less than 1% of pesticides applied in order to protect crops from insect pests, reach the target pests, whilst more than 99% kill non-target organisms, contaminate soil, air, water and foods. Contamination of foods result into food poisoning to human being which can lead to chronic conditions such as cancerous diseases and disruption of reproductive hormones (Asante and Ntow, 2009; Mpumi *et al.*, 2021b). Moreover, Darko and Akoto (2008) revealed that, about three million people are exposed to pesticide poisoning each year worldwide and approximately 20,000 deaths are linked straightly to the use of pesticides. In developing countries, food products usually have pesticide residues beyond the maximum limit (Boyer *et al.*, 2012). Moreover, synthetic pesticides persist in the soil for many years and destroy soil ecosystems which eventually interfere the soil fertility and productivity (Darko and Akoto, 2008; Mpumi *et al.*, 2020).

In order to reduce the negative effects of synthetic pesticides, sustainable and safer alternative tactics for managing *C. binotalis* in *B. oleracea* crop should be considered by smallholders of *B. oleracea* growers in African countries. Strong enough, the world's plants are rich reservoir of phytochemicals which can be widely used in place of synthetic pesticides for the protection of crops and crucifers from insect pests (Bernard *et al.*, 2012). Phytochemicals also are called botanicals are the chemical compounds which can be extracted from plants and serves many purposes from traditional medicines to pesticides. The use of phytochemicals for insect controls are more friend and safer to the environment compared with synthetic pesticides. Phytochemicals can act as larvicide, ovipositor attractant, insect growth regulators and repellent (Bempah *et al.*, 2011; Bempah and Donkor, 2011). Moreover, the phytochemicals are safer to non-target organisms, less persistence, less toxic to human being and therefore can be more preferable serve as alternative to synthetic insecticides (Charleston *et al.*, 2006). Most groups of phytochemicals like steroids, terpenoids, phenolics, flavonoids, alkaloids and essential oils obtained from different plants have previously been reported to have insecticidal activities against insect pests in crops (Ghosh *et al.*, 2012; Kawuki *et al.*, 2005).

For instance, phytochemicals extracted from *Cassia sophera, Ocimum americanum, Securidaca longepedunculata, Synedrella nodiflora, Capsicum frutescens*, *Allium sativum* and *Carica papaya* have been reported for various insect pest controls in cereal crops (Bempah and Donkor, 2011) either in the field or during storage. Moreover, Kawuki *et al.* (2005) reported that, crude extracts of tobacco and *Tephrosia sp.* were effective relative to Cypermethrin and Fenitrothion for reducing the damage caused by bruchid beetle, *Callosobruchus sp.* in cowpea. However, there are limited information about insecticidal efficacy of the aqueous extracts from *S. aromaticum*, *T. vogelii* and *C. dichogamus* against *C. binotalis* larvae insect pest despite the potentialities of these plants as insecticides, repellents and ant-feedants. For example, *T. vogelii* is commonly known as “fish-poison bean” (Orwa *et al.*, 2009) and has been used by Many smallholder farmers in African countries to eliminate ticks, lice, scabies and mites on livestock and also have been used as medicines in treatments of skin diseases (Munthali *et al.*, 2014). Also, according to Kamatou *et al.* (2012), the extract from *S. aromaticum* possesses a spicy characteristic which discourage insect from feeding the plants. Therefore, the spicy characteristic of *S. aromaticum* extract is essential in protecting crops from insect pests during storage (Araujo *et al.*, 2016; Tian *et al.*, 2015) and can be used in the protection of *B. oleracea* against *C. binotalis*. Moreover, *C. dichogamus* is used as traditional medicines for the treatment of numerous health complications such as constipation, cancer, diabetes, digestive problems and dysentery (Aldhaher *et al.*, 2017; Silva *et al.*, 2018). Therefore, this study reports the environmental benign control of the aqueous extracts obtained from *Syzygium aromaticum*, *Tephrosia vogelii* and *Croton dichogamus* against *Crocidolomia binotalis* in the field grown *B. oleracea* crops.

Methodologies and materials

Study location

This study used the methods of Mpumi *et al.* (2021b) with slight adjustments. The field experiments were conducted between July and November in 2019 and 2020 season in Northern part of Tanzania for the aim of studying the efficacy of aqueous extracts obtained from *C. dichogamus, T. vogelii* and *S. aromaticum* against *C. binotalis* on *B. oleracea* fields. The experimental sites were located in Arusha and Kilimanjaro regions, of Tanzania. In Arusha region, the experimental plots were laid out at Tengeru located at latitude 3°23′4.5′′S and longitude 36°48′26.7′′E at an elevation of 1262 m above sea level (Mpumi *et al.*, 2021b) in both seasons. The total rainfall precipitations were 566.4mm and maximum temperature ranged from 25.9 to 34.5 ℃ in 2019 season (Mpumi *et al.*, 2021a). In 2020 season, the total annual rainfall precipitations were 2029.7mm and the maximum temperature ranged from 26.1 to 31.9 ℃ (Mpumi *et al.*, 2021b) and humidity ranged from 78 to 80% in both seasons. In Kilimanjaro region, the experimental plots were laid out at Boro 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 both seasons. The total annual rainfall precipitations were 1184.4mm and the maximum temperature ranged from 21.1 to 30.2 ℃ in 2019 season (Mpumi *et al.*, 2021a) whereas in 2020 season, the total rainfall precipitations were 1674.9mm and the maximum temperature ranged from 22.7 to 28.3 ℃ (Mpumi *et al.*, 2021b). The humidity ranged from 78 to 80% in 2019 season while in 2020 season the humidity ranged from 80 to 86%.

Collection, drying and grinding of plant materials

The fresh leaves from *T. vogelii* and *C. dichogamus* were collected from different locations in Manyara, Arusha and Kilimanjaro regions in Tanzania, around the roads and homes of the residents. The flower buds of *S. aromaticum* were collected from Tanga region.

The plant leaves were washed thoroughly with water and then 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 powder using electric blender. The powder was then extracted separately by using water and soap to get the aqueous plant extracts for field applications. Liquid soap was used in the extraction process in order to extract compounds which are not water soluble from plant materials and to spread the extract onto the plant leaves more efficiently during treatments applications (Mpumi *et al.*, 2021a).

Land preparation and transplanting

Clearing and preparation of land was performed before seedling transplanting. The land was ploughed and harrowed before seedlings transplanting at both sites using a plough and a hand hoe in both seasons. The seeds of *B. oleracea* were sown nearby the study plots in 2019 and 2020 seasons. Then after one month a week, the seedlings were transplanted into the experimental plots laid out in the middle of July to November (2019 and 2020) seasons at both sites. The spacing of *B. oleracea* seedling crops was 50cm between the rows and 45cm within the rows in the study plots. The plot size was 2.0m × 2.5m at both experimental sites. The distance from one plot and another plot was 0.5 m. Each treatment plot contained 12 *B. oleracea* crops. Watering was done in the morning and in the evening for one week after transplanting, then it was done once a day throughout the growing of the crops.

Experimental design and treatments preparation

The experiment was conducted in a Randomized Complete Block Design (RCBD) with 14 treatments replicated four times. The treatments contained of aqueous plant extracts of three plants (*C. dichogamus, T. vogelii* and *S. aromaticum*), a positive control (chlorpyrifos) and two negative controls (water and water plus soap). Three concentrations 1%, 5% and 10% w/v of aqueous extract from each plant was prepared. One percent (1%), five percent (5%) and ten percent 10% of aqueous plant extracts were made by dissolving 10g, 50g and 100g of the plant powder in one litre of water, respectively. In each concentration, 0.1% soap was used during the extraction of the compounds from the pesticidal plant materials in water. In this case there was 12 treatments in each site with 4 plot replicates of each treatment randomly across the field making a total of 48 plots. Aqueous plant extracts with combination of the plants were prepared by mixing 25g and 50g from each plant (*T. vogelii, C. dichogamus* and *S. aromaticum*) in equal ratio and dissolved in one litre of water (w/v) separately to make 2.5% and 5% concentrations respectively. Therefore, the on-station field contained 56 treatment plots. Mixing of the plant material was done to evaluate the synergistic insecticidal action of extracts from *S. aromaticum, C. dichogamus* and *T. vogelii* against *C. binotalis* pests on *B. oleracea* crop field.

Treatment applications

The aqueous plant extracts were applied into the *B. oleracea* crops in the field at the interval of 7 days throughout the growing season of the *B. oleracea* crops. The concentration of the synthetic pesticide (chlorpyrifos) was applied as per manufacturers' recommendations. The aqueous plant extracts were applied, on top and under the leaves of *B. oleracea* crops by using a 2L sprayer during the evening in the whole growing period of the *B. oleracea* crops. The spraying was done during evening hours in order to avoid direct sun light which may cause the decomposition of bioactive compounds of the botanicals (Mpumi *et al.*, 2021). Each plot required approximately 250mL per spray at both study sites. The sprayer was thoroughly washed with water and soap before re-filling it again with another formulation for application.

Counting of C. binotalis and cabbage plants' damage assessment

C. binotalis larvae were counted one day before application of the treatments by randomly selecting five inner *B. oleracea* crops inside the plot each week. Assessment of damage severity of *B. oleracea* was conducted through counting and recording the number of leaves damaged and head of *B. oleracea* crops. Also, the damage severity assessment was done by observation of the extent of damage through counting the total number of plant parts damaged and were differentiated into four scale; 0% damage, 0 - 25% damage, 26 - 50% damage, 51 - 75% damage and 76 -100% which depend up on the number of leaves and head damaged (Mkenda *et al.*, 2015)

Data Analysis

The field data collected were analyzed using three-way Analysis of Variance by STATISTICA software program. The Fisher's Least Significance Difference (LSD) was used to compare treatment means at P = 0.05 level of significance. The graphs were drawn by using excel software.

Results

The response of C. binotalis larvae per plant to the treatments

In the field experiment, *C. binotalis* larvae was identified on the *B. oleracea* crops in the 4th week after transplanting and the population increased quickly during the head formation. The larvae were found hidden within the wrapper leaves, completely shielded from the sun. Basing on seasons, the results show that, the mean population of *C. binotalis* was significantly (P ≤ 0.05) lower (0.37 ± 0.07, 0.34 ± 0.06, 0.36 ± 0.07) in 2019 season compared with 2020 season (0.48 ± 0.08, 0.52 ± 0.08, 0.59 ± 0.09) on weeks 3, 4 and 5 after treatment applications, respectively (Table 1). But on week 1 before treatment applications, weeks 1 and 2 after application of the treatment, the population abundance of *C. binotalis* was significantly the same (Table 1) between the two seasons. In addition, the mean population abundance of *C. binotalis* varied significantly (P ≤ 0.05) between Tengeru study site and Boro study site from week 1 to week 6 during the experiments (Table 1). In week 1 before and week 3 after application of the treatments, the population abundance of *C. binotalis* was significantly lower (0.26 ± 0.02 and 0.32 ± 0.06) at Tengeru study site compared with Boro study site (0.33 ± 0.03 and 0.53 ± 0.09), respectively (Table 1). But it was vice versa in weeks 1 and 5 after treatment applications at both study sites. In weeks 2 and 4 after application of the treatments, the number of *C. binotalis* was significantly the same between the two experimental sites.

Table 1. Mean population of *C. binotalis* per *B. oleracea* crop in response to weekly application of treatments.

Location and Treatments	Week 1 before Treatment	Weeks after treatments (Mean ± SE) 1	2	3	4	5
Seasons						
Season 1 (2019)	0.28 ± 0.02a	0.26 ± 0.05a	0.32 ± 0.06a	0.37 ± 0.07b	0.34 ± 0.06b	0.36 ± 0.07b
Season 2 (2020)	0.31 ± 0.02a	0.25 ± 0.03a	0.34 ± 0.04a	0.48 ± 0.08a	0.52 ± 0.08a	0.59 ± 0.09a
Locations						
Tengeru	0.26 ± 0.02b	0.29 ± 0.05a	0.33 ± 0.06a	0.32 ± 0.06b	0.39 ± 0.06a	0.54 ± 0.03a
Boro	0.33 ± 0.03a	0.22 ± 0.03b	0.33 ± 0.05a	0.53 ± 0.09a	0.47 ± 0.08a	0.41 ± 0.07b
Treatments						
W	0.45± 0.07a	1.01 ± 0.17a	1.44 ± 0.26a	1.91 ± 0.33a	1.86 ± 0.33a	2.29 ± 0.16a
W + s	0.33 ± 0.05a	0.99 ± 0.21a	1.29 ± 0.18a	2.03 ± 0.29a	1.73 ± 0.12a	2.34 ± 0.24a
S. p	0.19 ± 0.06a	0.05 ± 0.02b	0.06 ± 0.02b	0.05 ± 0.02c	0.08 ± 0.03cd	0.06 ± 0.03d
C. d (1%)	0.25 ± 0.05a	0.21 ± 0.05b	0.23 ± 0.04b	0.33 ± 0.05b	0.31 ± 0.05b	0.30 ± 0.05bc
C. d (5%)	0.31 ± 0.06a	0.11 ± 0.03b	0.20 ± 0.05b	0.20 ± 0.06bc	0.28 ± 0.05bc	0.20 ± 0.04bcd
C. d (10%)	0.30 ± 0.06a	0.09 ± 0.03b	0.11 ± 0.03b	0.11 ± 0.04bc	0.20 ± 0.04bcd	0.15 ± 0.05bcd
S. a (1%)	0.33 ± 0.05a	0.28 ± 0.06b	0.24 ± 0.05b	0.34 ± 0.07b	0.35 ± 0.07b	0.31 ± 0.08b
S. a (5%)	0.28 ± 0.05a	0.18 ± 0.06b	0.19 ± 0.05b	0.25 ± 0.07bc	0.18 ± 0.05bcd	0.16 ± 0.04bcd
S. a (10%)	0.33 ± 0.04a	0.13 ± 0.04b	0.14 ± 0.04b	0.13 ± 0.03bc	0.13 ± 0.03bcd	0.13 ± 0.04bcd
T. v (1%)	0.25 ± 0.06a	0.16 ± 0.05b	0.23 ± 0.07b	0.24 ± 0.08bc	0.34 ± 0.07b	0.33 ± 0.04b
T. v (5%)	0.26 ± 0.06a	0.11 ± 0.05b	0.18 ± 0.04b	0.15 ± 0.06bc	0.21 ± 0.05bcd	0.13 ± 0.04bcd
T. v (10%)	0.30 ± 0.06a	0.08 ± 0.03b	0.11 ± 0.03b	0.08 ± 0.03bc	0.11 ± 0.04cd	0.09 ± 0.03cd
M. p. (2.5%)	0.25 ± 0.03a	0.14 ± 0.04b	0.11 ± 0.04b	0.11 ± 0.04bc	0.19 ± 0.04bcd	0.13 ± 0.04bcde
M. p. (5%)	0.34 ± 0.05a	0.05± 0.03b	0.08 ± 0.03b	0.03 ± 0.02c	0.04 ± 0.02d	0.05 ± 0.03d
3 - way ANOVA	(F- Statistics)					
Season (S)	0.80ns	0.16ns	0.44ns	6.93**	16.89***	30.21***
Location (L)	7.21**	2.68*	0.02ns	21.69***	3.49ns	9.27***
Treatments (T)	1.35ns	18.12***	45.35***	64.33***	53.20***	98.34***

Location and	Week 1 before	Weeks after treatments (Mean ± SE)				
S * L	31.65***	15.48***	70.23***	46.85***	23.59***	0.01ns
S * T	0.75ns	2.63**	4.54***	1.44ns	0.56ns	1.31ns
L * T	0.98ns	0.44ns	0.25ns	4.22**	3.47***	1.06ns
S * L * T	0.80ns	1.80ns	9.28***	13.07***	17.35***	1.94ns

Each value is a mean ± standard error of sixteen 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 Fisher's 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* and M. p- mixed plants

The insecticidal action of the aqueous extracts from *C. dichogamus, T. vogelii,* and *S. aromaticum* differed significantly (P ≤ 0.05) among the treated plots in the field relative to negative controls in both study sites in the two seasons (Table 1). It was found that the aqueous extracts from *C. dichogamus, T. vogelii* and *S. aromaticum* were significantly (P ≤ 0.05) as effective as synthetic pesticide on week 1 and 2 after treatment applications (Table 1).

But the 5% concentration of the extract from the mixed plants, had significantly (P ≤ 0.05) lower (0.03 ± 0.02, 0.04 ± 0.02, 0.05 ± 0.03) mean number of *C. binotalis* compared with other concentrations of aqueous extracts on weeks 3, 4 and 5, respectively (Table 1). Moreover, 1, 5 and 10% of the extracts from *T. vogelii, C. dichogamus* and *S. aromaticum* and 2.5% of the aqueous extracts from the mixed plants, significantly reduced the mean number of *C. binotalis* compared with the negative controls (Table 1).

The interactive effect of experimental sites' weather conditions, seasons and treatments significantly (P ≤ 0.05) enhanced the reduction of the number of *C. binotalis* compared with the negative controls in the plots in weeks 1, 2, 3, 4 and 5 of the experimental treatments (Fig. 1 & 2). The interaction effects among experimental sites' weather conditions, treatments and seasons significantly (P ≤ 0.05) enhanced the reduction of the number of *C. binotalis* compared with the negative controls (water and water plus soap) in the plots (Fig. 2).

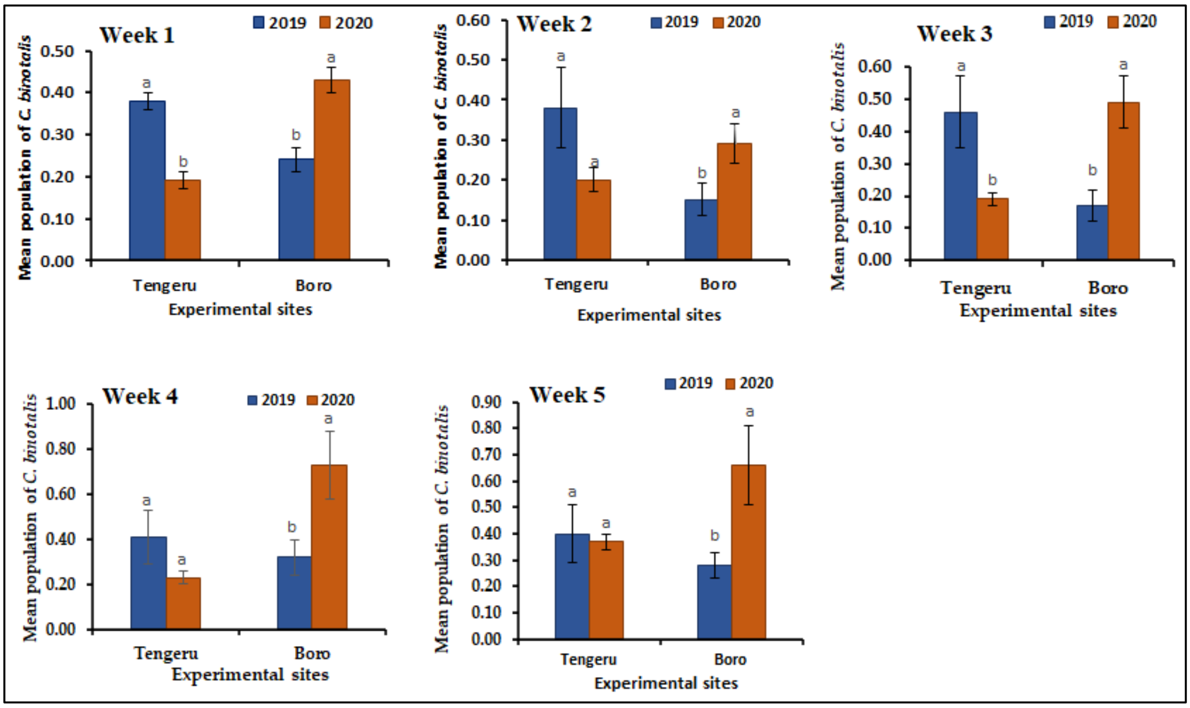

Fig. 1. Interactions of experimental sites with the seasons for reduction of the *C. binotalis* (Week 1, 2, 3, 4 and 5) in 2019 and 2020 seasons.

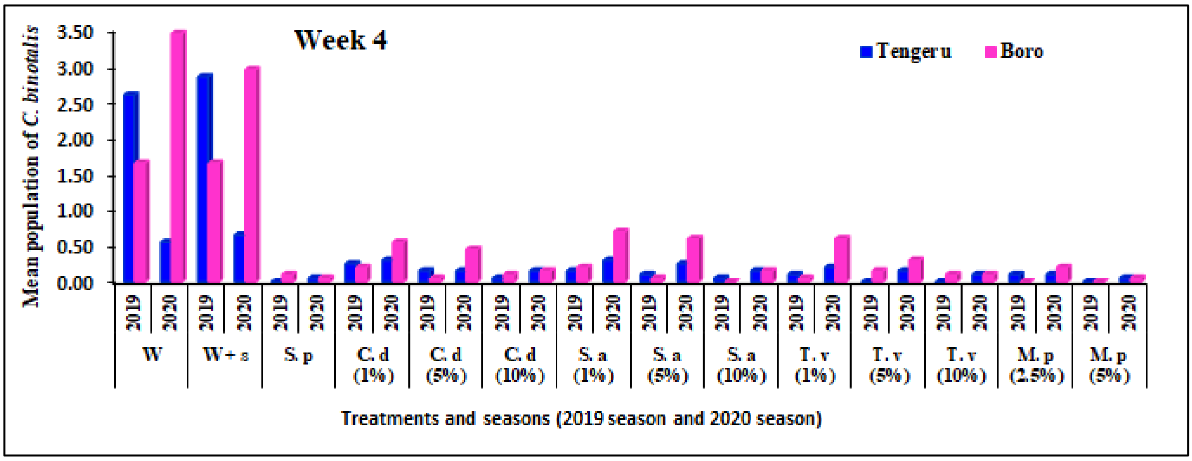

Fig. 2. Interactions of treatments, sites' weather conditions and seasons for reduction of *C. binotalis* (Week 4). Note: W - water, w + s- Water plus soap, S. p- Synthetic pesticide, *C. d- Croton dichogamus*, *S. a- Syzygium aromaticum*, *T. v- Tephrosia vogelii* and M. p - mixed plants

The percent damage of B. oleracea

The percentage damage of *B. oleracea* was significantly (P ≤ 0.05) higher (15.3 ± 1.2, 17.5 ± 1.5, 18.8 ± 1.7) in 2020 season compared with 2019 season (13.7 ± 1.0, 14.6 ± 1.1, 15.0 ± 1.3) from week 2 to 4 after treatment applications, respectively (Table 2). But the percentage damage was significantly the same on week 1 and 5 after applications of the treatments in both seasons (Table 2) which might be contributed by higher population of *C. binotalis* observed in 2020 season compared with 2019 season. In addition, percent damage varied significantly between Tengeru study site and Boro study site (Table 2). In week 1 before and weeks 1, 2 after applications of the treatments the percentage damage of *B. oleracea* was significantly lower 14.7 ± 0.6, 12.2 ± 0.8 and 13.3 ± 1.1) at Boro study site compared with Tengeru study site (20.1 ± 0.7, 16.4 ± 0.9 and 15.6 ± 1.1), respectively (Table 2). In weeks 3 and 5 after treatment applications, the percentage damage of *B. oleracea* was significantly the same between the two study sites. But in week 4 the percentage damage was significantly higher (17.8 ± 1.7) at Boro study site relative to Tengeru study site (16.0 ± 1.2).

Table 2. Mean damage (%) per *B. oleracea* crop on weekly bases for 2019 and 2020 seasons.

Location and	Week 1 before	Weeks after treatments				
Treatments	Treatment	1	2	3	4	5
Seasons						
Season 1 (2019)	15.1 ± 0.8b	14.1 ± 1.0a	13.7 ± 1.0b	14.6 ± 1.1b	15.0 ± 1.3b	18.4 ± 1.9a
Season 2 (2020)	19.6 ± 0.5a	14.5 ± 0.8a	15.3 ± 1.2a	17.5 ± 1.5a	18.8 ± 1.7a	19.8 ± 1.9a
Experimental sites						
Tengeru	20.1 ± 0.7a	16.4 ± 0.9a	15.6 ± 1.1a	15.5 ± 1.3a	16.0 ± 1.2b	19.6 ±1.6a
Boro	14.7 ± 0.6b	12.2 ± 0.8b	13.3 ± 1.1b	16.6 ± 1.5a	17.8 ± 1.7a	18.7 ± 2.1a
Treatments						
W	20.6 ± 1.9a	32.8 ± 3.1a	37.2 ± 3.0a	44.4 ± 3.8a	47.8 ± 3.5a	65.0 ± 3.2a
W + s	19.4 ± 2.5a	27.8 ± 2.9a	35.0 ± 2.5a	45.3 ± 2.9a	50.0 ± 4.4a	61.6 ± 2.7a
S. p	17.8 ± 1.9a	9.1 ± 1.7d	4.7 ± 1.1f	4.7 ± 1.1f	5.3 ± 1.2fg	4.4 ± 1.1g
C. d (1%)	17.8 ± 1.4a	16.3 ± 1.8b	16.9 ± 1.6b	17.8 ± 1.4b	18.4 ± 1.3b	20.0 ± 1.4b
C. d (5%)	18.1 ± 2.0a	11.6 ± 0.9bcd	15.0 ± 2.0b	15.6 ± 1.9bcd	15.0 ± 1.3bcd	15.0 ± 1.7cd
C. d (10%)	15.6 ± 1.5a	10.6 ± 1.0cd	9.1 ± 1.1cdef	9.4 ± 1.1ef	10.6 ± 1.6def	10.0 ± 1.8ef
S. a (1%)	16.3 ± 1.5a	14.7 ± 1.7bc	16.3 ± 1.3b	17.8 ± 1.7b	19.4 ± 1.3b	20.0 ± 1.6b
S. a (5%)	15.0 ± 1.5a	12.5 ± 1.5bcd	13.1 ± 0.9bc	11.6 ± 1.6cde	12.2 ± 1.4cde	12.5 ± 1.5de
S. a (10%)	16.6 ± 1.6a	10.0 ± 1.4cd	10.0 ± 1.6cd	9.4 ± 1.7ef	10.3 ± 1.4def	10.0 ± 1.4ef
T. v (1%)	14.4 ± 1.8a	13.4 ± 1.2bcd	15.9 ± 2.3b	16.6 ± 1.4bc	16.6 ± 0.9bc	18.8 ± 1.5bc
T. v (5%)	17.8 ± 1.9a	11.6 ± 0.9bcd	9.4 ± 1.0cde	10.6 ± 1.1de	9.7 ± 1.2efg	10.6 ± 1.6def
T. v (10%)	15.6 ± 1.4a	10.6 ± 1.5cd	6.3 ± 1.1def	6.9 ± 0.9ef	7.2 ± 1.1efg	6.9 ± 1.1fg
M. p. (2.5%)	19.4 ± 2.2a	10.6 ± 1.0cd	8.4 ± 1.0def	10.3 ± 1.5e	9.7 ± 1.6efg	8.8 ± 1.7efg
M. p. (5%)	19.1 ± 2.3a	8.8 ± 1.7d	5.3 ± 1.0ef	4.4 ± 0.9f	4.4 ± 1.0g	4.4 ± 1.4g
3 - way ANOVA						

Location and Treatments	Week 1 before Treatment	Weeks after treatments				
		1	2	3	4	5
Season (S)	31.91***	0.25ns	4.10*	14.07***	17.86***	3.18ns
Experimental sites (L)	45.80***	26.45***	8. 56**	2.00ns	3.94*	1.19ns
Treatments (T)	1.56ns	22.44***	45.70***	75.59***	76.00***	178.72***
S * L	34.49***	35.01***	18.28***	2.64ns	2.49ns	9.29**
S * T	0.58ns	0.66ns	1.61ns	2.37ns	2.71ns	4.36***
L * T	0.98ns	1.00ns	0.59ns	1.76ns	2.62ns	3.43**
S * L * T	1.08ns	1.61ns	2.85ns	5.37***	1.94ns	1.63ns

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= 0.0 from each other using Fisher's 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* and M. p- mixed plants

The treatments applied significantly (P ≤ 0.05) lowered the percentage damage of *B. oleracea* in the field. It was found that, the percentage damage of *B. oleracea* in the 5% concentration of aqueous extract from the mixed plant treated plots was significantly (P ≤ 0.05) lower (8.8 ± 1.7, 5.3 ± 1.0, 4.4 ± 0.9, 4.4 ± 1.0, 4.4 ± 1.4) as in chlorpyriphos treated plots (9.1 ± 1.7, 4.7 ± 1.1, 4.7 ± 1.1, 5.3 ± 1.2, 4.4 ± 1.1) from weeks 1 to 5 after applications of the treatments, respectively (Table 2). Then, it was followed by the 10% concentration of aqueous extracts from *C. dichogamus, T. vogelii,* and *S. aromaticum*. However, 1 and 5% concentrations of the individual plants and the 2.5% concentration of aqueous extract from the mixed plants significantly reduced the percentage damage of *B. oleracea* relative to the negative controls (Table 2).

Moreover, the interactive effect of study sites' weather conditions and seasons significantly (P ≤ 0.05) enhanced the lowering of the damage percentage of *B. oleracea* compared with the negative controls (water and water plus soap) in the plots in the weeks 1, 2, 3 and 6 of the treatment experiments (Fig. 3). Moreover, the interactions among of experimental sites' weather conditions, treatments and seasons significantly (P ≤ 0.05) enhanced the reduction of the percentage damage of *B. oleracea* compared with the negative controls (water and water plus soap) in the plots in week 4 of the experimental treatments (Fig. 4).

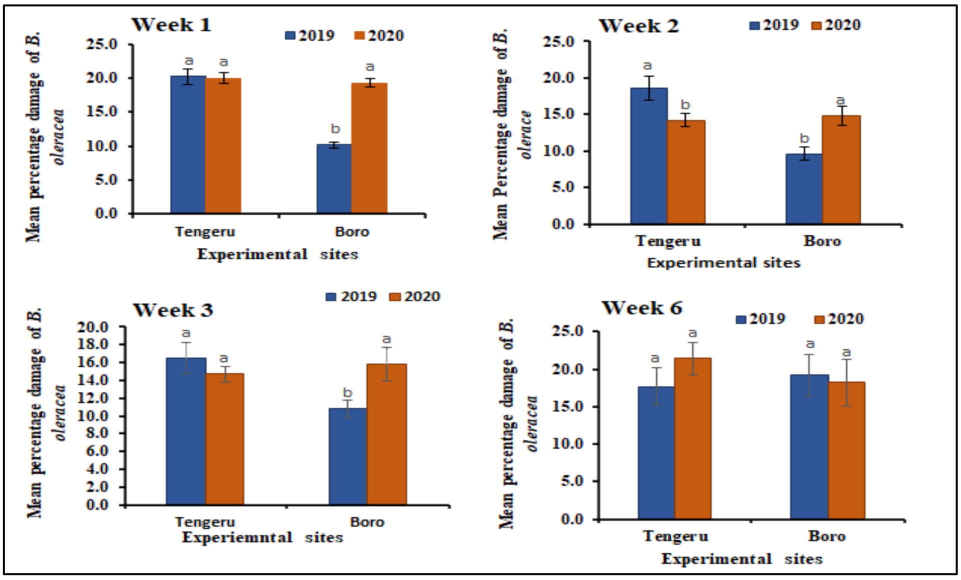

Fig. 3. Interaction of experimental sites with the seasons for reducing the damage of *B. oleracea* (Week 1, 2, 3 and 6) in 2019 and 2020 seasons.

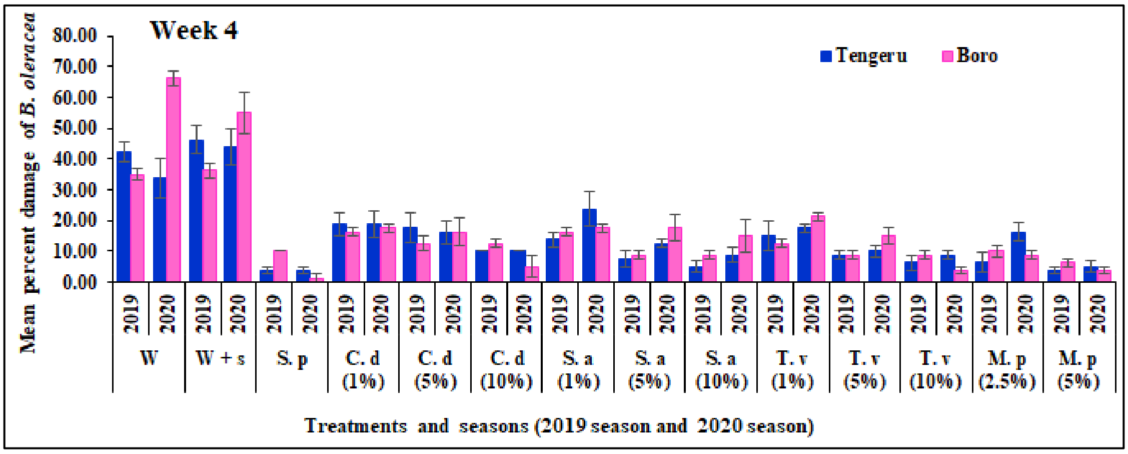

Fig. 4. Interactions of experimental sites, seasons and treatments for reduction of the damage of *B. oleracea* (Week 4) in 2019 and 2020 seasons.

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

The relationship between the population abundance of C. binotalis larvae and the % damage of B. oleracea crop

Fig. 5 shows the relationship between the mean number of *C. binotalis* and the percentage damage of *B. oleracea*. The percentage damage was highly related with the population abundance of *C. binotalis* larvae (Fig. 5). It was discovered that, the percentage damage of *B. oleracea* was highest in the negative controls (water and water plus soap) as there was larger number of *C. binotalis* larvae compared with the synthetic pesticide and plant extract treatments. Also, the percent damage was lowest in the synthetic pesticide used (chlorpyrifos) followed by 5% of the mixture of aqueous plant extracts (Fig. 5) because the number of *C. binotalis* larvae were also low. Moreover, in 10% of *S. aromaticum, C. dichogamus* and *T. vogelii* extracts, the percentage damage was also lower (Fig. 5) as there was lower population abundance of *C. binotalis* larvae compared with 1 and 5% of the aqueous extracts which possessed higher number of *C. binotalis* larvae. But *T. vogelii* (5%), *S. aromaticum* (5%) and *C. dichogamus* (5%) plots possessed lower percentage damage of *B. oleracea* crop compared with 1% of aqueous extracts from each pesticidal plant (Fig. 5) due to lower population abundance of *C. binotalis* larvae. However, 1% concentrations of the aqueous extracts of the *T. vogelii*, *S. aromaticum* and *C. dichogamus* had lower percentage damage of *B. oleracea* compared with

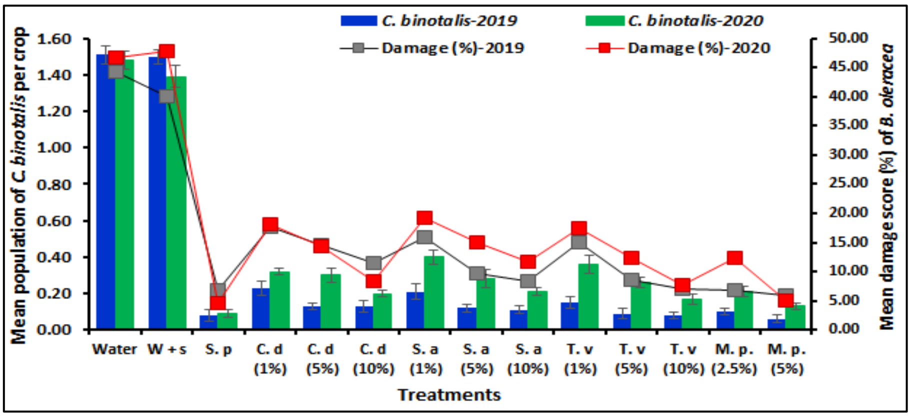

Fig. 5. The relationship of the population abundance of *C. binotalis* larvae and damage (%) of *B. oleracea*.

Note: W + s- Water plus soap, S. p- Synthetic pesticide, *C. d- Croton dichogamus*, *S. a- Syzygium aromaticum*, *T. v- Tephrosia vogelii* and M. p- mixed plants

With negative controls (water and water plus soap) due to higher populations *C. binotalis* larvae (Fig. 5). Furthermore, the percentage damage of *B. oleracea* was slightly higher in 2020 season compared with 2019 season which could be contributed by slightly higher mean number of *C. binotalis* (Fig. 5).

Discussion

This study reports the environmentally benign control of *C. binotalis* on *B. oleracea* crops in the fields. The assessment of the efficacy of the aqueous extracts of *S. aromaticum*, *T. vogelii* and *C. dichogamus* against *C. binotalis* larvae in the field was conducted. Two study sites were established. The results show that, *C. binotalis* larvae began to infest the *B. oleracea* plant in the field on the 4th week after transplanting. The aqueous extracts from *S. aromaticum, C. dichogamus* and *T. vogelii* were as effective as synthetic pesticides in lowering of the population of *C. binotalis* and the damage of *B. oleracea* crop. The aqueous extracts form mixed plants at 5% concentration was the most effective for controlling *C. binotalis* larvae which as a result significantly ($P \leq 0.05$) reduced the percentage damage of the *B. oleracea* crop in the fields. The effectiveness of the 5% concentration of aqueous extracts from the mixed plants might be contributed by the presence of the mixture of phytochemical compounds found in the extracts from *S. aromaticum, C. dichogamus* and *T. vogelii* which could have enhanced the reduction of the population of *C. binotalis* and the damage of *B. oleracea*. The results of effectiveness of mixed botanicals concur with Tak and Isman (2017) who indicated that, the mixture of chemical compounds in plants can enhance the insecticidal effect of the extracts. Generally, plants make and produce several secondary metabolites either for defense, production of signal to trap predators or to discourage herbivores while approaching to the plants for feeding (Tak *et al*., 2016).

Apart from that, the aqueous plant extracts used in this study was more effective in lowering of the number of *C. binotalis* larvae and the damage of *B. oleracea* crop compared with the negative controls. The results of this study concur with the earlier studies (Belmain *et al*., 2012; Do Ngoc Dai *et al*., 2015; Grzywacz *et al*., 2014). For example, Grzywacz *et al*. (2014) and Belmain *et al*. (2012) showed that, the insecticidal effect of extracts from pesticidal plants against insect pests is contributed by the presence of botanicals in the plants. In *T. vogelii* there are rotenone, deguelin, sarcolobine, α-toxicarol and tephrosin (Belmain *et al*., 2012) which mighty be responsible for the control efficacy of this plant against *C. binotalis* larvae on *B. oleracea* crop. Also, the aqueous extracts from *S. aromaticum* significantly ($P \leq 0.05$) reduced the *C. binotalis* relative to negative controls. The results of this study concur with Araujo *et al*. (2016) and Tian *et al*. (2015). For instance, Araujo *et al*. (2016) reported that, *S. aromaticum* contains eugenol, β-caryophyllene, α-humulene and eugenol acetate whereby, eugenol is the most effective chemical compound, which mighty be responsible for the control of *C. binotalis* in the field. Moreover, the report of this study is in line with Tian *et al*. (2015) who indicated that, *S. aromaticum* has a variety of pharmacological activities including analgesic, anticancer activities, anti-inflammatory, antimicrobial and anti-oxidant. Therefore, these potentialities can be used by African smallholder growers to protect *B. oleracea* crops against *C. binotalis* in the field. Moreover, *C. dichogamus* aqueous extracts significantly ($P \leq 0.05$) reduced the number of *C. binotalis* relative to negative controls. These results agree with the report of Aldhaher *et al*. (2017) and Silva *et al*. (2018) who discovered that, the *Croton species* contain alkaloids, phenolics and terpenoids possessing toxicity, repellent and deterrent effects to various insect pests. Therefore, these botanicals mighty be accountable for the insecticidal and larvicidal activity against *C. binotalis* on *B. oleracea* crops in the field.

Interactive effectiveness of weather conditions of the study sites, seasons and treatments was also observed in some weeks of application of aqueous plant extracts for the control of *C. binotalis* larvae in the field. The interaction of weather conditions of the study sites with the seasons significantly ($p \leq 0.05$)

enhanced the reduction of the population of *C. binotalis* larvae and the damage compared with the negative controls.

The interactions of weather conditions, seasons and the treatments could be contributed by the variations of the weather conditions and vegetation density of the experimental sites which could have enhanced the culturing of the natural enemies which together with plant extracts, limited the growth and survivorship of *C. binotalis* larvae. Therefore, it can become easy and cheap for African smallholder cabbage growers to manage *C. binotalis* in different regions depending on the weather conditions of the regions using the botanicals as alternative strategy to synthetic pesticides.

Conclusion

The decrease in population of *C. binotalis* larvae and damage of *B. oleracea* on the treated plots indicates the efficacies of the extracts of *S. aromaticum*, *T. vogelii* and *C. dichogamus* against *C. binotalis* larvae. The mixing of the plant materials during extractions enhanced the insecticidal activity and broadened the spectrum of efficacies in reduction of the number of *C. binotalis* and the damage of *B. oleracea* in the fields compared with the negative controls and individual plant concentrations at lower concentrations. Therefore, the present study proposes the use of aqueous extracts from *S. aromaticum*, *T. vogelii* and *C. dichogamus* at higher concentrations (10%) and the aqueous extracts of the mixture of these plants at 5% concentrations as an ecofriendly insecticide in place of synthetic pesticides for the control of *C. binotalis* at larvae stages.

Author Contributions

All authors read and approved the final manuscript for Publication.

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Conflicts of interest

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

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