



ARTICLE

Controlling Greenhouse Whitefly with *Erectomocerus eremicus* Rose & Zolnerowich and Crude Plant Extracts of Garlic and Chilli Improves Yield of Tomato

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ABSTRACT

Despite its economic importance of tomato (*Solanum lycopersicum* L.), many growers are unable to achieve maximum yield of high quality due to insect pest infestation. This study was aimed at determining the effectiveness of parasitoid *Erectomocerus eremicus* and crude plant extracts of garlic and chilli as an integrated alternative control method of greenhouse whitefly (GHW) on yield of tomato variety “Anna F1”. The study was conducted at Egerton University using a split plot arrangement in randomized complete block design, replicated three times. Parasitoid was the main plot factor at two levels (with and without *E. eremicus*) while sprays of distilled water (negative control), Abamectin (positive control), chilli and garlic extracts formed the sub-plot factors. Data on GHW incidence, population density, parasitisation rate, and yield was collected. Data collected was subjected to analysis of variance and means of significant treatments separated using Tukey’s test at $p = 0.05$. Botanical extracts and *E. eremicus* helped to control whitefly population, infestation, and in enhancing growth and yield of greenhouse tomato plants compared to where they were not applied. Botanical plant extracts and/or *E. eremicus* can be used in the management of GHW and to improve tomato yields.

1. Background Information

Tomato (*Solanum lycopersicum* L) is one of the most widely consumed vegetables worldwide. Its popularity stems from the fact that it has several uses ranging from being eaten fresh as a salad to multiple forms of processed products. Three of the major processed products include: i) tomato preserves which are whole peeled tomatoes, tomato juice, tomato pulp, tomato purée, tomato paste and pickled tomatoes; ii) dried tomatoes including forms like tomato powder, tomato flakes, dried tomato fruits and iii) tomato-based foods including tomato soup, tomato sauces, chilli sauce and ketchup. It has high nutritional value

with important vitamins, mineral and antioxidants^[30]. Consumption of tomato has been associated with the prevention of several diseases mainly due to the content of anti-oxidants, such as carotenes, ascorbic acid, tocopherol and phenolic compounds^[6,25].

Worldwide, tomato is the second most important vegetable crop after potato. Current world production stands at about 1.68 billion tons on approximately 3.2 million hectares (ha) of land. China is currently the largest producer of the crop in the world with an annual production of 50,664,255 tons under an area of 920,803 ha while Egypt is the largest producer in Africa with a total of 8,533,803 tons in 212,946 ha of land. Kenya is also among the major

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producers of tomato, ranking 37th in the world and 8th in Africa with a total production of 503,172 tons on 61,385 ha of land ^[10]. In the country, tomato is still among the most commonly grown and consumed vegetables ranking second to potato in value and fourth in the area under production among vegetable crops grown (HCD, 2017) ^[15]. Tomato is one of the promising horticultural crops for agricultural expansion and development programmes in Kenya, accounting to about 14% of the total vegetable produce and 6.72% of the total horticultural crops ^[15]. With the availability and pricing of the produce in the market mostly dictated by weather conditions ^[15], the demand for the crop remains high throughout the year, ensuring a ready market.

In Kenya, large acreages are under the crop with yields averaging 8.2 tons per ha being recorded against a world average of 52.1 tons per ha ^[10]. This yield difference has been attributed to a number of biotic and abiotic stresses, mainly diseases, nematodes and insect pests. The greenhouse whitefly (GHW) is a significant pest of vegetables and many ornamental plants in greenhouses. Over two hundred and fifty plant species most of which are vegetables have been identified as hosts for GHW worldwide (Osborne and Landa, 1992) ^[24]. This pest damages plants in three ways: by extracting sap from phloem during feeding and reducing the nutrients available to the plant for growth and reproduction ^[4], producing honeydew which supports sooty mould growth on the plant limiting its photosynthetic potential and causing aesthetic damage to fruits, thereby reducing their commercial value ^[16] and by transmitting viruses such as the Tomato Chlorosis Virus, Tomato Yellow Leaf Curl Virus (TYLCV) and Tomato Infectious Chlorosis Viruses ^[18] via its saliva. Closterovirus plant viruses e.g. Beet Pseudo Yellows Virus (BPYV) and Tomato Infectious Chlorosis Virus (TICV) are also transmitted by the GHW.

Numerous conventional manmade pesticide classes have been used in the management of whitefly including pyrethrins, pyrethroids, neonicotinoids and spirocyclic phenyl-substituted tetronic acids ^[9]. Effective use of conventional chemical pesticides has however become difficult due to evolving resistance of whiteflies to most active ingredients. While stringent rules restrict the availability of approved products, consumers have raised concerns over chemical persistence in the environment, which may impact upon non-target and beneficial organisms ^[19].

According to Bale *et al.* ^[3], biological control is an alternative and effective method for managing the GHW in greenhouses, with two main methods identified: classical biological control and augmentative biological control ^[7,28]. In classical biological control, imported organisms

are released which establish themselves and spread to permanently control a pest. Augmentation is a way of building-up the population of a natural enemy that attacks pests. This is mainly through mass production pests in a laboratory and later being released into the field at the appropriate time or breeding a better natural enemy that can attack its prey more effectively. Mass-reared agents can be released at special times when the pest is most susceptible and natural enemies are not yet present, or they can be released in such large numbers that few pests go untouched by their enemies.

Several bio control agents (BCAs) have been used in pest management: *Verticillium lecanii*, predatory mirids, *Bacillus thuringiensis*, *Bauveria bassiana*, *Paecilomyces fumosoroseus* and *Encarsia formosa*. One successful BCA against the GHW is the *E. formosa*. This parasitoid wasp oviposits into the immobile nymphal stages of the whitefly, with the subsequent emerging larvae using the nymphs as a food source ^[13]. Most BCAs are a moderately effective control measure but have several limitations. Multiple releases, mostly on a weekly basis, are required to manage whitefly numbers. Use of BCAs is thus labour-intensive, requiring that wasps be dispensed rapidly after arrival for maximum efficacy.

Bio control agents (BCAs) alone are not always sufficient to reduce whitefly numbers below acceptable thresholds, with bio control often breaking down under extreme pest pressure, or in the face of a natural movement of hyper-parasitoids into the system. In these instances, it becomes necessary to apply chemical pesticides as a “second line of defence” to redress balances between pest and parasitoid or to replace bio-control where it has failed to function due to the appearance of a fourth trophic level that has resulted in pesticides being a key component to tomato greenhouse cultivation ^[11].

Due to the challenges with current control methods of the GHW, alternative methods of reducing the pest impact on crops are currently being sought, with significant recent effort directed to investigating the potential of bio pesticidal and bio-rational products against the GHW ^[11]. Integrated Pest Management (IPM) systems using a combination of predatory mites, soapy water solutions, hot chilli, and garlic are being used by farmers with good control activities although they have not been validated ^[5]. Various plant extracts Tumha (*Cirullus colosynthis*), Datura (*Datura innoxia*) Neem (*Azadirachta indica*), Castor (*Ricinus communis*), Hing (*Firula asafetida*), eucalyptus (*Eucalyptus spp.*), bitter gourd (*Momordica charantia*) and garlic (*Allium sativum*) have been found to have insecticidal, repellent and acaricidal properties effective against Jassid (*Amrasca bugutulla bugutulla*), Whitefly

(*Bemisia tabaci*) and Thrips (*Thrips tabaci*) with neem and garlic proving as the most promising plant extracts with minimum population of sucking insect pests and minimum fruit damage ^[1,8]. Objective of the study was to determine the effectiveness of parasitoid *Erectomocerus eremicus* and crude plant extracts of garlic and chilli as an integrated alternative control method of GHW and how the treatments influence yield and quality of tomato variety “Anna F1”.

2. Materials and Methods

2.1. Experimental Site

The study was done at Egerton University, Njoro, Kenya in a low tunnel for two seasons. The field lies at a latitude of 0°23' S and longitude 35°35' E in the Lower Highland III Agro-Ecological Zone (LH3) at an altitude of approximately 2,238 M above sea level. The soils are predominantly well-drained sandy-vitric mollic andosols with a pH 6.0 to 6.5 ^[17].

2.2 Planting Material and *Erectomocerus eremicus* Strips

Plant material used in the study was tomato variety “Anna F1” seeds. “Anna F1” is an indeterminate tomato variety with high resistance to Alternaria stem canker, nematodes, verticillium and fusarium wilts. In addition, it is high yielding under greenhouse conditions. Seeds were purchased from a registered seed merchant in Kitui. *E. eremicus* strips were sourced from Koppert Biological Systems, Nairobi.

2.3 Experimental Design, Treatment Combinations and Field Layout

The study was conducted using split plot arrangement in randomized complete block design (RCBD) with three replications. The main plot factor under study was the Parasitoid (*E. eremicus*) at two levels (with (P_1) or without (P_0) *E. eremicus*). The different types of sprays comprising of distilled water (D), chemical (CH), garlic (G) and chilli (C) extract sprays made the sub-plot factors giving a total of 8 treatment combinations as shown in Table 1. Each main plot measured 11.1 m × 2.6 m while each sub-plot was 2.6 m × 2.3 m. There were six main plots arranged in three blocks each comprising of four sub-plots. Each block measured 23.2 m × 2.6 m. The entire experimental area measured 70.6 m × 2.6 m. One-meter path separated main-plots within a block while a 0.5 m path demarcated the sub-plots. One-meter path (Figure 1) was left between individual blocks. All main plots and sub-plots were sep-

arated and covered using screens to control movement of the GHW and parasitoid from one plot to the other. A knapsack sprayer was used to apply sprays. One week later, *E. eremicus* was applied at four parasitised GHW pupae per plant.

Table 1. Treatment Combinations and Description

Treatment	Description
$P_0 + D$	No <i>E. eremicus</i> + Distilled water
$P_0 + G$	No <i>E. eremicus</i> + Garlic extract
$P_0 + CH$	No <i>E. eremicus</i> + Abamectin
$P_0 + C$	No <i>E. eremicus</i> + Chilli extract
$P_1 + D$	<i>E. eremicus</i> + Distilled water
$P_1 + G$	<i>E. eremicus</i> + Garlic extract
$P_1 + CH$	<i>E. eremicus</i> + Abamectin
$P_1 + C$	<i>E. eremicus</i> + Chilli extract

2.4 Collection, Extraction and Constitution of Crude Plant Extracts

Red-ripe African bird’s eye chilli (ABEC) fruits were purchased from the local merchants washed and dried under shade for 14 days. Garlic bulbs were separated into bulblets peeled and chopped using a knife and ground using an electric blender. The dried ABEC was ground using an electric grinder into a fine powder ^[1]. Stock solutions of 10% concentration of each plant extract were prepared by mixing 100 g powder in distilled water in a conical flask to make a final volume of 1 litre. The mixture was shaken thoroughly, left to stand for 24 hours, shaken and filtered through a filter paper to remove the impurities. Final 5% concentration for the two extracts for treatment applications was prepared from the stock solutions as described by Ali *et al.* ^[1].

2.5 Crop Establishment and Maintenance

Tomato seedlings were started in a nursery until they attain the stage of 3-4 true leaves. Prior to transplanting, the experimental field was prepared mechanically by hand digging to break soil clods and produce a fine tilth before demarcation of the experimental units. Planting holes were dug using a hand hoe and diammonium phosphate (DAP, 18% N, P₂O₅, 46%) incorporated in every planting hole at 240 kg/ha ^[15]. Tomato seedlings were transplanted at a spacing of 60 cm × 45 cm ^[22]. Four rows with five plants each were planted in each sub-plot, giving twenty plants. Gapping was done after one week.

Thereafter, routine management practices including weeding and irrigation were done uniformly for all sub-plots. Two weeks after transplanting, Calcium Ammonium

Nitrate (CAN) was applied at the rate of 200 kg/ha in two equal splits. The first split was done two weeks after transplanting and the second split two weeks later. At the onset of flowering, one split of a top dress with NPK (17:17:17) at 200 kg/ha was done and a second split repeated after the first harvest^[22]. Micronutrient deficiencies were corrected by applying foliar fertilizers. Sucker pruning was done when necessary up to the eighth week and disease control was done uniformly in all plots. Tomato plants were trellised to a single stem. Diseases were monitored and control done using appropriate preventative and curative fungicides. Weeding was done when necessary.

2.6 Data Collection

Six plants randomly selected within the middle rows in each subplot were tagged for data collection, which commenced in the second week after transplanting. Data was collected on the following variables:

2.6.1 Percentage Greenhouse Whitefly Infestation

This was done by counting the number of plants infested by GHW in the two middle rows early in the morning when the insects were inactive and calculating the percentage infestation using the following formula:

$$\% \text{ GHW Infestation} = \frac{\text{Number of Plants Infested}}{\text{Total Number of Sample Plants}} \times 100$$

2.6.2 Greenhouse Whitefly Population Density

The population density of GHW adults was counted on the randomly selected six plants and recorded before first treatment application and at two weeks interval after treatment applications. Counting was done early in the morning when the insects were inactive. This data was compared subsequently to get the progressive trend.

2.6.3 Parasitized Nymphs of Greenhouse Whitefly

GHW parasitized nymphs were counted from the randomly selected six plants from the middle rows in each sub-plot. The percentage parasitization was computed using the formula:

$$\% \text{ GHW Parasitization} = \frac{\text{Total Number of GHW Parasitised Nymphs}}{\text{Total Number of GHW Nymphs}} \times 100$$

2.6.4 Tomato Yield Components and Fruit Yield

Throughout the reproductive phase, number of flowers was counted. Full ripe tomato fruits were harvested in each subplot twice weekly until the crop was exhausted.

Harvesting begun when first fruits reached the full ripe stage.

Fruits were graded soon after harvesting, based on size using a vernier calliper and categorized as small (below 4 cm), medium (4-6 cm as grade 3), large (6-8 cm as grade 2), extra-large (above 8 cm as grade 1) in transverse diameter^[20,26]. Marketable fruits size were all fruits with diameter above 4 cm, free from cracks, blemishes, disease infection and other physiological disorders while unmarketable fruits (rejects) were all fruits below 4 cm diameter and those with physical defects such as cracks and non-uniform color development and physiological disorders such as blossom end rots or other blemishes^[20]. The numbers of marketable and unmarketable fruits were summed up to give the total numbers and weight of harvested tomato fruits expressed in number per plant (no. / plant). Marketable fruits were weighed and expressed in kg/plant.

2.6.5 Yield Loss

Fruits from sample plants were used to determine yield loss based on non-marketable (damaged) and total fruits. Yield loss was expressed as a percentage as shown below:

$$\% \text{ Yield loss} = \frac{\text{Number of nonmarketable}}{\text{Total Number of Fruits}} \times 100$$

2.7 Data Analysis

Data collected was subjected to analysis of variance (ANOVA). and means of significant treatments separated using Tukey's Honestly Significant Difference (HSD) Test at 5% level of significance. Statistical analysis was performed using SAS (Version 10). There was no interaction between season and the treatments. Therefore, data from the seasons were analyzed separately using the statistical model:

$$Y_{ijk} = \mu + \rho_i + \tau_j + (\tau\rho)_{ij} + \delta_{ij} + \beta_k + (\tau\beta)_{jk} + \epsilon_{ijk} \quad i=1, 2, 3 \dots r, j=1, 2 \dots a, k=1, 2, 3, 4 \dots b$$

Where,

Y_{ijk} : Observation corresponding to the k^{th} level of sub-plot factor B (Sprays), the j^{th} level of main plot factor A (*Eretmocerus eremicus*) and the i^{th} replication.

μ : overall mean

ρ_i : i^{th} block effect

τ_j : j^{th} main plot treatment effect

β_k : k^{th} sub-plot treatment

$(\tau\rho)_{ij}$: interaction between i^{th} block effect j^{th} main plot treatment effect

$(\tau\beta)_{jk}$: interaction between j^{th} level of main plot and k^{th} level of sub-plot treatment

The error components δ_{ij} and ϵ_{ijk} are independently and normally distributed with means zero and respective variances s^2_{δ} and s^2_{ϵ} .

3. Results

3.1 Effect of Botanical Extracts and Biological Control with *E. eremicus* on Percentage of Greenhouse Whitefly Infestation on Tomato Plants

Significant interaction ($p \leq 0.05$) was observed between botanical extracts and parasitoids. In both seasons use of distilled water or garlic acid without parasitoid had the highest whitefly population compared with the rest of the treatments which were not significantly different (Table 2).

3.2 Effect of Botanical Extracts and Biological Control with *E. eremicus* on Number of Parasitized Whitefly Nymphs (no. /plant) on Tomato Plants

Significant interaction ($p \leq 0.05$) was observed between botanical extracts and biological control with *E. eremicus* on the number of parasitized whitefly nymphs, both in season one and two. In most of the evaluation period, higher number of parasitized whitefly nymphs were observed in plants where botanical extracts was applied together with *E. eremicus*. The results were comparable with the use of synthetic pesticide (abamectin) together with *E. eremicus*. The lowest number of parasitized nymphs was observed in all treatments where *E. eremicus* parasitoid was not applied (Table 3).

Table 2. Interaction effect of botanical extracts and parasitoid, *E. eremicus* on whitefly population density (no. /plant) on tomato plants in season one and two, 2019

Treatment	7 days		14 days		21 days		28 days		35 days	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Distilled water - <i>E. eremicus</i>	9.6 ^a	5.1 ^a	10.9 ^a	15.2 ^a	15.2 ^a	22.7 ^a	21.9 ^a	17.6 ^a	25.2 ^a	15.2 ^a
Distilled water + <i>E. eremicus</i>	5.2 ^b	1.3 ^b	3.2 ^b	3.2 ^b	2.8 ^b	9.4 ^b	3.9 ^b	5.6 ^b	1.9 ^b	6.6 ^b
Abamectin - <i>E. eremicus</i>	3.9 ^b	0.4 ^c	3.6 ^b	2.3 ^b	2.6 ^b	8.4 ^b	11.9 ^{ab}	6.6 ^b	3.4 ^b	6.8 ^b
Abamectin + <i>E. eremicus</i>	4.4 ^b	0.4 ^c	5.5 ^b	1.9 ^b	4.5 ^b	6.6 ^b	2.0 ^b	7.7 ^b	3.5 ^b	4.2 ^b
Chilli extract - <i>E. eremicus</i>	5.9 ^b	1.4 ^b	4.4 ^b	4.3 ^b	3.3 ^b	11.3 ^b	17.7 ^{ab}	4.7 ^b	26.3 ^a	10.2 ^{ab}
Chilli extract + <i>E. eremicus</i>	4.2 ^b	0.9 ^{bc}	3.2 ^b	2.7 ^b	3.6 ^b	9.4 ^b	4.9 ^b	6.3 ^b	2.6 ^b	8.2 ^{ab}
Garlic extract - <i>E. eremicus</i>	6.8 ^{ab}	6.2 ^a	2.9 ^b	9.8 ^{ab}	2.6 ^b	23.3 ^a	27.9 ^a	16.1 ^a	26.6 ^a	16.1 ^a
Garlic extract + <i>E. eremicus</i>	4.7 ^b	1.4 ^b	5.1 ^b	1.9 ^b	3.2 ^b	12.0 ^b	2.4 ^b	5.6 ^b	18.5 ^a	5.5 ^b

Note: Means in the same column followed by the same letter are not significantly different according to Tukey's test at $\alpha = 0.05$.

Table 3. Effect of botanical extracts and parasitoid, *E. eremicus* on number of parasitized whitefly nymphs (no. /plant) on tomato plants in season one and two, 2019

Treatment	7 days		14 days		21 days		28 days		35 days	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Distilled water - <i>E. eremicus</i>	1.2 ^b	1.7 ^b	3.5 ^{ab}	1.8 ^b	1.1 ^b	4.7 ^b	3.8 ^b	6.4 ^{ab}	3.1 ^b	4.7 ^b
Distilled water + <i>E. eremicus</i>	4.6 ^{ab}	4.9 ^{ab}	5.6 ^{ab}	7.9 ^{ab}	14.1 ^{ab}	15.5 ^{ab}	9.4 ^{ab}	8.3 ^{ab}	7.7 ^{ab}	11.6 ^a
Abamectin - <i>E. eremicus</i>	1.2 ^b	1.6 ^b	1.4 ^b	0.7 ^b	1.2 ^b	1.9 ^b	2.1 ^b	2.2 ^b	1.8 ^b	3.7 ^b
Abamectin + <i>E. eremicus</i>	3.4 ^b	3.8 ^{ab}	3.4 ^{ab}	3.8 ^b	4.2 ^b	5.4 ^b	5.8 ^b	6.8 ^{ab}	6.8 ^{ab}	8.3 ^{ab}
Chilli extract - <i>E. eremicus</i>	1.2 ^b	1.1 ^b	1.9 ^b	2.7 ^b	3.8 ^b	4.0 ^b	4.8 ^b	6.2 ^{ab}	6.1 ^{ab}	3.2 ^b
Chilli extract + <i>E. eremicus</i>	7.2 ^a	6.8 ^a	10.2 ^a	13.7 ^a	25.3 ^a	20.7 ^a	19.2 ^a	14.3 ^a	17.4 ^a	15.1 ^a
Garlic extract - <i>E. eremicus</i>	1.1 ^b	0.8 ^b	0.4 ^b	0.7 ^b	1.8 ^b	1.4 ^b	0.9 ^b	2.7 ^b	2.2 ^b	4.3 ^b
Garlic extract + <i>E. eremicus</i>	5.5 ^{ab}	4.4 ^{ab}	5.0 ^{ab}	5.8 ^{ab}	7.7 ^b	7.9 ^b	6.8 ^b	7.0 ^{ab}	7.6 ^{ab}	8.6 ^{ab}

Note: Means in the same column followed by the same letter are not significantly different according to Tukey's test at $\alpha = 0.05$.

3.3 Effect of Botanical Extracts and Biological Control with *E. eremicus* on Number of Flower Clusters (no. /plant) on Tomato Plants

Use of botanical extracts and biological control with *E. eremicus* had significant interaction ($p \leq 0.05$) effect on tomato flowers in both seasons. In most of the evaluation period, use of botanicals with *E. eremicus* resulted in the highest number of flowers compared with the use of distilled water without *E. eremicus*. However, this was not significantly different with the rest of the treatments, irrespective of whether *E. eremicus* were applied or not. (Table 4).

Table 4. Effect of controlling glasshouse whitefly with botanical extracts and parasitoid, *E. eremicus* on average number of flower clusters per tomato plant in season one and two, 2019

	21 days		28 days		35 days	
	S1	S2	S1	S2	S1	S2
Distilled water - <i>E. eremicus</i>	0.9 ^b	1.1 ^b	1.7 ^{bc}	1.3 ^c	2.6 ^b	2.2 ^b
Distilled water + <i>E. eremicus</i>	4.8 ^{ab}	5.5 ^{ab}	6.4 ^{abc}	6.6 ^{ab}	8.3 ^a	8.5 ^a
Abamectin - <i>E. eremicus</i>	3.3 ^{ab}	3.8 ^{ab}	4.2 ^{abc}	4.9 ^{abc}	5.4 ^{ab}	5.7 ^{ab}
Abamectin + <i>E. eremicus</i>	4.7 ^{ab}	5.6 ^{ab}	5.9 ^{abc}	7.3 ^a	7.8 ^a	8.0 ^a
Chilli extract - <i>E. eremicus</i>	2.4 ^{ab}	4.1 ^{ab}	3.1 ^{abc}	6.0 ^{abc}	4.6 ^{ab}	7.0 ^{ab}
Chilli extract + <i>E. eremicus</i>	5.9 ^a	5.4 ^{ab}	7.0 ^a	7.3 ^a	7.6 ^a	7.6 ^a
Garlic extract - <i>E. eremicus</i>	4.0 ^{ab}	4.4 ^{ab}	4.7 ^{abc}	5.0 ^{abc}	5.8 ^{ab}	5.7 ^{ab}
Garlic extract + <i>E. eremicus</i>	6.6 ^a	6.2 ^a	8.2 ^a	6.8 ^{ab}	8.8 ^a	7.7 ^a

Note: Means in the same column followed by the same letter are not significantly different according to Tukey's test at $\alpha = 0.05$.

3.4 Effect of Botanical Extracts and Biological Control with *E. eremicus* on Tomato Marketable Fruits (no./plant)

Use of botanical extracts and biological control with *E. eremicus* had significant effect on marketable yield in both seasons. The highest marketable yield in terms of fruit number was observed when botanical extracts were applied with *E. eremicus* but not different from the rest of the treatments compared to when distilled water was applied with or without *E. eremicus* (Figure 1).

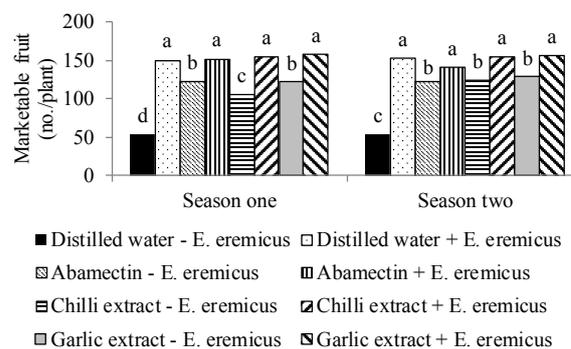


Figure 1. Effect of botanical extracts and biological control with *E. eremicus* on tomato marketable fruits (no./plant) in season one and two. Means followed by the same letter are not significantly different according to Tukey's test at $\alpha = 0.05$

3.5 Effect of Controlling the Glasshouse Whitefly with Botanical Extracts and Parasitoid, *E. eremicus* on Average Weight of Tomato Fruits (kg/plant)

The lowest fruit yield in terms of weight was recorded when distilled water was applied with or without *E. eremicus* compared with the rest of the treatments which were not significantly different (Figure 2).

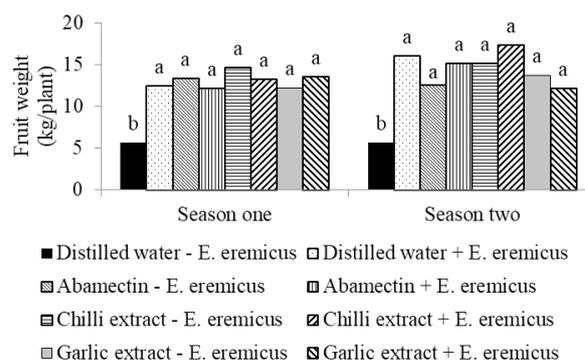


Figure 2. Effect of botanical extracts and biological control with *E. eremicus* on tomato fruit weight (kg/plant) in season one and two. Means followed by the same letter are not significantly different according to Tukey's test at $\alpha = 0.05$

3.6 Effect of Botanical Extracts and Biological Control with *E. eremicus* on Tomato Nonmarketable Fruits (no. /plant)

The lowest nonmarketable yield in terms of fruit number was recorded when distilled water was applied with or without *E. eremicus* compared with the rest of the treat-

ments which were not significantly different (Figure 3).

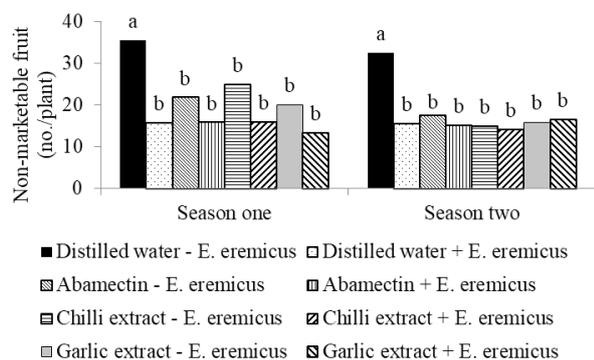


Figure 3. Effect of controlling GHW with botanical extracts and Parasitoid, *E. eremicus* on tomato number of non-marketable fruits per tomato plant in season one and two. Means followed by the same letter are not significantly different according to Tukey’s test at $\alpha = 0.05$

3.7 Effect of Controlling GHW with Botanical Extracts and Parasitoid, *E. eremicus* on Tomato Yield Loss (fruit no. /plant)

The highest tomato yield loss was recorded when distilled water was applied with or without *E. eremicus* compared with the rest of the treatments which were not significantly different (Figure 4).

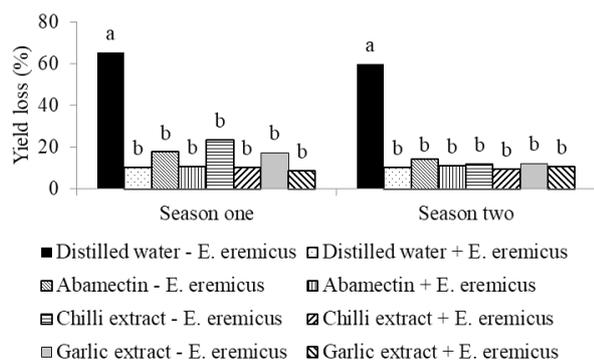


Figure 4. Effect of controlling GHW with botanical extracts and parasitoid, *E. eremicus* on tomato yield loss (no. /plant) in season one and two. Means followed by the same letter are not significantly different according to Tukey’s test at $\alpha = 0.05$

4. Discussion

The present study focussed on effectiveness of *Eretmocerus eremicus* and crude plant extracts of garlic and chilli as an integrated alternative control method of greenhouse whitefly and its effect on tomato yield. This explored the use of integrated pest management systems

using a combination of a parasitoid and botanical extracts for use against greenhouse whiteflies and to improve growth and yield of greenhouse tomato plants. The study showed that use of botanical plant extracts or *E. eremicus* parasitoid alone or in combination helped to reduce whitefly population and improve yield of greenhouse tomato plants.

Use of botanical extracts and biological control with *E. eremicus* helped to reduce greenhouse whitefly population on tomato plants when compared with where *E. eremicus* parasitoid was not applied. Use of botanical extracts was not different with the use of synthetic pesticide (abamectin) compared with use of distilled water. In addition, botanical extracts and biological control with *E. eremicus* parasitoid helped to reduce greenhouse whitefly infestation on tomato plants when compared with when *E. eremicus* parasitoid was not applied. Garlic bulbs contain biochemical compounds such as sacrid volatolic oil and sulpho-oxides which is derived from allacin. These biochemicals are responsible for the antifeedant, repellent and toxicant properties against various insect pests such like whiteflies [23]. Similarly, in another study, 5% green chilli extract was effective against whiteflies when compared with the untreated tomato plants [21]. Whiteflies were effectively managed in tomato plants by fermented plant extracts of neem leaf and wild garlic compared with the untreated plots [23], while chilli contain chemical compounds such as capsaicin which have been used as deterrents against various pests such as whiteflies [21]. Therefore, it is possible that the lower whitefly population and therefore reduction in whitefly infestation on greenhouse tomato plants was as a result of these phyto-chemicals that may have either repelled or killed them. The Parasitoid, *E. eremicus* oviposited significantly more eggs on whitefly nymphs and were effective in the management of whiteflies as observed in the study [29].

Use of botanical extracts and biological control with *E. eremicus* parasitoid helped to improve on number of parasitized greenhouse whitefly nymphs on tomato plants. The results were comparable with the use of synthetic pesticide (abamectin) together with *E. eremicus* parasitoids. The lowest number of parasitized nymphs was observed in all treatments where *E. eremicus* was not applied. Urbaneja *et al.* [27] observed that botanical extracts such as garlic and chilli did not have negative effects on *E. eremicus*. Similarly, augmentation of parasitoids such as *E. eremicus* enhanced their parasitization [27]. Therefore, the enhanced parasitization when botanical extracts and when *E. eremicus* was used as observed in the study is probably because of the non-toxicity and augmentation effects as reported in the previous studies study [27].

Use of botanical extracts and biological control with *E. eremicus* helped to increase tomato flowers. *E. eremicus* resulted in the highest number of flowers compared with the use of distilled water without *E. eremicus*. Greenberg *et al.* [14] also observed that *E. eremicus* enhanced increase in tomato flowers compared with when they were not applied. Al-Obady [2] also observed that use of botanical extracts like garlic and chilli resulted in enhanced flowering in tomato plants. Whiteflies have been reported to reduce flowering on tomatoes, as well as, causing flower abortion [23]. Therefore, the increase in flower numbers on tomato plants was attributed to repellent and toxicity effects botanical extracts on greenhouse tomato whiteflies and parasitization effect enhanced by augmentation using *E. eremicus*. This reduced whitefly infestation on greenhouse tomato plants and therefore flower number as observed in the study.

Use of botanical extracts and biological control with *E. eremicus* helped to increase marketable yield. The highest marketable yield in terms of fruit numbers and weight was observed when botanical extracts were applied with *E. eremicus* compared to when distilled water was applied with or without *E. eremicus*. *E. eremicus* also helped to increase marketable fruit numbers. The results are in agreement with the findings of Al-Obady [2] who observed that use of botanical extracts like garlic and chilli resulted in higher tomato yield and similarly, Urbaneja *et al.* [27] observed that *E. eremicus* helped to improve growth and yield of tomato. Whiteflies have been reported to suck photosynthates from tomato plants, as well as transmit viral diseases which severely affect their growth and yield [2]. The increase in yield of tomato plants could be attributed to reduction in whitefly population as well as infestation, resulting in better growth and yield of tomato plants.

Use of botanical extracts and biological control with *E. eremicus* helped to reduce greenhouse tomato non-marketable yield and therefore yield loss. The lowest nonmarketable yield in terms of fruit number was recorded when distilled water was applied with or without *E. eremicus* compared with the rest of the treatments which were not significantly different. Similar results were observed by Urbaneja *et al.* [27] who observed 50% increase in tomato yield when various plant extracts were used to manage whiteflies on tomatoes. Whiteflies affect tomato plant directly by feeding on the plants and indirectly through transmission of viral diseases resulting in yield and poor-quality fruits [2]. Therefore, reduction in yield, nonmarketable fruit numbers and yield loss by use of botanical extracts or *E. eremicus* as observed in the study could be attributed to reduction whitefly population and infestation on tomato plants.

5. Conclusion

Botanical extracts had similar effects to synthetic pesticide (abamectin) in controlling whitefly population, infestation and enhancing yield of greenhouse tomato plants. Use of *E. eremicus* helped in controlling whitefly population, infestation and enhancing yield of greenhouse tomato plants. Combined use of botanical extracts and *E. eremicus* had better effects on the management of greenhouse whitefly population, infestation, and in enhancing growth and yield of greenhouse tomato plants compared with when they were used alone.

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