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Towards Expanding Quinoa Cultivation in Egypt: The Effect of Compost and Vermicompost on Quinoa Pests, Natural Enemies and Yield under Field Conditions

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Abstract

Increasing production and reducing pests' population while preserving the environment is an essential goal nowadays. New strategies are needed to achieve this goal, to bridge food gap and achieve food security. Quinoa is a promising crop and could partially substitute wheat in baked products and assist in overcoming wheat gap in Egypt. This study aimed to identify pests and their natural enemies in quinoa plantation, the population dynamics of both and the effect of compost and vermicompost fertilization on pests' population and quinoa yield under field conditions. The study was carried out in El Giza Research Station of the Agricultural Research Centre—Egypt, from November till March, in two successive seasons, 2016/2017 and 2017/2018. The experiment was set up in a complete randomized block design. Variety Masr 1 was tested and yellow sticky traps were used to monitor insects' numbers. Three main pests were detected: *Aphis craccivora*, *Empoasca. decipiens* and *Bemisia tabaci*. The most common pest was aphids followed by potato leafhoppers. Compost fertilized quinoa attracted fewer pests and resulted in less yield compared to vermicompost. Parasitoids appeared earlier than predators and their numbers were the highest throughout the two seasons. Pests' and natural enemies' peaks were determined to facilitate IPM interventions. It is recommended to use vermicompost in quinoa production rather than compost, as it increased yield, provided that an IPM strategy is implemented in which natural enemies are the main players. Further investigations are needed to understand the interaction between predators and parasitoids in quinoa field in order to maximize the benefit of their existence in IPM programs.

Keywords

Quinoa, Organic Fertilization, Pests, Parasitoids, Predators, Population Dynamics

1. Introduction

Quinoa (*Chenopodium quinoa* Wilid.) is one of the goosefoot family members (Chenopodiaceae) [1]. It was selected by FAO as one of the crops destined to offer food security in the next century [2]. Quinoa is a grain that has exceptional characteristics, *i.e.* it is gluten-free, has high nutritional value properties with an average of 14.8% protein and an extraordinary balance between starch, oil and protein [3]. Its high protein contents strengthen the immune system and assist in fighting various diseases including cancer [4]. Quinoa is also high in lysine value, in addition to manganese, magnesium, iron and vitamin B2 that are essential for growth, metabolism, and enzymes functions in the body [5] [6] [7].

Egypt has an area of about 1 million km^2, most of which is under arid and hyper-arid climatic conditions; only 3% is used in agricultural production [8]. According to Jacobsen *et al.* [9], no crop other than quinoa can resist the combination of adverse factors, and therefore, a national campaign to expand the cultivation of quinoa has been launched by the Egyptian Ministry of Agriculture [10] due to its adaptability to adverse climate and soil conditions [11], in addition to its tolerant to drought and salinity [12] and its low production cost attributed to the low inputs and labor needed. Quinoa, therefore, can play a key role in food production in Egyptian reclaimed desert lands [13]. It is hoped also that this initiative will reduce the country's dependence on wheat imports. Historically, quinoa was first introduced in Egypt in 2005, being first cultivated in South Sinai. The cultivated area of quinoa has reached more than 80 feddans (1 feddan = 0.42 hectare) in the period since 2010 [10].

Despite all these advantages, quinoa is attacked by a wide variety of insect pests that can cause damage during its different life stages and even in storage as stated by Oelke *et al.* [14]. Reports from Northern and Southern Europe identified *Aphis fabae* L. (Homoptera Aphididae) and leafhoppers (Homoptera Cicadellidae) as pests causing injury in quinoa [15] [16]. Furthermore, Tawfik *et al.* [17] identified aphids, *Tuta absoluta* and cotton leaf worm as pests attacking quinoa plants in different places in Egypt and caused considerable yield damage.

Organic crops proved to be more tolerant/resistant to insect infestation [18]. The same conclusion was mentioned by Altieri *et al.* [19] who stated that organic farming practices offer balanced nutrition to crops and thus they become less susceptible to insect pests and diseases. Not only insect's pests are affected by the type of fertilization but also the natural enemies of those pests [20]. Vermicompost has been advocated as good organic manure for use in integrated management practices in field crops. Vermicompost not only increases organic carbon status of the soils but also increases soil water holding capacity, flocculation of soil and availability of nutrients and thus improves soil and crop production sustainability [21] In addition, fertilization with compost showed higher values in most quality traits of biomass in quinoa crop other than synthetic fertilizers [22]. In comparing the effect of compost and vermicompost on *Amaranthus viridis* production; Islam *et al.* [23] found that vermicompost application gave higher result for growth, yield indices and nutrient content than the conventional aerobic compost. In the present investigation, the two organic fertilizers were chosen as they provide all nutrients in readily available forms and also enhance uptake of nutrients by plants and play a major role in improving growth and yield of different field crops [24]. Consequently, this study aimed to identify pests attacking quinoa crop under Egyptian conditions, the population dynamics of these pests together with their natural enemies in relation to the fertilization with compost and vermicompost. In addition, the effect of these two organic fertilizers on quinoa production yield was also investigated.

2. Materials and Methods

2.1. Experiment Location

The present study was carried out in El Giza Research Station affiliated to the Agricultural Research Centre (ARC)—Egypt. El Giza Governorate is located on the west bank of the Nile, 4.9 km southwest of central Cairo on 30.01˚N latitudes and 31.21˚E longitude. A soil analysis test was carried out in the Soil, Water and Environment Research Institute, ARC, to identify the soil properties in the experimental area. The analysis showed that the soil is clay with 36.3% clay, 37.6% silt and 26.1% sand. Percentages of organic matter, nitrogen, phosphorus and potassium were 1, 0.003, 0.001 and 0.03, respectively. Soil pH was 7.73 whereas EC, wilting point and field capacity recorded 0.5 ds/m, 20.2% and 43.8%, respectively.

2.2. Experiment Date and Weather Conditions

The study extended from November till March, in two successive seasons, 2016/2017 and 2017/2018. Quinoa was sown on 20th of November of each season. Weather conditions including average temperature, average relative humidity, precipitation and average wind speed were daily recorded with the assistance of colleagues in the Central Laboratory for Agricultural Climate, ARC (**Table 1**). The climate is arid, characterized by no precipitation during the experiment period, relative humidity was moderate most of the time and wind speed was light as it did not exceed 0.8 m/sec.

2.3. Organic Fertilizers

Two types of fertilizers were used, *i.e.* compost and vermicompost made up of plant wastes and cattle manure (in case of vermicompost the earth worm *Eisenia foetida* was used). Both fertilizers were provided by the Central Laboratory of Organic Agriculture (CLOA), ARC. Compost and vermicompost were incorporated in the soil before sowing quinoa at rates of 5 and 4 m^3/feddan, respectively (1 feddan = 0.42 hectare). **Table 2** and **Table 3** present the compost and vermicompost analyses that were carried out in CLOA.

2.4. Design and Cultivation

Treatments were arranged in a complete randomized block design. There were

Table 1. Weather conditions during the experimental period (November-March) in the two seasons 2016-17 and 2017-18.

Months	Aver. wind speed [m/sec]	Aver. temperature (˚C)	Aver. relative humidity [%]	Precipitation sum [mm]
Season 2016/2017				
November	0.6	20.3	59.4	0.0
December	0.5	14.7	61.4	0.0
January	0.6	14.0	59.2	0.0
February	0.8	16.1	57.6	0.0
March	0.8	19.1	53.1	0.0
Season 2017/2018				
November	0.7	20.4	57.6	0.0
December	0.6	18.1	62.6	0.0
January	0.7	16.2	57.1	0.0
February	0.4	17.5	59.3	0.2
March	0.6	21.2	48.0	0.0

Table 2. Results of compost analysis.

Parameters and Minerals													
pH	Fe (1:10) ds/m	OC %	N %	P %	K %	Ca %	Mg %	Moist %	Org. m. %	C:N	H_2S	Ws	Nem.
7.53	2.67	27.1	1.2	0.9	0.8	0.4	0.7	28	30	20:1	-	-	-

Ws = Weed seeds, Nem. Nematodes.

Table 3. Results of vermicompost analysis.

Parameters and Minerals													
pH	EC (1:10) ds/m	OC %	N %	P %	K %	Ca %	Mg%	Moist %	Org. m.	C:N	H_2S	Ws	Nem.
7.7	1.3	40.2	2.4	1.7	1.1	0.8	0.6	30	68.4	17:1	-	-	-

Ws = Weed seeds, Nem. Nematodes.

three replicates for each treatment, *i.e.* compost, vermicompost, and untreated control. Each plot had an area of 21 m^2 and consisted of 10 rows, every row measured 6 m long and 3.5 m width. Space between rows was adjusted to 60 cm; whereas, within-row spacing between plants was 20 cm. Quinoa grains, variety Masr 1, were provided by the Department of Maize and Sugar Crops, Plant Pathology Research Institute, ARC. After one month of cultivation quinoa plants were thinned to 2 plants per hill. All agronomic practices were maintained constantly when required. Manual weed control was carried out when necessary and quinoa was irrigated monthly during the whole season (4 irrigations). No fungicide or pesticide treatments were applied.

2.5. Data Collection

1) *Pests, parasitoids and predators incidence*

Yellow sticky traps measuring 45 × 25 cm were used to detect insects' numbers attracted to quinoa crop under field conditions. Using sticky traps was encouraged by the low wind speed recorded during the experimental period as mention in Table 1. Four traps were used in each plot including the control plot. Three weeks post cultivation traps were hanged with the help of wooden stakes 30 cm above the top of the plants reversing wind direction. Traps were adjusted vertically whenever the crop attained additional growth and they were inspected every two weeks on a regular basis. Upon the collection of the sticky traps, they were wrapped with clear plastic cling film for protection, transferred to the laboratory for sorting, identifying and counting. The identification and counting of insects on the traps was carried out in the Plant Protection Research Institute, ARC. Meanwhile traps were replaced with new ones after each inspection date.

2) ***Grain yield measurements***

Quinoa grains were harvested when about 95% of the plants reached maturation phase. Ten plants were randomly chosen from each plot, bulked and weighted. Grain yield/plot was measured and converted to Kg/ ha. In addition, a sample of 1000 seeds from the bulked seeds of each plot was weighed.

2.6. Statistical Analysis

Data were subjected to one way Analysis of Variance (ANOVA) and the treatment means were statistically differentiated by performing Least Square Means test (LSD) at $p < 0.05$ level using SPSS software.

3. Results

3.1. Identification of Insects in Quinoa Field

Upon the collection of the sticky traps, they were transferred to the laboratory for identification. Table 4 presents the insects pests, parasitoids and predators found on the sticky traps.

Table 4. Scientific classification of the insects on the yellow traps in quinoa field.

Type	Common name	Scientific name	Order	Family
Pests	Black legume aphid	*Aphis craccivora*	Hemiptera	Aphididae
	Potato leafhoppers	*Empoasca decipiens*		Cicadellidae
	Silver leaf whitefly	*Bemisia tabaci*		Aleyrodidae
Predators	Green lacewing	*Chrysoperla carnea*	Neuroptera	Chrysopidae
	Lady bug	*Coccinella vicina* *Coccinella septempunctata*	Coleoptera	Coccinellidae
Parasitoids	Green bug aphids parasitoids	*Lysiphebus fabarum* *Lysiphebus testacoipes*	Hymenoptera	Braconidae
	Aphids parasitoids	*Bracon* sp.		
	Aphids parasitoids	*Trioxys* sp.		

3.2. Pests in Quinoa Field

1) *Aphis craccivora*

The black legume aphid was one of the pests found in large numbers on the yellow sticky traps in quinoa field. Aphids' numbers fluctuated from December to March during the two seasons of the experiment in all the treatments, as illustrated in Figure 1. Aphids had two peaks (on January 23rd and March 7th). Mean number of aphids' population ± SD in compost, vermicompost and control treatments during the month of December were 29.7 ± 4, 57.7 ± 4.1 and 68.3 ± 4.2, respectively. One-Way ANOVA showed that there was a high significant difference between aphids mean numbers in the three treatments ($p = 0.002$). During the month of January aphids' population mean numbers in all treatments decreased and then increased again. In compost treatment, 9th of January, it reached 14.3 ± 3, whereas, vermicompost and control treatments recorded 22.3 ± 2.5 and 37.3 ± 3, respectively. Results proved that there was a high significant difference between all the treatments, where $p < 0.001$. Two weeks later, on the 23rd of the same month, mean numbers increased to reach 165 ± 65, 296 ± 55 and 232.3 ± 3 in the three treatments, respectively, with a significant difference between treatments ($p = 0.047$).

February population, on the other hand, showed a slightly different trend in pest mean numbers where they decreased during the two periods of data collection. In compost treatments during the 7th and 21st of February, mean numbers of aphids recorded 149.7 ± 8.9 and 78 ± 3. Vermicompost recorded 177 ± 9 and 92 ± 3.2, whereas, aphids in control plots reached 182 ± 9.1 and 107.3 ± 3 in the two periods, respectively. Moreover, mean numbers continued to fluctuate again during the month of March where pest population increased on the 7th of March, then decreased on the 21st of March, as illustrated in Figure 1.

2) *Empoasca decipiens*

The potato leafhopper, *Empoasca decipiens*, did not appear in quinoa field till the last week of January, where its mean number in compost plot recorded 5.3 ± 1.8 and increased in vermicompost and control treatments to reach 20 ± 2 and 25 ± 1, respectively. ANOVA test showed that there was a high significant

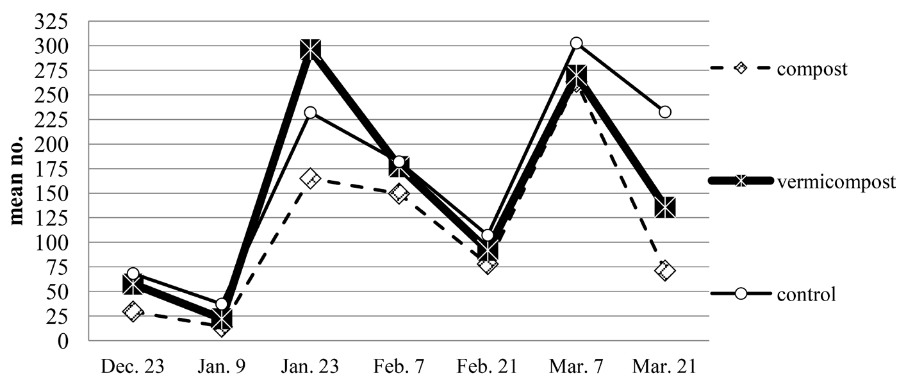

Figure 1. Aphids mean numbers throughout quinoa growing season (Dec. till March) in compost, vermicompost and control treatments.

difference between treatments where p = 0.001. During the month of February, on the 7th, population of *E. decipiens* increased to reach 17.7 ± 4, 26.7 ± 3.8 and 37 ± 3.84 in compost, vermicompost and control treatments, respectively. Two weeks later the numbers increased up to 42.3 ± 3.6, 41.7 ± 4 and 68 ± 3.61, in the three treatments, respectively. High significant differences were noticed in both dates, where on the 7th of February $p < 0.001$ and on the 21st no significant differences were found between compost and vermicompost (p = 0.3) whereas, control results and both fertilizers showed high significant differences as p = 0.003. Only one peak occurred during quinoa growth which was on the 7th of March where numbers of *E. decipiens* increased as illustrated in Figure 2, while on the 21st of March mean numbers of the pest decreased again till it reached 33 ± 1.6, 20 ± 2 and 37.6 ± 1.61, in compost, vermicompost and control treatments, respectively, with high significant differences between all treatments ($p \le 0.001$).

3) *Bemisia tabaci*

Whiteflies appeared early in quinoa crop (in December) where mean numbers of the pest on the yellow traps recorded zero, 5.3 ± 1.5 and 8.3 ± 0.5, in compost, vermicompost and control plots, respectively, with High significant differences between the three treatments, where $p < 0.001$. As shown in Figure 3, data

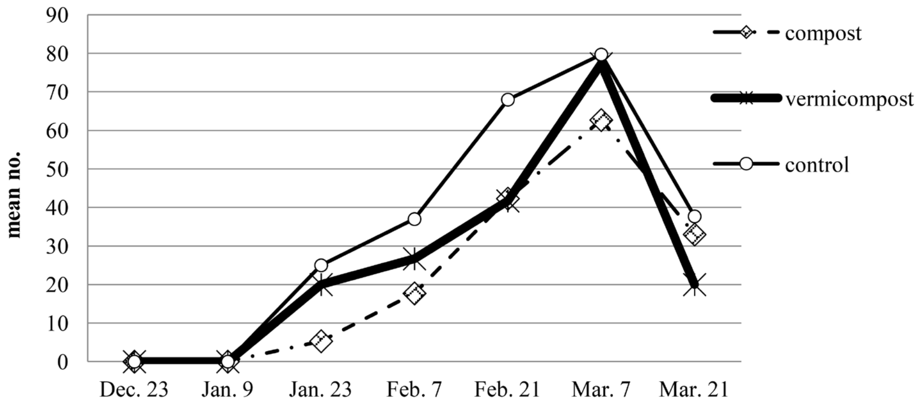

Figure 2. Leafhoppers mean numbers throughout quinoa growing season (Dec. till March) in compost, vermicompost and control treatments.

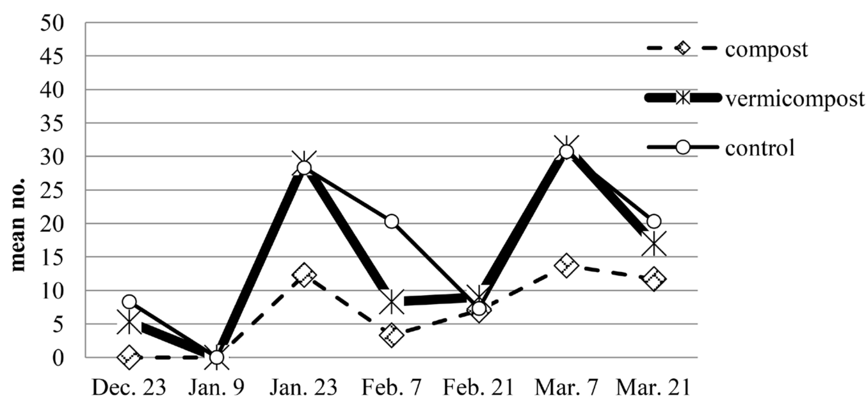

Figure 3. Whiteflies mean numbers throughout quinoa growing season (Dec. till March) in compost, vermicompost and control treatments.

collection after two weeks showed that *B. tabaci* disappeared from the field completely and then after another 14 days it appeared again recording mean numbers of 12.3 ± 2.5, 29 ± 3.6 and 28.3 ± 3 in compost, vermicompost and control plots, respectively, and this date (Jan. 23rd) represents the first peak of the pest population. High significant differences were noticed between compost on one hand and vermicompost and control on the other hand, where $p < 0.001$, while no significant differences appeared between control treatment and vermicompost ($p = 0.7$).

On February 7th mean numbers of the pest decreased to 3.3 ± 1.2, 8.3 ± 1.5 and 20.3 ± 1.6 in the three treatments, respectively. Mean number of whiteflies did not increase significantly when results were recorded 14 days later, whereas on the 7th of March pest's mean number increased up to 13.7 ± 2, 31.3 ± 2.2 and 30.7 ± 2.5 in compost, vermicompost and control treatments, respectively, showing the second peak of the pest population. One way ANOVE test revealed high significant differences between quinoa fertilized with compost and quinoa in control and vermicompost plots where $p < 0.001$. Whereas, both vermicompost and control plots did not show any significant differences as $p = 0.8$. Finally, on the 21st of March numbers of the pest declined again to reach 11.6 ± 2.1, 17 ± 3.6 and 20.3 ± 1.5, respectively.

3.3. Predators in Quinoa Field

Two types of predators were detected in quinoa field, *i.e.* the green lacewing *Chrysoperla carnea* and the ladybugs *Coccinella vicina and Coccinella septempunctata*. Numbers of predators were very low compared to the number of pests, as shown in **Figure 4** & **Figure 5**. During December, the green lacewing appeared in few numbers (0.7 ± 1.1, 1.7 ± 1.5 and 2.7 ± 0.6). One way ANOVA test showed significant differences between compost and both vermicompost and control as $p = 0.1$. There was no significant difference between vermicompost and the control treatments ($p = 0.005$). On the other hand, the ladybugs did not appear till the 9th of January. The *Coccinella* spp. recorded 2 ± 1, 6 ± 0.6 and 5.3 ± 1.5 in the three treatments, respectively. Mean numbers of *C. carnea* on the 9th of January were 0.7 ± 1.1, 3 ± 1 and 4.7 ± 1.1 in compost, vermicompost and control plots, respectively.

Two weeks later, no ladybug individuals were found on the yellow sticky traps, whereas the green lacewing recorded mean numbers of 3 ± 1.7, 5 ± 1 and 12 ± 1.5, in the three treatments, respectively. One way ANOVA showed significant differences between all treatments ($p \le 0.001$). Both predators disappeared again during the next two weeks and started to reappear on the 21st of February. *C. carnea* recorded 0, 4.3 ± 1 and 5.3 ± 2, whereas *Coccinella* spp. mean numbers increased up to 4 ± 1, 10 ± 0.9 and 2.7 ± 1.1, in the three treatments, respectively (as illustrated in **Figure 4**). Mean numbers of *C. carnea* increased again to reach 8 ± 1.5, 14 ± 1 and 17 ± 1.2 in compost, vermicompost and control plots, respectively. On the 21st of March, all treatments recorded zero number for this predator.

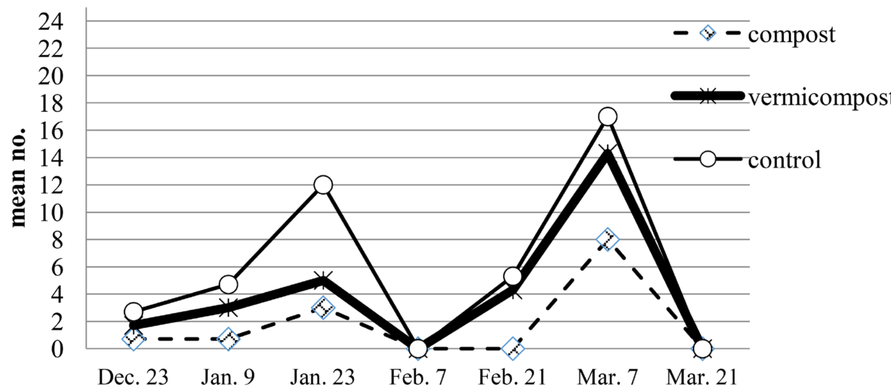

Figure 4. *C. carnea* mean numbers throughout quinoa growing season (Dec. till March) in compost, vermicompost and control treatments.

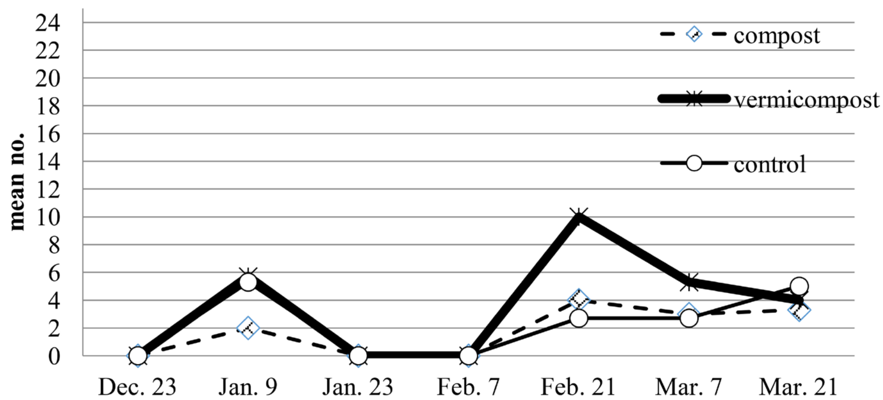

Figure 5. *Coccinella* mean numbers throughout quinoa growing season (Dec. till March) in compost, vermicompost and control treatments.

On the other hand, results of the ladybug on the two data collection dates of March were closed to each other, as shown in Figure 5.

3.4. Parasitoids in Quinoa Field

All the parasitoids detected in quinoa fields were aphid's parasitoids, *i.e.* the green bug aphid's parasitoids (*Lysiphebus fabarum*, *Lysiphebus testacoipes)*, *Bracon* sp. and *Trioxys* sp. Those parasitoids appeared in quinoa field on the 23rd of December recording mean numbers of 14 ± 1.7, 20.8 ± 2 and 30.6 ± 3.7 in compost, vermicompost and control plots, respectively. High significant differences appeared by ANOVA test as $p \le 0.001$. Mean numbers decreased when data were collected 14 days later as shown in Figure 6 and then increased again on the 23rd of January to reach 38 ± 5.2, 73.3 ± 15.2 and 74.3 ± 4 in the three treatments, respectively. During the next two dates of data collection mean numbers of the parasitoids continued to decrease as shown in Figure 6, then numbers increased on the 7th of March to record 18 ± 5, 9 ± 1 and 30.3 ± 2.5, respectively. One way ANOVA analysis proved significant differences between treatments as $p \le 0.001$. By the end of March parasitoids mean number decreased again to reach 3.3 ± 1.5, 4 ± 1 and 5 ± 1, respectively. No significant difference was recorded as p = 0.3.

3.5. The Effect of Fertilization Type on Insects' Incidence in Quinoa

Results showed that the yellow sticky traps in the plots fertilized with compost caught the least numbers of insects during the two seasons. As shown in Figure 7, in compost plot the total average mean numbers of aphids were 110 while both vermicompost and control average mean numbers were 160 and 166, respectively. Leafhoppers, on the other hand, recorded its highest number in the control plot (35) while the least number was recorded in the compost treatment, *i.e.* 23. Although *B. tabaci* was less in its number compared to the other two pests, still, its number in compost was less than those in vermicompost and control treatments as shown in the same figure.

Numbers of predators in the field were not high compared to the parasitoids where total average number of parasitoids was 12, 19 and 25 in compost, vermicompost and control treatments whereas predators numbers did not exceed 6 individuals in their highest presence as shown in Figure 7.

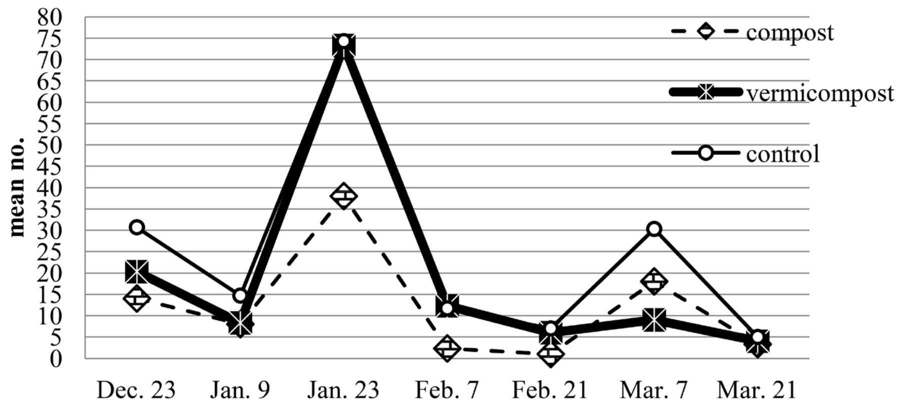

Figure 6. Parasitoids mean numbers throughout quinoa growing season (Dec. till March) in compost, vermicompost and control treatments.

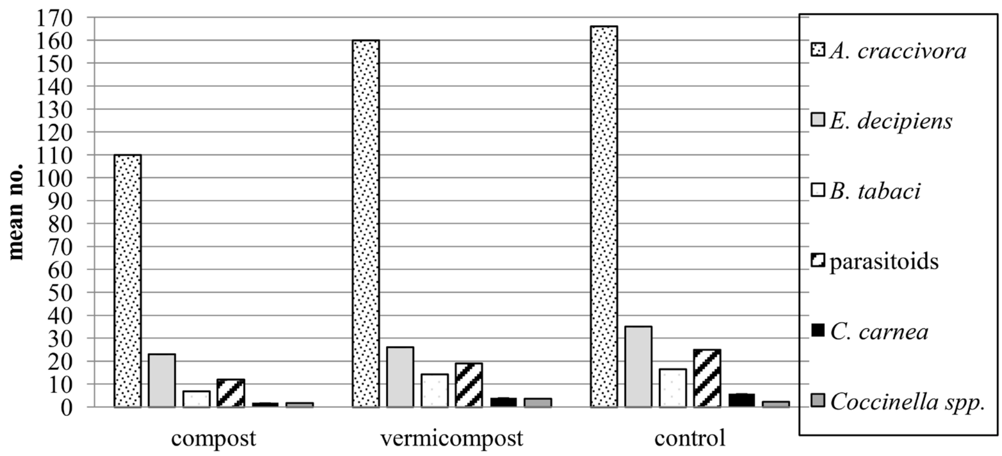

Figure 7. Average mean numbers of insects during quinoa growing seasons (Dec.-March) in compost, vermicompost and control treatments.

3.6. Effect of Fertilization on Quinoa Yield

Fertilization, either vermicompost or compost, had a positive effect on quinoa yield/plant compared to control plot. The analysis of variance of data revealed high significant differentiation between both fertilizers and the control treatment (p = 0.4) whereas no significant difference was noticed between the two fertilizers. Both fertilizers resulted in seed yield of 27 ± 1.9 and 26.4 ± 1 gm. plant, respectively, whereas control plants gave yield of 23.6 ± 1.4 gm. plant, as shown in Figure 8(a).

Further, 1000 seeds weight reached in case of vermicompost plots 467.4 ± 39 gm. while control treatment gave the least weight, *i.e.* 363.25 ± 41 gm. and compost fertilized plants gave 1000 seeds weight of 353 ± 30 gm. as illustrated in Figure 8(b). Significant differences were noticed between all treatments, yet, it was higher between vermicompost and both control and compost treatments, *i.e.* $p < 0.001$.

On the other hand, vermicompost showed higher yield values per ha compared to both compost and control plots, *i.e.* 843 ± 90, 801 ± 92 and 771 ± 92 Kg/ha, respectively (Figure 8(c)). Data analysis proved there were high significant

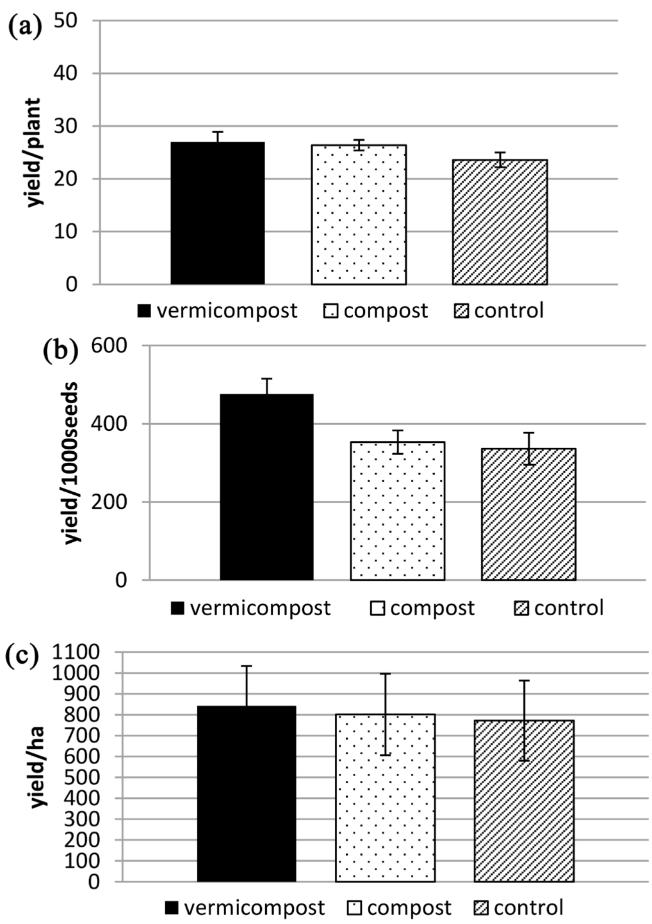

Figure 8. Quinoa yield in relation to used fertilizers and control treatment ((a) yield/plant, (b) yield/ ha and (c) weight of 1000 seeds).

differences between vermicompost yield and both control and compost ($p = 0.86$), whereas compost and control plots showed no significant differences ($p < 0.001$).

4. Discussion

Food security is one of the main challenges in Egypt, despite the availability of different natural resources; agriculture did not achieve the sufficient production increase to meet food demand, which in return increased food gap [12].

Two main questions are important to answer in the context of the current study:

4.1. Why Organic Fertilizers?

Reaching high yielding production occurs through good nutrition management. Several researchers discussed the importance of organic fertilization in improving plant health. Organic fertilization keeps soil moisture as organic matter improves soil water-holding capacity and increases water and nutrients availability for plants which in return gives strong and healthy crops with high production rates and less pests' infestation, something that is not provided by synthetic fertilization [25] [26]. Crops grown in organic fertilized area harbor less number of insect pests [27]. Moreover, organic fertilizers found to be more effective than chemical fertilizers in inducing rice growth and its tolerance to insect pests and diseases [28]. Application of organic fertilizers was sound effect to protect natural enemies under field condition. Shifting from organic to chemical soil management increased the potential of certain insects and diseases to cause economic losses [29].

4.2. Why Quinoa Crop?

Egypt has huge wheat gap, as the total production of wheat grains covers only 55% of the Egyptian needs and therefore, it is extremely necessary to search for suitable alternatives that could be integrated in making wheat flour bread to overcome the wheat gap and satisfy consumers' needs [30]. Quinoa flour can partly replace wheat flour in baked products [31]. Besides, quinoa is a drought-tolerant crop that resists adverse conditions, has a high nutritive value and is able to adapt different ecological environments and climates [32]. Further, quinoa has the highest income and is the most profitable compared to other grain crops such as wheat, soybean and canola [12].

4.3. Pests' Population and Quinoa Crop

Considering the above mentioned issues and as quinoa is a new crop in Egypt, more efforts are needed to raise awareness about all aspects related to quinoa's cultivation. The current study investigated the effect of compost and vermicompost on quinoa yield, pests' and natural enemies' incidence and population dynamics.

No specialized quinoa pests were found, rather, polyphagous pests were detected together with generalized natural enemies. This finding is in accordance with what Rasmussen *et al.* [16] declared. Few types of pests were found in the current experimental field, *i.e.* the black legume aphid *A. craccivora*, the potato leafhopper *E. decipiens* and the whitefly *B. tabaci*.

Several authors mentioned the association of *Aphis* spp. in quinoa fields, *i.e.* [33] [34] [35]. Additionally, *Aphis* was stated as an important quinoa pest in Europe [16]. Nampeera *et al.* [36] mentioned that 87% of their survey respondents, in Kenya, determined aphids as a major pest attacking amaranths spp. and 96.8% ranked them as number-one insect pest. They also declared whiteflies as one of the pests attacking amaranths and causing damage. Quinoa shoots were also found to be attacked by sapsuckers (Aphididae and Cicadellidae) [37]. On the other hand, leafhoppers were declared as one of the pests attacking quinoa crop [16]. This data resembles the results obtained in the current study as these three pests were detected in the experimental area and aphids were the most abundant pest compared to the other two pests, *i.e.* whiteflies and leafhoppers.

It was noticed that aphids peaked twice during quinoa growth season, *i.e.* 23rd of January and 7th of March; these results are in conformity with Ya' bar *et al.* [37] who revealed that Aphididae had two peaks, at the beginning and end of quinoa growth season.

It is noteworthy that the present investigation provides basic information on seasonal incidence of whitefly on quinoa crop, as no data was found in the literature concerning this issue; rather the pest population was studied on many other crops. In the current study whiteflies peaked two times, *i.e.* 23rd January and 7th March (the same dates of aphids peaks). This confirms the findings of Yadav *et al.* [38] and Swathi [39] who declared that whiteflies peaked two times also but during tomato, soybean and green gram growth seasons in India. It seems that the pest behaves the same way in quinoa cultivation as demonstrated by the current findings.

The present study is also considered as first attempt that broadens our knowledge on the dynamics of potato leafhoppers on quinoa crop. It was proved that this pest peaked one time only during quinoa growth season; on the 7th of March. This might be due to the increase in temperature and decrease in the relative humidity (19˚C and 53%) compared to the other months. A similar belief was expressed by Naseri *et al.* [40] and Rassoulian *et al.* [41] who said that population density of leafhoppers increased with increasing temperature and decreasing relative humidity on bean and soybean. Yet, other researchers, *i.e.* [42] [43] stated that *E. decipiens* peaked two times on kidney bean and some other plantation under Egyptian conditions. Thus, it could be concluded that plant species might have an effect on the population dynamics of *E. deipiens*.

The current investigation proved that although compost and vermicompost showed direct effect on the mean numbers of pests attacking quinoa crop under the experimental condition, yet, the date each pest peaked did not change from one fertilizer to the other.

Likewise, this research demonstrated that pests found in organic fertilized quinoa plots are low in numbers compared to those in unfertilized plots. Altieri and Clara [29] found similar results and mentioned that crops grown in soils with organic matter exhibit lower abundance of several insect herbivores, reductions that could be attributed to lower nitrogen content in organically farmed crops. They added that quinoa plants fertilized with compost attracted less numbers of pests as proved in the current study. The superior of compost over vermicomopost might be explained according to Saranraj and Stella [44] who said that during preparation of vermicompost it retains more N than the traditional composts, therefore, using vermicompost increases the levels of total nitrogen in the soil and subsequently decreases plant resistance to pests as mentioned above. This interpretation could be applied here, as the parameters and minerals analysis of both compost and vermicompost proved that the percentage of nitrogen in vermicompost is double its percentage in compost, *i.e.* 1.2 and 2.4%.

4.4. Natural Enemies' Population in Quinoa Field

Parasitoids and predators were present in quinoa field. Four species of parasitoids were detected, *i.e.* Lysiphebus fabaru, Lysiphebus testacoipes, Bracon sp. and Trioxys sp. whereas, predators were represented by the existence of two families, *i.e.* family Chrysopidae: Chrysoperla carnea and family Coccinellidae: Coccinella vicina and Coccinella septempunctata. It was noticed that parasitoids peaked two times; January, 23rd and March, 7th which happened to be the same peak dates of aphids, grasshoppers and whiteflies. On the other hand, although predators were few in numbers; they peaked twice as well. Results verified that parasitoids appeared much earlier than predators and their mean numbers in the field were higher than predators in all treatments, although their numbers were less in compost treatments than both vermicompost and control plots; that might be attributed to the decrease in pests' numbers in compost treatments. The superiority of parasitoids over predators in the current investigation might be assigned to their early appearance in the field which allowed their early parasitism that led to reduction in predation rate and consequently predators' numbers. This explanation is supported by the findings of Tan *et al.* [45] who justified that the predator *Harmonia axyridis* of the family Coccinellida exhibited the lowest rates of predation when released in the presence of whitefly specific parasitoids (*Encarsia formosa* and *Encarsia sophia*) and showed a significant preference for non-parasitized nymphs as prey. Further research work is needed to prove this explanation. Reduction in predators number might also be attributed to the prevailed temperature during the current experiment which was 14.7˚C, 14˚C and 16.1˚C during December, January and February, respectively, and which is not favorite for the development of coccinellidae individuals as proved by Katsarou *et al.* [46] who stated that mortality of immature stages of these predators was the highest at the temperature of 14˚C whereas egg and larval mortality exceeded 80% at 17˚C and 18˚C. The same verification could be applied to *C. carnea* as low temperature causes high mortalities among the predator individuals and the suitable development temperature ranges from 25˚C to 31˚C [47]. Costa and Stary [48] proved that *L. testaceipes* follows its host aphids apparently in all environments and its occurrence covers most of the season.

4.5. Quinoa Yield

Results showed that using compost and vermicompost enhanced crop yield (seeds/plant, weight of 1000 seeds and yield/ha). Yet, vermicompost resulted in more yield when compared to compost and control. These results are in accordance with many researchers; Islam *et al.* [23] demonstrated that vermicompost application showed higher result for growth, yield indices and nutrient content of *Amaranthus viridis* compared to conventional aerobic compost and therefore, they recommended farmers to use vermicompost in crop production. Edwards *et al.* [49] reported that vermicompost has a much finer structure than compost and there is a considerable difference in their performances and effects on plant growth. In addition, Saranraj and Stella [44] stated that vermicompost plays a major role in crops growth and yield.

5. Conclusions

In a country characterized by a desert area that exceeds 90% and limited water resources, tolerant crops are needed. Through the current work it is concluded that:

- Quinoa is a promising solution to bridge wheat gap production in Egypt.
- Organic fertilizers can be the key to increase productivity and decrease pests' infestation in quinoa.
- Vermicompost is more effective in raising quinoa yield than compost although quinoa fertilized with it attracted more pests; therefore, an integrated pest management approach should be implemented to overcome this point in which natural enemies should play the main role, especially now that we know their peaks dates which is a good start for IPM interventions.
- More efforts should be made to raise farmers' awareness of vermicompost importance and efficiency and the community acceptance to quinoa as wheat alternative or supplement.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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