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Monitoring the Effect of Larvae and Adult Parasitoid *Bocchus hyalinus* (Hymenoptera: Dryinidae) and Egg Parasitoid *Pseudoligosita babylonica* (Hymenoptera: Trichogrammatidae) on Dubas Bug *Ommatissus lybicus* De Berg., (Hemiptera: Tropiduchidae) on Date Palm in (Harmet village) in the Sultanate of Oman

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ABSTRACT

Dubas bug Ommatissus lybicus (Hemiptera: Tropiduchidae) is one of the major insects of the date palm (Phoenicx dactylifera) trees, in Oman and the most of Arab Peninsula. The main objective of this experiment was to study monitoring of larvae and adult parasitoid Bocchus hyalinus (Hymenoptera: Dryinidae) and egg parasitoid Pseudoligosita babylonica on Dubas bug O. lybicus De Berg., on date palm in Harmet village in Bahla Wilayat in the Sultanate of Oman. This work was started in autumn generation 2010 and continued until spring 2019. In this village where insecticides were not sprayed earlier, natural enemies have ability to minimize the infestation of Dubas bug in the following generation. In the laboratory studies, the samples of egg, nymph and adult stages of Dubas were inspected by using stereomicroscope to study the life cycle and behavior of the parasitoids and to find a host for mass rearing purposes. Besides, the life cycle of B. hyalinus and P. babylonica were observed, and the development of immature stage of B. hyalinus and P. babylonica were recorded. In the field studies, the seasonal activity and population density of the two natural enemies of the insect in both the spring and autumn generations were monitored in the nature where no chemicals were applied. In case of egg parasitoid P. babylonica, observations on parasitism were taken during the period from May to July of spring generation and from October to December of autumn generation. The results indicated that the percentages of parasitism of both spring and autumn generations from spring 2010 to spring 2015 were respectively as 1.9% & 5.3% in 2010, 11.5% & 13% in 2011, 9.9% & 18.3% in 2012, 7.7% & 14.8% in 2013, 10.8% & 15.6% in 2014. Whereas in spring 2015 was failed to 6.1% and then was increased in autumn by 10.4%. However, in the next seasons which included spring 2017 and 2018 was reduced approximately from 4.4% to 2.7%, respectively. The graphs and charts wear illustrated that Dubas percentage was reduction from 96.3% in spring 2010 to 84.5% in autumn 2014 after 10 generations which scored 12.3% as a reduction rate. Among all 17 generations from spring season in 2010 until spring generation in 2019 the highest parasitism percentage of P. babylonica was 19.7% in autumn 2012. In addition, there was a laboratory work for egg parasitoid P. babylonica which included the releasing of the parasite to new Dubas eggs

and then dissecting under the microscope to identify the differentiation of immature stages and in determining its morphology forms.

The seasonal activity of nymph and adult parasitoid B. hyalinus was recorded from spring 2010 to spring 2015. The results indicated that the percentages of parasitism of both spring and autumn generations from spring 2010 to spring 2015 were respectively as 0% & 42.2% in 2010, 2.4% & 6.5% in 2011, 67.5% & 0% in 2012, 50.8% & 0% in 2013, 0% & 0% in 2014 and was 0% in spring 2015, respectively. The biological studies of Bocchus were continued by following the situation of parasitism by counting the infestation of Dubas and by collecting specimens of parasitized individuals and dissecting under the microscope. In addition, many female adults of parasitoid were collected and exposed to a number of Dubas bugs nymphs and adults for about 24 hours in the laboratory. After that Dubas bug adults were dissected to identify the immature stages of B. hyalinus. As a result, we observed the fourth (part inside and other outside) and fifth (inside soil) instars of larva and the pupa stage (inside soil).

Keywords
Dubas bug, *Ommatissus lybicus*, Date palm (*Phoenix dactylifera*), Biological control, Egg parasitoid, *Pseudoligosita babylonica*.

Introduction

Dubas bug *Ommatissus lybicus* (Hemiptera: Tropiduchidae)

The date palm *Phoenix dactylifera* L. is a major crop grown in the Sultanate of Oman and the Gulf countries. The number of date palms was approximately 7.6 million date palm trees in Oman, whereas 6 million are productive [1] increased to 9.1 million date palm trees in 2023 [2] with production of (372572) Date yield (tons) [4]. Oman Date import (23866.3) tons and export (21128.3) tons [1,4]. Among the productive date palms, 64% are for fresh consumption and 36% are for industrial consumption [5]. The total cultivated area of date palms in the Sultanate is about 25381.8 thousand hectares, which occupies more than 82% of the total fruit area and about 42% of the total agricultural land. Over 250 varieties of date palms are grown throughout Oman [6]. Oman is among the top ten countries in the production of date palm fruits [3]. Recover the variation between export and import by raising the yield through increasing the population of date palm trees, or therapy the stress of yield production, for example, insects and diseases.

The significant economic importance of insects affecting the growth and yield of date palms quantitatively and qualitatively was Dubas bug *Ommatissus lybicus* Bergevin, red palm weevil *Rhynchophorus ferrugineus* Olivier, lesser date moth *Batrachedra amydraula* Meyer, old world date mite *Oligonychus afrasiaticus* McGregor, the date palm stem borer *Jebusea hammerschmidti* Reiche and the fruit stalk borer *Oryctes agmemnon* Burmeister [7-9]. Dubas Bug's *Ommatissus lybicus* (Hemiptera: Tropiduchidae) (egg, nymph, and adult) was a series of harmful insects in date palm (*Phoenicx dactylifera*) trees nursery in the Sultanate of Oman [10-23]. Dubas bug in Oman was first recorded in Oman in 1962 [24]. Dubas pest recorded that Falaj Al Hamra and the wells were arid in Al Hamra town, Ad Dakhiliyah Governorate, during the drought event around 1670 [25]. During the period from 1993 to 2010, about 523 tons of insecticides were used in aerial applications to control *O. lybicus,* with an estimated cost of £18.5 million, ≈ approximately 8 million Omani rial [26,27]. In 2009, the Agricultural and Fisheries Development Fund (AFDF) in Oman estimated that the profits from controlling Dubas bug in the autumn generation were US$15 million, representing the value of crops saved. In addition, the majority of costs for the Ministry of Agriculture, Fisheries, Wealth, and Water Resources during flight operations and pesticide expenses are in US dollars. 4.6 million [28]. Pesticides were associated with many environmental pollutants and human cancer diseases. Primary cancers included Lung, Pancreas, Colon, Rectum, Leukemia, Multiple myeloma, Bladder, Prostate, Brain, Melanoma, lymphoid and hematopoietic systems, and non-Hodgkin lymphoma [29,30]. From 1996 to 2015, over 21000 cases of cancer were registered among Omanis, with an average of 1050 cases/year. The frequency of cases among both genders was similar (51% men vs. 49% women) [31].

Up to 50% of the economic losses of date palms yield as a result of infestation by the Dubas bug in Iraq [32]. Hussain [33] reported that the dates of infested palms are smaller and ripen more slowly, with a high percentage of reducing sugars and a low percentage of sucrose. Moreover, extremely heavy populations of Dubas lead to the death of palms [34]. Dubas bug is the famous insect pest of date palms in Oman, and it causes colossal economic losses [35]. In Oman, the maximum damage has been reported on the variety Fardh (mid-late season) (31.7%), followed by Khanesi (medium season) (28.6%) and Naghal (early season) (24.7%) in terms of yield. Consequently, the width, length, diameter, and weight of the fruit seeds dramatically reduced [35]. Date palm yields decreased to an extent of (28.33%), in the case of Dubas infestation, particularly in interior Oman. According to Hussain [36], repeated heavy infestation causes the weakening and death of the date palms, especially during the extensive out-breaks of insects [37]. Since the recording of the Dubas bug in Oman, the Ministry of Agriculture, Fisheries, Wealth, and Water Resources has been concerned each year with managing the infestation. Several pesticides were evaluated for controlling the Dubas bug through aerial and ground spraying in fields. However, the infestation is becoming more permanent and has consequences all over the country. As a result, the full potential of leveraging the high diversity of native natural enemies in the Omani environment has rarely been realized in integrated pest management programs to minimize the economic threat of this insect.

Natural enemies of Dubas bug *Ommatissus lybicus* (Hemiptera: Tropiduchidae)

There are many of local natural enemies attack Dubas bug as

predators such as *Scymnus levaillanti* Mulsant (Coleaptera: Coccinellidae), *Cheilomenes* (=*Menochilus*) *sexmaculata* Fabricius (Coleaptera: Coccinellidae), *Coccinella sptempunctata* L, *Coccinella undecimpunctata* L, *Ischiodon aegyptiaca, Chrysoperla carnea* Stephens (Neuroptera: Chrysopidae) and egg predator mites *Runcinia* sp. (Araneidae: Thomisidae) and *Bochartia* sp. (Acari: Erythraeidae) [7,8,38]. Kinawi [7] recorded that several types of spiders such as Garden spider (Family: Araneidea), Jumping spider (Family: Salticidae) found feed in nymph and adult of Dubas in date palm nursery and field. In addition, there was some predators such as mantids (*Nilomantis floweri* Werner) (Mantodea: Mantidae), lacewing larvae (*Chrysoperla* sp.) (Neuroptera: Chrysopidae), lady beetle larvae and adults (*Cheilomenes sexmaculata* Fabricius) (Coleoptera: Coccinellidae), jumping spiders (*Plexippus paykulli* Audouin) (Araneae: Salticidae) and crab spiders (Araneae: Thomisidae) [39]. Besides, a number of parasitoids include *Aprostocetus* sp (Hymenoptera: Eulophidae) as egg parasitoid and also *Pseudoligosita babylonica* (Hymenoptera: Trichogrammatidae) [8,12,40-42] and larvae and adult parasitoid *Bocchus hyalinus* (Hymenoptera: Dryinidae) [8,40,43]. Moreover, Hyperparasitoid *Aphanogmus* sp. (Hymenoptera: Ceraphronidae) [38]. Furthermore, when check approximately 570 nymphs and adults of Dubas bug collected in Mussandam yielded 2 specimens of a Dryinid, Hymenoptera [44].

Pseudoligosita babylonica (Hymenoptera: Trichogrammatidae)

Al-Khatri [12,41] found *P. babylonica* (Hymenoptera: Trichogrammatidae) attacks the eggs of Dubas bug in Oman and the percentage of eggs that the parasite came out of reached between 6 and 25% in March and May 2005, respectively. In 2008 he noted the spread of the parasite attributed from one location to another, and it did not exist in Kasip district in Musandam Governorate (Coordinates: 25°55′N 56°17′E), while the percentage of parasite eggs reached 60% in the village of Tiwi in Ash Sharqiyah South Governorate (Coordinates: 22.566667°N 59.528889°E) in eastern region, thus it is very clear that the parasitoid played a good role to control the date palm Dubas insect. In Iraq, the parasites have been classified in Italy by Viggiani and found a new type and named it *Pseudoligosita babylonica* n.sp. (Hymenoptera: Trichogrammatidae) [45-47]. It was recorded *P. babylonica* attack the eggs of Dubas bug [46] and it was noted that it reduces the population density of Dubas eggs well. Hassan et al. [48] also studied the life cycle of the parasite in the laboratory and found that the age of the parasite is 31 days at a temperature of 28°C, and pointed out that females and males of the parasite feed on the honey material produced by the Dubas insect. It has been shown that when there is no honey the age of gender lowers. Hubaishan and Bagwaigo [49] have followed the presence of this parasite in Yemen in Hadramout since 2005 before they recognized it in 2007 in Gail-Alhalikah village, and for identification they sent the samples to France (CIRAD) and found the same type which was found in Iraq. After further investigation we found that the Dubas egg parasite exist all the time and it does not overwinter in all areas of our study [49]. These results were totally different from those in Iraq according to Hassan et al. [48] where he said that it has only two generations, similar to the dubas insect. In addition, this parasitoid was distributed in most nursery and field of date palm tree in different governorate in the Sultanate of Oman [7,8,41]. The percentage of parasitism *P. babylonica* covered some villages of Al-Dakhiliya governorate include Ghamar (13.6%), Al-Towaya (51.8%), Al-Fatah (58.8 %), Horomt (29%), Masfate Al-Sheriqieen (15.7%), Al-Showaiei (32.2%), Twi Seda (30%), Wadi Meiden (31.5%), Bin Omair (32.8%) and Bin Masood (38.9) [8]. The variation of parasitism according to some villages over 50% such as Ghyadhah (60.1%), Mihlah (52.3%) both from A'Sharqiyah governorate, Misfat A'Shureqiyyin (50.5%) from Al-Batinah governorate and from Al-Dakhiliya governorate both Al-Towaya (51.8%) and Al-Fatah (58.8 %). The location was at Al-Hajer village at Samail Wilayat (N 23° 03' 38.5", E 057° 56' 57.8") and Qariyat bani Subh village at Al-Hamra Wilayat (N 23° 06' 01.4", E 057° 18' 42.0") were following the percentage of parasitism *P. babylonica* from 2016 to 2018 for both season spring and autumn respectively generations as follow 32.64% and 71.23% in 2016, 33.67% and 50% in 2017, 16.87% and 85.75% in general, the parasitism percentage was higher in autumn season than spring season [50]. The highest peak of parasitism at last week of January and first week of February in spring season and during autumn season was at the first week of June and another peak was at first week of July [50]. The level of parasitism (%) was recorded in the laboratory studies at an average of 65.6% at different temperatures and 25% in the field at different locations in Oman [12]. Parasitism (%) of *P. babylonica* increased from 16.6% in spring 2008 to 20.9% in autumn 2009. As a result of or because the autumn generation had the longer emergence % of egg hatching (3.5 weeks and 9.9 weeks) duration compare to the spring generation (2.4 weeks and 4.0 weeks) under field and laboratory condition, respectively [12]. The internal egg parasitoid, *Pseudoligosita babylonica* Viggiani (Hymenoptera: Trichogrammatidae), was reported to coexist with the Dubas bug in Omani date palm orchards, Iran, and other Arab countries, including Iraq, Saudi Arabia, and Yemen [12,50]. The parasitoid is described as a small, stout, yellowish wasp measuring almost 0.60±0.1 mm in length. *P. babylonica* has been reported as a promising biocontrol agent of *O. lybicus* by causing up to 70% parasitism in different sites in Oman. In Iraq *P. babylonica* parasitism 22% in spring generation and 17% in autumn [46,51] and 2.5% and 23.6% in both generation, respectively in Yemen [49]. Each parasitoid wasp develops inside a single Dubas bug egg. It has three generations during each of the spring and autumn generations of the Dubas bug. The first generation coexist with the hibernating eggs which are about to hatch, the second generation coincides with the hatching eggs and third generation exists after the hatching of Dubas bug eggs [12,50]. Optimum temperature range for the survival or parasitoid is reported between 22.3 to 32.7°C with 30°C as an ideal temperature for its optimum growth. Our team suggested that the parasitoid could be a potential target as a biological control agent for the Dubas bug. The present study focused on the seasonal fluctuations, life cycle development, and morphological characteristics and behavior of the immature stage of *P. babylonica*, conducted under both field and laboratory conditions.

Bocchus hyalinus (Hymenoptera: Dryinidae)

Dryinidae (Hymenoptera: Chrysidoidea) includes 12 extent subfamilies (*Aphelopinae*, *Anteoninae*, *Apoaphelopinae*,

Apodryininae, *Bocchinae*, *Conganteoninae*, *Dryininae*, *Erwininae*, *Gonatopodinae*, *Palaeoanteoninae*, *Plesiodryininae*, *Ponomarenkoinae*, *Transdryininae*, *Thaumatodryininae*) [52,53]. Dryinidae (Hymenoptera: Chrysidoidea) are highly specialized parasitoids of leafhoppers, planthoppers and treehoppers (Hemiptera: Auchenorrhyncha) [54-58]. Representatives of the family have been successfully utilized in several instances for the biological control of crop pests [59,60]. *Bocchus hyalinus* Dryinidae (Hymenoptera: Chrysidoidea) was first recorded in Oman by Olmi. This parasitoid was found in several villages scattered in many towns such as Abry, Sohar and Bahla [7,8,41]. Indeed, in Bahla there is a village called Horumt (N23°06.064; E057°09.633) in Ad Dakhiliyah Governorate which has a high infestation of dubas bug [8]. *B. hyalinus* was recorded in different countries such as Sultanate of Oman, United Arab Emirates, Kenya and Iran [17,61,62].

Although spray hug amount of insecticides, the infestation still high and suffer with no economic yield of date palm production. However, when stop using chemicals and let natural enemies such as *B. hyalinus* and *P. babylonica* take place, the infestation of insect became much lower in recently years. The main objective of this work was: first, in the field studies, the seasonal activity and population density of the two natural enemies of the insect in both the spring and autumn generations were monitored in the nature where no chemicals were applied. Second, in the laboratory studies, the samples of egg, nymph and adult stages of Dubas were inspected by using stereomicroscope to study the life cycle and behavior of the parasitoids and to find a host for mass rearing purposes. Besides, the life cycle of *B. hyalinus* and *P. babylonica* were observed, and the development of immature stage of *B. hyalinus* and *P. babylonica* were recorded as can as possible.

Materials and Methods

Seasonal activities of *Pseudoligosita babylonica* (Hymenoptera: Trichogrammatidae)

The parasitism of Dubas bug eggs by the egg parasitoid *P. babylonica* has been estimated in both spring and autumn generations of Dubas from 2010 to spring 2019. The samples were taken biweekly during the autumn generation and also in the spring generation. Each sample consists of 50 leaflets taken randomly as 30 leaflets from the mature trees and 20 leaflets from the offshoots under the mature trees. The samples were taken from the third leaves whorl, which is preferable for deposition by females of autumn generation, while the samples were collected from fifth whorl in spring generation [11]. In the case of offshoots samples, they were taken from internal leaves. The leaflet samples were inspected in the laboratory using a stereomicroscope.

Establishment of *Pseudoligosita babylonica* colonies: The rearing technique adopted by Mokhtar et al. [63,64], was followed. The date palm seedlings were grown in the laboratory in black plastic pots 16cm in diameter and 14cm in height for about 7 months. Colonies of *P. babylonica* were established in cubical cages (length 75cm x width 75cm x height 60cm) that had several of date palm seedlings under condition humidity of 70-80% and temperature (25°C). After that a number of *O. lybicus* adults (male and females) were collected from the field and released inside the cages to deposit their egg in the leaflet of seedling. By using sucking mouth trap collected the adult of *P. babylonica* from the field and from the leaf and leaflet of date palm that infestation of dubas bug which keep it in plastic cylindrical container in the laboratory (Figure 1). Then the parasite released inside the cages for egg parasitism and for mass reared population.

Figure 1: Sucking mouth trap and plastic cylindrical container in the laboratory with the leaf and leaflet of date palm for the adult of *P. babylonica* collection.

Parasitism observations of *Pseudoligosita babylonica*: A mount of date palm seeds were soaking for about one day. After that several numbers of date palm seedling prepared in separate cage. And then appeared to adult of dubas bug for egg (laid singly within the leaf and leaflet tissue) deposit purpose for 24 hours. Furthermore, *P. babylonica* collected from the reared cage and released randomly number directly inside the transparent plastic cylindrical bottle (4cm in diameter and 20cm in length) total number approximately 1948 males and females of *P. babylonica* were used (Figure 2) with about 1576 Dubas egg and keep for parasitism exposure for 24 hours. The studies were conducted under incubations of was 27 ± 2°C and humidity of 70-80% with photo period 12L: 12D regime. In the next day a randomly number of dubas eggs were selected and started dissected under Carol Zeiss werk Gottingen (Germany) stereomicroscope. Dissections were conducted daily until the parasitoid adults emerged from the egg. The data recorded the morphological characteristic of the immature stage. According to that we can identify the eggs, larval instars and pupal stages of *P. babylonica*.

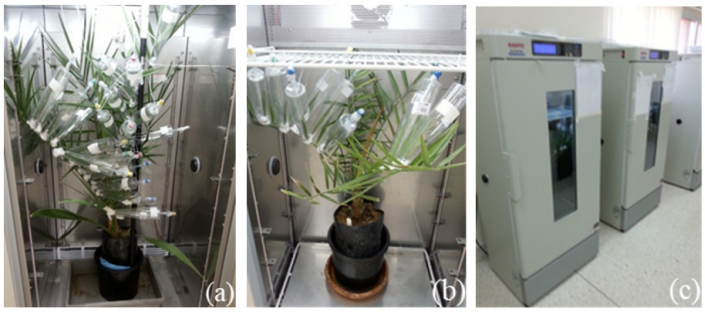

Figure 2: The transparent plastic bottle with *O. lybicus* egg and left for parasitism with *P. babylonica* exposure for 24 hours under incubations.

Bocchus hyalinus (Hymenoptera: Dryinidae)

Establishment of Dubas bug *Ommatissus lybicus* colonies: The rearing technique adopted by Mokhtar et al., [63,64] was followed. The date palm seedlings were grown in the laboratory in black plastic pots 16cm in diameter and 14cm in height for about 7 months. Each seedling was kept under a cylindrical transparent cage 15cm in diameter and 35cm in height and its top was covered with mish textile for ventilation. Irrigation was given by placing the pots in plastic trays by adding some water in the tray to allow the water taken by the roots of the seedling through the holes at the base of the pots. A number of *O. lybicus* adults (male and females) were collected from the field mass reared population and cultured on some seedling of date palm in the laboratory in a separate small room (3m x2.8m) for future experimental purposes under condition humidity of 70-80% and temperature 25°C.

Establishment of *Bocchus hyalinus* colonies: Colonies of *B. hyalinus* in cubical cages (length 75cm x width 75cm x height 60cm) were established from nymphs and adults of *O. lybicus* collected from date palm fields in Harmet village (Figure 3), during 2011 and 2012. Nymphs and adults with visible signs of parasitism, such as a dark cyst on their thorax or abdomen [37,43,65], were isolated and reared in a small drained rearing cage to obtain *B. hyalinus* larvae that emerged from them to pupate in a silk cocoon in the sandy soil [37,65]. The regime of rearing conditions included humidity of 70-80% and temperature 25 °C.

Figure 3: Colonies of *B. hyalinus* in cubical cages (lenght75cm x width75cm x hight60cm) were established from nymphs and adults of *O. lybicus* collected from date palm fields.

Parasitism observations of *Bocchus hyalinus*: A number of *Ommatissus lybicus* nymph and adults approximately 50 specimens from the laboratory colonized population were collected by sucking mouth trap and released on each transparent caged seedling. After that a female of *B. hyalinus* was collected from the field and released directly inside the cage (15cm in diameter and 35cm) with Dubas nymph and adults and left for parasitism exposure for 24 hours (Figure 4). Unfortunately, the female of *B. hyalinus* died after exposed in the next day and we were able to collect only 3 females for parasitism process at the laboratory and have been made three replications. In the next day a randomly number of Dubas nymph and adults were selected by sucking mouth trap and started dissected under Carol Zeiss werk Gottingen (Germany) stereomicroscope. The data recorded were the place of depositing *B. hyalinus* egg in the host and the immature or mature stage. According to that we can identify the eggs, larval instars and pupa stage. All the studies were conducted under laboratory room condition of was 25˚C and humidity of 70-80% regime with photo period 12L: 12D regime.

Figure 4: The cage (15cm in diameter and 35cm) with *O. lybicus* nymph and adults and left for parasitism with *B. hyalinus* exposure for 24 hours.

Results

Seasonal activities of *Pseudoligosita babylonica* (Hymenoptera: Trichogrammatidae)

Seasonal activities of the Dubas and its egg parasitoid *P. babylonica* were recorded per weekly in the Horumt village from spring season in 2010 until spring generation 2019 which included 17 generations (Figures 5,6,7). Also, the figure shows the fluctuation of the density of the Dubas as an insect and its parasitism *P. babylonica* during that period which was about 9 years. Moreover, it can be clear seen that the correlative between the two population in density in case of risen or dropping. During season 2010 the season of appearance of *P. babylonica* was not common. However, as the infestation of Dubas in season 2011 was increased the peak point of *P. babylonica* was in May and in December. Furthermore, *P. babylonica* was recorded more in July 2012 and next in January 2013. In addition, the situation was same for *P. babylonica* concentrate compared between season 2011 and 2014 for more appearance in May and December. Furthermore, the situation of Dubas infestation was started high during spring generation 2010 which expand from February to June with minimum in parasitoid population with about 1.9% of parasitism (Figures 5,6,7). However, through autumn generation 2010 which expand from September to November the Dubas was decreased sharply and the parasitism percentage was risen to 5.3%. In addition, during spring generation in 2011 the population of Dubas was increased rapidly but *P. babylonica* had strong ability to bring it down and the parasitism percentage also increased to 11.5%. In autumn 2011 was recorded the highest picked of infestation but at the end of the year the population of Dubas fell dramatically and parasitoid scored approximately 13% of parasitism. Furthermore, during spring generation 2012 as the population of Dubas decreased also the presentation of *P. babylonica* decreased and keep insects under

control with nearly 9.9% of parasitism. In contrast to the previous generation the parasitism growing up to 18.3% in autumn. However, the parasitism percentage was little reduced through spring generation 2013 which about 7.7% but it was increased to double (14.8%) in autumn season. Next in the 2014 the parasitism percentage was raised from 10.8% to 15.6 for both generations respectively. Whereas in spring 2015 was failed to 6.1% and then was increased in autumn by 10.4%. However, in the next seasons which included spring 2017 and 2018 was reduced approximately from 4.4% to 2.7% (Figures 5,6,7), respectively. The graphs and charts wear illustrated that Dubas percentage was reduction from 96.3% in spring 2010 to 84.5% in autumn 2014 after 10 generations which scored 12.3% as a reduction rate (Figure 6). Among all 17 generations from spring season in 2010 until spring generation in 2019 the highest parasitism percentage of *P. babylonica* was 19.7% in autumn 2012. As a result, this parasitoid has a strong efficient to keep this insect under the economic threshold away from handling permanent insecticide with pure environment of natural enemies.

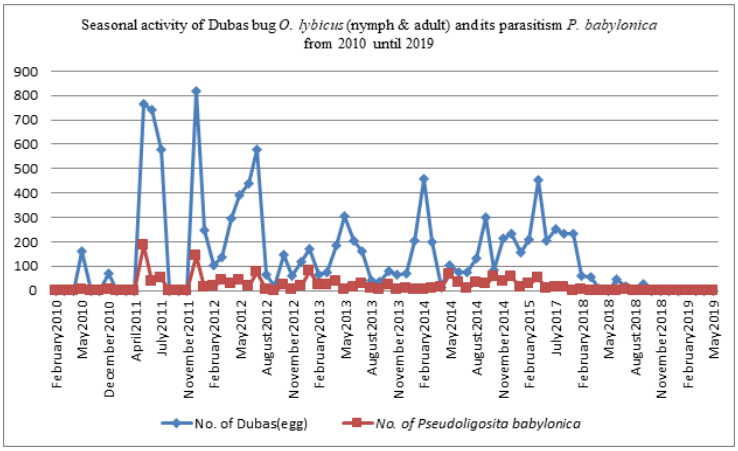

Figure 5: The population dynamic of the Dubas bug *O. lybicus* and its egg parasitoid *P. babylonica* from 2010 until 2019.

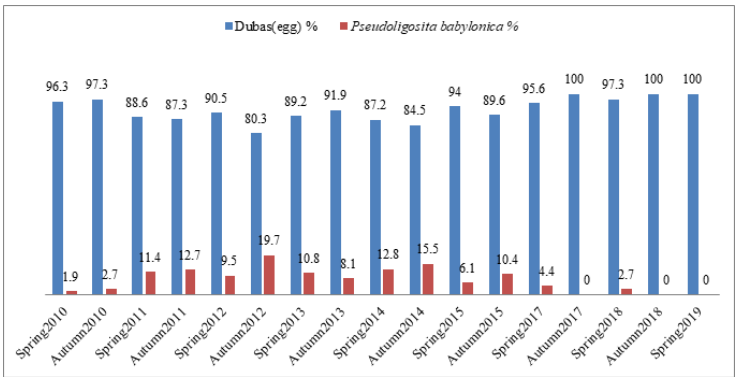

Figure 6: Dubas bug *O. lybicus* and its egg parasitoid *P. babylonica* parasitism percentage for both spring and autumn generations from 2010 until 2019.

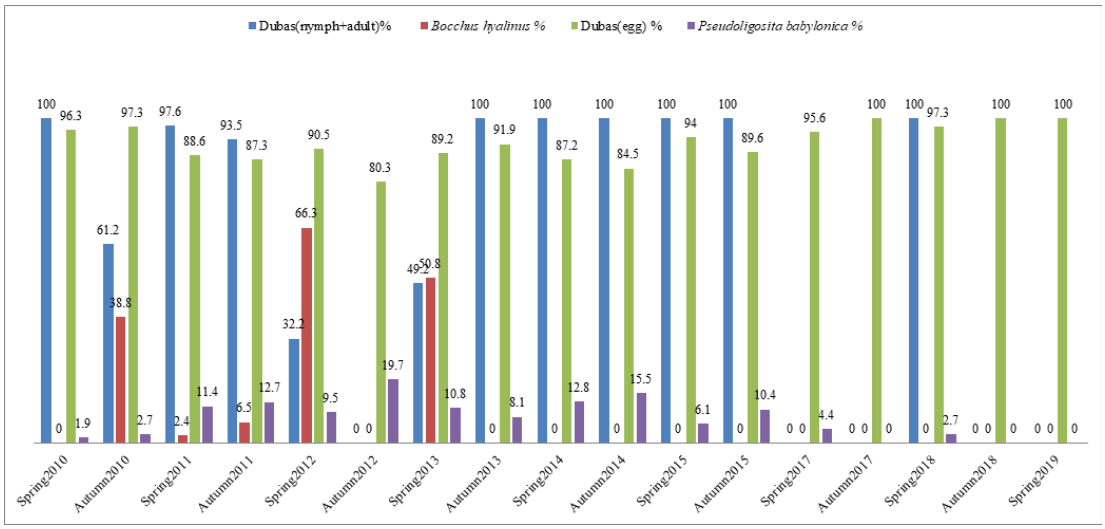

Figure 7: Dubas bug *O. lybicus* and its egg parasitoid *P. babylonica* and nymph and adult parasitoid *B. hyalinus* parasitism percentage for both spring and autumn generations from 2010 until 2019.

Biological study of *Pseudoligosita babylonica* (Hymenoptera: Trichogrammatidae):

Description of the immature egg stage of Dubas bug *Ommatissus lybicus*

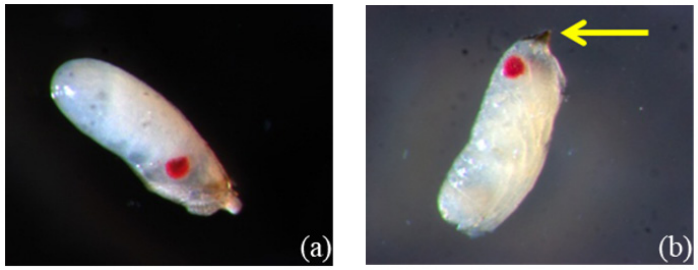

Figure 8: The Dubas bug *O. lybicus* embryo with red eye with spine or beak point (a-b).

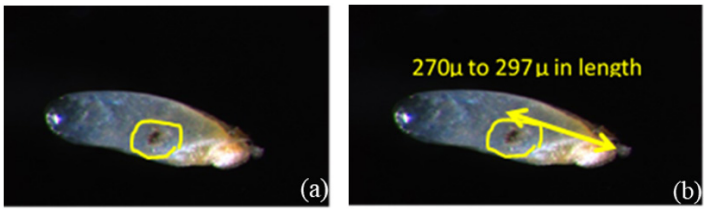

Figure 9: The attacked, penetration or ovipositor point by the parasitoid *P. babylonica* on Dubas bug *O. lybicus* egg (a-b).

The size of the white Dubas embryo (Figure 8) was 558 to 603µ in length and 216 to 234µ in width with red eyes similar that was found by [66] and the head had a tip point take the shape of thorn or spine or beak point or triangle area with size 90µ in length and 18µ in width for hatching purposes [67-69]. The distance between the top of Dubas egg and the attacked, penetration or ovipositor point or hole in brown or dark color by the parasitoid *P. babylonica* was approximately 270µ to 297µ in length (Figure 9).

Morphological characteristics of the immature stages of the parasitoid *Pseudoligosita babylonica* (Hymenoptera: Trichogrammatidae)

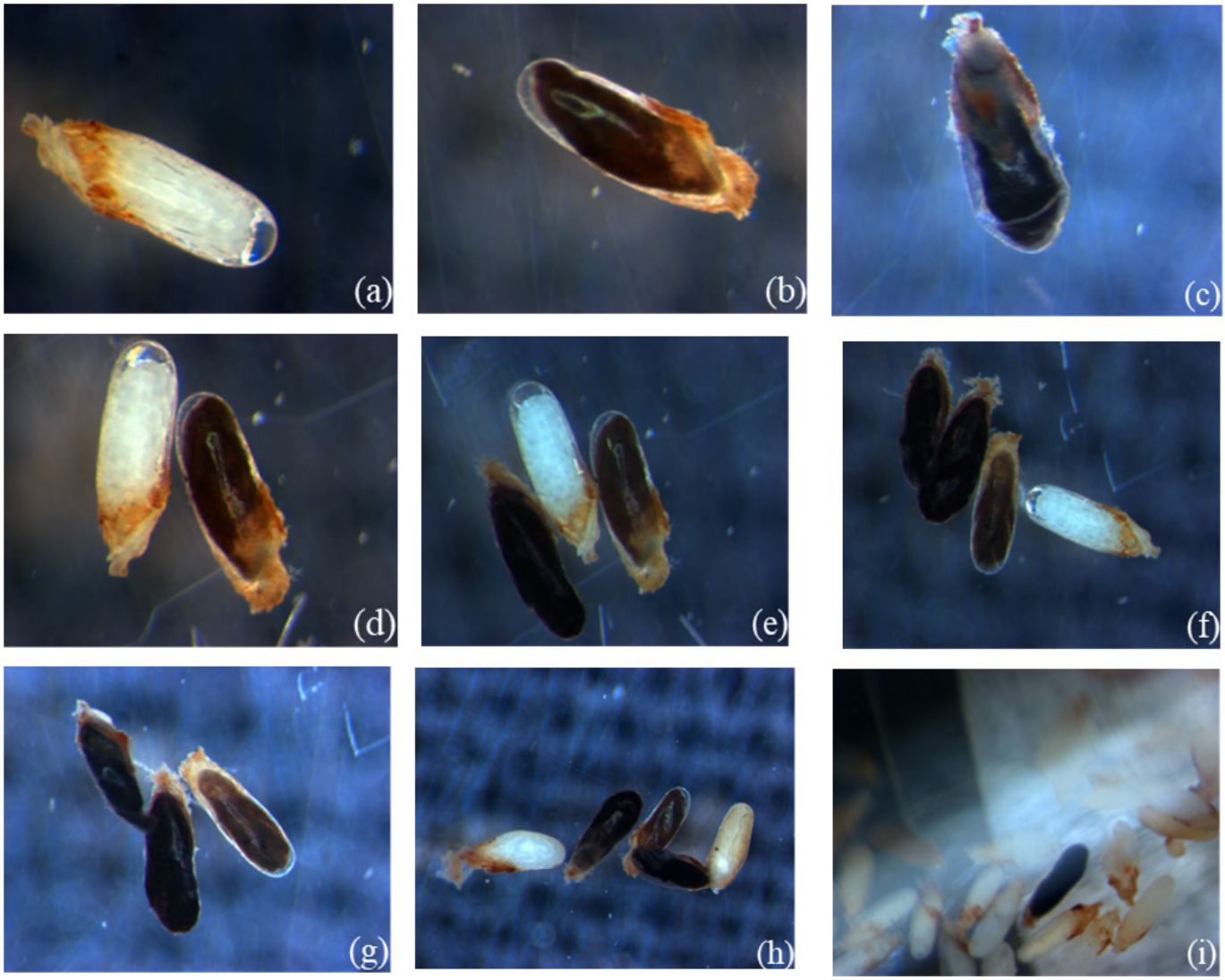

Figure 10: The Dubas bug *O. lybicus* egg in white color and its parasitized egg in dark color (a-i).

Morphologically, the immature stage of *P. babylonica* could be divided into an egg stage, followed by larval instars, a prepupal stage, pupal stage and postpupal and all life stages inside the coloured dark [66] Dubas egg (Figure 10) as the only host without going further to nymph or adult stage (Figure 13). The larval instars were defined based on the morphological characteristics as well as on the measurements of the body length and width. The measurements of the length and the width of the egg, larval stage and pupa are presented in (Table 1) with duration period (Table 2).

Description of the egg stage of *P. babylonica*

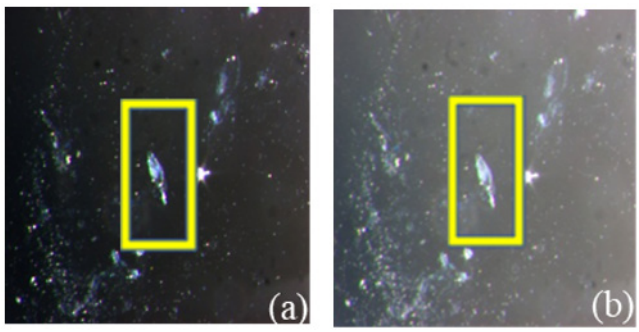

Figure 11: The Egg of *P. babylonica* (a-b).

Eggs of the parasitoid deposited inside Dubas egg. Eggs of *P. babylonica* were found to be hymenopteriform type [37,65,70] (Figure 11). Hagen [65] reported that this type of eggs is of general occurrence in most hymenopterous order and Trichogrammatidae families. Eggs were found to be had a longitudinal pear shape, expanded in the middle and transparence color and elongated similar was recorded by [71]. The egg mean size 65.25 ± 23.7µ in length and 23.25 ± 11.8µ in width with long neck or the upper part with size 45µ in length and 9µ in width (Table 1). The mean developmental time take about 3.46 ± 1.73 days with duration (days after egg laid) time from 1-5 days (Table 2). A single egg (solitary) or in groups (gregarious) or cluster of two to five eggs [72] was indicated inserted inside the Dubas egg. *P. babylonica* was found completed their life cycle in one stage of host life cycle which was egg stage which can called Idiobionts [70].

Description of the larval instars of *P. babylonica*

Larval stage of *P. babylonica* (Figure 12) were found to be mymaiform type [37]. Larval stage with minute mandibles or without were found inside Dubas egg to be had a longitudinal oval cylindrical shape, then develop to a mymariform and white color at beginning following by yellow to orange as a result of feeding. The mean size 234.02 ± 168.51µ in length and 88.62 ± 77.90µ in width (Table 1). The mean developmental time take about 17.45 ± 5.07days with duration (days after egg laid) time from 6 −25 days (Table 2). The host had many larval and end with one or two for molting to pupa and adult stage. The larvae of endoparasitic parasitism especially Trichogrammatidae and Mymaridae family, even it do not have spiracles, the respiration process of it take place by tack oxygen by its integument from the host fluids [65].

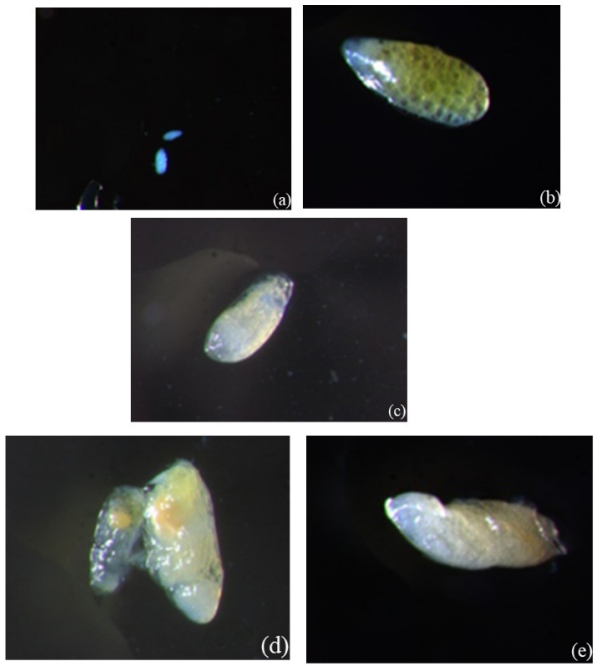

Figure 12: The larval stage of *P. babylonica*.

Description of the prepupa stage of *P. babylonica* after 25-30 days

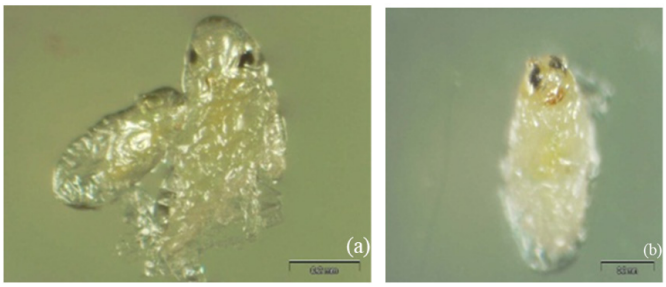

Figure 13: The prepupa stage of *P. babylonica* (a-b).

Some Dubas eggs have one prepupa (Figure 13), and others have many in white to yellow color. Most parasitoid organisms or regions beginning appeared as black eyes and brown mouth parts at the beginning [66].

Description of the pupa stage of *P. babylonica*

Pupa stage (Figure 14) was found two type one with wing and some without in the egg of the host. The three body regions (head, thorax and abdomen) were clearly identifiable. Some eggs have one pupa and other have many approximately two. The mean size 423.43 ±109.27µ in length and 205.07 ± 72.70µ in width (Table 1). The mean developmental time take about 17.45 ± 5.07days with duration (days after egg laid) time from 25 −30 days (Table 2). The emerging adult could be with or without wing [12] and the mean size 495 ± 1.50µ in length and 207 ± 2.12µ in width (Table 1). The mean developmental time take about 30 ± 0.31 days with duration (days after egg laid) time approximately 30 days (Table 2). The figure was illustrated that the image of body was in

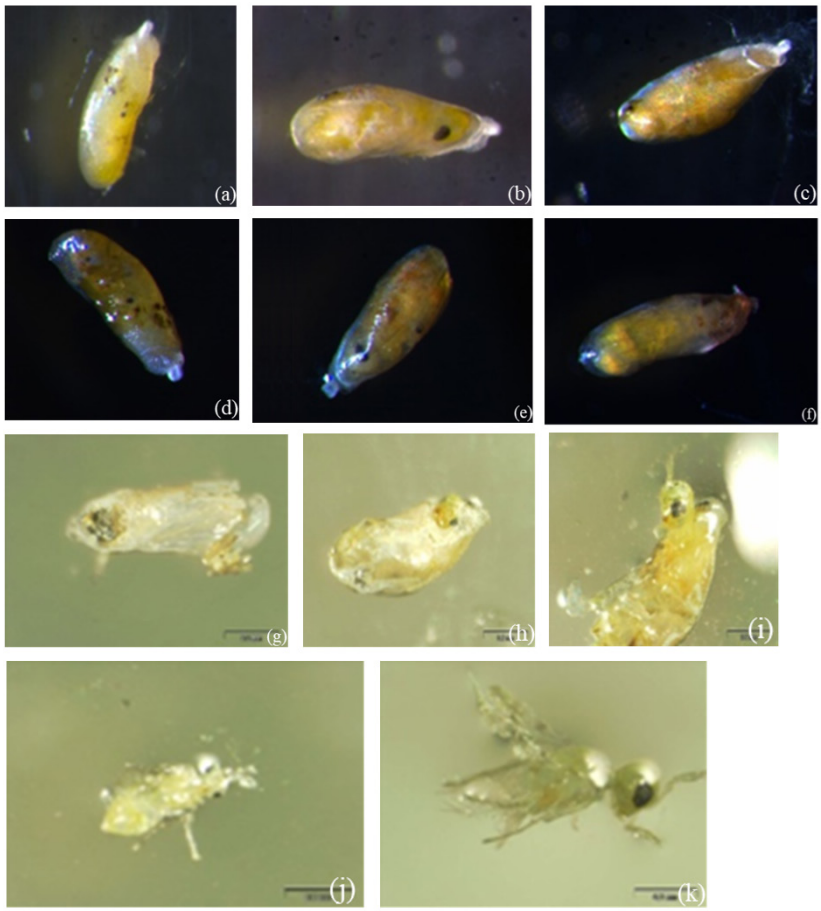

Figure 14: The pupa stage of *P. babylonic* (a-k).

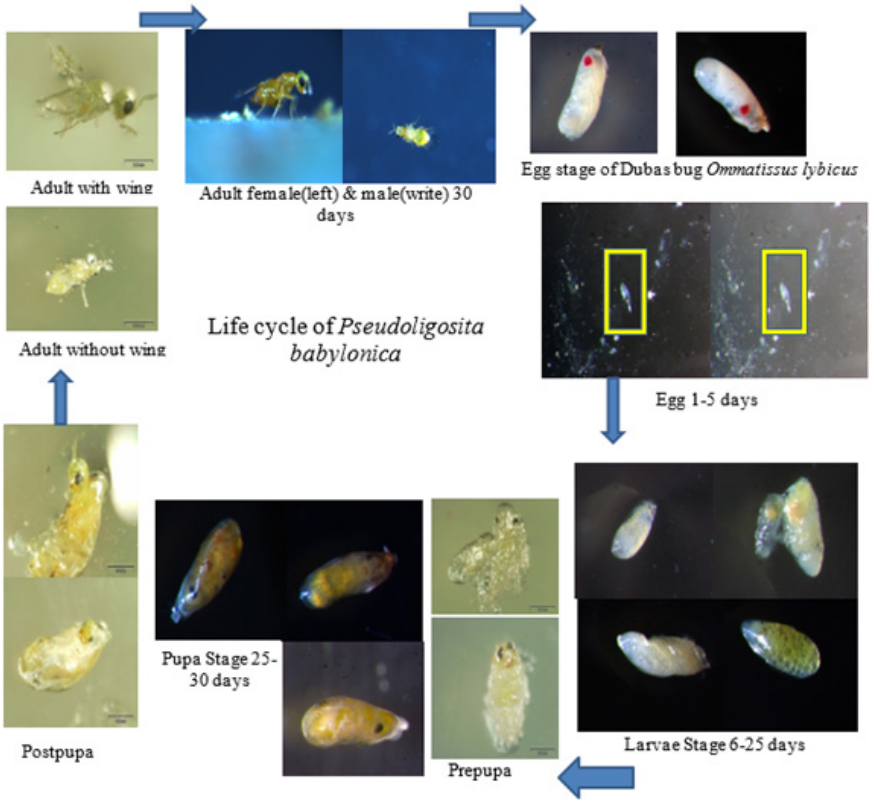

Figure 15: The life cycle of *Pseudoligosita babylonica (Hymenoptera:Trichogrammatidae)*.

honey yellow color with black eyes and red mouth inside the egg of Dubas bug which was the same recorded as a morphological behavior by [66,73]. Superparasitism was observed, with one or three *P. babylonica* successfully developed from the egg Dubas infestation and also effected in the reduced fitness especially adult with or without wings as a result of nutrients competition [12,67,69,74]. As a result of the superparasitism within the gregarious parasitoids was caused reduced fitness, minute and small parasitoid phenomenon [75].

Table 1: Sizes of each immature stage and adult of *Pseudoligosita babylonica* reared in *Ommatissus lybicus* at 27 ± 2°C.

		Body size (µ) (Mean ± SD)	
Stage	**N**	**Length**	**Width**
Egg	182	65.25 ± 23.7	23.25 ± 11.8
larvae	1117	234.02 ± 168.51	88.62 ± 77.90
Pupae	180	423.43 ±109.27	205.07 ± 72.70
Adult	97	495 ± 1.50	207 ± 2.12

Table 2: Durations of each immature stage and adult of *Pseudoligosita babylonica* reared in *Ommatissus lybicus* at 27 ± 2°C.

Stage	N	Developmental time (Days) (Mean± SD)	Duration (days after egg laid)
Egg	182	3.46 ± 1.73	1 −5
larvae	1117	17.45 ± 5.07	6 −25
Pupae	180	27.18 ± 1.66	25 −30
Adult	97	30 ± 0.31	30

Bocchus hyalinus (Hymenoptera: Dryinidae)

The population of both dubas bug and *Bocchus hyalinus* were illustrated in the (Figure 16). As can be seen from the graph the fluctuation of population for both insect and parasitoid were expanded from 2010 until 2015. In addition, there was very strong correlation between the two populations in case of risen or dropping of density. According to the chart in primary recorded of results of the seasonal activity of larvae and adult parasitoid *B. hyalinus* during 2010 it was concentrated in October, November and less in December and the parasitism were 0% and 42.2% for spring and autumn generation respectively (Figures 17,18). However, in 2011 it was more in November, March and April, and was declined in autumn generation because of rain fell and the parasitism was 2.4% and 6.5% for both generations respectively. Furthermore, the parasitism was increased 67.8% during spring generation 2012 and limit of *Bocchus* was appeared during autumn season because of less infestation of dubas bug. During spring generation 2013 the most concentrate of parasitism appeared in April and May and the highest percentage was at end of April approximately 50.8%. However, there was no recorded for parasitoid from autumn generation 2013 until spring 2015 (Figures 16,17,18). And that as a result of using insecticide by farmer's without inform the extension centers of the Ministry of Agricultures and Fisheries, besides the highly sensitive of *B. hyalinus* to these chemicals. In conclusion, the link of both insect and parasite very strong of appearance in the field observation especially the parasite was seen after approximately month of the infestation was recorded in the Horumt village.

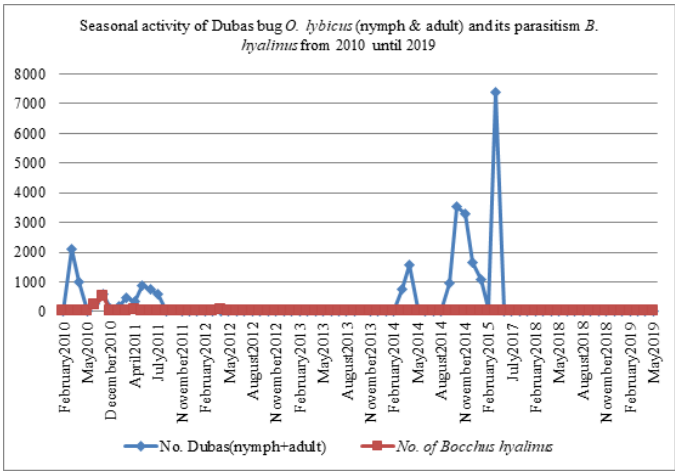

Figure 16: The population dynamic of the Dubas bug *O. lybicus* and its nymph and adult parasitoid *B. hyalinus* from 2010 until 2019.

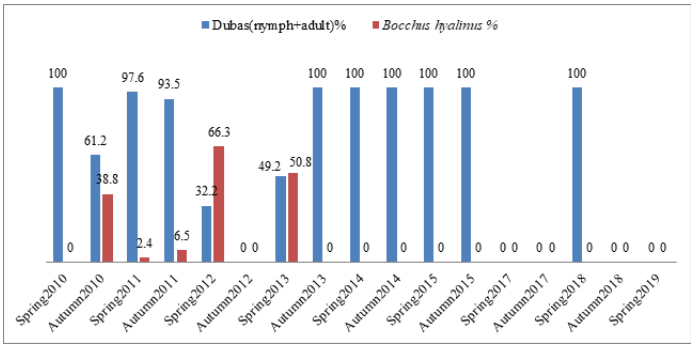

Figure 17: Dubas bug *O. lybicus* and its egg parasitoid *B.hyalinus* parasitism percentage for both spring and autumn generations from 2010 until 2019.

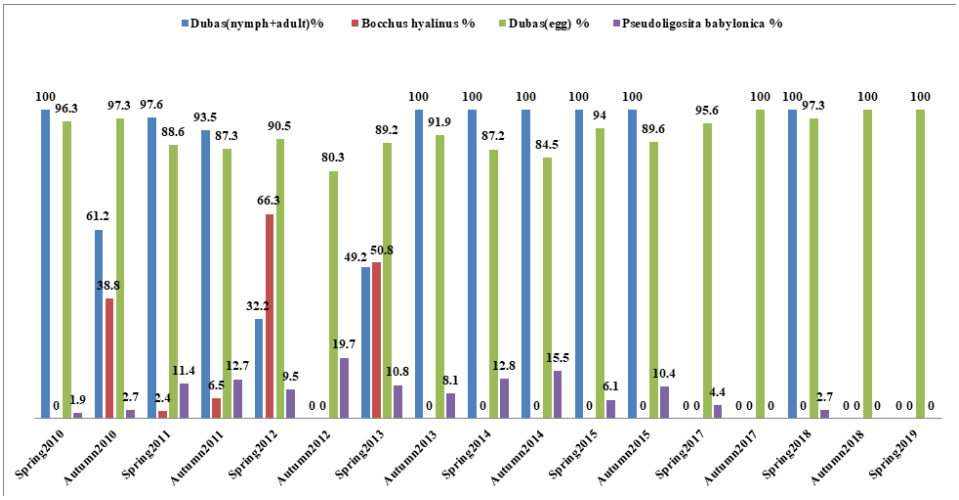

Figure 18: Population of Dubas bug *O. lybicus* and its egg parasitoid *P. babylonica* and nymph and adult parasitoid *B. hyalinus* parasitism percentage for both spring and autumn generations from 2010 until 2019.

Biological study of *Bocchus hyalinus* (Hymenoptera: Dryinidae)

The results of study show that the development of life cycle of *B. hyalinus* was able to observed the fourth immature larval instar and the fifth mature larval instar of the parasitoid *B. hyalinus* from the specimens that collected from the field directly and from the rearing or culture exposed cage. In fact, the life cycle consists of: egg, larva (4 to 5 instars), pupa and adult [76,77]. The fourth larval instar is hymenopteriform and develops as an ectoparasitoid in a sac or cyst formed from the cast skins of the developing larva and projecting from the host's body same was found by Guglielmino & Virla and Virla et al., [76,77]. The last larval instar is the mature larva. It is hymenopteriform and devours all the body content of the host. The mature larva emerges from the cyst and pupates in the sandy soil similar observed by Guglielmino & Virla and Virla et al. Besides, the final stage is adult both male in black colour and female in yellow colour (Table 3).

Table 3: Sizes of some larval stage and adult of *B. hyalinus* reared in *O.lybicus* at 25 ± 2°C.

		Body size (µ) (Mean ± SD)	
Stage	N	Length	Width
4rd instar larva	10	169.6 ± 26.3	72 ± 18.4
5th instar larva	10	163 ± 23.8	50 ± 4.7
cocoon	3	184.7 ±18.7	86 ± 5.8
Adult	3	301.9 ± 1.2	64 ± 1

The infestation of the parasitoid *B. hyalinus* in the nymph and adult of *O.lybicus*:

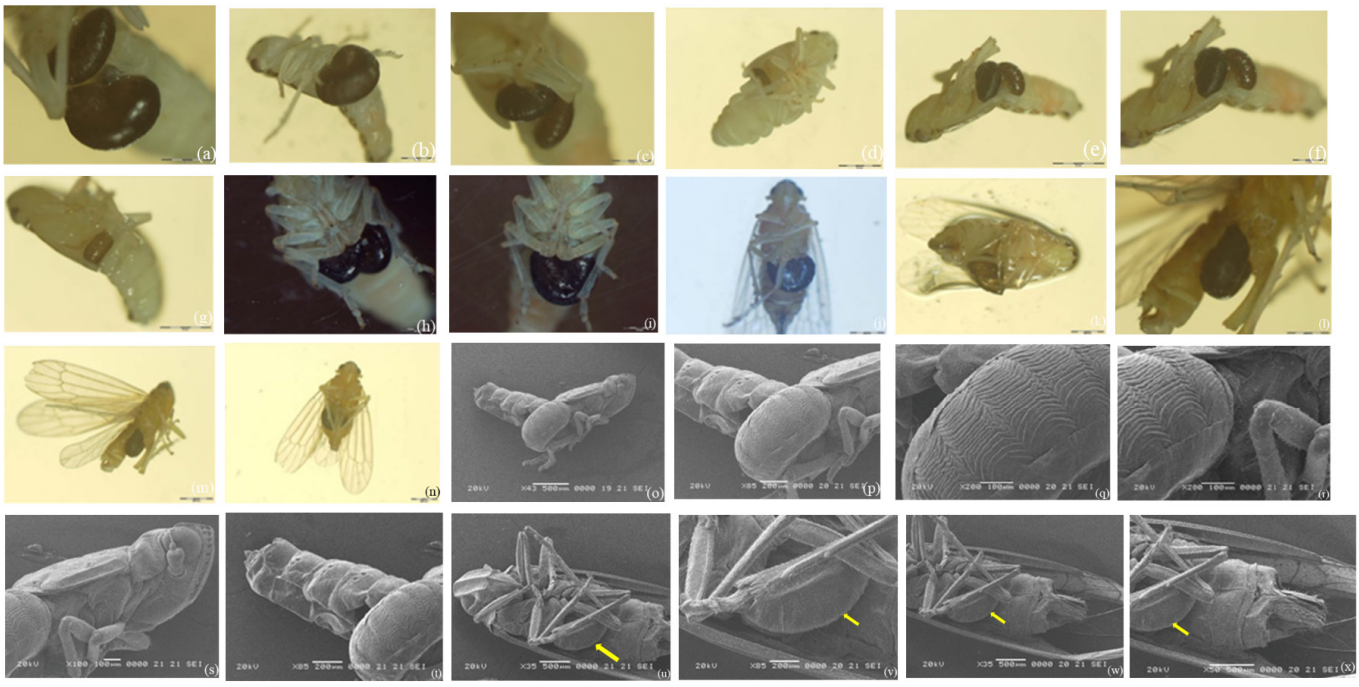

Figure 19: Nymphs and adults with dark cyst on their thorax or abdomen.

Nymphs and adults of *O. lybicus* with visible signs of parasitism, such as a dark cyst on their thorax or abdomen (Figure 19). In the field the parasitoid infestation was appeared more in adult and big nymph such as five and four instars of Dubas. The attacked point of parasitism includes the down surface in the center of abdomen and thorax or around the side of Dubas body.

The fourth immature larval instar of the parasitoid *B. hyalinus* (Hymenoptera: Dryinidae) (from field and LAB)

B. hyalinus fourth larval instar (Figure 20) was hymenopteriform or kidney shaped and develops as an ectoparasitoid (part inside and other outside) in a sac or cyst formed from the cast skins of the developing larva and projecting from the host's body with mandibles [37,65,76,77]. The mean size of this instar was 169.6 ± 26.3µ in length and 46.4 ± 0.0µ in width (Table 3). In this stage the mouth parts of the larvae inside the host and abdominal segments and the rest of its body outside surrounded by darkened cast cuticle skin [37,76-78].

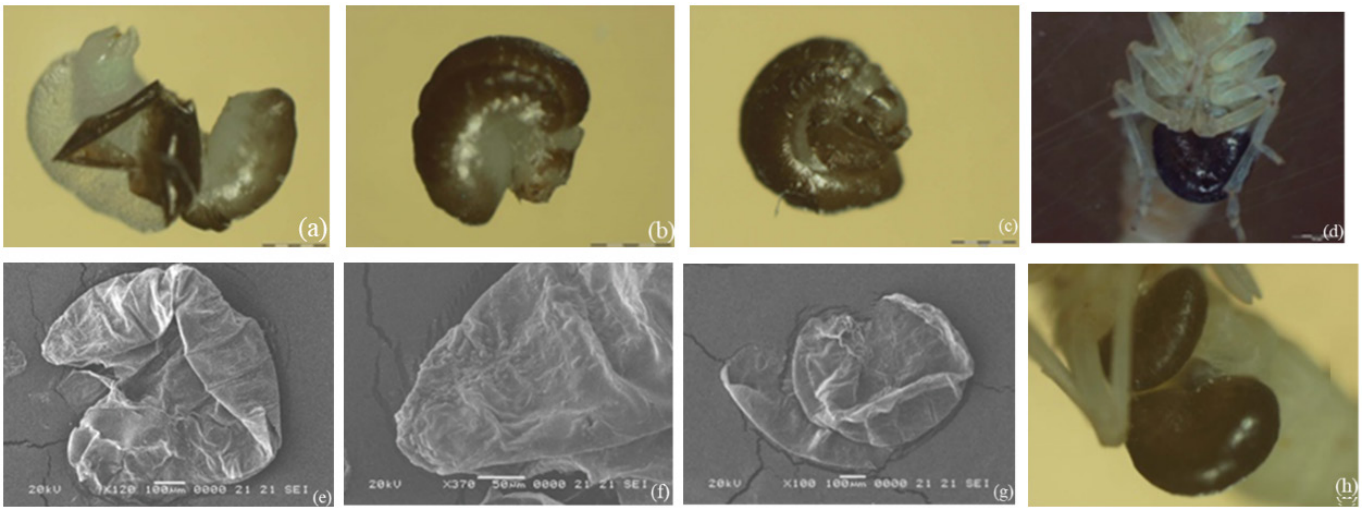

Figure 20: The fourth larval instar of *B. hyalinus*.

The fifth mature larval instar of the parasitoid *B. hyalinus* (Hymenoptera: Dryinidae) (from field and LAB)

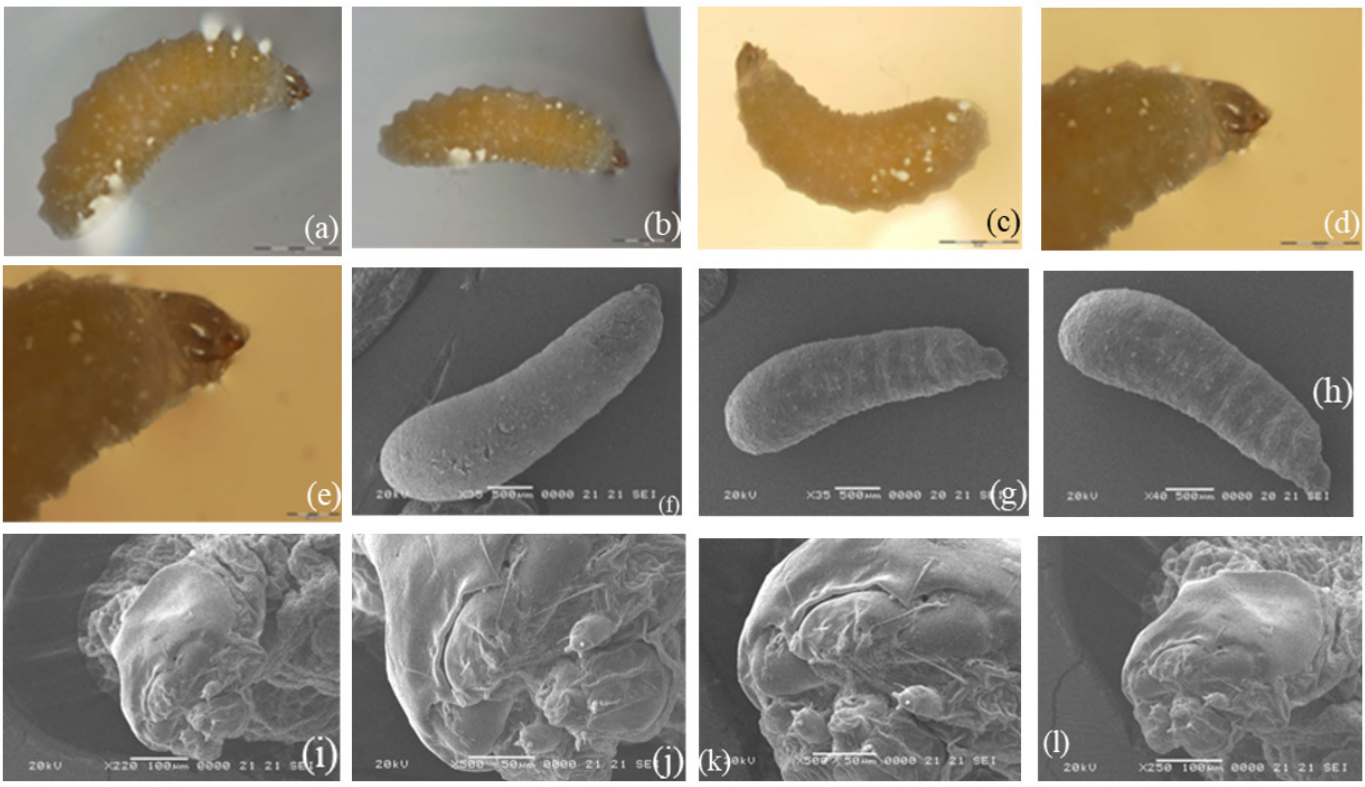

Figure 21: The fifth mature larval instar (outside host) of *B. hyalinus*.

B. hyalinus fifth mature larval instar which was the last immature larval instar (Figure 21) was ectoparasitic outside the host with mandibles fill down in the soil for pupation purposes [37,76-79]. The mean size of this instar was 163 ± 23.8µ in length and 50 ± 4.7 µ in width (Table 3). The fourth instar was hymenopteriform or kidney shaped [37,64,76-80]. The color of this stage was visible ranged between orange to brown.

Description of the cocoon stage of *B. hyalinus*:(from field and LAB)

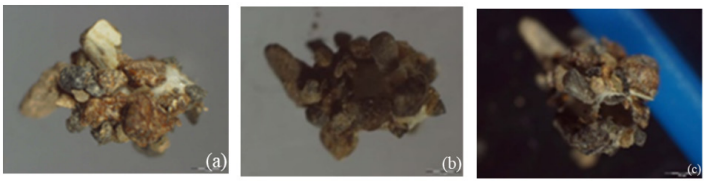

Figure 22: Cocoon of *B. hyalinus.*

B. hyalinus Cocoon (Figure 22) were undergoing outside the host and inside the soil surrounding by small and tiny stone tided by white threads or sheaths or spin a silken cocoon [37,76-81] in the field of date palm. The mean size 184.7 ±18.7µ in length and 86 ± 5.8 µ in width (Table 3).

Discussion

Pseudoligosita babylonica (Hymenoptera: Trichogrammatidae)

In the Sultanate of Oman found *Pseudoligosita babylonica* (Hymenoptera: Trichogrammatidae) attacked the eggs of Dubas bug in Oman [8,12,41]. The life period cycle of *P. babylonica* was approximately completed within 30 days in 27 ± 2°C similar that was recorded by Al-Khatri in Oman, and in Iraq close developed in 31 days at 28°C [72,82] and as similar species developed in 30 days *Chaetostricha pulchra* Kryg. (Hymenoptera: Trichogrammatidae) [80]. The *P. babylonica* life cycle classified as complete Metamorphosis (Holometabolous) with four possible stages in the life cycle: egg, larvae, pupa, and adult [37,69,83]. In addition, this is the first time to try to investigate in detail the biological and morphological characteristics of the individual immature stages of the parasitoid *P. babylonica*. In Oman the pomegranate tree *Punica granatumL.* (Lythraceae, Punicoideae) was attacked by fruit borer, *Deudorix* (=*Virachola*) livia Klug (Lepidoptera: Lycaenidae), in Jabal Akhdar [84] and was controlled by using *Trichogramma brassica* (Hymenoptera: Trichogrammatidae) and *T. evanescens* (Hymenoptera: Trichogrammatidae) [85,86], *T. cacoeciae*, *T. bourarachae*, *T. cordubensis* and Bracon sp. as a larva stage parasitoid [87] and the local or native one called *Telenomus nizwaensis* Polaszek [86,88]. The planthopper *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae) and *Sogatella furcifera* (Horváth) (Homoptera: Delphacidae) parasitized their eggs by *Pseudoligosita yasumatsui* (Hymenoptera: Trichogrammatidae) in Malaysia [89] also *Homalodisca vitripennis* (Germar) (Hemiptera: Cicadellidae) by *Pseudoligosita plebeia* (Perkins) (Hymenoptera: Trichogrammatidae) in California [90]. *Oligosita balcluthae* Viggiani et Laudonia (Chalcidoidea: Trichogrammatidae) was used against the leafhopper *Balclutha brevis* Lindberg (Homoptera: Cicadellidae) in Italy [66]. *Pseudoligosita longifrangiata* (Viggiani) (Hymenoptera: Trichogrammatidae) was egg parasitoid of *Argia insipida* Hagen (Odonata: Coenagrionidae) in Brazil [73]. *Pseudoligosita babylonica* Viggiani (Hymenoptera: Trichogrammatidae) was infected the eggs of Dubas bug in Iraq [72]. In Taiwan the leafhopper *Kolla paulula* (Hemiptera: Cicadellidae) was controlled by egg parasitoid *Pseudoligosita nephotetticum* (Mani) (Hymenoptera: Mymaridae and Trichogrammatidae) [91]. Leafhopper *Cicadella viridis* (Linnaeus) could controlled by using *Oligosita* sp. in Japan [92] or *Pseudoligosita krygeri* (Girault) in Denmark [93]. *Oligosita caerulocephala* (Fullaway) was hosted by leafhopper *Draeculacephala mollipes* (Say) in USA (Hawaii) [94]. *Oligosita clarimaculosa* (Girault), *Oligosita desantisi* (Viggiani), *Oligosita giraulti* (Crawford), *Pseudoligosita longifrangiata* (Viggiani) were recorded a parasitoid of the corn leafhopper, *Dalbulus maidis* (DeLong & Wolcott) eggs in Mexico and Argentina [95]. *Oligosita desantisi* (Viggiani) was a parasitoid of *Exitianus obscurinervis* (Stål) and *Dalbulus maidis* (DeLong & Wolcott) in Argentina [96]. Three species of *Aeneolamia* which included *A. varia* (Fabricius), *A. lepidior* (Fowler) and *A. flavilatera* (Urich) were suitable as a host of *Oligosita desantisi* (Viggiani), *Mahanarva posticata* (Stal), *Tomaspis saccharina* (Distant), and *Zulia pubescens* (Fabricius) (Cercopidae) were susceptible to the previous parasitoid [97-99]. *Oligosita americana* (Girault) was propagated by *Homalodisca insolita* (Walker) (Hemiptera: Cicadellidae) in USA (Georgia) [100,101]. *Pseudoligosita plebeia* (Perkins) (Hymenoptera: Trichogrammatidae) was reared by using of Homalodisca spp. (Hemiptera: Cicadellidae) in Mexico, *Tapajosa rubromarginata* in Argentina and *Homalodisca vitripennis* (Germar) (Hemiptera: Cicadellidae) in USA (California) [102,103]. *Goniozus omanensis* (Hymenoptera: Bethylidae), used against the lesser date moth *Batrachedra amydraula* Meyrick (Lepidoptera: Batrachedridae) in Oman [104]. Increasing of egg parasitoid *P. babylonica* population, one of the most important biotic factors working against Dubas in the date palm groves if the pesticides treatment excluded. This native egg parasitoid is promising bioagent in Oman and it should be protected against the negative effects of pesticides. The egg parasitoid *P. babylonica* promising suppression for Dubas population was noticed in some places where the Dubas infestation became negligible due to the presence of this parasitoid. The target of this work to identify and investigate the immature stage development, longevity and parasitism of *P. babylonica* on *O. lybicus* eggs and to be familiar with the life cycle and behavior of the parasitoids and to find a host for mass rearing purposes. However, Trichogramma and other hymenopterous parasitoids due to their minute size, it is difficult to detect morphological immature stage variations and to study the biology, behavior, reproduction and the suitable host for mass raring population with short period as integrate Dubas management. Furthermore, the possibility of the modern technology of the artificial egg parasitoid rearing for mass production with good parameters of temperature, humidity, and nutrition to improve the quality and quantity of the production of this organism.

Bocchus hyalinus (Hymenoptera: Dryinidae)

The target of this work to identify and be familiar with the life cycle and behavior of the parasitoids and to find a host for mass rearing purposes. *Dryinus* sp. (Hymenoptera, Dryinidae) was recorded as parasitoid of Plant hopper (*Issus* sp.) which appeared with sac and cyst of the host's body [60]. *Mirodryinus atlanticus* Olmi, (Hymenoptera: Dryinidae) was recorded as parasitoid against *Opsius versicolor* (Distant) (Hemiptera, Cicadellidae) and the same symptoms of sac and cyst on nymphs [62]. Nymphs and adults of *Caliscelis wallengreni* (Stål) (Hemiptera: Caliscelidae) were appeared with sac and cyst as a result of attacked by *Bocchus scobiolae* Nagy (Hymenoptera: Dryinidae, Bocchinae) [79,105], the same symptoms in nymphs and adults of Dubas. A nymphal sac was risen from the brown planthopper *Nilaparvata lugens* (Stål) (Hemiptera: Delphacidae) after parasitized by *Gonatopus flavifemur* (Esaki & Hashimoto) (Hymenoptera: Dryinidae) [106]. There were several species of *Bocchus* sp. such as *Bocchus bini* (Kenya, Uganda, widespread Afrotropical, East Africa, West Africa), *B. botswanensis* (Kenya, Madagascar, Southern Africa including Republic of South Africa), *B. brooksi* (Kenya, Madagascar), *B. confuses* (Kenya, Yemen), *B. hyalinus* (Kenya, Oman, United Arab Emirates), *B. johanssoni* (Kenya), *B. madagascolus* (Madagascar), *B. simoni* (Kenya, East Africa), and *B. whiteleyi* (Kenya, Southern Africa including Republic of South Africa) [61]. *Bocchus kibalensis* sp. n. and *Bocchus seyrigi* from Uganda [107]. Another species were *Bocchus arizonicus*, *B. dubius*, *B. flavicollis*, *B. flavipes*, *B. hainesi*, *B. laticeps*, *B. mirabilis*, *B. testaceus*, *B. texanus*, *B. wasbaueri* and *B. weemsi* from California, USA [108]. Planthoppers especially that related to families Tropiduchidae and Caliscelidae (Hemiptera, Auchenorrhyncha) were the most hosts preferred by the genus *Bocchus* of family Dryinidae and subfamily Bochinae (Hymenoptera, Dryinidae, Bocchinae) [58,109]. *B. hyalinus* Olmi, was registered in our neighbor in Iran in 1998 [62]. The most limitations were faced in this experiment was the deficiencies in specimens of Dubas parasitoid and the adult of *B. hyalinus*. Our investigations for this parasitoid will continue by survey and collecting more samples in the different governorates of the Sultanate of Oman. Each governorate includes several provinces (Wilayats or towns) and villages with random date palms from different fields. *P. babylonica* (Hymenoptera: Trichogrammatidae) and *B. hyalinus* (Hymenoptera: Dryinidae) were recommended as the parasitoid of leafhoppers, planthoppers, and treehoppers (Hemiptera) [58].

Conclusion

In the Sultanate of Oman can conceder the native and local parasitoid *P. babylonica* (Hymenoptera: Trichogrammatidae) and *B. hyalinus* (Hymenoptera: Dryinidae) have a good potential in the integrate pest management program against Dubas bug, save our security food depend in the date palm and environment from more insecticide was applied.

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