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New record of *Aphanogmus clavicornis* Thomson (Hymenoptera: Ceraphronidae) as a larval parasitoid of tomato leaf miner *Tuta absoluta* (Meyrick) in Syria

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Abstract
Tomato (*Solanum lycopersicum* L.) is an important edible and nutritious fruit regarded by nutritionist as a vegetable. It is an important source of vitamins and significantly contributes to economic development. However, the production of tomatoes is heavily affected by climate change, insect pests, disease and the new devastating pest of tomatoes, the tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). This study includes a description of *Aphanogmus clavicornis* Thomson, 1858 (Hymenoptera: Ceraphronoidea), a primary parasitoid of *T. absoluta* whose larvae feed on all parts of the tomato plant. It is the first record of *T. absoluta* as a host of genus *Aphanogmus* worldwide and a first record of *A. clavicornis* in both Syria and the Middle East. Description, biology and the taxonomic characters of the new species were provided. The new record of natural parasitism of *T. absoluta* by *A. clavicornis* would add knowledge on biological control of the pest and could become an additional option for the integrated pest management of those crops where *T. absoluta* is a key pest. This finding will be baseline for future research. It would be interesting to investigate if *A. clavicornis* can be produced in large scale under laboratory conditions and test its potential use as a biological control agent within integrated pest management programs.

Keywords: Tomato, *aphanogmus clavicornis*, *tuta absoluta*, first record, Syria

Introduction
Tomato (*Solanum lycopersicum* L.) is an important edible and nutritious fruit regarded by nutritionist as a vegetable. It is an important source of vitamins (Abdelmaksoud *et al*., 2020) [1]. It is widely cultivated all over the world. In Syria tomato grows both on small and commercial large scale as a cash crop by vegetable growers. Therefore, tomato production also contributes significantly to economic development and the ability to create employment. Syria was considered to be one of the top producers of tomatoes in the world after Tunisia and Protugal. However, the production of tomatoes is heavily affected by climate change such as heavy storms, drought, humidity, insect pests, disease and the new devastating pest of tomatoes, the tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). The superfamily Ceraphronoidea includes three families: Ceraphronidae, Megaspilidae and Stigmaphronidae (Johnson, 2004) [23]. There are 800 species described worldwide, although it is estimated that there could be 2000 species (Masner, 2006) [25]. The Ceraphronidae consists of 317 species in 15 genera world-wide mostly distributed in the Palaearctic Region (Belokobylski & Lele, 2019; Johnson, 2004) [7, 23]. It is a family of small endoparasitic wasps (0.5-2 mm) with a black or brown body, forewing with narrow and linear stigma, mesoscutal median furrows, and wide base of mesosctum. The family is easily identified by having a curved stigmal vein, lacking a pterostigma in the forewing. An expanded pterostigma, occipital depression, uniramous anterior protibial spur, a comb of the spur on the pro-and mesotibial spurs, a single mesotibial spur, an undivided synsternite, and axillular setae were observed (Broad, 2009; Mikó *et al*., 2009) [8, 26]. Normally, Ceraphronidae attacks species in the following insect orders: Diptera, Hymenoptera, Lepidoptera, Hemiptera (Homoptera), Neuroptera and Thysanoptera (Alekseev, 1987) [4]. They develop as endoparasitoids or hyperparasitoids (Gauld & Bolton, 1988) [17]. *Aphanogmus* contains 100 species (Johnson, 2004; Buhl *et al*., 2010; Evans *et al*., 2005) [23, 9, 14]. It contains ectoparasitoids (idiobiont) species (Parnell, 1963) [36] and endoparasitoids (koinobiont) species (Evans *et al*., 2005;

Luhman, 1999) [14, 24]. *Aphanogmus* species are usually parasitoids of cecidomyid flies and are sometimes reared as hyperparasitoids attacking hosts of various insect orders (Evans *et al*., 2005) [14]. *T. absoluta* is a Neotropical oligophagous pest attacking cultivated and wild plants with a high preference towards the species of Solanaceae plants especially tomato and other Solanaceous crops (Nurul Huda *et al*., 2020) [31]. It originated in South Ameria. It was first recorded in 2006 in Europe (Spain) (Urbaneja, 2007) [41] and then spread throughout the Mediterranean Basin, Central Europe and the Middle East (Ferracini *et al*., 2019) [15]. Since the time of its initial detection, the pest has caused serious damages to tomato in invaded areas, and it is currently considereccd as a key agricultural threat to tomato production in throughout the world (Ferracini *at el*., 2019) [15]. *T. absoluta* was first reported for Syria (Almatni, 2010; Ibrahim *et al*., 2012) [5, 20], neighboring Iraq (18 Abdul Razzak *et al*., 2010) [2], Yemen (Husin, 2021), Ethiopia (20 Reta & Berhe, 2015) [37], Jordan (Al Antary & Al Shaalan, 2013) [3] and Sudan (22 Mohamed *et al*., 2012) [27]. Many procedures were carried out to control this dangerous pest since its arrival in Syria (Mofleh *et al*., 2014) [28]. Desneux *et al*. (2010) [12] reported that this pest may responsible for the losses of up to 80-100% in tomato plantations if left uncontrolled as it is attacking all aerial parts of the host (leaves, stems and fruits). *T. absoluta* is a difficult pest to manage because of the larval feeding habits and its ability to build up insecticide resistance (Abdelmaksoud *et al*. 2020) [1]. Nurul Huda *et al*. (2020) [31] and Husin (2021) have described the life cycle of this pest. Abdelmaksoud *et al*. 2020 [1]; Husin (2017) [21], Nurul Huda *et al*. (2020) [31] and Tarusikirwa *et al*. (2020) [39] gave a review of the problems caused by *T. absoluta* and its management strategies (Tarusikirwa *et al*., 2020) [39]. Based on our knowledge, the family Ceraphronidae of Syria and neighbouring countries is poorly studied. This paper deals with reports of a new record of ceraphronid from Syria. The description, biology and the taxonomic characters of the newly recorded species *A. clavicornis* were provided together with discussion on the significance of this new record as an additional option for the integrated pest management of those crops where *T. absoluta* is a key pest.

Materials and Methods

The samples of infested tomato plants by Tomato leaf miner *T. absoluta* were collected from a greenhouse at Al-Snowbar in Lattakia in July, 2019, taken to the Agricultural Research Centre in Lattakia and examined by a stereoscope. The parasitized larvae of T. absoluta were placed in glass tubes and closed with cotton until the emergence of adult parasitoids. The species *Aphanogmus* was identified using the key (Austin, 1984) and the identification was kindly confirmed by Prof. Peter Neerup Buhl (Natural History Museum of Denmark).

The parasitoid was placed on a slide using Hoyer's medium. Images were taken with a stereomicroscope equipped with a computer-attached camera and Nikon-Eclipse 80i Digital microscope (40X) equipped with Camera Nikon E8800 (8,0 Megapixel 10x).

The specimen was deposited in the laboratory of Insects at the Scientific Agricultural Research Centre.

Results

This study recorded for the first time *T. absoluta* as a host of the genus *Aphanogmus* world-wide and the first record of *A. clavicornis* as a larval parasitoid of *T.* absoluta in both Syria and the Middle East. The description, biology and the taxonomic characters of the new species were provided with discussion on the significance of this new record as additional option for the integrated pest management of those crops where *T. absoluta* is a key pest.

Aphanogmus clavicornis Thomson, 1858

Examined material

1♀, Syria, Lattakia province, Al-Snowbar, 35°53′12″ N, 35°28′31″ E, collected from tunnel in leaf on larva of *T. absoluta*, from greenhouse planted with Tomato plants affected by *T. absoluta* in July, 2019.

Geographical distribution

Sweden, Denmark, Japan and Russia (Johnson, 2004; Noyes, 2020) [23, 33].

Biology

Larval parasitoid of various insects including Cybocephalidae (Coleoptera), Cecidomyiidae (Diptera), Bethylidae and Ichneumonidae (Hymenoptera) (Oatman, 1985; Evans *et al*., 2005; Godfray, 1994; Polaszak & Dessart, 1996; Gilkeson *et al*., 1993) [34, 14, 19, 35, 18]. Host information has not been studied widely.

Taxonomic characters (diagnosis)

Female is 0.5 mm long, black body, yellowish brown antenna, darker scape and clava segments, dark brown tibia and femur, and yellow tarsal segments. Antenna clavate and serrate with 11-segmented and long hair on serrate side, larger terminal segements, pedicel is longer than flagellomeres (Fig. 1a, b), club 3-segmented, scape longer than club, tarsus 7-segmented, and presence of short tibial spur. Mesosoma is almost two times longer than metasoma. Metasoma is almost 1.5 times longer than the head with wide base of metasoma. Striae on metasoma are without mesoscutal median furrow. Forewing with marginal, submarginal and distally curving radial vein (Austin, 1984).

Three groups of species are based on the characters of mesosoma and metasoma: *clavicornis* group: mesoscutal median furrow and metasomal basal carina absent. *Tenuicornis* group: mesoscutal median furrow absent, metasomal basal carina present. *Fumipennis* group: mesoscutal median furrow and metasomal basal carina present (Evans *et al*., 2005) [14].

The species belongs to the first group (*clavicornis*) According to the morphological straits of these three groups. Depending on the key of *Aphanogmus* (Szelényi, 1940) [38], the new recorded species is *A. clavicornis* Thomson, 1858.

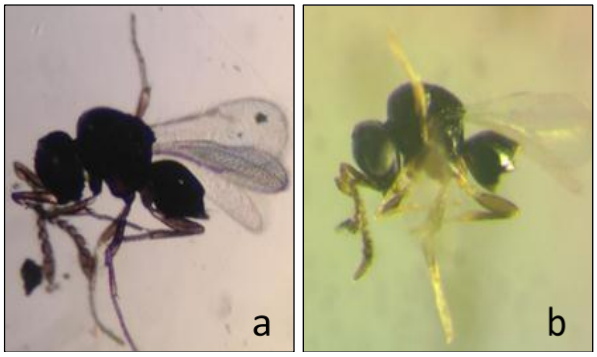

Fig 1: *Aphanogmus clavicornis* Female: (a) Female of lateral view; (b) Female mounted on slide using Hoyer's medium

Discussion

This study recorded for the first time *T. absoluta* as a host of the genus *Aphanogmus* world-wide and the first record of *A. clavicornis* as a larval parasitoid of *T. absoluta* in both Syria and the Middle East. Many pest species, especially lepidopterans, are known to increase their abundance if conditions are favorable and inflict significant damage in agriculture and forestry (EPPO, 2009) [13]. It is well documented that parasitoids especially those belonging to Hymenoptera, are important elements of agroecosystems (Gauld & Bolton, 1988; Evans *et al*., 2005; Gray *et al*., 2013) [17, 14, 20] and are one of the most potent biological control agents that can be used to control the population growth of *T. absoluta* (Bompard *et al*., 2013; Mollá *et al*., 2010) [10, 29]. Natural enemies such as parasitoids were successfully used in biological control of *T. absoluta* (Bompard *et al*., 2013; Mollá *et al*., 2010; Gabarra *et al*., 2013) [10, 29] revealed 13 larval-pupal parasitoid species including *Elasmus phthorimaeae* Ferriere (Elasmidae) and *D. crassinervis* occasionally parasitize *T. absoluta* in Spain (38 Gabarra *et al*., 2014) [16]. 16 hymenopterous species including *Diglyphus crassinervis* Erdös belonging to six families (Eulophidae, Elasmidae, Trichogrammatidae, Braconidae, Ichneumonidae and Pteromalidae) were detected in Italy (Zappalà *et al*., 2012) [43]. Natural enemies of *T. absoluta* have been recorded, in South America 87 species (Ferracini *et al*., 2019) [15], in North Africa, Europe and Middle East at least 50 parasitoids and predators some of which are used in IPM programmes, in western Palaearctic area, at least 70 natural enemies (Zappalà *et al*., 2013) [42]. Having said that there is no record of *A. clavicornis* attacking *T.* absoluta. This pest has rapidly spread throughout the Mediterranean Basin, in Europe, North Africa and the Middle East (Ferracini *et al*., 2019) [15], Nappo (2013) [30] listed the countries which are affected by *T. absoluta*: Albania, Algeria, Argentina, Austria, Bahrain, Belgium, Bolivia, Brazil, Bulgaria, Cayman Islands, Chile, Colombia, Cyprus, Czech Republic, Denmark, Ecuador, Egypt, Estonia, Thiopia, Finland, France, Germany, Greece, Hungary, Iran, Iraq, Ireland, Israel, Italy, Jordan, Kosovo, Kuwait, Latvia, Lebanon, Libya, Lithuania, Luxembourge, Malta, Morocco, Netherlands, Palestinian Authority (West Bank), Panama, Paraguay, Peru, Poland, Portugal, Qatar, Romania, Russia, Saudi Arabia, Senegal, Slovakia, Slovenia, Spain, Sudan, Sweden, Switzerland, Syria, Tunisia, Turkey, United Kingdom, Uruguay, Venezuela and Western Sahara (NAPPO, 2013) [30]. Consequently, the wide and rapid spread of *T. absoluta* has fueled the urgent need for biological and ecological studies to be undertaken. It is well known that agricultural pests can reduce yield, increase costs and lead to the use of pesticides which ultimately contribute to adverse effects on public health, environmental contamination, lost of biological diversity, harm to non-target beneficial arthropods, unsustainable costs to farmers, pesticide resistance and distruption of existing inregrated pest management. Therefore, pesticide should be used as a final option if other control strategies are insufficient and probable economic damage is expected (Urbaneja *et al*., 2013) [40]. The new record of natural parasitism of *T. absoluta* by *A. clavicornis* would add knowledge on biological control of the pest and could become an additional option for the integrated pest management of those crops where *T. absoluta* is a key pest. It will be important to investigate if *A. clavicornis* can be produced in large scale under laboratory conditions and test its potential use as a biological control agent within integrated pest management programs. Finally, there is an urgent need for more collaborative efforts among the researchers as well as growers to control *T. absoluta* in Syria and other parts of the world.

Author contributions: R.M.Y. performed the work, collected the parasitoid, mounted the parasitoid on slide using Hoyer's medium, took pictures, identified the parasitoid using the key, wrote the paper. N.H.A.K. was a major contributor in writing the manuscript, reviewing & editing the paper. R.A. reviewed and edited the paper. All author(s) read and approved the final manuscript.

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Conflict of interest: The authors declare that they have no competing interests.

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