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The Olive Leaf Moth *Palpita unionalis* (Hübner) (Lepidoptera: Pyralidae) as a Serious Pest in the World: a Review

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Abstract: *The olive leaf moth Palpita unionalis (Hübner) (Lepidoptera: Pyralidae) is an international lepidopteran pest originating in the Mediterranean Basin. The present article was prepared aiming to review several aspects of the distribution, economic importance, morphology, biology, ecology and physiology of this pest. Beside the worldwide distribution, economic losses and morphologic characterization, efforts of insect biologists in several parts of the world had been comprehensively highlighted including developmental biology and reproductive biology. From the ecological point of view, population dynamics, sexual and non-sexual behavioral patterns had been discussed. Also, special attention was paid to the laboratory rearing trials on artificial diets. It may be the first review focusing on these aspects of P. unionalis in the world. On the other hand, this pest still needs considerable research work for investigating several aspects such as energy metabolism, homeostasis, enzymatic patterns, hematology, resistance, immunity, reproductive physiology, environmental physiology and the hormonal regulation of these processes. Therefore, the present review enhances the research interests for these important aspects. However, information reviewed herein will support the development of strategies for management of this pest.*

Keywords: *behaviour, biology, development, distribution, ecology, embryonic, morphology, physiology, population, reproduction.*

1. INTRODUCTION

Olive (*Olea europaea* L.) is one of the first fruit trees cultivated by man. It is small evergreen tree in the family Oleaceae, native to the coastal areas of the eastern Mediterranean Region, from Lebanon and the maritime parts of Asia Minor to northern Iran at the south end of the Caspian Sea [1]. Olive is one of the economically important crops in the Mediterranean Basin. Nowadays it is grown in North America, South Africa, China, Japan and Australia [2], although it is considered that about 98% of the world's olive production is located in the Mediterranean area [3, 4].

Olive tree is subjected to attack by several insect pests causing considerable yield losses in quality and quantity. These pests belong to Diptera, Lepidoptera, Hemiptera, Orthoptera, Coleoptera, and Thysanoptera [5]. The most common pests observed in Egypt, as for example, include: *Bactrocera oleae* (Diptera: Tephritidae), *Prays oleae* (Lepidoptera: Yponomeutidae), *Palpita unionalis* (Lepidoptera: Pyralidae), *Zeuzera pyrina* (Lepidoptera: Cossidae), *Saissetia oleae* (Homoptera: Coccidae) and *Parlatoria oleae* (Homoptera: Diaspididae) [6, 7]. However, the olive moth *P. oleae* and olive leaf moth *P. unionalis* are two well known lepidopterous pest species of olives in Egypt and some of other Mediterranean countries [8-10].

The olive leaf moth has several vernacular names, such as olive leaf caterpillar, olive leaf worm, olive buds moth, Jasmine moth, Jasmine bud worm, Jasmine moth and jasmine leaf caterpillar. Its scientific name is *Palpita unionalis* (Hübner)(Lepidoptera: Pyralidae) with synonyms *Palpita vitrealis* (Rossi) [11], *Margaronia unionalis* (Hübner) [12] and *Pyralis unionalis* (Hübner) but Kirti and Rose [13] prepared an identification key for different species of *P. unionalis*, based on the internal and external differences of male genitalia in India, and suggested that this species belongs to the genus *Palpita*.

To develop efficient control measures against a pest and improve Integrated Pest Management (IPM) strategies, knowledge of its agronomic impacts, biology, ecology and other necessary information should be available. Therefore the objective of the present article was to review several aspects of distribution, losses, morphology, biology, ecology and physiology of the economically serious pest, *P. unionalis*.

2. WORLDWIDE DISTRIBUTION OF *P. unionalis*

From the Zoogeographical point of view, the Mediterranean Basin was reported as the original area of *P. unionalis*, where it is found from east to west, and south to the olive-growing regions of northern Africa, the Canary Islands and Madeira. Now it is an international lepidopterous migratory pest in the tropical and mildly subtropical regions of the Old World [14-16]. As reported in the literature, it is distributed in Turkey [10, 17, 18], Greece [19], Slovakia [20], Portugal [21], Israel [22], Italy [23-26], India [13] and Egypt [27]. Different dispersal regions of *P. unionalis* were reported such as Spain, Japan, Australia, North Africa, Tropic Regions of America and South America [28] like Brazil [29]. It is a highly mobile moth dispersing even to northern Europe, such as Sweden and Poland [30-32]. Also, it has been reported to attack wild olives in Southern Africa [33, 34] and jasmine *Jasminum fluminense* in Kenya [35].

For some details, *P. unionalis* was firstly recorded in 1969 in the Aegean region and reported as one of the main pests of olive in Marmara region, Turkey [17, 36, 37]. It was a secondary pest of olive cultivars but now it is considered as a primary pest in olive nurseries, irrigated young olive plantations as well as in mature olive trees [10, 38]. Within a few years later, the pest became an epidemic in olive nurseries throughout the country [39]. In Syria, *P. unionalis* was observed in the last few years in Aleppo and identified as olive buds moth or Jasmine moth [40, 41]. Within a short period, the pest became epidemic in olive nurseries throughout the country [42]. In Malta, *P. unionalis* was reported for the first time to be associated with olive trees [43]. After few years later, its local occurrence was described as an immigrant pest feeding on olive and jasmine [44-46]. Depending on a survey carried out by Haber and Mifsud [1], the moth was recorded during most of the year in many localities of the Maltese Islands. In Egypt, this pest has been known as jasmine moth or olive leaf moth. Rahhal [47] carried out a survey during the first two years of seventh decade of 20th century. Infested samples of olive branches were obtained from different orchards and farms in Alexandria, Mersa Matrouh, Bourg El-Arab, Siewa Oasis, Kaliobia, Cairo, Giza and Fayoum. It is reported as a destructive pest of young olive farms [6, 48] and the old trees [49, 50]. In addition to Mediterranean region, *P. unionalis* was recorded as a serious pest in some Asian countries such as Iran in which the pest was firstly reported in olive orchards of Roudbar City in August 1999 [51]. It took only a few years to spread as a serious pest throughout the country [52-54].

3. HOST PLANTS AND ECONOMIC LOSSES OF P. *unionalis*

P. unionalis is a polyphagous lepidopteran attacking the family Oleaceae, especially the genera of *Ligustrum*, *Oleae*, *Fraxinus*, and *Phyllyrea* [15, 55]. However, a range of host plants had been reported in different parts of the world. In Turkey, *Fragaria ananassa* (Rosaceae) and *Viburnum* spp. (Adoxaceae) are also reported as alternative hosts for this pest [56]. In Greece, the pest has also been reported on a range of other plant hosts including, *Arbutus unedo* (Ericaceae)[57]. In Iran, *Ligustrum vulgare* was found as a desirable host for breeding of the pest in laboratory in comparison with olive cultivars [58]. In Egypt, *P. unionalis* is a pest of olive, as the main host, but it attacks also the jasmine

Jasminum officinale, *L. vulgare*, *A. unedo* and *Phyllyrea media*, particularly in the new reclaimed lands [6, 49]. Thus, olive is the main host for this pest but Jasmine, *Fraxinus ananassa*, *Viburnum* spp. and *A. unedo* can be considered as alternative hosts [56, 57].

With regard to the economic losses, *P. unionalis* attacks its host plants in different countries causing mild or severe damage, depending on its population density and the host plant. Different losses had been reported in Greece [19], Italy [23, 24, 26], Israel [22] and Egypt [27, 59]. The most important damage of the pest occurs on young trees, nurseries and shoots of old trees [60, 61].

In some detail, *P. unionalis* is considered in Greece a serious pest feeding on young leaves and shoots of *Jasminum* sp. and *Ligustrum* sp. [55, 57]. Young larvae consume entire leaves and buds in the first generation and in second generation, they feed on fruits and seeds if they reach to high population levels [61]. In France, ornamentals, such as jasmine cultivated for perfume production, suffer from larval attacks of *P. unionalis* on leaves and flower buds [62, 63]. In Spain, both leaves and fruits of olive are damaged by *P. unionalis*. In nurseries or young orchards, feeding damage by larvae can reach up to 90% of the leaf area, thereby seriously affecting the development of the plant shoots. During the fruit ripening season, high larvae infestations may also reduce the fruit yield by 30% [64]. In years of high population densities, larvae attack also olive fruits, making them unsuitable for marketing [26, 57]. During heavy *P. unionalis* infestations in Italy, the most important damage occurs on young trees, nurseries and shoots of old trees [23, 60]. In Sicily, if 90% of olive branches have been damaged, loss rate of yield will not be more than 20% [24]. In Malta, the most damage was observed on the new growth of olive trees, where not only new leaves and buds were eaten but occasionally entire shoots up to 15 cm were completely eroded [1]. In Turkey, *P. unionalis*, was a secondary pest of olive cultivars but now it is considered as a primary pest in olive nurseries or irrigated young olive plantations causing important economical yield losses by fruit fall as well as by damage on leaves, flowers and fruits [10, 17, 36, 38, 65]. Quality of the product may be impaired by larval feeding on all phenological stages of the olives [39]. In Egypt, *P. unionalis* was considered as a destructive pest of young olive groves [63, 66] and new branches of old trees [49]. Its damage increases in the olive groves, particularly in the new reclaimed lands [6]. Significant direct yield loss in olive plantations can be recorded due to fruit fall [67, 68] and destruction of a large part of the crop can be caused by the highest population density of *P. unionalis* [50]. In South Africa, *P. unionalis* seemed to be of negligible potential economic importance to olives in the Eastern Cape [69]. Thus, *P. unionalis* has been considered as a secondary or minor pest in some countries but as a primary, serious or even key pest in others, depending on the attacked plant species, seasonal climatic conditions of the region, densities of the endemic natural enemies, etc. In a similar course, it can be recorded as a minor pest in a country and as a serious one later, depending on the previously mentioned factors.

4. Morphological Characterization of P. *unionalis*

Knowledge of insect morphology is essential for the identification of a species without which all efforts exerted in biology, ecology, physiology and pest control can be wasted. Several studies had been carried out on the descriptive morphology of *P. unionalis* in different parts of the world. We have compiled here some of reported works, including the morphological appearance and diagnostic characteristics of all developmental stages (*viz*. adults, eggs, larvae and pupae).

4.1. Adult Moths

Adults are characterized mainly by shiny semitransparent or white wings with a brown leading edge of the forewing and two black spots in the middle. Kacar and Ulusoy [70] shed some light on the morphological characteristics of this insect in Turkey. Depending on this study, body length was 13.9±0.17 mm for females while 13.90±0.18 mm for males. The wings bear frenolum, and in resting position stand on the body in gable roof form. The wings appear, also, with two black spots in the middle. It is interesting to refer that front wings are wider than the hind ones. Wing span was in average of 28.93±0.30 mm and 28.27±0.30 mm of females and males, respectively. Dissimilarly, Yilmaz and Genc [10] measured the wingspan in an average of 22.6±5.1 mm and 25.0±3.3 mm for females and males, respectively. The males and females do not differ in length and width albeit females possess a mating pore on the 8^{th} segment of abdomen and an oviposition pore on the 9^{th} one. As seen by naked eye, female moth can be discriminated by her light green abdomen covered with white scales, but abdomen in males has terminal part bearing sets of hair. It should be mentioned that the internal reproductive system in adult male and female was described by Santorini and Vessiliana-Alexopoulou [12]. Also, special attention had been paid to the morphology of antennal sensory receptors as principal organs of intra-specific pheromone-steered communication [9, 71].

4.2. Egg

Depending on the study of Kacar and Ulusoy [70], in Turkey, averages of the egg size and width were determined as 0.95±0.011 mm and 0.72±0.008 mm, respectively. Eggs are white, flattened, with reticulated appearance and 0.5-1.0 mm in length [56]. As described by Yilmaz and Genc [10], eggs were elongated, flattened, and about 0.80 ± 0.10 mm in length, 0.5 1± 0.07 mm in diameter, weigh about 0.1 mg. According to Noori and Shirazi [16], in Iran, eggs are flat oval, light greenish yellow, 1.02 mm long and 0.49 mm wide, exhibiting a mesh appearance.

4.3. Caterpillars

Larvae are pale yellow in 1^{st} and 2^{nd} instars, later becoming gradually green with shading bluish toward the head and the tail. Maximum body length of mature larva ranged from 18 to 20 mm [56] or the average of 22.20±0.15 mm [70]. A detailed study on the larval morphology was carried out in Turkey, also. On the basis of this study, size of the head capsule was 0.18 ± 0.03 mm for the first instar and up to 1.53 ± 0.04 mm for sixth instar. Different characteristics, such as colour, weight, long, wide, and somebody structures had been described for all 6 instars [10]. According to the observation of Noori and Shirazi [16], in Iran, larva is eruciform with three thoracic and five abdominal legs on the 3, 4, 5, 6, and 10th abdominal segments. Crochets are seen in closed and complete spherical form at the end of prolegs. Sometimes a pair of black spots are seen on the body segments close to the pleural part at 3rd and 4th instar instars.

4.4. Pupae

As pointed out by some authors [10, 56, 70], pupae are initially soft and light green in color. Their color turned to brown on the following day. Female pupae measured about 3.07±0.23 mm wide and 14.01±0.90 mm long and weighed 73.61 ± 11.77 mg. Male pupae were about 13.38±0.80 mm long, 2.98±0.21 mm wide and weighed 70.6±12.78 mg. The sex differentiation depending on immature stages was, also, provided [65].

5. DEVELOPMENTAL BIOLOGY OF P. *unionalis*

It is important to know the basic biology of a pest so as to understand factors involved in population fluctuations which is necessary in planning an IPM programme to control this pest. The available literature has been enriched with many reported works on the biological characters of *P. unionalis* [9, 10, 16, 56, 58, 72]. Some of these works focused on its life table on different hosts [18], population dynamics and some of the environmental factors affecting it [17] and the influence of temperature on embryonic development [73]. On the contrary, very few reports on the rearing techniques of *P. unionalis* had been available. Herein, we reviewed both the embryonic and post- embryonic development of this insect.

5.1. Embryonic Development

The egg formation and development in insects had been studied by some researchers [74-76]. The egg shell, or chorion, of an insect is a complex of several layers. It is synthesized within the ovarioles by the follicular epithelium that surrounds the oocytes and begins once vitellogenesis takes place, that is, the uptake of vitellogenins [77, 78]. Following the union of the sperm from male and the egg in female, the newly formed zygote undergoes cleavage within the patterned environment that is present in the egg [79]. Further information about oogenesis and vitellogenesis through the successive stages of embryogenesis can be provided by some authors [80-83].

5.1.1. Embryonic Developmental Rate

Incubation period of the insect egg is usually the interval elapsed between the time of laying a fertilized egg and its hatching. This period may be used as a good indicator of the embryonic developmental rate, i.e., the shorter period indicates a fast rate and *vice versa*. Mean duration of the embryonic development of *P. unionalis* varied depending on the season, in the field studies, or constant rearing temperature in the laboratory studies. It was reported as a range of 15-16 days [23] but as 3 days in summer and about 9 days during winter [27, 47] or a range of 3 days (at 30°C) and 12 days (at 15°C) [84]. Loi [73] evaluated the effect of different temperatures, in a range of 10-35°C on *P. unionalis* embryonic growth and development. The fastest embryonic developmental rate was denoted by the shortest incubation period (3 days) at 30°C and the lowest one was denoted by the longest period (112 days) at 15 °C. On the basis of a study carried out on olive plants under the natural conditions in Adana (Turkey), the embryonic duration was recorded in a mean of 3.45±0.13 (3-5) days and 4.33±0.10 (4-5) days [85]. In Turkey, also, Yilmaz and Genc [10] estimated the mean duration in 4.16 ± 0.09 days at 24±1 °C. Dissimilarly, Noori and Shirazi [16] found the mean embryonic developmental duration as 5.8±1 days. In a detailed study, Yilmaz and Genc [10] followed up the successive developmental stages of the embryo day by day until the formation of mandibles and eyes which could be seen through the chorion just before hatching. Depending on the available literature, this was the first detailed study on embryonic development of this pest all over the world. In conclusion, the embryonic stage of *P. unionalis* has been a temperature-dependent.

5.1.2. Embryonic Survival

It may be reasonable to know the viability or ability of embryos to live as detected by the hatching percentage (hatchability). Although the embryonic survival has been affected by several factors, majority of entomologists paid their attention, until now, to the temperature only. Earlier, the hatchability of *P. unionalis* was determined as 84% [22], 78-95% in winter [47] or 68 % at 15^{o}C and 98% at 25 °C [73]. In contrast, the effect of relative humidity (R.H.) seemed to be negligible. In a study, selected diets were provided to adults aiming to investigate the effect of adult diets on different reproductive parameters. Egg hatchability was not affected by adult feeding [38].

5.2. Post-Embryonic Development

Upon hatching from eggs, juvenile insects embark on an excursion of post-embryonic development that will eventually take them to their adult forms. The change that occurs when an insect develops from an immature stage to an adult stage is called "metamorphosis", literally meaning "change in form". Insects show three major metamorphic strategies for reaching the adult stage, with the degree of metamorphosis dependent on the degree of divergence between the immature and adults [86]. In the holometabolous insects, like *P. unionalis*, newly hatched larvae feed and grow increasing to critical size and weight, then they moult to change new integument. Moulting has been repeated several times and the mature larvae prepare themselves to pupate. The pupae live certain period, during which the larval structures were destructed (histogenesis) and the adult structures will be constructed (histogenesis). At the end of pupal stage, adult moths can emerge. All vital processes, from the first point until the end have been undergone to hormonal regulation (For details, see: [79, 87-93]). Shortly, this is the dramatic journey of post-embryonic development during the life of *P. unionalis*. However, several aspects are reviewed herein.

5.2.1. Number of Larval Instars

Extensive studies had been conducted on the biology of *P. unionalis* in the laboratory showing the appearance of 5 instars in the larval stage [16, 54, 56, 61]. On the other hand, some investigators reported 6 instars [15, 27, 47, 72, 84]. No author obtained his observation depending on the head capsule measurements. An extensive study on the biology of this pest was carried out in Turkey revealing 6 larval instars in the larval stage, basing on direct quantification of molts and measurements of the head capsule [10].

5.2.2. Larval Development

Larval development can be indicated by the larval duration, i.e. shorter larval duration denotes faster developmental rate. The larval duration, and subsequently the larval development, of *P. unionalis* can be chronologically reviewed as follows. It was determined as 18-48 days [94], 14-19 days [22], ranged between 15.85 and 23.15 days [47], 21-26 days (at 25°C and 65% RH)[19], averaged about 15 days in summer and 23 days in winter [27], 24-30 days [24], 22.28±0.22 days [54], 25 days [95], 21.6±0.3 days [16], as well as 18.50±0.56 days in the first generation and 26.25±0.82 days in the second generation [85]. However, these differences can be due to the pre-pupation (prepupae) period since El-Kifl et al. [27] determined a pre-pupation period in about 1-1.6 days in summer and 2.5 days in winter. In the field, larvae feed on the leaves at the end of the twigs, forming silken webs in which they sheltered and pupated later [54]. In the laboratory, full grown larvae were observed to fold one or more leaves together with white silken webs, inside which pupation took place. Prepupae remained about 1.81±0.40 days and changed within 4-5 minutes into the characteristic pupal appearance [10]. The average prepupal duration was 1.63±0.18 days in the first generation and 1.73±0.35 days in the second generation [85]. Thus, the reported differences in larval duration may be understood because some authors considered the prepupal period within the larval duration but others considered it as a separate phase. Furthermore, durations of the successive larval instars had been determined separately. As for example, Badawi et al. [84] measured the duration of the last (6th) instar as almost double the duration of the first one. Yilmaz and Genc [10] recorded the durations of larval instars, in detail, as follows. First instar: 2.93±0.73 days, second instar: 3.42±1.55 days, third instar: 3.42±1.15 days, fourth instar: 3.00±0.96 days, fifth instar: 3.57±1.28 days and sixth instar: 7.00 ±1.56 days. It should be mentioned that the larval development has been usually affected by the ambient temperature (For some details, see: [9, 16, 54, 73, 85, 95]).

5.2.3. Pupation and Pupal Development

As reported by many authors [16, 58, 85, 96, 97], pupation took place in a silken cocoon under dry fallen leaves, under tree bark or in crevices on the stem. According to Rahhal [47], the pupal period ranged from 8.55 days during summer to 17.06 days during winter. El-Kifl et al. [27] and Noori and

Shirazi [16] determined longer period (9 days during summer and 17-18 days during the winter). Yilmaz [95] studied some biological parameters of this pest in Turkey and determined the pupal duration as about 10 days. In contrast, pupae lasted 7.83±0.112 days under the field and laboratory conditions in Iran [54]. In conclusion, the duration of the pupal stage was much affected by the climatic conditions, especially temperature and relative humidity (R.H.)[72].

5.2.4. Mortality Rate of Immature Stages

As pointed out by many authors [10, 56, 73, 84, 95], the mortality of immature stages was 100% at 10-35ºC and less than 50% at 13-30º C. Also, the survival rate was calculated in 60% and 80% for mature larvae and pupae, respectively. In a study, the survival rate of larvae was recorded as 61.6% by rearing in the laboratory on olive leaves (at 24 ± 1 °C, 65% RH and 16:8 h L:D). In addition, the egg stage was the most susceptible stage, whilst the susceptibility of the larvae was decreased as they grew up more so no mortality could be observed amongst the fifth instar larvae. The mortality of eggs depended on the temperature but different host plants, also, affect the insect survival [98-101].

5.2.5. Life Span from Egg to Adult (Total Developmental Period)

Total developmental period for *P. unionalis* was estimated in 26 days (by rearing on olive, at 26ºC) but in a range of 21-26 days (at 23.4ºC) [19]. It was measured in a range of 29.2-32.0 days by rearing on different host plants including olive, jasmine and ash tree [24, 84, 102]. Fodale and Mule [94] determined a life span of 29-38 days in field but from 24 to 39 days in laboratory. El-Khawas [103] measured the duration of pre-imaginal development (reared on young olive shoots at 27 ºC and 65% RH) ranging from 21 to 30 days. Kumral et al. [18] recorded the total developmental period ranging from 27.52 days to 30.00 days. Total developmental period on Zard olive cultivar (at 25±0.5°C, 65±5% RH and 12:12 L:D) was found to be ~32 days [16]. By rearing on Gemlik variety of olive plants (at 28.2 °C, 70.1% R.H), average life span was found about 38.4 days or 61.6 days (at 18.4 °C, 64.4% R.H.)[85]. Rearing on Ayvacik olive cultivar resulted in a period of 24 days [10]. As shown by these reported results, the total developmental period of *P. unionalis* is temperature-dependent. In addition, different host plants are known to affect the insect development [98-100]. Moreover, the differences of the mean total developmental period could be due to the environmental conditions under which the experiments performed and the pest biotype [9, 26, 84, 103].

5.2.6. Number of Generations per Year

It is important to point out that *P. unionalis* is a multivoltine species with several overlapping generations per year, ranging from 1 to 10, until now. As reported by Grossley [61], the pest has 2-3 generations in cold to mild regions while more than 5-6 in mid-tropical and tropical regions. It has 6 generations per year in Israel [15, 24, 104, 105], 5 in Spain [24], 1-2 in France [14], 4-5 in Italy [24, 94]. Moreover, this pest has varied number of generations annually in the same country, depending on the differences in environmental conditions. As for example, it has 2 complete generations and 1 partial generation every year [17] but 9 generations at constantly stable [56] in Turkey. In Iran, it completed 4-5 generations [16], 6 generations [72] or 8 generations [54]. In Egypt, it has 10 overlapping generations a year [27, 47, 106] or 9 generations in various regions of different ambient temperature and R.H. (for detail, see [48, 84]). Therefore, the pest has varying number of generations annually depending on the host plant, seasonal temperature and other environmental conditions of over its universal or regional distribution.

5.3. Adult Performance

To shed some light on the most important parameters of its adult performance (emergence, sex ratio, survival and longevity), the available literature can be reviewed herein.

5.3.1. Adult Emergence

When ready to emerge, the moth pushes its head against the pupal skin causing a median dorsal slit which extends longitudinally. Through this slit, the moth finds its way out. The highest% of emergence (about 90%) and the least% of deformities (below 2%) were obtained at 25 and 30 °C. At 15 °C, nearly 35% of the moths failed to emerge. This vital process increased with the increasing R.H. but the most favourable R.H. was found 65%, at which 90% of normal moths emerged [27, 72, 84, 85, 96].

5.3.2. Sex Ratio

Sex ratio of *P. unionalis* is 1:1. in all generations during the year but males tended to be slightly higher during the later generations [10, 16, 19, 47]. In contrast, some field and laboratory studies revealed lower males than females, such as 1:1.16 [24], 1: 1.12 [65] and 1:1.14 [54].

5.3.3. Adult survival

By rearing on leaves of olive, its natural host plant, in the laboratory (24±1 °C, 65% RH and 16:8 h L:D), the survival rate of emerged adults was estimated in 86.9 % in males and 82.8% in females [10]. Selected adult diets had been assessed on the adult performance. Female survival was better among those fed on honey solution, honeybee liquid food, Gatorade and water than males. The adult survival also can be supported by feeding on both flowering plants and honey solutions in the laboratory [38].

5.3.4. Adult longevity

Reported results in different parts of the world revealed variation of the total adult longevity of *P. unionalis*. It was measured in females and males, respectively, as follows: 13.5 days and 15.3 days [73], 9.92-11.4 days and 9.00-11.9 days [9], 9.92-11.64 and 9.00-10.57 days [18], 12.3 days and 14.1 days [56], 14 days and 13.6 days [72], 12.59±1.63 and 14.33±2.4 days [54], 16.0±1.57 days and 16.3±1.21 days [10] and 12.6 and 13.5 days [16]. This variation can be attributed to the host plant, or even its variety, as well as the climatic conditions under which the experiments had been conducted.

Considering the compartments of adult longevity, *P. unionalis* adults mate 2-3 days [27] or 2 days after emergence (pre-oviposition period) and females die immediately after egg lying with no post-oviposition period [65]. On the contrary, three main compartments, (*viz*., preoviposition period, oviposition period and post-oviposition period) had been recorded under controlled laboratory conditions and feeding on the olive leaves [10]. The pre-oviposition period was recently estimated in 2.3±0.3 days [10] which agreed with earlier result of 2-4 days [47] but disagreed with Shehata et al. [9] who reported a shorter period (1.7 days). Shorter period was also estimated (1-2 days after emergence) by Noori and Shirazi [16]. With regard to the oviposition period (Reproductive life-time**)**, Rahhal [47] reported 4.2 and 8.5 days during summer and winter months, respectively. Longer period (10.5 days, [9] or 8.0±0.7 days, [10]) was reported but shorter period (5.60-9.15 days, [18] or 3-7 days, [16] was recorded. The unique study determining a postoviposition period for this insect was conducted by Yilmaz and Genc [10] who calculated its mean in 2.4±0.4 days.

In respect of the mating effect on longevity, unmated males tended to live statistically insignificant longer than mated ones [18]. To a great extent, similar result had been earlier reported by Badawi et al. [84]. As pointed out by some authors [18, 84, 38], the adult longevity was much affected by feeding. However, some characteristics such as leaf morphology, chemical composition of the host plant or other interactions were not examined [9, 19].

5.4. Laboratory Rearing on Artificial Diet

The successful insect culturing in the laboratory is necessary for efficient and productive research on virtually every aspect of insect biology [107]. Rearing of *P. unionalis* mainly depends on natural host plants, such as olive leaves. Availability of host leaves, transferring larvae from old leaves to fresh young leaves, and susceptibility of larvae to pathogen infections are important issues to be considered. Such rearing is excessively cost in time and labor [108-110]. Therefore, mass-reared insects tend to be provided with artificial diets that bear little resemblance to their natural host or food source but nonetheless permit satisfactory growth and development of the mass-reared insects [111]. A laboratory rearing method for *P. unionalis* on artificial diet needs to be developed to facilitate the studies of different aspects and responses of this pest which are necessary requirements before planning of pest management strategies.

Since the first attempt by Bottger [112] to rear a phytophagous insect, *Ostrinia nubilalis*, on an artificial diet, a number of insects have been reared on artificial diets [113-117]. As easily appeared in the literature, Çiğdem Yilmaz, singly or with her colleagues, conducted some trials for development an appropriate artificial diet for *P. unionalis*, under the laboratory conditions, in Turkey. Yilmaz [95] compared some biological parameters of this pest after feeding the natural host plant and artificial diets and observed no differences. Almost, similar results were obtained by Sahin and Genc [39]. Along two generations of *P. unionalis* in the laboratory, Yilmaz and Genç [97] assessed the effects of feeding on different artificial diets on some biological parameters and maintenance of a colony on an artificial diet. They used the artificial diet developed for rearing *Spodoptera* spp. [118] and *Phyciodes phaon* [119] basing on pinto bean, wheat germ and torula yeast which have been previously used to rear *Spodoptera* spp. [118]. It was concluded that this diet seemed to be the most adequate diet to rear *P. unionalis*. On the other hand, there are many factors that affect the larval feeding on artificial diet, such as proportion and balance of nutrients, moisture level and texture of diet [120]. Also, addition of some host plant materials in artificial diets often promotes growth, survival and fecundity, and may act as necessary stimulants for oviposition and successful rearing [119]. However, further studies should be conducted to determine the possibility of rearing larvae on the artificial diet for successive generations.

6. Reproductive Biology of P. *unionalis*

6.1. Net Reproductive Rate

The net reproductive rate is considered as a parameter of life table (life table will be discussed thereinafter in the present review). It is a key statistic that summarizes the physiological capability of an animal relative to its reproductive capacity. Comparison of net reproductive rate often provides considerable insight beyond that available from the independent analysis of individual life history parameters [100]. It is an important indicator of population dynamics [121, 122]. Also, the net reproductive rate may reflect the potential of host plants to contribute to *P. unionalis* populations. It varied among different host plants. For example, the net reproductive rate of this species varied from129.8 females/female on ash to 298.3 on olive. Thus, ash was relatively less suitable because of the lower reproductive rate of the insects reared on it [18].

6.2. Female Fecundity

As recorded in Greece, the number of laid eggs /female (fecundity) of *P. unionalis* ranged from 86 to 515, with an average of 209 [19]. On the basis of some studies carried out in Iran, various means of fecundity, such as 231, 125±29 and 182±18.1 had been recorded [16, 54, 72]. Several biological and reproductive studies had been conducted on the present pest in Turkey. Fecundity was determined in a range of 194-390 eggs/female at 25ºC[18], 385 eggs/female [56], between 4 and 638 eggs during a period from August to September 2009 but between 29 and 643 eggs during a period from September to December 2009 [85] and 352±42.9 eggs/ female, at natural conditions in Adana region [10]. Several biological and reproductive studies had been conducted on the same pest, also, in Egypt. Different values of the female fecundity as 86-515, 141-882 and 414 eggs per female had been documented, depending on the region [27]. As well as Badawi et al. [84] determined the mean fecundity as 414 egg/female under constant conditions of 27.5º C and 65% RH and Shehata et al. [9] estimated a range from 630 to 653 eggs in the first generation but from 425 to 493 eggs in the second one, under the same laboratory conditions.

These various values of fecundity, as previously compiled, can be attributed to different factors. To shed some light on the factors interfering with the female fecundity, Badawi et al. [84] reported the necessity of copulation and fertilization of adult females for producing the production of fertile eggs. This report supported the previous observation of Rahhal [47] who dissected females just after death and observed a number of well developed eggs in their ovaries. Age of the adult females seemed to be another factor, since they laid more eggs in early ages and then fecundity decreased towards the end of their lives [10, 84]. Also, different host plants and the host plant's nutritional value are known to affect the insect reproduction [98-101]. It is interesting to refer the role of chemical stimuli in the oviposition. Kombargi et al. [123] examined the possible role of surface waxes as chemical stimuli. They found that surface waxes vary greatly within and among varieties and also contain compounds that hinder oviposition. Furthermore, according to this hypothesis, when many hosts are simultaneously offered to a female, it is expected that she will follow a hierarchical order of host preference by laying eggs on the best larval diet first, and then on the second best diet, and so forth [124]. According to Kumral et al. [18], the olive Shamy variety discouraged gravid females of *P. unionalis* from oviposition (lower fecundity), compared with Toffahi or Sennara varieties of olive. In addition to these factors, it has been found that feeding of adult females stimulate oviposition and fecundity. The number of eggs laid by fertilized females offered water (134.5 eggs per female) was much lower than those offered honey solution (414 eggs per female)[38]. Other factors interfering with the oviposition and fecundity can be added, such as the pest biotype differences, etc.

7. Ecological Parameters and Ethological Phenomena of P. *unionalis*

Many studies on various ecological aspects and behavioural characterization of *P. unionalis* had been reported in the literature (e.g., [15, 17, 18, 22, 24, 50, 63, 67, 68, 125-128]. We have reviewed here the reported works concerning the life table, population dynamics, sexual behaviour of adults, non-sexual behavioral patterns with special to the feeding and flight behaviors.

7.1. Life-Table Parameters as Affected by Biotic Factors

Leopold was the first to identify the value of life table in study of natural population [129]. Computing life tables become later a fairly current approach used by entomologists to study the insects' population dynamics. In other words, life table is an important analytical tool which provides detailed information of population dynamics to generate simple but more informative statistics. It also gives a comprehensive description of the survivorship, development and expectation of life [130-133]. Life table studies provide an opportunity to assess and evaluate the impact of specific mortality factors acting on insect population [134-136]. In addition, life tables used can make quantitatively and qualitatively evaluation of various host plants [137]. From a pest management standpoint, it is very useful to know when (and why) a pest population suffers high mortality. This is usually the time, when it is the most vulnerable. By knowing such vulnerable stages from life table, we can make time based application of control measure for the management of insect pests, to conserve the biotic and abiotic environmental constituents (for reviews, see [138, 139]).

The quantity and quality of food available to insects have important consequences for growth and development of larvae as well as the adult reproductive performance [86,140-144]. In other words, different host plants are known to play an important role in the life table parameters of phytophagous insects [98-100] such as the population increase and spread of the pest [100].

With regard to *P. unionalis*, few biological observations on the effects of several host plants of Oleaceae, such as olive, privet, jasmine and lilac, had been published [19, 22, 102]. Intrinsic rate of increase and mean generation duration reflect the suitability of the host plant, therefore three host plants (*viz*., olive, ash and jasmine) were tested on some biological aspects. The insect could complete its life cycle on all plants, but ash was relatively less suitable because of the lower reproductive rate of the insect reared on it [18]. In addition to the role of host plants, life table parameters of *P. unionalis* can be affected by other biotic factors like natural enemies. As for example, parasitoid wasp *Goniozus legneri* affected the life table of this pest at different densities of it in Egypt [49]. Depending on this study, mortality due to parasitism and paralysis by *G. legneri* was density-dependent. This undoubtedly yielded a very low generation survival and population trend in all parasitoid-released treatments comparing to control.

Concerning the overwintering stage under field conditions, P. unionalis was observed overwintering in Italy during all developmental stages almost throughout the year, but mostly as the 2^{nd}- and 3^{rd}-instar larvae [23, 25]. In an extensive study on biology of this pest in Iran, the 5th generation provided the overwintering stages that mostly were as 3^{rd} instar-5^{th} instar larvae and pupae [54]. Overwintering larvae had been, also, observed in Turkey [56].

7.2. Population Dynamics

Suffice it to report the important studies including the population dynamics of *P. unionalis* in some being infested countries of Mediterranean region and Middle East. Many factors contribute to the population fluctuations. As for example, white-colored funnel traps captured significantly more males than brown traps, but were only marginally better than yellow or green funnel traps in Central and Northern Greece [55]. In the same country, Athanassious, et al. [145] studied the population dynamics of this pest. In the coastal region and Middle Egypt, El-Kenawy [146] recorded its highest populations in the month of May. Lababidi [42] carried out an ecological study during 2003 and 2004 in two regions in Syria and determined the population fluctuations of *P. unionalis*. In Iran, field observations indicated that the first generation being completed by the end of March and in early April. However, the population reaches its peak during the third and forth generations [16].

The intrinsic rate of population increase is a basic parameter which an ecologist may wish to establish for an insect population [147]. In consistent with those results of Greenberg et al. [98] on *Spodoptera* *exigua* and Hansen et al. [99] on *Sitotroga cerealella*, the intrinsic rate of population increase indicated that *P. unionalis* reared on three host plants exhibited exponential population growth in Turkey [18]. Recently, Kacar and Ulusoy [148] determined the adult and larval population fluctuations of the same pest in the same country by using sexual pheromone capsule, between the years 2009-2010. It was observed that shoot development and climatic factors (temperature and humidity) affected the larval population fluctuation.

7.3. Sexual Behaviour of Adults

Insects are especially suited for research of behavior because they are readily available in large quantities and have a short lifespan. Learning is involved in processes determining sexual selection and incipient speciation [149, 150]. Research in the past few decades has demonstrated that many insect species rely heavily on learning to decide about a variety of behaviors [151-153]. The role of learning in insect sexual behaviour has been either neglected or considered negligible. Quantifying the effects of learning on sexual behaviour in male and female insects can help us understand sexual selection and incipient speciation [154, 155]. In insects, courtship behaviour often includes the extensive use of the antennae, as reported from various insect orders [156-160]. This behavioral pattern had not been investigated for *P. unionalis*. According to the literature available to us, sexual behaviour of *P. unionalis* had not been fully described until now. However, studies on the female calling and male response, for copulation, can be reviewed herein.

7.3.1. Female Calling and Male Response

As reported by some authors [161-164], female calling in many species and pheromone production is synchronous and usually depended on the adult age as well as on other endogenous and exogenous factors. Also, specific pheromone components or their blends can be responsible for several aspects of male copulation in many moth species [165-167]. Few studies had been conducted to investigate the calling behaviour and pheromone production of *P. unionalis* in the world. Its adult females may follow a calling and pheromone biosynthesis pattern of many lepidopterous species in which pheromone production occurs during the period where females are calling and releasing pheromone [163, 168]. Mazomenos et al. [126] achieved a valuable study in this context. According to their results, compounds (E)-11-Hexadecenal and (E)-11-hexadecen-1-yl acetate were found in the abdomen tip extracts from *P. unionalis* females. In laboratory bioassays, both components elicited a low level of upwind flight by males. The two components were inactive when tested separately in the field, but their blend (3:7) was highly attractive to males. Because knowledge of the role of each component is essential for understudying the behavioral mechanisms associated with male mating behaviour, Mazomenos et al. [57] conducted another interesting study on the same insect. Calling activity and pheromone production is periodic and synchronous. Maximal calling and pheromone production was obtained in the fourth day.

7.3.2. Egg-Laying Behaviour

Different patterns of egg-laying behaviour of *P. unionalis* had been reported in different countries as reviewed herein. In Iran, adults were active early in the morning or during sunset while exhibiting a low level of activity, possibly with short flights during the warmer hours of the day [16]. The female mates one day after emergence and deposits her eggs in third day individually or in one row on the lower surfaces of leaves [54, 72]. Almost, similar observations had been reported in Italy [23] while Alford [169] observed the eggs singly or in small groups. In Turkey, adult females deposit their eggs individually or usually in egg-masses (of 6-36 eggs) [10, 56, 85]. In Egypt, Badawi et al. [84] reported that the copulation took place 24 hours after emergence and often after mid-night. It lasted for a period ranging from 45 to 105 minutes. According to the observation of Shehata et al. [9] adults were active at night, laying eggs singly at twilight. However, more than 60 **%** of eggs were laid singly, 36.3% in small groups (of 2-5 eggs) and 1.24% in groups (of 5 eggs) [47]. The egg mass contains 2-6 eggs or 2-86 eggs [27].

7.4. Non-Sexual Behavioral Patterns

Thoroughly examination of the available literature exhibited no other than the feeding behaviour of larvae and flight behavior of the *P. unionalis* adults as non-sexual behavioral patterns.

7.4.1. Feeding Behaviour

The first instar larvae (caterpillars) of *P. unionalis* aggregated and usually fed on the parenchyma of the olive leaves and on the tender buds. As they grow, they consume entire leaves and buds [10]. In its second generation, larvae feed on fruits and seeds if they reach high population levels [49, 54, 61].

7.4.2. Flight Behaviour

Stelanescu [170] reported some notes on butterflies and moths recorded at sea off Eivissa and Barcelona (Western Mediterranean) in October 1996. All the species reported display a well-known migratory behaviour. One of them was *P. unionalis*. Before this report, Eitschberger et al. [171] recorded the same insect among seasonal migrants of the first order, and late in the season the offspring of the early migrants are involved in return flights to the southern areas from where their parents originated. Now *P. unionalis* is an international lepidopterous migratory pest in the tropical and mildly subtropical regions of the Old World [14-16]. It is a highly mobile moth dispersing even to northern Europe [32]. Another point of interest is the short and local flight. In Iran, Noori and Shirazi [16] observed active adults in early morning and during sunset while exhibiting a low level of activity, possibly with short flights during the warmer hours of the day. Also, Hegazi et al. [50] determined the seasonal flight trend of the same pest in three large plots of olive varieties during two successive fruiting seasons in Egypt.

8. Enhancement of Research Interests in Physiology of P. *unionalis*

Different metabolic and energetic aspects in insects were studied, such as: physiological and environmental considerations in bioenergetics [172, 173], energy metabolism during flight [174, 175], hormonal regulation on the energy metabolism [176-179], regulation of fat metabolism [180, 181], Chitin metabolism [182], reproductive physiology [183-185] and environmental physiology [142, 186, 187]. Unfortunately, the available literature contains no reported works on the metabolism, enzymology, hematology or other physiological aspects of *P. unionalis*. However, Mostafa et al. [188] characterized the proteins in pupal abdominal cuticle during the ecdysial periods of sclerotization in Egypt. In Egypt, also, Solaiman [189] studied the host preference of *P. unionalis* under laboratory conditions. Tophahy variety of olive plant was the preferable variety for the larvae followed by the Agyzy, while the Ballady variety was the least preferable. Also, the food consumption and host preference had been studied on certain leaf olive varieties [190].

9. Conclusions

The olive leaf moth *Palpita unionalis* gained a remarkable attention of researchers all over the world for its biological parameters and some of its ecological characteristics, beside the geographic distribution and economic impacts. On the other hand, this pest still needs research attention for investigation of several aspects such as energy metabolism, homeostasis, enzymatic patterns, chitin metabolism, hematology, resistance, immunity, reproductive physiology, environmental physiology the hormonal regulation of these processes, etc. Therefore, the present review enhances the research interests for these important aspects. However, information reviewed in this article will support the development of strategies for management of this pest.

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