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Predicting the development of critical biological stages of Sunn pest, *Eurygaster integriceps* Put. (Hemiptera: Scutelleridae), by using sum of degree-days for timing its chemical control in wheat*

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Abstract: This investigation was carried out for possible use of sum of degree-days (total effective temperatures) in order to predict the critical biological stages in chemical control of Sunn pest, *Eurygaster integriceps* Put. (Hemiptera: Scutelleridae), in 28 wheat fields of Adıyaman, Diyarbakır, and Şanlıurfa provinces from 2007 to 2010, and in climate chamber conditions. Development threshold temperature (°C) of Sunn pest in terms of the life span, starting from egg to new generation of adults, was found as 13.30 °C. Sums of degree-days starting from 1 January to appearance of the eggs, first-stage nymphs (n_1), second-stage nymphs (n_2), and fourth-stage nymphs (n_4) were found with the averages of 44.6, 84.4, 123.3, and 223.1 degree-days, respectively. The results from the field studies reflected that developmental biological data on sum of degree-days as a predictive tool could be useful in better decision making to start chemical applications as soon as the appearance of n_1 until n_4 for Sunn pest control.

Key words: Sunn pest, *Eurygaster integriceps* Put., development threshold, sum of degree-days

1. Introduction

Sunn pest, *Eurygaster integriceps* Put. (Hemiptera: Scutelleridae), is one of the most harmful insect pests of wheat and barley from West Asia (Near and Middle East), including many of the newly independent states of Central Asia, to East and South Europe and North Africa as well as in Turkey (Lodos, 1961; Schuh and Slater, 1995; Javahery et al., 2000; Kazzazi et al., 2005).

Severe crop losses in quality and quantity occur when control measures for the pest are ignored, especially in wheat production. Yield loss has been expected at 50%–90% in wheat and 20%–30% in barley. Sunn pest sometimes causes a low yield in large wheat production areas. Especially the nymph stages, as well as the adults of Sunn pest, damage these crops by sucking on leaves, stems, and grains. During feeding, they also inject enzymes that degrade gluten proteins, and thus the baking quality of flour made from damaged wheat is greatly reduced (Rajabi, 2000). If 2%–3% of the grain is damaged, entire lots may be ruined because the flour will be unpalatable and bread will not rise.

Eurygaster integriceps has a univoltine life cycle, with diapause occurring at the adult stage. The life cycle develops in two biotopes. Growth and development take place in wheat, whereas diapause (estivation and hibernation) occurs in a different habitat, such as oak-forest litter in Europe or in bushes of *Artemisia* spp., *Acantholimon* spp., or *Astragalus* spp. in the mountains of Asia. The insects migrate to the wheat fields in the spring and the diapause sites in the summer (Paulian and Popov, 1980; Lodos, 1982; Koçak and Babaroğlu, 2005).

Control attempts of Sunn pest were performed by physical, chemical, and biological methods from 1927 to 1954, but integrated pest management (IPM) practices have been gradually applied since 1955 in Turkey.

In Turkey, wide areas where Sunn pest was controlled by agrochemical pesticides have different topographical and ecological features. Pesticide applications must be timed precisely to improve efficiency of pest control because of the fact that an accurate prediction of insect development is essential for effective pest management.

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Therefore, based on the pest's biology, starting dates of pesticide applications vary based on years and locations.

Improperly timed applications result in not only insufficient levels in efficacy but also cause decreases in populations of natural enemies. Insects emerge earlier generally in warm years or localities than in cool ones. Since insect development is dependent on temperature, monitoring degree-days accumulation is a valuable tool for predicting pest activity (Herms, 2004). Thus, the monitoring system can be more accurate compared to the calendar method for estimating insect development and timing management strategies.

Thermal constant (Th. C.), sum of degree-days (total effective temperatures), and lower development threshold values are more convenient for predicting development time of insect populations over a range of biologically significant temperatures. The right decision on the usability of control measures will be dependent upon factors like the level of damage or the life stage of the insect, because the wheat kernel is especially susceptible to the early nymph stages' (n_{1-3}) damage. Treatment, if decided upon, would be timed to correspond with some point within the sum of the degree-days range. Therefore, predicting the appearance of the eggs and the early nymph stages, which are critical biological stages of Sunn pest, is inevitable for successful chemical control in different wheat areas where surveys need to be carried out by "Sunn pest teams" in millions of acres within a limited period. All these activities are time-consuming and costly.

Developmental characteristics of *E. integriceps* have not been documented in detail on wheat with the exception of the studies of Ionescu and Mustatea (1973), Şimşek and Yılmaz (1992), and Kıvan (2008). Hence, this study was carried out during the years 2007–2010 in order to solve the problem mentioned above by predicting the proper time for chemical control of Sunn pest, regarding the development of critical biological stages of the pest by using sum of degree-days in wheat growing areas of Adıyaman, Diyarbakır, and Şanlıurfa provinces in Southeastern Anatolia, where the largest Sunn pest chemical control application area of Turkey is located.

2. Materials and methods

The study was conducted both in insecticide-free wheat fields in Adıyaman, Diyarbakır, and Şanlıurfa provinces of the Southeastern Anatolia region of Turkey during 2007–2010 and in laboratory conditions.

Predicting the proper application time for chemical control of Sunn pest regarding the development of n_1 to n_4, which are critical biological stages of the pest, by using sum of degree-days in the field and the development thresholds (°C) and thermal constant (Th. C.) values of each biological stage (eggs, nymph stages, and new-generation adults (NGAs)) in climate chambers were studied.

For this purpose, Sunn pest cultures were set up in plastic boxes (29 × 21 × 21 cm), the top surface of which was covered with cheese-cloth and kept at 25 and 30 ± 1 °C and 65 ± 5% relative humidity with illumination of 1500 lx for 16 h of light per day in climate chambers. The culture was started with 10 overwintered adults (5 ♀, 5 ♂) per box, which were collected on 23 March 2011 from Karacadağ Mountain, Diyarbakır. The experiment was set up with 10 replications and initiated with 10 fresh egg masses. Duration of egg and nymph stages of Sunn pest were observed and recorded twice a day from eggs to NGAs. Wheat plants were given as food to both adults and nymphs. The plants were renewed when necessary. The development threshold (°C) and thermal constant (Th. C.) of Sunn pest were calculated according to the equation given below (Sanderson and Peairs 1913):

$$\text{Th. C.} = t\,(T - C),$$

where Th. C. is the species (or stage-specific) thermal constant of a poikilothermic organism, which is expressed as the number of degree-days (in °C) and provides an alternative measure of the physiological time required for the completion of a process or a particular developmental event; t is development duration (days); T is temperature (°C); and C is developmental threshold or baseline (°C), the minimum temperature at which insects first start to develop. The base temperature is that which below the insect does not develop (also called "threshold temperature"). The growth rate of the insect increases with temperature above the developmental threshold. Growth and development are closely related to daily temperature mean accumulations above the developmental threshold. The thermal constant (Th. C.) provides a measure of the physiological time required for the completion of a developmental process and is measured in degree-days (Önder, 2004; Damos and Savopoulou-Soultani, 2012; Kansu, 2012). By using the relationship between temperature and rate of development, when insects will pass through certain stages can be predicted. This method of estimating time is called the degree-day method. A degree-days is the same as an average of one degree over the threshold temperature for a 24-h period. The ability of these models to predict insect development depends partly on the accuracy of the data used in determining degree-days (Bessin, 2016). The degree-days were calculated using the simple formula given below for the average daily temperature, calculated from the daily maximum and minimum temperatures, minus the developmental threshold (Herms, 2004; Murray, 2008).

$$\text{Degree - days} = \left[\frac{\text{dailymax.temperature} + \text{dailymin.temperature}}{2}\right] - \text{developmental threshold}$$

Appearances of the first eggs, the early stage nymphs, and the NGAs of Sunn pest were surveyed and detected once a week in 28 wheat fields in Adıyaman, Diyarbakır, and Şanlıurfa provinces. Sunn pest eggs, nymphs, and new adults were sampled and recorded at four spots in each of the fields by two methods, with a triangular sweep net (50 × 50 × 50 cm) and an iron square frame (0.25 m^2) to avoid any sampling error (Yiğit et al., 2003). The lowest and the highest temperature values for each location were recorded daily starting from 1 January to appearance of the first eggs, the early stage nymphs, and the NGAs from the nearest meteorological station. Sums of degree-days for appearance of the first egg packages, early stage nymphs (n_{1-3}), and NGAs of Sunn pest in different locations were computed for observation dates according to the above formula.

3. Results

Duration of immature stages of Sunn pest at 25 °C and 30 °C, development threshold temperature (°C), and thermal constant (Th. C., accumulation of degree-days) values are shown in Table 1.

Development threshold temperature from egg to NGAs for Sunn pest was 13.30 °C, and Th. C. values for embryonic development of eggs and first stage nymphs (n_{1-3}) were 93.20 and 214.24 degree-days, respectively. Physiological time required for the completion of Sunn pest from egg to adult was Th. C. = 527.67 degree-days (Table 1).

Sum of degree-days (accumulation of effective temperatures) starting from 1 January to observation dates for critical biological stages for chemical control of Sunn pest in wheat fields in Adıyaman, Diyarbakır, and Şanlıurfa provinces during 2007–2010 are given in Table 2.

When the findings were evaluated together, it was understood that the Sunn pest began to lay eggs by the first half of April and continued until the first week of May, when the sum of degree-days reached an average of 44.6 (30.8–67.5) degree-day, starting from 1 January in wheat fields of Adıyaman, Diyarbakır, and Şanlıurfa provinces. The first-stage nymphs appeared from the second half of April to the first half of May, when the sum of degree-days reached an average of 84.4 (69.0–106.8) degree-days. The second-stage nymphs appeared from the end of April to the second half of May, when the sum of degree-days reached an average of 123.3 (96.1–145.4) degree-days in the study area. The fourth stage nymphs appeared from early-May to the end of May, when sum of degree-days reached the average of 223.1 (191.7–260.8) degree-days, while new generation adults appeared when sum of degree-days reached the average of 342.5 (270.0–405.4) degree-days (from end of May to mid-June) (Table 2).

4. Discussion

Development threshold temperature (from eggs to NGAs) and Th. C. values for embryonic development of Sunn pest eggs were found as 13.30 °C and 93.20 degree-days, respectively. The embryonic development was completed within 5.3 days at 30 °C (Table 1). In a previous study, Kıvan (2008) reported that the egg development time was 4.5 days at 32 °C, which required 90.9 degree-days above the theoretical development threshold of 11.7 °C for the pest. Duration of immature stages of Sunn pest nymphs (n_{1-5}) at 25 °C and 30 °C were found as 34.9 ± 0.52 and 24.7 ± 0.32 days, respectively (Table 1). Şimşek and Yılmaz (1992) reported that Sunn pest nymphs (n_{1-5}) completed their development in 36.5 ± 0.96 and 26.0 ± 0.60 days at 25 °C and at 30 °C, respectively. Based on the

Table 1. Duration of immature stages of Sunn pest, *Eurygaster integriceps* Put., at 25 °C and 30 °C, threshold temperatures (°C), and thermal constant (Th. C.) results (accumulation of degree-day totals).

Biological stages of Sunn pest	Development time (days)		Development threshold temperature (°C)	Thermal constant (Th. C. 'degree-days')
	25 °C	30 °C		
Egg	7.4 ± 0.22	5.3 ± 0.26	12.40	93.20
n_{1-3}	20.8 ± 0.93	14.0 ± 0.78	14.70	214.24
n_{1-5}	34.9 ± 0.52	24.7 ± 0.32	12.89	422.61
Egg-NGA*	45.1 ± 0.69	31.6 ± 0.57	13.30	527.67

*NGA: New generation adult.

Table 2. Sum of degree-days (accumulation of effective temperature totals) starting from 1 January to observation dates for critical biological stages for chemical control of Sunn pest, *Eurygaster integriceps* Put., in wheat fields in Adıyaman, Diyarbakır, and Şanlıurfa provinces during 2007–2010.

Years	Provinces	Districts	Villages*	Sum of degree days (accumulation of effective temperatures) - dates, observed critical biological stages of Sunn pest				
				Appearance of the first eggs	Appearance of the first-stage nymphs (n_1)	Appearance of the second-stage nymphs (n_2)	Appearance of the fourth-stage nymphs (n_4)	Appearance of the new generation of adults
2007	Adıyaman	Merkez	1, 2, 3, 4	57.1 (30 April)	72.2 (7 May)	118.3 (12 May)	212.0 (24 May)	362.8 (7 June)
	Diyarbakır	Ergani	5, 6	39.9 (6 May)	83.5 (11 May)	125.7 (16 May)	273.0 (30 May)	372.3 (7 June)
	Şanlıurfa	Hilvan	7, 8, 9	-	74.1 (10 May)	104.1 (14 May)	191.7 (23 May)	270.0 (30 May)
2008	Adıyaman	Merkez	10, 11, 12	67.5 (14 April)	106.8 (20 April)	145.4 (26 April)	209.7 (12 May)	274.3 (21 May)
		Kâhta	13	35.1 (10 April)	91.1 (19 April)	138.7 (24 April)	198.1 (3 May)	300.4 (22 May)
	Diyarbakır	Ergani	14, 15	-	105.5 (24 April)	133.5 (4 May)	199.5 (20 May)	342.6 (2 June)
2009	Adıyaman	Merkez	16, 11, 17, 18, 19	40.3 (23 April)	76.0 (9 May)	96.1 (13 May)	-	362.8 (10 June)
		Kâhta	20, 21	38.9 (24 April)	79.8 (10 May)	113.0 (15 May)	209.5 (23 May)	335.8 (4 June)
	Diyarbakır	Ergani	5, 15	49.5 (3 May)	69.0 (11 May)	127.0 (18 May)	-	405.4 (12 June)
2010	Şanlıurfa	Bozova	22, 23	30.8 (12 April)	90.0 (30 April)	117.0 (6 May)	260.8 (21 May)	380.7 (2 June)
		Hilvan	24, 25	33.9 (17 April)	92.0 (3 May)	138.4 (10 May)	252.3 (22 May)	359.5 (2 June)
		Siverek	26, 27, 28	52.6 (22 April)	72.6 (4 May)	122.1 (11 May)	224.8 (24 May)	343.6 (9 June)
Average (min–max)				44.6 (30.8–67.5)	84.4 (69.0–106.8)	123.3 (96.1–145.4)	223.1 (191.7–260.8)	342.5 (270.0–405.4)

*: 1- Çemberlitaş, 2- Doyuran, 3- Karaburç, 4- Battalhöyük, 5- Pınarkaya, 6- Tevekli, 7- Bahçecik, 8- Faik, 9- Üçüzler, 10- Yenice, 11- Hasankendi, 12- Karburç, 13- Kemerkaya, 14- Yolköprü, 15- Saluca, 16- Toptepe, 17- Küçükkavak, 18- Gümüşkaya, 19- Canhor, 20- Bölükyayla (1), 21- Bölükyayla (1), 22- Merkez, 23- Arıkök, 24- Gölcük, 25- Oymaağaç, 26- Çaylarbaşı, 27- Karakeçi, 28- Şekerli.

reported data above, the threshold temperature could be computed as C = 12.61 °C and Th. C. = 452.14 degree-days for development of nymphs. These values were compatible with our findings given in Table 1.

As seen from Table 2, Sunn pest began to lay eggs when the sum of degree-days reached an average of 44.6 (30.8-67.5) degree-days, and the first- and second-stage nymphs appeared when the sum of degree-days reached an average of 84.4 (69.0–106.8) and 123.3 (96.1–145.4) degree-days respectively in the study area starting from 1 January. Variations in localities and years in sum of degree-days for appearance of the first eggs, n_1, n_2, etc. could be attributed to the slightly long period of sampling intervals (1 week). Daily or every other day samplings and/or observations in the field would have been useful to minimize the variations, instead of weekly samplings, in the determination of the sum of degree-days for critical biological stages of this phytophagous insect.

In addition, we calculated the development threshold temperature and Th. C. values based on only two temperature levels (25 °C and 30 °C), which might have slightly affected the development threshold temperature of Sunn pest compared to cases where more than two levels of temperature are studied (Mazzei et al., 1999). The variations may also be attributed to the temperature data collected from different locations that have different climatic conditions depending on altitudes. It was reported that the temperature summation rule is valid within the species-specific temperature range of development; therefore, several empirical linear and nonlinear regression models including the derivation of biophysical models have been proposed to define the critical temperatures for development (Damos and Savopoulou-Soultani, 2012). On the other hand, geographical variation in thermal requirements for insect development was pointed out by Honek (1996).

Intensive samplings are necessary by the appearance of the first-stage nymphs (n_1) and the technical staff should be warned by the appearance of the second-stage nymphs (n_2) for pesticide applications when the sum of effective temperatures reaches close to 70 (average: 84.4) and 100 (average: 123.3) degree-days, respectively, starting from 1 January (Table 2).

When the results are taken into consideration, looking from an IPM approach, dates for starting chemical control attempts should be planned according to localities regarding the embryonic development of eggs reaching 20%–30% "anchor sign" prior to the eclosion period, combined with an egg parasitization survey and determining the ratio of the second-stage nymphs in Sunn pest populations (Şimşek, 1986).

Ionescu and Mustatea (1973) stated that the first eggs of Sunn pest were laid 25 days after their migration, when the sum of daily effective temperatures reached 87 degree-days (in early May). The nymphs appeared when the sum of daily effective temperatures reached 70–80 degree-days, starting from oviposition (i.e. 157–167 degree-days). Pest control units were informed about the appearance of the first nymphs. Warning bulletins giving information on optimum application dates were prepared when the third-instar nymphs appeared in Romania.

In light of this preliminary study, climatic data recorded from meteorological stations set up in representative locations where the Sunn pest is a problem, combined with daily or every other day observations for the appearance of n_1 until to n_4 nymphs, critical biological stages of the pest in the field, would be useful to predict the accurate timing of Sunn pest chemical control for further studies.

In conclusion, more sensitive predictions and warnings about starting dates for chemical control of Sunn pest seem to be possible with observations of critical biological stages of the pest in the field by combining the proposed sum of degree-day data, and thus more effective labor planning would be feasible for the surveys.

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