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Adult dispersal of *Sitotroga cerealella* in a conventional small-farm in Southern Italy

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Abstract

Using sex pheromone traps baited with 1 mg of Z, E-7-11-hexadecadien-1-yl acetate (or HDA), observations of male adult presence and dispersion of the Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Lepidoptera Gelechiidae), in warehouse and in field-plots were carried out. The studies were realised during 2012 and 2013 in a conventional small-farm of 10.5 ha located in hilly areas of Benevento, Campania region, Central-Southern Italy. The farm was divided into plots as follows: nursery truffle plants, vineyard, spring wheat, clover, oak grove, corn, tobacco, oats, barley, and olive grove. According to the results, infestations of *S. cerealella* occurred during both preharvest plantation and postharvest storage. The field occurrence showed various levels of presence, with different insect abundances in the plots. The highest numbers of males were trapped in the warehouse in which different cereals are stored all year long. *S. cerealella* activity suggests adult dispersal from the warehouse to field-plots during the spring-summer season up to 600 meters from the warehouse. The activity of *S. cerealella* in the Southern-Central Italy agricultural territory is mainly affected by the presence of small traditional warehouses. The crop succession in the fields does not seem to be very important for the presence and dispersion of the moth.

Key words: Angoumois grain moth, dispersal, warehouse, fields.

Introduction

The Angoumois grain moth, *Sitotroga cerealella* (Olivier) (Lepidoptera Gelechiidae), is considered a major pest of stored agricultural products worldwide. Infestations of *S. cerealella* occur during storage, in preharvest or postharvest. Plants are attacked at a postharvest stage, although some are also attacked at the fruiting stage; the damage caused is crucial in temperate and tropical regions. Large populations of *S. cerealella* can build up if crop is left in the field to dry (CABI, 2004). The larvae of *S. cerealella* attack a variety of kernels, such as: corn, sorghum, wheat, soybean, rice, paddy, products prepared from these kernels, and many other non-crop wild-plant. It is often found alongside other pests, with which it may act synergistically (Bitran *et al.*, 1978; Singh *et al.*, 1978; Trematerra and Gentile, 2002; Perez-Mendoza *et al.*, 2004; Butron *et al.*, 2008; Ukeh *et al.*, 2008; Ashamo, 2010).

In a previous paper Trematerra and Gentile (2002) presented a study carried out on stored insect pests of *Triticum dicoccum* Schubler, *T. monococcum* L. and *T. spelta* L. in traditional crop areas of Molise and Basilicata regions (Central-Southern Italy); among other insects, the ecology of *S. cerealella* was studied. In those regions, the field occurrence of *S. cerealella* showed various levels of infestation, with different population abundance in the various areas. The highest numbers of moths were trapped in Molise hulled wheat fields. These fields were in the same area as many traditional warehouses wherein different cereal species, generally used as animal food, were stored. The other fields examined in Basilicata were located near industrial silos or in crop areas with no storage facilities. According to these results Trematerra and Gentile (2002) suggested that in hulled wheat crop areas the outdoor activity of the Angoumois grain moth could be influenced by adult migration from stored cereals.

Keys and Mills (1968) extracted a sex attractant from female Angoumois grain moths. In between times, adults have been monitored by Vick *et al.* (1974); synthetic sex pheromone of *S. cerealella* has been used to attract and monitor males in flour-mills by Buchelos (1980) and Levinson and Buchelos (1981); Stockel and Sureau (1981) determined the optimum dose for sex trapping applications in corn. Studies carried out by pheromones to monitor activity and movement of *S. cerealella* in storage and field situations revealed also adult dispersal. Stockel (1971) studied dispersal of Angoumois grain moths to maize fields; Cogburn and Vick (1981) monitored the distribution of *S. cerealella* in rice fields and rice stores in Texas (USA). Vick *et al.* (1987) studied distribution in storage and field situations in North-Central Florida (USA). Barney and Weston (1994; 1996) monitored *S. cerealella* movement in a small-farm ecosystem in Kentucky (USA) and Arbogast (2005) studied seasonal flight activity of *S. cerealella* in South Carolina (USA). Trematerra and Gentile (2002) reported studies on ecology and dispersal of *S. cerealella* adults in traditional crop areas of Central-Southern Italy.

Using sex pheromone traps, the purpose of the present study is to monitor *S. cerealella* movement among habitats on a conventional small-farm in Central-Southern Italy. The objective is to determine presence and dispersion of *S. cerealella* in warehouse and in field.

Materials and methods

The experiment was conducted during 2012 and 2013, in a conventional small-farm of 10.5 ha situated between 300 and 800 m above sea level in a hilly area of Benevento, Campania region (Central-Southern Italy).

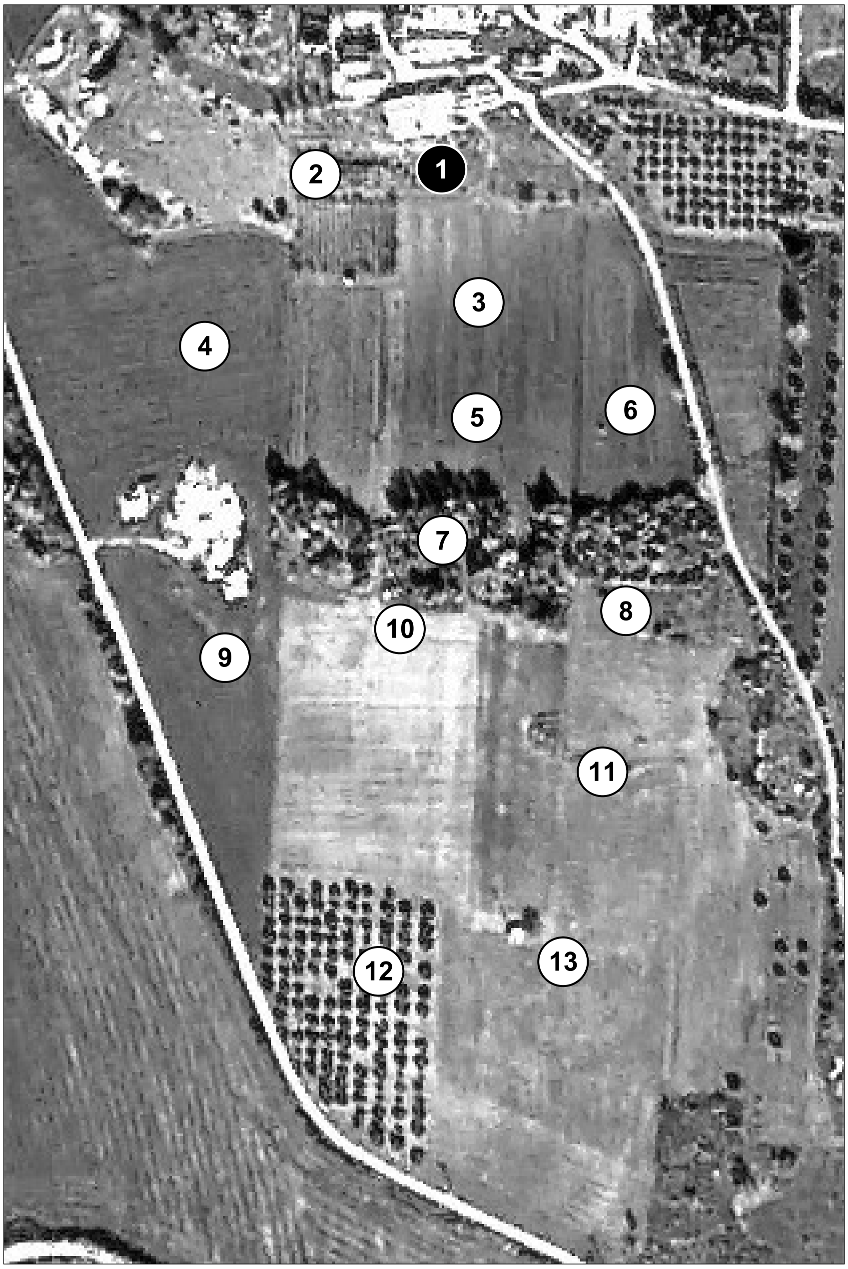

Figure 1. Map of the experimental farm with arrangement of sex pheromone traps: 1) warehouse; 2) truffle plants; 3) vineyard; 4) clover A; 5) spring wheat A; 6) oats; 7) oak grove; 8) tobacco; 9) clover B; 10) corn; 11) spring wheat B; 12) olive grove; 13) barley.

In this area the annual harvest of cereals is carried out from early June to mid-July. The trapping regime consisted of two parts: monitoring *S. cerealella* males in the farm warehouse; monitoring *S. cerealella* across the farm field-plots.

The farm warehouse, used for storing cereals and other products harvested from fields (spring wheat, barley, corn, and oats), was 300 m^2 (10 × 30 m). Traditionally, the different cereal species, generally used as animal food, are stored for the whole year. The area of the farm was divided into the following plots: nursery of truffle plants (2,000 m^2 with mycorrhizal plants of *Tuber melanosporum* Vittadini); vineyard (3,000 m^2 with plants of *Vitis vinifera* L.); clover (*Hedysarum coronarium* L.) divided in parts A and B of 5,000 m^2 each; spring wheat (*Triticum aestivum* L.) divided in two parts, field A of 30,000 m^2 and field B of 10,000 m^2; oats (*Avena sativa* L.) of 5,000 m^2; oak grove (*Quercus coccifera* L.) of 5,000 m^2; corn (*Zea mays* L.) of 5,000 m^2; tobacco (*Nicotiana tabacum* L.) of 30,000 m^2; olive grove (*Olea europea* L.) of 10,000 m^2; barley (*Hordeum vulgare* L.) of 10,000 m^2. The surrounding land of the experimental farm was cultivated with clover and spring wheat (figure 1, table 1).

Pheromone traps for monitoring *S. cerealella* males consisted of sticky traps (delta type) baited with 1 mg of synthetic sex pheromone Z, E-7-11-hexadecadien-1-yl acetate (or HDA) (Novapher, San Donato Milanese, Milano, Italy). During 2012, two traps, suspended at 2.5 m, were placed in the farm-warehouse. During 2013 a trap

Table 1. Field-plots characteristics, trap distance from warehouse and *S. cerealella* males trapped in 2013.

Field-plots 2013	Field-plots 2012	Trap distance m	Males trapped n
Warehouse	Warehouse	0	2270
Truffle plants	Truffle plants	60	118
Vineyard	Vineyard	80	36
Spring wheat (A)	Spring wheat	110	29
Clover (A)	Spring wheat	140	12
Oats	Tobacco	150	28
Oak grove	Oak grove	250	28
Tobacco	Barley	300	62
Corn	Barley	300	25
Clover (B)	Spring wheat	380	18
Spring wheat (B)	Barley	400	21
Olive grove	Olive grove	600	17
Barley	Barley	600	13

was placed in the farm-warehouse and twelve traps, suspended on a support at 1.5 m above ground, were placed in the field-plots (one trap for each plot). *S. cerealella* males found in the various traps were counted and removed weekly; pheromone dispensers and sticky surface of traps were replaced with new ones at intervals of 6 weeks and 2-4 weeks respectively. In 2012 and 2013 surveys were carried out from the beginning of April until the end of November.

During the monitoring period, no insecticide treatment was carried out in the warehouse and in the experimental field-plots. During 2013, temperature data were recorded by Campania regional meteorological system (http://www.sito.regione.campania.it/agricoltura/meteo/agrometeo.htm).

The data were submitted to one-way ANOVA analysis (SPSS 17.0) to look at the effect of time (in months), distance (plots), and the interaction between time and distance, in order to assess if significant differences ($P \leq 0.01$) existed at spatial or temporal level.

Results

In 2012 in the warehouse the Angoumois grain moths were trapped from late-April to mid-October, in total 2,301 males were trapped. The capture of males varied according to the two trap-positions. *S. cerealella* were collected before and after harvesting cereals from 24-April to 9-October. Flight peaks were recorded on 9-May, 12-June, 17-July, 9-August, 28-August and 18-September, with a maximum of 234 specimens caught in the mid July (figure 2). During 2013 male moth activity across the farm, as measured by pheromone trapping, was very heavy during July-August and in early October; field activity was much lower than that observed in warehouse. In figure 3 are reported catches of *S. cerealella* males observed in warehouse and in the field-plots from early April to late November.

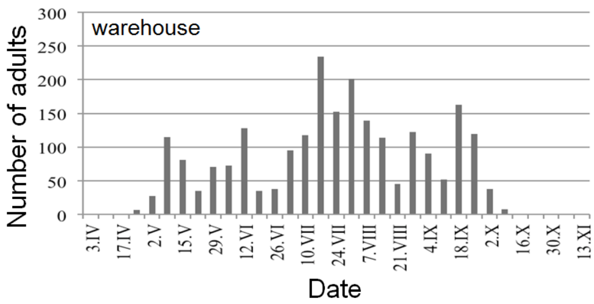

Figure 2. Number of *S. cerealella* males caught weekly with two pheromone traps in warehouse during 2012.

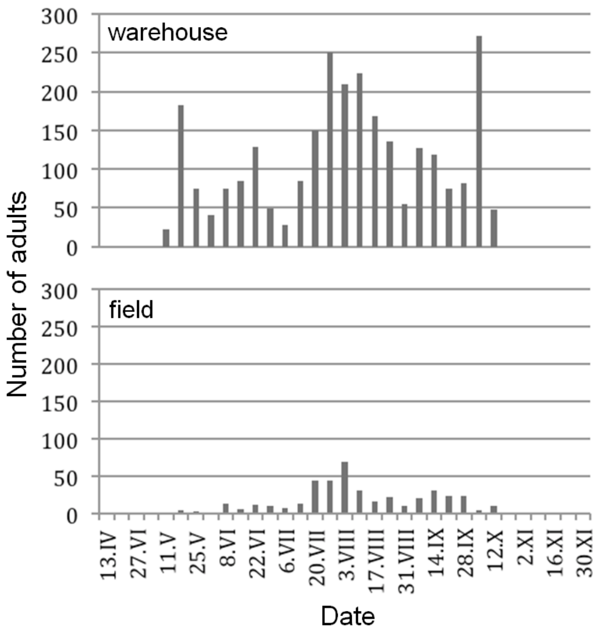

Figure 3. Number of *S. cerealella* males caught weekly with pheromone traps, in warehouse (one trap) and in field-plots (12 traps).

In total 2,677 males were trapped, 2,270 were trapped inside the farm-warehouse and 407 were trapped in the various field-plots. As can be seen, the capture of males varies according to the field-plots location (table 1, figure 4).

In the experimental farm, adult males of *S. cerealella* were collected before and after harvesting cereals. In the warehouse, males were trapped from 11-May to 12-October, while in field plots first adults were observed one week later, from 18 May to 12 October (figure 3).

In general, flight peaks were recorded on 18-May, 22-June, 27-July, 10-17 August, 7-September and 5-October, with a maximum of 271 specimens caught in the first days of October (figure 3). All pheromone traps positioned in field-plots were affected by the presence of *S. cerealella* males; as it can be seen in table 1 and in figure 4, few catches have occurred also in the fields of the olive grove and barley which are located 600 meters from the farm warehouse (figure 4, m-n). In nursery

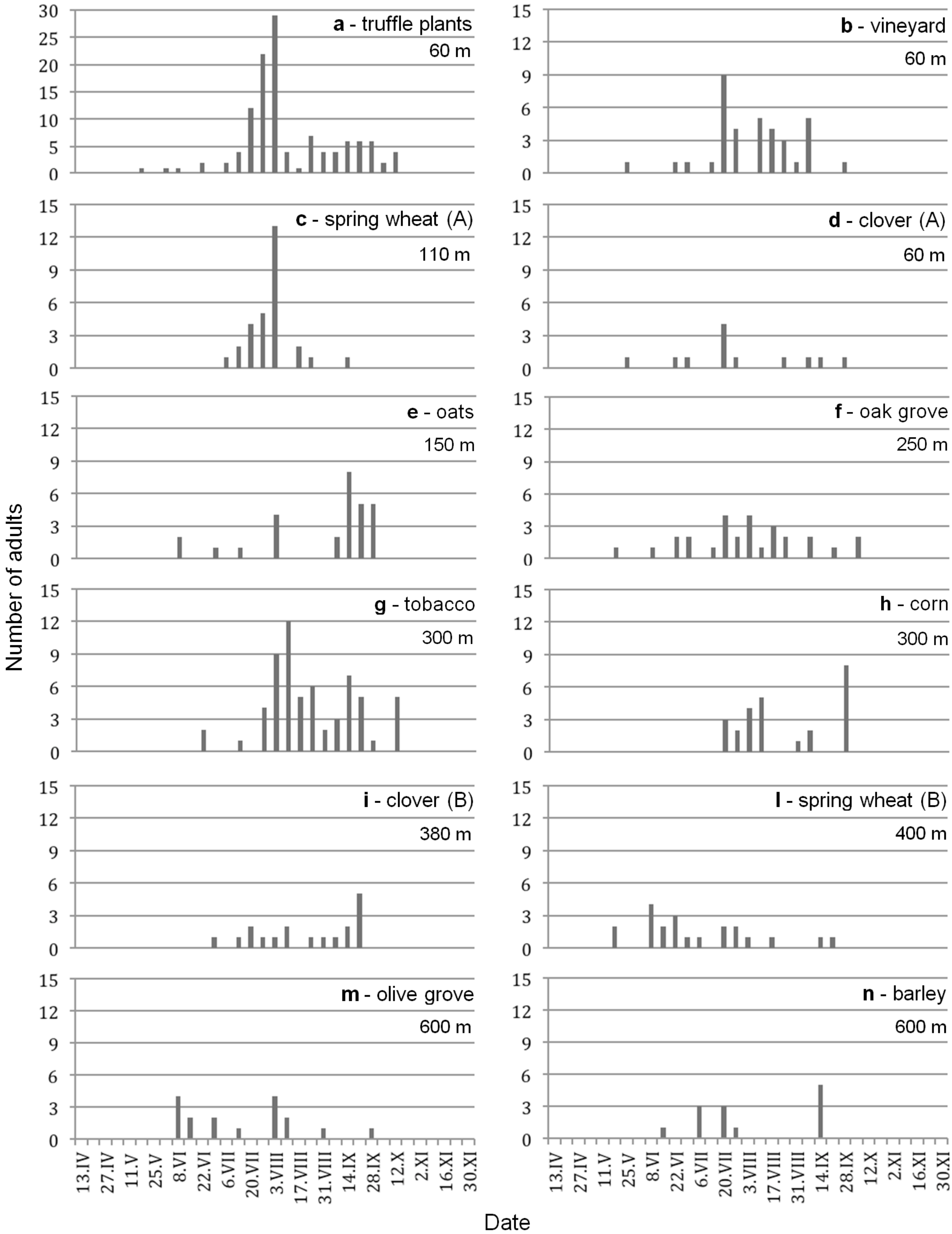

Figure 4. Catches of *S. cerealella* males from April to November 2013 in the different field-plots.

truffle plants plot, about 60 meters away from the farm warehouse, were captured 118 males. The first males of *S. cerealella* were caught on 18 May; during the season the population has remained relatively low until the end of July; in the first days of August catches increased with a peak of 29 adults trapped; afterwards, the number of specimens observed in trap has decreased and remained relatively low until 12 October (figure 4, a). In the vineyard-plot trap, positioned at about 80 meters from the warehouse, were trapped 36 males. In this case, the catches were always very low, with a peak on 20-July; a small increase was observed during August, and the last capture was observed on 28-September (figure 4, b). In the two plots of spring wheat, plot A being located at about 110 meters from the warehouse and plot B at about 400 meters, were captured 29 and 21 adults respectively. In the trap in plot A, *S. cerealella* have been observed from 6-July to 14-September with a peak on 3-August; in plot B trap, the first catches were found on 18-May and a low presence of adults has been observed until the 21 of September (figure 4, c-l). In the cultivation of clover, divided in two plots of 5,000 m^2 each, situated at about 140 meters (plot A) and 380 meters (plot B) away from the warehouse, were trapped 12 and 18 males respectively. The males of *S. cerealella* were caught sporadically and with few specimens from 25 June to 28 September in plot A, whereas in plot B adults were trapped from 29-June to 21-September (figure 4, d-i). In the field of oats, at about 150 meters from the farm-warehouse, were trapped 21 males; specimens were captured from 8-June to 28-September with a peak on 14-September (figure 4, e). In the oak grove, at about 250 meters from the warehouse, were trapped 28 males; from 18 May, the catches of *S. cerealella* have remained constantly very low until 5-October (figure 4, f). In the tobacco field, located about 300 meters away from the warehouse, were trapped 62 males. In this plot, males' presence was quite persistent from 22-June to 12-October, with a peak on 10-August (figure 4, g). In the corn field, situated about 300 meters away from the warehouse, were trapped 25 males; a few males were sporadically observed into the traps from 20-July to 28-September, with a peak on 28-September (figure 4, h). In the olive grove, about 600 meters from the warehouse, were trapped 17 males; the first catches were found on 8-June and a low presence of males has been observed until 28-September (figure 4, m). In the field of barley, at about 600 meters away from the farm warehouse, were trapped 13 males. The males of *S. cerealella* were captured only on a few occasions: on 15-June, in July and on 14-September (figure 4, n).

In the ANOVA analysis performed in order to statistically investigate the effect of time (in months) and distance (plots) on number of males trapped, when the factors were analysed singularly, the effect of distance was found statistically highly significant ($P \leq 0.01$) while the effect of time was null ($P \geq 0.05$). However, when considering the correlated effect of factors, both the time and the distance were found statistically significant ($P \leq 0.01$). Consequently the high significance ($P \leq 0.01$) of the correlated model ensured that the numbers of males trapped resulted predictable from time and space (table 2).

Discussion

According to Cogburn and Vick (1981) sticky traps baited with synthetic sex pheromones captured Angoumois grain moths in both storage and field environments. Populations in storage environments resulted high during all warm months, populations in field environments were highest in August, but were detectable during all months except January and February. Adults were captured in fields located 0.9 km from a known source of infestation and also in a forest about 5 km from the nearest storage facilities or fields.

In order to have flexible nutritional requirements, *S. cerealella* is highly mobile and a primary colonizer. Adults are strong fliers and cross-infestation occurs easily. These attributes allow *S. cerealella* to survive in a variety of habitats and move from patch to patch as conditions change (Cogburn and Vick, 1981). Candura (1926) in Italy and Simmons and Ellington (1933) in Maryland (USA), had hypothesised already that *S. cerealella* was able to move from grain storages to ripening wheat fields in summertime.

S. cerealella revealed preference to some kernel characteristics in the selection of its host for feeding, oviposition and sex communication. In fact, as reported by Fouad *et al*. (2013), males and females respond to three active compounds to kernel volatiles, present in corn and also in other plants; such compounds were identified as n-nonanal, n-decanal and geranyl acetone.

In southern Europe there are about 5 generations per year, but in warmer climates *S. cerealella* is brooded continuously, to an extent of 10-12 generations per year (CABI, 2004). In temperate countries, *S. cerealella* overwinters at larval stage in stored grain kernels or in scattered wheat in litter, straw piles or baled straw. Stockel (1971) reported that *S. cerealella* have 3 generations per year in France: the first two in grain storage or wild grasses and the third on ears of maize in the field. In Greece this pest develops from 3 to 5 generations in closed room storages (Buchelos, 1998), and in Slovenia 2 generations (Trdan *et al*., 2010). In Central-Southern Italy, 4 to 5 generations are observed from March to November: in the fields, the moth can have 1-2 generations attacking whole grains, while in the warehouses there are usually 3 generations (Trematerra and Gentile, 2002).

In *S. cerealella* the rate of development is mainly dependent on temperature (Throne and Weaver, 2013). Although larvae will hatch at a lowest temperature of 12 °C and a maximum of 36 °C (Cox and Bell, 1981), 16 °C and 30% RH are cited as the minimum conditions for population increases (Boldt, 1974) and the upper temperature limit is 35 °C (Dobie *et al*., 1984). Mondragon and Almeida (1988) found that the development was easier at 25 °C, and that at this temperature, with 70 ± 2% RH and a diet of maize, the mean period of development for the larval stage was 29.4 days. At 30 °C and 80% RH, the complete life cycle can take as little as 25 to 28 days, although at 25 °C, the total life cycle was found to last 48.6 days. The nature of the host may also affect the rate of larval development, with a lenght of 20 days reported for wheat (Cocurt X-71) and 22.4 days for barley (Cleaper) (Mahdi and El-Najjar, 1988).

Table 2. ANOVA analysis, effect of time (in months) and distance (plots) on total number of *S. cereaella* males trapped.

	Source	Sum of squares	d.f.	Mean square	F	Sig.
Time	Between Groups	36370.452	7	5195.779	0.583	0.768
	Within Groups	855913.538	96	8915.766		
	Total	892283.990	103			
Distance	Between Groups	578052.053	10	57805.205	17.108	0.000*
	Within Groups	314231.938	93	3378.838		
	Total	892283.990	103			
Interaction between time and distance	Corrected Model	891888.490	87	10251.592	414.729	0.000*
	Intercept	85706.778	1	85706.778	3467.278	0.000*
	Time	44446.997	7	6349.571	256.873	0.000*
	Distance	578052.053	10	57805.205	2338.517	0.000*
	Time Distance	277465.986	70	3963.800	160.356	0.000*
	Error	395.500	16	24.719		
	Total	961191.000	104			
	Corrected Total	892283.990	103			

* statistically significant differences at $P \leq 0.01$

Life table studies for the *S. cerealella* on stored maize, in West Africa, were conducted by Stengard-Hansen *et al*. (2004). The effects of four temperatures (20, 25, 30, and 35 °C) and two relative humidity levels (44 and 80%) on developmental time, age-specific survivorship and fecundity, sex ratio, and intrinsic rate of natural increase of *S. cerealella* were investigated. Minimum development time occurred at nearly 32 °C and 80% RH for both males and females. Immature survivorship was highest between 25 °C and 30 °C and 80% RH and lowest at 35 °C under both humidity conditions. A similar low level was found at 20 °C and 44% RH. If compared with the few other life table studies conducted on this species on maize in India and North America (Weaver and Throne, 1994), some variation among the strains becomes evident. A weak correlation has been found between moisture content and infestation, which suggests that storing grain in a dry place can reduce the chances of infestation. Hermetic storage at low humidity also gives good levels of control (Mantovani *et al*., 1986). According to Schulten (1973) there are two kinds of factors implicated in the onset and spread of infestation by *S. cerealella*, namely conditions in the field and conditions during storage.

In Central-Southern Italy, traditional farm granaries are generally of poor construction, and farmers are mostly unaware of safe storage practices, such as warehouse preparation for reception of new produce, the removal of old product, regular checks of the sanitary state of the warehouse, product control during the storage season and quick intervention with appropriate measures if pests emerge. Consequently, these storage facilities are frequent sources of stored pests (Trematerra and Gentile, 2002).

As reported, in our study the highest numbers of moths were trapped in the warehouse in which different cereal species, generally used as animal food, are stored for the whole year. In the field, occurrence of *S. cerealella* showed various levels of infestation, with different population presence in the 12 plots of the experimental farm. Results from trapping at different distances and directions from the warehouse were observed; activity at 600 m was high in July-August and September, when the activity peaked also at the warehouse. The significant interaction between the time (in months) and the distance (plots) ensured that the numbers of males trapped resulted predictable from time and space (table 2). The attractiveness of volatile substances produced by host plants in the environment, alongside with the wind speed and direction, can both influence the dynamics of moths' dispersion from the warehouse to the cultivated fields. Therefore, storage, fields, and wild hosts distributed on the territory can each serve as sources of both reproduction and aggregation, depending on the time of year. Considering the temperatures measured in the study area that are favourable to the development of *S. cerealella* for many months during the year, and according to the catches realized by sex pheromone traps positioned in field-plots and in farm-warehouse, it is assumed that *S. cerealella* in small-farms of the Central-Southern Italy produces 5-6 generations per year, partly in the field and mainly carried out in the warehouses.

Our two years results suggest that the activity of *S. cerealella* in the Southern-Central Italy agricultural territory is mainly affected by the presence of small traditional warehouses. On the contrary, the crop succession in the fields does not seem to be relevant for the presence and dispersion of the moth. Consequently, exclusion and sanitation are essential practices in maintaining pest control and a special care must be exercised to prevent adult insect movement from or to the storage facilities. At this purpose, it is very important to eliminate or isolate the waste of food stored in the previous year. Thus, this information may be used as a tool in integrated pest management programs for stored product pests (Phillips and Throne, 2010; Trematerra, 2013; Bushra and Aslam, 2014).

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