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Impact of Climatic and Environmental Factors on the Distribution of *Sitotroga Cerealella* (Olivier) and *Sitophilus Oryzae* (Linnaeus) in Benin

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Abstract

Angoumois grain moth (*Sitotroga cerealella* (Olivier)) and rice weevil (*Sitophilus oryzae* (Linnaeus)) are devastating pests of stored cereals throughout the world. This study aims to establish the effect of the climatic and environmental factors on the distribution and infestation source of these two species in Benin. For the purpose, 138 farmers' rice stocks were monitored and sampled in 52 locations throughout the country. At each location, pest populations were monitored in storage, in rice fields and in the natural habitat. The monitoring methods comprised visual observation, monitoring of harvested panicles for the emergence of adults and use of sex pheromone or aggregation traps. During the inspection, parameters such as relative humidity, temperature, and grain moisture content were measured. Finally, collected rice samples were taken to the laboratory to identify insect species and count the number of individuals. Both species occurred at high population densities in the southern and central regions of the country where average temperatures (30.42 ºC to 31.2 ºC) and high humidity (85.2% to 76.8 %) prevailed. However, in the northern region, the densities of these species were very low due to the dry weather conditions of the region. Angoumois grain moth was observed in paddy fields and warehouses, and its initial infestations were observed at rice maturation. Rice weevil was mostly observed in the storage areas; it was less frequent in paddy fields. These results helped to identify the distribution and the potential habitats of these two species in relation to the climatic conditions of the surveyed ecozones and the moisture content of stored grain.

Keywords: Habitats, Geographic regions, Initial infestation, *Sitotroga cerealella*, *Sitophilus oryzae*

Introduction

Due to increasing crop production in most of African countries, rice (*Oryza* spp.) is commonly stored for consumption, trade, and seed. Consequently, the damage due to storage insect pests, which have been neglected for a long times on this cereal, has become a major concern for producers, processors, and traders. Insects that attack rice during the storage period belong to the orders Coleoptera and Lepidoptera (Reed, 2010). Among them, Angoumois grain moth *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelechiidae) and rice weevil *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) are the most economically important species (Howe, 1965; Togola et al., 2010; Rizwana et al., 2011; Hamed and Nadeem, 2012).

These pests are cosmopolitan (Cotton, 1960; CABI, 2005; Plague et al., 2010) and are widely distributed in the world due to diversification of human feeding habits and also to transboundary movements of cereals products encouraged by regional and international trade (Reardon et al., 1987; Fleurat-Lessard and Pronier, 2006; Youm et al., 2011). Apart from rice, these pests can also infest other cereals such as wheat (*Triticum aestivum* L. subsp. *aestivum*, *T. turgidum* L. subsp. *durum* (Desf.) Husn .) (Paliwal et al, 2004), sorghum (*Sorghum bicolor* (L) Moench) (Shazali and Smith, 1990; Shazali, 2011), millet (various species) (Seck, 1991), and maize (*Zea mays* L. subsp. *mays*) (Teetes et al., 1995; de Groot, 2004; Ahmed and Raza, 2010; Félicia et al., 2012). Damage on rice is especially important in paddy stored for more than 3 months (Togola et al., 2010).

In order to secure the quantity and the quality of stored rice, it is necessary to control the primary insect pests, including rice weevil and Angoumois grain moth. As a prelude to any decision to control these pests, it is necessary to evaluate their population and distribution patterns over time and space, and to identify the main climatic and environmental causal factors. In Benin, rice weevil has been known for a long time as a common pest of stored cereals. However, the presence of Angoumois grain moth has only been noted during recent years in many areas of the country, especially in rice production sites (Togola *et al. 2010*).

Factors such as temperature, relative humidity, and grain moisture content can influence these insects' population levels and the likelihood of their attacking stored foodstuffs. Conducive environmental and grain conditions may be created for the spread of both insects and their associated microorganisms (Appert, 1987; Ratnadass and Sauphanor, 1989). Other parameters such as the texture of the grain (Appert, 1987) and the duration of storage (Giles and Leon, 1974; Togola et al., 2010) can also play an important role in determining the level of infestation.

The objective of this study was to identify the potential habitats and the initial periods of infestation of *S. cerealella* and *S. oryzae* in the country in order to determine the appropriate intervention periods and actions to control them.

Materials and Methods

Site and Stock Selection

From 2011 to 2013, surveys were carried out in Benin, in which 138 stocks of rice were inspected at 52 sites. Site selection was primarily in major rice-production zones from the south to the north of the country, including the center. Temperature, relative humidity, and geographic data of the storage units were recorded. The criteria for selection of a farmer's stocks included long storage duration (at least 2 months) where the risk of insect attack is high. Untreated stocks were targeted (treated stocks were not sampled). In each site, an average of three rice producers were identified with the help of a village-based resource person (village head, village guide, or president of the rice growers' association) and their rice stocks were inspected and sampled.

Sampling technique for monitoring of insect populations on stored rice

At each site, two or three storage units were inspected (taking care to avoid treated stock). For each farmer's stock, where quantities ranged from some 10 kg to several dozen tonnes of paddy, a series of samples were taken at random following the technique recommended by the World Food Programme (Walker and Farrell, 2003) in order to obtain an initial representative sample. For bagged rice (the most frequently encountered mode of storage at the sites), a representative number of bags were randomly sampled. For bulk grain in bins or in earthenware pots (a minority of the producers were using this method), all or part of the stock were sampled accordingly.–Finally, for rice stored in sheaves (the least frequently encountered method), a representative sample of sheaves was collected. The initial samples collected (between 5 and 10 kg) were brought to the research station and stratified until a sample of just 1 kg of paddy was retained for entomological investigations.

On-farm monitoring of insects population

The on-farm population monitoring of *S. cerealella* and *S. oryzae* consisted of using pheromone and bait traps, visual observation, and harvest of panicles to monitor emergence of adults. These activities were carried out in all the study sites, but advanced surveys were undertaken annually in 15 locations selected as representative of the climatic zones of the country (Table 1).

Table 1: List and location of selected sites for annual field monitoring

No.	Site	Climatic regions	Location
1	Togoudo	South	06°28′18.2″ N 02°21′41.5″ E
2	Ouèdèmè	South	06°42′57.2″ N 01°40′54.4″ E
3	Deve	South	06°45′53.3″ N 01°39′52.2″ E
4	Niaouli	South	06°43′23.3″ N 02°09′36.3″ E
5	Dangho	South	06°34′59.2″ N 02°33′11.6″ E
6	Dassa	Center	07°46′33.5″ N 02°11′50.6″ E
7	Lema	Center	07°50′12.0″ N 02°13′32.1″ E
8	Bohicon	Center	07°07′53.2″ N 02°05′19.9″ E
9	Savalou	Center	07°56′41.6″ N 01°58′55.7″ E
10	Sowe	Center	07°58′43.1″ N 02°10′00.0″ E
11	Ndali	North	09°29′11.6″ N 02°37′34.2″ E
12	Cocota	North	10°26′10.5″ N 01°21′54.3″ E
13	Toumssega	North	10°47′04.0″ N 01°09′37.3″ E
14	Gogounou	North	10°50′00.2″ N 02°50′03.1″ E
15	Dassari	North	10°48′36.0″ N 01°08′24.0″ E

Trapping

Synthetic sex pheromone of *S. cerealella* (TRECE, Laboratory Salinas, USA) was used for the monitoring of the population of this species in the field. The trap was composed of a capsule containing the synthetic pheromone, the (Z, E)-Hexadeca-7,11-dienyl acetate (Stockel and Sureau, 1981; Swords and Van Ryckeghem, 2010) and a sticky rectangular cardboard box to catch males of *S. cerealella*. For monitoring of *S. oryzae* in the field, food bait composed of cracked wheat and residue of infested rice was used. The cracked wheat was used to serve as an attractive food for the weevil as described by Likhayo and Hodges (2000), while the infested rice residue was used as source of aggregation pheromone (sitophinone) mainly composed of (4s,5r)-5-hydroxy-4-methyl-3-heptanone (Delobel and Tran, 1993). At each site, traps were laid in rice fields at various development stages (from tillering to maturity) and in natural vegetation adjacent to the rice field. Selected fields were remote, at least 1 km from each other, to avoid the proximity effect of pheromones. Averages of three traps were laid for each insect species in each location. Approximately 60 m of distance was observed between traps. Checking occurred the day after trap-setting.

Visual Observation

Visual observations were made throughout the seasons to monitor the populations of *S. cerealella* and *S. oryzae* in the field during the full maturation of the crop. In each location, rice fields were observed to monitor populations of adult weevils and Angoumois grain moths in the environment. For this purpose, 50 hills were selected at random along a diagonal of the field. For each hill, the panicles were observed and the number of insects recorded.

Monitoring of Adults Emerged from Harvested Panicles

In each field, a total of 30 panicles were collected at three periods after rice heading (Milky-doughy stage, mid-maturation and rice maturity). They were stored in three plastic boxes (10 panicles per box) that were covered with nylon mesh and kept under ambient conditions for 45 days (average life cycle of the two species). Then, the number of emerged adults of the two species were counted in each box.

Statistical Data Analysis

Data collected during this study were:

- The insect populations from paddy samples from stored rice units, from trapping, visual observation, and harvested panicles;
- The moisture contents of the grains at Milky-doughy stage, mid-maturation rice maturity and in storage;
- The average relative humidity and temperature of the storage environments;
- GIS data.

Means of the different parameters were calculated. Analysis of variance (ANOVA) was then carried out using statistical analysis software (SAS v.9.1). The Student–Newman–Keuls test was used to separate the means.

Results

Population of S. Cerealella and S. Oryzae Collected from Stored Rice

Significant regional variations were shown by the populations of both species.*Sitotroga cerealella* densities were significantely ($P \leq 0.001$) higher in the southern and central region regions (10.13 and 7 individuals per kg of paddy, respectively) compared to the northern region (average population zero). The population of *S. oryzae* followed the same geographic gradient showing significantly ($P \leq 0.001$) higher densities in the southern and central regions (11.05 and 5 individuals per kg of paddy, respectively) than in the northern region (1.08 individuals per kg of paddy).

Of the climate measurements made at the diffentes sites, temperatures were slightly lower in the southern region (30.4°C) and center (31.2°C), than in the northern region where they were the highest (33.1°C). Conversely, the relative humidity gradient was from 85.2% to 58.4% from south to north (Table 2).

Table 2: Average population of *Sitotroga cerealella* and *Sitophilus oryzae* and climatic data on farmers' stored rice in the various regions of Benin

Climatic regions	No. insects/kg of paddy		Mean temperature (°C)	Mean relative humidity (%)
	S. cerealella	S. oryzae		
Southern region	10.13 ± 1.6a	11.04 ± 2.2a	30.4 ± 1.8a	85.2 ± 1.0a
Central region	7.0 ± 1.5a	5.0 ± 0.9b	31.2 ± 1.5a	76.8 ± 0.9a
Northern region	0 ± 0b	1.8±0.7b	33.1 ± 1.7b	58.4 ± 2.2b

Means in a column with same letters are not significantly different at 5% (Student–Newman–Keuls test).

Populations of S. Cerealella and S. Oryzae in the Field

The trapping method allowed noting the presence of *S. cerealella* in rice fields during all crop stages and also in the wild vegetation. The capture was greatest during maturation stage, especially in the southern and central regions (10.58 and 8.80 individuals per trap, respectively). In the northern region, although the trapping revealed the presence of *S. cerealella* in the environments, the density was relatively low (Table 3).

Table 3: Average populations of *Sitotroga cerealella* and *Sitophilus oryzae* from trapping

	S. cerealella			S. oryzae		
	Southern	**Central**	**Northern**	**Southern**	**Central**	**Northern**
Tillering	0.48±0.1b	00.32±0.08b	0.13±0.0.04b	0b	0a	0a
Booting	0.40±0.07b	00.32±0.06b	0.12±0.04b	0b	0a	0a
Milky-doughy	0.64±0.09b	0.61±0.1b	0.20±0.05b	0b	0a	0a
Mid-maturation	0.81±0.12b	0.58±0.09b	0.25±0.06b	0b	0a	0a
Full maturation	10.58±0.66a	8.80±0.55a	1.86±0.23a	0.08±0.04a	0.06±0.04a	0.02±0.02a
Natural savannah	0.72±0.13b	0.54±0.1b	0.29±0.07b	0b	0a	0a

Means followed by the same letter in a column are not significantly different at 5% (Student–Newman–Keuls test).

For rice weevil, trapping was inefficient during all the phenological stages of rice and in the natural savannah. Only a slight presence was noted in all regions during full-maturation stage (Table 3).

The visual observation recorded the presence of *S. cerealella* at most of the targeted sites. The highest densities were observed at Ouèdèmè, Niaouli, and Togoudo (southern region) with 39, 32.7, and 30.3 individuals per 50 observed hills, respectively. In the central region, high insect density was also recorded, especially at Dassa and Bohicon (24 and 23.7 individuals, respectively, in 50 observed hills), compared to the northern region (0–9 individuals per 50 observed hills).

Sitophilus oryzae was recorded only at the sites of Togoudo, Ouèdèmè, and Niaouli, but the density was very low (2, 1.3, and 0.7 individuals per 50 observed hills, respectively) (Table 4).

Table 4: Average populations of *Sitotroga cerealella* and *Sitophilus oryzae* from visual observation

Site	Climatic region	S. cerealella	S. oryzae
Togoudo	S	30.33±2.84ab	2.0±0.57a
Ouèdèmè	S	39.0±11.15a	1.33±0.66ab
Deve	S	26.0±5.03abc	0.0±0b
Niaouli	S	32.66±6.96ab	0.66±0.66b
Dangho	S	26.0±6.11abc	0±0b
Bohicon	C	23.66a±3.28bc	0±0b
Dassa	C	24.0±10.6abc	0±0b
Lema	C	15.0±5.68abc	0±0b
Savalou	C	11.33±1.45bc	0±0b
Sowe	C	17.33±3.33abc	0±0b
Ndali	N	0.66±0.66c	0±0b
Cocota	N	0±0c	0±0b
Toumssega	N	7.33±2.40bc	0±0b
Gogounou	N	9.0±1.73bc	0±0b
Dassari	N	0±0c	0±0b

Means followed by the same letter in a column are not significantly different at 5% (Student–Newman–Keuls test).S= south, C= central, N = north.

The monitoring of harvested panicles showed significant difference ($P \leq 0.001$) between the numbers of emerged adults of *S. cerealella* on samples collected in the southern and central regions and those in the northern region. On samples from southern and central regions, the emerged Angoumois moth adults were significantly more numerous on fully mature panicles than on other samples. In the northern region, no significant difference was noted between the number of *S. cerealella* adults emerged from the various samples. No emergence of *S. oryzae* was observed (Table 5).

Table 5: Average populations of *Sitotroga cerealella* and *Sitophilus oryzae* from harvested panicles

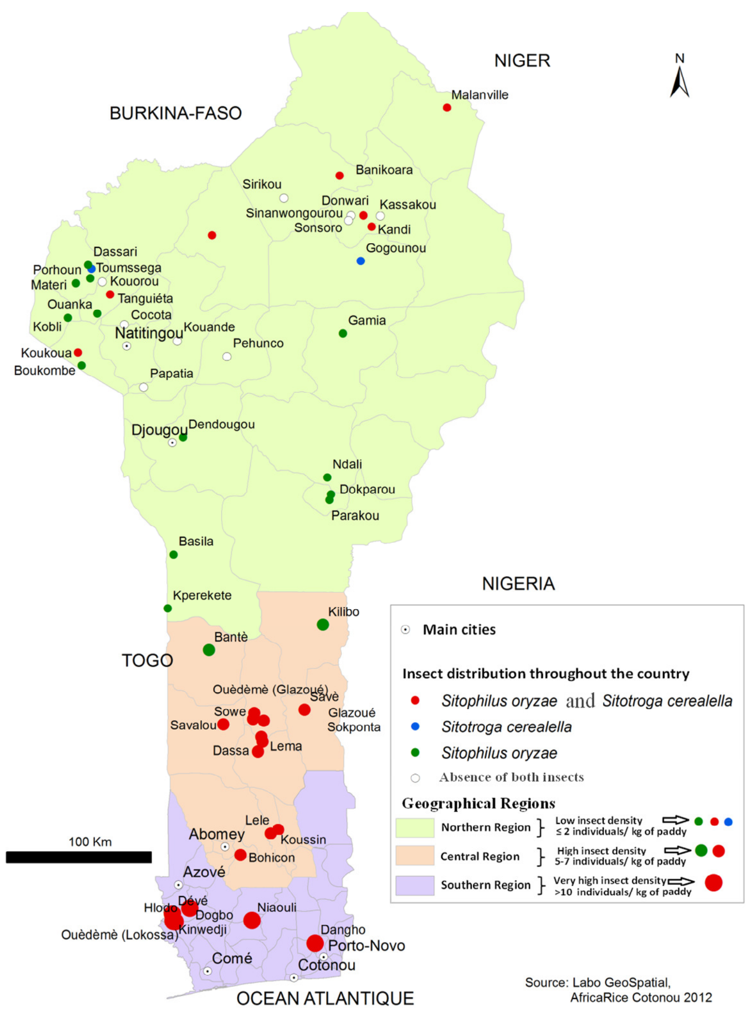
Stage of rice	S. cerealella			S. oryzae		
	Southern	Central	Northern	Southern	Central	Northern
Milky-doughy	0a	0a	0a		0	0
Mid-maturation	0.40±1.54a	0a	0.13±0.73a		0	0
Full maturation	7.47±4.78b	4.2±3.94b	1.10±1.27a		0	0
Means followed by the same letter are not significantly different at 5% (Student–Newman–Keuls test).						

Distribution of S. Cerealella and S. Oryzae in Benin

Results of entomological investigations in both storage and field environments allowed us to establish the distribution map of *S. cerealella* and *S. oryzae* in Benin (Fig. 1). The presence of the two species, their density, and habitats showed a large variation among the agroclimatic regions of the country. The Angoumois grain moth *S. cerealella* was common in the southern region and also in the central region (except at Bantè and Kilibo), where high density of this insect was observed in both stored rice and in the field. In the northern region, a few populations of *S. cerealella* were noted on stored rice (only at Gogounou) and in the field (only at Banikouara, Donwari, Kandi, Koukoua, Malanville, Tanguieta, and Toumssega).

Sitophilus oryzae appeared to be well distributed in the three climatic regions; it was more abundant in stored rice than in the field (Fig. 1). However, its density was greater in the southern and central regions than in the north.

Fig. 1: Distribution map of *Sitotroga cerealella* and *Sitophilus oryzae* in Benin**.**

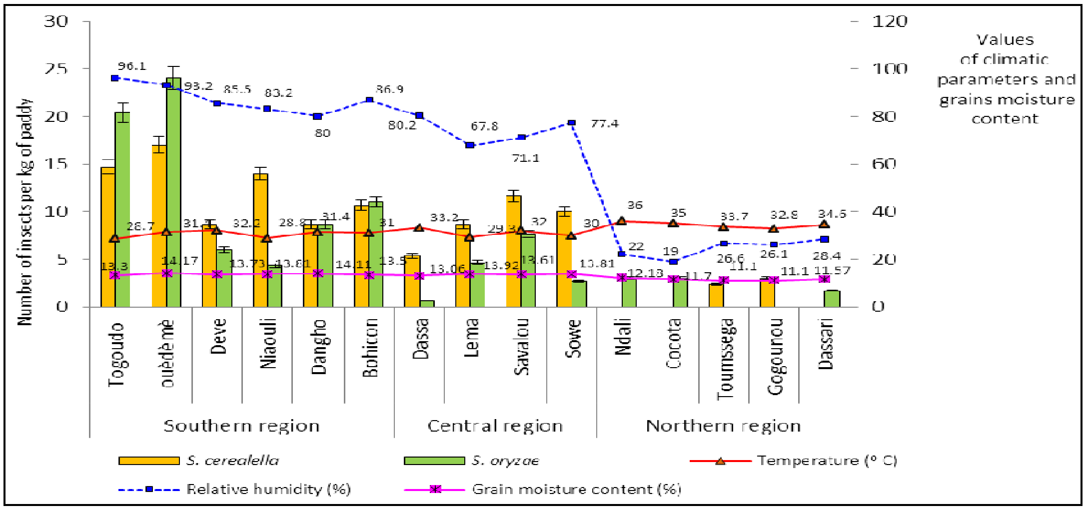


Influence of Climatic Factors on Population Growth

The results showed an increase of insect density following the gradient of relative humidity and grain moisture content from northern locations toward the southern ones.

The highest values of relative humidity and grain moisture content were recorded in the southern region as 96.1% (Togoudo) and 14.17% (Ouèdèmè), respectively. The lowest values of these parameters were recorded in the northern region as 19% (Cocota) and 11.1% (Toumssega and Gogounou), respectively. High pest densities were recorded in locations with low temperatures. The average values of temperature decreased from the northern region to the southern region (Fig. 2).

Fig. 2: Insect population, climatic parameters and grains moisture content in the 15 selected sites.



Discussion

Although *S. cerealella* and *S. oryzae* were present in all geographical regions of Benin, the distribution pattern and the habitats of the two species were quite different.

In the southern and central regions, *S. cerealella* was present in warehouses and in rice fields and adjacent natural savannah. In the northern region, its presence was mostly limited in paddy fields during the cropping season. The regular presence of *S. cerealella* in the southern and central regions may be due to trophic and climate conditions that are more favorable to the development of the insect. While its weak presence in stored rice in the northern region may be due, on one hand, to the adverse climatic conditions of this region (high temperature and low relative humidity) and, on the other hand, to the low moisture content of the grain resulting from the intense and regular sunshine and high temperature. The field investigation showed clearly that this species colonizes rice fields from tillering to maturation, but we established that the initial infestation begins during rice maturation. These results not only confirm the thesis that the infestation of *S. cerealella* comes from the fields (Seck, 1991), but also reveals the specific timing of its attack. In addition, the study demonstrated the presence of the Angoumois grain moth in the natural savannah dominated by wild grasses. However, there was no serious damage in this environment. The wild grasses might be used by the adults of this species as natural alternative habitat. It is not excluded that wild rice (*Oryza barthii* A.Chev) could be a potential host plant for this species. In addition, the seasonal presence of the Angoumois grain moth in the northern region means that the species may observe a diapause, unlike in the southern and central regions where its reproduction is continuous.

Sitophilus oryzae was noted in all regions of the country, but its population was greater in southern and central regions. It was noted mainly in stored rice rather than paddy fields. We can therefore conclude that the primary source of *S. oryzae* in Benin is the warehouse or the local cereal markets. This conclusion contrasts the theses of Kranz et al. (1977), Haines (1991), Seck (1991), and

Likhayo and Hodges (2000), who report that rice weevil populations build up mainly in paddy fields. However, Cruz et al. (1988) report that field infestation by weevils depends on its ability to fly. Thus, the races that have lost this ability, which can be the case for rice weevil (Delobel and Tran, 1993), may be rarely encountered in the field. The strain of the weevil in Benin could be part of this category according to our observations, which may explain its low presence in the paddy fields.

Thus, the importance of populations of *S. cerealella* and *S. oryzae* varied according to climatic regions. In southern and central Benin, where temperatures are lower and relative humidity higher, the climatic conditions are favorable for the development and multiplication of the major part of the primary species. As reported by Hansen et al. (2004) and Perez-Mendoza et al. (2004), the favorable temperature for the development of *S. cerealella* and *S. oryzae* ranges between 15° and 32.5°C. The species thrive best in relative humidity ranging between 50 and 90% (Longstaff, 1981; Joost et al., 1996). These climatic conditions can promote an increase in grain moisture content, which represents a significant risk factor for the attacks of insects during the storage (Ratnadass and Sauphanor, 1989; Arbogast and Throne, 1997; Hagstrum et al., 2008).

In the northern region, the grain moisture contents are very low resulting from the particular weather conditions. Consequently, the density of the species remained low in warehouses and in paddy fields. Moreover, Angoumois grain moth occurred only during the cropping season, which means that this species may diapause in that region.

Conclusion

This study revealed that *S. cerealella* is very common in the south and center of Benin where it infests both paddy fields and warehouses. In the northern region, the species is rare and its presence is essentially limited to the field where it attacks the rice during the maturation of grain. On the other hand, the study showed that *S. oryzae* is distributed in all regions of the country, but its presence is mainly noted in warehouses rather than in paddy fields, indicating that the warehouses are the source of its initial infestation. The main factors influencing the ecology of these two species remain temperature, relative humidity, and grain moisture content. Understanding the ecology and related factors of these species will help to develop the best strategies to control these pests.

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