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Spatial distribution of food trap catches of *Tribolium castaneum*, *T. confusum* and *Typhaea stercorea* and precision Integrated Pest Management in a semolina mill

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Abstract

From the second half of May 2003 to mid-July 2004 (sampling period) we evaluated the presence and spatio-temporal distribution of insect pests using food-bait traps in a food processing mill, with particular attention to the adults of *Tribolium castaneum* (Herbst), *T. confusum* du Val and *Typhaea stercorea* (L.). The main peak for *T. castaneum* occurred in June; *T. confusum* was collected on all sampling dates, with two main peaks in the second half of June until the beginning of July and in the first half of August. *T. stercorea* was most abundant from the second half of May to the beginning of July and in the first half of September. After the annual fumigation of the mill, carried out in the second half of August, only a small number of captures of the two *Tribolium* species took place until the end of the sampling period; in contrast, *T. stercorea* remained to colonize the mill until the end of November. The contour maps drawn to represent the spatial distribution of *T. confusum* before the fumigation treatment showed that the most abundant focus of the adult population were confined to the corners of the milling area and at the base of the adjacent walls of every floor, where a large amount of dust and debris usually accumulates. The same distribution was found for *T. castaneum*, but this species was observed only on the upper floors of the mill. Adults of *T. stercorea* were confined to the I and II floors, the main moisture areas of the mill contaminated with mould. Of particular interest was the presence in traps of *T. confusum* adults in a mixed population with equal numbers of males and females; furthermore, the spatial distribution of the two sexes was almost the same during the entire sampling period. The indications obtained were used in precision pest management procedures after fumigation, based essentially on the improvement of good sanitation practices.

Key words: Spatial distribution, precision IPM, semolina mill.

Introduction

Accurate and comprehensive monitoring of pest populations is essential in precision Integrated Pest Management (IPM) programs, particularly monitoring methods that not only detect infestation but also estimate its degree and location.

In this regard, the use of spatial analysis of pest populations, together with a comparative risk assessment into standardized pest management

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operations, can be useful to: quantify the spatial aspects of pest populations and their inherent risk; improve precision targeting of intervention technologies; evaluate and compare the intervention technologies; reduce pesticide use, also eliminating the need for routine preventive treatments; shift operations to proactive monitoring and prevention of pest problems.

Geostatistical techniques are also useful in communicating infestation problems to management, maintenance, sanitation, and pest control personnel. They provide documentation of insect problems and the effectiveness of control interventions that can be used in sanitation reports. Such techniques have been recently used in various stored products and types of food industries and storage facilities, such as flour-mills, feed-mills, warehouses and commodity facilities, against several moth and beetle pests providing crucial knowledge to improve monitoring and precision targeting control methods (Arbogast and Mankin, 1999; Arbogast et al., 1998, 2000a,b, 2002a,b; Brenner et al., 1998; Campbel et al., 2002; Trematerra and Sciarretta, 2002, 2004; Trematerra et al., 2004, 2006; Athanassiou et al., 2005; Trematerra and Gentile, 2006).

In the present study, we evaluated the spatio-temporal distribution of insect pests in a semolina-mill by means of geostatistical techniques applied to catch data of food-bait traps, with particular attention to the most abundant species *Tribolium castaneum* (Herbst), *T. confusum* du Val and *Typhaea stercorea* (L.). Our study also focused on the effectiveness of spatial analysis in improving pest management procedures, such as good sanitation practices, and in optimizing pest monitoring plans. Moreover, the results of surveys carried out on the spatio-temporal dynamics of females and males of the confused flour beetle are also reported.

The surveys were planned when the manager of the food processing mill requested the development of an insect pest monitoring system that could be useful to improve pest management procedures applied to the factory in an IPM approach.

Materials and methods

Study area, traps and data collection

The observations were carried out in an industrial semolina-mill located in Southern Italy, from the second half of May 2003 to mid-July 2004 (sampling period). The mill was a large building of 18,000 m^3, with seven floors (I-VII), processing 500 tons of hard wheat (*Triticum durum* Desf.) per day.

Food-bait traps were used to collect insect pests; the traps were 10 x 20 cm and made of welded plastic mesh with a 3 mm aperture, folded and sealed to form a pouch for food materials. Each bag contained 30 grams of mixed spelt, maize, rolled oats, cracked hazelnuts and carobs, raisins and dried bananas. Traps were placed on 21 May 2003, and checks were conducted until 16 July 2004. A fumigation treatment of the mill, with methyl bromide, took place on 13 August 2003. For this reason the traps were removed on 12 August and reinstalled on 28 August.

To monitor insect populations from 21 May to 12 August 2003 (first sampling interval) and from 28 August to 18 December 2003 (second sampling interval) 85 traps were placed in the semolina-mill. From 18 December 2003 to 14 April 2004 (third sampling interval), and from 14 April to 16 July 2004 (fourth sampling interval), the number of traps used was 66. On each floor, the position of the traps was defined by the x and y coordinates that were used in the subsequent spatial analyses.

Single traps were left at sampling sites for 2 weeks in the first, second and fourth sampling intervals and for 1 month in the third sampling interval, and then were replaced by new ones. Before the traps were used again, they were maintained at -20 °C for at least 1 week to kill any arthropods that remained in the food-bait. Identification of insects present in the traps was carried out in the laboratory.

For every sampling date during the surveys, visual inspections were carried out to monitor the presence of insect pests and to verify the general cleanliness and orderliness of the mill.

Spatial analysis

Spatial interpolations of trap catch counts of adult pests were carried out by means of Surfer version 8.02 (Golden software, Golden, Colorado, USA) using a linear model with zero nugget, as suggested by Brenner et al. (1998) who explain this type of analysis in more detail. By interpolating the data with linear kriging, the software produces a dense grid of values. The interpolation grid obtained is used to produce a contour map which shows the configuration of the surface by means of isolines representing equal density values. A base map showing the plan of each floor, with the same coordinate system, was placed on top of the contour map. In the case of low catch numbers, spatial analyses were conducted using the default of the software to obtain an indication of the spatial distribution of the insect pests to be compared with the results of other sampling intervals.

Geostatistical techniques were used to portray the distribution of the most abundant insects trapped on every sampling date; the maps obtained were sent to the management personnel of the mill in reports also containing the results of the visual inspections.

In this investigation, spatial analyses by means of linear kriging were utilized to represent the distribution of *T. castaneum*, *T. confusum* and *T. stercorea*, analyzing the accumulated catch data of the three pests obtained in each sampling interval. The geostatistical techniques were also applied to the trap counts of females and males of *T. confusum* obtained in the first sampling interval, considering the sum of two consecutive sampling dates.

Results and discussion

During the sampling period, a total of 1,765 insect specimens were checked in the food-bait traps belonging to 14 *taxa*, mainly Coleoptera (Table 1). The majority of insects was found in the traps before the fumigation treatment, in the first sampling interval (1,283 insects); after treatment, in the second and third sampling intervals, only a few specimens were trapped (a total of 193 insects), whereas in the fourth sampling interval trap counts increased to 289 catches. The most abundant species were *T. confusum* (1,225 adults), *T. stercorea* (197 adults) and *T. castaneum* (140 adults).

As represented in Figure 1, the confused flour beetle was collected on all the sampling dates. In the first sampling interval, the species population had two main peaks in the second half of June till the beginning of July and in the first half of August. After the fumigation of the mill, only a small number of captures occurred until mid April 2004: a total of 29 and 15 adults in the second and third sampling intervals, respectively; however, in the fourth, trap counts increased continuously up until the last sampling date.

The presence of the rust-red flour beetle was constant during the first sampling interval, with a main peak in the first half of June. In subsequent sampling intervals, the species was present only with few trap catches: 2 adults in the second, 14 in the third and 15 in the fourth sampling intervals.

The hairy fungus beetle catches were obtained especially from the second half of May until the beginning of July 2003 (in the first sampling interval). After the fumigation treatment, adults of *T. stercorea* re-colonized the mill until the beginning of December, during the entire second sampling interval in which it was most abundant in the first half of September. In the third sampling interval no specimen was collected, whereas in the fourth sampling interval the captures occurred from the first half of June, increasing up until the first half of July.

Figure 2 shows the contour maps obtained by geostatistical analyses carried out using linear kriging applied to the total trap catches of *T. confusum*, *T. castaneum* and *T. stercorea*, respectively, obtained in each sampling interval.

In the first sampling interval, the greatest portion of *T. confusum* adults was found on the IV, VI and VII floors. On every floor, the most abundantly populated foci were confined to the corners of the milling area and at the base of the adjacent walls; this was true especially for the same corner from the II to the VII floor. On the other hand, the area encompassed by the contours appeared to involve equipments located in the central zones of the floors, only in an irrelevant manner. In the second and third sampling intervals, it was possible to draw only isolines ranging from 1 to 5. The results referring to the fourth sampling interval show that the infestation foci were almost in the same positions as in the first sampling interval, with a lower level of detection.

Table 1. Insects and number of specimens collected in the semolina-mill during the sampling period.

Species / Data	First sampl int			Second sampl int				Third sampl int				Fourth sampl int			
	21.V-17.VI.2003	17.VI-15.VII.2003	15.VII-12.VIII.2003	28.VIII-26.IX.2003	26.IX-23.X.2003	23.X-21.XI.2003	21.XI-18.XII.2003	18.XII.2003-16.I.2004	16.I-18.II.2004	18.II-17.III.2004	17-III-14.IV.2004	14.IV-12.V.2004	12.V-15.VI.2004	15.VI-16.VII.2004	Total
Ahasverus advena	-	-	-	*1*	-	-	-	-	-	-	-	-	-	-	*1*
Cryptolestes ferrugineus	1	17	5	1	-	1	-	-	2	1	15	10	4	2	59
Lasioderma serricorne	7	4	4	-	3	-	-	-	-	-	-	1	1	-	20
Latheticus oryzae	1	3	-	-	-	-	-	-	-	-	-	-	-	1	5
Oryzaephilus surinamensis	2	1	2	2	1	-	-	-	-	1	-	-	4	-	13
Rhyzopertha dominica	3	2	9	-	-	-	-	-	-	-	-	-	-	1	15
Sitophilus oryzae	13	4	4	5	-	5	1	-	-	2	3	3	4	4	48
Tribolium castaneum	48	46	15	1	-	-	1	6	1	3	4	3	6	6	140
Tribolium confusum	274	317	384	17	7	3	3	1	4	4	7	12	42	150	1225
Trogoderma granarium	1	1	2	-	-	-	-	2	-	-	-	-	-	-	6
Typhaea stercorea	57	29	4	23	23	22	9	-	-	-	-	-	3	27	197
Anticidae spp.	-	5	1	-	1	1	-	-	-	-	-	-	-	-	8
Rhynchota spp.	9	4	-	-	-	-	-	-	1	-	-	-	-	1	15
Staphylinidae spp.	-	3	1	-	1	-	-	2	-	2	-	-	3	1	13

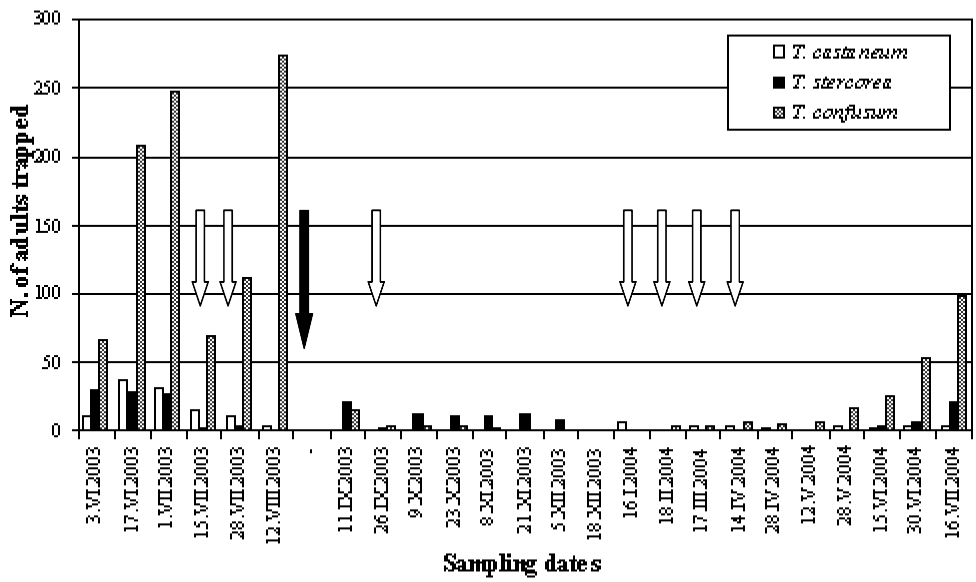

Figure 1. *Tribolium castaneum*, *Typhaea stercorea* and *Tribolium confusum* adults collected in the food-bait traps placed in the semolina-mill during the sampling period (white arrows: general cleaning; black arrow: general cleaning and annual fumigation).

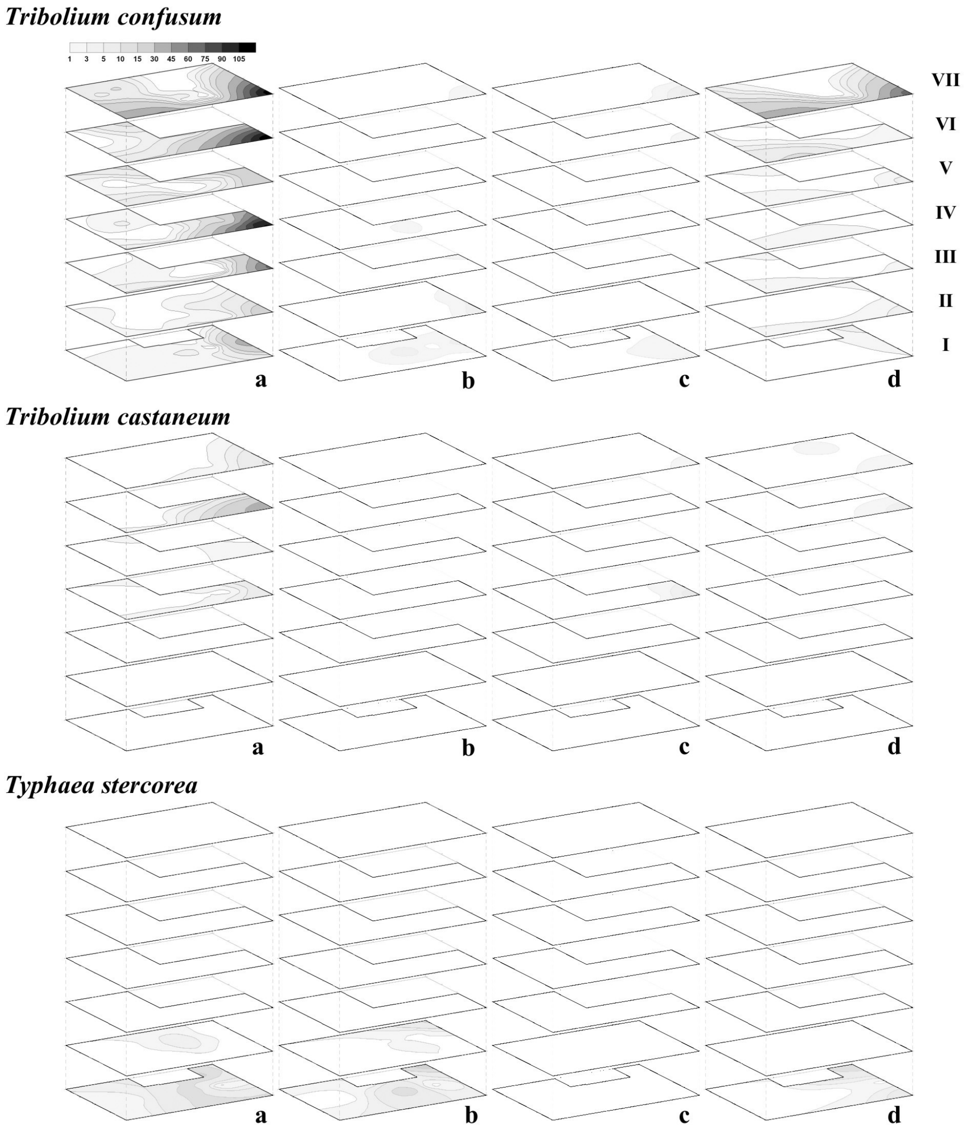

Figure 2. Contour maps of *Tribolium confusum*, *Tribolium castaneum* and *Typhaea stercorea* distribution by means of kriging applied to total trap counts obtained in each sampling interval (a: first sampling interval; b: second sampling interval; c: third sampling interval; d: fourth sampling interval).

Almost the same distribution of the confused flour beetle was found for *T. castaneum* during the first sampling interval, but this species was observed only on the upper floors of the mill and most abundantly on the VI floor. In this sampling interval, mixed populations of *T. confusum* and *T. castaneum* were found in the traps distributed on the IV-VII floors.

The adults of *T. stercorea* were confined to the I and II floors, during the first and second sampling intervals, whereas in the fourth sampling interval trap catches were found only on the I floor.

The presence and spatial distributions of insect pests in the mill are influenced by the position of key areas of interest, such as the entry and access points and areas with large amounts of food resources and environmentally favourable conditions, such as heat and moisture.

The results obtained during the surveys show that only in particular situations did the points of access to the mill seem to be relevant for the presence and patterns of the insect pests. This is the case for the detection of pests specimens on the first sampling date after the fumigation treatment (almost 1 month later) when the catches were found exclusively on the I and II floors, near the entry from the raw materials silos area, outside the mill, and near the dust and debris accumulated on the two floors. As reported by the mill personnel, before replacement of food-bait traps, infestation of *Sitophilus oryzae* (L.), *T. confusum* and *T. stercorea* in a nearly empty wheat silo was detected. To control this situation, general cleaning was carried out in the mill, specifically in the external areas near the wheat silos and in the infested silo. Besides, during the visual inspections in the external areas of the mill, such as the wheat silo and loading areas, evidence of migration of the adult hairy fungus beetles to the I and II floors was found .

Both the results of the visual inspections and the geostatistical analyses of the trap catches revealed that the most abundantly populated foci were placed in particular zones of the mill-floors, almost the same on every sampling date; this was true especially for the data of the first and fourth sampling intervals in which the beetles were more abundant.

Pest populations were mostly confined to the corners and wall bases of the milling areas. In these debris points, dust and residual food material were generally deposited, particularly on the following sampling dates: 17.VI, 1 and 28.VII, 12.VIII (first sampling interval), 11.IX (second sampling interval), 28.V, 15 and 30.VI, 14.VII (fourth sampling interval). For these dates, principally for the ones of the first and fourth sampling intervals, a higher number of specimens was found compared with the other sampling dates, at which time the mill was cleaned.

By means of the spatial distribution maps of the two *Tribolium* species, it was found that from the II to VII floors the flour beetles were most abundant in the same corner of the milling areas and at the bases of the nearby walls. This corner is directly exposed to the south, thus it is the warmer zone of the mill. In this corner, from floors IV to VII there are machineries which generate dust that is difficult to remove, whereas on floors II and III in the same corner there are electric boards that produce heat. It is also possible that infestation might be transmitted vertically between floors because there are pipe-ducts near the walls.

Regarding the distribution of the two sexes of *T. confusum* during the first sampling interval, on every sampling date the proportions of female and male adults observed in the different traps were almost the same, approximately 49 % and 51%, respectively (Trematerra et al., 2006). The contour maps drawn to represent the spatial distribution of adult females and males of *T. confusum* showed that their population densities almost coincided (Figure 3). In some situations, especially in the last couplet of sampling dates (28 July-12 August), the areas infested by females seemed to be slightly more extended than those infested by males.

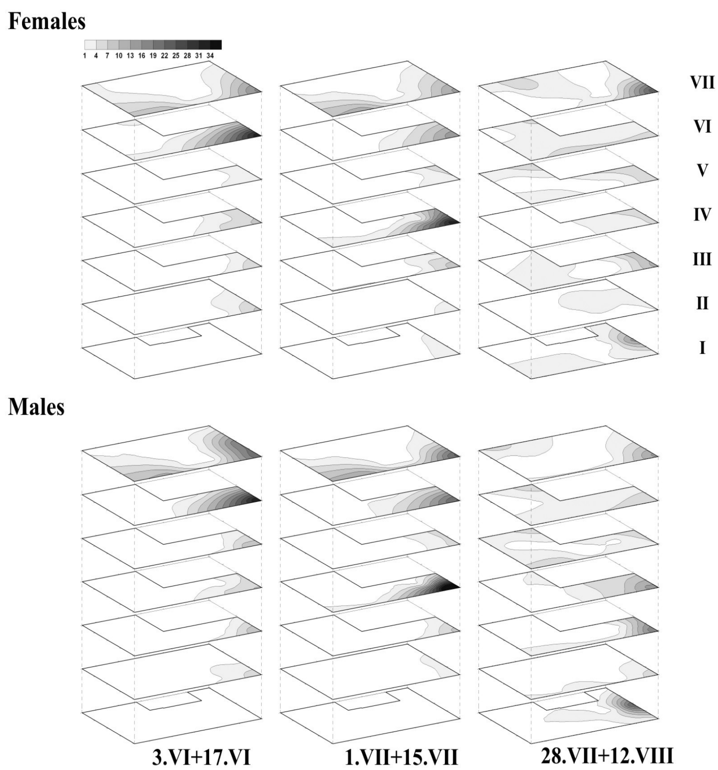

Figure 3. Contour maps of females and males of *Tribolium confusum* distribution by means of kriging applied to the trap counts obtained in the first sampling interval.

In the case of *T. stercorea*, this pest was trapped only on the I and II floors of the mill, with a larger number of catches on the I floor. Besides the migration of the adults from the external areas, this floor is the main area of the mill containing moisture because of the presence of workers' changing rooms and bathrooms; thus, it can be temporarily contaminated with mould.

Conclusions

Pest control carried out in Italian mills is generally based on one or two general fumigations per year and several routine treatments with contact insecticides, especially during the summer period. Pest monitoring is normally recognized as an effective tool to obtain information about infestations. However, data are not often used for deciding on the immediate corrective actions to carry out for pest control but are considered only as a measure of pest problems that are to be resolved by means of general fumigations. On the other hand, preventive measures against infestations, such as good hygienic procedures, are often not considered as important in insect pest management.

Spatial analysis of trap counts applied to storage pest monitoring can provide support decision making in determining pest control interventions: how, when and where to operate.

In our surveys, the main purpose was to improve and optimize good hygienic procedures, as requested by the manager of the mill, directed toward a reduction of routine chemical treatments. In this way, the results and indications obtained by applying geostatistical techniques to trap catches were combined to risk assessment obtained by the information received from the management personnel of the mill and by the observations during the visual inspections carried out on every sampling date.

The laboratory personnel of the mill reported that *T. confusum* and *T. castaneum* were the insects that caused more contamination problems in semolina production; thus, the attention of pest management procedures focused on these two species.

Using the results of pest monitoring and spatial distribution maps of the most abundant insect species obtained during the first and second sampling intervals, cleaning schedules were established in December by the management personnel of the semolina-mill as well as the general housekeeping of the milling areas each month, as reported in Figure 1. Consequently, the sanitation practices, both routine and general cleaning of the mill, focused primarily on the milling areas of each floor with the highest foci of infestation (i.e., the corner exposed to south and the bases of the adjacent walls). With these measures, during the third sampling interval, the level of insect pests was kept low compared to the level observed in the same months of the previous years. However, from April 2004 onward, it was not possible to carry out the monthly general cleaning because of production and management problems. The main consequence was that pest counts, especially of *T. confusum* and *T. stercorea*, increased in the fourth sampling interval.

Considering insect pest monitoring, the results of the geostatistical analyses were useful to optimize the initial sampling plan during the third sampling interval, decreasing the number of food-bait traps from 85 to 66 and adapting the trap positions in the structure. These actions were finalized to simplify the monitoring procedures without decreasing the effectiveness of this tool as a base component of the IPM program established in the semolina-mill.

The results concerning the distribution of female and male pest populations can contribute to the discussion of the role of semiochemicals in insect management.

The next step to a complete precision IPM approach in pest management of the mill will consist in a more significant reduction of pesticide use, with further implementation of precision targeting in chemical control methods based on the indications obtained utilizing geostatistical tools. The surveys carried out in our study suggest that for food processing mills the spatial analysis techniques applied to a standardized pest management operation can be useful if representing the distribution of insect pests. In this way it is possible to assess the risks inherent to spatial aspects of pest populations and to implement the precision IPM methods, concentrating on the main foci of the infestations. Furthermore, the information obtained by using geostatistical techniques provides fundamental knowledge for both the application of preventive actions and to optimize the pest monitoring system.

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