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Spatial and temporal aggregation of *Oryzaephilus surinamensis* from Peninsular Malaysia

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The saw-toothed grain beetle, *Oryzaephilus surinamensis* (Linnaeus) is a secondary pest of rice grains and other stored products. Lack of information on the population abundance, spatial, and temporal distribution of *O. surinamensis* rendered the management control strategy of this pest species less effective. The objective of this study was to investigate the abundance, spatial and temporal pattern of *O. surinamensis* populations from nine rice warehouses in three zones of Peninsular Malaysia (i.e., the northern, central and southern zones) for three continuous months. The results showed that the abundance of *O. surinamensis* populations varied significantly ($p<0.05$, $p= 0.00$) between zones, with the highest abundance for this species (69%) recorded from the Klang District, in the central zone, followed by Pasir Gudang (27%) in the southern zone, and Seberang Prai (4%) in the northern zone. The patterns of population abundance also showed significant differences between months, $p<0.05$ (p-value= 0.00-0.011) between all the warehouses. The factors that could be associated with the highest abundance of the pest were attributed to poor sanitation at the warehouses and inconsistency in the fumigation regime. For the spatial distribution analysis, SADIEShell_122 and Surfer8 software were applied. The distribution patterns of *O. surinamensis* populations varied significantly in all the warehouses, being significantly aggregated at $p<0.05$ (p=0.0385-0.0513) and $I_a>1.0$ (1.212-1.579), whilst being non-significantly and randomly distributed at $p>0.05$ (p=0.1154-0.91032) and $I_a>1.0$ (0.852-0.929). The significance of the aggregation might be due to the rapidly changing volume of the rice stock caused by the active and rapid turnover of the storage inventory. The results obtained were very valuable and informative in managing *O. surinamensis* infestation of stored rice by incorporating the spatial and temporal information of the pest populations in the management strategy for improving the rice and other stored products.
Keywords: storage pest, behavior, movement, rice storage, Malaysia.

INTRODUCTION

Oryzaephilus surinamensis (Linnaeus), or commonly known as the saw-toothed grain beetle, is one of the most ubiquitous storage pests worldwide (Rossiter *et al*., 2001; Hashem *et al*., 2012; Syarifah Zulaikha *et al*., 2018). Both the adult and larva of this species are known to be cosmopolitan (Highland, 1991; Mowery *et al*., 2002) due to their ability to attack and infest a large variety of food products such as flour (Ogebegbe and Edoreh, 2014), chocolates, nuts (Barnes, 2002), dried fruits and cereals. *Oryzaephilus surinamensis* is also known as a secondary pest which plays its role in infesting and damaging the broken food kernel affected by primary pests such as *Sitophilus* spp. and *Rhyzopertha dominica* (Trematerra and Throne, 2012). Larvae and adults of *R. dominica* would infest grain products causing broken kernels, powdery residues and pungent odour (Toews *et al*., 2006), which were then attacked by the secondary pests and fungi (Shah and Khan, 2014).
Several earlier studies have been conducted to measure the infestation rate of storage pests and the diversity, as well as abundance of the pest species over the three-month study duration. For example, weight losses of up to 40% of brown rice were reported by Sittisuang and Imura (1987) after three months of exposure to *R. dominica*. Besides that, the favorable conditions of the warehouses with optimal temperature and humidity could provide the best shelter for storage pests to thrive in (Reichmuth, 2000). Of greater concern was the fact that these conditions could cause inter- and intra-dispersal of the pest species through grain transportation and marketing networks (Hernandez Nopsa *et al*. 2015).
According to Arbogast *et al*., (2000a), spatial and temporal distribution analysis is a fundamental study for the effective

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management system of storage pests. The main purpose of this study is to determine (by spatial and temporal mapping) the behavior and distribution of *O. surinamensis* in the warehouses and its association with biotic and abiotic factors. This is because the movement and population dynamics of the pests are largely influenced by factors such as the location and arrangement of the rice stacks, the layout and built structure of the different warehouses (Arbogast *et al*., 2000a; Reichmuth, 2000).

The foundation of an effective pest management programme through Integrated Pest Management (IPM) is an understanding of the pest ecology and behavior, and such understanding must be at an appropriate spatial and temporal scale suited for the pest species and the environment (Semeaoa *et al*., 2014). The ecological processes such as population dynamics, movement patterns and spatial distribution could be influenced by the structure of the landscape mosaic in which an organism lived. Stored-product pests occupy spatially and temporally fragmented habitats that can have profound impacts not only on their population dynamics, but also on our ability to monitor their populations and effectively target pest management. Therefore, the aim of this study is to determine the population abundance, spatial and temporal distribution of the pest, *O. surinamensis* over a three-month period in various parts of Peninsular Malaysia.

MATERIALS AND METHODS

***Sampling location*:** A total of nine warehouses from three geographical zones in Peninsular Malaysia, i.e., the central part (Klang, namely A, B and C), the southern part (Pasir Gudang, namely M, N and O) and the northern part (Seberang Prai, namely X, Y and Z) had been randomly selected for the three-month study period to conduct sampling for the abundance, spatial and temporal distribution of *O. surinamensis* populations infesting stored rice. The main abiotic factors (temperature, humidity, CO_2 concentration and light intensity) in all the warehouses were standardized and monitored.

***Insect Sampling*:** The *O. surinamensis* individuals were sampled continuously by using the sticky traps for three months. A total of 24 traps (A4 sized) had been placed in each warehouse in four line transects with 6 plots at 5-meter intervals, and each transect was separated from the others at 10-meter intervals. The sticky traps were placed for 24 hours in the beginning of each month and were then replaced gradually during the three-month study period. All the traps were placed on the warehouse floor. Figure 2 shows the placement of the 24 sticky traps in every warehouse, with a total plot size of 25 x 30m and was standardized for all the warehouses.

***Species Identification and Data Collection*:** The *O. surinamensis* had been identified morphologically by referring to the taxonomic key of Ferrer *et al*. (1995) using the stereomicroscope StemiD4 (Zeisz). The individuals of *O. surinamensis* were sampled and counted for the population abundance study, and for spatial and temporal distribution analysis.

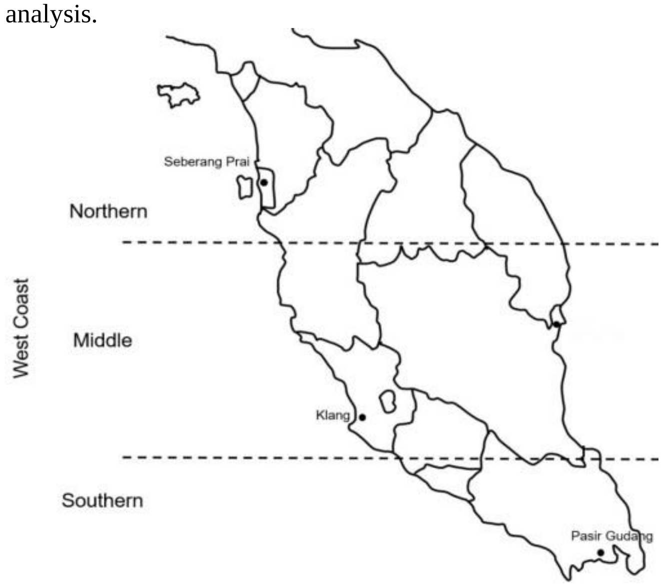
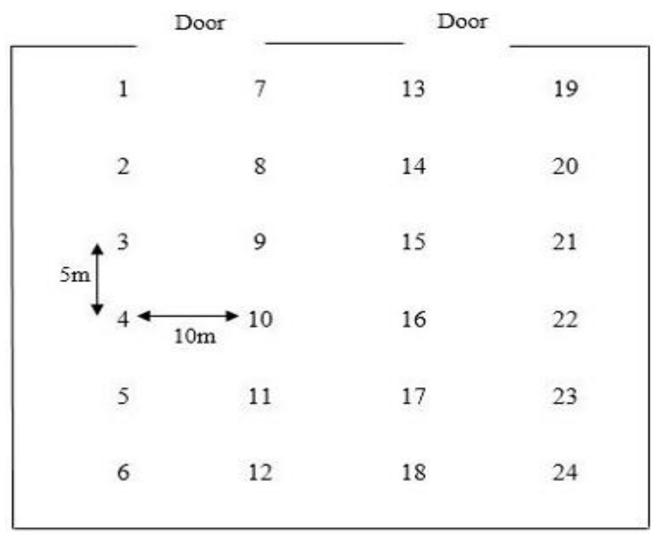


Figure 1. **Localities of *O. surinamensis* collected from three geographical zones in Peninsular Malaysia**



*1-24 is the number of sticky traps used

Figure 2. **Illustration of the sticky trap placement in the warehouses**

***Data Analysis*:** The significant abundance (p- value) of *O. surinamensis* between months for each warehouse was measured using one-way ANOVA, as well as the total abundance of this species over the three-month study duration at all the warehouses according to zones (Klang, Pasir Gudang and Seberang Prai).

***Spatial and Temporal Distribution Analysis of O. surinamensis*:** The spatial analysis was carried out using the software SADIEShell_122 and Surfer8 (Golden software, Golden, CO, USA). The x and y coordinates represent the position of the traps, while the z coordinates (24 points) represent the total number of *O. surinamensis* captured in each trap. The Z values produce the grid values which are used for the interpolation of contour maps by using the Kriging method (Lazzari *et al*., 2010). Spatial analysis introduces a way for the entomologist in the management of spatial distribution of stored product pests in warehouses, and this technique has been used in precise monitoring and control method on moths and beetle pests (Arbogast *et al*., 2000a, b; Sciarretta *et al*., 2001).

RESULTS

***Population Abundance*:** The abundance of *O. surinamensis* populations varied significantly at $p<0.05$, $p=0.00$ according to the geographical zones, with the highest abundance of this species in the central part of Peninsular Malaysia (Klang, at 69%), followed by the southern part (Pasir Gudang, at 27%), and the lowest was in the northern part (Seberang Prai, at 4%) (Figure 3).

The patterns of population abundance showed significant differences between months, ($p<0.05$, (p-value=0.00-0.011). For the Klang area (B and C), there were two warehouses that showed significant differences for the first and second months compared to the third month, whilst for the M and N warehouses in the Pasir Gudang area, the abundance pattern for the second month differed significantly compared to the first and third months. However, all the warehouses in Seberang Prai did not show any significant differences between months, ($p>0.05$, (p-value=0.141-0.648) (Figures 4a to 4c).

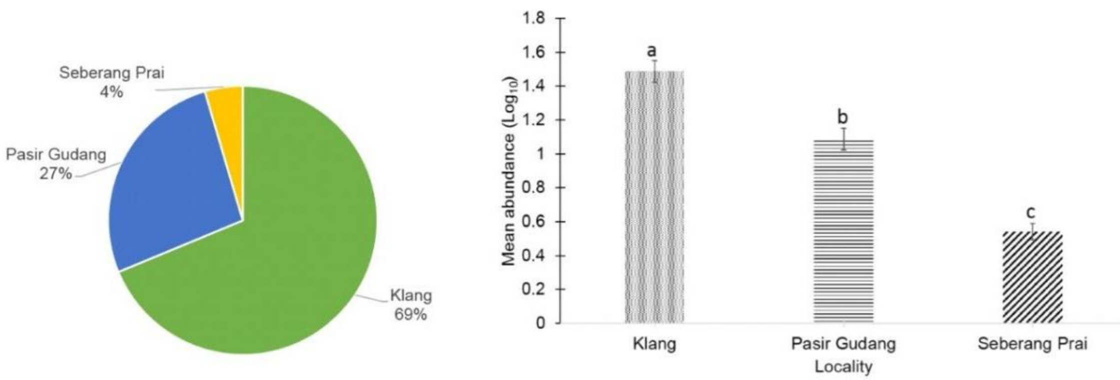
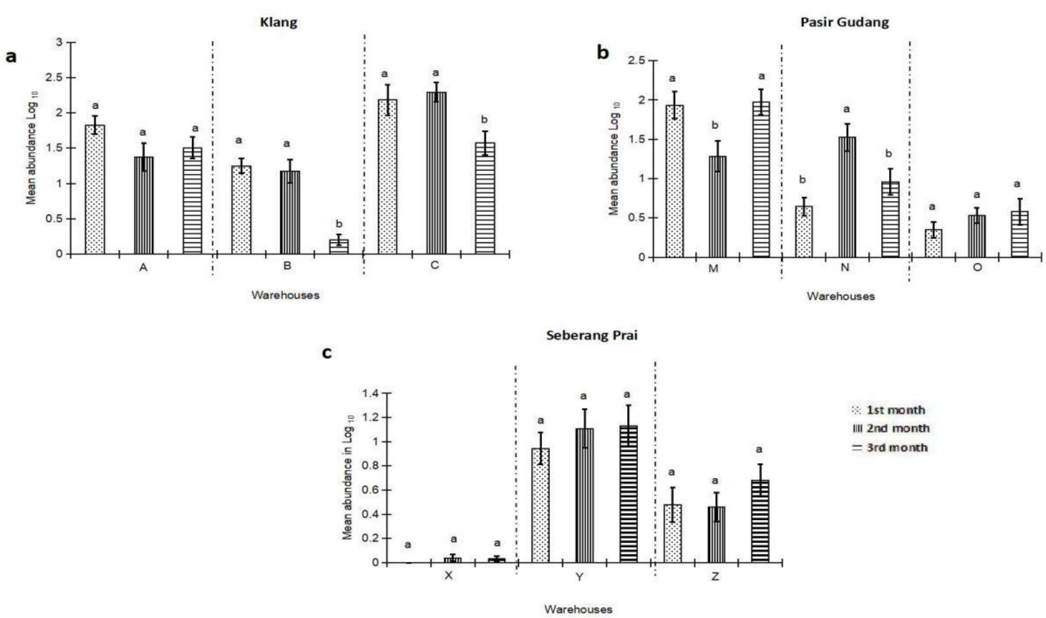


Figure 3. Composition of total abundance of *O. surinamensis* in three zones of Peninsular Malaysia



Figures 4a-c. Abundance of *O. surinamensis* in nine warehouses throughout the three-month period.

Table 1. Aggregation index, cluster and space value for nine warehouses for the specific three-month duration.

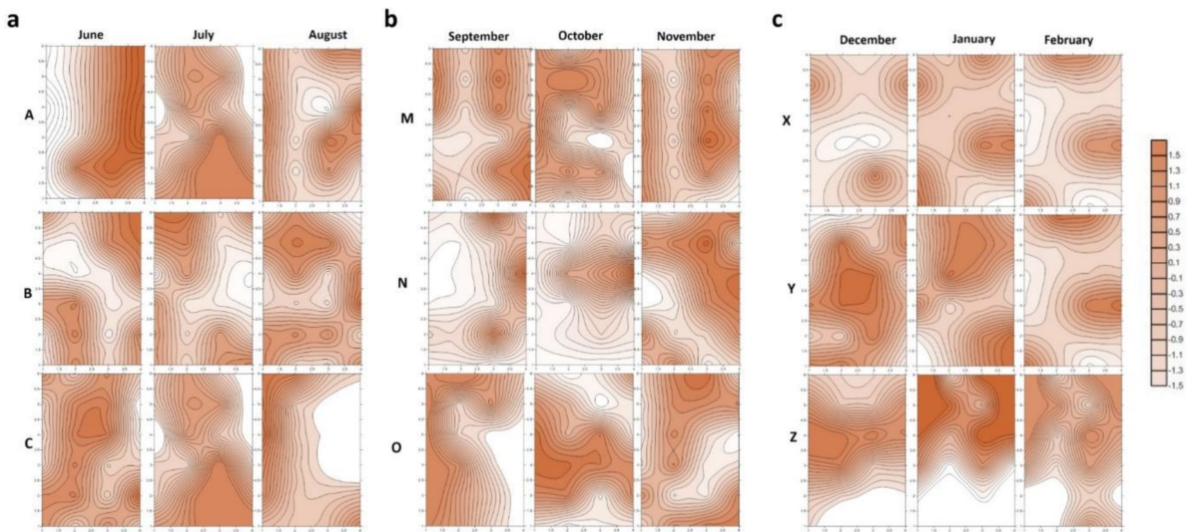
Warehouses	Month	P_a	I_a
A	June	0.0897	1.293
	July	0.0128*	1.579
	August	0.5385	0.949
B	June	0.3974	1.001
	July	0.1923	1.102
	August	0.5897	0.937
C	June	0.5769	0.929
	July	0.0128*	1.579
	August	0.1154	1.300
M	September	0.5385	0.959
	October	0.0128*	1.319
	November	0.2179	1.091
N	September	0.1410	1.222
	October	0.0128*	1.387
	November	0.2564	1.070
O	September	0.0256*	1.501
	October	0.1667	1.155
	November	0.7564	0.874
X	December	0.9103	0.769
	January	0.7436	0.870
	February	0.8077	0.852
Y	December	0.5769	0.945
	January	0.3462	1.039
	February	0.8077	0.852
Z	December	0.0513*	1.212
	January	0.0128*	1.844
	February	0.0385*	1.482

Legend: P_a < 0.05 = significant distribution*; I_a is a distribution pattern aggregated, random or regular; I_a >1.0 (aggregated); I_a= 1.0 (random); I_a< 1.0 (regular)

Spatial and Temporal Distribution**:** The spatial distribution during the three-month study duration of *O. surinamensis* populations in all the warehouses in three zones were significantly variable, either being aggregated or randomly distributed (Figures 5a to 5c, and Table 1). In Klang, the spatial pattern of *O. surinamensis* showed significantly aggregated distribution only in A and C warehouses in July, at $p<0.05$ (p=0.0128) and I_a =1.579. Meanwhile, the Pasir Gudang warehouses (M and N) showed significantly aggregated distribution in October at $p<0.05$ (p=0.0128 and I_a =1.319-1.387, while warehouse O showed a similar pattern in September, at $p<0.05$ (p= 0.0256) and I_a= 1.501. Interestingly, the Z warehouse in Seberang Prai also showed significantly aggregated distribution in December, January and February at p=0.0128-0.0513 and I_a=1.212-1.844), while the other two warehouses in this zone (i.e. X and Y) showed a largely non-significant and randomly distributed pattern of *O. surinamensis* populations over the three-month period, at $p>0.05$ (p=0.3462-0.9103 and I_a=0.769-0.945).

DISCUSSION

According to Beckel *et al*. (2007), the significant increment of *O. surinamensis* infestation as a secondary pest of rice grain in the storage facilities was attributed to the increase of broken grains production, the damage occurring during the post-harvest handling by the mechanical equipment. The abundance of the pest species in the warehouse should be monitored precisely for better management and control strategy of the pest species. Nine warehouses located within three geographical zones, i.e. northern, central, and southern parts of Peninsular Malaysia were randomly studied for a three-month period. However, the abiotic parameters such as



Figures 5a-c. Spatial distribution pattern of *O. surinamensis* in the rice warehouses observed for three months using the Krigging method; A, Klang, B, Pasir Gudang, C, Seberang Prai.

ambient temperature, relative humidity and CO_2 concentration were not monitored because the dispersal activity, distribution, and isolation of the species were affected only by the different climatic zones (Shiferaw, 2017), and different regions or continents (Tuda *et al*., 2014).

The infestation rates of different pests varied according to abiotic factors such as humidity and temperature ranges, which could affect their population abundance and distribution (Isikber et al., 2016). However, Malaysia is located in a tropical region with an equatorial climate of uniformly high temperatures and relative humidity, and heavy rainfall throughout the year. Since the sampling areas and distances involved are small (maximum distance of 650 km apart), the abiotic factors are relatively similar between the sampling locations. As such, the temperature and humidity conditions are standardized and well regulated under warehouse conditions in this study.

The rationale behind the three-month study period is significant because *O. surinamensis* would complete its life-cycle (one generation) after three months by producing more than 2000 individuals of progeny at certain temperature and moisture conditions (Lessard *et al*., 2005a). This species is also known as a cosmopolitan insect due to its high reproduction rate (Arthur, 2001). Previous studies had reported that other pests such as mites and psocids would decrease the seed germinability, causing kernel damage and weight loss after three months of infestation by the primary pests such as beetles (*Sitophilus* sp., *Tribolium* sp., *Oryzaephilus* sp.) and moths (*Plodia* sp.) (Stejskal *et al*., 2014). The damaged kernels would then be consumed by *O. surinamensis*, as a secondary pest.

The Klang warehouses showed the highest abundance of *O. surinamensis* for the entire three months, followed by those of Pasir Gudang and Seberang Prai. The results were significantly different between populations from the three zones, at $p<0.05$ ($p= 0.00$). This might be due to the prevailing poor sanitary conditions in the warehouses in terms of diligent cleaning process, as well as a thorough and detailed inspection schedule of the warehouses. Under suitable moisture and moderate heat conditions, the dust, chaff, mold and damaged grains would provide ample food sources for the secondary pests such as *O. surinamensis* (Lord, 2008; Aulicky *et al*., 2015).

However, the practice of mixing different rice varieties in one warehouse would also enhance the severity and infestation rate of the pest (Nadeem *et al*., 2011; Upadhyay and Ahmad, 2011). In this study, the quantity of rice stock and the variety of rice stored differed among the warehouses, and these two factors could well be contributing to the different amounts of stored grains being damaged and the percentage of pest abundance observed, where the highest infestation rate was recorded in Klang (Khidir personal communication). A study by Khan and Halder (2012) proved that the mean number of rice weevils emerging after 22 weeks of infestation in six varieties of rice differed significantly, mainly due to the rice aroma, and also the chalkiness and the amylose content of the different rice varieties (Reddy and Bhotmange, 2014). However, our own observations in this study were not conclusive due to lack of information on the different rice varieties stored in each warehouse.

The different patterns of pest abundance exhibited in each of the warehouses during the three-month study period showed significant differences between months, $p<0.05$ (p-value=0.00-0.011) in all the locations. This was probably due to various factors, namely the inconsistent and irregular fumigation schedule, the residual pests from the old rice stock, unclean storage bags and insanitary warehouse conditions (Ogebegbe and Edoreh, 2014). Toews and Subramanyam, (2003), noted that the efficacy of pesticide application could be reduced in an unclean environment, thus, increasing the rate and severity of infestation.

Data on the spatial and temporal distribution of the pest species could provide very valuable information in monitoring the storage pests, especially for the main ones, which are the moth and beetle species (Arbogast *et al*., 2000a, b; Sciarretta *et al*., 2001). The different areas of commodities appear to have different species, population and infestation rates (Lazzari *et al*., 2010). Our results differed from the findings of Trematerra (2004) who reported that the spatial distribution of the Apple sawfly population was clumped due to behavioral or environmental effects in distinct parts of the State of Santa Catarina rice facilities. Since the environmental factors were standardized in our study, we surmised that the behavior of *O. surinamensis* played the most important role in its distribution pattern. Multiple studies have also reported that the insect pests of stored products have spatially and temporally patchy distributions inside built structures (Arbogast *et al*., 2000a; Nansen *et al*., 2004) and including around the outside of the structures (Campbell *et al*., 2002).

Based on the results presented (Table 1 and Figures 5a to 5c), several population patches were found to show aggregated and isolation patterns on the contour map. This might be due to the rapidly depleting rice stock because of a rapid turnover or in-out inventory of the storage, which referred to the exportation and importation of rice stacks among the warehouses between zones, especially in Klang and Johore Bahru. Such an inventory could well be one of the possible reasons for the wide and rapid spread of this pest species.

As observed in our study and also noted by Campbell et al. (2006), *O. surinamensis*, being a poor flyer, was relatively unaffected by differences in land-cover and land use, or by the placement and location of the rice stacks in the warehouses. However, physical and chemical environmental changes that occurred during pesticide applications could affect the pest movements around the warehouses while in search of suitable sites for mating and egg laying (Jian, 2019). Such behavioural changes could affect their distribution pattern significantly (Guedes et al., 2000; Jian, 2019).

Our results indicated that the X and Y warehouses at Seberang Prai distinctly showed a regular distribution of the pest population, although not significantly supported by the statistical analysis, $p>0.05$ ($p= 0.3462-0.9103$) and $I_a=0.769-0.945$). High mobility and adaptive behaviour, and the ability to attack packaged food also enabled *O. surinamensis* to live freely in the warehouse at high population abundance under suitable environment and with abundant food source (Beckel *et al*., 2007). Our further observations showed that the volume of stored rice was higher in the X and Y warehouses compared to the Z warehouse and the other warehouses in the Klang and Pasir Gudang areas, due to the inactive in-out inventory activities (turnover). Since the main reason for insect movement is to find new food sources, the larger rice stocks in the warehouse would induce more active and free movements of *O. surinamensis* to avoid clumping and overcrowding at any one place, and such active movements would result in a regular distribution pattern (Jian, 2019). In contrast, the Z warehouses had much lower rice stock, and *O. surinamesis* moved less randomly due to lack of preference in food source and thus, they became aggregated at their favorable position (Jian, 2009).

Conclusion**:** This study has successfully reported the population abundance, spatial and temporal distribution of *O. surinamensis* pest of stored rice from three different zones (south, north and central parts of Peninsular Malaysia) under well-regulated warehouse conditions. The abundance of *O. surinamensis* was found to be highest in the Klang District of Selangor at 69%, followed by the Pasir Gudang area of Johor Bharu in the southern zone at 27%, and the Seberang Prai, Penang in the northern zone at 4%, during the three-month study period. The patterns of the species abundance also showed significant differences between months, $p<0.05$ (p-value=0.00-0.011) in all the warehouses. The environmental factors that could be associated with the population abundance and distribution pattern of the rice pest could be due to poor sanitation and inconsistency in the fumigation schedule.

The spatial and temporal distribution of *O. surinamensis* showed either aggregated or regularly distributed patterns in all the warehouses. However, the distribution of the pest species was significantly aggregated in many of those warehouses which had lower volume of the rice stock due to the less active in-out storage inventory. Likewise, the reverse is true for the regularly distributed pattern of the pest population in the other two warehouses (X and Y), although this surmise is not significantly supported by the statistical analysis. These findings are regarded as fundamental data and are very valuable and significant in structuring and implementing pest management strategies for pests of stored grain products, such as *O. surinamensis.* Several recommendations are suggested, viz. frequent and regular cleaning process, scheduled to coincide with the timing of fumigation and proper inventory to regulate the volume of rice stock in storage and good general housekeeping in the respective warehouses.

Conflict of Interest**:** The authors declare that there is no conflict of interests regarding the publication of this article.

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