J. Crop Prot. 2021, 10 (2): 281-293

Research Article

Physicochemical characteristics of stored products affect host preference and biology of *Acarus siro* (Acari: Acaridae)

Retno Dyah Puspitarini*, Ito Fernando, Tita Widjayanti, Annisatur Ramadhatin and Nurul Lailatul Husna

Department of Plant Pests and Diseases, Faculty of Agriculture, University of Brawijaya, Jl. Veteran, Malang 65145 Indonesia.

Abstract: Flour mite *Acarus siro* (Acari: Acaridae) is an injurious postharvest pest of various stored products. The objective of this study was to investigate the effect of physicochemical characteristics of stored products on *A. siro*. In this research, the host preference and biology of the mite were studied in three varieties of rice, two varieties of sticky rice, and three different types of cheese. We considered the differences in grain granulometry (whole, broken, and flour) as variation in physical characteristics of the stored products, and proportions of basic nutritional content as variation in chemical characteristics. The results indicated that when offered to grain with different granulometry, *A. siro* selected broken grain as their host and oviposition site. Furthermore, the mite's host preferences were also influenced by the nutritional content variation of the stored products. In biology experiments, the total development of *A. siro* lasted from16.78 ± 0.13 to 20.60 ± 0.51days and its fecundity ranged from 17.65 ± 1.75 to 53.05 ± 0.09 eggs per female. However, the results suggested that faster development and higher fecundity of the mite were generally found in a diet(s) with higher protein, fat, and water content. Additionally, we demonstrated that *A. siro* is better adapted to flour products, indicating the influence of particle size on the development and reproduction of the mite. Therefore, physicochemical characteristics of the stored products strongly affected the host selection and biology of *A. siro*, which in turn determines the degree of product susceptibility upon mite infestation.

Keywords: postharvest pest, rice, sticky rice, cheese, grain granulometry, nutritional content

Introduction

Environmental factors play an important role in the initiation of stored product pest infestation. In favorable conditions such as high humidity or moisture content, stored products are easily damaged by arthropods, including mites detrimental to human food supplies (Cunnington, 1976; Armitage, 1980; Armitage and Stables, 1984). Stored product mites mostly attack a wide range of foodstuffs, including seeds/grains and their derivatives (Zaher *et al*., 1986; Athanassiou *et al*., 2005; Palyvos and Emmanouel, 2006), food products e.g. vegetables, fruits, and edible mushrooms (Skubala *et al*., 2006), as well as dairy products such as cheeses (Carvalho *et al*., 2018). The most damaging species of storage mites predominantly belong to the family Acaridae i.e. *Acarus, Aleuroglyphus* and *Tyrophagus* genera. They are popularly named flour, grain, or cheese mites (Xia *et al*., 2009; de

Handling Editor: Hamidreza Hajiqanbar

* Corresponding author: retnodyah@ub.ac.id
Received: 23 July 2020, Accepted: 31 January 2021
Published online: 16 February 2021

Assis *et al*., 2011; Kavallieratos *et al*., 2018). There are many adverse effects of stored product mites infestation mostly seen in damp and moist grains which affect germination rate and decrease nutritional content (Armitage *et al.*, 2002; White *et al*., 2003b). Other telltale signs are grains heating and tainting, contamination, and spreading of fungal pathogens (Hughes, 1976; Sinha, 1979; Collins, 2012). It is essential to recognize such infestations and locate them as soon as possible to prevent mite's establishment and migration. The mites also cause serious health problems including skin allergies, respiratory disease, and urinary acariasis (Hubert *et al*., 2005; Valdivieso *et al*., 2006; Stejskal and Hubert, 2008; Cui, 2014), which leads to rejection of products by consumers and affects the economy.

In Indonesia, due to lack of knowledge or inadequate technology, these noxious mites are found in facilities that embark on poor infrastructure and cleanliness mostly in semi-rural or rural areas. Nonetheless, the presence and infestation are neither realized nor reported by the farmers despite the mite's occurrence in storage facilities. During several years of investigation, we have found that various species of mites inhabit the grains and meals in storage facilities located across East Java. Mite aggregations are more abundant in damaged/broken grains or grains residues. However, *Acarus siro* L. commonly known as flour mite is found to be ubiquitous species and responsible for causing most of the deterioration and destruction of products. It is reportedly an injurious pest that has a cosmopolitan distribution, especially in temperate regions with a cool and moist climate (Cunnington, 1985; Parkinson *et al.*, 1991; Hagstrum *et al*., 2013). To date, *A. siro* infestation on stored products is still reported around the world (Dizlek *et al*., 2019; Senba *et al*., 2020).

The damage by *A. siro* is directly related to its population density, which is strongly influenced by environmental factors (Cunnington, 1976; Stejskal and Hubert, 2008). Food quality is one of the key factors determining the survival, growth, development, and host preferences of stored product mites (Rodriguez and Rodriguez, 1987; Zhang *et al*., 2018). In this sense, food quality could be described as the overall condition of physical and chemical (nutritional content) characteristics of a product. Furthermore, although mites can utilize numerous food sources, the suitability and palatability of the food strongly affect their life history (Hubert *et al*., 2009; Hubert *et al*., 2013). Grain structure or physical characteristics including grain hardness, size, wholeness, and also the thickness of outer layers affect the feeding and egg-laying activity of stored product pests (Beckel *et al*., 2007; Chanbang *et al*., 2008). Along with that, each type and variety of stored product shows different levels of suitability to the biology of stored product mites (Fejt and Zdarkova, 2001; Hubert *et al*., 2009). Henceforth, it is crucial to examine thoroughly the characteristics of a product that influence the biological parameters of *A. siro* to predict the mite occurrence and/or its population dynamics.

The agrarian fields of Indonesia have produced numerous varieties of rice, *Oryza sativa* L. Each variety has its genetic properties with different physical characteristics and nutritional content (Suprihatno *et al*., 2009). Taking into consideration that *A. siro* may become a potential threat in Indonesia, therefore there is a requirement to unequivocally determine the main physicochemical characteristics of stored products that affect its life history background. To the best of our understanding, the present work pioneers the researches attempting to study the host preferences and biology of *A. siro* on several varieties of rice and sticky rice. Similarly, evaluation of the mite on different types of cheese was assessed as a precaution of the mite infestation in Indonesian artisanal cheesemaking farms. Our findings would give an insight into the importance of *A. siro* as, an emerging stored product pest in Indonesia, and provide fundamental knowledge for the development of a proper control strategy through integrated pest management.

Materials and Methods

Mite rearing

The *A. siro* mite was initially collected from infested rice taken from local storage (Malang, East Java) and morphologically identified to ensure the species identity. In the laboratory, mites were introduced into a small glass jar and reared on a culture medium consisting of flour and dried yeast under room condition at 27 ± 2 °C, 70% RH, and LD 11: 13 h (Thind and Dunn, 2002). To provide adult mites of known age, mites that entered the last quiescent stage (resting tritonymph) were arbitrarily taken using a single-haired camel brush and transferred into a Petri dish. Subsequently, the newly emerged adults (0-24 hours old) were obtained and readily used for the experiments. Adult *A. siro* exhibits sexual dimorphism, thus sexing was based on their secondary sexual characteristics (Hughes, 1976).

A. siro life history on several stored products

These studies consisted of host preference tests and biology assessment of *A. siro* on several stored products/diets. These studies attempted to determine the main physicochemical characteristics which affect the life history of *A. siro.* Different grain granulometry (intact/whole, broken, or flour) was considered as the physical variation, whereas the nutritional content of each experimental diet represented the chemical variation. Three different sets of experiments were conducted separately i.e. (i) study on three varieties of rice in intact versus broken grain condition, (ii) on two varieties of sticky rice in broken grain versus flour condition, and (iii) on three types of cheese.

Preparation of the experimental diets

For our experiments, we used three varieties of rice, two local varieties of sticky rice, and three types of cheese (Table 1). All the varieties were obtained from the Sumberngepoh farmers' group (Malang), whereas cheeses were purchased from a local dairy store. These varieties were selected because they are liked by the community and widely cultivated by the farmers in Indonesia.

Grains were cold sterilized to eliminate living insects or mites before being utilized as our experimental treatments, following a method adapted from Heinrichs *et al.* (1985) (cheese were hermetically packaged and free from pests infestation). After sterilization, rice and sticky rice were sorted into intact/whole or broken grains. Grains that were quarter or half the normal size were considered as broken grains. Furthermore, a sum of sticky rice was milled into flour.

The experimental diets were sent to the Food Quality and Safety Testing Laboratory, University of Brawijaya and subjected to proximate analysis to determine their basic nutritional content (i.e. proportions of carbohydrate, protein, fat, water, and ash). The proximate composition of the experimental diets was determined by a standard method provided by AOAC (2019).

Table 1 Kind of experimental diets used in the experiments and their chemical characteristics.

Experiment	Rice type	Variety	Chemical characteristics				
			Carbohydrate (%)	Protein (%)	Fat (%)	Water (%)	Ash (%)
1st	White rice	IR 64	78.60	8.40	0.64	11.84	0.52
	Red Rice	Aek Sibundong	75.94	8.94	2.28	11.58	1.26
	Black Rice	Hare Kwa	75.65	8.78	2.68	11.38	1.51
2nd	White stickyrice	Lusi	75.59	9.87	2.16	10.43	1.95
	Black sticky rice	Setail	81.21	6.72	0.26	11.51	0.30
3rd	Parmesan	-	13.19	22.43	25.44	34.13	4.81
	Cheddar	-	27.92	5.78	27.90	32.92	5.48
	Edam	-	17.99	19.09	26.78	29.37	6.77

Host preference of *A. siro*

The free choice test was used to assess the host preferences of *A. siro.* Each treatment was replicated ten times. Experiments were carried out in a preference cage made from a modification of a medium-sized Petri dish (9 cm in diameter) consisting of either six chambers (1st experiment), four chambers (2nd experiment), or three chambers (3rd experiment). The cage was put above a soaked sponge which previously was placed on a large Petri dish (15 cm in diameter) (Fig. 1). Each chamber in the preference cage contained 2 g of one of each experimental diet. Twenty pairs of adult *A. siro* aged 0-24 hours were released in the center of the cage. The females were allowed to lay their eggs in 3 days oviposition period. After the oviposition period had finished, the number of adults present and the number of eggs (oviposition preference) in each chamber were counted.

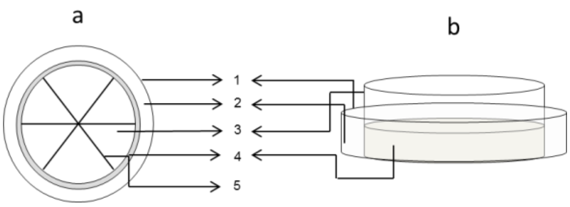

Figure 1 Preference cage used in host preference experiment as seen (a) from above and (b) from lateral view. The cage was divided into either six, four or three chambers depending on the number of experimental diets. 1: large sized Petri dish; 2: water; 3: medium sized Petri dish; 4: sponge; and 5: mica plastic.

Biology of *A. siro*

This study was conducted with only two different diets chosen from the results of previous tests. The most preferable diets were selected based on the *A. siro* preferences (adults present and number of eggs laid). Experiments were conducted with twenty units of replication to obtain accurate biological parameters data. The immature developmental period of *A. siro was* evaluated by placing an individual mated female into a small-sized Petri dish (6 cm in diameter) filled with each experimental diet (0.5 g) (no-choice test). After 24 hours, only a single egg was kept in the dish and others were removed. The newly laid egg was monitored at 6 hours intervals until reached adulthood. The total developmental time of *A. siro was* then determined by calculating the duration of each life stage i.e eggs, larva, nymphs, and quiescent (resting) stage between each active life stage.

A pair of newly emerged virgin adults obtained from individual cultures (reared on each corresponding diet treatment) was used to investigate the period of adult phases, fecundity, and longevity. Under the same condition described above, the observation was conducted daily. The first day of oviposition was noted to determine the pre-oviposition period. The observation was continued to determine the oviposition period, daily eggs production/female/oviposition day, the total number of eggs/female (fecundity), post-oviposition period, and adult longevity.

Data Analysis

The differences among data obtained from the host preference test were analyzed using a non-parametric Kruskal-Wallis analysis followed by Dunn's test. Meanwhile, all data obtained from biology experiments were analyzed by the Mann-Whitney test. Pearson's correlation was conducted to determine the relationship between chemical characteristics variables of each experimental diet with the observed life-history parameters of *A. siro.* In all experiments, significant differences between mean values were assumed when $P < 0.05$. Analyses were conducted using GraphPad Prism version 8.0.2 and R statistics.

Results

Host preference

In general, our results suggested that the chemical characteristics of experimental diets and grain granulometry affected the host preference of *A. siro* (Table 2). In the first set of experiments, *A. siro* was found in the highest abundance on red and black rice with a broken grain condition. However, in the latter experiment, it was revealed that mites reacted differently.

Table 2 The number of adults present (mean ± SE) in preference chambers containing one of each experimental diets on the third day after infesatation.

Experiment	Kinds of rice/cheese	Types of rice/cheese	Number of adults present		
			Male	Female	Total adults
1st	Intact grain	White rice	2.30 ± 0.33 b	2.70 ± 0.33 ab	5.00 ± 0.53 b
		Red Rice	2.00 ± 0.21 b	2.20 ± 0.48 b	4.20 ± 0.62 b
		Black rice	1.80 ± 0.20 b	1.90 ± 0.31 b	3.70 ± 0.42 b
	Broken grain	White rice	1.80 ± 0.38 b	1.60 ± 0.42 b	3.40 ± 0.79 b
		Red Rice	5.90 ± 0.56 a	6.00 ± 0.68 a	11.90 ± 1.20 a
		Black rice	6.20 ± 0.46 a	5.60 ± 0.33 a	11.80 ± 0.72 a
		P value	< 0.001	< 0.001	< 0.001
2nd	Broken grain	White sticky rice	5.40 ± 0.58 a	6.90 ± 0.43 a	13.30 ± 0.51 a
		Black sticky rice	4.90 ± 0.56 a	4.30 ± 0.26 bc	9.00 ± 0.61 bc
	Flour	White sticky rice	5.80 ± 0.46 a	6.00 ± 0.36 ab	11.90 ± 0.52 ab
		Black sticky rice	3.90 ± 0.58 a	2.80 ± 0.32 c	5.80 ± 0.67 c
		P value	0.137	< 0.001	< 0.001
3rd	Cheese	Parmesan	8.10 ± 0.23 a	9.50 ± 0.90 a	17.60 ± 0.96 a
		Cheddar	7.70 ± 0.53 a	6.90 ± 0.72 ab	14.60 ± 0.92 a
		Edam	4.20 ± 0.44 b	3.60 ± 0.60 b	7.80 ± 0.81 b
		P value	< 0.001	< 0.001	< 0.001

Means followed by different letters on a same column in each set of experiment indicate significant difference (Kruskal-Wallis followed by Dunn's test, $P < 0.05$).

The population of Mites was higher on white sticky rice regardless of the grain condition, compared to black sticky rice. Meanwhile, the third experiment indicated that the mites preferred Parmesan and Cheddar as their hosts. For oviposition preference, we found an exactly similar pattern of host selection, and the differences were statistically significant. The higher number of eggs laid was observed in the respective preference chambers containing broken grains of red and black rice (Fig. 2a), white sticky rice (Fig. 2b), and Parmesan and Cheddar cheese (Fig. 2c).

From the calculation of Pearson correlation, we did not find any significant relationship between the nutritional content of rice varieties with host preferences of *A. siro* in the first experiment. However in the second experiment, we found significant positive relationship between total adult present and number of eggs laid with protein ($r = 0.77$, $P < 0.001$) and fat content ($r = 0.77$, $P < 0.001$. Finally, the water content of cheese was highly correlated with total adults present ($r = 0.83$, $P < 0.001$), which in turn increased the number of eggs laid by the females on Parmesan and Cheddar.

Biology of *A. siro* in several stored products

The duration of life stages of *A. siro* was similar when reared on red and black rice with broken grain condition as the diets (Table 3), only the duration of tritonymph was statistically different by the Mann-Whitney test. Total developmental time from egg to adult was16.78 ± 0.13 and 17.24 ± 0.26 days, respectively. By contrast, the immature developmental period of *A. siro* was affected by grain granulometry, as evidenced in the second experiment. The duration of larva, protonymph, and total development was shorter on white sticky rice with flour condition rather than broken grain (Table 4). When comparing the suitability of Parmesan and Cheddar cheese, *A. siro* had faster total immature developmental time on Parmesan although the duration of each life stage was not significantly different (Table 5).

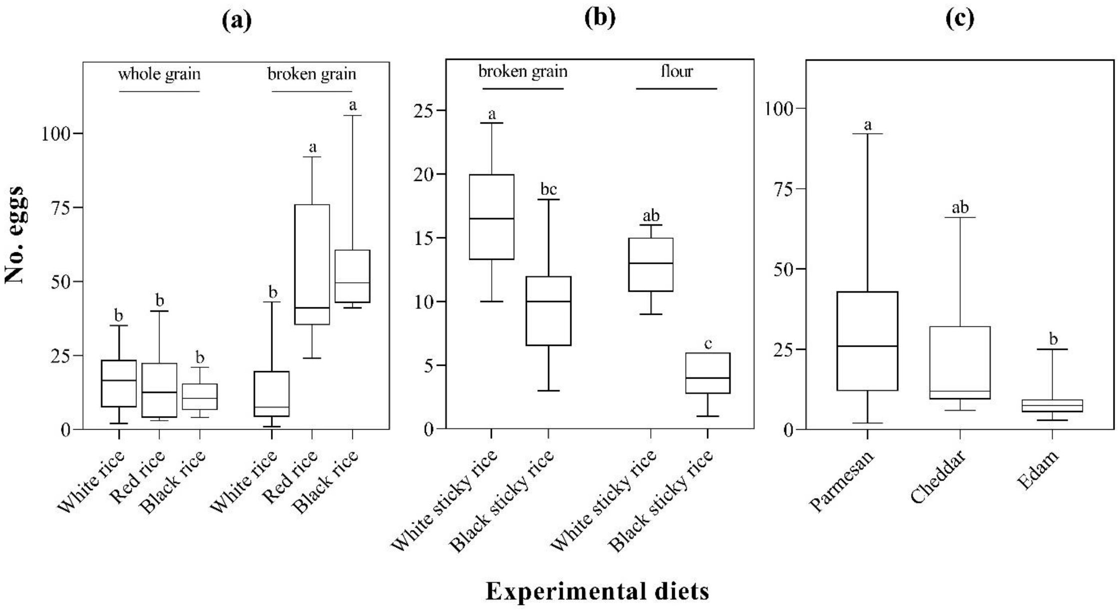

Figure 2 Box plot of the number of eggs laid in preference chambers containing one of each experimental diets, (a) first experiment using three varieties of rice in wholeversus broken grain condition ($P < 0.001$), (b) second experiment using two varieties of sticky rice in broken grain versus flour condition ($P < 0.001$), and (c) third experiment using three types of cheese ($P = 0.024$). Different letters indicate significant difference (Kruskal-Wallis followed by Dunn's test, $P < 0.05$).

When reared on broken grains of red or black rice, the reproduction parameters, adult phases, and longevity of *A. siro* were not varied (Table 6). Nevertheless, in the second experiment, the oviposition period, total eggs/female, and daily egg production were better on white sticky rice with flour condition, but not on broken grain (Table 7). Lastly, on Parmesan cheese, the mite had longer oviposition and post-oviposition periods, as well as higher daily eggs production, which in turn lead to a greater fecundity (Table 8). Fecundity on Parmesan was 42.75 ± 4.80 eggs/female and positively correlated with cheese chemical characteristics i.e. protein ($r = 0.50$, $P = 0.001$) and water content ($r = 0.50$, $P = 0.001$). Regarding adult longevity, our experiments did not find any significant differences among the tested experimental diets. However, the adult male tended to live longer on Parmesan than on Cheddar cheese.

Table 3 Developmental time (days ± SE) from egg to adult of *A. siro* reared on red and black rice in broken grain condition.

Stage	Red rice (broken grain)	Black rice (broken grain)	*P* value
Egg	4.16 ± 0.04	4.17 ± 0.04	0.999
Larva	3.42 ± 0.09	3.45 ± 0.08	0.797
Resting larva	1.10 ± 0.03	1.17 ± 0.04	0.222
Protonymph	1.70 ± 0.03	1.76 ± 0.04	0.334
Resting protonymph	1.90 ± 0.03	1.90 ± 0.03	0.999
Tritonymph	2.46 ± 0.03	2.60 ± 0.04	0.039*
Resting tritoymph	2.02 ± 0.05	2.17 ± 0.06	0.116
Egg to adult	16.78 ± 0.13	17.24 ± 0.26	0.365

* indicates significant difference at $P < 0.05$ (Mann-Whitney test).

Table 4 Developmental time (days ± SE) from egg to adult of *A. siro* reared on white sticky rice in broken grain and flour condition.

Stage	White sticky rice (broken grain)	White sticky rice (flour)	*P* value
Egg	4.19 ± 0.21	4.77 ± 0.30	0.053
Larva	4.95 ± 0.41	3.07 ± 0.34	0.001***
Resting larva	1.34 ± 0.08	1.23 ± 0.10	0.587
Protonymph	3.75 ± 0.44	1.94 ± 0.23	<0.001***
Resting protonymph	1.53 ± 0.15	1.13 ± 0.12	0.062
Tritonymph	3.16 ± 0.46	2.83 ± 0.41	0.465
Resting tritoymph	1.65 ± 0.15	1.37 ± 0.12	0.198
Egg to adult	20.60 ± 0.51	16.27 ± 0.54	<0.001***

*** indicate significant difference at P < 0.001 (Mann-Whitney test).

Table 5 Developmental time (days ± SE) from egg to adult of *A. siro* reared on Parmesan and Cheddar cheese.

Stage	Parmesan	Cheddar	*P* value
Egg	4.09 ± 0.20	4.49 ± 0.26	0.163
Larva	2.44 ± 0.27	3.16 ± 0.41	0.060
Resting larva	2.56 ± 0.49	2.50 ± 0.36	0.372
Protonymph	2.97 ± 0.45	3.89 ± 0.38	0.077
Resting protonymph	1.40 ± 0.18	1.18 ± 0.11	0.440
Tritonymph	2.81 ± 0.24	3.02 ± 0.37	0.856
Resting tritoymph	1.37 ± 0.17	1.15 ± 0.12	0.337
Egg to adult	17.68 ± 0.57	19.42 ± 0.53	0.036*

* indicates significant difference at P < 0.05 (Mann-Whitney test).

Table 6 Mean duration (days ± SE) of adult phases and longevity, and reproduction parameters (mean ± SE) of *A. siro* reared on red and black rice in broken grain condition.

Parameter	Red rice (broken grain)	Black rice (broken grain)	*P* value
Pre-oviposition period	1.80 ± 0.13	1.80 ± 0.13	>0.999
Oviposition period	10.20 ± 0.29	9.90 ± 0.32	0.455
Post-oviposition period	6.15 ± 0.24	5.85 ± 0.20	0.420
Female longevity	18.15 ± 0.37	20.20 ± 0.35	0.237
Male longevity	20.85 ± 0.33	17.55 ± 0.38	0.279
Total fecundity (total eggs/female)	53.05 ± 1.80	49.40 ± 2.06	0.189
Daily eggs/female	5.20 ± 0.09	4.96 ± 0.07	0.070

Table 7 Mean duration (days ± SE) of adult phases and longevity, and reproduction parameters (mean ± SE) of *A. siro* reared on white sticky rice in broken grain and flour condition.

Parameter	White sticky rice (broken grain)	White sticky rice (flour)	*P* value
Pre-oviposition period	2.40 ± 0.32	1.55 ± 0.16	0.065
Oviposition period	6.90 ± 0.77	10.95 ± 0.88	0.001***
Post-oviposition period	3.30 ± 0.39	2.40 ± 0.27	0.101
Female longevity	12.60 ± 0.94	14.90 ± 0.89	0.165
Male longevity	14.65 ± 0.79	16.45 ± 0.83	0.270
Total fecundity (total eggs/female)	17.65 ± 1.75	42.55 ± 5.20	<0.001***
Daily eggs/female	2.62 ± 0.17	3.71 ± 0.29	0.005**

** and *** indicate significant difference at P < 0.01 and 0.001, respectively (Mann-Whitney test).

Table 8 Mean duration (days ± SE) of adult phases and longevity, and reproduction parameters (mean ± SE) of *A. siro* reared on Parmesan and Cheddar cheese.

Parameter	Parmesan	Cheddar	*P*-value
Pre-oviposition period	1.95 ± 0.18	2.50 ± 0.25	0.127
Oviposition period	12.05 ± 1.21	8.25 ± 1.22	0.021*
Post-oviposition period	2.00 ± 0.24	1.35 ± 0.13	0.024*
Female longevity	15.30 ± 1.28	11.75 ± 1.24	0.069
Male longevity	15.10 ± 1.23	11.65 ± 0.86	0.032*
Total fecundity (total eggs/female)	42.75 ± 4.80	21.65 ± 3.45	>0.001***
Daily eggs/female	3.68 ± 0.27	2.82 ± 0.18	0.039*

* and *** indicate significant difference at $P < 0.05$ and 0.001, respectively (Mann-Whitney test).

Discussion

Hostphysicochemical characteristics have been known as one of the most important factors determining the life history of arthropod pests. They are closely associated with the degree of product vulnerability upon pests infestation, which is known as antixenosis or non-preference) and antibiosis mechanisms (Lopez-Castillo *et al*., 2018; Mawenda *et al*., 2019). These two mechanisms are primarily evaluated by observing host preference and biology of particular pest species. In our study, it was shown that the host preference and biology of *A. siro* mite were affected by the physical condition and/or chemical characteristics of their diets. Firstly, we found that a greater number of adults and the higher number of eggs laid were observed on red and black rice with broken grain conditions. Based on chemical analysis, the chemical characteristics of the three rice varieties were quite similar and we found no major statistical relationship between rice nutritional content and *A. siro* host preference. Here, it was obvious that the grain physical condition (whole versus broken grain) was the major factor affecting *A. siro* preferences. Upon closer investigation, we found that the protective aleurone layer in the broken grain was damaged, and there were crevices mostly seen at the tip of the grain. These tiny crevices or holes give *A. siro* easier access to the soft nutritious germ of the grain and provide a place for them to live and reproduce. This phenomenon was following previous researches conducted by Solomon (1969) and White *et al*. (2003a). Additionally, there was a tendency for the females to choose the broken grains as their oviposition site and keep their eggs hidden from predators (da Silva *et al*., 2018). Conclusively, whole grain could be considered as an unsuitable host or environment for stored product mites. It should be noted that white rice does not have germ because of milling processes, presumably, that was the plausible reason explaining *A. siro's* lack of attraction towards white rice. Parkinson's (1990) research indicated that *A. siro* seldom attacked the endosperm, and instead preferred to hollow out the germ part, which is present only in red and black rice.

Considering that *A. siro* attacks various kinds of grains, we also compared its host preference on different varieties of sticky rice. Interestingly, *A. siro* preferred and laid significantly more eggs on white sticky rice than black sticky rice. Our analysis revealed that higher content of protein and fat in white sticky rice positively correlated with the number of adults present and the number of eggs laid. It is known that acarid mites such as *A. siro* and *Tyrophagus putrescentiae* (Schrank) are more frequently found infesting stored products with high protein and fat content (Hughes, 1976; Parkinson, 1990; Aygun *et al*., 2007). Nutritional content is an inherent varietal trait that becomes one of the limiting factors which hinders stored product mites from exploiting the grain. When offered with different types of cheese simultaneously, adults *A. siro* and their eggs were more abundant on Parmesan and Cheddar. We assumed that the greater amount of water on these cheeses was the sole main factor affecting *A. siro* behavior. Generally, increases in the water content of stored products will produce a favorable habitat and condition for the mite pests (Palyvos and Emmanouel, 2006), and eventually makes the products more susceptible (White *et al*., 2003a; Athanassiou *et al*., 2003; Aygun *et al*., 2007).

Biological parameters of stored product mites are influenced by the quality of their diets, which in turn affect the population growth rate (White *et al*., 2003b). On red and black rice with broken grain condition, *A. siro* development time and reproduction rate did not differ significantly. Our analysis revealed that chemical characteristics between these two rice varieties were identical, thereby it did not affect the observed biological parameters. Probably both diets provided adequate and balanced nutrients. Da Silva *et al*. (2018) experiments demonstrated that diets that had a balanced nutrient content were more suitable for stored product mite *T. putrescentiae* than a diet that had a significantly higher amount of one nutrient and lacked the other essential nutrients. In our second experiment on biology, the faster period of immature development, the longer period of oviposition, and the greater number of eggs were observed in white sticky rice in flour condition. It is known that particle size is one of the limiting factors which affect the feeding activity of stored product mites. As a flour mite, *A. siro* prefers and mostly feeds on loose or fine particles (Hughes, 1976). Presumably, flour condition is more suitable because it might provide a better microhabitat for the living and feeding of the mite. In agreement with the results of Astuti *et al.* (2020), variation in particle size is one of the influential factors determining the development of stored product pests.

Previous research demonstrated that several acarid mites adapt poorly to diets rich in carbohydrates, while, they prefer and develop faster on foodstuffs high in protein and fat content (Erban *et al*., 2015). Corroborating that statement, our research explains the faster development of *A. siro* on Parmesan cheese with four times higher amount of protein and lower carbohydrate content compared to Cheddar, even though the amount of fat was slightly higher in Cheddar. The suitability of Parmesan as *A. siro* host was also represented by a longer oviposition period and higher reproduction rate. The fecundity of arthropods, including mites, is generally superior on a protein-rich diet (Khanamani *et al*., 2017). Protein is needed for the maturation and optimum production of eggs. Even though the quantity of nutrition is important, the balance between nutritional ingredients is suggested as the factor determining the overall development and fitness of arthropods. In the nutritional ecology of arthropods, the balance between protein and carbohydrate (P: C ratio) has profound effects on their survival, growth, and fecundity (Wang *et al*., 2018). We hypothesized that the P: C ratio in Parmesan cheese was in suitable proportions for the biology of *A. siro.* Also, during our experiments, we did not see any mite which passed through the hypopus or deutonymph stage. Hypopus is an extra nymphal stage in acarid mites that are only triggered under harsh environmental conditions, food scarcity, or nutrient deficiency (Griffiths, 1996; Collins, 2012). Therefore, our research indicates that *A. siro* mite successfully utilized all experimental diets as its host, although the degree of suitability was different among the products.

This research work indicates that the differences in physicochemical characteristics of stored products affect the host preference and biology of *A. siro.* Regarding physical characteristics, broken grain and flour conditions are likely selected by the mite as its preferred host. Stored products rich in protein and fat, as well as higher water content are more preferable and suitable for *A. siro.* Therefore, a proper storage condition is needed for products that are expected to be susceptible to an infestation of the mite. This research also alarms *A. siro* as a new emerging pest in Indonesia, hence complementary studies are urgently needed to determine the demographic parameters of *A. siro* on some stored products.

Conflict of interests

The authors state that there is no conflict of interests.

Authors' contributions

Retno Dyah Puspitarini: Conceptualization. Methodology, Writing–Review & Editing, Supervision. Ito Fernando: Data Analysis, Writing Original Draft, Methodology, Investigation. Tita Widjayanti: Methodology, Writing-Review & Editing, Supervision. Annisatur Ramadhatin: Methodology, Investigation. Nurul Lailatul Husna: Methodology, Investigation.

Acknowledgments

This study was fully supported by the Faculty of Agriculture, University of Brawijaya.

References

AOAC. 2019. Official methods of Analysis of Association of Official Analytical Chemists (21st edition). AOAC International.

Armitage, D. M. 1980. The effect of aeration on the develpopment of mite population in rapeseed. Journal of Stored Products Research, 16: 93-102.

Armitage, D. M. and Stables, L. M. 1984. Effects of aeration on established insect infestations in bins of wheat. Protection Ecology, 6: 63-73.

Armitage, D. M., Cook, D. A. and Baxter, D. E. 2002. Farm-scale experiments to compare infestation and quality changes in malting barley stored at three moisture contents. Journal of the Institute of Brewing, 108: 178-186.

Astuti, L. P., Rizali, A., Firnanda, R. and Widjayanti, T. 2020. Physical and chemical properties of flour products affect the development of *Tribolium castaneum.* Journal of Stored Products Research, 86: 101555.

Athanassiou, C. G., Kavallieratos, N. G., Palyvos, N. E. and Buchelos, C. T. 2003. Three-dimensional distribution and sampling indices of insects and mites in horizontally-stored wheat. Applied Entomology and Zoology, 38: 4113-4126.

Athanassiou, C. G., Kavallieratos, N. G., Palyvos, N. E., Sciaretta, A. and Trematerra, P. 2005. Spatiotemporal distribution of insects and mites in horizontally stored wheat. Journal of Economic Entomology, 98: 1058-1069.

Aygun, O., Yaman, M. and Durmaz, H. 2007. A survey on occurrence of *Tyrophagus putrescentiae* (Acari: Acaridae) in Surk, a traditional Turkish dairy product. Journal of Food Engineering, 78: 878-881.

Beckel, H. S., Lorini, I. and Lazzari, M. N. 2007. Rearing method of *Oryzaephilus surinamensis* (L.) (Coleoptera: Silvanidae) on various wheat granulometry. revista Brasileira de Entomologia, 51: 501-505.

Carvalho, M. M., Oliveira, E. E., Matioli, A. L., Ferreira, C. L. L., da Silva, N. M. and Lindner, J. D. D. 2018. Stored products mites in cheese ripening: Health aspects, technological and regulatory challenges in Brazil. Journal of Stored Products Research, 76: 116-121.

Chanbang, Y., Arthur, F. H., Wildec, G. E. and Throne, J. E. 2008. Hull characteristics as related to susceptibility of different varieties of rough rice to *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae). Journal of Stored Products Research, 44: 205-212.

Collins, D. A. 2012. A review on the factors affecting mite growth in stored grain commodities. Experimental and Applied Acarology, 56: 191-208.

Cui, Y. 2014. When mites attack: domestic mites are not just allergens. Parasit Vectors.7: 411-417.

Cunnington, A. M. 1976. The effect of physical conditions on the development and increase of some important storage mites. Annales of Applied Biology, 82: 175-201.

Cunnington, A. M. 1985. Factors affecting oviposition and fecundity in the grain mite *Acarus siro* L. (Acarina: Acaridae), especially temperature and relative humidity. Experimental and Applied Acarology, 1: 327-344.

da Silva, G. L., Esswein, I. Z., de Souza Radaeli, T. F., Rocha, M. S. and Ferla, N. J.

2018. Influence of various diets on development, life table parameters and choice oviposition test of *Tyrophagus putrescentiae* (Acari: Acaridae): An illustration using scanning electron microscopy (SEM). Journal of Stored Products Research, 76: 77-84.

de Assis, C. P. O., Gondim, Jr. M. G. C., de Siqueira, H. A. A. and da Camara, C. A. G. 2011. Toxicity of essential oils from plants towards *Tyrophagus putrescentiae* (Schrank) and *Suidasia pontifica* Oudemans (Acari: Astigmata). Journal of Stored Products Research, 47: 311-315.

Dizlek, H., Karagoz, M., Faraji, F. and Cakmak, I. 2019. Mites in dried figs of Turkey: diversity, species composition and density. Systematic and Applied Acarology, 24(6): 992-997.

Erban, T., Rybanska, D. and Hubert, J. 2015. Population growth of the generalist mite *Tyrophagus putrescentiae* (Acari: Acaridida) following adaptation to high- or low-fat and high- or low-protein diets and effect of dietary switch. Environmental Entomology, 44: 1599-1604.

Fejt, R. and Zdarkova, E. 2001. Bionomics of *Acarus siro* L. (Acarina: Acaridae) on oilseeds. Plant Protection Science, 37: 111-114.

Griffiths, D. A. 1996. Nutrition as a factor influencing hypopus formation in the *Acarus siro* species complex (Acarina, Acaridae). Journal of Stored Products Research, 1: 325-340.

Hagstrum, D. W., Klejdysz, T., Subramanyam, B. and Nawrot, J. 2013. Atlas of Stored-Products Insects and Mites. AACC International Press, St. Paul, MN, USA.

Heinrichs, E. A., Medarno, E. G. and Rapusas, H. R. 1985. Genetic Evaluation for Insect Resistance in Rice. International Rice Research Institute, Los Banos, Laguna, Philippines.

Hubert, J., Doleckova-Maresova, L., Hyblova, J., Kudlikova, I., Stejskal, V. and Mares, M. 2005. *In vitro* and *in vivo* inhibition of α-amylases of stored-product mites *Acarus siro*. Experimental and Applied Acarology, 35: 281-291.

Hubert, J., Kucerova, Z., Aulicky, R., Nesvorna, M. and Stejskal, V. 2009. Differential levels of mite infestation of wheat and barley in Czech grain stores. Insect Science, 16: 255-262.

Hubert, J., Pekar, S., Aulicky, R., Nesvorna, M. and Stejskal, V. 2013. The effect of stored barley cultivars, temperature and humidity on population increase of *Acarus siro, Lepidoglyphus destructor,* and *Tyrophagus putrescentiae.* Experimental and Applied Acarology, 60: 241-252.

Hughes, A. M. 1976. The mites of stored foods and houses. Technical Bulletin, 9. Ministry of Agriculture, Fisheries and Food, Her Majesty's Stationery Office, 2nd Edition, London.

Kavallieratos, N. G., Athanassiou, C. G., Boukouvala, M. C. and Rumbos, C. I. 2018. Acaricidal effect of three zeolite formulations on different life stages of *Tyrophagus putrescentiae* (Schrank) and *Acarus siro* L. (Sarcoptiformes: Acaridae). Journal of Stored Products Research, 78: 39-44.

Khanamani, M., Fathipour, Y., Talebi, A. A. and Mehrabadi, M. 2017. Evaluation of different artificial diets for rearing the predatory mite *Neoseiulus californicus* (Acari: Phytoseiidae): diet-dependent life table studies. Acarologia, 57: 407-419.

Lopez-Castillo, L. M., Silva-Fernandez, S. E., Winkler, R., Bergvinson, D. J., Arnason, J. T. and Gracia-Lara, S. 2018. Postharvest insect resistance in maize. Journal of Stored Products Research, 77: 66-76.

Mawenda, E. T., Ringo, J. H. and Mbega, E. S. 2019. The implication of kernel phenology in convening resistance to storage weevil and varietal development in sorghum. Journal of Stored Products Research, 83: 176-184.

Palyvos, N. E. and Emmanouel, N. G. 2006. Seasonal abundance and vertical distribution of mites in flat storage containing wheat. Phytoparasitica, 34: 25-36.

Parkinson, C. L. 1990. Population increase and damage by three species of mites on wheat at 20 ºC and two humidities. Experimental and Applied Acarology, 8: 179-193.

Parkinson, C. L., Barron, C. A., Barker, S. M., Thomas, A. C. and Armitage, D. M. 1991. Longevity and fecundity of *Acarus siro* on four field and eight storage fungi. Experimental and Applied Acarology, 11: 1-8.

Rodriguez, J. G. and Rodriguez, L. D. 1987. Nutritional Ecology of Stored-Product and House Dust Mites. In: Slansky, F. andRodriguez, J.G.(Eds.). Nutritional Ecology of Insects, Mites, Spiders, and Related Invertebrates. John Wiley & Sons. pp. 345-368.

Senba, S., Tsuji, T., Kikuchi, R., Iwai, Y., Kawagoe, J., Nakamura, H. and Aoshiba, K. 2020. Oral mite anaphylaxis after ingestion of Korean pancake. Respiratory Medicine Case Reports, 30: 101026.

Sinha, R. N. 1979. Role of Acarina in the Stored Grain Ecosystem. In: Rodriguez, J. G. (Ed.). Recent Advances in Acarology. Vol. 1. Academic Press, pp. 263-272.

Skubala, P., Marzec, A. and Skolowska, M. 2006. Accidental acarophagy: mites on fruits, vegetables, and mushrooms. Biology Letters, 43: 249-255.

Solomon, M. E. 1969. Establishment, growth and decline of populations of the grain mite *Acarus siro* L. on a handful of wheat. In: Evans, G. O. (Ed.). Proceedings of 2nd International Congress Acarology. Budapest: Akademiai Kiado. pp. 255-260.

Stejskal, V. and Hubert, J. 2008. Risk of occupational allergy to stored grain arthropods and false pest-risk perception in Czech grain stores. Annals of Agricultural and Environmental Medicine, 15: 29-35.

Suprihatno, B., Daradjat, A. A., Satoto, Baehaki, S. E., Widiarta, I. N., Setyono, A., Indrasari, S. D., Lesmana, O. S. andSembiring, H. 2009. Deskripsi varietas padi. Balai Besar Tanaman Padi. (In Indonesian).

Thind, B. B. and Dunn, J. A. 2002. A laboratory evaluation of a regulated airflow through wheat at four combinations of temperature and humidity on the productivity of three species of stored product mites. Experimental and Applied Acarology, 27: 89-102.

Valdivieso, R., Iraola, V., Estupinan, M. and Fernandez-Caldas, E. 2006. Sensitization and exposure to house dust and storage mites in high-altitude areas of ecuador. Annals of Allergy, Asthma &Immunology, 97: 532-538.

Wang, Z. L., Wang, X. P., Li, C. R., Xia, Z. Z. and Li, S. X. 2018. Effect of dietary protein and carbohydrates on survival and growth in larvae of the *Henosepilachna vigintioctopunctata* (F.) (Coleoptera: Coccinellidae). Journal of Insect Science, 18: 1-7.

White, N. D. G., Demianyck, C. J. andJayas, D. S. 2003a. Multiplication of stored-product mites on canadian wheat and oilseeds cultivar. In: Credland, P. F., Armitage, D. M., Bell, C. B., Cogan, P. M. and Highley, E. (Eds.), Proceedings of the 8th International Working Conference on Stored Product protection. CAB International. pp. 402-405.

White, N. D. G., Henderson, L. P. and Sinha, R. N. 2003b. Effects of infestation by three stored-product mites on fat acidity, seed germination, and microflora of stored wheat. Journal of Economic Entomology, 72: 763-766.

Xia, B., Luo, D., Zou, Z. and Zhu, Z. 2009. Effect of temperature on the life cycle of *Aleuroglyphus ovatus* (Acari: Acaridae) at four constant temperatures. Journal of Stored Products Research, 45: 190-194.

Zaher, M. A., Mohamed, M. I. and Abdel-Halim, S. M. 1986. Incidence of mites associated with stored seeds and food products in upper Egypt. Experimental and Applied Acarology, 2: 19-24.

Zhang, X., Jasmine, D.H., Campbell, Y. L., Phillips, T. W., Goddard, J., Cheng, W. H., Kim, T., Wu, T. L. and Schilling, M. W. 2018. Biology and integrated pest management of *Tyrophagus putrescentiae* (Schrank) infesting dry cured hams. Journal of Stored Products Research, 79: 16-28.

بررسی خصوصیات فیزیکی شیمیایی محصولات انباری بر ترجیح میزبانی و زیست‌شناسی کنه ***Acarus siro*** **(Acari: Acaridae)**

رنتو دیاه پوسپیتارینی*، ایتو فرناندو، تیتا ویدجایانتی، آنیساتور راماداتین و نورول لیلاتول حسنا

گروه آفات و بیماری‌های گیاهی، دانشکده کشاورزی، دانشگاه براوجایا، وتران، مالانگ، اندونزی.

پست الکترونیکی نویسنده مسئول مکاتبه: retnodyah@ub.ac.id

دریافت: ۲ مرداد ۱۳۹۹؛ پذیرش: ۱۲ بهمن ۱۳۹۹

چکیده: کنه آرد *Acarus siro* (Acari: Acaridae) یک آفت زیان‌آور پس از برداشت برای محصولات انباری به‌شمار می‌رود. هدف این پژوهش، بررسی اثر ویژگی‌های فیزیکوشیمیایی محصولات انباری روی کنه آرد بود. در این پژوهش، ترجیح میزبانی و زیست‌شناسی کنه روی سه رقم برنج، دو رقم برنج شفته، و سه نوع مختلف پنیر مطالعه شد. در این پژوهش دانه‌بندی غلات (کامل، شکسته، و آرد) و میزان محتویات غذایی محصولات بررسی شدند. نتایج نشان داد کنه آرد، غلات شکسته را برای تغذیه و تخم-ریزی ترجیح می‌دهد. به‌علاوه، ترجیح‌های میزبانی کنه به‌وسیله تغییر محتویات غذایی در محصولات انباری تحت تأثیر قرار می‌گیرد. در آزمایش‌های زیست‌شناسی، رشدونمو کنه از ۰/۱۳ ± ۱۶/۷۸ تا ۰/۵۱± ۲۰/۶۰ روز، و زادآوری آن از ۱/۷۵ ± ۱۷/۶۵ تا ۰/۰۹ ± ۵۳/۰۵ تخم در هر کنه ماده متغیر بود. نتایج حاکی از آن است که رشدونمو سریع‌تر و زادآوری بیش‌تر کنه عموماً در رژیم‌های غذایی با محتوای پروتئین، چربی و آب بیش‌تر یافت می‌شود. به‌علاوه، کنه آرد به محصولات آردی سازگارتر است که این خود حاکی از تأثیر اندازه ذرات در رشدونمو و تولیدمثل کنه است. بنابراین، ویژگی‌های فیزیکوشیمیایی محصولات انباری به‌شدت انتخاب میزبان و زیست‌شناسی کنه آرد را تحت تأثیر قرار می‌دهد، که این امر به‌نوبه خود مشخص‌کننده میزان حساسیت محصول به آلودگی کنه انباری است.

واژگان کلیدی: آفات پس از برداشت، برنج، برنج شفته، پنیر، دستگاه اندازه ذرات بذر، شاخص کیفیت غذایی