Effect of three rearing diets on longevity, fecundity and development of the German cockroach (Dictyoptera: Blattellidae), the American cockroach (Dictyoptera: Blattidae), and the smoky-brown cockroach (Dictyoptera: Blattidae)

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Abstract: Immediately after eclosion or hatching Blattella germanica, Periplaneta americana and Periplaneta fuliginosa were reared with three types of diets (canned beef, fresh cabbage and onions [vegetables], and rat chow). The survival time of female and male P. fuliginosa was longest with the vegetable diet, while that of female and male B. germanica and P. americana was longest with the rat chow and canned beef diets. The optimum diet for reproduction was rat chow in B. germanica and P. americana adults, and vegetables in P. fuliginosa adults. The optimum diet for development was rat chow in the three species of cockroach nymphs. These results indicate that optimum diets for survival and reproduction are different between species of adult cockroaches.

Key words: cockroach, rearing diet, longevity, fecundity, development

Introduction

Blattella germanica (L.), Periplaneta americana (L.), and Periplaneta fuliginosa (Serville), which are typical sanitary insect pests, are omniphagy, and they consume various food items. Examination of an optimum diet for survival, development, and reproduction in each cockroach species is important because it could lead to the development of ideal insecticidal bait, and optimum food to maintain experimental cockroach strains. The protein content of diets strongly affects nymphal development and fecundity of adult B. germanica and P. americana (Haydak, 1953; Singh, 1977). However, few studies have been performed in P. fuliginosa (Wills et al., 1958). Appel and Smith (2002) reported that P. fuliginosa used various foods. Utsumi et al. (2014a, b) reported that the feeding habits of P. fuliginosa adults were entirely different from those of B. germanica adults, and that P. fuliginosa prefers more botanical diets. However, it is not clear whether the inter-specific difference in food preference is based on the difference in nutrient requirement among species.

This study investigated the longevity, fecundity, and development of B. germanica, P. americana, and P. fuliginosa, which were reared with three types of diets and characterize the three species by feeding biology.

Materials and Methods

Cockroaches

Laboratory colonies of B. germanica, P. americana and P. fuliginosa were used for the study. B. germanica and P. fuliginosa were collected in Akou City (Hyogo Prefecture) in the 1970s, and P. americana was collected in Kochi Prefecture in the 1970s. These colonies had been maintained with rat chow (Oriental Yeast Co., Ltd.; MF) as single food item and water. These cockroaches prefer a warm and moist environment in nature, and are common household pests in warm environments where food is prepared and stored. These species live outdoors in warm regions (Cornwell, 1968). Rearing the cockroaches and all of the experiments were performed at 25±2°C under a long-day photoperiod (14 h of light: 10 h of dark). These cockroaches were an insecticide-susceptible strain.

Rearing diets

Canned beef, fresh cabbage and onions (vegetables), and rat chow were used in the study. Canned beef was manufactured by Watties Food Industry in New Zealand and is sold as dog food with the brand name “Menu-wan” in Japan by Earth Chemical Co., Ltd. The nutrient composition of the canned beef was as follows: crude protein was greater than 8.0% (44.5% as dry weight), crude fat was greater than 5.0% (27.8% as dry weight), ash was less than 2.5% (13.9% as dry
weight), and moisture was less than 82.0%. Fresh cabbage and onions were bought in the market. The protein content of fresh cabbage and onions is less than 2% (25.0% as dry weight), crude fat was less than 0.1% (1.3% as dry weight), and moisture was less than 92%. Rat chow was the same as that used for rearing the cockroaches until the time of the study, and contained amino acids, fatty acids, lipids, and minerals affluent for well-development of rats. Crude protein content of rat chow was greater than 23% as dry weight. Canned beef was used as more animal diet. Fresh cabbage and onions are foods, which are usually used in the home and restaurants, and these were used as a vegetable diet in the current study. Rat chow is the standard diet generally used for cockroach rearing. These diets were provided in sufficient amounts so that some remained the following day. The amount given to cockroaches at one time was ca. 20g in canned beef, ca. 40g in vegetables (fresh cabbage and onions=1:1) and ca. 30g in rat chow. Canned beef rearing, vegetables rearing, and rat chow rearing were abbreviated as following BR, VR, and RR, respectively.

Methods

In all experiments we used a plastic container (38 cm in length, 28 cm in width, and 23 cm in height) that contained some cardboard harborage and water-absorbed cotton. The inner sides were painted with calcium carbonate to prevent cockroaches from escaping. To compare survival and fecundity of adults, 20 females and 20 males of B. germanica were released to each container within 5 days after eclosion, and 10 females and 10 males of P. americana, and the same number of P. fuliginosa adults were released into each container within 7 days after eclosion. We recorded the number of days of survival of adults, the number of oothecae, hatchability, and the number of nymphs per hatched ootheca in the three species of cockroach. To compare development and survival in the nymphal stage, 30 B. germanica nymphs were released into the container within 5 days after hatching and 30 P. americana and P. fuliginosa nymphs were released within 7 days after hatching. We recorded the development rate of nymphs in the three species of cockroach. These insects were reared with each rearing diet separately. Each insect had been reared with rat chow before being reared with the experimental rearing diet. Canned beef and vegetables were replaced with fresh food every day, and rat chow and water were supplied at any time.

As the indicators of fecundity, the number of oothecae, hatchability, and the number of nymphs per hatched ootheca were examined. Oothecae of P. americana and P. fuliginosa were collected every day, and they were placed in a plastic Petri dish (9.5 cm in diameter, 1.8 cm in height) one each. These were then placed in a sealed large plastic container (38 cm in length, 28 cm in width, and 23 cm in height) containing water in the bottom to maintain ca. 100% relative humidity until hatching. Oothecae eaten by adults and destroyed by accidents were excluded from calculation of hatchability in P. americana and P. fuliginosa. Oothecae of B. germanica were kept in with adults until nymphs hatched; hatched nymphs and sloughs of ootheca were counted and removed every day. In all experiments, dead insects were removed from the rearing container every day. Mann–Whitney U test was used to compare the number of days of survival of adults and days to eclosion of nymphs between the species. Chi-square test was used to compare the hatchability and eclosion rate of nymphs between different diet conditions. These experiments were continued until all cockroaches died. Each examination was carried out once.

Results

Longevity of adults

The adult longevity of the three cockroach species fed with different diets was compared in Fig. 1. Both female and male adults of B. germanica survived longest with RR (median, 193 days and 125 days, respectively) and shortest with VR (114.5 days and 19.5 days). The survival time with BR (165.5 days and 92 days) was slightly shorter than that with RR. In both sexes, the survival time with VR was significantly shorter than that with BR or RR both (p<0.01 for each). In male, the survival time with RR was significantly longer than that with BR (p<0.01).

Female adults of P. americana survived longest with RR (median, 415.5 days) and shortest with VR (281.5 days), similarly to B. germanica adults. Male adults of P. americana survived longest with BR (442 days) and shortest with VR (342.5 days). In female, the survival time with VR was significantly shorter than that with BR (p<0.05), and that with VR was significantly longer than that with BR (p<0.05). In male, the survival time with BR was significantly longer than that with VR (p<0.05).

In contrast to B. germanica and P. americana, both female and male adults of P. fuliginosa survived longest with VR (median, 161 days and 117.5 days, respectively) and shortest with BR (60 days and 82 days). In female, the survival time with VR was significantly shorter than that with BR (p<0.01), and with RR (p<0.05). Further, the survival time with VR was significantly longer than that with RR (121.5 days, p<0.05). In male, the survival time with VR was significantly longer than that with BR (p<0.05), and that with RR (91 days) was slightly shorter than that with VR.

Fecundity of adults

The fecundity of the three cockroach species fed with different diets was compared in Table 1. The number of B. germanica and P. americana oothecae was largest in RR, followed by BR in the former and VR in the latter. Unlike these species, P. fuliginosa showed the largest
Hatchability of *B. germatica* oothecae was high in VR (100%) and BR (92.8%), but slightly lower in RR (85.5%; significantly lower than VR). Hatchability of *P. americana* was similar in three conditions (69.0% – 74.2%; not significantly different among treatments). Hatchability of *P. fuliginosa* was highest in VR (87.2%) but that in BR (52.4%) was significantly lower than VR or RR. The cumulative number of hatched nymphs and mean number of nymphs per ootheca of *B. germanica* were largest in RR and smallest in VR. The cumulative number of hatched nymphs of *P. americana* was nearly proportional to the number of oothecae and the number of nymphs per ootheca was similar among the three conditions (12.7 – 13.8). The cumulative number of hatched nymphs of *P. fuliginosa* was slightly larger in VR (2198) than in RR (2102), and it was much smaller in BR (208). The number of nymphs per ootheca was similar among conditions (18.9 – 23.4).

Eclosion and development rate of nymphs

Eclosion and development rate of the three cockroach species fed with different diets was compared in Table 2. In all species, eclosion rate was highest in RR and lowest in BR. The difference in eclosion rate between different conditions was significant in the three species except VR and RR in *P. americana*. The days to eclosion were shortest with RR in all species of cockroach nymphs, and those were longest with BR in *B. germanica* and *P. fuliginosa*. The difference in the days to eclosion was significant in all comparisons in each species. Statistical analysis was not performed for BR in *B. germatica* and *P. americana* because there were few or no emerged adults.

In addition to above comparisons, we observed number of oothecae in VR, followed by RR and BR.

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The cumulative number of hatched nymphs and mean number of nymphs per ootheca of *B. germanica* were largest in RR and smallest in VR. The cumulative number of hatched nymphs of *P. americana* was nearly proportional to the number of oochae and the number of nymphs per ootheca was similar among the three conditions (12.7 – 13.8). The cumulative number of hatched nymphs of *P. fuliginosa* was slightly larger in VR (2198) than in RR (2102), and it was much smaller in BR (208). The number of nymphs per ootheca was similar among conditions (18.9 – 23.4).

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In addition to above comparisons, we observed...
differences in some morphological and behavioral aspects among rearing conditions. Body color of nymphs with BR and VR became lighter at approximately 30 days after initiating feeding, whereas it did not change with RR in the three species of cockroach. In *B. germanica* and *P. fuliginosa*, cannibalism was observed in VR and BR but not in RR. In *P. americana*, cannibalism was observed in all rearing condition, but it was limited in the early stage in RR. All of the nymphs that did not develop into adults died within 136 days in BR in *B. germanica*. Adults, which started appearing at 379 days, had curly wings in BR in *P. fuliginosa*. In *P. americana*, a few nymphs in BR survived for 500 days, but they did not develop into adults, and all of them died.

**Discussion**

In the present study, the number of days of survival of female and male *P. fuliginosa* was longest with VR, but that of *B. germanica* and *P. americana* was longest with RR or BR. Haydak (1953) reported that the optimum protein level for the longevity of cockroach adults is 11–24% in *B. germanica* and 2.5–49% in *P. americana*. Hamilton and Schal (1988) reported that *B. germanica* reared with diet containing 5% protein survived longest. These findings indicate that diets containing a low level protein, such as fresh cabbage and onions, are not suitable for *B. germanica* and *P. americana* adults. However, the results of *P. fuliginosa* adults were different from those of *B. germanica* and *P. americana* adults. These results suggest that optimum diets for the longevity of *P. fuliginosa* adults include a low protein, such as fresh cabbage and onions, which contain less protein than canned beef. In particular, the number of oothecae and hatched nymphs is large in *P. fuliginosa* because the number of oothecae and hatched nymphs was slightly larger than that of rat chow in *P. fuliginosa*. These results suggest that optimum diets for reproduction are different between species.

In the present study, the optimum diet for development was rat chow in *B. germanica* and *P. americana* adults, and vegetables in *P. fuliginosa* adults. Furthermore, hatchability changed depending on the type of rearing diet. Particularly, hatchability of *P. fuliginosa* adults reared with canned beef was low. Similarly, *B. germanica* and *P. americana* showed highest fecundity in terms of total number of oothecae and that of hatched nymphs in RR, whereas those of *P. fuliginosa* were highest in VR. Aguilera et al. (1998) reported that the reproductive capacity of *B. germanica* increased, when their food contained protein. Cooper and Schal (1992) also reported that oocytes of *B. germanica* raised on rat food matured more quickly than those raised on dog food when reared on three commercial diets. In our study, the results in *B. germanica* reared with canned beef or rat chow, which contains an abundant amount of protein, are similar to those of Aguilera et al. However, the results in *P. americana* and *P. fuliginosa* were different to those of *B. germanica* because the number of oothecae and hatched nymphs is large in vegetables, which contain less protein than canned beef. In particular, the number of oothecae and hatched nymphs was slightly larger than that of rat chow in *P. fuliginosa*. These results suggest that optimum diets for reproduction are different between species.

In the present study, the optimum diet for development was rat chow, followed by vegetables in the three species of cockroach nymphs. *B. germanica* and *P. americana* require a high protein diet for good nymphal development (Haydak, 1953; Singh, 1977). Cooper and Schal (1992) reported that *B. germanica* nymphs fed with rat food developed significantly faster than those fed with two commercial dog foods. Aguilera et al. (1998) showed that nymphal development of *B. germanica* was faster, when their food contained protein. Utsumi et al. (2014b) also showed that *B. germanica* adults ate canned beef, whereas *P. fuliginosa* adults hardly ate canned beef but preferred vegetables. The results of the present study suggest that the inter-specific difference in diet preference reported in the previous reports was based on the species-specific nutritional requirement.

In our study, the optimum diet for reproduction was generally rat chow in *B. germanica* and *P. americana* adults, and vegetables in *P. fuliginosa* adults.
study, the development rate of *B. germanica* nymphs reared with canned beef was slow. It is necessary to research more though the reason is uncertain. At least, it was clear that rat chow is suitable for development of the three species of cockroach nymphs. Body color changed to a lighter color with BR and VR during the rearing period, but it did not change with RR in all species of cockroach nymphs. Cannibalism did not occur with RR in *B. germanica* or *P. fuliginosa* nymphs, but it occurred in all rearing conditions in *P. americana*. We assume that cannibalism and feeding of oothecae influence the results. In addition, adults that started appearing at 379 days had curly wings with BR in *P. fuliginosa*. Change in body color, increased cannibalism, and curly wing of adults in BR or VR also suggest that canned beef and vegetables are not suitable diet for nymphal development. In *P. fuliginosa*, rat chow was optimum diet for nymphal development, while vegetables was optimum diets for survival and reproduction of adults.

The present study has some limitations. First, each experiment was carried out only once. Second, food items used in the present study was limited and mixed items were not given. In addition, the newly emerged adults used in the experiments were fed with rat chow, which might influence the results. These issues need to be addressed in future studies.

In conclusion, unlike *B. germanica* and *P. americana* which survive and reproduce best with rat chow, the highest survival and reproduction of *P. fuliginosa* adults were observed when they were fed with vegetables. In the nymphal stage, however, all the three species survived and developed best with rat chow. These findings indicate that all cockroaches have their own optimum diets for survival, reproduction, and development. This information could lead to the development of the ideal insecticidal bait, and that is available for maintenance of experimental cockroach strains. In particular, in *P. fuliginosa*, some nourishment elements included in vegetable might be able to be used for insecticidal baits and rearing diets. These results also suggest that diet influences the location of domestic and peridomestic cockroaches.

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**References**


