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Interspecific competition between the Smooth cockroach *Symploce pallens* and the German cockroach *Blattella germanica* (Dictyoptera: Blattellidae) under different food and water regimes

Bujang, N.S.[1] and Lee, C.Y.[2,3]
[1] Department of Entomology and Nematology, Ft Lauderdale Research and Education Center, University of Florida, Institute of Food and Agricultural Sciences, 3205 College Ave, Ft Lauderdale, FL 33314.
[2] Urban Entomology Laboratory, Vector Control Research Unit, School of Biological Sciences, Universiti Sains Malaysia, 11800 Penang, Malaysia.
[3] Corresponding author email: chowyang@usm.my
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Abstract. The interspecific competition between a new cockroach pest species in Southeast Asia, the Smooth cockroach, *Symploce pallens* (Stephens) and the ubiquitous German cockroach, *Blattella germanica* (L.) was studied under different food and water regimes (unlimited food and water [control], limited water, limited food and limited food and water). Both species were found to have equal chances to coexist when both food and water are unlimited, when food is a limiting factor, and when both food and water are limited. However, under shorter evaluation periods (eg. 60 and 120 days), the intrinsic rate of increase (r_n) of *S. pallens* appeared to be significantly lower than that of the *B. germanica*. This is possibly due to the shorter nymphal development period and higher fecundity of the latter species when compared to *S. pallens*. Both the food and water availability factor showed significant effects on the r_n of both species.

INTRODUCTION

Cockroaches are an important group of insect pests in the urban environment. In the tropics, infestation may be caused by more than one cockroach species in a specific location. In Southeast Asia, the German cockroach, *Blattella germanica* (L.) and the American cockroach, *Periplaneta americana* (L.) are the two most common cockroach species found in buildings and structures. In addition, other species such as brown-banded cockroach (*Supella longipalpa* [F.]), brown cockroach (*Periplaneta brunnea* Burmeister), Australian cockroach (*Periplaneta australasiae* [Fab.]) and Harlequin cockroach (*Neostylopyga rhombifolia* [Stoll]) are also considered as sympatric species (Lee & Robinson, 2001; Lee, 2007; Lee & Ng, 2009).

Symploce pallens (Stephens) is a relatively new pest cockroach species found to infest domiciles in Malaysia and Singapore (Jeffery *et al.*, 1997; Lee & Lee, 2000; Lee *et al.*, 2000; Lee & Ng, 2009; Bujang & Lee, 2010). This species is small (12.5 – 14.5 mm in length), yellowish-brown in colour, and the antenna is black with a light brown base. Its nymphs are dark brown with no distinct feature on their pronotum (Jeffery *et al.*, 1997).

Little is known about *S. pallens*' coexistence with other species of cockroaches. It would be interesting to determine how this species competes with the common cockroach species in Southeast Asia under different environmental regimes (eg. under limited food and water conditions. We address this issue by examining interspecific competition between *S. pallens* and *B. germanica* under different food regimes.

MATERIALS AND METHODS

Cockroach colony

Symploce pallens used in this study was obtained from laboratory colonies established earlier from wild cockroaches collected from Kampung Melayu and Sungai Batu in Penang Island, Malaysia between June and December 1998. The susceptible strain (ICI) of *B. germanica*, used in this study, had been reared for more than 40 years without insecticide exposure. Both species were reared in polyethylene aquaria measuring 35 x 19 x 28 cm (Guppy Plastic Ind. Sdn. Bhd., Selangor, Malaysia) under the conditions of 27.5 ± 2.0 ºC in temperature, 60 ± 5% R.H. and 12/12 hour photo/scotoperiod. Rolled corrugated cardboards as harbourages, water and mouse pellets (Gold Coin, Penang, Malaysia) were provided *ad libitum*.

Interspecific competition

Late instars of *B. germanica* and *S. pallens* were collected from the culture into new polyethylene tanks (35 x 19 x 28 cm) where they were immediately segregated by sex every 12 hours after emerging into adults to prevent mating. For the purpose of this study, five pairs of virgin adults, ten early instars, ten intermediate instars and ten late instars of each species were placed together with those of the other species in the same tank for interspecific competitions. We tested the insects under one of the following three conditions: (1) food and water once every three days, (2) food once every three days with a continuous supply of water, or (3) water once every three days with a continuous supply of water. We performed three replicates for each of these regimes. Three tanks provided with continuous water and food supplies served as control.

Absolute counting was made at 30 days interval up to 360 days where the individuals were sorted by both the species and nymphal age groups. For *B. germanica*, instars 1 to 2, instars 3 to 5 and instars 6 to 8 were considered as early, intermediate and late nymphs, respectively. For *S. pallens*, the early, intermediate and late nymphs' age group were instars 1 to 3, instars 4 to 7 and instars 8 to 10, respectively. Counts were made using a hand tally (Model: H-102, Line, Tokyo, Japan) by removing every individual from the culturing tank using a glass vial. During this time and whenever the need arose, cleaning was done while keeping the number of unavoidable deaths at a minimum level.

Data analysis

The calculation for population intrinsic rate of increase, r_n followed exactly that of Lee *et al.* (1996): $r_n = [\ln(n_{t+1}) - \ln(n_t)] / \text{time}$, where r_n = daily rate of population increase, n_t = population at time t, n_{t+1} = population at time t+1, and time = difference between t = 1 and t. The r_n calculations were made on both the categories and the total number of individuals as a whole. The differences of the population r_n between species under different regimes were analyzed using one-tailed two-sample *t* test (SPSS Inc., version 11.0.1). Two-way ANOVA was used to determine the interaction of species and different feeding regimes on the r_n using Minitab 11 (Minitab Inc., State College, PA).

RESULTS AND DISCUSSION

The effects on the interspecific competition between *S. pallens* and *B. germanica* (r_n) placed under different feeding regimes were shown in Table 1 – Table 4. For cockroaches provided with unlimited access to food and water (Table 1), the r_n for all stages of *S. pallens* was significantly reduced in the first two months after establishment compared to that of *B. germanica*, possibly because *S. pallens* had a longer nymphal development period when compared to *B. germanica*. Bujang & Lee (2010) reported that the mean nymphal development period for *S. pallens* was 118.2 ± 1.7 days, when compared to that of the German cockroach which registered only 42.4 ± 0.4 days (Bujang, 2004). However, the r_n rebound after 60 days and both species showed an equally intense degree of competitiveness over time. At the end of the one year, the mean r_n of both species were insignificantly different from each other. This suggested that both species had an equal chance to coexist in an environment where food and water were plentiful.

Table 1. Interspecific competition between *S. pallens* and *B. germanica* (r_n) under normal regime (control)

Days after establishment	Stage	Mean r_n ± S.E.M. (day^{-1}) [1]	
		S. pallens	*B. germanica*
30	Male	0.0228 ± 0.0053	0.0010 ± 0.0084
	Female	0.0143 ± 0.0044	0.0177 ± 0.0011
	Early	-0.0768 ± 0.0000	0.1089 ± 0.0038
	Intermediate	-0.0125 ± 0.0090	-0.0312 ± 0.0049
	Late	-0.0104 ± 0.0121	-0.0213 ± 0.0094
	All	0.0010 ± 0.0017	0.0589 ± 0.0033*a*
60	Male	0.0123 ± 0.0013	-0.0146 ± 0.0061
	Female	0.0096 ± 0.0020	0.0025 ± 0.0005
	Early	0.0486 ± 0.0025	0.0405 ± 0.0033
	Intermediate	-0.0148 ± 0.0062	0.0580 ± 0.0021
	Late	-0.0179 ± 0.0046	-0.0169 ± 0.0016
	All	0.0256 ± 0.0021	0.0387 ± 0.0035*a*
90	Male	0.0084 ± 0.0007	0.0251 ± 0.0008
	Female	0.0060 ± 0.0009	0.0208 ± 0.0015
	Early	0.0449 ± 0.0020	0.0252 ± 0.0047
	Intermediate	-0.0110 ± 0.0017	0.0359 ± 0.0012
	Late	-0.0205 ± 0.0026	0.0245 ± 0.0046
	All	0.0278 ± 0.0018	0.0284 ± 0.0004*b*
120	Male	0.0033 ± 0.0015	0.0212 ± 0.0001
	Female	0.0008 ± 0.0026	0.0206 ± 0.0004
	Early	0.0224 ± 0.0095	0.0100 ± 0.0050
	Intermediate	0.0215 ± 0.0010	0.0248 ± 0.0014
	Late	-0.0173 ± 0.0019	0.0138 ± 0.0010
	All	0.0266 ± 0.0033	0.0199 ± 0.0009*b*
150	Male	-0.0020 ± 0.0013	0.0099 ± 0.0016
	Female	-0.0032 ± 0.0009	0.0152 ± 0.0003
	Early	0.0272 ± 0.0014	0.0280 ± 0.0048
	Intermediate	0.0217 ± 0.0005	0.0276 ± 0.0008
	Late	-0.0129 ± 0.0025	0.0087 ± 0.0028
	All	0.0141 ± 0.0043	0.0234 ± 0.0020*b*
180	Male	-0.0057 ± 0.0044	0.0086 ± 0.0010
	Female	-0.0015 ± 0.0022	0.0115 ± 0.0014
	Early	0.0237 ± 0.0011	0.0260 ± 0.0010
	Intermediate	0.0204 ± 0.0016	0.0275 ± 0.0011
	Late	-0.0022 ± 0.0012	0.0113 ± 0.0025
	All	0.0713 ± 0.0013	0.0223 ± 0.0003*c*

Table 1, continued

210	Male	0.0017 ± 0.0004	0.0083 ± 0.0007
	Female	0.0019 ± 0.0007	0.0094 ± 0.0004
	Early	0.0218 ± 0.0003	0.0212 ± 0.0005
	Intermediate	0.0181 ± 0.0013	0.0219 ± 0.0003
	Late	0.0027 ± 0.0006	0.0102 ± 0.0018
	All	0.0161 ± 0.0006	0.0178 ± 0.0001*b*
240	Male	0.0037 ± 0.0005	0.0076 ± 0.0004
	Female	0.0030 ± 0.0003	0.0082 ± 0.0006
	Early	0.0197 ± 0.0004	0.0190 ± 0.0004
	Intermediate	0.0189 ± 0.0005	0.0191 ± 0.0006
	Late	0.0025 ± 0.0004	0.0091 ± 0.0012
	All	0.0157 ± 0.0004	0.0157 ± 0.0002*b*
270	Male	0.0036 ± 0.0005	0.0061 ± 0.0007
	Female	0.0029 ± 0.0004	0.0077 ± 0.0004
	Early	0.0168 ± 0.0003	0.0166 ± 0.0003
	Intermediate	0.0173 ± 0.0005	0.0174 ± 0.0004
	Late	0.0029 ± 0.0003	0.0073 ± 0.0010
	All	0.0138 ± 0.0003	0.0149 ± 0.0002*b*
300	Male	0.0039 ± 0.0003	0.0056 ± 0.0005
	Female	0.0034 ± 0.0004	0.0067 ± 0.0002
	Early	0.0153 ± 0.0004	0.0147 ± 0.0003
	Intermediate	0.0159 ± 0.0004	0.0159 ± 0.0003
	Late	0.0037 ± 0.0007	0.0072 ± 0.0007
	All	0.0127 ± 0.0001	0.0127 ± 0.0001*b*
330	Male	0.0038 ± 0.0003	0.0048 ± 0.0004
	Female	0.0029 ± 0.0003	0.0056 ± 0.0002
	Early	0.0141 ± 0.0004	0.0131 ± 0.0002
	Intermediate	0.0142 ± 0.0003	0.0142 ± 0.0004
	Late	0.0041 ± 0.0004	0.0068 ± 0.004
	All	0.0115 ± 0.0001	0.0113 ± 0.0002*b*
360	Male	0.0041 ± 0.0003	0.0044 ± 0.0004
	Female	0.0032 ± 0.0004	0.0057 ± 0.0005
	Early	0.0125 ± 0.0001	0.0128 ± 0.0003
	Intermediate	0.0132 ± 0.0004	0.0133 ± 0.0004
	Late	0.0042 ± 0.0003	0.0057 ± 0.0004
	All	0.0106 ± 0.0001	0.0108 ± 0.0001*b*

[1] Means within the same row followed by a letter are significantly different ($P < 0.05$; One-tailed two-sample *t* test). To compare means, letters used were *a* ($\mu_{S.\ pallens} < \mu_{B.\ germanica}$), *b* ($\mu_{S.\ pallens} = \mu_{B.\ germanica}$) and *c* ($\mu_{S.\ pallens} > \mu_{B.\ germanica}$).

Under the situation where water was scarce (Table 2), results demonstrated that *S. pallens* species had a significantly ($P < 0.05$) higher r_n compared to that of *B. germanica* after 4 months, suggesting that this species could withstand a drier environment better than the *B. germanica*. However, under longer evaluation period (eg. >150 days), the mean r_n of *S. pallens* appeared to be comparable with that of the

B. germanica. Cochran (1983) reported high susceptibility towards food and water deprivation in *B. germanica*, causing smaller-sized and less ootheca to be produced. According to Tucker (1977), late instar nymphs lost weight more slowly and lived longer than adult *Periplaneta americana* due to the large lipid storage in their body fat. A study conducted earlier by Melton (1995) suggested the *B. germanica* and *S. longipalpa* did not differ in vulnerability towards the lack of water, but *S. longipalpa* nymphs were more able to produce and utilize extra metabolic water from the limited food source. Therefore, the need for supplementary water decreased with the increase in body size.

Table 2. Interspecific competition between *S. pallens* and *B. germanica* (r_n) given continuous food but water once every 3 days

Days after establishment	Stage	Mean r_n ± S.E.M. (day^{-1}) [1]	
		S. pallens	*B. germanica*
30	Male	0.0127 ± 0.0015	0.0074 ± 0.0067
	Female	-0.0028 ± 0.0075	0.0076 ± 0.0031
	Early	-0.0768 ± 0.0000	-0.0320 ± 0.0212
	Intermediate	0.0083 ± 0.0057	-0.0104 ± 0.0015
	Late	-0.0243 ± 0.0147	-0.0295 ± 0.0125
	All	-0.0046 ± 0.0015	-0.0062 ± 0.0037*b*
60	Male	0.0037 ± 0.0069	-0.0195 ± 0.0044
	Female	0.0041 ± 0.0021	-0.0027 ± 0.0022
	Early	0.0378 ± 0.0012	0.0270 ± 0.0118
	Intermediate	-0.0074 ± 0.0049	0.0474 ± 0.0004
	Late	-0.0157 ± 0.0025	-0.0384 ± 0.0000
	All	0.0170 ± 0.0008	0.0273 ± 0.0032*a*
90	Male	0.0029 ± 0.0017	-0.0164 ± 0.0015
	Female	-0.0024 ± 0.0040	-0.0033 ± 0.0048
	Early	0.0414 ± 0.0110	0.0171 ± 0.0050
	Intermediate	-0.0105 ± 0.0037	0.0254 ± 0.0010
	Late	-0.0171 ± 0.0052	0.0246 ± 0.0019
	All	0.0243 ± 0.0009	0.0180 ± 0.0018*b*
120	Male	-0.0084 ± 0.0008	-0.0173 ± 0.0019
	Female	-0.0109 ± 0.0042	-0.0131 ± 0.0031
	Early	0.0294 ± 0.0004	0.0036 ± 0.0039
	Intermediate	0.0127 ± 0.0021	0.0142 ± 0.0017
	Late	-0.0192 ± 0.0000	-0.0142 ± 0.0027
	All	0.0173 ± 0.0003	0.0039 ± 0.0010*c*
150	Male	-0.0154 ± 0.0000	-0.0129 ± 0.0025
	Female	-0.0154 ± 0.0000	-0.0129 ± 0.0025
	Early	0.0130 ± 0.0031	-0.0052 ± 0.0054
	Intermediate	0.0153 ± 0.0021	0.0089 ± 0.0026
	Late	-0.0154 ± 0.0000	0.0047 ± 0.0010
	All	0.0060 ± 0.0020	0.0021 ± 0.0020*b*

Table 2, continued

180	Male	-0.0128 ± 0.0000	-0.0022 ± 0.0028
	Female	-0.0128 ± 0.0000	-0.0014 ± 0.0010
	Early	0.0120 ± 0.0010	0.0028 ± 0.0004
	Intermediate	0.0050 ± 0.0020	0.0044 ± 0.0013
	Late	-0.0128 ± 0.0000	-0.0056 ± 0.0005
	All	0.0047 ± 0.0008	00008 ± 0.0006*b*
210	Male	-0.0110 ± 0.0000	-0.0110 ± 0.0000
	Female	-0.0110 ± 0.0000	-0.0092 ± 0.0018
	Early	0.0088 ± 0.0005	0.0031 ± 0.0045
	Intermediate	0.0065 ± 0.0003	0.0066 ± 0.0006
	Late	-0.0110 ± 0.0000	-0.0018 ± 0.0015
	All	0.0035 ± 0.0003	0.0023 ± 0.0011*b*
240	Male	-0.0096 ± 0.0000	-0.0086 ± 0.0010
	Female	-0.0096 ± 0.0000	-0.0086 ± 0.0010
	Early	0.0069 ± 0.0004	0.0010 ± 0.0040
	Intermediate	0.0052 ± 0.0004	0.0032 ± 0.0009
	Late	-0.0011 ± 0.0005	-0.0023 ± 0.0015
	All	0.0029 ± 0.0003	0.0001 ± 0.0011*b*
270	Male	-0.0077 ± 0.0008	-0.0077 ± 0.0008
	Female	-0.0085 ± 0.0000	-0.0077 ± 0.0008
	Early	0.0058 ± 0.0003	0.0011 ± 0.0029
	Intermediate	0.0041 ± 0.0004	0.0030 ± 0.0015
	Late	-0.0005 ± 0.0006	-0.0016 ± 0.0014
	All	0.0021 ± 0.0003	0.0002 ± 0.0011*b*
300	Male	-0.0077 ± 0.0000	-0.0069 ± 0.0008
	Female	-0.0077 ± 0.0000	-0.0077 ± 0.0000
	Early	0.0049 ± 0.0003	-0.0001 ± 0.0027
	Intermediate	0.0031 ± 0.0004	0.0035 ± 0.0010
	Late	-0.0007 ± 0.0005	-0.0023 ± 0.0013
	All	0.0015 ± 0.0003	0.0001 ± 0.0009*b*
330	Male	-0.0063 ± 0.0007	-0.0063 ± 0.0007
	Female	-0.0070 ± 0.0000	-0.0056 ± 0.0007
	Early	0.0040 ± 0.0004	0.0002 ± 0.0019
	Intermediate	0.0020 ± 0.0002	0.0029 ± 0.0007
	Late	-0.0013 ± 0.0005	-0.0026 ± 0.0017
	All	0.0008 ± 0.0002	-0.0001 ± 0.0006*b*
360	Male	-0.0054 ± 0.0010	-0.0064 ± 0.0000
	Female	-0.0058 ± 0.0006	-0.0047 ± 0.0009
	Early	-0.0043 ± 0.0071	-0.0007 ± 0.0020
	Intermediate	0.0013 ± 0.0001	0.0026 ± 0.0009
	Late	-0.0023 ± 0.0006	-0.0017 ± 0.0012
	All	0.0001 ± 0.0001	-0.0002 ± 0.0006*b*

[1] Means within the same row followed by a letter are significantly different ($P < 0.05$; One-tailed two-sample t test). To compare means, letters used were *a* ($\mu_{S.\ pallens} < \mu_{B.\ germanica}$), *b* ($\mu_{S.\ pallens} = \mu_{B.\ germanica}$) and *c* ($\mu_{S.\ pallens} > \mu_{B.\ germanica}$).

Table 3 demonstrated the interspecific competition between *S. pallens* and *B. germanica* held under an environment where water was plentiful but the food supply was limited. Both species demonstrated an equal competitiveness in co-existence displayed by comparable r_n values with no significant ($P > 0.05$) difference, except at day 60 when the mean r_n of *S. pallens* was significantly higher than that of the alternate species. After one year, the population growth was not significantly different from each other. Noland & Baumann (1951), Haydak (1953), Hamilton & Schal (1988) and Cooper & Schal (1992) reported that *B. germanica* was highly sensitive to food deprivation. Similar situation was obviously applicable to *S. pallens*.

Table 3: Interspecific competition between *S. pallens* and *B. germanica* (r_n) given continuous water but food only once every 3 days.

Days after establishment	Stage	Mean r_n ± S.E.M. (day^{-1}) [1]	
		S. pallens	*B. germanica*
30	Male	0.0061 ± 0.0097	-0.0022 ± 0.0060
	Female	-0.0019 ± 0.0106	0.0068 ± 0.0045
	Early	-0.0768 ± 0.0000	0.0084 ± 0.0205
	Intermediate	0.0100 ± 0.0037	-0.0243 ± 0.0153
	Late	-0.0089 ± 0.0043	-0.0292 ± 0.0122
	All	-0.0017 ± 0.0014	-0.0073 ± 0.0108*b*
60	Male	0.0110 ± 0.0020	-0.0384 ± 0.0000
	Female	0.0176 ± 0.0098	-0.0001 ± 0.0010
	Early	0.0240 ± 0.0090	-0.0140 ± 0.0128
	Intermediate	-0.0024 ± 0.0006	0.0009 ± 0.0068
	Late	-0.0168 ± 0.0053	-0.0307 ± 0.0039
	All	0.0109 ± 0.0039	-0.0076 ± 0.0031*c*
90	Male	0.0076 ± 0.0012	-0.0230 ± 0.0026
	Female	0.0037 ± 0.0010	-0.0042 ± 0.0017
	Early	0.0382 ± 0.0016	0.0246 ± 0.0009
	Intermediate	-0.0041 ± 0.0009	0.0254 ± 0.0022
	Late	-0.0164 ± 0.0015	0.0219 ± 0.0032
	All	0.0219 ± 0.0014	0.0189 ± 0.0018*b*
120	Male	-0.0005 ± 0.0021	0.0121 ± 0.0028
	Female	-0.0077 ± 0.0058	0.0139 ± 0.0020
	Early	0.0302 ± 0.0011	0.0154 ± 0.0023
	Intermediate	0.0199 ± 0.0019	0.0193 ± 0.0007
	Late	-0.0117 ± 0.0040	-0.0054 ± 0.0064
	All	0.0189 ± 0.0014	0.0144 ± 0.0011*b*
150	Male	-0.0026 ± 0.0011	0.0054 ± 0.0032
	Female	-0.0020 ± 0.0013	0.0117 ± 0.0017
	Early	0.0236 ± 0.0016	0.0240 ± 0.0034
	Intermediate	0.0194 ± 0.0011	0.0172 ± 0.0012
	Late	-0.0154 ± 0.0000	0.0099 ± 0.0015
	All	0.0160 ± 0.0012	0.0171 ± 0.0024*b*

Table 3, continued

180	Male	-0.0089 ± 0.0022	-0.0002 ± 0.0064
	Female	-0.0076 ± 0.0034	0.0021 ± 0.0075
	Early	0.0177 ± 0.0014	0.0209 ± 0.0024
	Intermediate	0.0156 ± 0.0018	0.0155 ± 0.0020
	Late	-0.0128 ± 0.0000	-0.0023 ± 0.0053
	All	0.0118 ± 0.0016	0.0143 ± 0.0022*b*
210	Male	0.0009 ± 0.0005	0.0036 ± 0.0016
	Female	-0.0006 ± 0.0014	0.0046 ± 0.0026
	Early	0.0164 ± 0.0009	0.0175 ± 0.0022
	Intermediate	0.0150 ± 0.0005	0.0151 ± 0.0012
	Late	-0.0077 ± 0.0019	0.0061 ± 0.0012
	All	0.0116 ± 0.0007	0.0130 ± 0.0016*b*
240	Male	0.0020 ± 0.0001	0.0036 ± 0.0013
	Female	0.0010 ± 0.0006	0.0043 ± 0.0020
	Early	0.0149 ± 0.0007	0.0146 ± 0.0018
	Intermediate	0.0131 ± 0.0005	0.0128 ± 0.0014
	Late	-0.0018 ± 0.0022	0.0046 ± 0.0008
	All	0.0106 ± 0.0006	0.0107 ± 0.0014*b*
270	Male	0.0018 ± 0.0004	0.0026 ± 0.0009
	Female	0.0007 ± 0.0009	0.0036 ± 0.0020
	Early	0.0128 ± 0.0009	0.0131 ± 0.0016
	Intermediate	0.0118 ± 0.0004	0.0113 ± 0.0011
	Late	0.0029 ± 0.0004	0.0035 ± 0.0005
	All	0.0096 ± 0.0012	0.0095 ± 0.0013*b*
300	Male	0.0011 ± 0.0005	0.0023 ± 0.0005
	Female	0.0010 ± 0.0004	0.0035 ± 0.0014
	Early	0.0119 ± 0.0007	0.0065 ± 0.0041
	Intermediate	0.0102 ± 0.0005	0.0105 ± 0.0010
	Late	0.0014 ± 0.0004	0.0035 ± 0.0004
	All	0.0084 ± 0.0006	0.0087 ± 0.0010*b*
330	Male	0.0006 ± 0.0004	0.0008 ± 0.0008
	Female	0.0014 ± 0.0003	0.0024 ± 0.0018
	Early	0.0109 ± 0.0004	0.0109 ± 0.0013
	Intermediate	0.0092 ± 0.0006	0.0092 ± 0.0011
	Late	0.0042 ± 0.0035	0.0037 ± 0.0003
	All	0.0076 ± 0.0004	0.0079 ± 0.0010*b*
360	Male	0.0004 ± 0.0008	0.0015 ± 0.0011
	Female	0.0006 ± 0.0006	0.0022 ± 0.0020
	Early	0.0090 ± 0.0010	0.0101 ± 0.0011
	Intermediate	0.0085 ± 0.0004	0.0083 ± 0.0010
	Late	0.0011 ± 0.0004	0.0030 ± 0.0006
	All	0.0070 ± 0.0003	0.0072 ± 0.0009*b*

[1] Means within the same row followed by a letter are significantly different ($P < 0.05$; One-tailed two-sample t test). To compare means, letters used were *a* ($\mu_{S.\ pallens} < \mu_{B.\ germanica}$), *b* ($\mu_{S.\ pallens} = \mu_{B.\ germanica}$) and *c* ($\mu_{S.\ pallens} > \mu_{B.\ germanica}$).

The interspecific competition between *S. pallens* and *B. germanica* where both food and water were scarce were shown in Table 4. The r_n value fluctuated between both species over time towards the end of the one-year period. The mean r_n of both species was only markedly different 30 days after inauguration. This suggested that both species, although showing evident food and water interdependence, had an equal survival rate in a dry and starved place, showing matching competitiveness in fight for food and water. Wharton *et al.* (1965) reported that the longevity of cockroaches was relatively longer than that of flies and locusts under conditions of complete food deprivation.

Reynierse *et al.* (1972) reported that in *Nauphoeta cinerea* (Olivier), water availability was more important than food. The effects of food and water deprivation have been reported to cause physiological changes such as blood volume (Wharton *et al.*, 1965), juvenile hormone synthesis and oocyte development in cockroaches such as *P. americana* (Weaver, 1984) and locusts such as *Schistocerca americana gregaria* (Drury) (Tobe & Chapman, 1979).

Overall results demonstrated that different feeding regimes affected the interspecific competition between both species. When evaluating under shorter period (eg. 60 and 120 days), *B. germanica* had an advantage over *S. pallens* when food and water were abundant because it has shorter life-cycle. However, if the evaluation period is prolonged up to 1 year, there appeared to be no significant difference between the two species of cockroaches. Both species showed equal chance of survival and it is concluded here that both species are possibly likely to co-exist in infested premises.

Table 4. Interspecific competition between *S. pallens* and *B. germanica* (r_n) given food and water only once every 3 days

Days after establishment	Stage	Mean r_n ± S.E.M. (day^{-1}) [1]	
		S. pallens	*B. germanica*
30	Male	0.0142 ± 0.0015	-0.0057 ± 0.0301
	Female	0.0142 ± 0.0015	0.0077 ± 0.0024
	Early	-0.0768 ± 0.0000	0.0148 ± 0.0469
	Intermediate	-0.0089 ± 0.0072	-0.0052 ± 0.0075
	Late	-0.0122 ± 0.0039	-0.0168 ± 0.0102
	All	-00026 ± 0.0020	0.0104 ± 0.0162*a*
60	Male	0.0101 ± 0.0008	-0.0127 ± 0.0138
	Female	0.0091 ± 0.0009	-0.0029 ± 0.0030
	Early	0.0383 ± 0.0009	-0.0036 ± 0.0188
	Intermediate	-0.0052 ± 0.0007	0.0355 ± 0.0044
	Late	-0.0235 ± 0.0122	-0.0205 ± 0.0089
	All	0.0180 ± 0.0006	0.0151 ± 0.0035*b*
90	Male	0.0072 ± 0.0006	-0.0170 ± 0.0052
	Female	0.0069 ± 0.0004	-0.0082 ± 0.0049
	Early	0.0402 ± 0.0016	0.0122 ± 0.0061
	Intermediate	-0.0052 ± 0.0012	0.0238 ± 0.0015
	Late	-0.0215 ± 0.0041	0.0179 ± 0.0032
	All	0.0237 ± 0.0015	0.0147 ± 0.0010*b*

Table 4, continued

120	Male	0.0038 ± 0.0008	0.0075 ± 0.0016
	Female	0.0012 ± 0.0006	0.0120 ± 0.0007
	Early	0.0281 ± 0.0049	0.0078 ± 0.0055
	Intermediate	0.0176 ± 0.0015	0.0113 ± 0.0053
	Late	-0.0134 ± 0.0033	0.0074 ± 0.0031
	All	0.0179 ± 0.0031	0.0104 ± 0.0022*b*
150	Male	-0.0008 ± 0.0007	0.0073 ± 0.0011
	Female	-0.0030 ± 0.0019	0.0118 ± 0.0003
	Early	0.0243 ± 0.0029	0.0283 ± 0.0017
	Intermediate	0.0213 ± 0.0003	0.0099 ± 0.0053
	Late	-0.0092 ± 0.0015	0.0031 ± 0.0028
	All	0.0174 ± 0.0015	0.0193 ± 0.0010*b*
180	Male	-0.0037 ± 0.0009	0.0010 ± 0.0032
	Female	-0.0048 ± 0.0020	0.0089 ± 0.0009
	Early	0.0191 ± 0.0027	0.0176 ± 0.0009
	Intermediate	0.0183 ± 0.0003	0.0191 ± 0.0023
	Late	-0.0087 ± 0.0020	-0.0015 ± 0.0057
	All	0.0140 ± 0.0014	0.0143 ± 0.0015*b*
210	Male	-0.0099 ± 0.0011	-0.0045 ± 0.0041
	Female	-0.0067 ± 0.0023	0.0014 ± 0.0032
	Early	0.0136 ± 0.0013	0.0126 ± 0.0016
	Intermediate	0.0146 ± 0.0008	0.0146 ± 0.0017
	Late	-0.0023 ± 0.0044	0.0054 ± 0.0045
	All	0.0101 ± 0.0006	0.0102 ± 0.0019*b*
240	Male	-0.0086 ± 0.0010	-0.0006 ± 0.0026
	Female	-0.0058 ± 0.0020	0.0000 ± 0.0036
	Early	0.0110 ± 0.0003	0.0047 ± 0.0071
	Intermediate	0.0127 ± 0.0005	0.0111 ± 0.0004
	Late	0.0016 ± 0.0004	0.0069 ± 0.0021
	All	0.0083 ± 0.0002	0.0084 ± 0.0007*b*
270	Male	0.0020 ± 0.0002	-0.0012 ± 0.0004
	Female	0.0019 ± 0.0003	0.0010 ± 0.0020
	Early	0.0120 ± 0.0001	0.0094 ± 0.0094
	Intermediate	0.0142 ± 0.0027	0.0096 ± 0.0005
	Late	-0.0005 ± 0.0006	0.0058 ± 0.0013
	All	0.0064 ± 0.0019	0.0071 ± 0.0006*b*
300	Male	0.0025 ± 0.0002	-0.0001 ± 0.0005
	Female	0.0026 ± 0.0003	0.0014 ± 0.0006
	Early	0.0104 ± 0.002	0.0083 ± 0.0011
	Intermediate	0.0104 ± 0.0005	0.0088 ± 0.0006
	Late	-0.0001 ± 0.0020	0.0061 ± 0.0007
	All	0.0077 ± 0.0003	0.0066 ± 0.0006*b*

Table 4, continued

330	Male	0.0025 ± 0.0002	0.0001 ± 0.0004
	Female	0.0025 ± 0.0003	0.0019 ± 0.0006
	Early	0.0113 ± 0.0002	0.0076 ± 0.0006
	Intermediate	0.0093 ± 0.0002	0.0084 ± 0.0003
	Late	0.0001 ± 0.0011	0.0045 ± 0.0009
	All	0.0079 ± 0.0001	0.0060 ± 0.0003*b*
360	Male	0.0021 ± 0.0002	0.0003 ± 0.0004
	Female	0.0025 ± 0.0001	0.0017 ± 0.0006
	Early	0.0100 ± 0.0007	0.0066 ± 0.0004
	Intermediate	0.0085 ± 0.0002	0.0075 ± 0.0003
	Late	0.0008 ± 0.0002	0.0045 ± 0.0006
	All	0.0071 ± 0.0004	0.0053 ± 0.0003*b*

[1] Means within the same row followed by a letter are significantly different ($P < 0.05$; One-tailed two-sample t test). To compare means, letters used were a ($\mu_{S.\ pallens} < \mu_{B.\ germanica}$), b ($\mu_{S.\ pallens} = \mu_{B.\ germanica}$) and c ($\mu_{S.\ pallens} > \mu_{B.\ germanica}$).

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