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Guild structure of stored grain insects reflects food resource availability in tropical forest ecosystems

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ABSTRACT

The Guild concept has been of great interest to ecologists, and widely applied in entomology, particularly to study the activity of insects in various ecosystems. However, the guild concept in storage entomology is understudied. We hypothesized that the feeding guild structure of stored grain insect (SGI) community changes with different food resources available. In the present study, we examined the community structure of insects in the tribal grain storage system. Further, we established a classification system for the stored grain insect species based on their food resource exploitation pattern and the role of associated factors involved in the spatial and temporal structure of the SGI community. The species richness showed that cereal feeder was dominated in tribal grain storage system, abundance varied greatly, and high number of pulse feeders reflect the availability of resources. Further, it shows non-significant association among the number of species in each feeder community at different altitudes of the study area and SGI from different feeding guilds were randomly distributed, however, congregated more on their preferred food sources.

Author's statement

NLN: Conceptualization, Investigation, Formal analysis and Writing-original draft preparation, SS: conceptualization, Supervision, Methodology, Writing-review editing, SSR: Resources, Writing-review editing. All authors read and approved the manuscript.

1. Introduction

Ecologists opine that a guild is a group of species involved in the exploitation of available similar or different resources in an associated manner (Root, 1967; Simberloff and Dayan, 1991), However, the precise definition is not clear (Adam, 1985; Uetz et al., 1999), and the guilds are the basis of community organization (Root, 1967; Landreas and MacMahon, 1980, Cobbold and MacMahon, 2012). Ecological guild or community structure helps to study spatial and temporal structure of plant and animal communities including arthropods for their feeding habit, habitat, and other ecological conditions in various environments (; Stork, 1987; Hawkins and MacMahon, 1989; Simberloff and Dayan, 1991; Uetz et al., 1999; Wardhaugh et al., 2012). In general, biodiversity and diversity in resources have positive relationships, a large number of resources with diverse nature attract a number of species (High species richness), particularly in arthropod communities of forest ecosystem (Wardhaugh et al., 2012). Estimation of feeding guild structure of insects conglomerated in microhabitats was studied in forest ecosystems (Moran and Southwood, 1982; Stork, 1987). However, it is a reasonable assumption that the distribution of the insect community reflects resources they exploit (Hawkins and MacMahon, 1989; Wardhaugh et al., 2012). For example, cereal grains feeding insects are expected to be concentrated more on the cereals, whereas insects feeding on pulses to be aggregated on the pulses. In some cases, each food resources (microhabitat) provide space for insects from different guilds for feeding, reproduction, and protection from unfavorable conditions (Stork, 1987; Wardhaugh et al., 2012). Further, they provide information on their distribution which helps to understand the dynamics of the food web (Novotny et al., 2010) in tropical forest ecosystems. Majority of the earth's species diversity inhabits tropical ecosystems (Armbruster et al., 2002), these tropical ecosystems are challenging for ecological studies, due to their huge diversity of undescribed species (Godfray et al., 1999; Armbruster et al., 2002). However, tropical habitats provide

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a space for community structure and diversity studies (DeVries et al., 1999; Armbruster et al., 2002).

There is a paucity of community structure studies on stored grain insects (SGI) in a forest dwelling tribal substance farming situation. Given their nature of biology, a restricted and isolated ecosystem, there are often less scope in wider adaptability of research outputs. A few comparative studies on food habit/habitat of insects in forest ecosystems (Wardhaugh et al., 2012), plants (Dilling et al., 2007), field crops, (Muller, 1989; Uetz et al., 1999), birds (Siegfried, 1976; Antonio et al., 2020) and mammals (Tschapka, 2004), and no information is available on the guild structure of stored grain insect communities. Information on diversity and dominance hierarchies of SGI in different guilds can be utilized in targeting species and focusing future insect control/management interventions. In this paper, we report the community structure of stored grain insects in a forest based tribal grain storage system at the Biligiriranganatha Swamy Temple Wildlife Sanctuary. The study was undertaken with an aim to determine the diversity of insect communities in stored grain system, to establish a guild classification system for the stored grain insect species based on their food resource exploitation pattern and the role of associated factors within the spatio-temporal structure of the SGI ecosystem.

2. Materials and methods

2.1. Study site

The study was conducted in the Biligiriranganatha Swamy Temple Wildlife Sanctuary (henceforth referred as 'BRT wildlife sanctuary') at Chamarajanagar district of Karnataka, India (11°-13°N, 77°-78°E) (Fig. 1), which is a home for *Soliga* tribes. *Soligas* live in small settlements called, *Podus* and practice subsistence agriculture (Jadegowda, 2000), in addition to collecting non-timber forest produce (NTFP) for their livelihood (Hegde et al., 1996). BRT wildlife sanctuary has a wide variation in the climatic conditions *viz.*, temperature (12.3 °C–23.9 °C), vegetation (evergreen, riparian, dry deciduous, scrub and shola-grasslands), altitude (650m–1800m) and rainfall (898 ± 164 mm to 1750 ± 130 mm). A total of 31 *Podus* spread across BRT wildlife sanctuary were selected for the study (Fig. 1).

2.2. Sampling of the stored grain insect community

Based on the preliminary survey, a specially designed stored grain insect traps were used to sample stored grain insect community (Naveena et al., 2015). The traps were made by using plastic jars (250 ml; Sunrise Containers Ltd., Mumbai, India). The mouth of the jar was fitted with steel mesh (3 mm) for easy movement of insects. Each trap consisted of nine plastic jars fitted in a plastic tray (28 × 21cm), these plastic jars were filled with 100 g each of infestation free grains (Paddy, Sorghum, Maize) and seeds (cowpea, beans, greengram, fieldbean, cumin and roasted bengalgram), and placed inside the houses of *Soligas* in each of the 31 *Podus* located across the study area. In each *Podu* six trappings were carried out during the study period. For each trapping, one trap per *Podu* and more than one traps in *Podus* having higher population were placed. A total of 258 trap catches were made with a trapping duration of 45 days. After 45 days, each trap was sealed in a separate polyethylene bag to avoid cross movement of insects, transported to the laboratory, and incubated for 45 days for emergence of adults. Adult insects emerged from each trap were collected and stored in 70% alcohol for taxonomic identification. The identification of stored grain insects was carried out at the Insect Biosystematics Laboratory, Department of Entomology, University of Agricultural Sciences, Bangalore, India where reference specimens were available for comparison and identification. Dichotomous keys available in Rees (2008) were also used, where necessary, for species identification. Further, insects were assigned to various guilds based on their feeding mechanism and food habit. Biotic parameters like types of grains stored and extent of food grains infested were recorded. Similarly, abiotic parameters like temperature, relative humidity were recorded throughout the study period with an interval of 45 days in select *Podu* using handheld hygro-thermometer (Elinco Innovations, Ambala, Haryana, India) (Fig. 2).

2.3. Data analyses

Abundance of stored grain insects from different food resources placed at different *Podus* were compared using Means and Standard Error values (SE at 95% confidence limits). Insect diversity in different

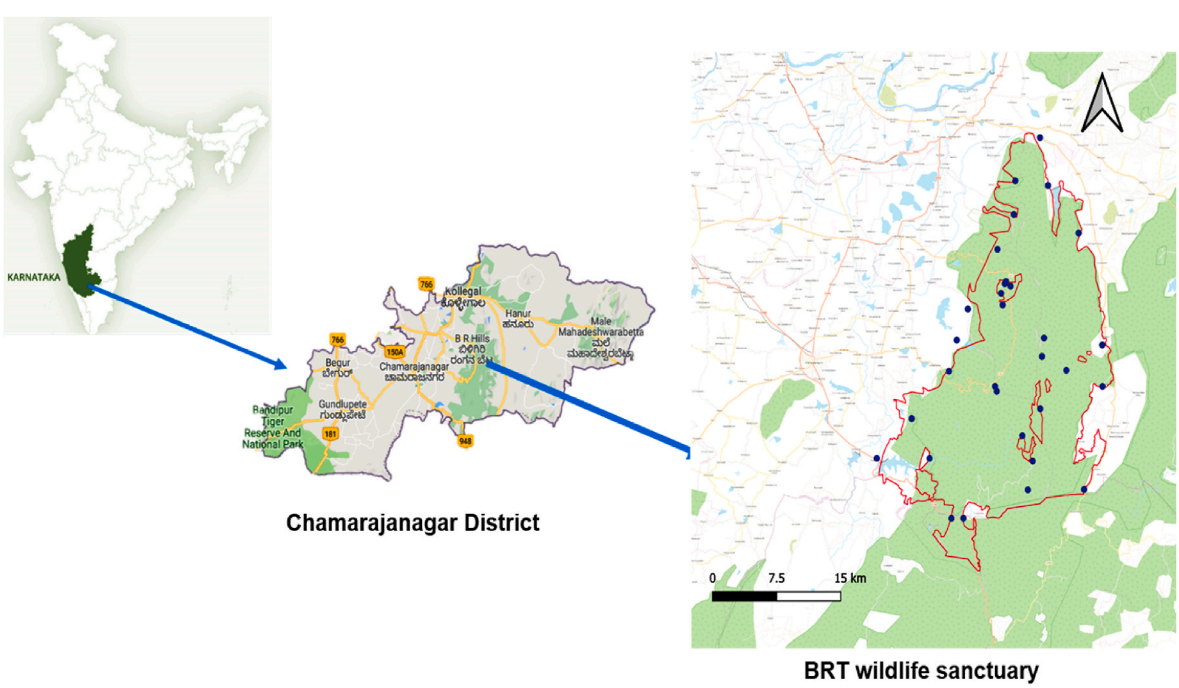

Fig. 1. Location of the Study area.

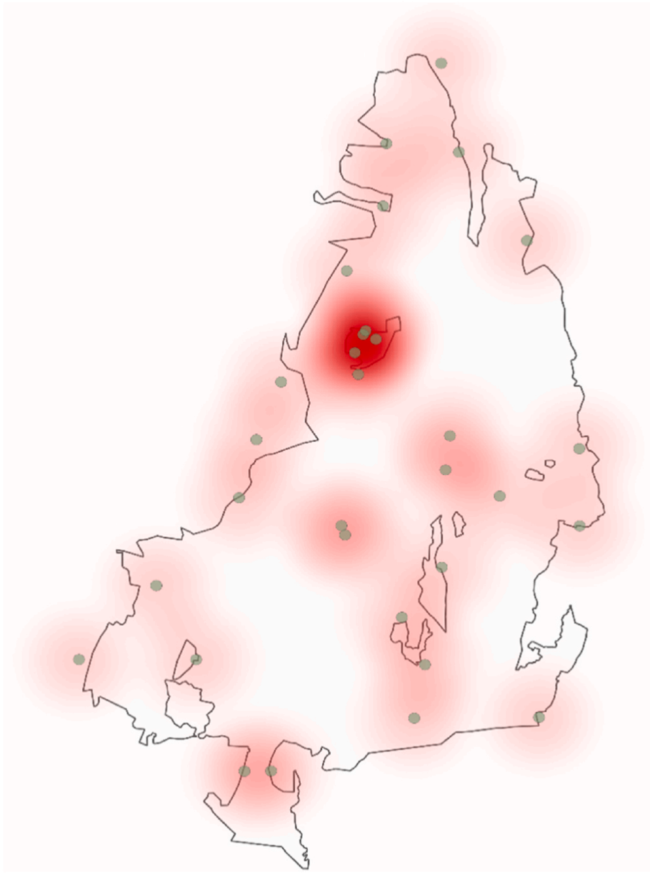

Fig. 2. Heat map of average Temperature (°C) in the study area.

food grains were calculated by species richness and Shanon-weiner index (H′), species evenness or equitability (J) was measured by Pielou's index (Southwood and Henderson, 2000) and dominance was measured by Berger-parker index. It expresses the proportional importance of the most abundant species (Berger and Parker, 1970).

$$d = \frac{N_{max}}{N}$$

where.

N_{max} = number of individuals in the most abundant species
N = total number of individuals in the sample

Podu occupancy scores for each species of SGI at sanctuary were computed by using Levin's Niche breadth index (Southwood and Henderson, 2000).

$$\frac{1}{B_j} = \sum P_{ij}^2$$

where.

B_j = niche breadth of species '*j*' and
P_{ij} = proportion of occurrences of individuals of jth species in ith *Podu*

Using the data collected on the number of individuals of each species collected across the 31 *Podus* during the six sampling events, the niche breadth index was used to understand the *Podu* occupancy status among the SGI at BRT wildlife sanctuary. Based on niche breadth analysis, species which had a high niche breadth scores were considered to be a widespread species and these species occurred at a large number of *Podus*. Species with low scores were considered as rarer species and these occurred in fewer *Podus*. All other species were considered to have intermediate distribution patterns.

In calculating the *Podu* occupancy scores for different species, species having a niche breadth score of >10 were grouped as wide-spread species, species having a score <5 were considered as having restricted range and the rest were considered as habitat intermediates.

Principal Component Analysis (PCA) was carried out in Excel data analysis add-on, XL STAT to group them according to the biotic (species richness, number of crops grown at each *Podu,* types of food grains infested, vegetation surrounding the *Podu*) and abiotic factors (temperature, relative humidity) which could potentially influence the number of stored grain insect species recorded at each *Podu*.

Hierarchical single linkage cluster analysis by applying squared Euclidean Distance was performed in Statistical Package for the Social Sciences (SPSS) 16.0 software (SPSS Inc., Chicago, IL, USA) using data on the type of stored grains and insects infesting them, for assigning guilds.

In order to examine differences in community structure among the *Podus*, species richness and abundance was analyzed separately using the multivariate analyses of variance (MANOVA) Repeated measures and wilk's lambda estimate, by using the JMP software (Sall et al., 2001) as suggested by Tsaganou et al. (2021). Cereals feeder, pulses feeder, spices feeder, oilseeds feeder, processed pulse feeder, millets feeder were considered to be the main effects, whereas elevation was considered to be the repeated variable.

3. Results

Thirteen species of stored grain insects [*Lasioderma serricorne* (F.) and *Stegobium paniceum* (L.) (Coleoptera: Anobiidae); *Rhyzopertha dominica* (F.) (Coleoptera: Bostrichidae); *Callosobruchus analis* (L.), *Callosobruchus chinensis* (L.) and *Callosobruchus theobromae* (L.) (Coleoptera: Chrysomelidae); *Sitophilus zeamais* Motschulsky and *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae); *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Laemophloeidae); *Carpophilus dimidiatus* (F.) (Coleoptera: Nitidulidae); *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae); *Corcyra cephalonica* Stainton (Lepidoptera: Galleriidae); *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelichiidae)] comprising 4059 individuals were collected from the 31 *Podus* for 17 continuous months spanning over six trapping events, each with an interval of 45 days. The number of species collected varied significantly between the food guilds (Fig. 3). Pulse feeders abundance dominated the list (42% of the total) followed by cereal feeders (33%) and millet's feeders (18%).

3.1. Community structure of stored grain insects at BRT wildlife sanctuary

Insects collected from the stored grains were grouped into two distinct communities, i.e., feeding community and feeding mode. The feeding community consisted of six sub-feeders namely, cereal feeders, pulse feeders, processed pulse feeders, spices feeders, oilseeds feeders, and millets feeders, while the feeding mode, consisted of primary feeders and secondary feeders (Table 1).

Among the feeding community, maximum numbers of stored grain insect species were attracted to cereals followed by pulses, processed pulse and millets. In spices, and oilseeds feeders included only one species each (Table 1; Fig. 4). This indicates that cereals oriented SGI feeding communities were common across BRT wildlife sanctuary.

In cereal feeders, a maximum of seven species was found in *Podus* such as Hosapodudoddi and Kannericolony, while Kalyanipodu and Seegebetta showed the least number of species (one species). A total of nine *Podus* recorded a maximum of three species in pulses feeders, while in two *Podus* no insects were found. Among processed pulse feeders, six *Podus* showed the presence of a maximum number of three species, while no insect species were found in other six *Podus*. With millets

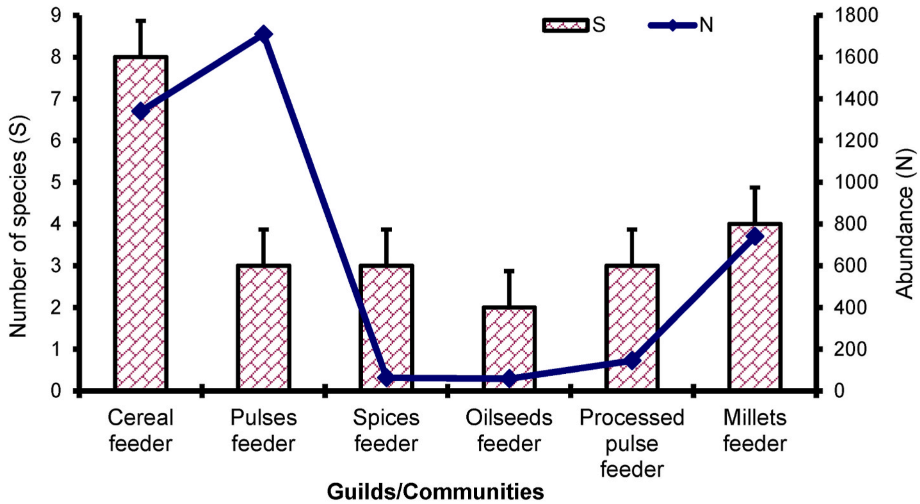

Fig. 3. Community structure of stored grain insects collected from different feeding communities.

Table 1
Classification of stored grain insect species and community structures.

Community structures	Grains/Seeds	Insects recorded
Feeding community		
Cereals feeders	Paddy, *Oryza sativa* L. Maize, *Zea mays* L.	*Sitophilus zeamais, Sitophilus oryzae, Rhyzopertha dominica, Carpophilus dimidiatus, Tribolium castaneum, Corcyra cephalonica, Sitotroga cerealella.*
Pulses feeders	Cowpea, *Vigna sinensis* (L.) Beans-Rajma, *Phaseolus vulgaris* L. Doublebeans Fieldbean, *Lablab purpureas* (L.) Greengram, *Vigna radiata* (L.) Horsegram, *Dolichos biflorus* L.	*Callosobruchus analis, Callosobruchus chinensis, Callosobruchus theobromae*
Processed pulse feeders	Fried bengal gram, *Cicer arietinum* L.	*Lasioderma serricorne, Rhyzopertha dominica, Tribolium castaneum*
Spices feeders	Jeera, *Cuminum cyminum* L.	*Stegobium paniceum*
Oilseeds feeders	Sunflower, *Helianthus annuus* L.	*Tribolium castaneum*
Millets feeders	Jowar, *Sorghum bicolor* L.	*Sitophilus oryzae, Cryptolestis ferrugineus, Corcyra cephalonica*
Feeding mode		
Primary feeders	*L. serricorne, S. zeamais, S. oryzae, R. dominica, S. paniceum, S. cerealella, C. analis, C. chinensis, C. theobromae, C. cephalonica*	
Secondary feeders	*C. dimidiatus, T. castaneum, C. ferrugineus*	

feeders, Bellata *Podu* recorded the highest number of species (3), while in Kadakalukandi and Srinivaspura Colony no insects were recorded (Table 2).

Among the 31 different *Podus*, two *Podus* (Hosapodudoddi and Kannericolony) recorded the highest number of primary feeder community species (9), followed by eight species in six different *Podus* (6.53 ± 0.261). A maximum of three species (2.03 ± 0.17) was found in secondary feeder's community in a *Podu*.

The occurrence of SGI species in cereal feeders ($\chi^2 = 8.96$; $df = 30$; $P = 0.175$), millets feeders ($\chi^2 = 32.87$; $df = 30$; $P = <0.001$), pulse feeders ($\chi^2 = 6.80$; $df = 30$; $P = 0.07$), spices feeders ($\chi^2 = 0.29$; $df = 30$; $P = 0.59$), oilseeds feeders ($\chi^2 = 2.61$; $df = 30$; $P = 0.10$) and processed pulse feeders ($\chi^2 = 1.13$; $df = 30$; $P = 0.10$) were non-significant. Chi-square values for primary feeders ($\chi^2 = 15.71$; $df = 30$; $P = 0.02$) and secondary feeder communities ($\chi^2 = 13.51$; $df = 30$; $P = 0.004$) were also non-significant, which indicates that the uniformity of stored grain insect species for different forms of community structures.

There was no statistically significant difference in the different forms of community structures across the *Podus*/elevation gradients (Table 3). Among the feeding community, maximum abundance of stored grain insect species was recorded in pulse feeders (1710) followed by cereal feeders (1340), millets feeders (741), and processed pulse feeders (145). Least abundance of insects was observed in oilseeds feeders (59) followed by spices feeders (64) (Table 4).

The abundance of SGI in pulse feeders ($\chi^2 = 3.38$; $df = 30$; $P = 1.00$), cereal feeders ($\chi^2 = 5.35$; $df = 30$; $P = 1.00$), millets feeders ($\chi^2 = 5.35$; $df = 30$; $P = 1.00$), spices feeders ($\chi^2 = 30.19$; $df = 30$; $P = <0.001$), oilseed feeders ($\chi^2 = 18.45$; $df = 30$; $P = 0.005$) and processed pulse feeders ($\chi^2 = 23.1$; $df = 30$; $P = 0.02$) were non-significant, which indicates the uniformity of stored grain insect species for different forms of communities.

Berger-Parker index for SGI in feeding communities at BRT wildlife sanctuary ranged from 0.06 to 0.18. The highest Berger-Parker index was observed in pulses food guild (0.18) followed by spices (0.13) and oilseeds (0.10). Least index was observed in cereal food guild (0.06) (Table 4). It indicates that the pulses feeding community of SGI dominated at BRT wildlife sanctuary.

The SGI evenness among the feeding guilds had ranged from 0.67 to 0.95. The highest evenness index was observed in cereal feeders (0.95), where, the proportions of different species were similar, while the least evenness index of 0.67 was recorded in spices feeder guilds.

3.2. Niche breadth analysis or podu occupancy of SGI

An effort was made to understand how wide-spread are the 13 species of SGI, recorded during the study, within BRT wildlife sanctuary. For this, the *Podu* occupancy or the number of *Podus* in which each species occurred was worked out and the same is presented in Table 5.

It was found that, only five species (S. oryzae, R. dominica, S. zeamais and C. theobromae, C. ferrugineus) had niche breadth scores above 10. Seven species (L. serricorne, S. paniceum, C. dimidiatus, T. castaneum, C. analis, C. chinensis and S. cerealella) had niche breadth scores between 5 and 10, while only one species (C. cephalonica) had a narrow niche breadth score of <5 (Table 5).

The results of PCA showed that the first two components accounted for 71 per cent of the variability (Table 6). Of this, the first, principal component (PC I) accounted for 50 per cent of the total variability in the data, while the second principal component (PC II) accounted for 20.59 per cent of the variability. PC I included environmental components

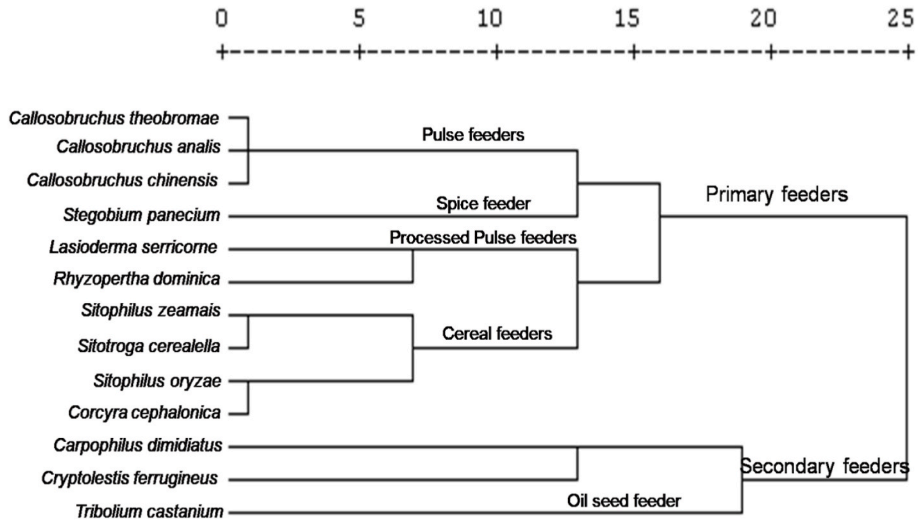

Fig. 4. Classification of communities based on feeding communities and feeding mode.

Table 2
Stored grain insect species richness in different guild communities at BRT wildlife sanctuary.

Podus	Elevation	Cereals	Pulses	Spices	Oilseeds	Processed pulse	Millets	Primary feeders	Secondary feeders
Laksmipura	665	2	0	1	0	0	1	4	0
Karalakatte	698	6	2	0	1	1	2	6	3
Devarahalli	699	6	1	1	0	2	1	7	2
Bellata	700	3	2	1	0	3	3	7	2
Putterammanadoddi	702	6	3	1	1	2	2	7	2
Yerekatte	727	4	2	1	1	1	2	7	2
Navodaya	729	4	2	0	1	2	1	6	2
Hithalagudda	736	2	1	0	0	0	1	2	1
Kaggalidoddi	743	4	2	0	1	1	2	6	2
Atgulipura	745	4	1	0	0	0	2	5	0
Budhipadaga	770	5	3	1	1	3	2	8	2
Hosapodudoddi	818	7	3	1	1	1	2	9	3
Kawalikattedam	823	3	3	1	1	3	2	8	2
Srinivasapuracolony	841	5	1	0	1	2	0	6	2
Jirigegadde	928	5	2	1	1	3	2	7	3
Puranipodu	943	4	1	0	0	2	2	5	2
Buthanipodu	1089	5	2	1	1	3	2	8	3
Ardanaripura	1091	5	2	0	1	2	1	6	3
Kanneyericolony	1094	7	3	1	1	2	1	9	3
Seegebetta	1144	1	1	0	0	2	2	6	0
Kalyanipodu	1160	1	0	1	0	0	1	3	0
Manjigundi	1160	3	3	1	1	1	2	7	2
Muttugadagadde	1174	6	2	0	1	0	2	7	2
Keredimba	1202	5	1	1	1	0	2	5	3
Banglepodu	1209	4	2	0	1	3	2	7	2
Gombegallu	1239	6	2	1	0	1	2	8	2
Bisilinakerepodu	1253	5	3	0	1	1	2	6	3
Monakaipodu	1253	3	3	1	0	1	2	8	1
Bedguli	1280	5	1	0	0	1	2	5	3
Nellikadaru	1359	6	3	1	1	1	2	8	3
Kadakalukandi	1663	4	2	0	1	0	0	5	2
Mean ± SE		4.38 ± 0.28	1.90 ± 0.16	0.54 ± 0.09	0.64 ± 0.08	1.41 ± 0.19	1.70 ± 0.18	6.38 ± 0.29	2.03 ± 0.17

(vegetation surrounding the *Podu* temperature and relative humidity as influencing factors), while PC II included biotic components (species richness and number of crops grown at each *Podu* as important factors). The Scatter diagram of factor scores over the 1st and 2nd principal components is illustrated in Fig. 5.

At different *Podus*, the average temperature ranged from 21.58 °C to 29.71 °C and relative humidity ranged from 30.58% to 57.50% during the study period. The minimum temperature and maximum relative humidity was recorded at high elevation *Podu*, Kadakalukandi (1663 m). Maximum temperature (29.71 °C) was observed at Budipadaga, located at lower elevation (770 m) (Fig. 2). However, temperature (−0.26, N = 31, $P = 0.05/0.01$) and relative humidity (0.19, N = 31, $P = 0.05/0.01$) did not show any significant relationship with species richness. Linear regression analysis on the effect of altitude and temperature & RH with the occurrence of SGI showed a very poor influence on SGI occurrence. The influence of altitude was only to an extent of 6 per cent ($y = 8.3–2.38e^{-002}x_2$), temperature influenced to an extent of 4 per cent ($y = 2.2 + 2.3e^{-001}x_2$) and RH to an extent of 5 per cent ($y = 3.9 + 1.05e^{-001}x_2$).

4. Discussion

Based on the type of food resources utilized and feeding habits of SGI, the 13 species of SGI recorded at BRT wildlife sanctuary could be

Table 3
Repeated measures MANOVA parameters for the SGI species richness and abundance at different Podus (in all cases error df = 56).

d.f.		Species abundance		Species richness	
		F	P	F	P
All between	6	0.4	0.8542	1.1	0.3747
Intercept	1	598.0	<0.0001	246.1	<0.0001
Cereals	1	0.0	0.9755	0.1	0.7135
Pulses	1	0.1	0.7523	1.7	0.2032
Spices	1	1.0	0.3371	0.0	0.8361
Oilseeds	1	0.3	0.5871	0.4	0.5388
Processed pulse	1	0.1	0.7193	5.1	0.0337
Millets	1	0.4	0.5165	0.0	0.8292
All within	12	0.6	0.7934	0.6	0.8404
Elevation	2	71.4	<0.0001	26.4	<0.0001
Elevation*cereals	2	0.0	0.9877	0.4	0.6764
Elevation*Pulses	2	0.1	0.9434	1.5	0.2294
Elevation*Spices	2	0.6	0.5453	0.1	0.9012
Elevation*Oilseeds	2	0.2	0.8235	0.4	0.6858
Elevation*Processed pulse	2	0.4	0.6542	4.3	0.0186
Elevation*Millets	2	0.3	0.7074	0.0	0.982

assigned to different feeding community and feeding mode communities. Based on the category of food grains infested, the SGI could be assigned to six different communities within BRT wildlife sanctuary. Some of the SGI are host specific, for example, *S. paniceum* restricts to spices feeder community, while few species of SGI having wider host range occurred on more number of communities, for example, *Sitophilus* spp. were found feeding on both cereals and millets. It was found that SGI composition was mostly cereal oriented. These results are similar to the studies on community structure of SGI in stored sorghum at North-Sudanian ecological zone of Burkina Faso, where they recorded 14 species of SGI in sorghum and identified two different communities viz., minor pests and a group of most abundant species (Waongo et al., 2015).

This community structure analysis supported the data on the occurrence of species richness (Birgit et al., 2009). The grouping of 13 species of SGI into six feeding and two feeding mode communities, showed that most *Podus* were not dissimilar with respect to occurrence of either different types of designated communities or by virtue of membership of different species within each community and this pattern

Table 5
Podu occupancy of different SGI species.

Sl. No	Species	Niche breadth value
1	*Sitophilus oryzae*	19.36
2	*Rhyzopertha dominica*	18.82
3	*Sitophilus zeamais*	16.91
4	*Callosobruchus theobromae*	14.15
5	*Cryptolestes ferrugineus*	12.30
6	*Stegobium paniceum*	8.48
7	*Tribolium castaneum*	8.28
8	*Sitotroga cerealella*	6.00
9	*Lasioderma serricorne*	5.89
10	*Carpophilus dimidiatus*	5.10
11	*Callosobruchus analis*	5.06
12	*Callosobruchus chinensis*	5.06
13	*Corcyra cephalonica*	4.16

Table 6
Principal Component Analysis (PCA) and classification of *Podus*.

	PC I	PC II	PC III
Eigen value	3.55	1.44	0.90
Variability (%)	50.7	20.59	12.9
Cumulative Percentage Variability Expressed	50.7	71.28	84.17
Vegetation Surrounding the Podu	22.03	2.58	1.87
Temperature (°C)	21.84	7.4	2.72
Relative humidity (%)	21.9	8.5	3.58
Number of crops grown	8.04	26.40	26.70
Crop grains stored	17.02	3.35	21.85
Species richness	0.002	37.38	30.72

Table 4
Abundance of SGI in different guild communities at BRT wildlife sanctuary.

Podus	*Podus* elevation	Cereals	Pulses	Spices	Oilseeds	Processed pulse	Millets
Laksmipura	665	49	0	1	0	0	28
Karalakatte	698	75	72	0	5	4	42
Devarahalli	699	27	34	20	0	4	14
Bellata	700	42	88	3	0	2	8
Putterammanadoddi	702	86	311	8	4	15	59
Yerekatte	727	47	48	1	1	17	20
Navodaya	729	52	49	0	3	4	28
Hitthalagudda	736	10	30	0	0	0	8
Kaggalidoddi	743	24	67	0	4	6	12
Atgulipura	745	22	58	0	0	0	14
Budhipadaga	770	18	157	2	3	19	2
Hosapodudoddi	818	72	35	5	5	4	48
Kawalikattedam	823	64	129	2	1	5	30
Srinivasapuracolony	841	34	10	0	1	3	0
Jirigegadde	928	24	5	8	3	7	13
Puranipodu	943	42	13	0	0	8	12
Buthanipodu	1089	24	9	1	3	5	8
Ardanaripura	1091	82	68	0	6	12	51
Kanneyericolony	1094	14	7	1	1	5	4
Seegebetta	1144	27	3	0	0	4	15
Kalyanipodu	1160	51	0	1	0	0	18
Manjigundi	1160	73	74	2	3	2	60
Muttugadagadde	1174	52	40	0	3	0	10
Keredimba	1202	49	33	1	1	0	48
Banglepodu	1209	5	5	0	2	4	3
Gombegallu	1239	34	49	5	0	4	15
Bisilinakerepodu	1253	72	77	0	6	1	41
Monakaipodu	1253	46	102	2	0	6	29
Bedguli	1280	53	40	0	0	3	17
Nellikadaru	1359	13	94	1	1	1	84
Kadakalukandi	1663	57	3	0	3	0	0
	Per cent share	(32.72%)	(41.76%)	(1.56%)	(1.44%)	(3.54%)	(18.10%)

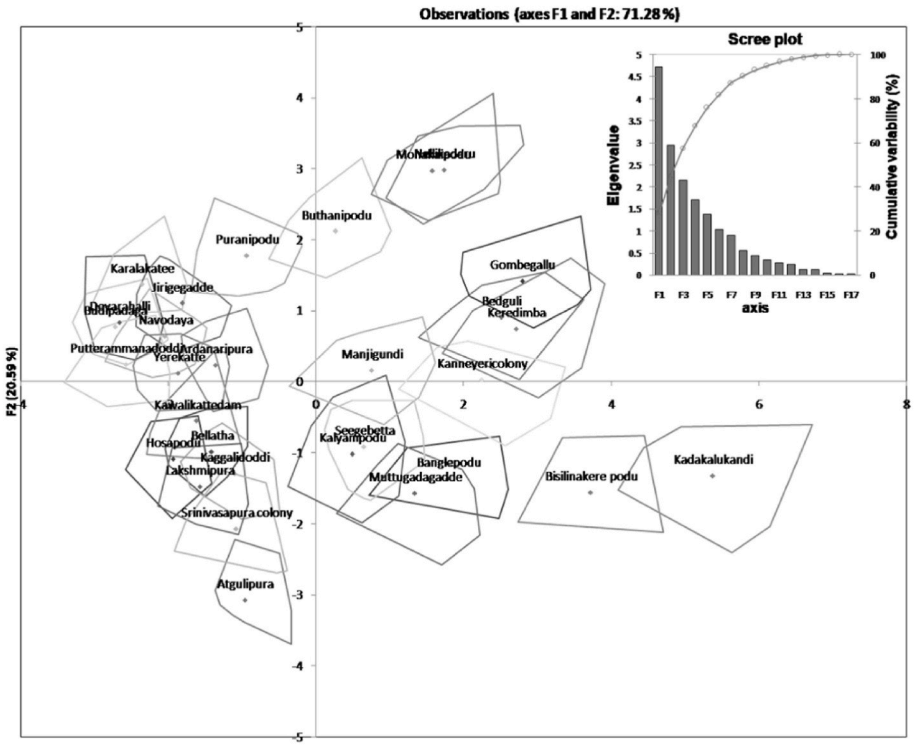

Fig. 5. Classification of *Podus* on various factors recorded in BRT wildlife sanctuary using Principal Component Analysis.

does not show any significant relationships. This is further indicated by the lack of significant association among species in each community.

Stored-product pests occupy spatially and temporally fragmented landscapes that can have profound impacts not only on their population dynamics (Semeao et al., 2012), but also on our ability to monitor populations and effectively target pest management (Jian, 2019). In the present study, proportional numbers of species within each feeding guild were remarkably uniform across the *Podus*, but proportional abundances of feeding guilds were non-uniformly distributed between food resources, regardless of *Podus*. For example, a high abundance of insects on stored pulses indicated an increased availability of resources at the local scale. These results are similar to those of studies on feeding guild structure of insects (beetles) on trees of Australian tropical rain forests (Wardhaugh et al., 2012).

The arthropod community associated with a stored grain ecosystem is often quite different from the other insect communities in nature, for the very fact that they survive in man-made environments. In any ecosystem, there exists a succession in the arthropod community over time, which is highly dependent on subsequent changes affecting the ecosystem and vice versa. One prominent factor that determines species richness and fluctuations in a community appears be the availability of food sources. With more niches (*i.e.*, food sources) available for colonization, greater will be the associated fauna within a community. The functional, spatial and temporal dimension of the niche is known to play a major role in regulating the variability in species encountered over the duration and amount of storage of grains. Greater the range of resources or niche available on a stored grain ecosystem for arthropods, the higher will be the species richness (Strong et al., 1984).

Grain storage (food resources) and other biotic and abiotic parameters found in *Podus* at BRT wildlife sanctuary are different from each other. SGI having the highest niche breadth score indicates their wider adaptability, and availability of wider resources in the study area. These results corroborate with the observations recorded by Dash and Mahanta (1993) in their studies on the community structure of amphibian species in paddy agro-ecosystem, natural hill forest and human habitations of Indian tropical environment.

Activity of insects in stored maize increased as relative humidity increased and temperature decreased (Manu et al., 2018). Rahbek (1995) argued that species richness of insects increases with increase in temperature and decreases with altitude. However, the present findings, (species richness of SGI community) does not show any such significant negative association with variations of altitude at BRT wildlife sanctuary.

Despite the variation in altitude which could drastically influence local temperature and humidity conditions, the majority of the SGI was found at all elevations. It thus appears that these SGI are thriving within the safe confines of *Soliga* households, where the outside temperature, relative humidity, rainfall may not be drastically affecting the microhabitat of SGI and this could very well have anthropogenic connotations as indicated by Naveena et al. (2015). These findings are similar to the results of Manu et al. (2018), where the temperature and relative humidity were not significantly correlated with capture of insect pests of stored maize in warehouses in two districts of Ghana. The abundance, species richness and high niche breadth clearly indicate that the availability of resources had a greater impact on the spatial and temporal structure of SGI community irrespective of biotic and abiotic factors present in our tribal study area. The distribution of *R. dominica* was also more uniform and widespread in trap captures in central Queensland, Australia (Holloway et al., 2020).

Insects are attracted to favorable food sources, but also select alternate food sources at the same time (Jian, 2019). *R. dominica* consume cereals and processed pulse, similarly *R. dominica* feeds on fruits of sandhill plum (*Prunus angustifolia*), chinkapin oak (*Quercus muehlenbergii*), hackberry (*Celtis occidentalis*), buckbrush (*Symphoricarpus orbiculatus*), and black walnut (*Juglans nigra*) in USA (Potter, 1935; Wright et al., 1990). Evenness index among the different guilds indicated that available food resource is widely distributed and SGI occurs in the congregation and few occur in a small number (lower population) in different guilds. Similar results were reported by Wardhaugh et al. (2012) in their study on the feeding guild structure of beetles on Australian tropical rainforest trees.

For developing a successful pest management strategy for safe food storage, one needs to understand which insect species are present and their spatial and temporal patterns of distribution (Manu et al., 2018). Guild structure of SGI at BRT have significant implications for the management of grains stored at local scale. Insect trapping helps to know the presence or absence of insect species and their abundance helps to determine the risk of insect infestation that the stored commodity is under, besides helping to assess potential infestation levels of stored products in those areas. This data is helpful for local policy makers/tribal administration for effective implementation of management strategies.

In summary, our results illustrate that an understanding of guild structure of stored grain insects reflects food resource availability in tropical forest ecosystems. A total of 13 species were trapped during the study period, and these were grouped in to eight different guilds based on their feeding and feeding-mode community and were also based on hierarchical classification. Diversity and dominance of these SGI were measured, and found that maximum species richness was in cereal feeding community and maximum abundance was in pulse feeder community. Temperature, relative humidity and altitude did not influence the occurrence of SGI greatly in BRT Wildlife Sanctuary.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Adam, J., 1985. The definition and interpretation of guild structure in ecological communities. J. Anim. Ecol. 54, 43–59.
Antonio, E.F., Pamela, M.L.L., Carlos, I.P., 2020. Bird community changes associated with cattle raising management in the delta forests of the Paraná River. Basic Appl. Ecol. 49, 13–21.
Armbruster, P., Hutchinson, R.A., Cotgreave, P., 2002. Factors influencing community structure in a South American tank bromeliad fauna. Oikos 96, 225–234.
Berger, W.H., Parker, F.L., 1970. Diversity of planktonic foraminifera in deep-sea sediments. Science 168, 1345–134.
Birgit, M., Frank, J., Ingolf, S.D., 2009. Contrasting resource-dependent responses of hoverfly richness and density to landscape structure. Basic Appl. Ecol. 10 (2), 178–186.
Cobbold, S.M., MacMahon, J.A., 2012. Guild mobility affects spider diversity: links between foraging behavior and sensitivity to adjacent vegetation structure. Basic Appl. Ecol. 13 (7), 597–605.
Dash, M.C., Mahanta, J.K., 1993. Quantitative analysis of the community structure of tropical amphibian assemblages and its significance to conservation. J. Biosci. 18 (1), 121–139.
DeVries, P.J., Walla, T.R., Greeney, H.F., 1999. Species diversity in spatial and temporal dimensions of fruit-feeding butterflies from two Ecuadorian rainforests. Biol. J. Linn. Soc. 68, 333–353.
Dilling, C., Lambdin, P., Jerome, G., Buck, L., 2007. Insect guild structure associated with eastern hemlock in the southern appalachians. Environ. Entomol. 36 (6), 1408–1414.
Godfray, H.C.J., Lewis, O.T., Memmott, J., 1999. Studying insect diversity in the tropics. Phil. Trans. Roy. Soc. Lond. B 354, 1811–1824.
Hawkins, C.P., MacMahon, J.A., 1989. Guilds: the multiple meanings of a concept. Annu. Rev. Entomol. 34, 423–451.
Hegde, R., Suryaprakash, B., Achuth, L., Bawa, K.S., 1996. Extraction of non-timber forest products in the forest of Biligiriranganath Hills, India. Econ. Bot. 50 (3), 243–251.
Holloway, J.C., Daglish, G.J., Mayer, D.G., 2020. Spatial distribution and flight patterns of two grain storage insect pests, *Rhyzopertha dominica* (Bostrichidae) and Tribolium castaneum (Tenebrionidae): implications for pest management. Insects 11, 715. https://doi.org/10.3390/insects11100715.
Jadegowda, M., 2000. Effect of FYM on Maize and Finger Millet Based Intercropping Systems at BR Hills. M. Sc (Agri) thesis submitted to University of Agricultural Sciences, Bangalore.
Jian, F., 2019. Influences of stored product insect movements on integrated pest management decisions. Insects 10, 100. https://doi.org/10.3390/insects10040100.
Landreas, P.B., MacMahon, J.A., 1980. Guilds and community organization: analysis of an oak woodland avifauna in Sonora, Mexico. Auk 97, 351–365.
Manu, N., Osekre, E.A., Opit, G.P., Campbell, J.F., Arthur, F.H., Mbata, G., Armstrong, P. R., Danso, J.K., 2018. Population dynamics of stored maize insect pests in warehouses in two districts of Ghana. J. Stored Prod. Res. 76, 102–110.
Moran, Southwood, T.R.E., 1982. The guild composition of arthropod communities in trees. J. Anim. Ecol. 51, 289–306.
Muller, H., 1989. Structural analysis of the phytophagous insect guilds associated with the roots of *Centaurea maculosa* Lam *C diffusa* Lam and *C v Mlesiaca* Jordan in Europe. Oecologia 78, 41–52.
Naveena, N.L., Subramanya, S., Setty, S., 2015. Diversity and distribution of stored grain insects among the *Soliga* Tribal settlements of Biligirirangana Hills Karnataka India. J. Stored Prod. Res. 62, 84–92.
Novotny, V., Miller, S.E., Baje, L., Balagawi, S., Basset, Y., Cizek, L., Craft, K.J., Dem, F., Drew Rai Hulcr, J., Leps, J., Lewis, O.T., Pokon, R., Stewart, A.J.A., Samuelson, G.A., Weiblen, G.A., 2010. Guild-specific patterns of species richness and host specialization in plant-herbivore food webs from a tropical forest. J. Anim. Ecol. 79, 1193–1203.
Potter, C., 1935. The biology and distribution of *Rhyzopertha dominica* (Fab.). Trans. R. Entomol. Soc. Lond. 83, 449–482.
Rahbek, C., 1995. The elevational gradient of species richness: a uniform pattern? Ecography 18, 200–205.
Rees, D., 2008. Insects of Stored Products. Australia. SBS publishers and distributors Pvt. Ltd., New Delhi, p. 181.
Root, R.B., 1967. The exploitation pattern of the blue-grey gnatcatcher. Ecol. Monogr. 37, 317–350.
Sall, J.E., Lehman, A., Creighton, L., 2001. JMP Start Statistics. A Guide to Statistics and Data Analysis Using JMP and JMP IN Software. - Duxbury Press, Belmont, CA, USA.
Semeao, A.A., Campbell, J.F., Whitworth, R.J., Sloderbeck, P.E., 2012. Influence of environmental and physical factors on capture of Tribolium castaneum (Coleoptera: Tenebrionidae) in a flour mill. J. Econ. Entomol. 105, 686–702.
Siegfried, W.R., 1976. Segregation in feeding behaviour of four diving ducks in southern Manitoba. Can. J. Zool. 54, 730–736.
Simberloff, D., Dayan, T., 1991. The guild concept and the structure of ecological communities. Annu. Rev. Ecol. Systemat. 22, 115–143.
Southwood, T.R.E., Henderson, P.A., 2000. Ecological Methods. Blackwell scientific.
Stork, N.E., 1987. Guild structure of arthropods from Bornean rain forest trees. Ecol. Entomol. 12, 69–80.
Strong, D.R., Lawton, J.H., Southwood, R., 1984. Insects on Plants: Community Patterns and Mechanisms. Harvard Press, Harvard.
Tsaganou, F.K., Vassilakos, T.N., Athanassiou, C.G., 2021. Influence of temperature and relative humidity on the efficacy of thiamethoxam for the control of three stored product beetle species. J. Stored Prod. Res. 92, 101784.
Tschapka, M., 2004. Energy density patterns of nectar resources permit coexistence within a guild of Neotropical flower-visiting bats. J. Zool. Lond. 263, 7–21.
Uetz, G.W., Halaj, J., Cady, A.B., 1999. Guild structure of spiders in major crops. J. Arachnol. 27, 270–280.
Waongo, A., Ba, N.M., Dabire-Binso, L.C., Sanon, A., 2015. Diversity and community structure of insect pests developing in stored sorghum in the Northern-Sudan ecological zone of Burkina Faso. J. Stored Prod. Res. 63, 6–14.
Wardhaugh, C.W., Stork, N.E., Edwards, W., 2012. Feeding guild structure of beetles on Australian tropical rainforest trees reflects microhabitat resource availability. J. Anim. Ecol. 81 (5), 1086–1094.
Wright, V.F., Fleming, E.E., Post, D., 1990. Survival of *Rhyzopertha dominica* (Coleoptera, Bostrichidae) on fruits and seeds collected from woodrat nests in Kansas. J. Kans. Entomol. Soc. 63, 344–347.