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Infestation and distribution of chigger mites on Chevrieri's field mouse (*Apodemus chevrieri*) in Southwest China

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A R T I C L E I N F O

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A B S T R A C T

Based on a long-term field investigation on chigger mites in southwest China from 2001 to 2019, the present study analyzed the infestation and distribution of chigger mites on the Chevrieri's field mouse (*Apodemus chevrieri*) in the region. A total of 12,516 individuals of chigger mites were collected from 1981 *A. chevrieri* mice, and 12,281 chiggers were identified as 107 species, 11 genera and 3 subfamilies in 2 families, which revealed a high species diversity of the mites on *A. chevrieri* mice. Of 1981 *A. chevrieri* mice, 633 ones were infested with chiggers with a relatively high overall prevalence (P_M = 31.95%), mean abundance (MA = 6.32) and mean intensity (MI = 19.77). Of the 107 chigger species identified from *A. chevrieri* mice, three ones were the most dominant and they were *Leptrombidium scutellare*, *L. densipunctatum* and *L. cricethrionis*, which showed aggregated distribution among different individuals of the mice. A slightly positive association existed between every two dominant chigger species, which implied that the dominant chigger species tend to co-exist on *A. chevrieri*. The infestations of *A. chevrieri* with chiggers varied in different latitudes, altitudes and landscapes and they showed some heterogeneity along different environmental gradients. The logistic regression analysis showed that the risk factors for chigger infestations on *A. chevrieri* were landscapes, ages and altitudes, which implied that the environmental factors and host ages could influence the infestations of the mice with the mites. A theoretical curve of the species abundance distribution of chigger mites on *A. chevrieri* was successfully fitted by Preston's lognormal model, suggesting that the species abundance distribution conforms to the lognormal distribution pattern. The expected total species of chigger mites on *A. chevrieri* was roughly estimated to be 136 species and about 29 rare chigger species were probably missed in the sampling field investigation.

1. Introduction

Chigger mites (trombiculid mites) are a group of tiny arthropods and they belong to families Trombiculidae and Leeuwenhoekiidae in the subclass Acari (Li et al., 1997; Ren et al., 2014; Ding et al., 2021a). Some literatures claim that there are over 3000 species of chigger mites recorded in the world and more than 400 species in China (Li et al., 1997; Zhan et al., 2013; Lv et al., 2021). Some other literatures, however, indicate that over 3700 species of chigger mites have been documented throughout the world and more than 510 species in China (Ding et al., 2020, 2021a, 2021b). Of many chigger mite species documented in various literatures, some species are actually synonyms or invalid species, and therefore it has been a long time to obtain an exact number of chigger mite species (Nielsen et al., 2021; Li et al., 1997; Vercammen-Grandjean and Langston, 1976). A latest review on the annotated world checklist of chigger mites indicates that there are 3013 species of chigger mites (Trombiculidae and Leeuwenhoekiidae) in the world, excluding some synonyms or invalid species (Nielsen et al., 2021). However, the exact species of chigger mites recorded in China are still unknown and they may have exceeded 500 species (Li et al., 1997; Duan et al., 2009).

In the complicated life cycle of chigger mites, only the larvae (often called "chiggers") are the ectoparasites of some other animals, especially rodents (Li et al., 1997). The larvae of chigger mites (chiggers) are the exclusive vector of scrub typhus (tsutsugamushi diseases) caused by the causative agent *Orentia tsutsugamushi*, Ot (Xiang and Guo, 2021). In current years, scrub typhus is widespread in the Asia-Pacific region including many parts of China (especially in the south and southwest)

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with around 1,000,000 cases appearing annually (Li et al., 1997; Latif et al., 2017). Besides transmitting scrub typhus, chiggers are also proved to be the potential vector of hemorrhagic fever with renal syndrome, HFRS (Peng et al., 2018; Xiang and Guo, 2021).

Rodents and some other small mammals (e.g. insectivores and tree shrews) usually harbor lots of chiggers on their body surface and chiggers are common ectoparasites of rodents (Peng et al., 2016; Ding et al., 2021a). The Chevrieri's field mouse, *Apodemus chevrieri* (Miline-Edwards, 1868), is a common species of rodent in China and it is widely distributed in many parts of China such as Yunnan, Guizhou, Sichuan and Chongqing, etc. (Wlison et al., 2017). As a typical wild rodent species, *A. chevrieri* is often found in crop fields and various farmlands, bush areas, grasslands and open woodlands in its distributed regions (Wlison et al., 2017). Besides destroying crops and other agricultural plants as an important pest in the distribution regions, *A. chevrieri* is also a common reservoir host and infectious source of some zoonotic diseases (zoonoses), e. g. bartonellosis, plague, HFRS and some other zoonoses (Men et al., 2007; Tsai et al., 2010; Wang et al., 2018).

From 2001 to 2019, a long-term field investigation on chigger mites was carried out in southwest China, which covered five provincial regions including Yunnan, Guizhou, Chongqing, Sichuan and the east part of Tibet (Xizang Autonomous Region). Based on the investigation data, the present paper studied the infestation and distribution of chigger mites on *A. chevrieri* in southwest China, which is the first time to study the chigger mites of *A. chevrieri* in such a wide geographical region.

2. Materials and methods

2.1. Field investigation and collection of chigger mites

All the *A. chevrieri* mice, together with some other rodents and small mammals (insectivores and tree shrews, etc.), were captured with mousetraps (Guixi Mousetrap Apparatus Factory, Guixi, Jiangxi, China). The mousetraps were set in different type of habitats in the evening and checked the following morning. Every trapped animal host was put into a pre-marked cloth bag separately and then brought to the field laboratory where the animal host was anesthetized with ether. Over a large white tray, chiggers were collected from each host with a special bistoury or curette (Lv et al., 2019, 2021). After the collection of chiggers, every host was identified to species according to its appearance (the body size, body shape and coat color, etc.) and some measurements such as the body weight, body length and the lengths of ears, tail and hind feet (Huang et al., 1995; Wlison et al., 2017). The ages and genders (sexes) of *A. chevrieri* mice and other small mammal hosts were determined based on the body size, the relative ratio of head to trunk, color depth of pelage, the developmental status of genitalia and the distance from urethra to anus, etc. (Zheng et al., 2012; Zhuo et al., 2016; Morris, 1972). The identified *A. chevrieri* mice, together with the chiggers on the mice, were selected as the target of the present study. In the laboratory, the preserved chiggers in 70% of ethanol were isolated from some other "non-mite" impurities, the scurf and debris from the mice's skin, under a stereo microscope, and then made into slide-mounted specimens with Hoyer's medium. With the help of some relevant taxonomic literatures including taxonomic monographs and identification keys, the slide-mounted chiggers were identified to species under microscopes after dehydration and transparent process (Li et al., 1997; Vercammen-Grandjean and Langston, 1976). The capture and use of animals for research were officially approved by the local wildlife affairs authority and the Animal Ethics Committee of Dali University, which followed the international standards of animal euthanasia, 2013 AVMA guidelines (Cima, 2013). The representative specimens of animal hosts and chigger mites are deposited in the specimen repository of the Institute of Pathogens and Vectors of Dali University.

2.2. General statistics of chigger mites

The constituent ratio (C_r), prevalence (P_M), mean abundance (*MA*) and mean intensity (*MI*) were used to calculate the infestation of *A. chevrieri* with chigger mites (Ding et al., 2021a; Liu, 2020a), in which C_r represents the percentage of a certain chigger species on *A. chevrieri* mice, P_M the percentage of the infested mice with chiggers, *MA* the average number of chiggers per examined mouse and *MI* the average number of chiggers per infested mouse. The richness index (richness, *S*), Shannon-Wiener's diversity index (H'), Pielou's evenness (*E*) and Simpson's dominance index (D) were used to describe the chigger community structure on the mice (Magurran, 1998; Ding et al., 2021a; Lv et al., 2021).

$$S = \sum S_i;\ H' = -\sum_{i=1}^{S}\left(\frac{N_i}{N}\right)\ln\left(\frac{N_i}{N}\right);\ D = \sum_{i=1}^{S}\left(\frac{N_i}{N}\right)^2;$$

In the above formulae, N_i = the individuals of chigger mite species *i* on the host (*A. chevrieri*), N = the total individuals of all the species of chigger mites and S_i = the species *i* in the community.

2.3. Logistic regression analysis of risk factors related to chigger infestations

The logistic regression model was used to analyze the risk factors of infestations of *A. chevrieri* mice with chigger mites. All the observation variables with statistical significance ($P < 0.05$) were taken as single factor covariates, and the infestation of *A. chevrieri* mice with chigger mites was taken as dependent variables. The statistics and the 95% confidence interval (CI) were made under SPSS 25.0 software, and $P < 0.05$ was considered to be of statistical significance. (Truett et al., 1967; Jiang, 2015; Liu, 2020).

2.4. Distribution of species abundance and estimation of total species of chigger mites

In a semi-logarithmic rectangular system, X-axis scaled with log-intervals ($\log_3 N$) was marked with chigger individuals and Y-axis with arithmetic scales was marked with chigger species. Preston's lognormal model was used to fit the theoretical curve of species abundance distribution as the following formula (Preston, 1948; Peng et al., 2016). Based on the species abundance distribution, the expected total species of chigger mites (S_T) on *A. chevrieri* were estimated by the method based on Preston's lognormal model (Ding et al., 2021a; Preston, 1948; Peng et al., 2017).

$\widehat{S}(R) = S_0 e^{-[\beta(R-R_0)]^2}$ (e = 2.71828 ...) (Preston's lognormal distribution model)

$$R^2 = 1 - \frac{\sum_{R=0}^{n}\left[S(R) - \widehat{S}(R)\right]^2}{\sum_{R=0}^{n}\left[S(R) - \overline{S}(R)\right]^2};\ \overline{S}(R) = \frac{1}{n}\sum_{R=0}^{n} S(R);\ S_T = \left(S_0\sqrt{\pi}\right)/\beta$$

where $\widehat{S}(R)$ stands for the theoretical species number at *R*-th log interval, $S(R)$ the actual chigger mite species in *R*-th log interval, *R* the log interval *R* and R_0 the mode log interval. And S_0 represents the mite species at R_0 log interval and β the spread constant of the distribution. The value of β was determined according to the best determination coefficient (R^2) in statistics, *n* is the number of log intervals in the fitting of theoretical curve, and S_T is the estimated total species of chigger mites on *A. chevrieri* mice (Peng et al., 2017; Ding et al., 2021a).

2.5. Measurement of spatial distribution patterns

The Cassie index (C_A) and clumping index (*I*) were used to measure the spatial distribution pattern of the dominant mite species among the different individuals of the host, *A. chevrieri* mice (Kuno, 1991; Xiang et al., 2021b; Ding et al., 2021a).

$$C_A = \frac{\sigma^2 - m}{m^2};\ I = \frac{\sigma^2}{m} - 1$$

In the above formulae, *m* and σ^2 represent the mean and variance of chigger mites on the host *A. chevrieri*. When C_A and $I > 0$, the spatial distribution was determined as the aggregated distribution.

2.6. Measurement of interspecific association

Based on the establishment of a contingency table (see Table 4 in “Results”), the association coefficient (*V*) was used to calculate the interspecific association between any two species of chigger mites (chigger species) on the mouse host, *A. chevrieri* mice. Chi-square test was used for testing the statistical significance of *V* (Guo et al., 2006; Yin et al., 2021).

$$V = \frac{ad - bc}{\sqrt{(a+b)(c+d)(a+c)(b+d)}}$$

In the above formula, V = the association coefficient between chigger species X and Y; a = the host individuals on which chigger species X and Y simultaneously occur; b = the host individuals on which chigger species Y occurs, but chigger species X does not occur; c = the host individuals on which chigger species X occurs, but chigger species Y does not occur; and d = the host individuals on which both chigger species X and Y do not occur. When $V > 0$ and $P < 0.05$, the interspecific relationship between chigger species X and Y is determined as the positive association, and when $V < 0$ and $p < 0.05$, the negative association. And *P* is the significance probability in Chi-square test (χ^2).

3. Result

3.1. Collection and identification of chigger mites

A total of 1981 *A. chevrieri* mice were captured from 30 sites of 91 investigated ones in southwest China. The result showed that *A. chevrieri* mice were not distributed in all the region of southwest China and they were mainly from Yunnan, Sichuan and Guizhou (Fig. 1, Table 1). From the body surface of 1981 *A. chevrieri* mice, 12516 individuals of chigger mites (chiggers) were collected. Of 12,516 collected mites, 12,281 ones were identified as 107 species, 10 genera in 3 subfamilies under 2 families (Table 2), and the rest 235 mites remained unidentified because of broken body, dirt-covered body, blurred structure or suspected new species.

3.2. Infestation, community structure and spatial distribution of dominant species of chigger mites

A total of 12,516 individuals of chigger mites were collected from 1981 *A. chevrieri* mice (hosts). Of 1981 *A. chevrieri* hosts, 633 of them were infested with chigger mites with 31.95% of overall prevalence (P_M = 31.95%, 633/1981), 6.32 of overall *mean* abundance (*MA* = 6.32, 12516/1981) and 19.77 of overall mean intensity (*MI* = 19.77, 12516/633). Based on the identified 107 species (12,281 individuals) of chigger mites, the community structure of the mites on *A. chevrieri* mice was calculated with the species richness S = 107, Shannon-Wiener’s diversity index H' = 3.27, Pielou’s evenness index E = 0.699 and Simpson’s dominance index D = 0.075. The unidentified 235 individuals of chigger mites (12516-12281 = 235) were not included in the community calculation because their exact species were unknown.

Of 107 species of chigger mites identified from *A. chevrieri* mice, three of them were dominant chigger species and they all belong to the genus *Leptrombidium*. The three dominant chigger species were *Leptrombidium scutellare* with the constituent ratio C_r = 18.47%, *L. densipunctatum* with C_r = 14.31%, and *L. cricethrionis* with C_r = 6.35%.

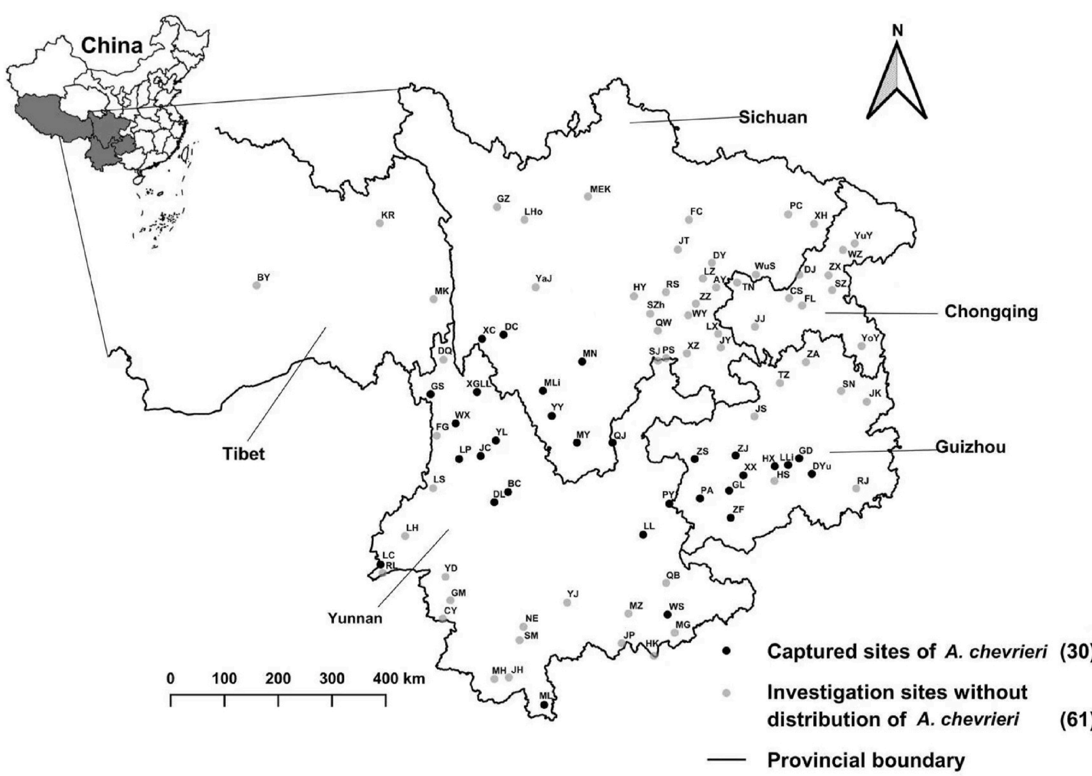

Fig. 1. The 91 investigation sites and the captured sites where Chevrieri’s field mice (*Apodemus chevrieri*) were captured in southwest China (2001–2019).

Table 1
The 91 investigation sites and the captured sites where Chevrieri's field mice (*Apodemus chevrieri*) were captured in southwest China (2001–2019).

No.	Abbr.	Investigation sites	No.	Abbr.	Investigation sites	No.	Abbr.	Investigation sites
1	AY	Anyue	32	JY	Jiangyang (Luzhou city)	63	SM	Simao
2	BC	Binchuan*	33	KR	Karuo (Changdu city)	64	SN	Sinan
3	BY	Bayi (Linzhi city)	34	LC	Longchuan*	65	SZ	Shizhu
4	CS	Changshou	35	LH	Lianghe	66	SZh	Shizhong (Leshan city)
5	CY	Cangyuan	36	LHo	Luhuo	67	TN	Tongnan
6	DC	Daocheng*	37	LL	Luliang*	68	TZ	Tongzhi
7	DJ	Dianjiang	38	LLi	Longli*	69	WS	Wenshan*
8	DL	Dali*	39	LP	Lanping*	70	WuS	Wusheng
9	DQ	Deqin	40	LS	Lushui	71	WX	Weixi*
10	DY	Daying	41	LX	Luxian	72	WY	Weiyuan
11	DYu	Duyun*	42	LZ	Lezhi	73	WZ	Wanzhou
12	FC	Fucheng (Mianyang city)	43	MEK	Maerkang	74	XC	Xiangcheng*
13	FG	Fugong	44	MG	Maguan	75	XGLL	Xianggelila*
14	FL	Fuling	45	MH	Menghai	76	XH	Xuanhan
15	FY	Fuyuan*	46	MK	Mangkang	77	XX	Xixiu (Anshun city)*
16	GD	Guiding*	47	ML	Mengla*	78	XZ	Xuzhou(Yibin city)
17	GL	Guanling*	48	MLi	Muli*	79	YaJ	Yajiang
18	GM	Gengma	49	MN	Mianning*	80	YD	Yongde
19	GS	Gongshan*	50	MY	Miyi*	81	YJ	Yuanjiang
20	GZ	Ganzi	51	MZ	Mengzi	82	YL	Yulong*
21	HK	Hekou	52	NE	Ninger	83	YoY	Youyang
22	HS	Huishui	53	PA	Puan*	84	YuY	Yunyang
23	HX	Huaxi (Guiyang city)*	54	PC	Pingchang	85	YY	Yanyuan*
24	HY	Hongya	55	PS	Pingshan	86	ZA	Zhengan
25	JC	Jianchuan*	56	QB	Qiubei	87	ZF	Zhenfeng*
26	JH	Jinghong	57	QJ	Qiaojia*	88	ZJ	Zhijin*
27	JJ	Jiangjin	58	QW	Qianwei	89	ZS	Zhongshanzx (Liupanshui city)*
28	JK	Jiangkou	59	RJ	Rongjiang	90	ZX	Zhongxian
29	JP	Jinping	60	RL	Ruili	91	ZZ	Zizhong
30	JS	Jinsha	61	RS	Renshou			
31	JT	Jintang	62	SJ	Suijiang			

Annotation: The investigated sites (counties) marked with "*" were the captured sites where *A. chevrieri* mice were captured.

The total constituent ratio of three dominant species of chigger mites reached 39.13% (4898/12516). *Leptotrombidium scutellare* was the first dominant chigger species with the highest constituent ratio (C_r = 18.47%), prevalence (P_M = 8.13%) and mean abundance (*MA* = 1.17) ($P < 0.05$). The mean intensity of *L. densipunctatum* (*MI* = 16.58) was higher than those of other two chigger species with statistical significance ($P < 0.05$).

The Cassie index (C_A) and clumping index (*I*) of three dominant species of chigger mites and all the 107 chigger species were all higher than the border value "0", and therefore all the chigger species were determined to be of the aggregated distribution among different individuals of *A. chevrieri* mice (Table 3).

3.3. Analysis on interspecific association between dominant species of chigger mites

The analysis on interspecific association between any two main species of chigger mites showed that a slightly positive association existed between the dominant chigger mite species *L. densipunctatum* and *L. scutellare* ($V = 0.05$, $\chi2 = 11.203$, $P < 0.05$), and between *L. cricethrionis* and *L. scutellare* ($V = 0.39$, $\chi2 = 6.109$, $P < 0.05$) on the mouse host, *A. chevrieri* (Table 4).

3.4. Chigger infestations in different landscapes and on different ages of hosts

The infestations of *A. chevrieri* mice with chigger mites varied in different landscapes and on different ages of the hosts. *Apodemus chevrieri* mice in the mountainous landscape harbored much more individuals of chigger mites than those in the flatland landscape. All the infestation indices of chigger mites in mountainous landscape (P_M = 34.35, *MA* = 6.20 and *MI* = 20.09) were significantly higher than those in the flatland landscape (P_M = 10.89, *MA* = 1.18 and *MI* = 10.86) ($P < 0.001$). The prevalence (P_M) and mean abundance (*MA*) of chigger mites on the adult *A. chevrieri* mice (P_M = 34.45 and *MA* = 7.29) were higher than those on the juvenile mice (P_M = 2.24, *MA* = 2.82) with $P < 0.001$. The mean intensity of chigger mites on the adult *A. chevrieri* mice (*MI* = 21.17) was also higher than that on the juvenile mice (*MI* = 12.21) with $P < 0.05$ (Table 5).

3.5. Infestations of Apodemus chevrieri mice with chigger mites in different latitudes and altitudes

As shown in Table 6, the *A. chevrieri* mice in latitude 24–26°N harbored much more individuals of chigger mites than those in other latitudes. The prevalence (P_M = 17.01%) and mean abundance (*MA* = 3.40) of chigger mites in latitude 24–26°N were also higher than those in other latitudes with $P < 0.001$. The mean intensity (*MI*) in latitude 28–30°N was higher than that in other latitudes ($P < 0.001$). The prevalence (P_M) and mean abundance (*MA*) of *A. chevrieri* mice in 2000–3000m (P_M = 36.97 and *MA* = 7.17) were higher than those in other altitudes ($P < 0.001$), and the mean intensity (*MI*) of *A. chevrieri* mice in altitude 1000–2000m was higher than that in other altitudes (P < 0.05) (Table 6).

3.6. Logistic regression analysis of the factors related to the infestations of chigger mites on Apodemus chevrieri mice

Based on the result of univariate factor analysis, the variables of landscapes ($\chi^2 = 45.894$ $P < 0.001$), altitude gradients ($\chi^2 = 31.675$ $P < 0.001$), latitude gradients ($\chi^2 = 27.185$ $P < 0.001$) and host ages ($\chi^2 = 19.983$ $P < 0.001$) were put into the logistic regression analysis. Of the above variables, the variables of latitude gradients (OR = 0.670 95%, CI: 0.564–0.797) were negatively correlated with the infestations of chigger mites on *A. chevrieri* mice, which were the protective factors. The variables of landscapes (OR = 4.652 95%, CI: 2.947–7.342), altitudes (OR = 1.243%, CI: 1.068–1.446) and host ages (OR = 1.995 95%, CI: 1.552–2.565) were the risk factors for the infestations of chigger mites

Table 2
Identified chigger mites from Chevrieri's field mice (*Apodemus chevrieri*) in southwest China between 2001 and 2019.

Taxonomic taxa of chigger mites(Family, Subfamily, Genus and Species)	Individuals	Taxonomic taxa of chigger mites(Family, Subfamily, Genus and Species)	Individuals	Taxonomic taxa of chigger mites(Family, Subfamily, Genus and Species)	Individuals
1. Family Trombiculidae		*L. imphalum* Vercammen-Grandjean and Langston, 1975	6	*N. sinica* (Wang, 1964)	4
1.1 Subfamily Trombiculinae		*L. jinmai* Wen and Xiang, 1984	54	*N. tongtianhensis* Yang et al.,1995	13
1.1.1 Genus *Ascoschoengastia*		*L. kunmingense* Wen and Xiang, 1984	5	1.1.7 Genus *Trombiculindus*	
A. leechi (Domrow, 1962)	1	*L. laojunshanense* Yu et al., 1986	4	*T. bambusoides* Wang and Yu, 1965	255
1.1.2 Genus *Eutrombicula*		*L. lianghense* Yu et al., 1983	12	*T. chilie* Wen and Xiang, 1984	2
E. wichmanni (Oudemans, 1905)	1	*L. linji* Wen and Sun, 1984	1	*T. cuneatus* Traub and Evans,1951	3
1.1.3 Genus *Helenicula*		*L. longchuanense* Yu et al., 1981	5	*T. jilie* Wen and Xiang, 1984	1
H. kohlsi (Philip and Woodward, 1946)	4	*L. longimedium* Wen and Xiang, 1984	277	*T. nujiange* Wen and Xiang, 1984	136
H. lanius (Radford, 1946)	1	*L. lushanense* Wang and Song, 1991	12	*T. yunnanus* (Wang and Yu, 1965)	125
H. hsui Zhao, 1990	86	*L. neotebraci* Xiang and Wen,1986	6	1.1.8 Genus *Walchia*	
H. simena (Hsu and Chen, 1957)	247	*L. nyctali* Wen and Sun,1984	2	*W. acutascuta* Chen, 1980	1
H. yunnanensis Wen and Xiang, 1984	12	*L. pallidum* (Nagayo et al., 1919)	5	*W. enode* Gater, 1932	1
1.1.4 Genus *Herpetacarus*		*L. parapalpale* (Womersley et al., 1952)	2	*W. ewingi* (Fuller, 1949)	204
H. hastoclavus Yu et al., 1979	393	*L. qujingense* Yu et al., 1981	39	*W. koi* (Chen and Hsu, 1957)	59
H. tenuiclavus Yu et al., 1979	15	*L. rufocanum* Wang and Liu,1989	1	*W. micropelta* (Traub and Evans, 1957)	36
1.1.5 Genus *Leptrombidium*		*L. rupestre* Traub and Nadchatram, 1967	61	*W. xishaensis* Zhao et al., 1986	11
L. akamushi (Brumpt, 1910)	9	*L. robustisetum* Yu et al., 1983	36	1.2 Subfamily Gahrliepiinae	
L. alpinum Yu and Yang, 1986	61	*L. saltuosum* Yu et al., 1982	11	1.2.1 Genus *Gahrliepia*	
L. apodevrieri Wen and Xiang,1984	125	*L. scutellare* (Nagayo et al., 1921)	2312	*G. agrariusia* Hus et al., 1965	4
L. bambicola Xiang and Wen, 1984	78	*L. shuqui* Wen and Xiang, 1984	88	*G. chekiangensis* Chu, 1964	33
L. baoshui Wen and Xiang, 1984	89	*L. shuyui* Wen et al., 1984	254	*G. chungkingensis* Jeu et al., 1963	1
L. bayanense Yang, 1994	1	*L. sinicum* Yu et al., 1981	222	*G. eurypunctata* Jeu et al., 1983	1
L. biji Wen and Xiang, 1984	421	*L. svnotupaium* Wen and Xiang, 1984	5	*G. deqinensis* Yu and Yang, 1982	9
L. biluoxueshanense Yu et al., 1982	2	*L. spicanisetum* Yu et al., 1986	3	*G. latiscutata* Chen and Fan, 1981	15
L. bishanense Yu, 1986	84	*L. suense* Wen, 1984	19	*G. lengshui* Wen and Xiang, 1984	1
L. cangjiangense Yu et al., 1981	37	*L. trapezoidum* Wang et al., 1981	19	*G. linguipelta* Jeu et al., 1983	41
L. caudatum Wen et al., 1984	386	*L. turdicola* Vercammen-Grandjean et Langston, 1976	20	*G. longipedalis* Yu and Yang, 1986	2
L. cricethrionis Wen et al., 1984	795	*L. wangi* Yu et al., 1986	611	*G. madun* Wen and Xiang, 1984	6
L. cuonae Wang et al., 1996	2	*L. wenense* Wu et al., 1982	17	*G. megascuta* Hsu et al., 1965	61
L. deliense (Walch, 1922)	42	*L. xiaguanense* Yu et al., 1981	318	*G. miyi* Wen and Song, 1984	106
L. densipunctatum Yu et al., 1982	1791	*L. xiaowei* Xiang and Wen, 1984	37	*G. myriosetosa* (Wang, 1964)	9
L. deplanoscutum Yu et al., 1981	1	*L. xishani* Wen and Xiang, 1984	24	*G. orientalis* Wen and Xiang, 1984	10
L. dianchi Wen and Xiang, 1984	20	*L. yongshengense* Yu and Yang, 1986	87	*G. radiopunctata* (Hsu et al., 1965)	7
L. ejingshanense Yu et al., 1982	11	*L. yui* (Chen and Hsu, 1955)	205	*G. silvatica* Yu and Yang, 1982	15
L. eothenomydis Yu and Yang, 1986	77	*L. yunlingense* Yu et al., 1981	97	*G. yunnanensis* (Hsu et al., 1965)	204
L. fujianense Liao and Wang,1983	718	*L. zhongdianense* Yu et al., 1981	12	2. Family Leeuwenhoekiidae	
L. gongshanense Yu et al., 1981	39	1.1.6 Genus *Neotrombicula*		2.1 Subfamily Leeuwenhoekiinae	
L. gemiticulum (Traub et al.,1958)	1	*N. aeretes* Hsu and Yang,1985	108	2.1.1 Genus *Chatia*	
L. hiemale Yu et al., 1982	217	*N. deqinensis* Yu and Wang,1981	1	*C. alpina* Shao and Wen, 1984	7
L. hsui Yu et al., 1986	19	*N. japonica* (Tanaka et al., 1930)	69	2.1.2 Genus *Shunsennia*	
L. huangchuanense Yang,1994	32	*N. longmenis* Wen and Xiang, 1984	6	*S. scabriselosa* (Huang, 1986)	7
Total	12,281 individuals, 107 species, 11genera, 3 subfamilies, 2 families				

Annotation: Of 12,516 collected chigger mites, 12,281 ones were identified to species.

Table 3
The constituent ratios, infestation indices and dispersion coefficients of three dominant species of chigger mites on Chevrieri's field mice (*Apodemus chevrieris*) in southwest China (2001–2019).

Dominant species of chigger mites	Constituent ratios of chigger mites		Infestations of chigger mites			Dispersion coefficient	
	Individuals	C_r (%)	P_M (%)	*MA*	*MI*	C_A	*I*
Leptotrombidium scutellare	2312	18.47	8.13	1.17	14.36	106.76	124.60
Leptotrombidium densipunctatum	1791	14.31	5.45	0.90	16.58	74.31	67.18
Leptotrombidium cricethrionis	795	6.35	6.11	0.40	6.57	54.27	21.78
Total 107 species of chigger species	12516	100	31.95	6.32	19.77	15.47	97.77

on *A. chevrieri* mice ($P < 0.001$) (Table 7).

3.7. Species abundance distribution and total species estimation of chigger mites on Apodemus chevrieri mice

Of the 107 species and 12516 individuals of chiggers collected from *A. chevrieri* mice, most chigger species were rare species with 5–13 individuals (Table 8). By using Preston log-normal distribution model, the species abundance distribution of chigger mite community on *A. chevrieri* mice was fitted as $\widehat{S}(R) = 23e^{-n0.3R)^2}$ ($\beta = 0.30$, $R^2 = 0.68$), and the theoretical curve showed a parabolic tendency (Table 8 and Fig. 2). Based on fitting the species abundance distribution, the expected total species of chigger mites on *A. chevrieri* mice were estimated to be 136 species ($S_T = 136$), 29 more than the actually collected species ($S = 107$).

4. Discussion

4.1. Species diversity, infestation and community structure of chigger mites on Apodemus chevrieri mice

The original data of the present study came from a long-term field

Table 4
Analysis on interspecific association between any two dominant species of chigger mites on Chevrieri's field mice (*Apodemus chevrieri*) in southwest China (2001–2019).

		Leptotrombidium densipunctatum			Leptotrombidium cricethrionis		
		+	−	total	+	−	total
Leptotrombidium scutellare	+	15 (*a*)	146 (*b*)	161 (*a* + *b*)	63 (*a*)	104 (*b*)	167 (*a* + *b*)
	−	93 (*c*)	1727 (*d*)	1820 (*c* + *d*)	64 (*c*)	1756 (*d*)	1820 (*c* + *d*)
Total		108 (*a* + *c*)	1873 (*b* + *d*)	1981 (*n*)	127 (*a* + *c*)	1860 (*b* + *d*)	1987 (*n*)
Association coefficient		$V = 0.05$			$V = 0.39$		
Chi-square		$\chi^2 = 11.203$			$\chi^2 = 6.109$		
Significance		<0.05			<0.05		

investigation in 91 sites (counties) of southwest China, which covered the five provincial regions, Yunnan, Guizhou, Sichuan, Chongqing and Tibet. The present study is the first time to systematically report the infestation and distribution of chigger mites on *A. chevrieri* in southwest China where is a very wide geographical region with a total of 2,500,000 km^2. A previous study from Yunnan province of southwest China reported that 1414 chigger mites (61 species) were collected from 1113 brown rats (Norway rat), *Rattus norvegicus* (Berkenhout, 1769), with overall $P_M = 13.39\%$, $MA = 1.27$ and $MI = 9.49$ (Ding et al., 2021a), which are much lower than the chigger infestations on *A. chevrieri* mice in the present study. Another previous study revealed that a total of 49,850 individuals of chigger mites (175 species) were identified from 2463 *Eothenomys miletus* (Thomas, 1914) in three provinces of southwest China, Yunnan, Guizhou and Sichuan (Peng et al., 2015, 2016). The overall infestations of chigger mites on *E. miletus* voles ($P_M = 57.69\%$, $MA = 20.24$ and $MI = 35.08$) are obviously higher than those on *A. chevrieri* mice in the present study (Peng et al., 2015, 2016). The species diversity and infestations of chigger mites on rodents (rats, mice and voles, etc.) can be influenced by a series of factors, including host species and various environmental factors. Different species of rodents with different biological characteristics are usually different in the susceptibility of infesting with chigger mites and some other ectoparasites (Ding et al., 2021a; Peng et al., 2015, 2016). The cross infestations of chigger mites among different hosts are very common because of their low host specificity. The rodents living in complicated wild habitats with diverse vegetation usually harbor more chigger mites and some other ectoparasites with higher species diversity and infestations than those living the residential areas of humans (Peng et al., 2016; Guo et al., 2013). *Apodemus chevrieri* mice and *E. miletus* voles are two species of typical wild rodents (Peng et al., 2016; Guo et al., 2013; Huang et al., 1995), and therefore the species diversity and

Table 5
Overall infestations of Chevrieri's field mice (*Apodemus chevrieri*) with chigger mites in different landscapes and on different ages of the hosts in southwest China (2001–2019).

Different landscapes and different ages of hosts	Number of captured hosts, *A. chevrieri*	Infested hosts, *A. chevrieri*	Individuals of chigger mites		Overall infestations of chigger mites on the host, *A. chevrieri*		
			Individuals	*Cr* (%)	*PM* (%)	*MA*	*MI*
mountainous landscape	1779	611	12277	98.09	34.35	6.20	20.09
flatland landscape	202	22	239	1.91	10.89	1.18	10.86
Total	1981	633	12516	100.00	31.95	6.32	19.77
Juvenile hosts	429	99	1209	9.66	2.24	2.82	12.21
Adult hosts	1550	534	11307	90.34	34.45	7.29	21.17
Total[a]	1979	633	12516	100	31.99	6.32	19.77

[a] Annotation: Two individuals of *A. chevrieri* mice without gender record were not included in the above table.

Table 6
Overall infestation of Chevrieri's field mice (*Apodemus chevrieri*) with chigger mites in different latitude gradients and altitude gradients in southwest China (2001–2019).

Different latitude gradients and altitude gradients	Number of captured mice	Infested mice	Individuals of chigger mites		Overall infestations of chigger mites on the mice		
			Individuals	C_r (%)	*PM* (%)	*MA*	*MI*
latitude <24°N	2	1	19	0.15	0.05	0.01	19.00
latitude 24–26°N	770	337	6740	53.85	17.01	3.40	20.00
latitude 26–28°N	1101	205	2626	20.98	10.35	1.33	12.81
latitude >28°N	108	90	3131	25.02	4.54	1.58	34.79
Total	1981	633	12516	100.00	31.95	6.32	19.77
altitude <1000M	3	1	19	0.15	0.33	6.33	19.00
altitude 1000–2000M	604	145	3662	29.26	24.01	6.06	25.26
altitude 2000–3000M	1117	413	8014	64.03	36.97	7.17	19.40
altitude >3000M	257	74	821	6.56	28.79	3.19	11.09
Total	1981	633	12516	100.00	31.95	6.32	19.77

Table 7
Logistic regression analysis of the factors related to the infestations of chigger mites on Chevrieri's field mouse (*Apodemus chevrieri*) in southwest China (2001–2019).

		B	S.E.	Wald	df	Sig.	OR	95% CI	
								Lower	Upper
Step 4[d]	landscapes (1)	1.537	0.233	43.570	1	0.000	4.652	2.947	7.342
	altitudes	0.217	0.077	7.894	1	0.005	1.243	1.068	1.446
	latitudes	−0.400	0.088	20.552	1	0.000	0.670	0.564	0.797
	host ages	0.691	0.128	29.012	1	0.000	1.995	1.552	2.565
	constant	−2.983	0.426	48.980	1	0.000	0.051		

Table 8
Theoretical curve fitting for the species abundance distribution of chigger mite community on Chevrieri's field mice (*Apodemus chevrieri*) in southwest China (2001–2019).

Log intervals	Individual ranges in each log interval	Midpoint values of each individual range	Actual chigger mite species	Theoretical chigger mite species
0	0–1	1	15	16.05
1	2–4	3	12	21.02
2	5–13	9	23	23.00
3	14–40	27	18	21.02
4	41–121	81	18	16.05
5	122–364	243	13	10.23
6	365–1093	729	6	5.45
7	1094–3280	2187	2	2.42

Annotation: $R_0 = 2$, $S_0 = 23$ and $\beta = 0.30$ ($R^2 = 0.68$) in the theoretical curve fitting for the species abundance distribution of chigger community.

infestations of chigger mites on *A. chevrieri* mice and *E. miletus* voles are much higher than those on *R. norvegicus* rats which often lives in the residential areas of humans (Ding et al., 2021a; Peng et al., 2016; Guo et al., 2013).

Because of low host specificity of chigger mites, the species diversity and infestations of chigger mites on the same species of host often vary in different geographical regions, latitudes, altitudes, landscapes and habitats (Ding et al., 2021a; Peng et al., 2017). Through cross infestation, the same host species can harbor different mite species in different environments (Ding et al., 2021a; Peng et al., 2017). Different geographical regions with different latitudes, altitudes and climates can lead to the different species richness (species diversity) and species compositions of chigger mites and some other ectoparasites on the same species of hosts (Peng et al., 2016; Ding et al., 2021a), and this may explain that the infestations of *A. chevrieri* mice with chigger mites varied in different latitudes and altitudes. The environmental gradients could be the important risk factors of influencing the infestations of chigger mites on *A. chevrieri* mice. The high species diversity of chigger mites (107 species) on *A. chevrieri* mouse may reflect the mouse's high potential of harboring abundant mite species. The complicated topography and diverse climate types in southwest China may also contribute to the high species of chigger mites in the region (Peng et al., 2016; Ding et al., 2021a; Yin et al., 2021). Besides, the wide investigation scope in 91 investigation sites of five provincial regions with large host samples (1981 *A. chevrieri* mice) is also an important factor to lead to the high species of chigger mites in the present study.

The community structure of chigger mites on *A. chevrieri* mice showed a high diversity with a high species richness ($S = 107$) and diversity index ($H' = 3.27$) as well as a high evenness index ($E = 0.699$), but a relatively low dominance index ($D = 0.075$). The results may indicate that there were many chigger mite species on *A. chevrieri* mice, but no obviously dominant species.

4.2. Dominant chigger species on Apodemus chevrieri mice and their spatial distribution patterns and interspecific relationship

Of the 107 species of chigger mites identified from *A. chevrieri*, there were three dominant chigger species and they were *L. scutellare* (C_r = 18.47%), *L. densipunctatum* (C_r = 14.31%) and *L. cricethrionis* (C_r = 6.35%). Of the three dominant chigger species, *L. scutellare* was the most abundant, and *L. densipunctatum* and *L. cricethrionis* came next (Table 3). *Leptotrombidiu scutellare* is one of six main vectors of scrub typhus in China, and *L. cricethrionis* is considered a potential vector of the disease (Su et al., 2012; Wu et al., 2013). As a typical wild rodent species, *A. chevrieri* is often found in various wild and outdoor habitats including crop fields, various farmlands, bush areas, grasslands and open woodlands and it is closely associated with human activities (Wlison et al., 2017; Huang et al., 1995). The abundant occurrence of *L. scutellare* and *L. cricethrionis* on the body surface of *A. chevrieri* mice would increase the possibility of transmitting scrub typhus from the mouse to humans.

The Cassie index (C_A) and clumping index (I) was adopted to measure the spatial distribution of three dominant species of chigger mites among different individuals of their mouse host, *A. chevrieri* mice (Table 3). As a result, all the dominant species of chigger mites was determined as aggregated distribution among different individuals of *A. chevrieri* mice. The aggregated distribution is a very common distribution pattern of ectoparasites including chigger mites (Ding et al., 2021a; Xiang et al., 2021). The aggregated distribution is considered to be beneficial to the survival, spread, mating, reproduction and defense of the parasites (Peng et al., 2016; Liu et al., 2020b; Ding et al., 2021a), and it may also facilitate the transmission of some zoonotic diseases by vector mites from rodents to humans.

The association coefficient (V) used in the present study is a common and applicable way to measure the interspecific relationship between any two species of chigger mites on their hosts (Liu et al., 2020b; Yin et al., 2021). The result showed that the interspecific association between any two of three dominant chigger species (*L. scutellare*, *L. densipunctatum* and *L. cricethrionis*) were slightly positive ($V > 0$, $P <$

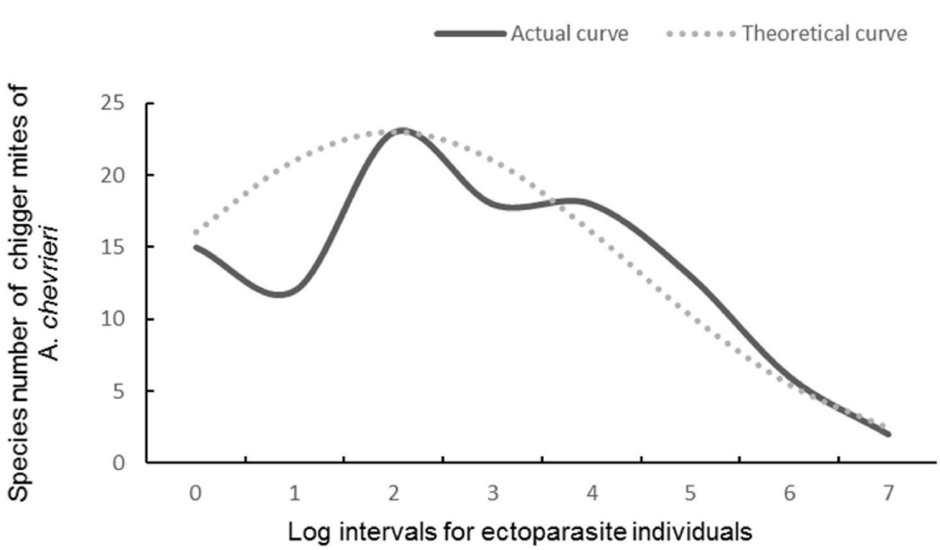

Fig. 2. Theoretical curve fitting for the species abundance distribution of chigger mite community on Chevrieri's field mice (*Apodemus chevrieri*) in southwest China (2001–2019).

0.05), which indicates that the dominant chigger species have a tendency to co-exist on the body surface of *A. chevrieri* mice.

4.3. Infestation variations of chigger mites in different environments and on different ages of hosts

In comparison with the *A. chevrieri* mice in the flatland landscape, the mice in the mountainous landscape harbored much more chigger mites with much higher infestation indices (P_M, *MA* and *MI*) with statistical significance ($P < 0.001$) (Table 5). The result reflects the infestation variations of chigger mites in different landscapes. In southwest China, the mountainous landscapes are usually associated with complex environments, diverse vegetation and high biodiversity in comparison with the flatland landscapes (Ding et al., 2021a; Pongsiri et al., 2009; Peng et al., 2018). The complex environments, diverse vegetation and high biodiversity in the mountainous landscape may lead to the higher infestations of chigger mites on *A. chevrieri* mice.

The infestations of chigger mites in different latitudes and altitudes also showed some variations. The *A. chevrieri* mice in the N24°-26° latitude harbored more chigger mites with higher P_M and *MA* ($P < 0.001$). The mean intensity (*MI*) in the N28°-30° latitude was higher than that in other latitudes ($P < 0.001$) (Table 6). *Apodemus chevrieri* mice in the altitude 2000–3000m harbored a large number of chigger mites with higher P_M and *MA* (Table 6). Some previous studies also reported the infestation variations of gamsid mites and chigger mites on the same rodent species, the Asian house rat (oriental house rat) *Rattus tanezumi* (Temminck, 1844) and the brown rat *R. norvegicus* in different latitudes and altitudes (Yin et al., 2021; Lv, 2021). The infestation variations of chigger mites in different latitudes and altitudes reflect the influence of environmental factors on the mites, which may be associated with the different vegetation, temperature, humidity and rainfall in different environmental gradients (Yin et al., 2021; Lv, 2021).

The adult *A. chevrieri* mice harbored much more chigger mites with significantly higher infestations (P_M, *MA* and *MI*) than the juvenile mice (Table 5), and this is consistent with some previous studies (Ding et al., 2021a; Peng et al., 2015). The result suggests an age-bias of the *A. chevrieri* mice in the infestations of chigger mites. The larger body size of adult hosts and their wider range of activities in the external environments may increase the risk of infesting ectoparasites including chigger mites (Poulin, 1997; Kataranovski et al., 2011).

The logistic regression analysis used in the present study is a common way to evaluate the risk factors of some diseases in clinical studies (Truett et al., 1967; Liu, 2020), but it was seldom used in analyzing the infestations of chigger mites on rodent hosts. The result of the present study showed that the risk factors of influencing the infestations of *A. chevrieri* mice with chigger mites included the landscape, host age and altitude. The infestations of rodents (rats, mice and voles, etc.) with ectoparasitic mites and some other ectoparasites can be influenced by a series of complex factors including host species, environmental factors and climatic factors (Kataranovski et al., 2011; Liu, 2020). This result of the present paper reflects the influence of the host factor (host age) and environmental factors (landscape and altitude) on chigger mites.

4.4. Species abundance distribution of chigger mites on Apodemus chevrieri mice

The species abundance distribution is to illustrate the relationship between species and individuals in a certain community (Ding et al., 2021a; McGill et al., 2007; Preston 1948). In the present study, the log-normal distribution model based on Preston' methods was applied to describe the species abundance distribution of the chigger mite community on *A. chevrieri* mice. The theoretical species abundance distribution of chigger mites (chigger mite community) on *A. chevrieri* mice was fitted as $\widehat{S}(R) = 23e^{-(0.3R)^2}$ by the lognormal distribution model with the determination coefficient $R^2 = 0.68$ (Fig. 2), which is similar to that of chigger mites and some other ectoparasites on some other species of rodents (Ding et al., 2021a; Guo et al., 2016).

In ecological studies, it is often necessary to roughly estimate the expected total number of species in a given community. There are a series of methods to estimate the expected total species and one of them is the method based on Preston's lognormal model in the present study (Ding et al., 2021a). The total expected number of chigger species on *A. chevrieri* mice was roughly estimated to be 136 species ($S_T = 136$), and the result suggests that there are about 29 rare chigger species probably missed in the actual field investigation. Some rare species are too rare to be found, and it is impossible to collect all the rare species in an actual field investigation (Ding et al., 2021a; Chao and Shen, 2003; Peng et al., 2017). In order to find more rare species of chiggers and some other ectoparasites, abundant host samples with a wide geographical scope are often recommended in the field investigations (Peng et al., 2016).

5. Conclusion

The Chevrieri's field mouse (*A. chevrieri*) has a great potential to harbor lots of chigger mites with high species diversity and infestation. *Leptrombidium scutellare*, *L. densipunctatum* and *L. cricethrionis* are the dominant chigger species on the mouse in southwest China and they are of aggregated distribution on the host *A. chevrieri*. The infestations of *A. chevrieri* with chigger mites vary with different latitudes, altitudes and landscapes, and the environmental factors and host ages often influence the infestations of the mouse with the mites. Abundant host samples with a wide geographical scope are recommended in the field investigations to find more rare chigger species and some other ectoparasites.

Supplemental statement

The capture of *A. chevrieri* mice was officially approved by the local authority of wildlife service in Dali Prefecture, Yunnan Province, China. The use of animals for the research was officially approved by the Animal Ethics Committee of Dali University.

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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