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食虫沟瘤蛛的饥饿耐受性

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摘要：对我国多数稻区共享的优势种蜘蛛食虫沟瘤蛛进行饥饿耐受性测定，结果显示食虫沟瘤蛛的耐饥时间以及组内个体耐饥力的变异幅度与温度高低呈负相关。在35、25℃和15℃ 3种试验温度下，食虫沟瘤蛛的耐饥时间及变异幅度均与龄期呈正相关；在5℃时，耐饥时间极大延长，组内变异系幅度亦急剧增大，但此时耐饥时间和变异幅度均与龄期呈负相关。在高温35℃和低温5℃下，3个龄期组的耐饥时间差异不显著（$p>0.05$）；但在适宜温度25℃和15℃时，3个龄期组之间的耐饥时间差异显著（$p<0.05$）。同一龄期组的食虫沟瘤蛛在任意两种不同的温度条件下，其耐饥时间的差异性均达到极显著水平（$p<0.01$）。4种试验温度条件下，处于饥饿状态的食虫沟瘤蛛各龄期组的阶段死亡率均具有正态分布特点，可用正态分布模型 $M=\frac{1}{\sigma\sqrt{2\pi}}\cdot e^{-\frac{(T-\mu)^2}{2\sigma^2}}$ 进行拟合；并可根据正态分布的特点得出食虫沟瘤蛛的饥饿半致死时间（T_{50}）和致死时间（T_{95}）。

关键词：食虫沟瘤蛛；饥饿耐受性；温度；龄期

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The starvation endurance of *Ummeliata insecticeps*

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Abstract: The paddy spider is one of the primary predators of rice pests — accounting for around 51.2% to 89.5% of the total kinds of predators in paddy fields. The paddy ecosystem is complex and unstable because of climate variation and the activities of living organisms and human beings. The paddy spiders must endure starvation periods because the populations of their prey are occasionally reduced in a large amount by the cold climate in winter or by farming activities like spraying chemicals, gathering, plowing and so on. Studying the starvation endurance of the paddy spider can provide more detailed and precise parameters for protecting and utilizing them. This paper focuses primarily on the starvation endurance of *Ummeliata insecticeps* (Boesenberg et Strand), which is common in most rice-planting areas in China. The results show that the survival time of *U. insecticeps* and the variation among individuals are positively related with the spider's instar age at 35, 25℃ and 15℃, but negatively related at 5℃. In addition, both the survival time and the variation among individuals of all test groups increased greatly at 5℃. Whereas the differences of survival time among the three instar-groups are insignificant ($p>0.05$) at 35℃ and 5℃, the survival times of the

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three instar-groups are significantly different ($p < 0.05$) at the favorable temperatures of 25℃ and 15℃. Temperature influences the spider's starvation endurance greatly. The survival time of a certain instar-group that lived in one kind of temperature is greatly different from that of the same instar-group at any other kind of temperature ($p < 0.01$).

There is a close relationship between the stage-mortality (M) and the survival time (T) of *U. insecticeps* in starvation. It can be fitted with a normal distribution model: $M = \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{(T-\mu)^2}{2\sigma^2}}$. The starvation endurance thresholds and lethal times of different *U. insecticeps* instar-groups can be calculated according to the equation of the normal distribution model.

Key words: *Ummeliata insecticeps*; starvation endurance; temperature; instar

The natural predator is one of the important biotic factors to regulate pest populations in ecosystems[1–3]. A predator's capacity to adapt to unfavorable conditions is an important characteristic for evaluating it. McMurtry J A took "the survival capacity during starvation periods" as one of the general characteristics of effective predators[4]. The paddy ecosystem is complex and unstable, to some degree, because of climate variations and the activities of living organisms and human beings. The paddy predators have to deal with starvation aperiodically because the populations of their prey in the paddy field are occasionally reduced in a large amount by the cold climate in winter or by farming activities like spraying chemicals, gathering, plowing and so on[5–7]. There were already some reports on starvation endurance of phytoseiid mites, *Chrysopa phyllochroma*, *Microvelia horvathi*, *Chilocorus rubidus*, etc.[8–11].

Spiders are essential predators against many insects in paddy fields because of their vigorous predation habits and large population sizes in a variety of species[12, 13]. It is important to investigate spiders' starvation endurance to strengthen their role as insect regulators. There have been quite a few studies focusing on community structure and predation function of spiders[14–18]. As far as spiders' starvation endurance is concerned, however, there are just a few rough descriptions at natural, variable temperatures[19–21]. In order to provide more detailed and precise parameters for protecting and utilizing spiders, this paper aims to test the starvation endurance of *U. insecticeps*, the dominant species of spiders found in most rice planting areas in China, at four kinds of controlled temperatures.

1 Material and Method

1.1 Material

The spiders (*U. insecticeps*) were collected from a rice field in a western suburb of Changsha, Hu'nan Province, China. Only healthy, uninjured individuals of *U. insecticeps* were collected for the test.

1.2 Method

Each spider was weighed by electronic analytical balance (1/10000, Shanghai Balance Instrument Plant), then put into a 30ml cuvette with a little wet cotton to provide suitable humidity. Then the spiders were separated into three instar-groups according to their instar age: 1^{st} — 2^{nd} instar-group, 3^{rd} — 4^{th} instar-group and 5^{th} instar-adult-group. Four temperatures were set in the test: 35, 25, 15℃ and 5℃. At each temperature, three control groups and three test groups were studied. The spiders were fed with sufficient drosophilae for three days, after which no drosophila were given to the test groups. The control groups continued to be fed with sufficient drosophila every week. The number of dead spiders in each group was recorded every 5 days. The experiment was repeated 2 times.

1.3 Data analysis

1.3.1 The stage mortality $M = M_t - M_c$ (M_t stands for mortality of the test groups, and M_c stands for mortality of the control groups)

1.3.2 The model of normal distribution $M = \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{(T-\mu)^2}{2\sigma^2}}$ (M stands for mortality, T stands for survival time, σ is the standard deviation, μ is the mean)

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1.3.3 The data accorded with the normal distribution. The variances of all the data groups were homogeneous according to the method of Bartlett. The analysis of variance was taken by the fixed effect model, and the means were separated by the method of Duncan's Multiple Range Test. The analysis of linear regression, correlation coefficient and variance analysis were completed by EXCEL. Curve equations to fit the model of normal distribution, starvation endurance threshold (T_{50}) and lethal time (T_{95}) were calculated by SPTOOL in software MATLAB5.3.

2 Result and Analysis

2.1 The survival time of *U. unsecticeps* individuals in starvation. The first death occurred earlier in the young instar-group living at high temperature than the first death in old instar-group living at low temperature. The times of the first death occurrence and last death occurrence of the test spider groups are listed in Table 1.

Spiders can survive longer in a cold environment than in a warm environment. Furthermore, spiders with high instar survived longer than those with low instar at 35℃, 25℃ and 15℃ but died more quickly at 5℃. The average survival time of the test spider groups is shown in Table 2.

Table 1 Survival time of *U. insecticeps* individuals of different groups

Items	Test temperature (℃)	Survival days (d)		
		1st—2nd instar-group	3rd—4th instar-group	5th instar-adult-group
The time of first death occurrence	35	5	7	8
	25	7	11	14
	15	10	18	26
	5	19	22	29
The time of last death occurrence	35	21	24	27
	25	34	44	57
	15	43	55	61
	5	270	257	196

The results of variance analysis are as follows: The differences of survival time among three instar-groups are insignificant at the high temperature of 35℃ and low temperature 5℃ ($F_{5℃} = 0.34 < F_{35℃} = 2.90 < F_{(2.80,0.05)} = 3.11$, $p > 0.05$). At the favorable temperature of 25℃ and 15℃, however, the difference of average survival time between 1st—2nd instar-group and 3rd—4th instar-group is significant ($p < 0.05$). Furthermore, the differences between the 5th instar-adult-group and the other two instar-groups are extremely remarkable ($p < 0.01$). The differences between the test groups at any two different temperatures are also extremely remarkable ($p < 0.01$).

Table 2 The average survival time of test spider groups

Test temperature (℃)	Survival days (d)		
	1st—2nd instar-group	3rd—4th instar-group	5th instar -adult-group
35	9.036 ± 1.395 aa	10.857 ± 1.751aa	12.285 ± 2.068 aa
25	17.154 ± 2.153 ab	20.308 ± 2.785 bb	25.042 ± 2.679 cb
15	32.105 ± 4.822 ac	38.053 ± 3.858 bc	45.105 ± 3.612 cc
5	99.464 ± 12.002 ad	93.107 ± 11.910 ad	85.964 ± 9.906 ad

Data are mean ± SD. Means of same row or column followed by different letters are statistically different (ANOVA followed by LSD $p < 0.05$, Duncan's Test $p < 0.05$)

It can be concluded that the older spiders display great superiority in resisting starvation when the environmental temperature is favorable but are nearly the same as the young ones at the extreme temperatures. Because the spider's body and instar are limited by the exuvial time, the higher the spider's instar is, the larger its body is. Large spiders need more food and are able to prey on more insects. Large spiders also maintain much more energy storing material, like fat, than small spiders. Moreover, with growth, spiders' physiological function improves and their regulation ability strengthens gradually. Therefore, large spiders can endure difficult conditions like prey scarcity more efficiently and survive longer than small spiders.

The environmental temperature makes a great impact on spiders' starvation endurance. In ectotherms the metabolic rate is relatively slow at low temperatures and more rapid as the environment becomes warmer[22]. Therefore, the consumption of materials that store energy, such as fat, etc. increases at high temperatures. In addition, high

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temperatures may hinder normal metabolism of the spiders and disorder their physiological function. *U. insecticeps* has evolved to slow its metabolic rate by lessening activities to lengthen survival time in starvation when the temperature is extremely cold. This adaptation has played an important role in the spider's starvation endurance at cold conditions.

Regression analysis of the relationship between the survival time and instar shows that they display direct correlation at 35, 25, 15℃, but inverse correlation at 5℃. The linear equations are as follows:

$$\begin{cases} y_{35℃} = 1.625x + 7.477 & r = 0.9951^{**} \\ y_{25℃} = 3.944x + 12.947 & r = 0.9934^{**} \\ y_{15℃} = 6.500x + 25.421 & r = 0.9951^{**} \\ y_{5℃} = -6.750x + 106.35 & r = 0.9951^{**} \end{cases}$$

The survival time and temperature are inversly correlated as the linear equations show.

$1^{st}-2^{nd}$ instar-group: $y = -28.624x + 111.00$ $r = 0.8982^{**}$

$3^{rd}-4^{th}$ instar-group: $y = -26.450x + 106.71$ $r = 0.9282^{**}$

5^{th} instar-adult-group: $y = -24.110x + 102.37$ $r = 0.9663^{**}$

2.2 Variances of starvation endurance of the test-groups

The variation degree of data groups can be found by comparing the coefficient of variability. According to the formula $CV = \frac{s}{\bar{x}}$ (the denominator stands for the standard deviation, the numerator the mean), variance coefficients of survival time of different spider instar-groups are displayed in Figure 1.

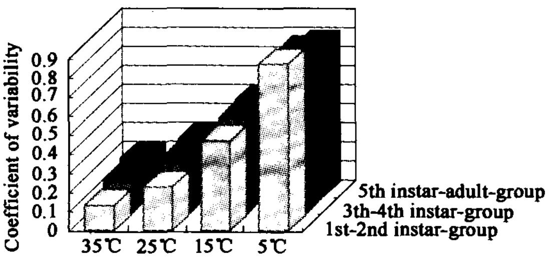

Fig.1 Variance coefficients of starvation endurance of the test-groups

The variance coefficient and temperature are inversely correlated as the linear equations show.

$1^{st}-2^{nd}$ instar-group: $y = 0.2449x - 0.1855$ $r = 0.9629^{**}$

$3^{rd}-4^{th}$ instar-group: $y = 0.2265x - 0.1135$ $r = 0.9739^{**}$

5^{th} instar-adult-group: $y = 0.1983x - 0.0468$ $r = 0.9793^{**}$

The relationships between variance coefficients and the spider's instar are positively correlated at 35, 25℃ and 15℃ but negatively at 5℃. They can be fitted by liner equations as follows:

$$\begin{aligned} y_{35℃} &= 0.0325x + 0.1027 & r &= 0.9994^{**} \\ y_{25℃} &= 0.0353x + 0.2036 & r &= 0.9389^{**} \\ y_{15℃} &= 0.0183x + 0.4548 & r &= 0.9355^{**} \\ y_{5℃} &= -0.0394x + 0.9184 & r &= 0.9994^{**} \end{aligned}$$

It could be deduced that some constitutional diversities existed among the spider individuals. As individuals grow, environmental factors exert more influences on their physiological functions. That's why the variability of starvation endurance increases with the spiders' growth at normal temperatures. At the low temperature of 5℃, however, some individuals in the $1^{st}-2^{nd}$ instar-group were especially able to resist low temperature and starvation and survived. Accordingly, the average survival time of the $1^{st}-2^{nd}$ instar-group lengthened greatly, and the range of variation increased correspondingly. Young spiders are able to resist starvation and cold temperatures more efficiently than old ones. The reason could be that *U. insecticeps* larvae have strengthened their resilience in the evolutionary process because *U. insecticeps* survives the harsh winter as larvae or sub-adult spiders. Another explanation could be that *U. insecticeps* larvae are insensitive to cold so they can survive longer in starvation than older spiders in low temperatures.

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2.3 Stage-mortality of *U. insecticeps* in starvation

Setting 5 test days as a stage when *U. insecticeps* lived at 35℃, 10 test days as a stage at 25℃ and 15℃, and 30 test days as a stage at 5℃, the number of dead in each instar-group was recorded in each stage. The stage mortalities of the three instar-groups were calculated according to $M = M_t - M_u$ (in 1.3.1). Taking survival time as abscissa and stage mortality as ordinate, the relationship between stage mortality and survival time in four kinds of temperatures are displayed in fig. 2.

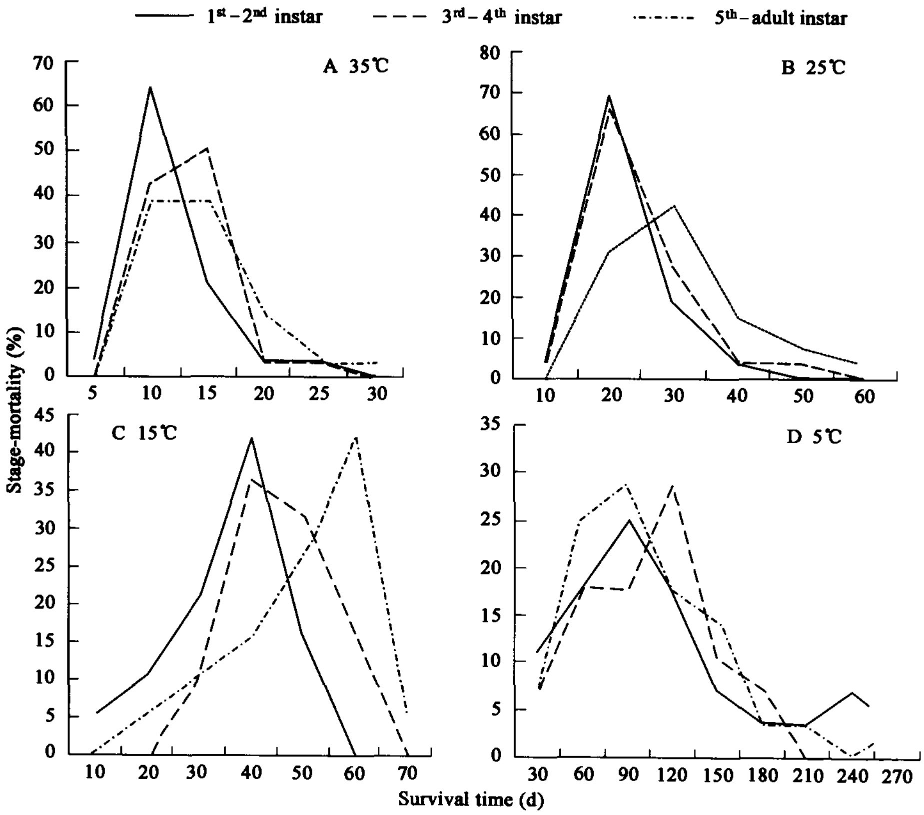

Fig.2 Stage-mortalities of *U. insecticeps* in starvation at different temperatures

It can be observed from fig. 2 that all curves take the form of a bell jar, which indicates that the curves possess characteristics of normal distribution. Fitting the curves with normal distribution model $M = \frac{1}{\sigma\sqrt{2\pi}} \cdot e^{-\frac{(T-\mu)^2}{2\sigma^2}}$, the correlation coefficients and the significance levels are shown in Table 3.

Obviously all the curves can be fairly well fitted with normal distribution. It can be concluded that at the four test temperatures, 35, 25, 15℃ and 5℃, stage mortalities of *U. insecticeps* instar-groups in starvation have normal distribution.

Table 3 The imitation of stage mortality curves of U. insecticeps to normal distribution model equation

Temperature (℃)	Correlation coefficients			$r_{0.05}$	$r_{0.01}$
	1st—2nd instar-group	3rd—4th instar-group	5th instar-adult-group		
35	0.915*	0.945**	0.891*	0.811	0.917
25	0.977**	0.856*	0.940**	0.811	0.917
15	0.942**	0.975**	0.782*	0.754	0.874
5	0.677*	0.762*	0.782*	0.666	0.798

2.4 Starvation endurance threshold (T_{50}) and lethal time (T_{95})

2.4.1 Starvation endurance threshold (T_{50}) of *U. insecticeps* Starvation endurance threshold may be considered the time when 50% of the test spiders had died from starvation and 50% of the individuals still survived. The curves of stage mortality are symmetrical about the line $X = u$ according to the property of normal distribution. Because is the peak of the

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curve, which can be explained by the equation of normal distribution, the value corresponding to is the starvation endurance threshold (T_{50}) of the spider (the average survival time in table 1). It can be seen that T_{50} of *U. insecticeps* instar-groups increases as the temperature decreases. When the test temperatures are 35, 25, 15℃ and 5℃, the T_{50} was 10.73, 20.84, 38.42 days and 92.85 days, respectively.

2.4.2 Starvation lethal time (T_{95}) of *U. insecticeps* When T obeys normal distribution (the mean is u, the standard deviation is σ), $X = \frac{T-\mu}{\sigma}$ obeys standard normal distribution $N(0,1)$. It can be known that $p(X \leqslant 1.65) = 0.95$ by checking the standard normal distribution table. From this the starvation lethal time (T_{95}) of different spider instar-groups can be calculated. The T_{95} values of the spider instar-groups at the four test temperatures are listed in Table 4.

Table 4 shows that when the environmental temperatures are 35, 25, 15℃ and 5℃, respectively, 95% *U. insecticeps* individuals, which were provided with water and space but no food, would die in 18.50, 32.54, 54.02 days and 98.30 days, on average.

Table 4 The lethal times of *U. insecticeps* instar-groups in starvation

Temperature	Starvation lethal time (d)			Mean values
	$1^{st}-2^{nd}$ instar	$3^{rd}-4^{th}$ instar	5^{th} instar-adult	
35℃	15.25	18.75	21.49	18.50
25℃	27.08	32.76	37.77	32.54
15℃	46.81	54.29	60.96	54.02
5℃	139.73	132.58	122.59	98.30

3 Conclusion and discussion

3.1 The spider is a predator that can endure starvation for a long time[11,12]. Liu F X *et al* measured the starvation endurance of 11 spider species (except for *U. insecticeps*) at four controlled temperatures, 20, 25, 30℃ and 35℃. Their study showed that the spiders in starvation survive longer and longer as they grow and develop, as well as with decreasing temperature[23]. This is consistent with the result of starvation endurance from 15℃ to 35℃ in this paper. By testing an extremely low temperature, this paper reveals further that the starvation endurance of *U. insecticeps* increases greatly at 5℃ and the young survive even longer than the old. It can be concluded:

First, low temperature plays a crucial role in starvation endurance of *U. insecticeps*. *U. insecticeps* has evolved to endure the challenges of the winter environment, such as cold and food scarcity. It survives cold conditions by reducing the amount and intensity of activities and by slowing down metabolism.

Second, *U. insecticeps* survive winter mainly as larvae. A population with more larvae is a growing population, and growing populations can control pests more efficiently. The *U. insecticeps* larvae have evolved to be superior to adults at enduring starvation and cold temperatures. For this reason, they are well adapted to rebuild the spider population each spring, making them ideal predators for controlling pest populations.

3.2 Human activities have a very significant influence on the development and decline of paddy ecosystems. One of the distinct characteristics of paddy ecosystems is that their communities decline and rebuild periodically along with farming activities. The starvation endurance of *U. insecticeps* can help them endure food scarcity caused by cold climate in winter or by farming activities such as spraying pesticide and plowing the paddy field. When the prey population increases, *U. insecticeps* can prey on them quickly and control the pest's population size effectively. Therefore, *U. insecticeps* is one of the most effective predator species in paddy fields.

3.3 The use of natural predators as a form of pesticide is not well developed in China. The challenge of preserving the commercial predators is one of the problems that are holding up production of predator stocks[24]. Strong starvation endurance of predators at low temperatures brings forward the theoretical foundation for a preservation technique for them. Further research on more spider species at lower temperatures is needed so that the best suitable temperature for preserving spiders can be obtained.

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