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Effects of Interspecific Competition on the Population Dynamics of Four Stored Grain Insect Pests

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Abstract: The effects of interspecific competition on the population dynamics of four insect grain Insecp pests (*Sitophilus zeamais*, *Rhizopertha dominica*, *Tribolium castaneum* and *Cryptolestes ferrugineus*) was studied at 30 ℃, 75% relative humidity. A regression analysis of the population dynamics was conducted. The results showed that population growth of *S. zeamais*, *R. dominica*, *T. castaneum* and *C. ferrugineus* was restrained under mixed rearing. Population growth of *T. castaneum* and *C. ferrugineus* was remarkably accelerated when they coexisted with *S. zeamais* or *R. dominica*, while that of *S. zeamais* and *R. dominica* was restrained to some extent. Regression analysis results showed that the population growth potential of *S. zeamais* was the largest and that of *C. ferrugineus* was the smallest, and the changing trends of population growth rates were not distinct.

Key words: Interspecific competition; Population dynamics; *Sitophilus zeamais*; *Rhizopertha dominica*; *Tribolium castaneum*; *Cryptolestes ferrugineus*

种间竞争对四种储粮害虫种群动态的影响

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摘要: 在 30 ℃、75%相对湿度条件下研究种间竞争对玉米象(*Sitophilus zeamais*)、谷蠹(*Rhizopertha dominica*)、赤拟谷盗(*Tribolium castaneum*)和锈赤扁谷盗(*Cryptolestes ferrugineus*)4 种主要储粮害虫种群动态的影响, 并对种群动态进行回归分析。结果表明, 玉米象与谷蠹、赤拟谷盗与锈赤扁谷盗混合饲养种群增长均受到显著抑制, 玉米象和谷蠹对赤拟谷盗和锈赤扁谷盗的种群增长具有明显的促进作用, 赤拟谷盗和锈赤扁谷盗对玉米象和谷蠹的种群增长具有一定的抑制作用。回归分析结果表明玉米象种群最大增长潜能最大, 锈赤扁谷盗最小, 种群增长率变化规律不明显。

关键词: 种间竞争; 种群动态; 玉米象; 谷蠹; 赤拟谷盗; 锈赤扁谷盗
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Sitophilus zeamais, *Rhizopertha dominica*, *Tribolium castaneum* and *Cryptolestes ferrugineus* are important pests during the storage period of many kinds of grains, including maize, paddy and wheat. They can cause huge losses of grain quantity and degrade the quality of stored grain (Silverio et al, 2004; Thanda &

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Kevin, 2003; Padin et al, 2002; Paul et al, 2004; Campbell & Hagstrum, 2002; Wang, 2002; Wang et al, 2004). Interspecific competition is an important ecological factor affecting population dynamics, as well as temperature, humidity, grain moisture content and food. Interspecific competition of stored grain pests is a common phenomenon, occuring between two or more populations occupying the same nutritional niche in a community, and will affect the degree of competition between populations (Li, 2000; Deng et al, 2003; Yukihiko et al, 1994; Zhao & Guo, 1990; Xu, 1987). Hou et al (1993) studied the population dynamics of *S. zeamais*, *R. dominica* and *T. castaneum* under mixed rearing conditions. The results showed that there was obvious interspecific competition between the three stored grain pests, but the study lacked further comparative analyses. Research on interspecific competition is useful to describe the changing trends of populations, which are important to predict and control populations of stored grain pests. Therefore, the population dynamics of four stored grain pests was studied in the presence of interspecific competition.

1 Materials and Methods

1.1 Materials

Insect source: The investigated insects, *S. zeamais*, *R. dominica*, *T. castaneum* and *C. ferrugineus* were all strains originally maintained by Chongqing Key Labortory of Entomology & Insect Control Engineering, College of Plant Protection in Southwest University, Chongqing, China. They have been reared for more than 30 generations under laboratory conditions.

Feed: Insects were fed wheat and whole wheat powder, with 15% moisture content, disinfected at 60 ℃ for 6 hours.

Equipment: Galvanothermy constant temperature cultural box, 30 ℃, 75% relative humidity (controlled by saturated NaCl solution); rearing bottles (300 mL).

1.2 Methods

The experiments were performed with two treatment groups: the first treatment group (No. 1) was singly reared. Ten pairs of intra-day eclosion adults of *S. zeamais*, *R. dominica*, *T. castaneum* or *C. ferrugineus* were respectively taken and reared separately in bottles (correspondingly named Treatment A, B, C and D). The rearing bottles of *S. zeamais* and *R. dominica* were supplied with 100 g wheat, and those of *T. castaneum* and *C. ferrugineus* with 50 g whole wheat powder. The second treatment group (No.2) was tested with mixed rearing. All combinations of pairs of the grain pests were tested, including: *S. zeamais* and *R. dominica* (Treatment E), *S. zeamais* and *T. castaneum* (Treatment F), *S. zeamais* and *C. ferrugineus* (Treatment G), *R. dominica* and *T. castaneum* (Treatment H), *R. dominica* and *C. ferrugineus* (Treatment I), and *T. castaneum* and *C. ferrugineus* (Treatment J). Each treatment consisted of five pairs of each insect at 24 hours old, and 10 pairs of eclosion adult for each combination, in one bottle. The bottles of treatments E, F, G, H and I were supplied with 50 g wheat and 25 g whole wheat powder. Treatment J was supplied with 50 g of whole wheat powder. The two treatment groups were all kept in the galvanothermy constant temperature culture box (30 ℃, 75% RH). *Sitophilus zeamais* and *R. dominica* belong to the primary stored grain pests, eating intact grain. *Tribolium castaneum* and *C. ferrugineus* belong to the secondary stored grain pests, which eat damaged grain and flour. As the insect age and grain quality selected were kept consistent, it was assumed that food and space resources were relatively consistent in all treatment groups. Each treatment was replicated five times and the adult numbers of living and dead insects were counted every five days for twenty-five days. Dead insects were removed and living insects were put back into the original bottle after investigation. The population size was based on the number of adults for each population. The investigation time lasted approximately seventy days.

1.3 Data Analysis

In order to keep the food and space resources consistent across treatment group No. 1 and No. 2, numbers of insects in treatment No. 1 was twice as much as that for No. 2. Therefore only half of the population from treatment group No. 1 were used in the data analysis.

One-way ANOVAs, Duncan's multiple range test and Logistic and Liner regression equation fits were carried out using SPSS.

$$\text{Logistic Equation}: N_t = \frac{K}{1 + \exp(a - rt)}$$

In the equation: N_t = population size at time t; K = maximal value; a = a intergration constant defining the position of the curve relative to the origin; r = intrinsic capacity for increase; t = time.

Liner Equation: $y = kx + b$

In the equation: k = slope; b = intercept.

2 Results and Analysis

2.1 Change of population number

2.1.1 Population size of *S. zeamais* The population size of *S. zeamais* in Treatments E, F and G was significantly lower than that of Treatment A after the 70th day (Fig. 1a). In Treatment A the population was 3833, and was 460, 847 and 1275 in Treatments E, F and G respectively. The population size of *S. zeamais* in Treatment E was less than that of the other treatments (Tab.1) and the results showed that population growth of *S. zeamais* was suppressed under mixed rearing. The restraining effect of *R. dominica* was the most significant. The effects of *T. castaneum* and *C. ferrugineus* were not distinct. Decreasing resources restrained the population growth of *S. zeamais* under mixed rearing conditions, as competition became gradually stronger with the increase of population size. *Sitophilus zeamais* and *R. dominica*, being primary stored grain pests, had similar food and space requirements, so population increases of *S. zeamais* was restrained by interspecific competition. Meanwhile both *T. castaneum* and *C. ferrugineus* belong to the secondary stored grain pests and exhibit separation of food niches from the primary pests due to long-term natural selection, such as competition. Their competition with the primary stored grain pest species were therefore just for space. As such their competition influence on *S. zeamais* was relatively smaller than that of *R. dominica*.

2.1.2 Population size of *R. dominica* The population size of *R. dominica* in Treatment B was more than that of Treatment E, H and I in all instances (Fig. 1b). Population numbers among treatments began to be obviously different after the 50th day and the difference was significant at the 70th day. Population numbers of *R. dominica* reached 158 in Treatment B in the 100th day, and 125 and 85 in Treatments I and H respectively. Treatment E was the smallest with only 78 adults (Tab.1). The results showed that population growth of *R. dominica* was suppressed under mixed rearing condition. The effect of *S. zeamais* on *R. dominica* was the greatest and that of *T. castaneum* and *C. ferrugineus* were smaller.

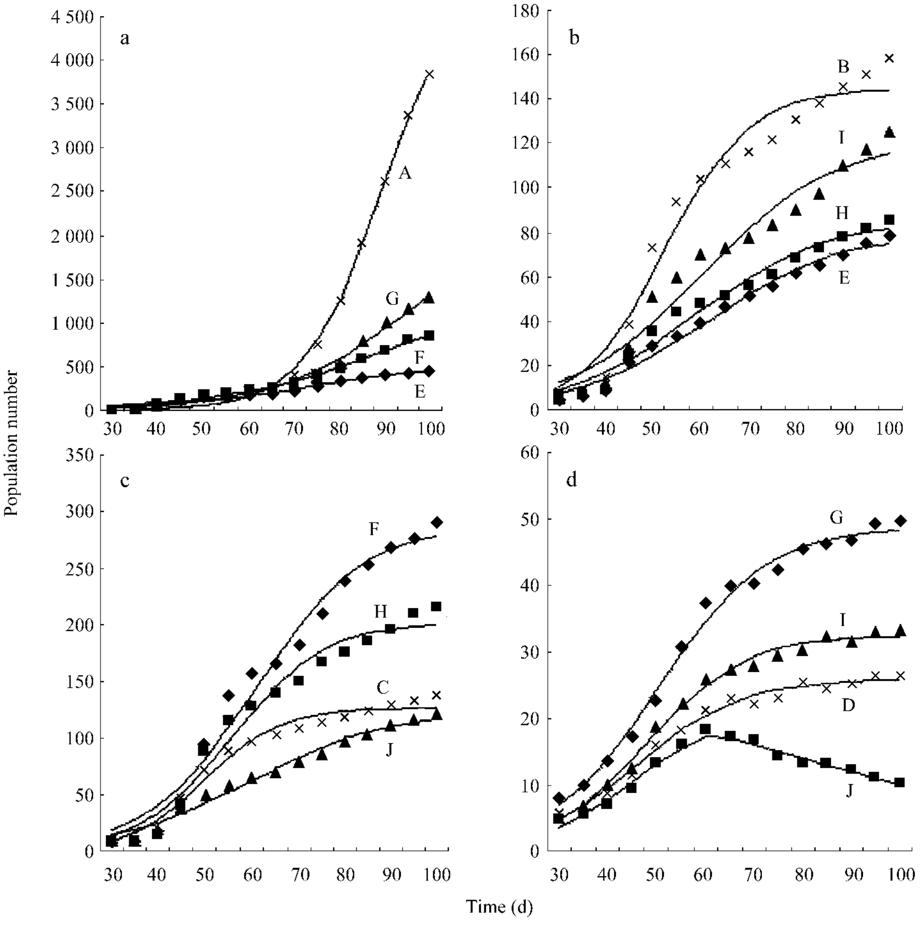

Fig. 1 Comparison of population size increases of *S. zeamais* (a), *R. dominica* (b), *T. castaneum* (c) and *C. ferrugineus* (d) under different treatments

2.1.3 Population size of *T. castaneum* Compared with 138 adults in Treatment C, the population size of *T. castaneum* in Treatments F and H were relatively large (Fig.1c), with 291 and 215 respectively on the 100th day. There was a significant difference in the population size of *T. castaneum* when the rearing conditions were different (Tab.1). Population growth of *T. castaneum* under mixed rearing with *C. ferrugineus* was suppressed, and the population size (121) was smaller than that under single rearing conditions (138) in the 100th day. The results showed that population growth of *T. castaneum* under mixed rearing with *S. zeamais* and *R. dominica* was distinctly advanced, especially with *S. zeamais*. This is because both species provided a large amount of broken grains and flour for *T. castaneum*, which aided the population growth. Interspecific competition between *T. castaneum* and *C. ferrugineus* occurred for similar food and space niche, so population growth of *T. castaneum* was restricted under these conditions.

Tab.1 Comparison of population growth of four stored grain pests under different treatment

Species	Treatment	Average population number (mean ± *SE*)		
		40th d	70th d	100th d
S. zeamais	E	57.333 3 ± 10.477 5[a]	217.333 3 ± 28.025 8[a]	460.666 7 ± 31.060 9[a]
	F	76.666 7 ± 18.809 0[a]	318.333 3 ± 35.144 2[bc]	847.000 0 ± 40.203 7[ab]
	G	73.666 7 ± 5.547 8[a]	290.666 7 ± 8.413 0[ab]	1 275.000 0 ± 50.083 3[b]
	A	70.000 0 ± 13.576 9[a]	398.666 7 ± 37.904 9[c]	383 3.333 3 ± 272.845 1[c]
R. dominica	E	8.666 7 ± 0.881 9[a]	51.333 3 ± 3.844 2[a]	78.666 7 ± 8.762 3[a]
	H	9.000 0 ± 1.000 0[a]	56.333 3 ± 8.838 1[a]	85.666 7 ± 6.173 4[a]
	I	12.000 0 ± 1.154 7[ab]	77.666 7 ± 6.333 3[a]	125.666 7 ± 9.061 5[b]
	B	15.000 0 ± 2.645 8[b]	116.666 7 ± 10.729 0[b]	158.666 7 ± 19.700 4[b]
T. castaneum	F	16.666 7 ± 0.666 7[a]	181.333 3 ± 4.484 5[d]	291.333 3 ± 5.238 7[c]
	H	13.666 7 ± 3.179 8[a]	150.666 7 ± 6.173 4[c]	215.666 7 ± 9.386 8[b]
	J	18.333 3 ± 0.881 2[a]	79.333 3 ± 3.527 7[a]	121.666 7 ± 4.409 6[a]
	C	16.333 3 ± 2.603 4[a]	108.666 7 ± 5.783 1[b]	138.666 7 ± 4.096 1[a]
C. ferrugineus	G	13.666 7 ± 0.666 7[b]	40.333 3 ± 1.333 3[d]	50.000 0 ± 2.081 7[d]
	J	7.000 0 ± 0.577 4[a]	16.666 7 ± 0.666 7[a]	10.333 3 ± 0.333 3[a]
	I	10.000 0 ± 1.527 5[a]	28.000 0 ± 0.577 4[c]	33.333 3 ± 1.201 9[c]
	D	8.666 7 ± 1.333 3[a]	22.333 3 ± 1.453 0[b]	26.666 7 ± 1.763 8[b]

Data followed by different letters means significance at 0.05 level (Duncan's multiple range test).

2.1.4 Population number of *C. ferrugineus* The population changing trends of *C. ferrugineus* was similar to that of *T. castaneum* (Fig. 1d, Tab.1) for similar reasons. Nevertheless the population size of *C. ferrugineus* was significantly smaller than that of the other three pests, ranging in number from 10 to 50 adults on the 100th day. The reason was that our research was carried out at 30 ℃, 75% RH, but the suitable development temperature and moisture for *C. ferrugineus* was 35 ℃ and 90 % RH. Therefore its development and reproduction were affected by the given conditions.

2.2 Regression analysis of population dynamics of four stored grain pests

The relationship between population size of four stored grain pests and time were fitted with Logistic regression equations (Tab.2). Data in Tab.2 shows that the greatest potential for population growth of *S. zeamais* or *R. dominica* under mixed rearing condition is smaller than that of single rearing conditions. Population growth potential of *T. castaneum* or *C. ferrugineus* under mixed rearing condition with *S. zeamais* or *R. dominica* was bigger than that under single rearing conditions, but the case was opposite when rearing *T. castaneum* and *C. ferrugineus* together. Population growth rates of *S. zeamais*, *R. dominica* and *T. castaneum* under mixed rearing conditions were smaller than that of the single rearing condition, while the difference between *C. ferrugineus* under single rearing and mixed rearing was not distinct. Generally speaking, the population growth potential of *S. zeamais* was the largest, next was that of *T. castaneum* and *R. dominica*. The smallest was that of *C. ferrugineus*. The population growth rates were not significantly different. Finally, the results of a One-way ANOVA analysis of regression equation showed that all the decision coefficients were all above 0.97, which proved the simulation was good.

Tab. 2 Regression analysis of single rearing and mixed rearing of population dynamics at different time

Species	Treatment	Regression equation ($y=$)	R^2
S. zeamais	E	557.991 5/[1 + exp(4.377 0 − 0.059 0*t*)]	0.984 4
	F	144 0.794 2/[1 + exp(4.900 5 − 0.053 2*t*)]	0.990 3
	G	246 7.322 4/[1 + exp(6.318 5 − 0.064 7*t*)]	0.984 1
	A	492 7.181 4/[1 + exp(10.472 6 − 0.117 8*t*)]	0.997 0
R. dominica	E	79.942 1/[1 + exp(4.518 7 − 0.073 6*t*)]	0.987 1
	H	85.266 0/[1 + exp(4.434 0 − 0.075 5*t*)]	0.975 2
	I	122.322 0/[1 + exp(4.357 7 − 0.072 3*t*)]	0.958 0
	B	144.688 6/[1 + exp(6.036 4 − 0.114 4*t*)]	0.970 8
T. castaneum	F	287.497 8/[1 + exp(5.336 7 − 0.087 8*t*)]	0.977 4
	H	202.323 9/[1 + exp(5.747 2 − 0.102 7*t*)]	0.971 7
	J	124.972 2/[1 + exp(4.144 7 − 0.068 8*t*)]	0.980 1
	C	127.218 4/[1 + exp(6.312 1 − 0.125 6*t*)]	0.974 3
C. ferrugineus	G	49.064 5/[1 + exp(4.522 7 − 0.089 9*t*)]	0.991 4
	J	20.771 3/[1 + exp(4.760 1 − 0.105 6*t*)](30 − 60 d) 29.953 6 − 0.198 5*t* (60 − 100 d)	0.972 2 0.979 8
	I	32.637 4/[1 + exp(4.784 7 − 0.099 5*t*)]	0.993 6
	D	26.094 0/[1 + exp(4.313 4 − 0.093 6*t*)]	0.988 6

3 Conclusion and Discussion

Research on the population dynamics of four stored product insect pests (*S. zeamais*, *R. dominica*, *T. castaneum* and *C. ferrugineus*) caused by interspecific competition showed that the population growth of *S. zeamais* and *R. dominica*, *T. castaneum* and *C. ferrugineus* under mixed rearing was distinctly restrained. The population growth of *T. castaneum* and *C. ferrugineus* were accelerated under mixed rearing conditions with *S. zeamais* or *R. dominica*, but that of *S. zeamais* and *R. dominica* under mixed rearing with *T. castaneum* or *C. ferrugineus* were restrained. Regression analysis of the population dynamics of four stored grain pests showed that the largest population growth potential of *S. zeamais* or *R. dominica* under mixed rearing conditions were smaller than that of single rearing conditions. The largest population growth potential of *T. castaneum* or *C. ferrugineus* under mixed rearing conditions with *S. zeamais* or *R. dominica* were greater than those under single rearing conditions, but the case was contrary when rearing *T. castaneum* and *C. ferrugineus* together. Population growth rates of *S. zeamais*, *R. dominica* and *T. castaneum* under mixed rearing conditions were smaller than that of single rearing conditions, but the difference for *C. ferrugineus* was not distinct. Generally speaking, the population growth potential of *S. zeamais* was the largest, next to that of *T. castaneum* and *R. dominica*, and the smallest was that of *C. ferrugineus*. The changing trends of population growth rates was not obvious. Hence *S. zeamais* was always the dominant species and its population was always the largest. However, population size of *C. ferrugineus* was always the smallest.

The population dynamics of four stored product insect pests (*S. zeamais*, *R. dominica*, *T. castaneum* and *C. ferrugineus*) caused by interspecific competition was studied under limited food and space resources in our experiment. Population dynamics of stored grain pests were also influenced by other factors such as temperature, humidity, grain moisture content and food. Interspecific competition is very complicated and affected by the factors of initial density, temperature, humidity, grain moisture content, climate, parasite and genetic characteristics of the population (Xu, 1987; Zhao & Guo, 1990; Yukihiko & Koichi, 1991; Giga & Canhao, 1993), so there were some limitations in our results. Until now, very few reports in this field could be found (Hou et al, 1993). In real warehouses, food and space resources are abundant and the trend, degree and course of population dynamics affected by interspecific competition can vary to some extent. Therefore further research should be carried out in real warehouses, especially in modern large warehouses, to provide a theoretical basis for prediction and control of stored grain pests.

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宋大祥，无脊椎动物学家。1935年6月9日生于浙江绍兴，1953年毕业于江苏师范学院（原东吴大学）生物系。1961年中国科学院动物研究所甲壳动物学专业研究生毕业。1999年当选为中国科学院院士。现为河北大学教授，动物研究所兼职研究员。曾任中国科学院动物研究所研究员、副所长，中国动物学会理事长。现任国际动物学会理事、国际蛛形学会理事、国际动物学命名委员会委员、韩国蛛形学研究所研究员等职。《中国动物志》副主编；《动物学报》顾问以及 *Integrative Zoology* 和 *Frontiers of Biology in China* 等刊物的编委。

早期研究甲壳动物桡足类、枝角类及环节动物的分类区系和生物学。上世纪70年代末开始研究蛛形类的系统学。近年来，从事节肢动物高级阶元的系统发生研究，并指导研究生在绒螯蟹及近缘属的亲缘关系、沼虾属的分类、多足类的系统发生和石蛃目无翅昆虫的系统学、蜘蛛丝腺蛋白基因、蛛毒、蜘蛛生态等研究领域开展研究并取得成果。代表作除300余篇论文外，还有《蚂蟥》、《中国蜘蛛》（英文）和有关甲壳类和蜘蛛类的《中国动物志》四卷，以及其他主编或参编的专著和工具书等数十部著作。