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Interspecific Competition Between Granary Weevil (*Sitophilus Granarius* (L.)) and Rice Weevil (Sitophilus Oryzae (L.)) in Four Different Cereals

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Abstract: The effect of food source on the outcome of interspecific competition between rice weevil, *Sitophilus oryzae*, and granary weevil, *Sitophilus granarius* and the food source effect on the competitive ability of both species and the effect of interspecific competition on the growth rates of both species were studied in barley, oats, rice and wheat at 27 °C and 70% R.H. by using the replacement series approach. This study predicts that the successful species in interspecific competition in all cereals was the rice weevil regardless of food source while the competitive ability of both species changed according to food source and the growth rates of both species were reduced by competitive interactions.
Key words: interspecific competition, food, growth rate, rice weevil, granary weevil, *Sitophilus*.

Dört Farklı Tahılda Beslenen Buğday Biti (*Sitophilus Granaries* (L.)) ile Pirinç Biti (*Sitophilus Oryzae* (L.)) Arasında Meydana Gelen Türler Arası Rekabet

Özet: Buğday biti, *Sitophilus granarius*, ile pirinç biti, *S. oryzae*, arasındaki türler arası rekabet buğday, arpa, yulaf ve pirinç tanelerinde 27°C sıcaklık ve %70 nemde laboratuar koşullarında araştırılmıştır. Bu çalışmada replacement metodu olarak adlandırılan rekabet yöntemi kullanılmıştır. Pirinç biti rekabet edilen tüm tahıl tanelerinde buğday bitine göre daha başarılı tür olarak ortaya çıkmıştır. Fakat besin kaynağına bağlı olarak türlerin rekabet etme yeteneğinde değişiklikler olduğu da saptanmıştır. Her iki türün de üreme kapasitelerinin bu rekabetten olumsuz etkilendiği, rekabettin üreme kapasitelerini düşürdüğü tespit edilmiştir.
Anahtar Kelimeler: türler arası rekabet, besin, pirinç biti, buğday biti, *Sitophilus*.

1. Introduction

The abundance and distribution of organisms in an environment are affected by abiotic and biotic factors. All living organisms have certain habitat zones that are restricted by abiotic factors, outside of this zone they cannot live for long time. Within this zone, populations of organisms show typical density fluctuations within limits. Although the habitat is suitable for many organisms at the same time, some plant or animal species could be more abundant in an area than other species. This could be associated with how well these species adapt to their environment. A high reproductive potential, tolerance to climate and ability to compete with others are among the factors contributing to adaptive superiority.

All living organisms, if they inhabit the same ecological niche and have limited sources, compete among themselves (intraspecific competition) or with other species (interspecific competition) to gain enough resource. Competition takes place for different limited resources such as food (Suzuki, 1986; Noel *et al.*, 1995; Currie *et al.*, 1996), shelter (Buchheim and Hixon, 1992; Soderback, 1994), mating partner (O'Neill, 1983) or territories (Haering and Fox, 1987; Smith *et al.*, 1995) in nature.

Insects, *Sitophilus* spp., *Tribolium* spp., *Rhizopertha* spp., have been extensively used in competition experiments because their life cycle is well known, they have generally a short life cycle and their environmental requirements can be maintained constant. All these advantages make stored product insects excellent material for use in ecological research.

The other reason for extensive research on them could be their economic importance, because they are most destructive pests of stored products. Nine hundred million ton of cereal grain are stored around the world at once time and that annual losses because of insects and rodents often reach about 10 % in North America and 30 % in Africa and Asia (Anonymous, 1981; Hill, 1990). Among the stored product insects *Sitophilus* spp. are the most destructive and the most common genus. *S. oryzae* causes a great lost in the majority of common cereals all over the world, *S. zeamais* is an important pest in the whole tropic area and the major pest of rice and *S. granarius* attacks wheat and barley in cool temperate regions (Champ and Dyte, 1976).

Zaklodnoi and Ratonova (1987) reported that during the development period of weevils, the larvae consume about 50% of the total weight of grain. Germinating capacity of the seed is also lowered in severely infested grains and grains infested by weevils become more susceptible to infestation by other associated pests like grain beetles and mites. This huge amount of loss could be associated with their biology because their all four larval stages and pupal stage occur inside the grain. Therefore their control and elimination in storage is very difficult. Their biology has been reviewed widely by many authors (Richards, 1947; Sharifi and Mills, 1971 a, b; Longstaff, 1981; Bhuiyan *et al.*, 1990).

The success in interspecific competition depends on many factors such as intrinsic rate of increase (Birch 1953a), intraspecific competition (Tripathi and Hodson, 1981), the temporal sequence of infestation (Howard, 1983; Erdoğan and Gürkan, 1995), parasites (Park, 1948;Utida,1953), temperature (Giga and Canhao,1993; Valle et al.,1989), moisture (Birch, 1953b; Evans, 1982) and food. One of the factors affects the success in interspecific competition is food. Birch (1954) examined the interspecific competition between the rice weevil and the maize weevil in maize and wheat. The rice weevil became the successful species and it eliminated the maize weevil in wheat. Whereas the maize weevil was the dominant species in competition when maize was food source. Howard (1983) examined the interspecific competition between *P. truncatus* and *S. zeamais* on maize flour, mixture of maize flour and maize grain and whole maize grain and he found that the population growth of the maize weevil was inhibited by *P. truncatus* when flour was present as a food source. Coombs and Woodroffe (1962, 1963, 1973) examined the interspecific interaction between *S. granarius* and *Ptinus tectus*. They found that *S. granarius* and *P. tectus* could coexist in same medium because their food preference was different but when whole wheat was used as the food source the population growth rate and survivorship of *P .tectus* was decreased.

Although food is an important factor which affects the outcome of competition, its effect has not been studied widely. Therefore, in this paper the outcome of interspecific competition between the rice weevil and the granary weevil in the different food resources was investigated.

2. Materials and Methods

The strain of Windsor S. stock of *S. granarius* and the Droxford strain of *S. oryzae* used in this experiment has been bred in wheat at 27 ^{O}C and 70% R.H (Relative humidity) as a laboratory culture in Central Science Laboratory, London where they were obtained since 1970. The insects have been bred on 13% moisture contained wheat at 27 ^{O}C and 60% R.H. until the experiment was set up. The weevil populations were counted and dead weevils were separated from the stock culture every two weeks. The population was recultured and the food was replenished to 200 g for 50 adult weevils every seven weeks. The cereals, barley, oat and rice were obtained from Wholefoods, wheat from Close House Field Station, Newcastle. All grains were sterilised at -18 ^{O}C for two weeks in the freezer and then allowed to equilibrate to room temperature in sealed containers before they use. The moisture contents of cereals were 14%, 13%, 15% and 13% for barley, oat, rice and wheat, respectively. The moisture content of cereals was expressed on a wet basis and its determination was made by following ASAE standard (1995).

The commonly used method of studying competition is to rear two species in the same medium and wait until one of the species dies out. In the present study instead of starting with a mixed species population and observing changes in time a short-time predictive approach using the replacement series design developed by de Wit (1960) was used. In this design the outcome of interspecific competition can be predicted from the shape of the species reproduction curves. If a species has a convex reproduction curve, it will probably become the successful species in any interaction. However, the species having a concave reproduction curve becomes extinct in competition because the concave reproduction curves indicates that the species suffers from competition effects and has a poor competitive ability (Smith and Howard, 1983).

Before setting up the experiment, the weevils were transferred from the stock culture to Petri dishes whose walls were painted with fluon. They were sexed under the microscope and then transferred to different jars according to their sex until the whole sexing process was finished for the species. The weevils were sexed by means of their rostrum characteristics and abdomen deflection (Halstead, 1963; Qureshio, 1963; Concela Da Fonseca, 1965; Tombes, 1971; Lum and Baker , 1975). In this experiment 10mm in diameter x 20mm high tubes were used. They were sterilised at 120 ^{O}C for 15 min and then a thick line of "Fluon (PTFE solution) " was painted near 0.5 cm top of tubes to prevent adults weevils escaping. Ten gram of each cereal was weighted and placed in a different tube. The weevils were randomly selected from each sex and were introduced into the tubes and then the top of tubes were sealed with cotton mesh and a rubber band. The sex ratio was held 1:1 because Birch (1954), Aviles *et al.* (1980) and Teil and Swatonek (1975) who reported that *Sitophilus* species generally have 1:1 sex ratio. The total density of competing species in a tube was held constant, 12, but the ratio of the two competing species was varied, 12-0; 10-2; 8-4; 6-6; 4-8; 2-10; 0-12. As a control single species population of each species was also set up the same time at densities 12, 10, 8, 6, 4 and 2 adults in each cereal. All tubes were placed in a 70 ± 5% R.H. contained humidity chamber which was put into the incubator at 27 ± 2.5 ^{O}C The humidity was kept constant inside the humidity chamber by using 26% KOH solution, prepared as Solomon (1951) described. The solution was placed at the bottom of a 250mmx250mmx120mm size humidity chamber. Inside the solution four 40mm high rubber props were placed. Metal mesh was put on these rubber props. This temperature and relative humidity was selected because they were reported to be most favourable conditions for population growth of both weevils (Longstaff, 1981). During the experiment the relative humidity and temperature were measured and recorded every day. The experiment was replicated three times.

The experimental replicates were opened after 45 days because different investigators (e.g. Sharifi and Millis, 1971; Howe, 1952; Khan, 1948) reported different mean times required completing the life cycle of *Sitophilus* species so that the reported longest required time was chosen (Longstaff, 1981). All tubes were placed in the oven at 80 ^{O}C to kill the beetles and avoid their escape since they are very mobile and the rice weevil can fly. All contents of a tube were sieved to separate the weevil and the cereal and also every grain inside was checked whether it contained a weevil or not, because when they were exposed to 80 ^{O}C in the oven most of the weevils hid inside the grain to escape the effect of temperature. After separation of cereal and the weevils, the weevils in mixture cultures were counted under a microscope; the rice weevil and the granary weevil were separated according to their prothorax structure. The granary weevil has oval-shaped punctures on the prothorax whereas the rice weevil has circular rather than oval punctures on the prothorax.

2.1 Data analysis

The progeny numbers of the two species after 45 days were counted and the results presented as reproduction curves. The observed data was plotted against parent density and was fitted curve by using Poolynominal regression. In order to analyse the effects of cereals on the competition ability of the rice weevil and the granary weevil, the Tukey test was performed after two-way Anova test. Since two-way Anova test only indicates a significant or non-significant difference between the cereals effect: it does not give which cereal effect differs from others. The effects of interspecific competition on the growth rate of the species was analysed by means of two-way Anova test. Each species mix population was compared with its single species population for each cereal.

3. Results

The mean numbers of progeny produced by the rice weevil and the granary weevil in barley, oats, rice and wheat are presented in Tables 1 and 2 for mixed and single species treatments at all initial densities. The rice weevil progeny production was higher than that of the granary weevil in both treatments. The mean number progeny production of the weevils showed a similar pattern: the progeny production increased in parallel to increasing parent density in the population.

The reproduction curves of *S. oryzae* and *S. granarius* in competition are shown in Figure 1 a, b, c and d in barley, oats, rice and wheat respectively. The rice weevil had a convex reproduction curve so that it appeared to be better competitor than the granary weevil in barley and would be dominant in the long term (Figure 1a). The granary weevil showed a concave reproduction curve that indicated it was badly affected by competition effects in this cereal. Figure 1b shows that both species had concave reproduction curves in oats and according to the shapes of the reproduction curves of the two species, either the rice weevil or the granary weevil would extinct in the interaction. However the granary weevil progeny production was very low, which suggests that the rice weevil would be the only species that survived in this grain. According to figure 1c, the granary weevil would be eliminated by the rice weevil in rice in the long term, as the latter species showed a convex reproductive curve, the former species reproduction curve was concave. Although the rice weevil had a linear reproduction curve in wheat rather than a convex curve, it would drive the granary weevil out in the interaction since the granary weevil reproduction curve was concave and the population growth of the granary weevil was lower than the rice weevil (Figure 1d).

The number of offspring produced by the rice and granary weevil in the mixed cultures changed depending on food source (Table 3). *S. oryzae* produce the greatest number progeny in barley, 150 progeny, followed by oat, 145 progeny, rice, 143 progeny, and there was no significant difference between progeny production of the pest in these three cereals. The lowest number the rice weevil offspring was counted in wheat, 117 progeny and this was significantly lower than those of in other three-tested grain. The food source, supplied to *S. granarius*, affected its competitive ability in the interaction with *S. oryzae*. A greater number of the grain weevil adult emerged in barley and wheat. The mean number of progeny produced in oat and rice by the weevil was significantly lower than those of barley and wheat (Table 3).

Interspecific competition between the rice and granary weevil caused a decrease in their reproduction performance. While the numbers of progeny produced by the rice weevil were 178, 163, 162 and 149 in barley, oat, rice and wheat respectively in the single species treatments, they dropped to 150, 145, 143 and 117 in the mixed species treatments (Table 4). There were significant differences between offspring number in the single and in the mixed species treatments in all cereals. These results showed that the rice weevil progeny production significantly related to presence of its competitor.

Reproduction of *S. granarius* was reduced in the mixed species treatments relative to the single species treatment. The evidence of effect of competition on reproduction was significant in the experiment (Table 5). The most dramatic decreased between single species and mixed species treatments of the granary weevil were observed in wheat from 47 to 27 and in barley from 42 to 29 progeny. While the weevil produced around 18 progeny in oat and rice in single species treatment the number declined to 15 in oat and 13 in rice in the mixed species treatments.

4. Discussion

S. oryzae produced more progeny in all cereals at all initial densities than *S. granarius* did in both treatments. The rice weevil has clearly had a greater intrinsic rate for increase, which made it superior to the granary weevil. The same findings was reported by Tripathi and Hodson (1981) who found that the progeny production of the rice weevil was two times higher than that of the granary weevil.

These studies of interspecific competition between the rice weevil and the granary weevil in barley, oats, rice and wheat have shown that the rice weevil have been found to be superior over the granary weevil in all cereals. Similar results were reported by Tripathi (1959) who stated that the rice weevil was superior over the granary in wheat. Phadke and Bhatia (1976) studied the interspecific competition between *Rhizopertha dominica* and *Sitophilus oryzae* in different wheat varieties and they reported that the rice weevil was the dominant species in all varieties.

The intraspecific competition in kernels may result in the rice weevils' success in the interaction (Tripathi, 1959). Since the rice weevil was reported to be less affected by intraspecific competition than the granary was (Tripathi and Hodson, 1981). Moreover, three larva of rice weevil were able to complete life cycle in a kernel, if more than one egg of the granary weevil is laid in a kernel, none of them complete their life cycle. Therefore the intraspecific competition in a kernel may lead to reduction in *S. granarius* interspecific competitive ability.

Interspecific competition within kernels may cause about the failure of the granary weevil in the interaction with the rice weevil. As *S. granarius* prefers to lay eggs on grains that are already infested by its own species, *S. oryzae* lays its eggs on grains that are infested by the granary weevil (Tripathi and Hodson, 1981). The rice weevil larval development time is shorter than that of the granary weevil and the required food to complete the larval development of the granary weevil is three times higher than that of the rice weevil (Golebiowski, 1969). As a result of these factors progeny reproduction of the granary weevil decreases so that it losses out in interspecific competition with the rice weevil in all cereals.

Another reason for the granary weevils' extinction in interaction may be associated with its egg free grain seeking behavior. If the granary weevil fails to find free grain to lay eggs, it stops egg laying (Coombs and Woodroffe, 1963). As the rice weevil adults start to lay eggs before the granary weevil is considered the lower progeny production and extinction of the grain weevil in the interaction can be explained (Golebiowski, 1969).

The effect of cereals on the competitive ability studies showed that there was a significant difference between the competitive ability of the species in different cereals. It has been known that diet and varietal difference within cereals affect development time and reproduction capacity of *Sitophilus* species (Sing *et al.*, 1974; Phadke and Bhatia, 1976; Singh *et al.*, 1980; Gomez *et. al*, 1983; Baker, 1988; Schuwatz and Burkholder, 1991). Other scientists have also reported that the successful species in interspecific competition between S. *oryzae* and S. *zeamais* (Birch, 1954) and between S. *zeamais* and *P. truncatus* (Howard, 1983) changed depending upon the food sources.

The present experiment showed that the rice weevil produced statistically equal numbers of progeny in barley, oats and rice. These are in accord with Baker (1986) who examined the development of different strain of *S. oryzae* on barley, maize, rice and wheat. He found that progeny production was the highest on barley followed by wheat and the lowest progeny production occurred in maize.

The granary weevil progeny production varied depending on food resource. The result of the study showed consistency with those of Schuwartz and Burkholder (1991). They investigated the effects of grain on development of the granary weevil in barley, oat, rice and wheat and found that the progeny production in wheat and in barley was four times higher than that in corn, seven times that in oats and nine times that in rice. This could be associated with the differences in the kernels morphological structure because the granary weevil is not able to reproduce in oats and rice because the size and structure of these grains do not favor the granary weevil for progeny production (Schuwartz and Burkholder, 1991).

The size of grains may also affect the progeny production of the granary weevil because larva of granary weevil requires 30 mg of food to complete its life cycle while rice weevil larvae needs only 10 mg of food (Golebiowska, 1969). However some kernels of tested cereals do not supply required the food to complete its life cycle.

Both species suffers from interspecific competition and the progeny production declined relatively single species treatments. Similar findings were reported by Helal and Berger (1996) who found that the presence of *S. oryzae* or *S. granarius* caused a reduction effect of the total number of progeny on *Sitotraga cerealella*. However, the result of present study contrasted with the findings of Tripathi (1959) who reported that the granary weevil was affected by interspecific competition but there was no negative effect of interspecific on the rice weevil. This difference be result of methodologies employed in the present study and in his experiment.

It can be concluded that the successful species in interspecific competition between the rice and granary weevil was the rice weevil in all cereals regardless of food sources, but the competitive ability of both species changed depending upon food source and the growth rates of both species were reduced by effect of interspecific competition. Further works at different temperatures and at relative humidity are needed to conclude the effect of food source on the outcome of interspecific competition between the rice and granary weevil.

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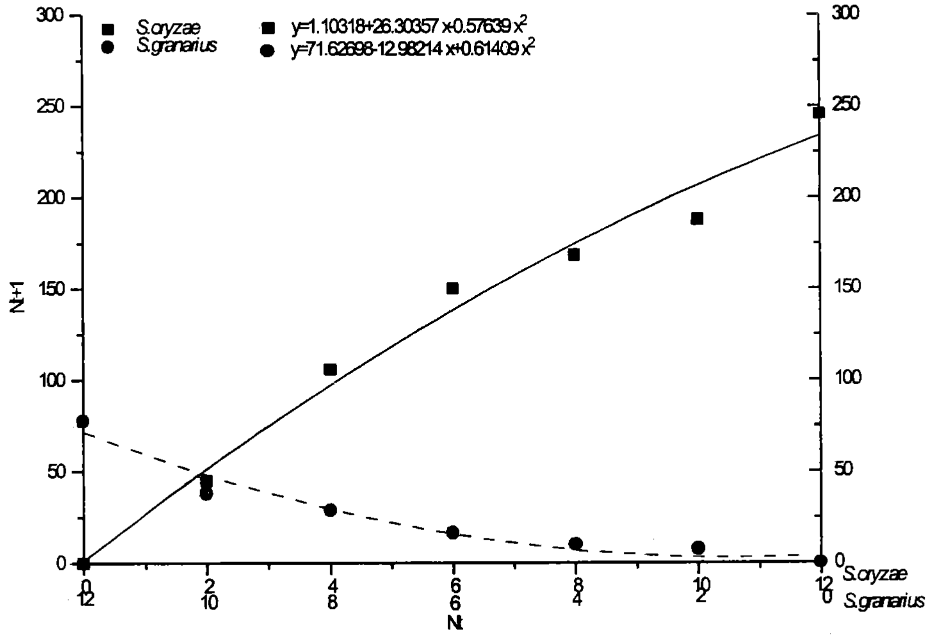
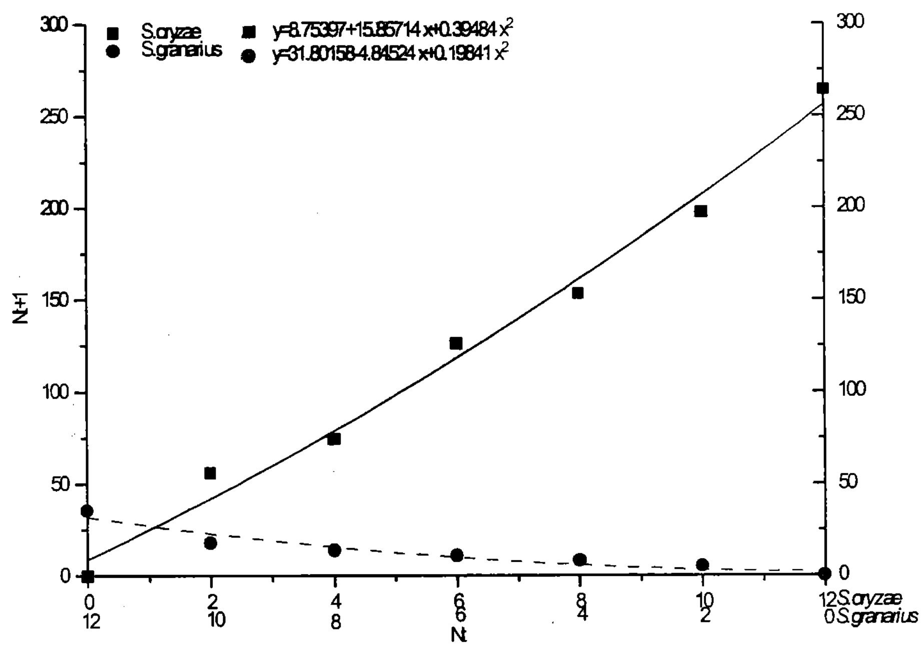


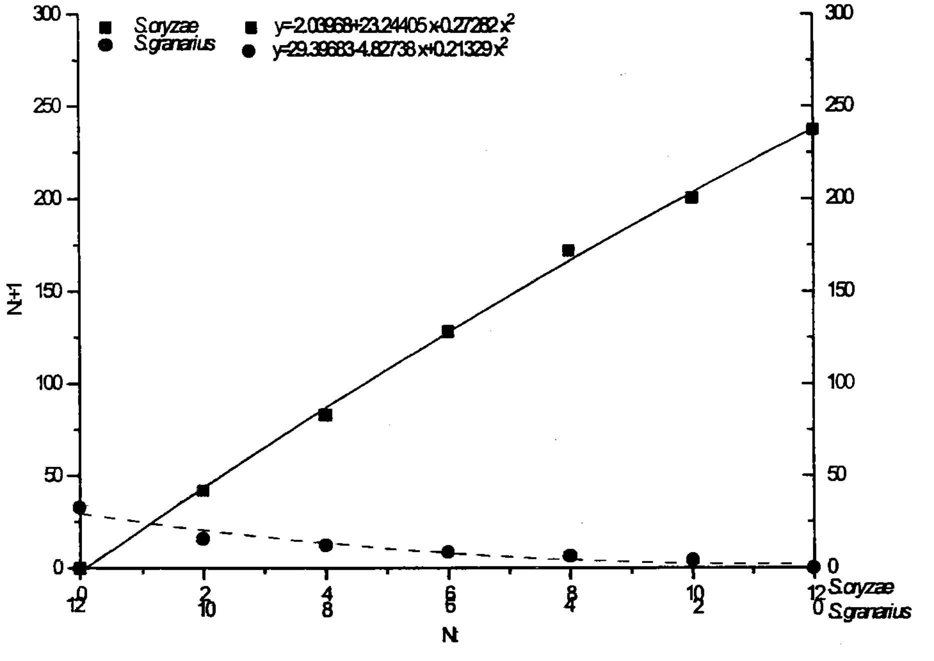
S.oryzae
S.granarius
y=1.10318+26.30357 x-0.57639 x²
y=71.62698-12.98214 x+0.61409 x²
Nt+1
Nt
S.oryzae
S.granarius

a

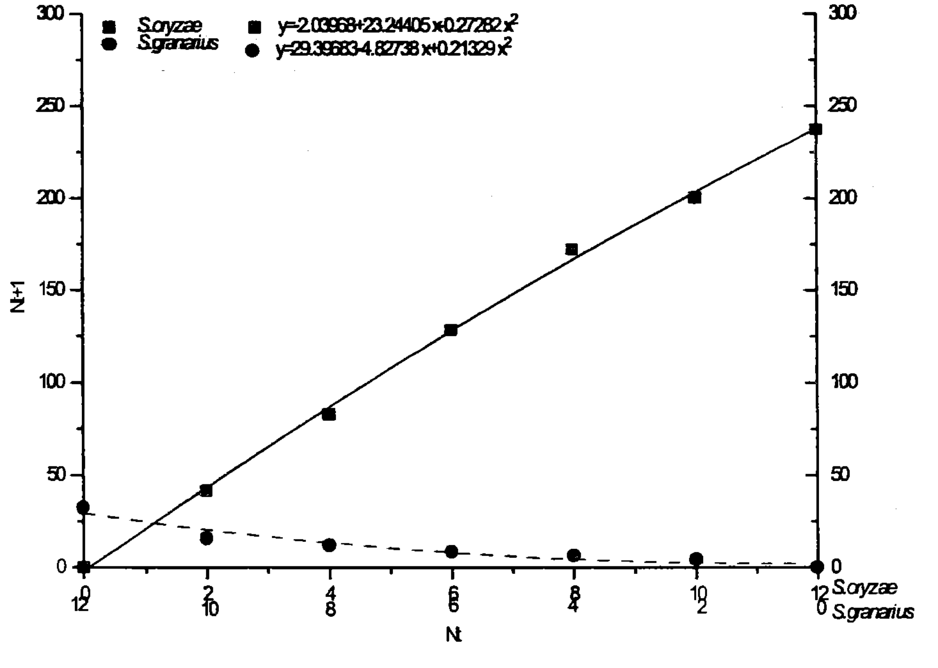


S.oryzae
S.granarius
y=8.75397+15.85714 x+0.39484 x²
y=31.80158-4.84524 x+0.19841 x²
Nt+1
Nt
S.oryzae
S.granarius

b



c



d

Figure 1. Fitted reproduction curves of *Sitophilus granarius* and *Sitophilus oryzae* at 24±1° and %70 RH in a-) barley, b-) oat, c-) rice and d-) wheat.

Table 1. The mean number of progeny produced (±SE) by *Sitophilus oryzae* and *Sitophilus granarius* by parents competing with the other species in barley, oat, rice and wheat.

	Sitophilus oryzae±SE				*Sitophilus granarius*±SE			
P.ratio	Barley	Oat	Rice	Wheat	Barley	Oat	Rice	Wheat
12-0	245.7±1.8	264.0±5.6	237.3±2.2	208.0±3.6	0	0	0	0
10-2	188.0±7.8	197.3±9.4	200.3±3.9	157.3±8.4	7.7±0.3	5.0±0.6	4.3±0.9	6.7±0.9
8-4	168.3±3.5	153.0±14.5	172.0±10.0	133.0±7.1	10.0±1.5	8.0±1.0	6.7±0.9	11.0±2.1
6-6	150.0±6.6	126.3±17.8	128.3±0.5	95.7±9.3	16.7±2.8	11.0±0.0	9.0±0.6	18.3±2.0
4-8	105.7±33.00	74.3±19.2	83.0±8.3	78.3±13.2	29.0±5.3	14.0±0.6	12.3±0.7	25.7±6.7
2-10	45.0±17.5	56.0±12.0	41.6±3.2	34.3±8.3	38.3±6.3	18.0±1.0	16.0±1.7	28.0±6.03
0-12	0	0	0	0	78.0±3.8	35.3±1.2	32.7±0.7	77.7±3.7

Table 2. The mean number of progeny produced (±SE) by *S.oryzae* and *S.granarius* in single species cultures in barley, oat, rice and wheat.

	Sitophilus oryzae±SE				*Sitophilus granarius*±SE			
P.densit	Barley	Oat	Rice	Wheat	Barley	Oat	Rice	Wheat
12	245.7±1.7	264.0±5.6	237.3±2.2	208.0±3.6	78.0±3.8	35.3±1.2	32.7±0.7	77.7±3.7
10	238.0±4.6	214.3±8.8	223.7±1.8	186.7±3.2	67.7±2.6	23.7±1.2	23.3±0.3	64.3±1.5
8	192.7±5.2	184.3±5.6	196.7±6.7	169.3±5.5	48.7±1.8	19.0±1.0	19.7±1.2	51.0±1.5
6	167.7±3.2	147.7±10.4	161.3±3.7	158.3±5.4	28.7±2.3	14.7±0.3	15.3±1.2	40.0±2.7
4	151.7±4.1	105.3±8.1	101.0±1.5	116.7±4.9	19.3±1.2	10.3±0.9	10.3±0.3	32.3±2.6
2	72.3±3.2	65±5.1	57.7±2.3	60.3±6.9	11.7±2.0	7.7±0.9	6.7±0.7	17.7±2.9

Table 3. Means value of progeny produced by *S.oryzae* and *S.granarius* in different cereals in mixed species treatment.

Species		Cereals		
	Barley	Oat	Rice	Wheat
S.oryzae	150.4 a	145.2 a	143.8 a	117.8 b
S.granarius	29.9 a	15.2 b	13.5 b	27.9 a

* Means in a row followed by different letter are significantly different (P<0.05, Two-way ANOVA, Tukey test).

Table4. Mean number of progeny produced by *S.oryzae* single and mixed species treatments.

Species	Barley	Oat	Rice	Wheat
S.oryzae (Sing.)	178 a	163.4 a	162.9 a	149.9 a
S.oryzae (Mix)	150.4 b	145.2 b	143.8 b	117.8 b

* Means in a column followed by different letter are significantly different (P<0.05, Two-way ANOVA, Tukey test).

Table 5. Mean number of progeny produced by *S.granarius* single and mixed species treatments.

Species	Barley	Oat	Rice	Wheat
S.granarius (Sing.)	42.3 a	18.4 a	18.0 a	147.2 a
S.granarius (Mix)	29.9 b	15.2 b	13.5 b	27.9 b

* Means in a column followed by different letter are significantly different (P<0.05, Two-way ANOVA, Tukey test).