Scientific Note

Mortality Resulting from Interactions Between the Red Flour Beetle and the Rusty Grain Beetle

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The rusty grain beetle, *Cryptolestes ferrugineus* (Stephens) (Coleoptera: Laemophloeidae) (Thomas 1999) is a cosmopolitan pest feeding on stored wheat, barley, and other cereals (Rilett 1949) and is also found in the nests of *Vespa* L. (Hymenoptera: Vespidae) (Linsley 1944), or under tree bark (White *et al*. 1995). The red flour beetle, *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae) is a polyphagous, cosmopolitan pest feeding mostly on stored flour and other milled cereal products, broken wheat (Cotton 1963), and farm-stored cereals (Madrid *et al.* 1990). Both *C. ferrugineus* and *T. castaneum* successfully feed on many species of storage fungi (Sinha 1965, 1966). Both are facultatively predaceous and scavengers (Linsley 1944; Rilett 1949). Their native habitat was probably under the bark of trees and shrubs (Linsley 1944). These insects often occur together in stored wheat in western Canada (Madrid *et al.* 1990). *Cryptolestes ferrugineus* larvae and pupae are protected from predation or cannibalism because they develop singly under the seed coat covering the germ of cereal seeds (Rilett 1949; White and Bell 1990). It has been observed that when *T. castaneum* and *C. ferrugineus* were reared together, the populations of *T. castaneum* were often sharply reduced, relative to controls, within a few months (Lefkovitch 1967; White 1979), perhaps because all life stages of *T. castaneum* were exposed to predation/cannibalism. To determine if interactions between or within the species could affect population growth, the levels of mortality of selected life stages of *C. ferrugineus* and *T. castaneum,* when starved or when feeding on ground wheat, were studied (Table 1).

Twenty-five individuals of each stage of insect were placed in 9 cm diameter plastic petri dishes with (1.5 g of ground wheat/dish) or without ground wheat and kept at 25 or 30°C at 70% RH for 7 d and observed for mortality (50 insects per dish; larvae were 4^{th} instar). There were four replicates for each treatment and a control of appropriate stages of individual species kept separately at the same rearing conditions. Treatment effects were compared using ANOVA with three-way classification (temperature, predator species, prey species), separately for stages or two-way ANOVA for larvae feeding on pupae (SAS 1999, GLM Procedure). Three-way least square means were compared using pair-wise *t*-tests ($P = 0.05$) with a pooled variance estimate from the ANOVA (PDIFF option in the GLM Procedure, Table 2). Comparisons between prey species mortality were made from the PDIFF Table. Control mortality was always less than 5%. All interactions were used in ANOVA.

In control dishes containing only eggs or pupae of either species or larvae of *C. ferrugineus*, mortality did not occur. In control dishes containing larvae of *T. castaneum*, mean ± SE mortality ranged from 3± 1 to 17 ± 2%, with mortality approximately twice as high when there was no grain or at the higher temperature. Without predators, mortality of all stages was low. With adult beetles of either species present and no grain to serve as an alternative food source, mortality of eggs, larvae and pupae was 100%. Without alternative food, adults of both species were effective predators of the immature stages of either species. Larvae of the two species were equally effective predators of eggs of either species, causing 100% mortality; however, larvae of *T. castaneum* were more effective predators of *T. castaneum* pupae (mortalities of 70 and 96% at 25° and 30°C, respectively) than were *C. ferrugineus* effective predators of *T. castaneum* pupae (mortalities of 14 and 23% at 25° and 30°C, respectively; see Table 1). Nevertheless, without an alternative food source, larvae of both species preyed on eggs and pupae.

Mortality was usually greater at the higher temperature, presumably because of greater insect activity. For all predator stage-prey stage combinations, the main effect of temperature was highly significant ($P < 0.01$) although some individual comparisons were not significant (Table 1). Adults of *T. castaneum* usually preyed on more immatures of both species than did *C. ferrugineus* (Table 1). *Cryptolestes ferrugineus* larvae caused significantly ($P < 0.01$) more mortality of *T. castaneum* eggs than of *C. ferrugineus* eggs at both temperatures. *Tribolium castaneum* larvae caused more mortality of *C. ferrugineus* eggs than of *T. castaneum,* eggs, but only at 30°C. *Tribolium casteneum* larvae caused higher mortality to *T. castaneum* pupae than did *C. ferrugineus* (Table 1). *Tribolium castaneum* adults are more effective predators or cannibals than *C. ferrugineus,* largely because of size, the former weighing about 2.0

mg (wet weight) and the latter about 0.2 mg (White and Sinha 1987; White and Demianyk 1999). However, it is likely that *T. castaneum* can rarely find immature *C. ferrugineus* in a grain bulk, while *C. ferrugineus* adults are effective predators of exposed *T. castaneum* eggs and larvae.

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Table 1. Mean per cent mortality ($n = 4$) of eggs, larvae, and pupae of *Tribolium castaneum* (*Tc*) and *Cryptolestes ferrugineus* (*Cf*) at two temperatures and 70% RH within 7 d of being exposed to adults or 4th instar larvae; 25 individuals of each insect stage in 9 cm diam dishes.

Predator stage	ANOVA Comparison	Prey stage & species	Ground wheat present	Predator			
				Tribolium castaneum		*Cryptolestes ferrugineus*	
				25 C	30 C	25 C	30 C
Adult		Eggs					
	┌	*Tc*	Yes	35 ± 4 c	73 ± 4 a	28 ± 3 c	47 ± 2 b
	└	*Cf*	Yes	42 ± 5 b	64 ± 4 a	24 ± 3 c	27 ± 4 c
		Larvae					
	┌	*Tc*	Yes	66 ± 3 a	75 ± 5 a	35 ± 3 c	53 ± 4 b
	└	*Cf*	Yes	79 ± 4 b*	100 a*	30 ± 3 d	48 ± 1 c
		Pupae					
	┌	*Tc*	Yes	51 ± 3 b	90 ± 2 a*	34 ± 3 c*	55 ± 3 b*
	└	*Cf*	Yes	48 ± 3 b	72 ± 2 a	7 ± 2 c	12 ± 1 c

Predator stage	ANOVA Comparison	Prey stage & species	Ground wheat present	Predator			
				Tribolium castaneum		*Cryptolestes ferrugineus*	
				25 C	30 C	25 C	30 C
Larvae		Eggs					
	┌	*Tc*	Yes	54 ± 2 b	73 ± 5 a	38 ± 4 c*	64 ± 4 ab*
	└	*Cf*	Yes	64 ± 6 b	85 ± 3 a*	19 ± 2 d	34 ± 3 c
		Tc	No	100	100	100	100
		Cf	No	100	100	100	100
		Pupae					
	┌	*Tc*	Yes	48 ± 3 b	70 ± 2 a	5 ± 1 c	11 ± 1 c
	└	*Tc*	No	70 ± 4 b	96 ± 2 a	14 ± 1 c	23 ± 2 c

Means followed by the same letter in a row are not significantly different ($P < 0.05$) on a comparison-wise basis.
*Indicates significantly higher mortality than the other prey species ($P < 0.05$) for the same prey stage, predator, and temperature.

Table 2. Summary of statistics from ANOVA comparisons presented in Table 1.

Source	DF	Sum of squares	Mean square	*F* value	*P* > *F*
Model	7	9294.00	1327.71	20.96	<0.0001
Error	24	1520.00	63.00		
Corrected total	31	10814.00			
R-Square	**Coeff var**	**Root MSE**	**pdead mean**		
0.859441	18.83	7.95	42.25		
Source	**DF**	**Type III SS**	**Mean square**	***F* value**	***P* > *F***
prey	1	288.00	288.00	4.55	0.0434
temp	1	3528.00	3528.00	55.71	<0.0001
prey*temp	1	578.00	578.00	9.13	0.0059
pred	1	4050.00	4050.00	63.95	<0.0001
prey*pred	1	200.00	200.00	3.16	0.0882
temp*pred	1	648.00	648.00	10.23	0.0039
prey*temp*pred	1	2.00	2.00	0.03	0.8604

dependent variable = prey dead (pdead); pred = ad; prey = egg.

Source	DF	Sum of squares	Mean square	*F* value	*P* > *F*
Model	7	15742.00	2248.85	43.81	<0.0001
Error	24	1232.00	51.33		
Corrected total	31	16974.00			
R-Square	**Coeff var**	**Root MSE**	**pdead mean**		
0.927418	11.79	7.16	60.75		

Source	**DF**	**Type III SS**	**Mean square**	***F* value**	***P* > *F***
prey	1	392.00	392.00	7.64	0.0108
temp	1	2178.00	2178.00	42.43	<0.0001
prey*temp	1	72.00	72.00	1.40	0.2479N
pred	1	11858.00	11858.00	231.00	<0.0001
prey*pred	1	1152.00	1152.00	22.44	<0.0001
temp*pred	1	18.00	18.00	0.35	0.5593N
prey*temp*pred	1	72.00	72.00	1.40	0.2479N
pred=ad; prey = larv					

Source	DF	Sum of squares	Mean square	*F* value	*P* > *F*
Model	7	22171.50	3167.35	84.46	<0.0001
Error	24	900.00	37.50		
Corrected total	31	23071.50			
R-Square	**Coeff var**	**Root MSE**	**pdead mean**		
0.960991	13.27	6.12	46.12		
Source	**DF**	**Type III SS**	**Mean square**	***F* value**	***P* > *F***
prey	1	4140.50	4140.50	110.41	<0.0001
temp	1	3960.50	3960.50	105.61	<0.0001
prey*temp	1	480.50	480.50	12.81	0.0015
pred	1	11704.50	11704.50	312.12	<0.0001
prey*pred	1	1200.50	1200.50	32.01	<0.0001
temp*pred	1	684.50	684.50	18.25	0.0003
prey*temp*pred	1	0.50	0.50	0.01	0.9090
pred=ad; prey = pupa					

Source	DF	Sum of squares	Mean square	*F* value	*P* > *F*
Model	7	13864.00	1980.57	25.72	<0.0001
Error	24	1848.00	77.00		
Corrected total	31	15712.00			
R-Square	**Coeff var**	**Root MSE**	**pdead mean**		
0.882383	16.24	8.77	54.00		
Source	**DF**	**Type III SS**	**Mean square**	***F* value**	***P* > *F***
prey	1	338.00	338.00	4.39	0.0469
temp	1	3362.00	3362.00	43.66	<0.0001
prey*temp	1	32.00	32.00	0.42	0.5253
pred	1	7442.00	7442.00	96.65	<0.0001
prey*pred	1	2592.00	2592.00	33.66	<0.0001
temp*pred	1	0.00	0.00	0.00	1.0000
prey*temp*pred	1	98.00	98.00	1.27	0.2704
pred=larv; prey = eggs					

Source	DF	Sum of squares	Mean square	*F* value	*P* > *F*
Model	7	11444.00	3814.66	154.65	<0.0001
Error	24	296.00	24.66		
Corrected total	31	11740.00			
R-Square	**Coeff var**	**Root MSE**	**pdead mean**		
0.974787	14.82	4.96	33.50		
Source	**DF**	**Type III SS**	**Mean square**	***F* value**	***P* > *F***
temp	1	784.00	784.00	31.78	0.0001
pred	1	10404.00	10404.00	421.78	<0.0001
temp*pred	1	256.00	256.00	10.38	0.0073
pred=larv; prey = pupa					