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INDIAN MEAL MOTH SURVIVABILITY IN STORED CORN WITH DIFFERENT LEVELS OF BROKEN KERNELS

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ABSTRACT

Survivability of Indian meal moth, *Plodia interpunctella* (Hübner) (Lepidoptera: Pyralidae), larvae fed a standard laboratory diet and whole corn with 0, 5 to 7, and 100% broken corn kernels, was assessed under laboratory conditions at 28°C, 65% relative humidity, and 14:10 h (L:D) photoperiod. A conventional yellow dent corn hybrid (about 3.9% oil content, dry basis) and a high-oil corn hybrid (about 7.7% oil content, dry basis) were tested. Survivability was measured as the percentage of pre-pupae, pupae, and adults observed at the end of the rearing period. For the standard laboratory diet, a mean of 97.5% larvae survived. Percentage of larval survival increased as the percentage of broken corn increased. Mean percentages of larval survival for the conventional yellow dent corn were 6.7, 63.8, and 80.0 for 0, 7, and 100% broken kernels, respectively. The mean percentages of larval survival for the high-oil corn hybrid were 28.3, 81.3, and 100.0 for 0, 5, and 100% broken kernels, respectively. Larval growth rate for high-oil corn was faster than for conventional corn. Results indicate that cleaning corn before storage could reduce *P. interpunctella* problems.

Mechanical forces such as impaction, abrasion, shear, and compression on grain during combine harvesting, high-temperature drying, and repeated handling can cause grain damage, broken grain, and grain dust. In corn, harvest and post-harvest operations can create as low as 1 to 4% and as high as 15 to 50% broken corn and foreign material (BCFM) (Paulsen and Nave 1980, Pierce and Hanna 1985, Converse and Eckhoff 1989, Bern and Hurburgh 1992). Also, these operations can result in 3 to 60% breakage susceptibility in corn (Pierce et al. 1991).

The presence of BCFM in corn can create many problems, and the important ones are: (1) BCFM leads to drop in grade and discount in market price (FGIS 1999); (2) BCFM increases the cost of processing and should be removed before wet or dry milling of corn (Watson and Ramstad 1987); (3) BCFM increases the airflow resistance of grain, which also increases fan power and cost of electrical energy for drying and aeration (Grama et al. 1984). Also, high levels of BCFM can result in non-uniform and inefficient grain cooling; (4) BCFM supports mold growth (Sauer et al. 1992); and (5) BCFM supports insect activity (examples are given below). Localized accumulation of BCFM in grain bins may lead to "hot-spots" where molds and insects grow readily (Flinn et al. 1992). To help reduce all of these problems, it is highly recommended that the grain be cleaned before storage (Wilcke and Hellevang 1992, Jones and Shelton 1996, Croissant 1998). The current study will further illustrate the importance of grain cleaning.

Insects that primarily feed on broken grain, grain dusts, grain debris, and molds without entering whole kernels are defined as secondary pests (or external

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feeders). Secondary pests in stored corn include: rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), Coleoptera: Laemophloeidae; flat grain beetle, *Cryptolestes pusillus* (Schönherr); confused flour beetle, *Tribolium confusum* (Jacq. du Val), Tenebrionidae; red flour beetle, *Tribolium castaneum* (Herbst); sawtoothed grain beetle, *Oryzaephilus surinamensis* (L.), Silvanidae; almond moth, *Ephesia cautella* (Walker), Lepidoptera: Pyralidae; and Indian meal moth, *Plodia interpunctella* (Hübner), Pyralidae, (Storey 1987). There have been only a few studies assessing the effects of broken corn on the insect development, survival, and fecundity. Development and progeny production of secondary beetles occurred more quickly in cracked and broken corn than in whole-kernel corn (Turney 1957, Throne and Culik 1989, Throne 1991). Also, higher insect survival and progeny production in wheat containing broken kernels and dockage (i.e., non-grain foreign material) than in undamaged wheat have been reported (Sinha 1975, White 1982, Higgins 1987, Fleming 1988). Furthermore, broken kernels and foreign material in grain also are known to affect the performance of grain protectants and fumigation (Flinn et al. 1992).

Although *P. interpunctella* is a secondary pest, it is a globally-distributed insect. This insect infests a wide variety of grain and grain products, nuts, dried fruits and vegetables, and processed and packaged foods (Sedlacek et al. 1995). In stored corn, *P. interpunctella* creates a variety of problems. Some of the problems are (reviewed by Kaliyan et al. 2003): (1) larvae feed on kernel germ which causes loss of germination, (2) larvae contaminate grain with silken webs and frass which may increase the airflow resistance of grain, inhibit fumigation, clog and damage equipment, and make grain unfit for human or animal consumption, and (3) larvae transmit spores of storage molds to grains. Several studies have been conducted to determine the effect of corn variety on the growth and survival of *P. interpunctella* with the goal of identifying resistant varieties (Abdel-Rahman et al. 1968, Hockensmith et al. 1986, Mbata 1990). Lecato (1976), Allotey and Goswami (1990), and Mbata (1990) attempted to show the effect of broken corn on egg to adult development time and on survival of *P. interpunctella*. However, in most of these studies, data on larval survival (or mortality) were not reported. Larval survival data can be important to model population dynamics of this species. The success of *P. interpunctella* population growth in stored corn depends on larval survival because larvae are the only feeding stages of *P. interpunctella*. Therefore, the objective of this study was to determine the effect of broken corn on survival of *P. interpunctella* larvae in two types of corn. Note that one of the corn hybrids tested has a high oil content - this is a newer type of corn that was probably not evaluated in previous studies.

MATERIALS AND METHODS

Larval Diet Preparation

Four types of diets were used to assess *P. interpunctella* larval survivability. The first was the standard laboratory diet which consisted of wheat bran, chick feed, corn meal, glycerol, honey, and water at a volumetric ratio of 30:20:10:6.5:1.5:1, respectively (Carrillo and Cannon 2005). The other three types of diets were derived from a conventional yellow dent corn (*cv.* Northrup King NK4242, 3.9% oil content, 14% moisture content) and a high-oil corn (*cv.* Pioneer P37H97, 7.7% oil content, 13% moisture content). Oil contents (% dry basis) were determined using a Near-Infrared Transmittance (NIRT) testing machine. Moisture contents (% wet basis) of the corn samples were determined by oven drying at 103°C for 72 h (ASAE Standards 2003a). Moisture contents around 13-14% are within the range recommended for long-term storage of corn (Cloud and Morey 1991). Although the moisture contents for the two corn samples were not identical, we did not attempt to adjust the moisture contents because the moisture values were close enough to one another that it would have been difficult to accurately adjust the moisture level and accurately measure the

adjusted moisture, and we wanted to avoid concerns that corn with artificially adjusted moisture content may behave differently from unadjusted corn.

Both corn types were harvested and shelled in 1997, and were stored in a -10°C freezer until used for the study. Upon removing corn samples from the freezer, they were warmed to room temperature. Corn samples were cleaned to remove BCFM by sieving with a round-hole sieve that had 4.8-mm (12/64-in.) diameter openings. The cleaned conventional and high-oil corn still had 7 and 5% (by weight) broken kernels larger than 4.8-mm diameter, respectively. Therefore, cleaned corn with these small percentages of broken corn (5 or 7%) was used as one type of diet for the *P. interpunctella* larval survivability test. Whole kernels of conventional and high-oil corn with 0% broken corn were handpicked and used as another type of diet. The last type of diet used was 100% broken corn of each type of corn. To obtain 100% broken corn samples, the cleaned corn was ground using a laboratory hand-operated attrition mill. The ground corn was sieved using the 4.8-mm diameter round-hole sieve, and the broken corn that passed through the sieve was collected and used for the test.

Particle size of the diets containing 100% broken corn was determined according to ASAE standard S319.3 (ASAE Standards 2003b). From the particle-size analysis, geometric mean diameter and geometric standard deviation of the particles were estimated. In addition, QuickstixTM Strip Test (EnviroLogix Inc., Portland, ME) was used to determine any potential presence of *Bacillus thuringiensis* Berliner (*Bt*) endotoxin in the two corn varieties.

Insects and Larval Survivability Test

Laboratory-reared *P. interpunctella* larvae were obtained from a culture initiated with Minnesota field-collected individuals maintained under laboratory conditions at $28 \pm 1^{\circ}\text{C}$, $65 \pm 5\%$ relative humidity, and 14:10 h (L:D) photoperiod on standard laboratory diet for about one year. This temperature and relative humidity are optimum conditions for the growth of *P. interpunctella* (Howe 1965). The 14:10 h (L:D) photoperiod was used to avoid larval diapause (Bell 1976). *P. interpunctella* larval survivability tests were conducted in an environmental chamber (Percival Scientific, Inc., Perry, IA) maintained at the above laboratory conditions. Plastic containers of 280-ml capacity were used for rearing the larvae in the environmental chamber. For each diet, three to four replications were conducted. Each container was filled with 40 g of diet and twenty 0 to 24-h old *P. interpunctella* larvae. One roll of corrugated cardboard (25-mm diameter and 30-mm height) was placed inside each container to provide pupation sites for the larvae. Containers were closed with a double-layer lid. The top layer of the lid was a filter paper (Whatman Filter Paper) and the bottom layer was a nylon screen. Nylon screens were used because preliminary experiments showed that mature *P. interpunctella* larvae bored through the filter paper and came out of the containers.

Larvae were reared in the chamber for 29 days. At the end of the rearing period, containers were removed from the chamber to count live insects [pre-pupae (mature larvae), pupae, and adults]. Survivability of *P. interpunctella* larvae in each diet was estimated as the percentage of initial larvae that molted to the pre-pupa, pupa, and adult stages at the end of the rearing period.

Statistical Analysis

The percentage of larval survival at the end of the experiment on different diets was analyzed in two ways. Initially, a one-way analysis of variance (ANOVA) (PROC GLM, SAS Institute 2001) was used to test for differences in the arcsine-square-root transformed proportion of larval survival between standard laboratory diet and diets containing 100% broken corn from the conventional and the high-oil corn. Diet was the sole predictor in the ANOVA models. This comparison was performed to determine any differences on the nutritional content of the diets since they were readily available for larval consumption from the beginning of the

experiment. Then, a one-way ANOVA (PROC GLM, SAS Institute 2001) was used to test for differences in the arcsine-square-root transformed proportion of larval survival among different percentages of broken corn within each corn type. When significant differences were observed, Tukey's Studentized Range test ($\alpha = 0.05$) was used for mean separation (SAS Institute 2001). Percentage of broken corn was the only predictor in the ANOVA model. Statistical comparison for larval survival between corn types was not performed because of differences in initial moisture content between conventional (14% wet basis) and high-oil corn (13% wet basis). Higher moisture contents have been reported to result in higher larval survival (Abdel-Rahman et al. 1968).

RESULTS AND DISCUSSION

Effect of Broken Corn on Larval Survivability

Geometric mean diameter and geometric standard deviation for the broken corn of the conventional corn hybrid were 1.4 mm and 0.35, respectively. Geometric mean diameter and geometric standard deviation for the broken corn of the high-oil corn variety were 1.6 mm and 0.31, respectively. The results for the Quickstix™ Strip Tests for the conventional and high-oil corn varieties were negative indicating that the corn varieties used for the experiment did not contain *Bt* endotoxin.

Imura and Sinha (1986) reported that the total development period from egg laying to adult emergence for *P. interpunctella* was 28.4 ± 1.5 days for females and 28.6 ± 1.3 days for males when *P. interpunctella* was reared on corn at 28°C, 65% relative humidity and 16:8 h (L:D) photoperiod. Therefore, it was assumed that all initial larvae would advance to at least the pupal stage after 29 days of rearing at our experimental conditions. This assumption was found to be satisfactory for most of the diets tested. However, it was difficult to determine a fixed length of time for the experiment because of high variations in the larval developmental periods among diets. At the end of the rearing period (30th day), the number of live insects [pre-pupae (mature larvae), pupae, and adults] was counted to estimate the larval survival percentage in each diet.

Higher moisture contents have been reported to result in higher larval survival (Abdel-Rahman et al. 1968). However, in the present study, conventional corn had higher moisture content but resulted in numerically lower larval survival than that observed for high-oil corn (Table 1). This result suggests that high oil content could increase larval survival during storage. Therefore, more research is needed to understand the effect of oil content on larval survivability.

The mean percentage of survival of *P. interpunctella* larvae was statistically similar between the standard laboratory diet and diets containing 100% broken corn from both conventional ($F = 3.6$; $df = 1, 6$; $P = 0.1063$) and high-oil corn ($F = 3.0$; $df = 1, 6$; $P = 0.1340$) (Table 1). Our results also indicate that the percentage of larval survival increased as the percentage of broken corn increased for both the conventional ($F = 23.8$; $df = 2, 8$; $P = 0.0004$) and high-oil corn ($F = 133.3$; $df = 2, 8$; $P < 0.0001$). Since we observed 100% larval survival in many tests, handling mortality of larvae can be considered to be negligible. The general trend for larval survival for the diets derived from the two types of corn was: percentage larval survival on 100% broken corn > whole corn with 5 to 7% broken corn > whole corn with 0% broken corn.

In general, first instars are unable to bore into whole kernels; therefore, very few larvae survived on whole corn with 0% broken corn. The numerical difference in larval survival on whole corn in the two corn varieties may be due to difference in grain hardness (Abdel-Rahman et al. 1968) and/or oil content. Hockensmith et al. (1986) reported that about 60% of *P. interpunctella* larvae survived on three corn varieties when they were reared on whole corn with manually damaged germs at 27°C. In the current study, we observed a lower larval

Table 1. Percentage of larval survival of *Plodia interpunctella* fed different diets. Larvae (0 to 24-h old) were reared at 28°C, 65% relative humidity, and 14:10 h (L:D) photoperiod for 29 days.

Diet	n ^a	Mean (%) ± SE
Conventional yellow dent corn		
[cv. Northrup King NK4242, 3.9% oil content (dry basis)]^b		
Whole corn with 0% broken corn	3	6.7 ± 1.67a
Whole corn with 7% broken corn	4	63.8 ± 2.39b
100% broken corn	4	80.0 ± 7.36b
High-oil corn hybrid		
[cv. Pioneer P37H97, 7.7% oil content (dry basis)]^b		
Whole corn with 0% broken corn	3	28.3 ± 7.26a
Whole corn with 5% broken corn	4	81.3 ± 2.39b
100% broken corn	4	100.0 ± 0.00c
Standard laboratory diet versus 100% broken corn^c		
Standard laboratory diet	4	97.5 ± 1.44
100% broken corn (conventional)	4	80.0 ± 7.36
100% broken corn (high oil)	4	100.0 ± 0.00

^a Each replicate represents 20 *P. interpunctella* larvae.

^b Means within a corn type followed by similar lowercase letters are not significantly different ($P > 0.05$).

^c Means between standard laboratory diet and 100% broken corn are not significantly different ($P > 0.05$). Statistical comparison for larval survival between corn types was not proper because of differences in initial moisture content.

survival percentage (7 to 28%) on whole corn than that reported by Hockensmith et al. (1986). This may be due to the fact that Hockensmith et al. (1986) used germ-damaged corn kernels whereas in this study undamaged whole corn kernels were used. Also, Hockensmith et al. (1986) used different corn varieties than those used for this study.

Results indicate that presence of even a small amount of broken corn (5 to 7%) increases survivability of *P. interpunctella* larvae by more than 50% compared to that of whole corn (Table 1). Therefore, cleaning corn before storage might reduce *P. interpunctella* problems in stored corn. This also suggests that cleaning corn could keep other secondary pests of stored corn under control.

Effect of Broken Corn on Larval Growth Rate

The effect of corn type on the growth rate of *P. interpunctella* (from egg to adult) has been reported in many studies (Abdel-Rahman et al. 1968, Hockensmith et al. 1986, Mbata 1990). Mbata (1990) observed faster growth rate of *P. interpunctella* (from egg to adult) on broken corn than whole corn in 13 corn hybrids. From the present study, growth rates of *P. interpunctella* larvae reared on standard laboratory diet, conventional corn (with 0, 7 and 100% broken corn), and high-oil corn (with 0, 5 and 100% broken corn) are presented in Table 2. Among the tested diets, only on the standard laboratory diet did 100% of the initial larvae molt to the subsequent life stages (pupa and adult). In addition, slowest larval growth was observed on whole, conventional corn with 0% broken corn, where no pupae or adults were observed. No adults were observed for any of the diets derived from the conventional corn. Conversely, a

Table 2. Percentage of *Plodia interpunctella* individuals in different life stages. Larvae (0 to 24-h old) were reared at 28°C, 65% relative humidity, and 14:10 h (L:D) photoperiod for 29 days.

Diet	n ^a	Pre-pupa ^b	Mean (%) ± SE Pupa	Adult
Standard laboratory diet	4	0.0 ± 0.0	75.5 ± 4.12	24.5 ± 4.12
Conventional yellow dent corn				
[cv. Northrup King NK4242, 3.9 % oil content (dry basis)]				
Whole corn with 0% broken corn	3	100.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Whole corn with 7% broken corn	4	72.8 ± 7.40	27.2 ± 7.40	0.0 ± 0.0
100% broken corn	4	87.7 ± 4.19	12.3 ± 4.19	0.0 ± 0.0
High-oil corn hybrid				
[cv. Pioneer P37H97, 7.7 % oil content (dry basis)]				
Whole corn with 0% broken corn	3	41.6 ± 17.37	27.8 ± 14.70	30.6 ± 2.78
Whole corn with 5% broken corn	4	24.5 ± 5.52	33.8 ± 2.59	41.8 ± 6.62
100% broken corn	4	3.8 ± 2.39	55.0 ± 6.12	41.3 ± 8.26

^a Each replicate was initiated with 20 *P. interpunctella* larvae.

^b Mature larvae (fourth or fifth instars) were counted as pre-pupae.

mixture of pre-pupae (mature larvae), pupae, and adults were observed in all of the diets derived from the high-oil corn. Therefore, larval growth rate in high-oil corn was greater than in conventional corn. Differences in larval growth rates between these two types of corn may be due to differences in nutritional qualities. This suggests that *P. interpunctella* problems in high-oil corn might be greater than in conventional corn (based on growth rate) if corn was held in storage for extended intervals. However, experiments on the fecundity and fertility of *P. interpunctella* fed conventional and high-oil corn should be conducted to further support the above conclusion.

Our results show that providing a small percentage of broken corn will increase larval survival and accelerate growth rate. Therefore, cleaning corn to remove broken kernels before storage might reduce problems of *P. interpunctella* in stored corn. The larval survival data reported in the present study could be useful for modeling population dynamics of *P. interpunctella* in stored corn. Furthermore, a larval growth rate model developed for *P. interpunctella* reared on a standard laboratory diet might not accurately predict larval growth rate on stored corn.

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