Oviposition Behavior and Larval Development of the European Corn Borer (Lepidoptera: Crambidae) on Sweet Versus Hot Peppers[1]

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Abstract Infestation of European corn borer, *Ostrinia nubilalis* (Hübner) (Lepidoptera: Crambidae), a key pest of peppers (*Capsicum annuum* L.), was studied to explore the cause of infestation differences in pungent versus sweet types of peppers. Our objectives were to determine whether *O. nubilalis* adults show an ovipositional preference or larval development effects among pepper types that vary in levels of capsaicin and dihydrocapsaicin, which is measured in Scoville heat units (SHU). Five pepper types with a range in hotness were tested: bell (0 SHU), sweet banana (0 SHU), hot wax (1125 SHU), jalapeño (5,000 SHU), and cayenne (40,000 SHU). Oviposition was studied after artificial infestation in laboratory cages, small and large field cages, and after natural infestation in choice and no-choice field trials. No ovipositional preference was detected for cage no-choice or choice assays. Field choice oviposition trials with 5 pepper types had no differences in either egg mass density or larval infestation. A no-choice field trial with 3 pepper types found there was no difference in oviposition, but larval infestation varied significantly, with bell peppers having the highest infestation and jalapeños the least. It is concluded that *O. nubilalis* females show no ovipositional preference among the pepper types tested. Larval development time was significantly longer on jalapeños and significantly longer on pungent than on sweet peppers. Larval survival was not significantly different among types. These results suggest that the difference in infestation must be due to behavioral or physical factors after egg laying and before larvae enter the fruit.

Key Words *Ostrinia nubilalis*, European corn borer, peppers, capsaicin

Peppers (*Capsicum annuum* L.) are an important crop in Ohio and worldwide. Peppers can be categorized as either bell or nonbell based on shape, or as sweet or hot based on pungency. Although the term nonbell often implies hot, there are many sweet nonbells. The sweet peppers, sometimes called mild peppers, include bell, pimento, sweet banana, and sweet cherry peppers. The hot peppers, sometimes called pungent or chile peppers, include jalapeños, cayenne, habanero (*C. chinense* L.), hot banana, and hot cherry peppers (Rubatzky and Yamaguchi 1997). Ohio had 626 ha of bell and 300 ha of nonbell peppers in 2007, and was ranked fourth in the nation in pepper production (USDA 2007). The hectares grown in both bell and nonbell peppers is increasing in Ohio. The most common nonbell peppers currently grown in Ohio are jalapeño, sweet banana, and sweet cherry.

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There are many insect pests of peppers of which the European corn borer, *Ostrinia nubilalis* (Hübner) (Lepidoptera: Crambidae), is by far the most devastating in the midwestern USA. Fruit that has been infested with *O. nubilalis* is unmarketable. The eggs of *O. nubilalis* are laid on the underside of the pepper leaves. The eggs hatch in 3 - 7 d. The young larvae do not feed on the leaves, but they enter the pepper fruit beneath the calyx within 24 - 36 h after eclosion. Infested fruit can drop or rot on the plant, but often the infested fruit remain on the plant and appear externally normal. The larvae can then move and infest other fruit (Jarvis and Guthrie 1972). Some damage can be caused by the larvae boring into the plant stems, which weakens branches and causes the loss of many fruits (Dupree et al. 1979, Ajlan et al. 1985). In Ohio there are usually 2 generations per year and sometimes a third generation. The first and second generations infest corn. Plant height and phenology influence levels of *O. nubilalis* infestation on corn, with taller and reproductive plants having greater infestation (Spangler and Calvin 2000, Ficht 1931, Patch 1929). The second and occasional third generations infest peppers, beginning when moths emerge around late July and early September, respectively (Ajlan et al. 1985, Welty 1995).

There has been much research on *O. nubilalis* biology and management on corn, but little on peppers. What has been done on peppers is mostly on chemical control of European corn borer on bell peppers. Three reports of host resistance to *O. nubilalis* in peppers have been published, and all focused on capsaicin's negative effect on larval survival as a key factor (Ajlan et al. 1985, Jarvis and Guthrie 1972, Frantz et al. 2004). Factors of fruit size and shape were found to have some effect, with bell-shaped and conical fruit being most susceptible (Jarvis and Guthrie 1972, Frantz et al. 2004). Spacing between fruit, plant compactness, leaf size, and location of fruit on outer versus inner branches were proposed to affect infestation (Ajlan et al. 1985). Frantz et al. (2004) studied the resistance of peppers to artificial infestation by *O. nubilalis* damage in a greenhouse environment and found that resistance did not always correlate with pungency.

Capsaicinoids are the compounds responsible for pungency in peppers with capsaicin and dihydrocapsaicin the dominant types (De 2003). The higher the level of capsaicin, the less damage there is to the peppers by *O. nubilalis* in artificial infestation tests (De 2003). Scoville heat units (SHU) are used to quantify the hotness of peppers (Padilla and Yahia 1998). Habanero peppers have 300,000 SHU, jalapeños have about 4,000 SHU, and bell peppers have zero SHU (De 2003). *Ostrinia nubilalis* larvae exhibit high mortality when fed diets containing capsaicin (Ajlan et al. 1985, Jarvis and Guthrie 1972). All published research on *O. nubilalis* and peppers has been conducted in the laboratory or under artificial infestation; there are no published field studies to determine why natural infestation rates differ between the bell and nonbell varieties. Whereas studies of capsaicin in artificial diets are informative, the levels tested do not necessarily correspond with natural levels in field-grown plants, and these studies do not provide definitive evidence for the cause of differential infestation in the field. There have been reports of infestation of hot peppers in the field, in contrast to greenhouse studies showing low infestation levels of *O. nubilalis* in hot peppers (Ajlan et al. 1985, Jarvis and Guthrie 1972, Frantz et al. 2004). None of these studies have addressed the issue of adult oviposition preference.

Capsaicin is not distributed evenly throughout the plant; the peduncles, leaves, stems, and roots have only small amounts. In the fruit, capsaicin is found in higher amounts in the pericarp tissues, and the placenta has higher total capsaicinoids than the pericarp (De 2003). Estrada et al. (2002) showed that removing the floral bud of the sweet pepper variety, Padron, resulted in no capsaicinoids in the stem and leaves; however, with fruit present, there was a gradient along the stem with more phenolic compounds at the apical end of the stem. Leaves had higher amounts of capsaicinoids than stems (Estrada et al. 2002). Dihydrocapsaicin was more abundant than capsaicin in the leaves and stems, but capsaicin was more abundant in the fruit (Estrada et al. 2002). Capsaicin is produced by modified epidermal cells called gland cells (Rowland et al. 1983). The size of the fruit affects levels of capsaicin, with the maximum level when the fruit is fully grown (De 2003). Capsaicin levels in the plant vary with plant genotype. Depending on the pepper variety, there is a peak of capsaicin around 40 - 50 days from fruit set. Zewdie and Bosland (2001) determined that capsaicinoids were not reliable as species characters due to the high levels of variation in the amount and type of capsaicinoid within species. Peroxidase has an inverse relationship with the level of capsaicinoids, and is thought to be the enzyme responsible for breaking down capsaicinoids (Padilla and Yahia 1998). Kirschbaum et al. (2002) evaluated fruit from plants grown in a greenhouse and found heterogeneity in the capsaicinoid content. This suggests that factors other than environment affect fruit capsaicin content. It is important to note that capsaicinoids (capsaicin and dihydrocapsaicin) are nonvolatile and odorless (De 2003). It is 2-methoxy-3-isobutyl pyrazine that gives bell peppers their characteristic aroma (Buttery et al. 1969). Tabasco peppers have ester compounds contributing the most to the aroma of the fruit (Haymon and Aurand 1971).

The goals of this study were to understand *O. nubilalis* behavioral and developmental response to plant characteristics that affect pepper infestation by this pest. An objective was to determine if the European corn borer moths have a preference for ovipositing on sweet peppers versus hot peppers and a second objective was to determine if the larvae are able to enter and develop in hot peppers at the same rate as in sweet peppers.

Materials and Methods

Laboratory cage oviposition trial, 2004. Five pepper varieties grown from seed (Rupp Seeds Inc., Wauseon, OH) were Socrates X3R (hybrid), Sweet Spot X3R (hybrid), Hungarian Yellow Wax Hot (open pollinated), Ixtapa X3R (hybrid), and Cayenne Large Thick (open pollinated). Characteristics of these varieties are shown in Table 1. Pepper plants were grown in a greenhouse in 200-cell plug trays from 27 April to 5 June (5.5 wks) when they were potted in 10 cm diam pots. All plants were maintained in a greenhouse until used in experiments.

All *O. nubilalis* moths were reared from pupa periodically purchased from French Agricultural Research Inc. (Lamberton, MN). Moths were held in 30 × 30 × 30 cm cages (BioQuip, Gardena, CA) with water supplied on moist cotton for at least 3 d until used in a trial. The cage was covered with a moist paper towel and covered with a plastic bag to increase the humidity in each cage.

Each replicate of the oviposition cage trial had one pair of plants in a wire mesh cage that was 28 × 28 × 51 cm (BioQuip, Gardena, CA) with 5 male and 5 female moths, which were tested for 5 d. Over time, each pepper variety was randomly paired with every other variety for a total of 10 pair combinations, with 3 replications in a randomized complete block design. The experiment was blocked by time. Plant varieties also were tested individually to determine oviposition in a no-choice situation. The number of eggs, eggs per mass, and number of masses were counted each day for

Table 1. Characteristics of five pepper (*Capsicum annuum*) varieties used in trials with European corn borer.

Variety	Type	Scoville heat units (mean + range)	Fruit shape	Overall plant height	Relative leaf size	Average fruit length/width (cm)	Placenta length/width (cm)	Average fruit pericarp thickness (cm)
Socates X3R	Bell	o	blocky	medium	large	9.5/9.3	2.9/5.0	thick, 0.83
Sweet Spot X3R	Sweet Banana	0	long, tapered	medium	medium	22.7/4.9	4.4/1.6	thick, 0.57
Hungarian Yellow Wax	Wax (hot)	1,125 (750 - 3,000)	long	short	large	12.2/3.3	3.9/1.4	medium thick, 0.37
Ixtapa X3R	Jalapeno	5,000 (4,000 - 6,000)	conical, short	tall	small	8.6/3.6	4.4/1.33	thick, 0.47
Cayenne Large Thick	Cayenne	40,000 (30,000 - 50,000)	long, thin, tapered	tall	small	19/2.6	3.13/0.8	medium thick, 0.33

Sources: Scoville heat units from catalog of Rupp seeds, all other observations taken from fruit harvested in Columbus site

5 d. Egg masses on the side of the cage also were counted to determine if moths were avoiding the plants and ovipositing on the cage. All cages were held in a growth chamber at 27°C during the day and 16°C at night, with a photoperiod of 16:8 (L:D) h.

Data were analyzed using SAS PROC MIXED V9.1 (SAS Institute 2001) with significance set at $\alpha = 0.05$. The model statement used was for a randomized complete block design with replication as the random effect. Waller-Duncan's mean separation was used when $P \leq 0.05$.

Small field cage oviposition trial, 2004. Seeds were started on 27 April and grown in a greenhouse until field-transplanted on 27 May at Ohio State University's Waterman Farm, Columbus, OH. Plants were hand planted followed by a drench with 10 - 34 - 0 fertilizer (7 l in 2000 l of water). The experimental design was a randomized complete block with 10 varietal pairs and 4 blocks. Each of 5 pepper varieties was randomly paired with each other variety, planted 30 cm apart in the pairs with 61 cm separating the pairs. The paired plants were in 2 rows of 5 paired plants, with each row separated by 76 cm. Once plants were established, cages were placed over the paired plants in the field. Fence posts were placed on each end of each row and rope extended 122 cm above ground between the 2 posts. Above each pair of plants, a 122 cm high cylindrical cage was hung, draped over the paired plants, and secured to the ground. The cage was made from nylon mesh fabric with a plastic hoop sewn into the mesh to keep it from touching the plants. The top of the cage was gathered at one point on a drawstring where it was secured to the rope above.

Twenty male moths and 20 female moths were released into each cage and left for 5 d. After 5 d, the cages were removed and the number of egg masses and the number of eggs per mass were counted. Trials were conducted over several days as moth numbers permitted. Data were analyzed using the same procedure and model as for the laboratory cage study.

Large field cage oviposition trial, 2005. The field cage oviposition trial was repeated in 2005, but with fewer pepper types, larger cages, and shorter oviposition times than in 2004. The larger cages were used to eliminate overlap of leaves between adjacent plants. The experimental design was a completely randomized design with 3 treatments and 26 replicates. The 3 varieties were Socrates, Sweet Spot, and Ixtapa, with 10 replicates conducted before fruit had formed and 16 replicates after fruit were present, to determine the effect of the presence of fruit on moth oviposition. Established field-grown plants at Waterman Farm were transplanted into 18 cm pots. One plant of each variety was placed in a 183 × 183 × 183 cm cage (Bioquip, Gardena, CA) that was placed adjacent to the same field from which the plants were growing. Twenty male and 20 female moths > 3 d old were released into each cage in late afternoon and left overnight in the cage. In the morning, egg masses were counted on each variety. New plants were transplanted from the field, potted, and placed in the cage for a new treatment replicate each day. Data were analyzed with total replicates and again for replicates with fruit versus no fruit. Data were analyzed using the same procedure and model as for the laboratory cage study.

Choice field trial on oviposition and larval infestation, 2004. The experimental design was a randomized complete block with 5 treatments and 4 replications. Each treatment was a different variety of pepper: Socrates, Sweet Spot, Hungarian, Ixtapa, and Cayenne. Five pepper varieties were seeded in the greenhouse on 27 April in 200-cell unit plug trays. Plants were transplanted in the field at Waterman Farm using a single-row carousel transplanter on 27 May. Each replicate of each variety was one 9 m long row with plants 36 cm apart. Rows were 1.5 m apart with 1.5 m alleys between replicates. As soon as the first summer-generation moths were detected in a blacklight trap, egg mass monitoring began. Every leaf on 3 plants of each variety in the middle of each plot was inspected for egg masses. Egg mass sampling was done weekly from 3 August to 2 September. Fruit of each variety were harvested to compare egg mass sampling with actual infestation by larvae, by sampling all ripe fruit from 10 plants from each row. Bell peppers were harvested when fully red. Three harvests of mature fruit occurred from 16 August to 1 October. Data were analyzed using the same procedure and model as for the laboratory cage study.

Choice field trials on oviposition and larval infestation, 2005. The choice oviposition trial used a randomized complete block design with 5 treatments and 4 replicates. The 5 treatments were 5 varieties: Socrates, Sweet Spot, Hungarian, Ixtapa, and Cayenne. The trial was identical to the trial in 2004 except that it was conducted at 3 locations: Waterman Farm, OH Agricultural Research and Development Center (OARDC), Western Branch (South Charleston, Clark Co., OH), and OARDC Vegetable Muck Crops Branch (Celeryville, Huron Co., OH). Peppers were seeded in a greenhouse in 200-cell plug trays on 7 - 13 April. Plants were field transplanted on 3 June at Western, 6 June at Waterman, and 7 June at Celeryville. The field was arranged with 5 varieties planted side by side in single 9 m long rows. Plants were separated by 46 cm. Rows were 1.5 m apart. No insecticides were used for the duration of the trial. Egg masses were sampled starting in late July, and weekly until the end of August, on 3 plants selected from the 20 plants in the plot row for each variety. Fruit were harvested when mature; 15 plants were harvested from each row a total of 3 times. Data were analyzed using the same procedure and model as for the 2004 choice field trial.

No-choice field trial on oviposition and larval infestation, 2005. The no-choice oviposition trial used larger plots than in the choice trial, in a randomized complete block design with 3 treatments and 4 replicates. The 3 treatments were 3 varieties: Socrates, Sweet Spot, and Ixtapa. The plots were established within a large field of early-planted corn at OARDC Western Branch. Pepper plots were separated by 31 m swaths of corn. The pepper plots were located along the outside edge of the corn field. Each plot consisted of 1 of 3 pepper varieties. Each plot had 6 rows each 9 m long. Plants were 46 cm apart, transplanted on 2 June. No insecticides were used during the trial.

Egg masses were sampled starting in late July, and continued weekly until the end of August, on 5 plants randomly selected in the middle 4 rows each week. Fruit was harvested when mature. Fifteen plants in each of the 4 middle rows were selected for harvest. Each plot was harvested 3 times. Data were analyzed using the same procedure and model as for the choice field trials except only 3 varieties were used.

Laboratory trial on larval feeding and development, 2004 and 2005. Larvae emerged from eggs laid by moths reared from pupae purchased from French Agricultural Research. One newly-emerged larva <1 h was placed on the calyx of 1 fruit of each of 5 varieties (Socrates, Sweet Spot, Hungarian, Ixtapa, Cayenne) after preliminary trials with 10 larvae per fruit had zero survival. All pepper fruit used was excised from field plots and inspected to be free of infestation. The fruit and larvae were kept in individual plastic deli dishes of 2 sizes. A 960 ml container (Solo Cup Company, Urbana, IL) was used for Socrates and Sweet Spot, and a 240-ml container was used for Hungarian, Ixtapa, and Cayenne. The containers were placed in a growth chamber at 27°C during the day and 16°C at night, with photoperiod of 16L:8D h. Data on survival were taken after 2 wks and then once per week until pupation; fruit were not examined earlier due to high probability of injuring small larvae. Fruit were replaced after each examination. Time to pupation and survival were calculated for 2 replications each containing 4 fruit of each variety in 2004, and 6 replications each containing 5 fruit of each variety in 2005. Data were analyzed using the same procedure and model as for the laboratory cage study.

Results

Laboratory cage oviposition trial, 2004. There was no difference in number of eggs oviposited on each day within a replicate, therefore sum of egg counts over the entire experimental period were used in each analysis. In no-choice tests, there was not a significant difference in the number of egg masses oviposited on individual pepper types when data excluded egg masses oviposited on the cage (*F* = 1.07; df = 4, 8; *P* = 0.43; Fig. 1) or when data included egg masses oviposited on the cage (*F* = 1.16; df = 5, 22; *P* = 0.35), which suggests there is no preference in oviposition on any pepper type alone. There was also no difference in oviposition between sweet (Socrates and Sweet Spot) versus pungent (Hungarian, Ixtapa, Cayenne) types (Masses: *F* = 0.01; df = 1, 8; *P* = 0.89; eggs: *F* = 0.02; df = 1, 8; *P* = 0.90). Hungarian received the fewest number eggs of all the varieties.

In choice tests, there was no difference in oviposition among the 5 pepper types when oviposition on paired pepper types was evaluated excluding eggs oviposited on the cage (Fig. 1) for egg masses (*F* = 0.99; df = 4, 36.9; *P* = 0.42), total eggs (*F* = 1.40; df = 4, 39.3; *P* = 0.25), or eggs per mass (*F* = 1.05; df = 4, 36.8; *P* = 0.39). A predetermined contrast of sweet versus pungent peppers also indicated no difference for all 3 variables (Eggs: *F* = 1.13; df = 1, 39.3; *P* = 0.29; masses: *F* = 0.42; df = 1, 36.9; *P* = 0.42; eggs per mass: *F* = 0.09; df = 1, 36.8; *P* = 0.77). When data included eggs oviposited on plants as well as the number of eggs oviposited on the cage, there also was no significant difference in oviposition for each treatment of eggs per mass (*F* = 1.28; df = 5, 61.1; *P* = 0.29). When comparing both number of masses and eggs on cages as well as number oviposited on plants, cages had significantly higher numbers

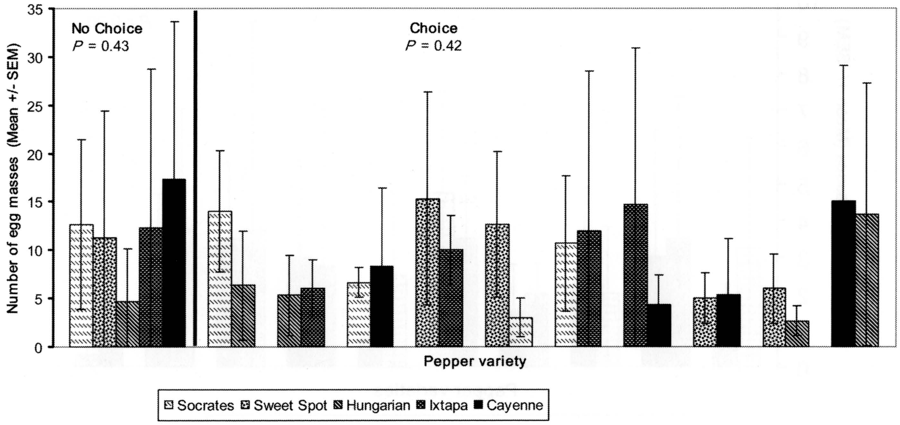

Fig. 1. **Mean number of *Ostrinia nubilalis* egg masses per plant on individual pepper varieties (no-choice) and on paired pepper varieties (choice) over a five day period in a laboratory cage trial, 2004.**

(Masses: $F = 9.08$; df = 5, 67.2; $P < 0.0001$; eggs: $F = 6.07$; df = 5, 70; $P < 0.0001$), but oviposition among the pepper plants was not significantly different among varieties.

Small field cage oviposition trial, 2004. There was no significant effect of pepper type on oviposition in the field cage trial for egg masses (Fig. 2; $F = 1.55$; df = 4, 51.1; $P = 0.20$), total eggs ($F = 0.74$; df = 4, 50.1; $P = 0.57$), or eggs per mass ($F = 1.09$; df = 4, 60.4; $P = 0.37$). When comparing sweet (Socrates, Sweet Spot) peppers versus pungent (Hungarian, Ixtapa, Cayenne) types, there was a significant difference in egg masses laid ($F = 4.32$; df = 1, 50.5; $P = 0.04$) with more on sweet peppers, but not in total eggs ($F = 2.42$; df = 1, 49.5; $P = 0.13$) or eggs per mass ($F = 2.42$; df = 1, 59.6; $P = 0.66$). If eggs oviposited on the cage were included in the analysis, again there was no difference in oviposition for either masses ($F = 1.05$; df = 5, 87.2; $P = 0.39$) or individual eggs ($F = 1.59$; df = 5, 79.9; $P = 0.17$).

The only general difference between laboratory and field cage trials was the overall number of eggs oviposited per day on plants, with more eggs in laboratory trials. Generally, there were more eggs oviposited on laboratory cages than on field cages. There was more variability in the number of eggs oviposited in field cages, which is probably due to the difference in weather among replicates, with fewer eggs oviposited during hot and drier weather.

Large field cage oviposition trial, 2005. In the large 183 × 183 × 183 cm cage, there was no difference in oviposition on pepper types either before fruit was present (eggs: $F = 2.29$; df = 2, 18; $P = 0.13$; masses: $F = 2.10$; df = 2, 18; $P = 0.15$; Fig. 3) or after fruit was present ($F = 0.91$; df = 2, 30; $P = 0.41$ for the total number of eggs; $F = 0.91$; df = 2, 30; $P = 0.41$ for number of masses; Fig. 3). There also was no difference in the number of masses oviposited on plants laid with or without fruit ($F = 0.01$; df = 1, 76; $P = 0.94$; Fig. 3).

Choice field trial on oviposition and larval infestation, 2004. Oviposition rates were low on all types of peppers, which is not unusual for the Columbus site. There were

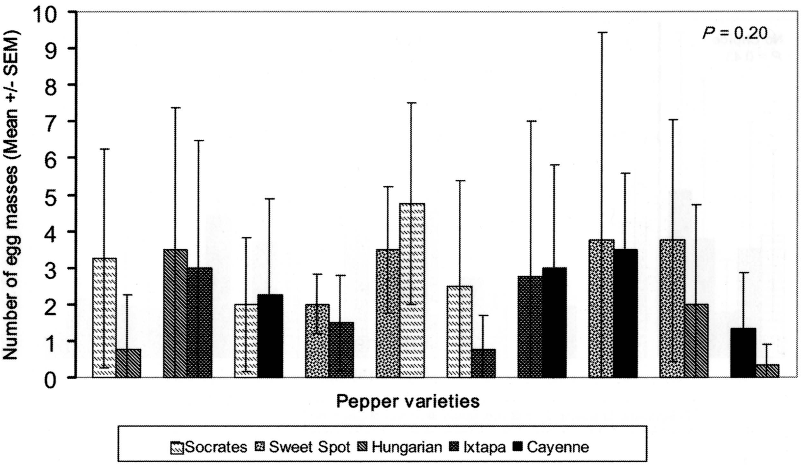

Fig. 2. Mean number of egg masses per plant laid by *Ostrinia nubilalis* on paired pepper varieties over a five day period in a field cage study, 2004.

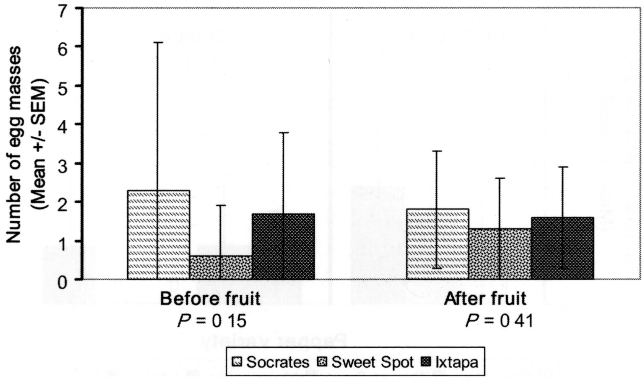

Fig. 3. Mean number of egg masses per plant laid in one night by *Ostrinia nubilalis* on pepper plants before and after fruit formation, in a field cage choice trial, 2005.

not enough data to conduct a statistical test. The only 2 egg masses found during 1 full month of scouting were on Hungarian peppers. Despite the lack of eggs detected, some larval infestations were found, but at low density; with 1.3% infested fruit of Sweet Spot, 2.3% infested fruit of Socrates, 0.4% infested fruit of Cayenne, 0.4% infested fruit of Hungarian, and 0.3% infested fruit of Ixtapa. These trends in larval infestation suggest that our egg scouting sample size was not sufficiently large.

Choice field trial on oviposition and larval infestation, 2005. Few eggs were found in the field trial at Columbus. In Celeryville, no egg masses or larvae were found, and monitoring blacklight traps yielded no *O. nubilalis* moths. Egg laying was also low at South Charleston, and there was no significant difference among types in the number of eggs ($F = 1.24$; df = 4, 32; $P = 0.31$) or the number of egg masses ($F = 1.11$; df = 4, 32; $P = 0.37$; Fig. 4). When comparing sweet (Socrates, Sweet Spot) versus pungent (Hungarian, Ixtapa, Cayenne) types, no difference in oviposition was detected (eggs: $F = 0.01$; df = 1, 32; $P = 0.97$; masses: $F = 0.01$; df = 1, 32; $P = 1.00$). There also was no significant difference in larval infestation among types ($F = 1.10$; df = 4, 44; $P = 0.37$; Fig. 5) or when sweet versus pungent types were compared ($F = 1.28$; df = 1, 44; $P = 0.26$). Larval infestation rates were low, with 1.5% infestation as the highest amount.

No-choice field trial on oviposition and larval infestation, 2005. Egg laying on the 3 types tested in this trial was low (Fig. 4), and there was no difference either in the total number of eggs ($F = 0.31$; df = 2, 42; $P = 0.48$) or in the number of egg masses ($F = 0.31$; df = 2, 42; $P = 0.73$). However, larval infestation rates were significantly different ($F = 19.27$; df = 2, 18; $P = <0.0001$; Fig. 5). Ixtapa received very low damage, whereas damage on Sweet Spot was about 20X higher, and about 80X higher on Socrates. The number of eggs masses found underestimated these larval infestation rates.

Laboratory trial of larval feeding and development, 2004 and 2005. There was no significant difference in survival of *O. nubilalis* larvae on different pepper types (Fig. 6; $F = 1.77$; df = 4, 133; $P = 0.13$). Survival of *O. nubilalis* larvae was not different on sweet versus pungent types ($F = 3.30$; df = 1, 133; $P = 0.07$). The majority of the larvae that did not survive died before the first examination (2 wks after neonates were added) for all types. Of all the larvae that did not survive, only Socrates in the

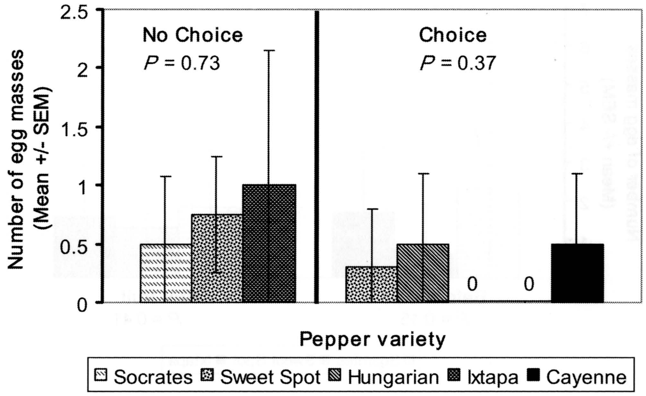

Fig. 4. Mean number of egg masses per plant laid by a natural population of *Ostrinia nubilalis* in no-choice and choice field oviposition trials, S. Charleston, OH, 2005.

fourth week of examination and Ixtapa in the sixth week of examination had larvae that survived beyond the third week of examination.

Development time, as measured by the number of weeks to pupation, was significantly different among types (Fig. 7; $F = 2.87$; df = 4, 67; $P = 0.03$). *Ostrinia nubilalis* larvae had a longer development time on Ixtapa than on Cayenne ($P = 0.02$), Sweet Spot ($P = 0.01$), or Socrates ($P = 0.01$). The number of weeks to pupation was significantly shorter on sweet than on pungent types ($F = 6.36$; df = 1, 67; $P = 0.01$).

Discussion

Patterns of oviposition by *O. nubilalis* on different pepper types were consistent among the laboratory cage trials in 2004, the small field cage trials in 2004, and large

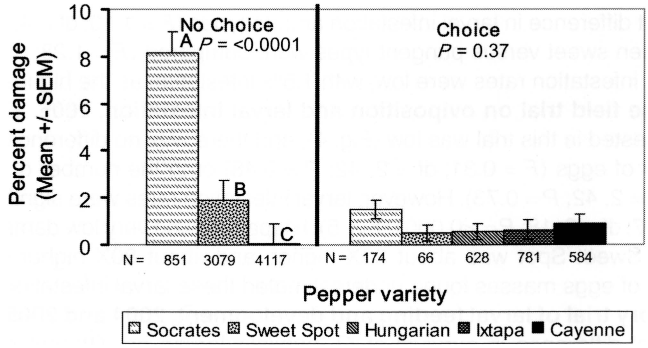

Fig. 5. Pepper fruit damage by a natural population of *Ostrinia nubilalis* larvae at harvest in no-choice and choice field trials, 2005, at South Charleston, OH. Bars with different letters are significantly different ($P < 0.05$).

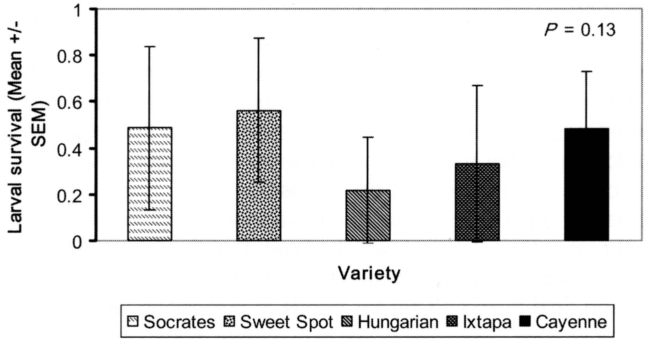

Fig. 6. Proportion of *Ostrinia nubilalis* larvae surviving on five pepper varieties in laboratory trial.

field cage trials in 2005 with eggs oviposited equally on the 5 pepper types. When comparing egg masses per plant, total eggs per plant, and eggs per mass, there were no differences in oviposition among types for any of the cage oviposition trials. Moths laid equally on the different types, but cage walls generally had more eggs than the plants. Analysis that included eggs oviposited on the cage allowed a comparison that took plant avoidance into account. Both laboratory and natural field populations had the same trend in oviposition, with no difference among the types. When sweet versus pungent types were evaluated, there was no difference in oviposition in laboratory cages, no-choice oviposition trials, and choice field trials. The field cage trial showed no difference in total eggs laid or eggs per mass when comparing sweet and pungent types, but showed numbers of masses were significantly different. Because the total eggs did not vary, the number of larvae should still be the same between sweet and pungent types. Clearly this research shows that there is no difference in oviposition. Other research (Ajlan et al. 1985, Jarvis and Guthrie 1972, Frantz et al. 2004) has

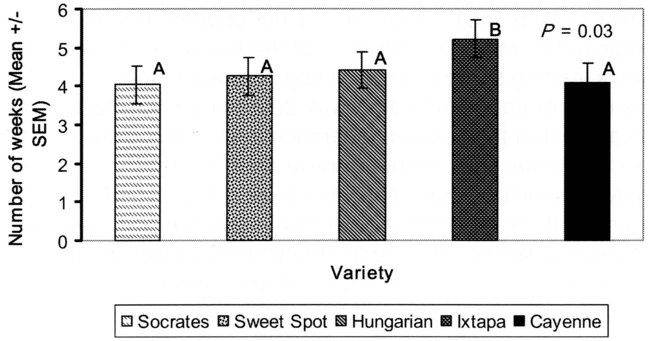

Fig. 7. Mean number of weeks from egg hatch to pupation for *Ostrinia nubilalis* in larval development trials on five pepper varieties. Bars with different letters are significantly different ($P < 0.05$).

dealt only with artificial infestations of *O. nubilalis* egg masses and, thus, did not compare differences in numbers of eggs laid on different types.

Capsaicinoids are produced by the fruit and, thus, the plant does not have pungency until the fruit is formed. Because some of the oviposition trials were started before fruit formation, the effect of fruit on oviposition was evaluated in the large field cage trial on plants both before and after fruit, but there was no significant difference in oviposition. The presence of fruit had no impact on oviposition rates. This clearly shows that the moths are not laying eggs in response to capsaicin amounts in the plants. Our oviposition data corroborate other research which shows that the larval infestation rates of *O. nubilalis* do not always correlate with pungency (Frantz et al. 2004).

Laboratory and field trials had similar trends in oviposition with the only differences being the number of eggs oviposited which was greater in the laboratory than in the field. This is probably an effect of varying weather conditions during the field trials, which affected both oviposition and moth survival. The lack of differences in oviposition among pepper types in both the choice trial and no-choice trials shows that even when the moths have options of different types the moths do not exhibit a preference in oviposition.

For choice and no-choice field trials, the method of searching for eggs was time consuming even with a small number of plants examined from the whole plot. The 1 wk time between evaluations could have allowed eggs to be deposited and hatch and burrow in without detection, which could have decreased the number of eggs found, although this is unlikely because remnants of hatched eggs were usually seen. When comparing pepper types, the trend was not consistently different in oviposition among treatments, although there was high variability within treatments. Larval infestation rates in field trials showed there was not a difference in choice trials, even when sweet and pungent types were compared. In no-choice trials, there was a highly significant difference in larval infestation. There must be host factors after eggs are oviposited that are impacting survival in the no-choice trials. A study testing the amount of damage by *O. nubilalis* found that smaller leaves and more fruit led to less infestation of peppers (Ajlan et al. 1985). Perhaps the smaller leaves of some types may impact the number of eggs oviposited but we did not see this trend among varieties with smaller leaves, such as Ixtapa and Cayenne, versus Socrates and Hungarian, which had large leaves, and Sweet Spot having medium sized leaves. Factors affecting survival could be differences in natural predators in the different varieties for the no-choice trial. Desiccation of eggs might occur on the hot peppers due to the smaller leaves being more exposed to wind. The behavior of the larvae might vary with competition among neonates leading to more larvae dropping from the plant.

An analysis of laboratory trials with larvae determined that there was no difference in larval survival but that there was a difference in larval development time. Because the majority of the larvae that did not survive died before the first examination at 2 wks, larvae may have difficulty successfully infesting the fruit. When comparing sweet and pungent types, there were no differences in survival, but development time differed. This shows that larvae are able to survive equally well in some hot and sweet peppers so there is not a consistent relationship between pungency and larval survival. These results differ from other research with larvae reared on artificial diets of capsaicin that found there was a higher mortality with higher amounts of capsaicin (Ajlan et al. 1985, Jarvis and Guthrie 1972, Frantz et al. 2004). The amount of capsaicin in the artificial diets corresponded with the amounts found naturally in pepper plants. Because the larvae were able to survive and develop equally in most peppers and there was no difference in oviposition, there must be some behavioral or physical factor between the time of oviposition and the time that larvae bore into the fruit that is affecting infestation rates.

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