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EGG PRODUCTION AND ADULT LONGEVITY OF *SPODOPTERA FRUGIPERDA*, *HELICOVERPA ZEA* (LEPIDOPTERA: NOCTUIDAE), AND *ELASMOPALPUS LIGNOSELLUS* (LEPIDOPTERA: PYRALIDAE) ON SELECTED ADULT DIETS

ALVIN M. SIMMONS AND ROBERT E. LYNCH
Insect Biology and Population Management Research Laboratory
Agricultural Research Service, U.S. Department of Agriculture
Tifton, Georgia 31793-0748

ABSTRACT

Survival and egg production data were collected for females of *Spodoptera frugiperda* (J. E. Smith), fall armyworm; *Helicoverpa zea* (Boddie), corn earworm; and *Elasmopalpus lignosellus* Zeller, lesser cornstalk borer, maintained on one of eight adult diets, two honey solution diets, sucrose solution, Gatorade, three beer diets, and water. Moth performance on beer was either equal to or less than that on the other diets. Corn earworm, one of two species fed a premium beer diet performed better than those on a lower cost beer. The addition of ascorbic acid to beer or of yeast to honey, generally did not influence moth performance. Moth performance was good on Gatorade, a moderately priced diet, and best on honey or sucrose diets. Consistently, moth survival was prolonged and egg production was high for moths on the low cost honey diet (8.4 days, 254 eggs per day, and 2375 eggs per female fall armyworm; 8.3 days, 241 eggs per day, and 1835 eggs per female corn earworm; 5.0 days, 26 eggs per day, and 122 eggs per female lesser cornstalk borer). Likewise, performance by the lesser cornstalk borer was good on sucrose, which is also a low cost diet.

RESUMEN

Datos de sobrevivencia y producción de huevos fueron recogidos para hembras de *Spodoptera frugiperda* (J. E. Smith), gusano cogollero *Helicoverpa zea* (Boddie), gusano del maíz; y *Elasmopalpus lignosellus* Zeller, gusano barrenador del maíz, mantenidas en una de las ocho dietas para insectos en fase adulta, dos dietas de soluciones de miel, solución de sacarosa, Gatorade, tres dietas de cerveza, y agua. La preferencia de las polillas por la cerveza fue igual a, o menos que, las otras dietas. El gusano del maíz, una de las dos especies alimentadas con una dieta de cerveza especial, lo hizo mejor que aquellas sometidas a una dieta de cerveza de un costo más bajo. Generalmente, añadiendole ácido ascórbico a la cerveza, o levadura a la miel no influyó la función de las polillas. La función de las polillas fue buena con Gatorade, una dieta de precio módico, y mejor con las dietas de miel o de sacarosa. Consistentemente, la sobrevivencia de las polillas se prolongó y la produccion de huevos fue mayor en las polillas con una dieta de bajo costo de miel (8.4 días, 254 huevos por día, y 2375 huvos por hembra del gusano cogollero; 8.3 días, 241 huevos por día, y 1835 huevos por hembra del gusano del maíz; 5.0 días, 26 huevos por día, y 122 huevos por hembra del gusano barrenador del maíz). Asimismo, la función del gusano barrenador del maíz fue buena en sacarosa, la cual es también una dieta de bajo costo.

Researchers use various types of diets to feed moths in the laboratory. A single diet, or a combination of diets, is often used to enhance moth performance. Three of the more commonly used diets for moths are beer, honey solution, or a sugar solution (Smith 1966, Fye & McAda 1972, Perkins 1979, Patana 1985). The beer is usually an inexpensive brand. Honey or sugar solution diets usually range from 5 to 10%, and occasionally 20% by volume of honey or sugar to water.

Published reports on fall armyworm, *Spodoptera frugiperda* (J. E. Smith), fecundity indicate a wide range of values (e.g., Luginbill 1928, 1000-1400 eggs; Randolph & Wagner 1966, 97-147 eggs; Leuck & Perkins 1972, 382-1387 eggs; Combs & Valerio 1980, 1007-1749 eggs; Pencoe & Martin 1981, 0-549 eggs; Castro & Pitre 1988, 88-1077 eggs; Lynch et al. 1989, 704-1093 eggs). This variation, as well as differences in adult survival may be influenced by temperature, diet of the larvae (Pencoe & Martin 1981, Combs & Valerio 1980, Lynch et al. 1989) and strain of the fall armyworm (Castro & Pitre 1988), but the role of adult diet has received little attention.

Nutritional requirements may vary among adults of different species. For example, varying the sugar concentration in the adult diet may affect one species of Lepidoptera but not another (Sharma & Chaudhary 1985). Because adult Lepidoptera produce primarily invertase, some compounds in an adult diet, e.g., starches, fats, and proteins, may not be used (House 1965). Among numerous nutrients (notably, proteins, carbohydrates, lipids, vitamins, and mineral elements) discussed by House (1965), it seems that carbohydrate is the most important ingredient in the adult diet affecting egg production and survival of many adult Lepidoptera. Apparently, much of the moths' dietary requirement is obtained during the larval stage.

Several species of moths are mass reared for research in our laboratory at Tifton, Georgia. Adults of all species are fed a beer diet (Old Milwaukee) with ascorbic acid. The purpose of this study was to select a good adult diet for use in our research, as well as for use by our insect rearing unit. Insect feeding which results in good egg production and longevity are two important considerations of a good diet. We tested the influence of selected diets on longevity and egg production of adults of the fall armyworm, corn earworm (*Helicoverpa zea* (Boddie)), and lesser cornstalk borer (*Elasmopalpus lignosellus* Zeller).

Materials and Methods

A virgin female of the fall armyworm, corn earworm, or lesser cornstalk borer (<12 h after adult eclosion) was caged with two males and fed one of six to eight diets: 1) distilled water, which was used as a control; 2) 10% honey solution, 10% honey by volume in distilled water; 3) 10% honey solution with yeast, 0.1 g of yeast per liter of solution; 4) sucrose solution, 8.3% sucrose by volume in distilled water; 5) orange flavored Gatorade, a commercial thirst quencher drink purchased in liquid form; 6) Old Milwaukee beer, which was allowed to stale by opening the can one day before use; 7) one day stale Old Milwaukee beer with 2.1 g ascorbic acid per liter of beer; and 8) Lowenbrau, a premium beer which also was allowed to stale for one day before use. Honey is composed of about 17% water (White et al. 1962). Therefore, the composition of the sucrose solution was equivalent to the honey solution in percentage of total sugars. Sucrose was fed only to the lesser cornstalk borer, and Lowenbrau beer was only fed to the corn earworm and the lesser cornstalk borer to limit the number of diets in the test or due to the unavailability of insects, respectively.

Fall armyworm adults were from a colony which began with collections from corn in Tift County, Georgia, in the fall of 1986 and had been maintained according to Perkins (1979). Corn earworm adults were from a colony which had been maintained in the laboratory since 1969 and maintained according to Perkins et al. (1973). Lesser cornstalk borers were from a laboratory colony which had been maintained since 1985 from feral males that were mated with laboratory females in 1987 and 1988. Larvae of all three species had been reared on a pinto bean diet (Perkins et al. 1973, Perkins 1979, Lynch & Reed 1985). Cages were 473 ml paper cups, and diet was dispensed via a pipette through the side of each cage. The pipettes were refilled daily. Wax-impregnated paper lined the inside and paper towel covered the top and bottom of each cage with fall

armyworm and corn earworm moths. For the lesser cornstalk borer, the top of each cage was covered with paper towel and the bottom was covered with organdy cloth.

The tests were conducted under a constant temperature regime of 27±2°C with a 16:8 L:D cycle. Relative humidity was maintained at 70±10% for the fall armyworm and corn earworm, and at 75±5% for the lesser cornstalk borer. During the course of the experiment, dead males were replaced with live ones. Eggs were recovered and female mortality was recorded daily. Corn earworm and lesser cornstalk borer eggs were either counted immediately or frozen and counted at a later time. For the fall armyworm, the liner of the cage was removed daily, from which disks of paper with eggs were cut out with a cork borer (2.2 cm in diameter) and weighed. The total number of fall armyworm eggs was estimated as described by Lynch et al. (1983). A sample of 35 paper disks containing eggs was weighed, allowed to hatch, and the larvae were counted. The number of larvae was then regressed on egg weight to estimate egg number. The regression coefficient ($r^2 = 0.81$) was highly significant ($P < 0.001$), and the regression equation was Y = 39.0 + X times 1.14, where X is the mg of egg mass weight and Y is the number of eggs in the egg mass. Exact counts were obtained when only few eggs (about 60 or less) were deposited.

Each experiment per species was designed in a randomized complete block with 20 females per species per diet. Data on fecundity and adult survival were analyzed by analysis of variance and means were separated by Waller-Duncans k-ratio t-test (SAS Institute 1985). Means of treatments within insect species, but not among species, were compared.

Results and Discussion

Mean longevity of adult females of fall armyworm, corn earworm, and lesser cornstalk borer on selected diets ranged from 8-13, 7-12, and 11-25 days, respectively (Table 1). With each species, adults required more than water for maximum longevity. The diet that promoted the longest female survival varied with species. Fall armyworm females lived longest when fed Old Milwaukee beer, Old Milwaukee beer and ascorbic acid, honey, or Gatorade. Likewise, the corn earworm survived well on these diets and

TABLE 1. Longevity for fall armyworm, corn earworm, and lesser cornstalk borer females maintained on selected adult diets (27±2°C, 16:8 L:D).

Diet[1]	Mean (± SEM) female longevity (day)[2]		
	Fall armyworm	Corn earworm	Lesser cornstalk borer
Honey	12.9(0.9)a	11.4(0.8)a	21.3(1.5)bc
Honey and yeast	10.6(0.8)b	8.9(0.8)bc	24.3(2.0)ab
Sucrose	—	—	24.9(1.4)a
Gatorade	12.2(0.8)ab	10.7(0.8)ab	19.4(1.4)cd
Beer (Old Milwaukee)	13.4(0.8)a	10.9(0.8)ab	15.6(1.1)e
Beer (Old M.) and AA	13.3(0.8)a	10.1(0.8)ab	16.1(0.7)de
Beer (Lowenbrau)	—	11.7(0.8)a	15.7(0.6)e
Water	8.0(0.8)b	7.4(0.8)c	11.4(0.7)f

[1]Old M. and AA = Old Milwaukee and ascorbic acid.

[2]Means in a column followed by the same letter are not significantly different, according to Waller-Duncan k-ratio t-test ($P > 0.05$); fall armyworm, $F = 7.16$, df = 5; corn earworm, $F = 3.58$, df = 6; lesser cornstalk borer, $F = 12.90$, df = 7.

Lowenbrau beer was among the diets on which they lived longest. Conversely, lesser cornstalk borer females lived longest on the sucrose, and on the honey and yeast diets; beer was only a moderately good diet for adults of this species. Overall, the honey diets were among those on which the moths survived longest (11-13 days for the fall armyworm, 9-11 days for the corn earworm, and 21-24 days for the lesser cornstalk borer). The addition of yeast to honey had no significant impact on longevity of the lesser cornstalk borer, but decreased survival of the fall armyworm and corn earworm. Gatorade provided moderate longevity for adults of all three species. The addition of ascorbic acid to beer did not significantly influence adult longevity of any of the three species. Lesser cornstalk borer adults survived longer on the sucrose diet than on any other diet. Survival on the water diet was consistently short for all species.

Significant differences in egg production were also noted among moths that were fed different diets (Table 2). For all three species, moths that fed only on water had low fecundity. Fecundity of moths that fed on honey or honey and yeast was comparably high for all three species. Likewise, fecundity of the lesser cornstalk borer was high (181 eggs per female) for females fed on the sucrose diet. Fecundity of females that fed on Gatorade was high for fall armyworm and lesser cornstalk borer, but only moderately high for the corn earworm. Egg production by moths on the beer diets was generally moderate for all three species, and the addition of ascorbic acid to beer had little influence on egg production. Of the two species that fed on Lowenbrau beer, the corn earworm was more fecund when females fed on Lowenbrau beer than when they fed on Old Milwaukee beer or Old Milwaukee beer and ascorbic acid, while the lesser cornstalk borer was equally fecund on all beer diets. Egg production was among the highest for the lesser cornstalk borer when females fed on sucrose.

Peak egg deposition occurred two to three days after eclosion for all three species, with most of the eggs deposited during the first half of the ovipositional period. The actual ovipositional period, i.e., the days that moths laid eggs, was considerably shorter than adult female survival for all three species. Moreover, the ovipositional period was shortest for all three species when adults fed on water (Table 2). Although all of the other diets significantly lengthened the ovipositional period for the fall armyworm, beer alone or honey alone significantly increased the oviposition period for the corn earworm; and sucrose, honey and yeast, and Lowenbrau beer significantly increased the oviposition period for the lesser cornstalk borer.

Mean daily egg production by females also varied with the diet (Table 2). For the fall armyworm, daily egg production was higher when females fed on honey and yeast, honey, water and Gatorade. Similarly, daily egg production for the corn earworm was higher when females fed on honey and yeast, or water. Daily egg production by the lesser cornstalk borer was comparable among all diets. Although daily egg production by females of all three species fed only on water was comparable with the production of eggs by females fed the best diet, total fecundity and longevity were low for females that fed only on water.

In addition to egg production and adult longevity, two other important values of a good adult diet are convenience and cost. It is desirable to have a diet that is easily prepared at low cost. Each of the diets used was convenient. The approximate cost per liter for each diet was determined by the retail value of the product(s) (Table 3). Sucrose and honey are relatively low in cost (about $0.08 and $0.32 per liter of diet, respectively). Gatorade is moderately priced at about $0.92 per liter. The price is higher for a liter of the less expensive beer and is even higher for the premium beer.

Adult longevity for the three species of moths in our study was similar to the longevity reported in the literature. However, fecundity among females in our tests was generally much higher than had been reported previously. Perkins et al. (1973), reported that different artificial diets of larvae influenced adult longevity (12.5-14.3 days)

TABLE 2. MEAN (±SEM) OVIPOSITIONAL PERIOD, RATE OF EGG DEPOSITION, AND FECUNDITY FOR THE FALL ARMYWORM, CORN EARWORM, AND LESSER CORNSTALK BORER MAINTAINED ON SELECTED ADULT DIETS (27±2°C, 16:8 L:D).

Diet[1]	Ovipositional period (days)[2]	Number eggs/day[2]	Number eggs/female[2]
		Fall armyworm	
Honey	8.6(0.5)a	284.1(21.3)a	2374.9(191.8)a
Honey and Yeast	7.5(0.6)a	287.7(24.2)a	2136.8(186.1)abc
Sucrose	—	—	—
Gatorade	7.5(1.0)a	252.0(32.3)ab	2162.2(290.4)ab
Beer (Old Milwaukee)	8.6(1.0)a	174.3(20.0)b	1550.8(168.6)cd
Beer (Old M.) and AA	9.0(1.1)a	178.5(20.8)b	1685.3(202.3)abc
Beer (Lowenbrau)	—	—	—
Water	4.1(0.5)b	277.4(40.0)a	1120.2(173.6)d
		Corn earworm	
Honey	8.3(0.9)a	240.5(25.0)cd	1834.9(191.3)ab
Honey and Yeast	6.5(0.6)ab	322.5(30.3)a	1877.6(128.3)a
Sucrose	—	—	—
Gatorade	6.9(1.0)ab	175.2(30.6)cd	1199.4(207.3)cd
Beer (Old Milwaukee)	8.1(1.0)a	155.1(27.5)d	1171.5(177.5)de
Beer (Old M.) and AA	5.2(1.1)b	139.0(31.1)d	750.9(159.3)d
Beer (Lowenbrau)	8.1(1.0)a	180.8(21.8)cd	1495.8(165.4)abc
Water	5.3(0.5)b	270.4(30.0)ab	1355.1(170.6)bc
		Lesser cornstalk borer	
Honey	5.0(0.7)abc	26.1(4.5)a	122.4(21.9)ab
Honey and Yeast	5.9(0.7)ab	23.6(3.2)a	153.8(28.6)ab
Sucrose	6.4(0.6)a	28.4(2.8)a	180.5(23.6)ab
Gatorade	4.4(0.7)bc	31.9(6.4)a	146.3(36.0)ab
Beer (Old Milwaukee)	5.0(0.7)abc	28.2(2.8)a	148.6(29.1)ab
Beer (Old M.) and AA	5.0(0.4)abc	29.2(3.8)a	153.3(26.6)ab
Beer (Lowenbrau)	5.8(0.3)ab	25.4(2.8)a	146.4(17.5)ab
Water	3.7(0.5)c	24.3(2.9)a	89.8(16.7)b

[1]Old M. and AA = Old Milwaukee and ascorbic acid.

[2]Means within column and followed by the same letter are not significantly different according to Waller-Duncan k-ratio t-test ($P > 0.05$).

TABLE 3. APPROXIMATE COST PER LITER OF DIETS USED TO MAINTAIN ADULT COLONIES OF THE FALL ARMYWORM, CORN EARWORM, AND LESSER CORNSTALK BORER IN THE LABORATORY.

Diet	Cost (U.S.$)
8.3% Sucrose	0.08
10% Honey	0.32
10% Honey and Yeast	0.34
Distilled Water	0.60
Gatorade	0.92
Beer (Old Milwaukee)	1.40
Beer (Old Milwaukee) and Ascorbic Acid	1.42
Beer (Lowenbrau)	2.82

and egg production (778-939 eggs per female) of the corn earworm. In a review of information on the lesser cornstalk borer, Chalfant et al. (1982) reported that fecundity varied from zero to 420 eggs per female. They also reported that longevity of the lesser cornstalk borer may be from about 7-9 to 38-42 days, depending on whether mating had occurred or whether they had fed or not.

Diets can play an essential role in egg production and in sustaining longevity of females. Generally, the performance of the moths on the honey solution diet was consistently good. Similarly, performance of lesser cornstalk borer on sucrose was good. In addition to enabling the moths to live longer and produce more eggs, the honey and sucrose diets are also relatively inexpensive; thus, they can be considered good diets for maintaining laboratory colonies of these species of moths. Performance of moths on the moderately priced Gatorade was consistently good. Survival of moths on the cheaper cost beer was good, but their egg production was marginal. Moreover, beer is relatively expensive compared with some of the other diets on which the insects performed well. Corn earworm moths that fed on the premium beer out-performed the moths that fed on the cheaper beer. However, the cost index of the premium beer was greater than the other diets.

Species specific requirements may vary, depending on the specific interaction of factors such as nutrition, photoperiod, temperature, and humidity (Engelmann 1970). Often, studies dealing with qualitative aspects (e.g., type of ingredients) of insect diets do not consider the quantitative aspects (e.g., the amount consumed) (Engelmann 1970). For example, if an insect consumes more of one diet than another, the response may be from the quantity of the diet and not necessarily from the quality of the diet. The sensory response of some moths to phagostimulants correlates with feeding behavior and may vary by species (Blaney & Simmonds 1988). Although we did not ascertain the quantity of diet consumed per moth, availability of any diet was not a limiting factor for moth performance.

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ENDNOTE

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