FALL ARMYWORM (LEPIDOPTERA: NOCTUIDAE) DEVELOPMENT AND FECUNDITY WHEN REARED AS LARVAE ON DIFFERENT MERIDIC DIETS[1]

R. E. Lynch, K. F. Nwanze[2], B. R. Wiseman, and W. D. Perkins
USDA-ARS
Insect Biology and Population
Management Research Lab
Tifton, GA 31793
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ABSTRACT

Fall armyworm, *Spodoptera frugiperda* (J. E. Smith), was reared on meridic diets containing pinto bean, peanut, peanut meal, soybean meal, bermudagrass pellets, and alfalfa pellets. Data were recorded on survival, weight of larvae at 10 days of age, days to pupation, weight of pupae, days to adult eclosion, sex, and fecundity. Pinto bean, bermudagrass pellets, alfalfa pellets, and peanut meal were suitable diets for laboratory production of the fall armyworm based on a host suitability index rating performance from high to low host suitability (Lynch et al. 1981). Peanut and soybean meal were unsuitable as a diet ingredient due to low survival of larvae or low fecundity for adults.

Key Words: Fall armyworm, *Spodoptera frugiperda*, Meridic diets, Development, Oviposition, Fecundity.

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The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith), is one of the most economically damaging insect species of the tropical and subtropical regions of the Western Hemisphere (Luginbill 1928). Because of its economic importance to agriculture, many studies have been conducted on rearing this insect. Walters (1937) reared the FAW in the laboratory on corn and bean leaves. One of the first artificial diets used to rear FAW was the wheat germ diet developed for the European corn borer, *Ostrinia nubilalis* (Hübner), where first instar larvae were started on corn and transferred to artificial diet in the second instar (Revelo and Raun 1964). Burton (1967) was the first to develop mass rearing techniques for the FAW solely on an artificial wheat germ diet. The more economical modified pinto bean diet, developed for rearing the corn earworm, *Heliothis zea* (Boddie) (Burton 1969), was subsequently used for rearing the FAW. Numerous modifications of the rearing procedures have been made to more efficiently rear the FAW, but the modified pinto bean diet remains the standard diet of choice (Perkins 1979). The FAW has been reared in the laboratory for over 360 generations on the modified pinto bean diet during the past 26 years. Approximately 10,000 FAW per day can be reared using the techniques described by Perkins (1979), and a potential of 100,000 FAW per day can be produced using multi-cell form-fill-seal equipment currently available.

[1] In cooperation with the University of Georgia College of Agriculture Experiment Stations, Coastal Plain Station, Tifton, GA 31793.

[2] ICRISAT, Patancheru P.O., Andhra Pradesh, India. Journal Article No. 824 of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

More recently, Parra and de Carvalho (1984) studied the development and quantitative nutrition of FAW larvae reared on seven varieties of pinto bean as ingredients in artificial diets. Differences in larval developmental time were noted with larvae reared on 'Branco-de-Uberlandia' completing development 18.7 days sooner than larvae reared on 'Moruna'. Approximate digestibility was also greatest on the diet containing 'Branco-de-Uberlandia'. The differences in digestibility of the diet and development of FAW larvae were attributed to differences in tannin content of the bean varieties.

Guillermo (1986) reared the FAW on an artificial diet similar to the modified pinto bean diet; soybean flour replaced pinto bean as the primary ingredient. Diluting the soybean flour diet by 60% with water resulted in more economical and efficient production of FAW larvae with only a slight decrease in their weight at 10 days. Larval duration, % pupation, and % adult eclosion were comparable when the soybean flour diet was diluted by 0, 20, 40, and 60%. Fecundity of the resulting females was actually improved by diluting the soybean flour diet 20, 40, and 60%.

The cost of producing FAW has steadily increased from $16.50/1000 pupae in 1967 to ca. $56.25/1000 pupae in 1988 (W. D. Perkins, personal communication). Increasing costs for pinto bean that is used in the diet represent a major portion of the increased costs for diet ingredients and is an ingredient that can be readily substituted. The use of peanut produced in field research conducted at the Insect Biology and Population Management Research Laboratory (IBPMRL) could reduce cost of production if suitable for rearing the FAW. Therefore, research was conducted to evaluate the effects of substitute ingredients that are more readily available and more economical than pinto bean on FAW larval development and adult fecundity.

MATERIALS AND METHODS

The FAW used in this study were from a colony maintained at the Insect Biology and Population Management Research Laboratory (Perkins 1979) on the modified pinto bean diet described by Burton (1969) (Table 1).

Two tests were conducted to evaluate the suitability of various foods substituted for the pinto bean in the FAW diet. Diet ingredients other than the pinto bean remained constant in the tests. In the first test, pinto bean (control), raw peanut, 50% peanut: 50% pinto bean (50%P:50%PB), bermudagrass pellets ('Coastal'), and 50% bermudagrass pellets: 50% pinto bean (50%BP:50%PB) were evaluated. A second test was conducted because peanut kernels were not suitable as a substitute for pinto bean for rearing the FAW. In the second test, pinto bean, soybean meal, peanut meal, alfalfa pellets, and bermudagrass pellets were evaluated. Each diet was prepared in quantities of 2 liters each as described by Perkins et al. (1973) and dispensed into 200 plastic diet cups (29.6 ml) at ca. 8 ml/cup. After the diet solidified and cooled, one neonate FAW was placed in each cup and the cup was capped with a paper lid. Trays of cups were then placed in an incubator maintained at 26.7 ± 2°C, 80 ± 5% RH, and a 14:10 (L:D) photoperiod.

Data were recorded on weight of larvae and % survival at 10 days, days to pupation, weight of pupae, % survival to pupation, days to adult eclosion, % survival to eclosion, and fecundity. Fecundity data were obtained by placing six pairs of FAW moths from a treatment in a 3.8-liter ice cream carton. Each carton

Table 1. Ingredients and cost per liter of Burton's (1969) modified pinto bean diet for rearing the fall armyworm.

Ingredient	Quantity	Cost ($)
Pinto bean	111.0 g	.085
Torula yeast	33.8 g	.090
Wheat germ	52.8 g	.085
Ascorbic acid	3.4 g	.040
Methyl p-hydroxybenzoate	2.1 ml	.025
Sorbic acid	1.1 g	.010
Formaldehyde, 10%	8.4 ml	.005
Water (in blender)	490.0 ml	.000
Water (agar solution)	338.0 ml	.000
Agar	13.5 g	.250

was lined with waxed paper and covered with a paper towel that was secured over the top of the container with a rubber band. One cotton dental roll (3.8 cm long × 1.0 cm diam.) was saturated with stale beer and placed in a container (4 cm diam. × 3 cm high) in the bottom of the oviposition carton each day as food for the adults. Each carton was checked daily for oviposition, beginning the second day, and the waxed paper and paper towel containing egg masses were removed. Fecundity was then determined by weighing the egg masses and applying the regression equation $Y = 14.87\,X$ where Y is the number of eggs/egg mass and X is the weight in mg of the egg mass (Lynch et al. 1983).

All experiments were designed in a randomized complete block. Initially, 100 replicates with two cups/replicate were used in each bioassay to measure the effects of the different diets on the developmental biology of larvae, pupae, and adults. Fecundity data were based on 4 to 10 replicates, i.e., unequal replication in the first test and 10 replicates in the second test. A host suitability index (HSI) was calculated for each diet using the equation HSI = [(fecundity/consumption)/ larval developmental time] × % survival (Lynch et al. 1981). A standard consumption rate of 164.5 mg, as determined by Chang et al. (1987) for the pinto bean diet, was used for all calculations. All data were subjected to an analysis of variance (SAS Institute 1985) and significantly different means were separated by Duncan's (1955) multiple range test.

RESULTS

The weight of FAW larvae feeding on bermudagrass pellets or 50% BP:50%PB diet was significantly greater after 10 days than the weight of larvae feeding on diets with pinto bean, peanut, or 50%P:50%PB (Table 2). Likewise, the larvae that fed on pinto bean diet were significantly heavier at 10 days than larvae that fed on peanut diet, and larvae that fed on peanut diet were significantly heavier than larvae that fed on 50%P:50%PB diet. Survival at 10 days was comparable for FAW larvae on the pinto bean, 50%P:50%PB, bermudagrass pellet, and 50%BP:50%PB diets, and significantly more larvae survived on these diets than larvae on the peanut diet.

Developmental time to pupation was significantly shorter for larvae that fed on bermudagrass pellet diet or 50%BP:50%PB diet than for larvae that fed on the other three diets (Table 2). Similarly, developmental time was significantly shorter for larvae that fed on pinto bean diet than for larvae that fed on the two diets with peanut, and significantly shorter for larvae that fed on 50%P:50%PB than for larvae that fed on peanut diet. The weights of male pupae from larvae that were reared on pinto bean, 50%P:50%PB, bermudagrass pellets, and 50%BP:50%PB diets were comparable, and all pupae except those from larvae that were reared on 50%P:50%PB were significantly heavier than pupae from larvae reared on peanut diet. Female pupae from larvae reared on peanut diet were also significantly lighter than pupae from larvae reared on any of the other four diets. Survival of larvae to pupation was comparable on the pinto bean, bermudagrass pellet, and 50%BP:50%PB diets, and all larvae from these diets had significantly greater survival to pupation than larvae that were reared on the two diets that contained peanut.

Developmental time prior to adult eclosion was comparable for FAW larvae reared on pinto bean, bermudagrass pellet, and 50%BP:50%PB diets, and larvae from these diets required significantly fewer days to adult eclosion than larvae from the two peanut diets (Table 3). Larvae reared on 50%P:50%PB diet also required significantly fewer days to adult eclosion than larvae reared on peanut diet. Survival of larvae to adults was significantly higher when larvae were reared on bermudagrass pellets than for larvae reared on pinto bean, peanut, or 50%P:50%PB. Survival of larvae to adults on 50%BP:50%PB diet was intermediate between survival for larvae reared on bermudagrass and on pinto bean. Survival of larvae to adults on peanut was significantly lower than survival of larvae to adults on any of the other diets. The addition of 50% pinto bean to the peanut significantly improved survival of larvae to the adult stage, but survival of larvae to adults on 50%P:50%PB was still significantly lower than survival of larvae to adults on pinto bean, bermudagrass, or 50%BP:50%PB diet. The sex ratio of adults from larvae reared on the five diets was comparable.

Insufficient larvae survived to adults on the peanut diet for the collection of fecundity data (Table 3). Females from larvae reared on the other four diets had a comparable ovipositional period and laid an equal number of egg masses. However, the number of eggs/female/day was significantly greater for females originating from larvae that were reared on bermudagrass and 50%BP:50%PB diets than for females originating from larvae that were reared on the 50%P:50%PB diet. Thus, since the ovipositional period and number of egg masses/female were equivalent for females from larvae that were reared on the four diets but the number of eggs/female/day differed, egg masses were larger for females from larvae that were reared on bermudagrass, 50%BP:50%PB, and pinto bean diets than egg masses for females from larvae that were reared on the 50%P:50%PB diet. Consequently, total fecundity was significantly greater for females from larvae that were reared on bermudagrass, 50%BP:50%PB, and pinto bean diets than total fecundity for females from larvae that were reared on 50%P:50%PB diet.

Analysis for host suitability index indicated that diets containing bermudagrass pellets (HSI = 43.3a), 50%BP:50%PB (HSI = 41.9a), and pinto bean (HSI = 35.5a) were the best hosts for rearing the FAW. Peanut (HSI = 0.0b) was an inadequate diet since larvae that fed on it had low survival to eclosion. The 50%P:50%PB diet

Table 2. Effects of substituting diet ingredients for pinto bean in the fall armyworm meridic diet on fall armyworm larval development.

Diet treatment†	Developmental Parameters*					
	10 d larval weight (mg)	Survival at 10 d (%)‡	Days to pupation	Pupal wt (mg) Male	Pupal wt (mg) Female	Survival to pupation (%)‡
Pinto bean	187.3 b	100.00 a	14.7 c	246.5 a	257.9 a	92.5 a
Peanut	90.5 c	82.0 b	19.9 a	202.1 b	92.2 b	11.5 c
50%P:50%PB	73.6 d	98.0 a	18.1 b	223.0 ab	232.0 a	60.0 b
Bermudagrass pellets	236.9 a	98.0 a	14.2 d	256.9 a	264.7 a	97.0 a
50%BP:50%PB	233.0 a	100.0 a	14.2 d	252.8 a	262.3 a	96.5 a

* Means within a column followed by the same letter are not significantly different ($P > 0.05$) using Duncan's (1955) multiple range test.

† 50%P:50%PB = 5 % peanut:50% pinto bean; 50%BP:50%PB = 50% bermudagrass pellets:50% pinto bean.

‡ Percentage data transformed to arcsin $\sqrt{\%}$ for analysis.

Table 3. Effects of substituting diet ingredients for pinto bean in the fall armyworm meridic diet on fall armyworm adult biology and fecundity.*

Diet treatment†	Days to adults	Survival to adults (%)‡	Sex ratio male:female	No. days ovipositing§	Egg masses/ female	Eggs/ female	Eggs/ female/day
Pinto bean	23.2 c	85.5 b	1.18:1.00 a	5.7 a	7.2 a	1003.6 a	176.5 ab
Peanut¶	29.0 a	1.0 d	1.00:1.00 a	-	-	-	-
50%P:50%PB	27.3 b	29.0 c	1.07:1.00 a	5.0 a	7.9 a	704.3 b	137.4 b
Bermudagrass pellets	22.7 c	92.5 a	1.00:1.00 a	5.6 a	6.0 a	1093.5 a	199.8 a
50%BP:50%PB	22.6 c	91.5 ab	1.00:1.08 a	5.7 a	6.3 a	1070.6 a	188.5 a

* Means within a column followed by the same letter are not significantly different ($P > 0.05$) using Duncan's (1955) multiple range test.

† 50%P:50%PB = 50% peanut:50% pinto bean; 50%BP:50%PB = 50% bermudagrass pellets:50% pinto bean.

‡ Percentage data transformed to arcsin $\sqrt{\%}$ for analysis.

§ Oviposition data based on 6 pairs of adults/replication and 10 replications.

¶ Insufficient survival on peanut precluded ovipositon data.

(HSI = 6.9b) was also inadequate with low survival of larvae to adult eclosion and reduced fecundity in resulting females.

In the second test, soybean meal promoted a significantly greater weight gain in larvae after 10 days of age than the other treatments (Table 4). Larvae that fed on pinto bean diet weighed significantly more at 10 days than larvae that fed on bermudagrass pellets, alfalfa pellets, or peanut meal diets. Larvae reared on diets with bermudagrass pellets and alfalfa pellets, had comparable weights at 10 days of age, and larvae from both diets were significantly heavier at 10 days of age than larvae reared on peanut meal diet. However, survival of larvae that fed on peanut meal diet was significantly greater at 10 days than survival of larvae that fed on bermudagrass pellets, alfalfa pellets, or soybean meal diet.

Soybean meal also promoted the most rapid larval development, as larvae reared on soybean meal required significantly fewer days to pupation than larvae that were reared on any other diets (Table 4). Larvae that fed on pinto bean and bermudagrass diet required significantly fewer days to complete larval development than larvae that fed on peanut meal or alfalfa pellet diet. However, survival to pupation was comparable for larvae reared on all diets.

The weight of male pupae from larvae that were fed on pinto bean, bermudagrass, and alfalfa diet was significantly greater than the weight of pupae for larvae that were fed on peanut meal or soybean meal diet (Table 4). The weight of male pupae from larvae that were fed on peanut meal diet was also significantly greater than the weight of pupae from larvae that were fed on soybean meal diet. The weight of female pupae from larvae fed on bermudagrass pellet and pinto bean diet was comparable and was significantly greater than the weight of pupae from larvae fed soybean meal or peanut meal diet. Survival of larvae to pupation was comparable on all diets.

The sex ratio of emerging adults was skewed in the second test. Significantly more females survived to adult eclosion than males when larvae were fed on peanut meal diet than when larvae were fed on pinto bean, bermudagrass pellet, or alfalfa pellet diet (Table 5). Conversely, significantly more males survived to adult eclosion than females when larvae were fed on bermudagrass pellet and alfalfa pellet diet than when larvae were fed on pinto bean, peanut meal, or soybean meal diet.

As in the previous test, no significant differences were recorded in the number of ovipositional days or the number of egg masses/female. However, number of eggs/female/day and total eggs/female were significantly greater for females originating from pinto bean, peanut meal, bermudagrass pellet, and alfalfa pellet diets than for females originating from soybean meal diet.

HSI was significantly greater for FAW reared on bermudagrass pellet (HSI = 37.8a), peanut meal (HSI = 35.5a), and alfalfa pellet (HSI = 34.1a) diets than for FAW reared on soybean meal diet (HSI = 20.0b). Insects reared on pinto bean diet had an intermediate HSI (HSI = 32.1ab). The lower HSI for insects reared on soybean meal diet was a result of reduced fecundity for females from larvae that fed on this diet in comparison with the fecundity for insects from larvae that fed on the other diets.

DISCUSSION

Two major required ingredients for an insect diet are proteins and fats (Davis 1972; Chippendale 1972). Legumes, such as peanut and soybean, are characterized

Table 4. Effects of substituting diet ingredients for pinto bean in the fall armyworm meridic diet on fall armyworm larval development.

Diet treatment	Developmental Parameters*					
	10 d larval weight (mg)	Survival at 10 d (%)†	Days to pupation	Pupal wt (mg)		Survival to pupation (%)†
				Male	Female	
Pinto bean	248.8 b	92.5 ab	14.4 b	264.2 a	281.7 ab	90.0 a
Soybean meal	295.2 a	88.0 b	14.0 c	240.0 c	257.3 c	87.4 a
Peanut meal	171.8 d	97.0 a	14.8 a	248.9 b	262.9 c	93.4 a
Bermudagrass pellets	203.0 c	89.7 b	14.5 b	264.3 a	286.8 a	90.0 a
Alfalfa pellets	210.2 c	89.6 b	14.8 a	263.2 a	276.8 b	90.5 a

* Means within a column followed by the same letter are not significantly different ($P > 0.05$) using Duncan's (1955) multiple range test.
† Percentage data transformed to arcsin $\sqrt{\%}$ for analysis.

Table 5. Effects of substituting diet ingredients for pinto bean in the fall armyworm meridic diet on fall armyworm adult biology and fecundity.*

Diet treatment	Days to adults	Survival to adults (%)†	Sex ratio male:female	No. days Ovipositing‡	Egg masses/ female	Eggs/ female	Eggs/ female/day
Pinto bean	22.7 c	90.0 a	1.00:1.08 ab	6.2 a	8.0 a	844.3 a	133.1 a
Soybean meal	22.1 d	87.4 a	1.00:1.25 ab	6.4 a	6.3 a	526.4 b	81.2 b
Peanut meal	23.1 b	93.4 a	1.00:1.44 a	6.2 a	8.0 a	924.4 a	149.6 a
Bermudagrass pellets	23.1 b	90.0 a	1.25:1.00 bc	6.1 a	7.0 a	1001.0 a	163.8 a
Alfalfa pellets	23.4 a	90.5 a	1.53:1.00 c	6.6 a	7.8 a	917.6 a	141.9 a

* Means within a column followed by the same letter are not significantly different (P > 0.05) using Duncan's (1955) multiple range test.

† Percentage data transformed to arcsin $\sqrt{\%}$ for analysis.

‡ Oviposition data based on 6 pairs of adults/replication and 10 replications.

by higher protein (26.0 and 37.9%, respectively) and fat (47.5 and 17.4%, respectively) content than is found in pinto bean (22.8% protein and 1.3% fat), bermudagrass pellets (14.9% protein and 3.6% fat), or alfalfa pellets (17.4% protein, 2.5% fat) (National Academy of Sciences 1971). All of these diet ingredients contain the 10 essential amino acids required by insects (Davis 1972), with the possible exception of peanut which has a low tryptophane concentration. Fats such as polyunsaturated acids and sterols also are required in low concentrations by insects (Chippendale 1972). Peanut meal and soybean meal contain relatively low concentrations of fat, 7.3 and 1.1%, respectively, with higher concentrations of protein, 47.6 and 37.9%, respectively (National Academy of Sciences 1971). However, as Vanderzant (1966) noted, small changes in concentrations of individual amino acids may result in an inadequate diet for the proper development of larvae, pupae, or the emergence of adults.

The ultimate test for a nutritionally adequate insect diet is the emergence of reproductively normal adults (Vanderzant 1966). Larval diets containing pinto bean, bermudagrass pellets, 50%BP:50%PB, peanut meal, or alfalfa pellets were adequate for laboratory production of the FAW; these diets promoted rapid larval development, female pupae of normal weight, excellent survival to adult eclosion, and excellent fecundity. Insects reared on diets containing raw peanut or soybean meal had a lower survival or fecundity. Apparently, the fat content of raw peanut, even when at only 50% concentration, was excessive for proper development of the FAW. Fat content was greater for peanut meal than for any of the other diet ingredients tested, but was only 15.4% of the fat content of raw peanut. FAW development, survival, and fecundity were drastically improved when larvae were fed peanut meal diet rather than raw, homogenized peanut.

The HSI provides a quantitative measurement of the insect-host relationship, enabling one to evaluate the overall performance of an insect on a particular host (Lynch et al. 1981). Although this index was originally developed to measure the effects of antibiosis on insects, it also is applicable to an insect's performance on meridic diets as reported here. Higher HSI's resulted when FAW's were reared on pinto bean, bermudagrass pellet, and 50%BP:50%PB, alfalfa pellet, or peanut meal diets than for insects reared on peanut, 50%P:50%PB, or soybean meal diets. Therefore, the former diets with higher HSI values are more suitable for rearing the FAW in the laboratory than the latter diets with lower HSI values.

The cost/kg for the diet ingredients evaluated here currently is $0.23 for peanut meal, $0.26 for alfalfa pellets, $0.32 for soybean meal, $0.76 for pinto bean, and $2.20 for peanut. Bermudagrass pellets are not commercially available, but could be produced for approximately $0.20/kg. Therefore, substitution of bermudagrass pellets, peanut meal, or alfalfa pellets for pinto bean in FAW rearing media would save 11.0, 10.2, or 9.3%, respectively. However, before new diets are accepted in lieu of the standard pinto bean diet, additional tests on the field establishment on different hosts of progeny from larvae reared on the new diet, parasitization rates for parasites of FAW larvae on the new diet, and adult and larval behavior of insects reared for several generations on a new diet must be conducted. Guillermo (1986) reported reducing rearing costs up to 60% by diluting FAW diet with water, with no increase in the developmental time for larvae or decrease in adult survival or fecundity. Further investigation in diluting the pinto bean diet as reported by Guillermo (1986) may be more directly applicable, and possibly reduce costs more than substituting diet ingredients for pinto bean.

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LITERATURE CITED

Burton, R. L. 1967. Mass rearing the fall armyworm in the laboratory. U.S. Dept. Agric., Agric. Res. Serv. 33-117, 12 pp.

Burton, R. L. 1969. Mass rearing the corn earworm in the laboratory. U.S. Dept. Agric., Agric. Res. Serv. 33-134, 8 pp.

Chang, N. T., R. E. Lynch, F. A. Slansky, B. R. Wiseman, and D. H. Habeck. 1987. Quantitative utilization of selected grasses by fall armyworm larvae. Entomol. Exp. Appl. 45: 29-35.

Chippendale, G. M. 1972. Insect metabolism of dietary sterols and essential fatty acids. In J. G. Rodriguez (Ed.), Insect and mite nutrition: significance and implications in ecology and pest management. North-Holland Publ. Co., London, England.

Davis, G. R. F. 1972. Application of insect nutrition in solving general nutrition problems. In J. G. Rodriguez (Ed.), Insect and mite nutrition: significance and implications in ecology and pest management. North-Holland Publ. Col., London, England.

Duncan, D. B. 1955. Multiple range and multiple F tests. Biometrics 11: 1-42.

Guillermo, G. V. 1986. Nutricion del gusano cogollero: una dieta larval economica para su cria masiva en el laboratorio. Southwestern Entomol. 11: 31-36.

Luginbill, P. 1928. The fall armyworm. U.S. Dept. Agric. Tech. Bull. No. 34, 92 p.

Lynch, R. E., W. D. Branch, and J. W. Garner. 1981. Resistance of *Arachis* species to the fall armyworm, *Spodoptera frugiperda*. Peanut Sci. 8: 106-109

Lynch, R. E., S. D. Pair, and R. Johnson. 1983. Fall armyworm fecundity: relationship of egg mass weight to number of eggs. J. Ga. Entomol. Soc. 18: 507-513.

National Academy of Sciences. 1971. Atlas of nutritional data on United States and Canadian feeds. Nat. Acad. Sci., Washington, D. C.

Parra, J. R. P., and S. M. de Carvalho. 1984. Biologia e nutricao quantitativa de *Spodoptera frugiperda* (J. E. Smith) em meios artificiais compostos de diferentes variedades de feijaho. An. Soc. Entomol. Brazil 13: 305-319.

Perkins, W. D. 1979. Laboratory rearing of the fall armyworm. Florida Entomol. 62: 87-91.

Perkins, W. D., R. L. Jones, A. N. Sparks, B. R. Wiseman, J. W. Snow, and W. W. McMillian. 1973. Artificial diets for mass rearing the corn earworm (*Heliothis zea*). U.S. Dept. Agric. Prod. Res. Rpt. 154, 7 p.

Revelo, M. A., and E. S. Raun. 1964. Rearing the fall armyworm under greenhouse conditions. J. Econ. Entomol. 57: 1000.

SAS Institute. 1985. SAS user's guide: statistics. SAS Institute, Cary, NC.

Vanderzant, E. S. 1966. Defined diets for phytophagous insects. In C. N. Smith (Ed.), Insect colonization and mass production. Academic Press, New York, NY.

Walters, H. 1937. Methods and equipment for laboratory studies of insecticides. J. Econ. Entomol. 30: 179-203.