A Synthetic Diet for the Spruce Budworm, *Choristoneura fumiferana* (Clem.) (Lepidoptera: Tortricidae)[1]

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The spruce budworm, *Choristoneura fumiferana* (Clemens), was reared on a synthetic diet. Comparison of two successive laboratory generations reared on synthetic diet and on frozen balsam fir buds showed that diet-fed insects had a higher survival, developed faster, were heavier, mated more successfully, and were more fecund.

Introduction

In Eastern Canada the spruce budworm, *Choristoneura fumiferana* (Clemens), feeds chiefly on the current shoots of white spruce, *Picea glauca* (Moench) Voss, and balsam fir, *Abies balsamea* (L.) Mill. Because the larvae require the succulent new growth, continuous laboratory rearing has been difficult. Quick-frozen balsam fir buds have been used quite successfully (Bergold 1951), and fresh terminal shoots of larch, *Larix laricina* (Du Roi) K. Koch, grown in the greenhouse can be used (Heron 1961). It has also been found that larvae will feed on an agar-base artificial diet to which crushed balsam fir buds have been added (Wellington 1949). An agar-base diet, developed for rearing the cotton bollworm, *Heliothis zea* Boddie (Berger 1963), was tested for rearing the spruce budworm in this laboratory. As budworm larvae did not establish on diet containing wheat germ from which the oil had been removed, the formula was modified by substituting wheat embryo for wheat germ. In the present paper the formula for the diet is described and comparative results are reported.

Methods

A Waring Blendor was used to obtain proper mixing. The quantities shown in Table I make approximately 100 ml. of mixture. If a quart-size blendor is used, the amounts can be increased six times, or by using the one-gallon size batches up to 3600 ml. can be prepared. The ingredients were added in the order given and mixed in the blendor for 20-30 seconds after each addition. The nutrient agar was dissolved in cold water, liquefied over steam, and added while hot, and the whole mixture was then blended for two or three minutes. Vials 23 x 57 mm. were satisfactory containers for insects reared individually or in groups of up to seven larvae. About 6 ml. of the warm liquid was dispensed into each vial and left to gel. Condensed moisture was allowed to evaporate or was removed with cotton gauze, and the vials were closed with screw caps. Larvae were placed on the diet within 24 hours and the vials were then stoppered with non-absorbent cotton. Diet may, however, be stored at 34°F. for three weeks with good results.

The insects used were collected as mature larvae from three separate localities in Ontario. They were allowed to pupate and the adults that emerged were then mated in single pairs in 5 oz. Flare Top Mono Paper Containers with No. 6 round tab lids*, punctured for ventilation, and held at 74°F. ± 1° and relative humidity 78-80 per cent, with no artificial lighting. A twig of balsam was provided for oviposition. After six days, matings were checked and needles with egg clusters from one female were glued to the bottom of a Petri dish 16 x 100 mm. The dish was tightly sealed with "Parafilm" to which a double layer of surgical gauze

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*Manufactured by Continental Can Company of Canada Ltd., Paper Division, New Toronto.

TABLE I
Composition of the diet and amounts of ingredients per 100 millilitres of media

Ingredient[a]	Quantity
Water (distilled)	22.0 ml.
Casein, vitamin free	3.5 g.
4 M Potassium hydroxide	0.5 ml.
Cellulose power (Alphacel)	0.5 g.
Salt mixture—W (per Wesson modification)	1.0 g.
Sucrose	3.5 g.
Wheat embryo	3.0 g.
Choline chloride	0.1 g.
Vitamin solution[b]	1.0 ml.
Ascorbic acid	0.4 g.
Antimicrobial agents:	
Formalin (37% formaldehyde)	0.05 ml.
Methyl parahydroxybenzoate	0.15 g.
Aureomycin	0.03 g.
Nutrient agar 4% W/V	62.0 ml.

a. Wheat embryo was obtained from H. G. Rainer Co., Toronto, Ontario; Aureomycin, a Lederle product, was obtained at a local drug store; other special ingredients from Nutritional Biochemicals Corporation, Cleveland, Ohio.
b. 100 ml. contain 100.0 mg. niacin, 100.0 mg. calcium pantothenate, 50.0 mg. riboflavin, 25.0 mg. thiamine hydrochloride, 25.0 mg. pyridoxine hydrochloride, 25.0 mg. folic acid, 2.0 mg. biotin, and 0.2 mg. vitamin B-12. The vitamin stock solution may be stored at 34-36°F. for at least one month.

had previously been attached. The cover was replaced and the dish then placed in a black envelope with a circular 1¼″ opening in the side next to the gauze. The envelope was inverted over light so that hatching larvae would be attracted downward to the gauze to spin hibernacula and moult (Stehr 1954). Larvae were held at room temperature approximately three weeks after hatching. A drop of water was added to prevent desiccation and the second-instar larvae were then stored at 34°F. four to four and a half months before being forced out for the rearing tests.

After removal from cold storage each family was divided. Each day emerging second-instar larvae were picked off with a camel's hair brush and set up individually, and alternately, one larva on freshly thawed balsam fir buds to one larva on the synthetic diet. Because there was not always an even number of larvae emerging, the numbers in the two test populations were not quite equal; 51.47% of the total available larvae were reared on balsam buds and 48.53% on diet. In the second generation larvae received the same food as their parents had in the first generation.

Vials containing larvae on buds were plugged with non-absorbent cotton for 24 hours after which the plugs were replaced with screw caps to prevent desiccation. Fresh buds were given at 7 days, and 14 days, and thereafter as required. Vials containing larvae on diet had non-absorbent plugs throughout the experiment, and it was not necessary to replenish the food. Both groups were exposed to 18 hours illumination daily and were held at a temperature of 72 ± 1°F. and relative humidity 70-74%.

Pupae were removed, weighed, and sex determined within 10 to 24 hours after pupation. Male pupae were held at 72°F. and female pupae at 74°F. to synchronize emergence.

Results

There was a marked improvement in the production of insects reared on the synthetic diet compared with those reared on buds (Table II). Survival of adults was 37% better (75% as compared with 54.9%), and production of larvae im-

TABLE II

Comparative survival and ratio of increase of *Choristoneura fumiferana* for two successive laboratory generations on balsam fir buds and synthetic diet, based on 712 larvae placed in cold storage of which 577 emerged

	Method of feeding			
	Balsam fir buds		Synthetic diet	
	No.	%	No.	%
Emerged II instar larvae	297	100	280	100
Pupae	178	59.9	224	80
Adults	163	54.9	210	75
Successful matings	47		84	
II instar larvae	3,760	1,266	11,296	4,034
Average no. of larvae produced per female	80		134.5	
Ratio of increase on balsam buds 10.27:1				
Ratio of increase on synthetic diet 32.65:1				
F_2 II instar larvae	368		640	
Emerged II instar larvae	195	100	312	100
Pupae	40	20.5	151	48.4
Adults	34	17.4	136	43.6
Successful matings	5		13	
II instar larvae	255	131	1,375	441
Average no. of larvae produced per female	51		105.8	
Ratio of increase on balsam buds 0.69:1				
Ratio of increase on synthetic diet 2.15:1				
Ratio of increase over two generations on balsam buds 7.09:1				
Ratio of increase over two generations on synthetic diet 70.20:1				

proved by 68% (134.5 larvae per female compared with 80). Since the starting population of 577 larvae was obtained from 712 originally placed in cold storage, it can be assumed that the 297 reared on buds were the survivors from 366, and the 280 on diet were survivors from 346, of the original stored stock. Defining "ratio of increase" as the multiplication in numbers from a given point in one generation to the same point in the succeeding generation, 366 larvae placed in storage and later reared on buds produced 3,760 to go into storage, a ratio of 10.27:1; and 346 larvae stored and then reared on diet produced 11,296, a ratio of 32.65:1.

For the second generation test, samples of the two populations were removed from storage, 368 of those produced on buds and 640 of those on diet. The results of these rearings are given in the second part of Table II. Although the actual survival in the second generation was considerably less than in the first, the overall superiority of the diet is the same. Survival on diet was better by 150% (43.6% adults compared with 17.4%), and fecundity by 107.4% (105.8 larvae per female compared with 51). Due to the severe reduction in emergence and establishment of the second-instar larvae on removal from storage (only about 50% for each population) the ratio of increase in this generation was drastically reduced. In fact on the buds there was actually a decrease to 0.69:1, while on the diet the increase was only 2.15:1. But as in the first generation the diet was still three times as good as the buds. Over the two generations the diet was ten times better, the increase being 70.20:1 compared to only 7.09:1 for buds.

Average pupal weight also showed a difference in favour of the diet, in both sexes and in both generations (Table III). Females were consistently heavier on the diet, but some males on diet were lighter than any on buds even though the average weight was greater.

TABLE III
Mean ♀ and ♂ pupal weights and weight range of *Choristoneura fumiferana* on balsam fir buds and on synthetic diet

	Balsam fir buds			Synthetic diet		
	No. weighed	Mean wgt. in mg.	Wgt. range	No. weighed	Mean wgt. in mg.	Wgt. range
F_1 ♀ Pupae	19	88.4	80.9-105.0	21	121.7	93.5-154.0
F_1 ♂ Pupae	24	60.5	47.5- 78.0	29	77.4	42.0- 92.0
F_2 ♀ Pupae	22	69.5	26.0-105.8	75	90.7	42.5-140.4
F_2 ♂ Pupae	39	43.4	30.8- 67.2	94	63.0	22.8- 93.5

There were more successful matings among adults from diet-reared stock. In the first generation it was 87.5% compared with 61.0%, and in the second generation 31.7% compared with 28.6%.

Fecundity was higher on the diet (Table IV). Not only were more eggs laid per family but there was considerably better percentage hatch. On this basis alone the increase in one generation was approximately doubled on diet.

Rate of development on diet, although not shown in the tables, was faster than on buds. On the average in the first generation both sexes pupated four days sooner on diet than on buds, and in the second generation the male pupae were again formed four days sooner, but the females only two days.

One interesting point is that eggs produced by females reared on diet are blue, rather than the normal green. Presumably this means that some component of the natural food is missing, and whether this will eventually have a deleterious effect remains to be determined.

Another group of insects has been reared on diet through three successive generations, but there was no parallel rearing on buds as a control. Therefore the results are not presented in detail. However, the third generation still showed a ratio of increase of 16.3:1, quite consistent with the results discussed here.

Conclusions

This synthetic diet appears to be quite satisfactory as a food for rearing *C. fumiferana*. Although prolonged rearing may eventually indicate that it requires modification to overcome some deficiencies, it has been demonstrated as

TABLE IV
Fecundity of *Choristoneura fumiferana* on balsam fir buds and synthetic diet

	Balsam fir buds			Synthetic diet		
	No. families	Mean no. per family	Range	No. families	Mean no. per family	Range
F_1 Larvae	47	80	3-160	84	134.5	15-234
F_2 Eggs	5	129	63-162	13	171	94-269
F_2 Larvae		51	2-126		105.8	52-160

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being adequate for production of several successive generations. Since it can be formulated in quantity at any time, it provides a very convenient way to rear this insect in large numbers for experimental work, and besides reducing the labour required it eliminates dependence on a supply of frozen buds for year-round rearings.

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Effects of Low Levels of the Nutrient Content of a Food and of Nutrient Imbalance on the Feeding and the Nutrition of a Phytophagous Larva, *Celerio euphorbiae* (Linnaeus) (Lepidoptera: Sphingidae)

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The present work demonstrates how important food quality is to an insect. When the dietary inadequacy in an artificial food was dilution of its nutrient content to 85, 70 and 50%, respectively, fifth-instar *Celerio euphorbiae* (Linnaeus) ate progressively more food but they gained no more body weight on one diet than on another. The rate of food intake depended on nutrient concentration. On all nutrient levels the larvae were about 20% efficient in converting the foodstuff into body material and the body content of protein did not differ significantly.

When the dietary inadequacy was immoderate proportions of several nutrients, the effects were not so clearly marked; nevertheless, the rate of food intake of the larvae could explain their body weight. The tendency seemed to be for the larvae to eat less and to gain less weight on the imbalanced diet than on an adequate diet. Moreover, conversion of foodstuff into body material did not seem as efficient on the imbalanced diet as on the control.

The ecological significance of food quality suggested by the first example is that the destructiveness of phytophagous insects, for example, may depend in part on the degree of succulence and corresponding nutrient concentration of food plant tissues; and by the second example, that perhaps nutritional imbalances may play a part in controlling the potential destructiveness of insect populations.

Introduction

Entomologists pay much attention to the quantity of food available to insects but too often overlook the importance of food quality. The present work demonstrates how important food quality can be.

Insects that feed on plants, for example, are variously affected by them. This is so because the nutritive quality of plants differs interspecifically and can vary