SC

EFFECTS OF PHOTOPERIOD, TEMPERATURE, AND DIET ON THE DEVELOPMENT OF THE BANDED WOOLLYBEAR, *PYRRHARCTIA* (*ISIA*) *ISABELLA* (J.E. SMITH) (LEPIDOPTERA:ARCTIIDAE)

BY

MARK S. GOETTEL

Thesis submitted to the School of Graduate Studies as partial fulfillment of the requirements for the degree of Master of Science.

at the

UNIVERSITY OF OTTAWA

....
Candidate

Supervisor

Ottawa, Canada, 1977

ProQuest LLC
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106-1346

Put cream and sugar on a fly, and it tastes very much like a black raspberry.

E.W. HOWE

ACKNOWLEDGEMENTS

I would like to express my appreciation to Dr. B. J. R. Philogène for his constant interest, guidance and criticism. Thanks are also due to the members of my research committee, Drs. C. F. Hinks and J. C. Fenwick.

The technical assistance of Marie Chagnon and Hérvé Jodoin, as well as, my sister, Barbara Lacroix, who typed the final manuscript, are greatfully acknowledged. Thanks are further due to Karen Toohey, Jeurel Singleton-Smith, Juan Chang, Peter Teal, Brenda Wright and Biology Department support staff for their help, encouragement and moral support.

Acknowledgements are also due to Dr. D. G. R. McLeod and Mr. M. Dupré, for their time and interest at the experimental farm at l'Assomption, and to Drs. J. Bissett and D. M. Wood who also contributed to the study.

Financial support for this work was received from the National Research Council of Canada.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF PLATES

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Cont'd)

ABSTRACT

The banded woollybear, Pyrrharctia isabella (J. E. Smith) was reared under laboratory conditions from egg to adult. Groups of individually reared larvae were kept at one of 8 photoperiods and in combination with one of 4 temperatures and were fed one of 6 artificial diets and fresh plantain. The times of moulting, head capsule widths, larval and pupal weights, and adult characteristics (fertility, sex) were recorded.

Larvae were easily reared on bean, wheat germ, casein-wheat germ and fresh plantain, while casein, alfalfa, and plantain diets proved unsatisfactory. Development time increased at photoperiods longer than 14 hours. This increase was characterized by extra instars. The results suggest that scotophase may be more important than photophase in influencing development. Temperature did not affect overall larval development time although higher temperatures did slow the growth rate. Mature larvae were found to undergo an obligatory diapause in the Montreal-Ottawa area. Chilling was not an absolute requirement for diapause development, although mortality was high at higher temperatures. Diapausing larvae at 30°C were found not to be cold hardy.

Increments in head capsule widths at each successive instar did not follow Dyar's rule. The relationships between voltinism and obligatory diapause, cold-hardiness and diapause, photoperiod, temperature and development, chilling and diapause development as well as Dyar's rule are discussed.

RESUME

Le lépidoptère Pyrrharctia isabella (J. E. Smith) a été élevé en laboratoire, de l'éclosion au stade adulte. Les larves ont été soumises individuellement à des combinaisons de 8 photopériodes et 4 températures et ont été alimentées par 6 diètes artificielles et du plantain frais. Les intervalles des mues, la largeur des capsules céphaliques, les poids des larves et des chrysalides ont été observés ainsi que les caractéristiques des adultes (fertilité, sexe).

L'élevage des larves a été facile sur les diètes de haricots, germe de blé, caséine-germe de blé, et plantain frais, tandis que les diètes de caséine, luzerne, et plantain broyé n'ont pas donné de résultats satisfaisants. La période du développement s'est allongée aux photopériodes supérieures à 14 heures. Cette augmentation s'est traduite par un nombre de stades larvaires supplémentaires. Les résultats suggérent que l'influence de la scotophase est peut-être plus importante pour le développement que celle de la photophase. La température n'a pas affecté, dans l'ensemble, la longueur de la période larvaire quoique les températures supérieures ont ralenti le taux de croissance. L'espèce entre en diapause obligatoire au stade larvaire dans la zône Ottawa-Montréal. Le refroidissement n'est pas un critère absolu pour développement en diapause, quoique la mortalité soit élevée à des températures plus chaudes. Les larves en diapause à 30°C ne sont pas résistantes au froid.

Les augmentations de largeur de la capsule céphalique à chaque stade larvaire successif n'ont pas suivi la Loi de Dyar. Ce travail discute enfin des relations entre le voltinisme et la diapause obligatoire, la résistance au froid et la diapause, la photopériode, la température et le développement, le refroidissement et de développement en diapause ainsi que de la Loi de Dyar.

I. INTRODUCTION

a) Insect Development

(i) Larval growth

The larval period of an insect is characterized by a continuous increase in weight. Growth of the tissues occurs through both cell division and increase in cell size (Imms, 1964). It is during the larval period that the final size of the adult is determined. The larva is the feeding stage in the insect's life whereas the adult is the reproductive stage. The growth rate of an insect is influenced by environmental factors such as temperature (Chapman, 1969), photoperiod (Beck, 1968; Danilevskii, 1961), availability and quantity of food (Butler, 1976), humidity and population density (Chapman, 1969).

In order for an insect to grow continuously, it must moult at certain intervals. Growth of the sclerotized parts occurs when the insect moults and produces a new cuticle, for sclerotized cuticle does not expand (Chapman, 1969; Gains and Campbell, 1935).

The interval between the moults is known as the stage or stadium and the form of the insect during a stadium is called an instar (Imms, 1964). There has been much controversy regarding the criteria used to mark the beginning and the end of an instar. Hinton (1973, 1976) claims that the new instar commences at the time of apolysis (i.e.: detachment of the cuticle) (Jenkin and Hinton, 1966) while Wigglesworth (1973) and Whitten (1976) support the older view that a new instar begins and ends at ecdysis (i.e.: shedding of the old cuticle). The latter definition is the one most used in describing the life histories of insects because ecdysis is more easily observed than apolysis.

In 1890, Dyar showed that the widths of the head capsules, of larvae in their successive stages, followed a geometrical progression. This soon became known or referred to as "Dyar's law" (or rule). There has been much controversy over Dyar's law as it pre-supposes that for each insect species the number of moults is constant and that the head capsule does not increase in size during the stadium.

Richards (1949) states that Dyar's rule only holds true when the stadia are all of the same length, as the longer the stadium, the greater the amount of head capsule growth. In the milkweed bug, Oncopeltus fasciatus (Dall.), the head capsule does increase in width during a stadium, however, this growth is negligible when applied to Dyar's law (Bliss and Beard, 1954). Head capsule size may be affected by interferences such as parasitism, demonstrated in the oakleaf caterpillar, Heterocampa manteo (Dbldy) (Surgeoner and Wallmer, 1975). At times, moulting can take place without any absolute growth, or, the insect may even moult into a smaller sized individual (Oldroyd, 1970; Wigglesworth, 1972). In the cereal leaf beetle, Oulema melanopus (L.), the increments in width of the head capsules do not follow Dyar's geometric progression because of a smaller ratio of growth in the last two instars (Hoxie and Wellso, 1974).

A variable number of instars has been recorded for many insects (Kishi, 1971; Moreau, 1964; Plantevin, 1975; Wigglesworth, 1972). This variation has been shown to be due to geographic location (Raske, 1976), host plant (Drooz, 1965, Fogal and Kwain, 1972; Gaines and Campbell, 1935), injury (Pipa, 1971), nutrition quality or quantity (McGinnis and Kastings, 1959; Nijhout, 1975; Poitout and Cayrol, 1969; Wigglesworth, 1972), temperature (Ingram, 1976; Pipa, 1976; Poitout and Cayrol, 1969; Wigglesworth, 1972) and temperature/photoperiod (Philogène and Benjamin, 1971).

The larvae of the tobacco hornworm, Manduca sexta (L.), must attain a certain size, in a variable number of instars before pupation will occur (Nijhout, 1975). This size can be determined by measuring the head capsule width. The head capsule width of a given instar is proportional to the weight that the M. sexta larva had attained at the end of the previous instar. Nijhout proposes that the larval size may be measured by a stretch receptor mechanism of some sort. As soon as the threshold size is attained, the corpora allata is inactivated and the insect pupates.

(ii) Temperature effects

Insects are poikilotherms and therefore the environmental temperature has a large effect on their development. As the temperature rises, so does the insect's metabolic rate and consequently it's rate of development (Chapman, 1969). The latter reaches a maximum beyond which the insect can no longer increase the amount of food ingested in order to satisfy it's increased metabolic needs (Bursell, 1974). The temperature at which the insect develops most rapidly is termed the "Optimum Temperature" (Hoar, 1975). There also exists a lower threshold called the basal or developmental threshold below which development does not occur (Bursell, 1974).

Although rising temperatures may increase the growth rate, fecundity, fertility, adult longevity as well as survival are usually decreased (Barlow, 1962; Barnes, 1976; Bursell, 1974; Greenfield and Karandinos, 1976; Janisch, 1932).

Temperature may also affect insect behaviour which in turn affects the developmental rate (Barlow and Kerr, 1969; Bursell, 1974) and this has been, and still is, neglected in many temperature studies (Wellington, 1960). Diapause is also a temperature-related phenomenon as discussed in part b, section ii of the introduction.

Many attempts have been made to relate growth and temperature by developing mathematical equations (e.g. Barlow, 1962; Butler and Henneberry, 1976; Butler and Scott, 1976; Janisch, 1932; Logan et al, 1976; Sanderson, 1910; Siddiqui and Barlow, 1973; Trottier, 1971) and by using the concept of day degrees (Arnold, 1960). In order for these mathematical equations to be applicable to field situations, they must incorporate other development affecting variables such as humidity, photoperiod and host plant.

(iii) Photoperiod effects

Photoperiod consists of a period of illumination (photophase) followed by a period of relative darkness (scotophase) (Beck, 1968). Natural recurring 24 hour photoperiods are due to the rotation of the earth around it's axis. Since the earth's axis is at an angle of 23.5^0 to the plane of the earth's orbit around the sun, a seasonal change in photoperiod (ratio of photophase to scotophase) occurs at each latitude.

Insects have evolved mechanisms which utilize photoperiod for seasonal information. The way in which they use photoperiod to prepare themselves for adverse conditions is discussed in part b, section ii.

Photoperiod regulates behaviour (locomotor and feeding rhythms, oviposition and mating), adult emergence and swarming, circardian rhythms and ecological adaptations (water conservation, reproduction (Barker and Herman, 1976; Deseő, 1973; Deseő and Sáringer, 1975) food acquisition (Ali, 1973; Philogêne and Benjamin, 1971) and seasonal development), morphology (Vepsäläinen, 1971, 1974; McPherson and Vangeison, 1975; McPherson, 1974, 1975), aphid polymorphism, as well as, certain physiological functions such as oxygen consumption. (The number of references on the subject is so numerous that only the most recent have been cited.)

Photoperiod has also been shown to affect the growth rate in some insects. In several species of lepidopterous larvae, the growth is slower under shorter photoperiods (Cayrol, 1975; Danilevskii, 1961; Geyspitz, 1953) while in other species the opposite effect was found (Danilevskii, 1961; Geyspitz and Zarankina, 1963). Beck (1968) suggests that these growth responses are correlated with the photoperiodic effect of diapause induction.

The effects of photoperiod on growth has been a neglected area in photoperiodic studies as too much emphasis has been placed on diapause. Extensive reviews on photoperiodic effects on insects have been prepared by Beck, 1968; Danilevskii, 1961; Lees, 1968; and Wilde, 1962.

b) Diapause

(i) Definition

Wheeler (1893) first coined the term "diapause" to describe a stage of arrested growth in the egg embryo of the grasshopper, *Xiphidium ensiferum* L.. Later, Henneguy (1904) suggested that the term be used to embrace all types of arrested development in insects. In 1929, Shelford suggested that the term diapause be used only for the spontaneous arrest in development which does not respond immediately to a change in the environment and the term "quiescence" for the cases in which development is temporarily inhibited due to an immediate unfavourable environment. In this latter case, as soon as the insect is placed in a favourable environment, development resumes.

Way (1962) reaffirmed Shelford's (1929) definition of diapause but also introduced a new term "dormancy" to define a diapause which "may not be related in a simple way to temperature, during the dormant state".

Müller (1965, 1970) tried to reclassify dormancy according to the factors which induce and terminate it. He used terms such as dormancy, quiescence, parapause, eudiapause and oligopause to identify different types of diapause.

A reclassification of dormancies in insects, on the basis of the evolutionary nature of dormancy, was suggested by Mansingh (1971). He divided dormancy into three major groups: hibernation, aestivation and athermopause. Each group was further subdivided into quiescence, oligopause and diapause. Unfortunately, Mansingh did not attempt to incorporate any of Müller's (1965, 1970) definitions into his own, and this too, resulted in much confusion (Thiele, 1973). Consequently, Shelford's (1929) definition of diapause is still the one most widely accepted and used (Andrewartha, 1952; Beck, 1968; Danilevskii _et al_., 1970; Harvey, 1962; Lees, 1956; Tauber and Tauber, 1973a, 1976; Wilde, 1962). At present there is a need for entomologists to come to an agreement on a reclassification of the types of diapause, for Shelford's definition is actually inadequate.

Diapause enables the insect to survive a period of unfavourable conditions. It synchronizes reproduction and development to favourable times of the season. Diapause is characterized by a reduction in endergonic activities, such as protein synthesis, and exergonic activities, such as respiration (Harvey, 1962). Usually there occurs a cessation of feeding, water loss and locomotory inactivity.

(ii) Factors inducing diapause

It has been shown that the major environmental factor inducing diapause in most species of insects is photoperiod (Adkisson, 1964, 1965, 1966; Andrewartha, 1952; Beck, 1963, 1968; Danilevskii, 1961; Danilevskii _et al_., 1970; Dickson, 1949; Lees, 1956, 1966; Saunders, 1976; Way _et al_., 1949; Wilde, 1959, 1962). Generally, short light periods and long dark periods induce diapause in most of the species studied.

Temperature also plays an important role in diapause induction and cessation. Thermoperiod without any photoperiod can induce diapause (Beck, 1962a & b, 1968; Galichet, 1964; Jacquemard, 1976; Menaker and Gross, 1965;

Saunders, 1973). High temperature can prevent diapause in some species, even in the presence of a short daylength (Beck, 1968; Danilevskii, 1961; Dickson, 1949; Lees, 1950, 1953 a, 1956; McLeod, 1964; Philogène and Benjamin, 1971; Way and Hopkins, 1950; Wilde, 1962), while low temperatures can induce diapause, even in the presence of a long daylength (Beck, 1968; Danilevskii, 1961; Danilevskii _et al_., 1970; Dickson, 1949; Wilde, 1962).

Diapause can be induced in some insects by the level of humidity, (Cousin, 1932; Morris, 1967; Watson _et al_., 1973) in that high humidity prevents diapause and low humidity induces it.

The quality of food also plays an important role in diapause induction (Burges, 1962; Dickson, 1949; Lees, 1955; McMullen, 1967, Tauber and Tauber, 1973 b; Tingle _et al_., 1971; Wilde, 1969). The fat content (Adkisson, 1961; Bull and Adkisson, 1962), and dryness (Raina and Bell, 1974) of the larval diet, as well as the crop maturity (Crowder _et al_., 1975), have been shown to induce diapause in the pink bollworm, _Pectinophora gossypiella_ (Saunders).

However, humidity and food appear to be only secondary factors in diapause induction with photoperiod and temperature having the critical effect (Adkisson _et al_., 1963; Andrewartha, 1952; Beck, 1968; Danilevskii _et al_., 1970; Morris, 1967; Wilde, 1962).

(iii) _Diapause termination_

Between the time of diapause initiation and termination, diapause development occurs. This is the physiological, developmental process that proceeds during the stage in preparation for the active resumption of morphogenesis (Andrewartha, 1952). The age-class distribution at the time of diapause induction, the diapause inducing stimuli, the innate characteristics of the biotype, and the conditions during diapause development can interact to determine the ultimate length of diapause (Tauber and Tauber, 1976).

Some species have a low temperature optimum for diapause development (Andrewartha, 1952; Beck, 1968; Church and Salt, 1952; Lees, 1955; Danilevskii et al., 1970; Mansingh, 1971; Tauber and Tauber, 1973 a, 1976). For some time it was believed that chilling was an essential requirement for diapause development. However, many insect species do not require a chilling period at all for diapause development to proceed (Church, 1955; Denlinger, 1972; Dickson, 1949; Hogan, 1960; Tauber and Tauber, 1973 b & c; Wilde, 1969). In some species, diapause development can be terminated by long-day photoperiods without simultaneous low temperature (Beck and Apple, 1961; McLeod and Beck, 1963). Low temperatures may prevent the exhaustion of fat body reserves by lowering the metabolic rate, thus enabling the insect to survive the period of diapause development (Beck, 1968).

Diapause development in some insects has been completed by mid-winter and postdiapause development is arrested until temperatures rise above the lower thermal threshold in the spring (Denlinger, 1972; Hans, 1961; Hodek, 1962, 1974; Philogêne and Massalski, 1976; Tauber and Tauber, 1973 a, 1974, 1976). Post diapause morphogenesis begins after diapause development is completed when environmental conditions such as temperature, photoperiod and humidity become favourable (Tauber and Tauber, 1976).

c) Artificial Diets

The use of artificial diets in rearing insects is very common and widely used (House, 1967 a; Singh, 1972; Smith, 1966; Vanderzant, 1974). Many diets are now available commercially (Bio-Serv, 1977).

An artificial diet for insects is defined as any diet that is not the insect's natural food (Vanderzant, 1974). Artificial diets are used in nutritional studies and for rearing healthy insects as uniformly as possible for various other studies.

There are three main types of artificial diets. The first, called holidic, is used mainly in nutritional studies. These diets include only constituents whose chemical formulae are known (Dougherty, 1959). Very few strictly holidic diets have been developed, although, diets which contain some undefined substances such as agar, protein, vegetable oil, starch and cellulose are sometimes considered holidic (Beck et al., 1968; Vanderzant, 1966, 1974).

The second type of diet is called meridic, and contains one or more unrefined substances such as wheat germ or brewer's yeast. Most artificial diets fall in this group. The incorporation of wheat germ into meridic diets contributed substantially to their success (Chippendale, 1972; Vanderzant, 1967, 1974).

Mainly crude plant materials are found in the third type of diet, called oligidic. These diets are usually used in mass rearing and maintenance of colonies, because they are the most economical. Few of these diets that use unrefined, or natural products, have proven successful (Vanderzant, 1974).

An artificial insect diet should contain all or most of the following: protein or amino acids, including 10 essential ones, (argenine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine), carbohydrate, fatty acids, cholesterol, choline, inositol, pantothenic acid, nicotinomide, thiamine, riboflavin, folic acid, pyridoxine, biotin, vitamin B_{12}, beta-carotene or Vitamin A, alfa-tocopherol, ascorbic acid, several minerals and water (Vanderzant, 1974).

Artificial diets are usually solidified with agar and/or sodium alginate, and most contain some form of roughage such as cellulose. These contribute to the physical properties of the diet which are important in promoting adequate growth and development in the insects (Vanderzant, 1969).

Antimicrobial agents such as sorbic acid or methyl paraben are also added to most artificial diets to reduce fungal and microbial growth. At certain levels, these antimicrobials have produced some detrimental effects to the host insect (Kishaba _et al_., 1968; Ouye, 1962; Singh and Bucher, 1971; Singh and House, 1970 a & b).

An adequate diet should yield 70% or more reproductive adults from eggs or immature forms (Vanderzant, 1964). Before a certain diet can be considered successful, many insect generations must be reared. Vanderzant (1966) has suggested that some nutrients lacking in the diet may be passed on through the egg, from field collected adults, from generation to generation, until, at some point, it is exhausted and the insect can no longer survive on the diet.

Insects reared continuously on artificial diets may lose vigour and suffer reduced fertility, (Vail _et al_., 1967) fecundity, and longevity (Lukefar and Martin, 1964). They may also lose the ability to survive on their natural host plant (Rathore, Guthrie and Carter, 1976). These changes may be due to genetic variation through inbreeding, rather than to the inadequacy of the diet (Hinks and Byers, 1976; Huettel, 1976; McDonald, 1976).

d) Biology of _P. isabella_

The larva of _Pyrrharctia_ (_Isia_) _isabella_[1] (J. E. Smith) (Lepidoptera: Arctiidae), the banded woollybear, was so named because of its dense investiture of setae. It has also been called the hedgehog caterpillar because of its tendency to roll into a ball when the larva is disturbed. The woollybear

---

[1] The current name for the banded woollybear is _Pyrrharctia isabella_ (D.C. Ferguson and E. G. Munroe, 1977, personal communications). To avoid confusion, _Pyrrharctia_ is used throughout the text although the authors cited might have used _Isia_.

is distributed throughout the United States and Canada (Mitchell and Zim, 1962; Saunders, 1873; Villiard, 1969).

There is some discrepancy concerning voltinism in P. isabella. According to Riley (1880), the species is monovoltine in New England and Canada and bivoltine in the more southern states. French (1877) and Marten (1880) report that it is monovoltine but that "in warmer latitudes there are probably two broods". Forbes (1900) states that P. isabella is normally two brooded in Illinois while Dirig (1975) reports that it is monovoltive in New York state. According to Metcalf, Flint and Metcalf (1962) and Mitchell and Zim (1962) there are generally two generations a year in the north.

In the larvae, the bristles are all of the same length and give the caterpillar the appearance of having been shaven. The first and last few segments usually have black bristles and the median segments have orange ones, but the colors may vary from all black to all orange (Gibson, 1915; Riley, 1880). Lutz (1909) reported that this variation in color was due to moisture; in a wet environment the larvae were all black and in a dry environment, all orange.

The larva is generally polyphagous, but feeds preferentially on plantain (Plantago spp.) (Chittenden, 1903; French, 1877). Shapiro (1968) has shown that the larvae will accept almost any plant offered. He tested 95 plant species representing 57 families but only one plant, the horsetail, Equisetum arvense (L.)., failed to elicit any feeding response.

The woollybear does not constitute a major economic pest. However, it has been reported feeding on cotton seedlings, corn, melon crops as well as ripening peaches, tomato fruits, damaging both blooms and pods of legumes (Fenton, 1937), cuttings of apple trees, blackberry and raspberry canes (Lugger, 1899), beets, peas and corn (Chittenden, 1903), willow (Peterson, 1946), and fall rye (Arnason and McDonald, 1951). A complete list of natural host plants was assembled by Tietz (1972).

Dyar (1890) reports that there are 10 larval instars and he gives the head capsule width for each one. Stages in the life history of P. isabella are shown in Plate I.

The woollybear overwinters as a mature larva under leaves, logs, debris, or any other sheltered place that it can find (French, 1877; Gibson, 1905; Lugger, 1899; Marten, 1880; Saunders, 1873). The findings of Baumberger (1907) indicate that the larva diapauses during the winter months. A small percentage of the population may avert diapause so that moths sometimes emerge in the fall (Saunders, 1868).

In early spring, the larva leaves its overwintering site and searches for a place to pupate. Some authors report that after overwintering, the woollybear will feed on any available green plants (Lugger, 1899; Saunders, 1873). The larva pupates in a cocoon that it constructs out of rough silk and hair shed from the body.

e) Summary and Objectives

The polyphagous nature, abundance, and ease of collecting of P. isabella potentially make it a very convenient experimental animal. Because of its size, and since it diapauses as a mature larva, the banded woollybear is an ideal insect for diapause and other physiological studies.

Surprisingly, very little work has been done with this species. Payne (1927) demonstrated that the diapausing woollybear lost water, and related this to cold-hardiness. Mansingh and Smallman (1972) also used P. isabella to study the relations between polyhydric alcohol content, diapause, and cold-hardiness. The banded woollybear has also been used for various other

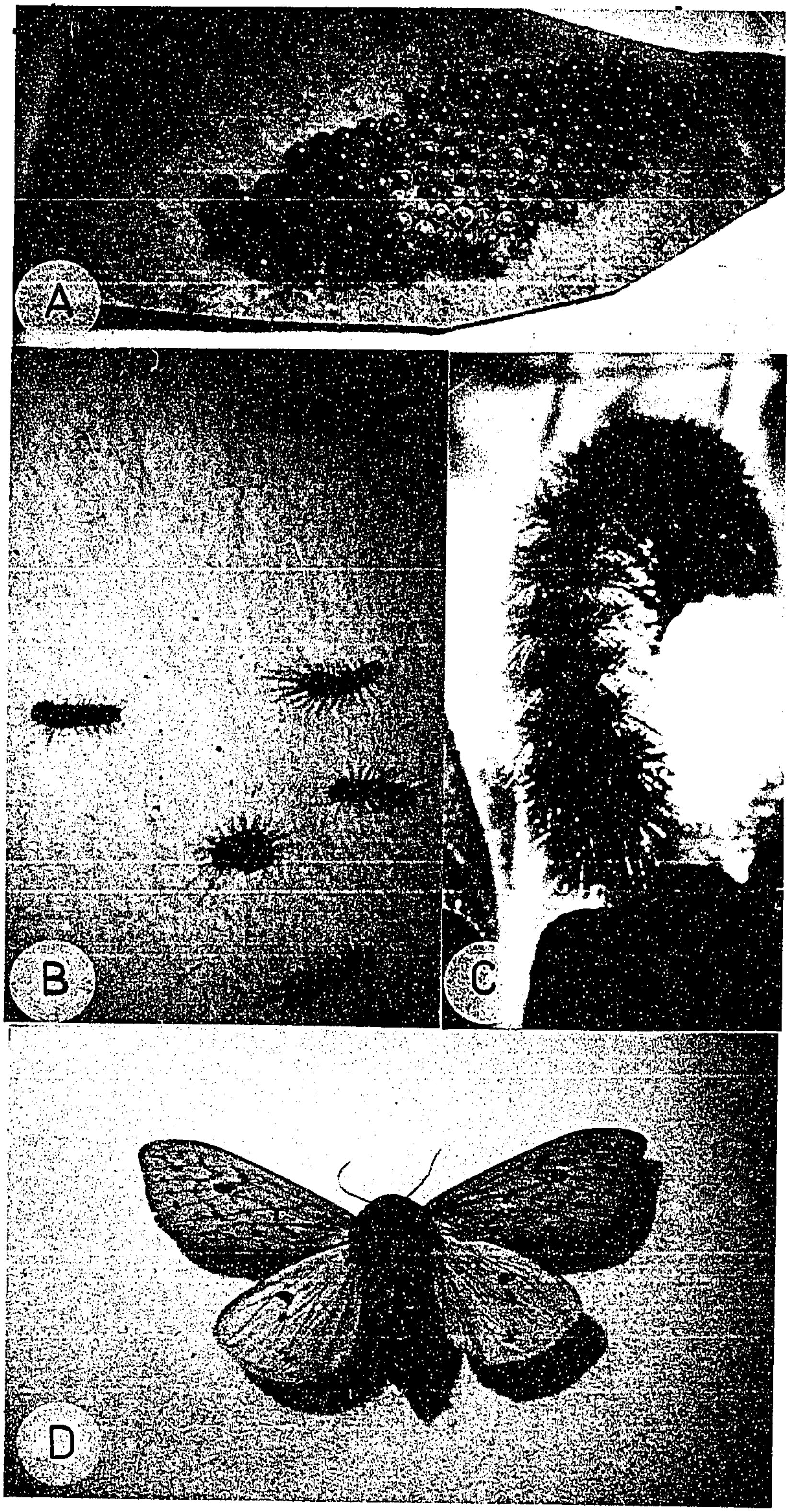
PLATE I: Stages in the Life History of *P. isabella*

A. Eggs (the darker eggs are within one day of eclosion)

B. First instar larvae

C. Last instar larva

D. Adult


A
B
C
D

studies: visual system; Dethier (1943), stemmata; Philogène (1975 a), tracheal glandular organ; Hinks and Byers (1975), Byers and Hinks (1976).

Dirig (1975) reported that P. isabella is difficult to grow from egg to adult, however Byers and Hinks (1976) found no difficulty in rearing the larvae on an artificial diet.

A literature review has shown that little is known about the biology of P. isabella in the laboratory, a rearing method using artificial diets has not been developed specifically for this insect, and there have been no studies investigating the development of P. isabella as affected by different environmental factors. This may explain why so little work has been done with this species. Most physiologists, interested in a specific problem seldom take the time to develop rearing methods for insects suited to their particular experiment.

In 1975, preliminary rearings of P. isabella larvae at the Agriculture Canada Experimental Station in l'Assomption, P.Q., indicated that the woollybear might respond differentially to photoperiod, according to the diet used. Such information could be useful in the planning of future experiments using artificial diets. Most photoperiod-diapause studies using such diets have been performed without proper comparisons to the insect's natural diet.

The objectives of this study were:1) to establish the biology of P. isabella under laboratory conditions; 2) to find diets suitable for laboratory rearing of the larvae, and; 3) to study the characteristics of larval development and diapause and the way they are affected by diet, photoperiod and temperature. While most diapause studies emphasize temperature/photoperiod effects, this study also deals with the dietary component of anticipatory regulation in insects.

II. MATERIALS AND METHODS

a) Experimental Conditions

The insect was reared from eclosion under a range of temperature, photoperiod and diet regimes as outlined in Table I.

(i) Temperatures

Environmental chambers maintained the experimental temperatures of 22°, 26° and 30°C within 1°C. The larvae kept at room (Rm) temperature were in a wooden rearing cabinet (Plate II) that included a constant air flow to minimize temperature difference between the photoperiods. Nevertheless, there was a fluctuation of approximately 4°C between light and dark periods. The absolute maximum and minimum temperatures attained during the rearing period for each photoperiod at Rm. temperature were (in °C) at light/dark (L/D); 9/15, 33-15.5; 11/13, 32-14.5; 12/12, 32-14.5; 13/11, 33-17; and at L/D: 15/9, 33-16°C.

(ii) Photoperiods

The photoperiods were provided by 24 hrs. time clocks. The light source for the room temperature (L/D: 9/15, 11/13, 12/12, 13/11 and 15/9) as well as the 22°C, L/D: 15/9 and 17/7 conditions were provided by one Westinghouse[1] F20 Cool White fluorescent lamp. The light source for the other photoperiods, (22°C-L/D 9/15, 16/8; 26°C-L/D 15/9; 30°C-L/D 12/12, 14/10, 15/9, 16/8) was provided by four Westinghouse[1] F40 Cool White fluorescent lamps. The spectral distribution of the light emitted by these lamps is included in the appendix (Fig. IX).

---

[1] Westinghouse Canada Ltd., Dorval, P.Q.

PHOTOPERIOD (L/D)	TEMPERATURE (°C)			
	RM	22	26	30
9/15	XA	XA		
11/13	XA			
12/12	XA			XB
13/11	XA			
14/10				XB
15/9	XA	XA	XB	XB
16/8		XB		XB
17/7		XB		

TABLE I: Combinations of photoperiod, temperature and diet used to rear P. isabella.

Diets: X - Bean, Casein, Wheat Germ, Alfalfa and fresh plantain

A - Plaintain

B - Casein-Wheat Germ

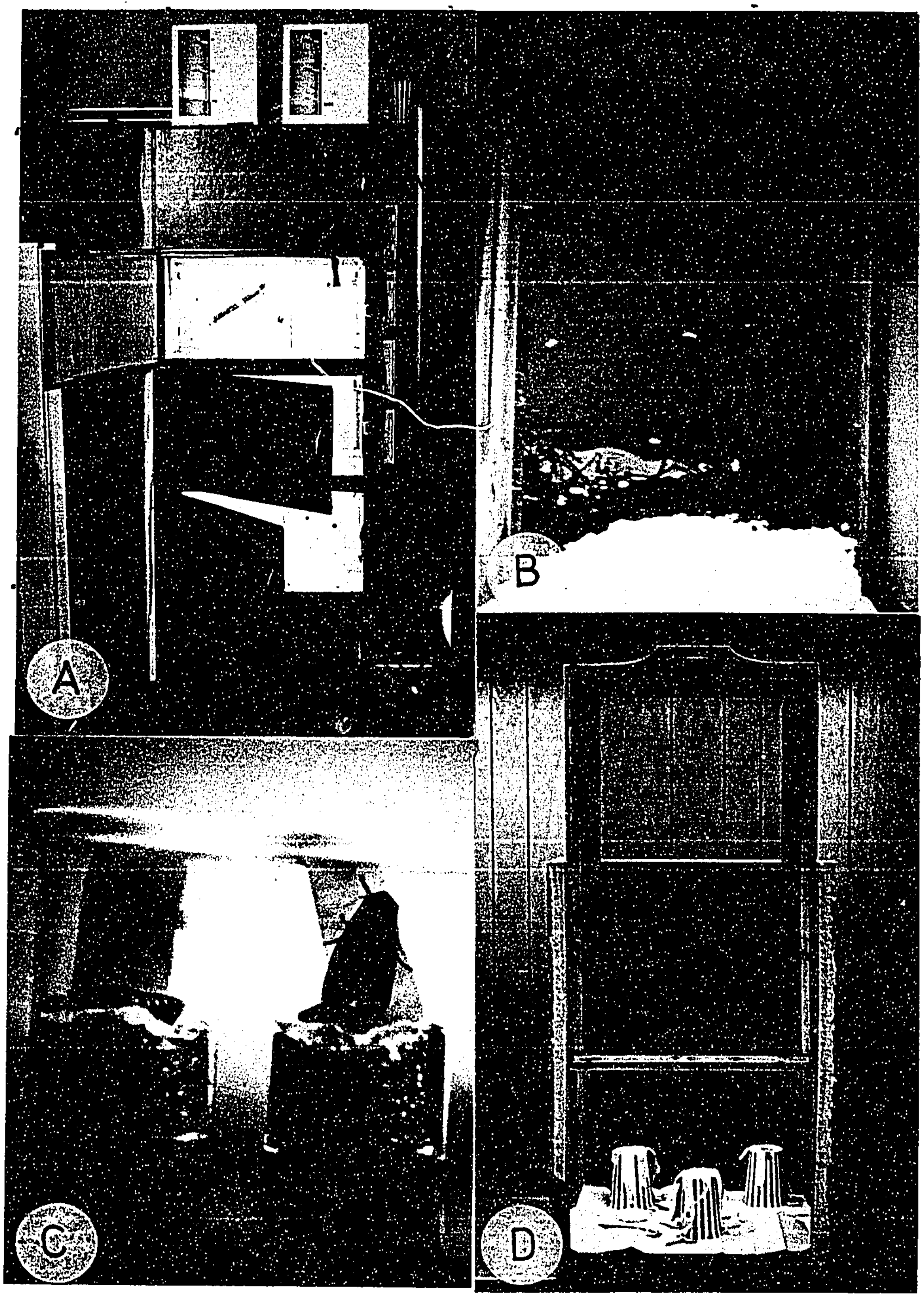
Twenty larvae were reared at each diet/temperature/photoperiod combination. No two diets were mixed.

PLATE II: A - Wooden cabinet used to rear *P. isabella* larvae at room temperature.

B - Screened cage used to overwinter *P. isabella* under natural conditions.

C - Plastic medicine vials containing moist sand used for *P. isabella* pupae showing pupa and newly emerged moth.

D - Screened cage provided with petri dishes containing cotton soaked with honey water and inverted wax containers used as mating and oviposition sites for *P. isabella*.


A
B
C
D

(iii) Diets

Six artificial diets and fresh plantain were used, the compositions of which are shown in Table II.

The bean diet was first developed by Hinks and Byers (1976). Corn oil and inositol were added and the concentration of water was increased (D. G. R. McLeod, 1975, personal communication). Antimicrobials were added to Vanderzant's (1976) wheat germ diet, and the plantain diet was essentially the same as the alfalfa diet, except that plantain leaf meal was substituted for alfalfa.

All the diets were prepared by homogenizing the ingredients in a blendor with approximately 1/3 of the water. The agar was autoclaved in the remainder of the water and then added to the homogenized diet mixture. This was then thoroughly mixed by hand and poured into 1 lb. (454 gm) plastic containers. Once the agar had solidified, the diets were covered, dated and refrigerated at 4^{o}C. The diets were cut into 1.5 cm cubes as needed and were never kept for more than one month.

Initially, the plantain used, (Plantago major L.), was grown in the greenhouse but due to an infestation of aphids and spider mites, it was later substituted with plantain from the field. The leaves of the plantain were collected and placed in a moist plastic bag at 4^{o}C to retard wilting prior to use and always used within 3 hours of collecting.

b) Experimental Animals and Rearing Methods

Approximately 300 larvae were collected in the Montreal, Quebec and Ottawa, Ontario areas between mid-September and the end of October, 1975.

Each larva was placed in a clear plastic medicine vial (6 x 3.5 cm -

CONSTITUENT / DIET	BEAN (Hinks & Byers) (1976)	CASEIN (Beck et al) (1968)	WHEAT GERM (Vanderzant) (1967)	ALFALFA (Vail et al) (1965) (PLANTAIN)	WHEAT GERM-CASEIN (Chippendale et al (1964)
Water	69.26^z	85.17	84.77	82.70	82.12
Beans (soaked in water)	19.71	----	----	----	----
Wheat Germ	4.62	----	2.95	2.85	4.83
Casein	----	4.13	3.45	3.32	3.38
Brewers Yeast	2.95	----	----	----	----
Sucrose	----	----	3.45	3.32	----
Dextrose	----	3.23	----	----	3.38
Agar	2.30	2.32	2.46	2.37	2.41
Cellulose (Alphacel)	----	3.23	----	.47	1.64
Alfalfa/Plantain	----	----	----	1.42	----
Wesson's Salt Mixture	----	----	.98	.95	----
Salt Mixture B.(Beck et al.1968)	----	.50	----	----	.48
Ethyl Alcohol	----	----	----	.90	----
Ascorbic Acid	.30	.39	.40	.40	.48
Potassium Hydroxide	----	----	----	.47	----
Sodium Alginate	----	.39	----	----	.48
Corn Oil	.27*	----	----	----	----
Corn Oil with 1% αtocopherol	----	.21	----	----	.19
Linseed Oil	----	----	.25	----	----
Cholesterol	----	.15	.05	----	.29
Choline Chloride	----	.07	.10	.09	.44
Methyl p-Hydroxy Benzoate	.18	----	.20*	.14	.14
Formaldehyde	.18	----	.20*	.13	----
Sorbic Acid	.09	.09	.10*	----	.06
Inositol	.09*	.03	.04	----	.02
L-Cystein Hydrochloride	----	.08	----	----	----
α-tocopherol	----	----	.01	----	----
TOTAL Vitamins	----	.03	.0032	.06	.0032
VITAMINS (x 10^{-4})					
Niacin		21.20	9.80	18.90	9.60
Calcium Pantothenate		54.50	9.80	18.90	9.60
Thiamine		1.80	2.40	4.70	2.40
Riboflavin		3.10	4.90	9.40	4.80
Pyridoxine Hydrochloride		2.40	2.40	4.70	2.40
Folic Acid		.80	2.40	4.70	2.4
Biotin		.5	.1	.3	.1
Cobalamine		.1	.01	.03	---
Para-aminobenzoic Acid		10.	---	---	---
pH	4.77	4.43	4.98	Alfalfa--- 5.60 Plantain-- 5.13	4.72

z = Modification of original recipe.

* = Additional to original recipe.

TABLE II: Composition of diets (% weight) used to rear *P. isabella*.

Plasma Vials No. 14)[1] containing about 2 cms of moist sterile sand covered with a piece of absorbent paper. These larvae were kept at four different temperatures (0, 5, 10 and 22°C) and were examined and weighed twice weekly. Periodically, drops of water were added to the sand to maintain proper humidity within the vial.

Every two weeks, randomly selected larvae were removed from each temperature group, then placed at 22°C, L/D: 17/7 and given fresh plantain.

Twenty-five larvae were kept under natural conditions approximately 12 meters above ground (The Biology Building roof) in a screened cage (60 x 60 x 90 cm) in which sawdust and leaves were placed for shelter (Plate II). One larva was removed in mid-February and the rest were removed in the spring.

The larvae at 22°C, L/D: 17/7, were weighed twice weekly and examined daily for pupation. Pupae were removed from the cocoon, weighed, sexed (according to Villiard, 1969) and placed in vials with moist sand at the same temperature and photoperiod. A strip of paper towel was placed in each vial to provide a vertical surface for the moths to crawl up and permit expansion of their wings upon emergence (Plate II).

Moths were placed in a screened cage (60 x 60 x 90 cm) provided with petri dishes containing cotton and honey water (Plate II). Inverted waxed milkshake containers (15 x 8.5 cm) with strips of paper towels attached were added as resting and oviposition sites (Plate III).

Eggs deposited were removed daily by cutting the paper around the egg masses, then the papers with the adherent eggs were put in vials containing moist sterile sand at 22°C, L/D: 17/7. Within 12 hrs. of

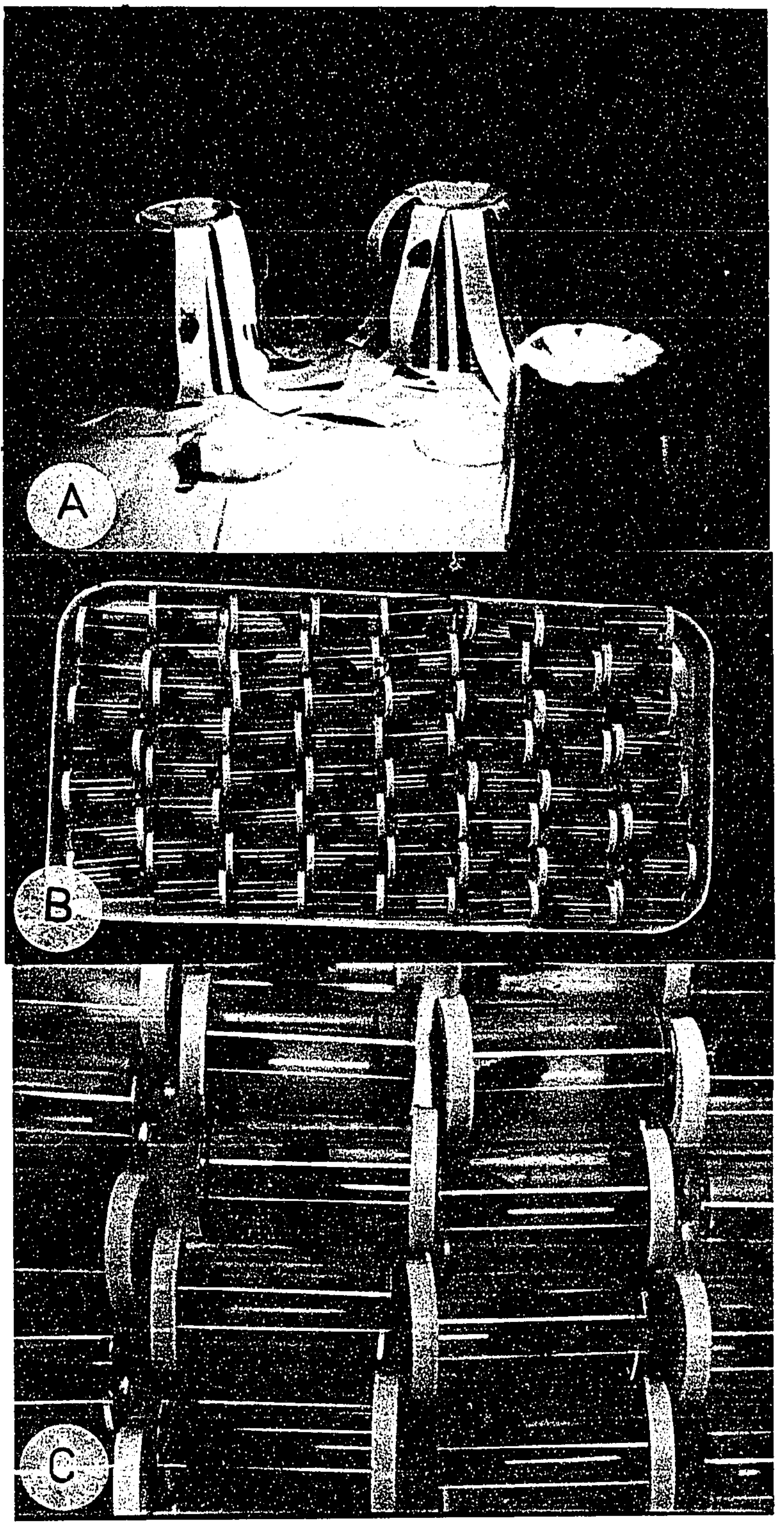
---

[1] Dominion Comb and Novelty Co., Warwick, P.Q.

PLATE III: A - Inverted waxed milkshake containers with strips of paper towels attached and used as resting and oviposition sites for *P. isabella* moths.

B - *P. isabella* larvae reared individually in plastic medicine vials placed laterally on a white enameled tray.

C - Medicine vials used to rear *P. isabella* showing larvae and cubes of artificial diet.


A
B
C

emergence, newly hatched larvae were transferred with the aid of a fine camel hair brush to the experimental conditions.

Twenty larvae were individually reared at each experimental condition (Table I) which represents a total of 1680 larvae. Each vial, placed laterally on white enameled trays, contained a cube of diet (about 1.5 cm) or 2-3 leaves of plantain (Plate III).

The larvae were examined daily during the photophase. Food was changed and the larvae were weighed every 2 to 3 days. To control disease, the weighing scale, bench top and forceps were rinsed periodically in a solution of 5% acetic acid in 70% alcohol (Hinks and Byers, 1976). All dead larvae were soaked with this solution in the vial for at least 24 hrs. before being removed. Time of moulting was recorded for each individual and the head capsule width was determined using an ocular micrometer at a magnification of 12.5x. Heads of dead larvae were cut off and also measured.

Approximately ten days after the continual decrease in mean weight of an experimental group, 2 to 4 larvae were left under the same experimental conditions to provide controls, while the rest were removed and the same procedure as outlined for the field collected larvae at 5°C was followed. After removal from 5°C, the larvae were provided with the initial diet on which they developed.

Moths from each diet group were kept in separate cages and fertility was noted.

Five to 10 larvae were also individually reared at each photoperiod and temperature regime on wheat-germ diet in opaque vials (5 X 3 cm empty film vials). These larvae were examined twice weekly under Kodak[1] safelight filter-Wratten series 2. Times of moulting and head capsule widths were recorded.

---

[1] Eastman Kodak Co., Toronto, Ont.

Approximately 100 newly emerged larvae were placed in screened cages on the Biology Building roof and were fed plantain growing in flats. In the fall these larvae were transferred to vials containing moist sand and maintained at $5^{o}C$.

III. RESULTS

a) Growth and Diapause of Larvae Reared on Different Diets

Developmental data on the larvae reared on different diets is summarized in Table III. The type of diet that the larvae fed upon did not affect the induction or prevention of diapause. Six percent of larvae reared on fresh plantain completed development without diapause while 100% of those on the casein diet entered diapause. Pre-diapause pupation ranged between .7% and 2.3% on the other diets.

There occurred 91% and 67% mortality on the plantain and alfalfa diets, respectively. Mortality on the other diets ranged from 5% to 32%. Most of the deaths on fresh plantain occurred during the first two instars (Tables XV a-d) because of drowning in water which had condensed from leaf transpiration.

The larvae on the plantain diet were the only ones whose mean maximum weight differed to any great extent from that of larvae on other diets. The mean maximum weight of these plantain-fed larvae was 1.0 gm while the mean maximum weights of the larvae on the other diets ranged between 1.3 and 1.4 gm.

The time required by the larvae to attain maximum weight (at which diapause occurs) ranged between 57 and 80 days; the larvae on the wheat germ diet requiring the shortest, and those on the plantain diet, the longest. The larvae on the other diets spent between 61 and 69 days in completing their development.

The number of instars fluctuated among the larvae reared on each separate diet. Some of the larvae which fed on the casein diet had up to 12 instars. The minimum number of instars was 6, although the mean number was close to 8 on all the diets.

TABLE III: Development of P. isabella larvae reared on 7 different diets. Data on diapause response, percent mortality, maximum weight, mean number of days from eclosion to diapause (maximum weight), range and mean number of instars. Data pooled from 8 photoperiods and 4 temperatures tested. (N - Sample size, S.D. - Standard Deviation)

DIET		BEAN	CASEIN	WHEAT GERM	ALFALFA	CASEIN-WHEAT. GERM	PLANTAIN	PLANTAIN (FRESH)
% PUPATED	(N)	1.4 (4)	0.0 (0)	.7 (2)	1.1 (1)	2.3 (3)		5.7 (11)
% IN DIAPAUSE	(N)	98.6 (263)	100.0 (233)	99.3 (266)	98.9 (88)	97.7 (124)		94.3 (179)
% PREDIAPAUSE MORTALITY	(N)	5.0 (13)	16.0 (45)	5.0 (13)	67.0 (189)	9.0 (13)	91.0 (127)	32.0 (89)
MAXIMUM WEIGHT	(N)	1.39 (162)	1.33 (160)	1.39 (159)	1.32 (55)	1.30 (71)	.98 (7)	1.35 (141)
	(S.D.)	(.28)	(.25)	(.25)	(.31)	(.27)	(.43)	(.30)
DAYS to DIAPAUSE	(N)	61 (160)	63 (159)	57 (159)	65 (55)	69 (91)	80 (7)	64 (140)
	(S.D.)	(24)	(20)	(21)	(15)	(22)	(17)	(17)
NUMBER of INSTARS	(N)	7.6 (267)	8.1 (237)	7.5 (270)	7.8 (89)	7.9 (127)	8.3 (15)	7.7 (193)
RANGE	(S.D.)	6-10 (.9)	6-12 (1.0)	6-10 (.9)	6-11 (1.0)	7-10 (.7)	7-11 (1.3)	6-10 (.7)

On the casein diet there was a mean lag period of 10 days longer than on the other diets before larvae began exponential growth (Fig. I). Furthermore, all adults emerged with deformed wings (Plate IV) and laid infertile eggs.

Larvae on all other diets except the plantain produced fertile females, but too few adults were obtained from the plantain diet to verify adult fertility.

b) Growth and Diapause of Larvae Reared at Different Photoperiods and Temperatures

The developmental parameters of larvae reared at the different photoperiods and temperatures are given in Table IV. Ninety-eight percent of all larvae entered diapause. The larvae that averted diapause, did so at photoperiods between L/D: 15/9 and 17/7, although two pupated at L/D: 12/12. Observations on the development of the non-diapause larvae are presented in the appendix, part c.

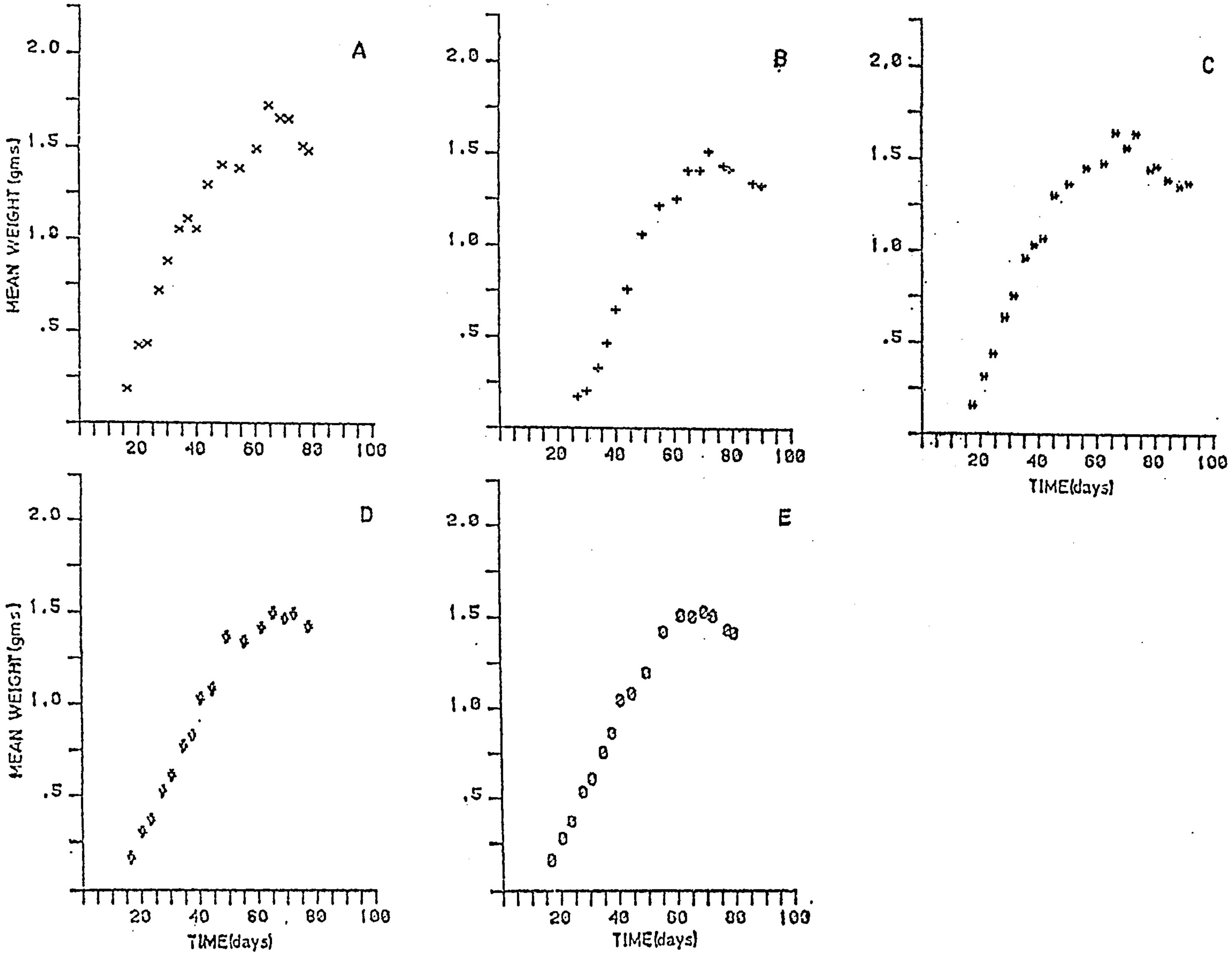
Photoperiod did not seem to affect mortality. Between 6% and 35% of the larvae died before attaining maximum weight. The highest mortality occurred at 30^{o}C, L/D: 16/8.

Maximum weight attained by the larvae was lowest at 30^{o}C, L/D: 15/9 and 16/8. The highest mean maximum weight occurred at room temperature, L/D: 15/9.

Development time (measured as days from eclosion to maximum weight) remained rather constant between the photoperiods of L/D: 9/15 and 13/11. As the photoperiod increased beyond L/D: 14/10, the time to diapause (maximum weight) also increased, and the growth rate decreased (see also Figs. VIII a-m). Temperature did not affect the amount of time required for the larvae to complete development, (Table V) although it did affect growth rates early in their development (Figs. VIII a-m). The growth rates

FIG. I: Growth rates of P. isabella larvae at 26°C and a photoperiod of L/D: 15/9 reared on different diets.

Diet A - Bean, B - Casein, C - Fresh plantain, D - Wheat Germ, E - Casein-Wheat Germ.


A
B
C
D
E
MEAN WEIGHT (gms)
2.0
1.5
1.0
.5
20
40
60
80
100
TIME(days)

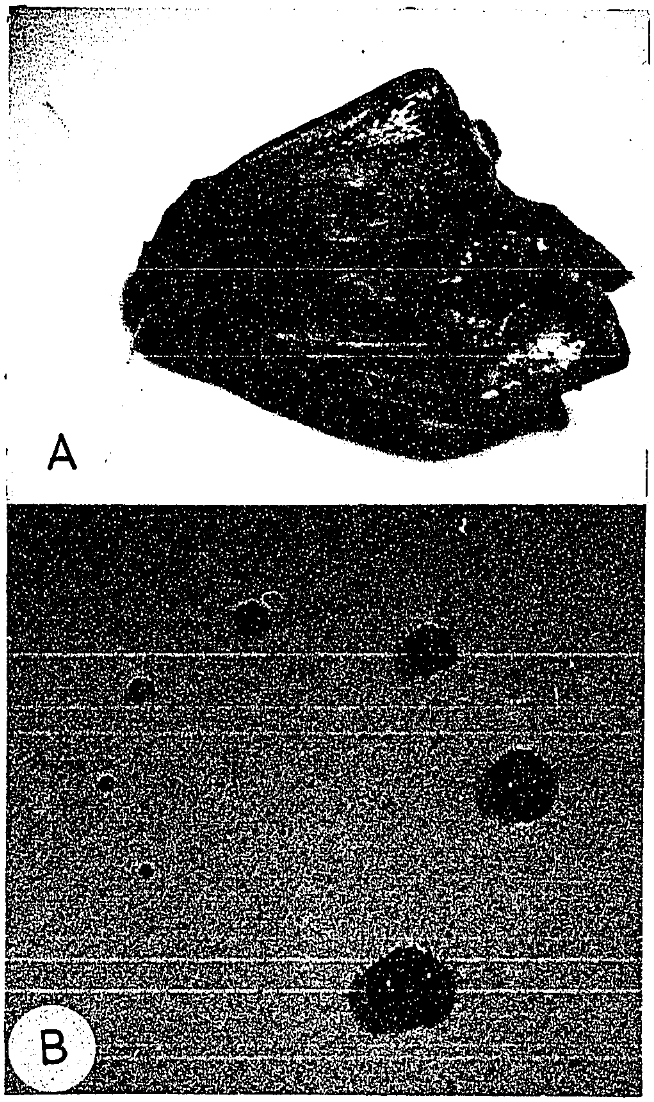


PLATE IV: A - *P. isabella* moth with deformed wings.

B - Head capsules of an eight instar larva of *P. isabella*. Head capsule widths (mm) - 1st instar (not shown) - .4, 2nd - .5, 3rd - .7, 4th - 1.1, 5th - 1.7, 6th - 2.4, 7th - 3.15, 8th - 3.9.

TABLE IV: Development of *P. isabella* larvae at different photoperiods and temperatures. Data on diapause response, mortality, maximum weight, mean number of days from eclosion to diapause (maximum weight), range and mean number of instars. Data pooled from 4 diets tested (Bean, Casein, Wheat Germ and fresh plantain).
N - Sample size, S.D. - Standard Deviation.

	PUPATED (N) %	DIAPAUSE (N) %	PREDIAPAUSE MORTALITY (N) %	MAXIMUM WEIGHT (N) (S.D.)	DAYS to DIAPAUSE (N) (S.D.)	NUMBER of INSTARS (N) (S.D.) RANGE
RM 9/15	(0) –	(79) 100	(20) 25	1.44 (33) (.23)	40 (33) (6.1)	7.0 (67) (.5) 6–8
RM 11/13	(0) –	(90) 100	(18) 22	1.37 (41) (.21)	42 (41) (7.7)	7.0 (76) (.4) 6–8
RM 12/12	(0) –	(72) 100	(13) 16	1.46 (32) (.20)	41 (32) (5.7)	7.1 (71) (.4) 6–8
RM 13/11	(0) –	(81) 100	(5) 6	1.39 (34) (.20)	44 (34) (7.6)	7.2 (62) (.4) 7–8
RM 15/9	(0) –	(89) 100	(5) 6	1.61 (53) (.14)	60 (52) (10.2)	7.6 (75) (.6) 7–9
22 9/15	(0) –	(72) 100	(11) 14	1.31 (40) (.22)	43 (40) (7.1)	7.2 (69) (.6) 6–9
22 15/9	(0) –	(80) 100	(9) 11	1.51 (44) (.15)	58 (44) (8.9)	7.4 (72) (.5) 7–9
22 16/8	(1) 1	(84) 99	(12) 15	1.37 (66) (.25)	101 (66) (14.7)	9.2 (71) (.9) 7–12
22 17/7	(6) 7	(85) 93	(7) 9	1.48 (47) (.26)	82 (47) (10.5)	8.3 (69) (.5) 7–10
26 15/9	(0) –	(89) 100	(8) 10	1.56 (49) (.23)	72 (48) (9.8)	8.2 (74) (.7) 7–10
30 12/12	(2) 2	(95) 98	(22) 27	1.28 (42) (.16)	41 (41) (9.6)	7.1 (58) (.4) 6–8
30 14/10	(0) –	(88) 100	(11) 14	1.34 (41) (.20)	55 (41) (10.7)	8.3 (71) (.8) 7–10
30 15/9	(5) 5	(92) 95	(9) 11	1.06 (48) (.17)	65 (48) (11.5)	8.2 (67) (.7) 7–10
30 16/8	(7) 9	(76) 91	(7) 35	.98 (52) (.17)	67 (51) (10.7)	8.2 (65) (.8) 7–10

TABLE V: Cumulative daily mean temperatures for P. isabella larvae from eclosion to diapause (maximum weight) at each combination of photoperiod, temperature, and diet (temperature in degrees Centigrade). Cumulative daily mean temperature - summation of $\frac{\text{low temp. of day + high temp. of day}}{2}$

DIET	BEAN	CASEIN	WHEAT GERM	ALFALFA	CASEIN-WHEAT GERM	PLANTAIN	PLANTAIN (FRESH)	TOTAL
RM 9/15	823	969	897	1205	——	1769	1227	1148
RM 11/13	867	956	795	1160	——	2113	1180	1178
RM 12/12	875	1006	875	1193	——	1604	1172	1121
RM 13/11	924	1077	898	1272	——	1272	1272	1119
RM 15/9	1183	1381	1139	1728	——	——	1606	1408
22 9/15	836	1122	814	1364	——	——	1034	1034
22 15/9	1122	1342	1056	1936	——	——	1430	1377
22 16/8	2420	2266	2156	——	2134	——	2046	2204
22 17/7	1760	1848	1760	——	1804	——	1848	1804
26 15/9	1924	1924	1768	——	1846	——	1872	1867
30 12/12	1170	1380	1170	——	1110	——	1260	1218
30 14/10	1740	1560	1710	——	1350	——	1560	1584
30 15/9	2070	1830	2130	2550	1890	——	1320	1965
30 16/8	2100	2130	1950	2490	2100	——	1650	2070
TOTAL	1415	1485	1366	1655	1748	1689	1463	

at 30°C were much slower than at the other temperatures. The increase in developmental time was characterized by increased number of instars. Increments in head capsule widths at each successive instar are shown in Fig. II, Plate III and Table XII.

The mean light/dark hours that the larvae received before entering diapause are presented in Table VI. The total number of light hours to diapause range from 315 and 1648 hours while the total number of dark hours to diapause showed less variation; i.e.: 418 and 880 hours, each depending on the photoperiod.

c) Diapause of Larvae Reared Under Natural Conditions

All of the larvae which were reared under natural conditions (photoperiod and temperature) entered diapause. These larvae ceased feeding by the end of September.

d) Larvae Reared at Constant Dark

The mortality of these larvae was very high. The dark vials had tight fitting lids which resulted in high humidities and possibly oxygen shortages within the vials. The number of surviving individuals was too small to warrant meaningful interpretation of the data.

e) Diapause Development

(i) Laboratory reared larvae

Because of the mortality levels during both larval and diapause developments, sample sizes are too small to allow comparison of diapause developments of the different photoperiod, temperature and diet groups. The results from all of these groups were therefore pooled.

All of the larvae from the 30°C group died within 3 weeks of being placed at 5°C while there was a 51% mortality at 5°C of larvae from the

FIG. II. Mean head capsule widths at each instar for larvae of <u>P</u>. <u>isabella</u> pupating after 7, 8, 9 and 10 instars. Data pooled from 7 diets, 8 photoperiods and 4 temperatures tested.

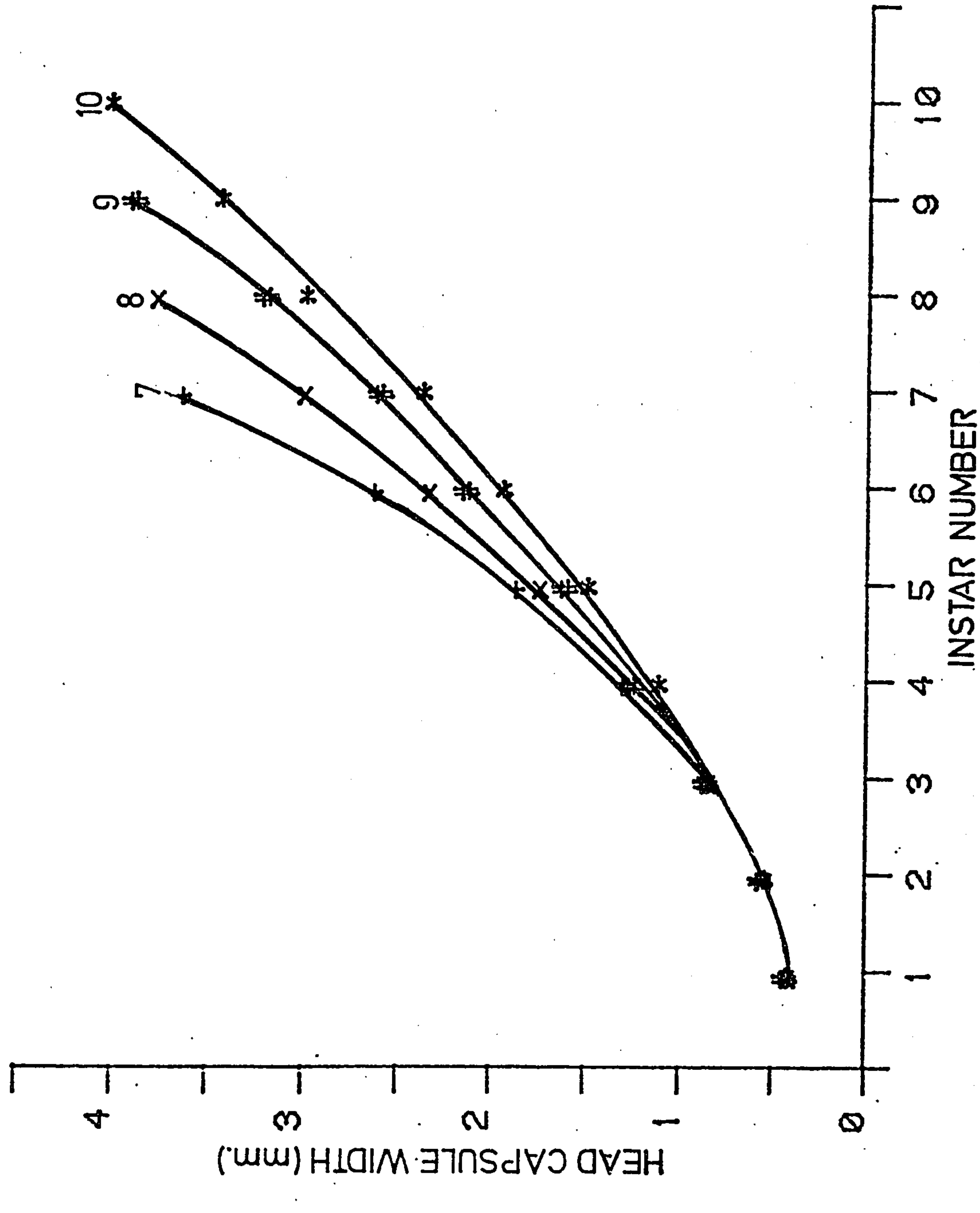

HEAD CAPSULE WIDTH (mm.)
0
1
2
3
4
INSTAR NUMBER
1
2
3
4
5
6
7
8
9
10
7
8
9
10

TABLE VI: Mean number of light/dark hours that the larvae of *P. isabella* received from eclosion to diapause. Data shown for each combination of photoperiod, temperature and diet. Upper numbers refer to light and lower numbers refer to dark (L/D).

DIET	BEAN	CASEIN	WHEAT GERM	ALFALFA	CASEIN-WHEAT GERM	PLANTAIN	PLANTAIN (FRESH)	TOTAL
RM 9/15	315/525	369/615	342/570	468/780		693/1155	477/795	444/740
RM 11/13	418/494	462/546	385/455	572/676		1023/1209	583/689	573/678
RM 12/12	456/456	528/528	456/456	636/636		864/864	624/624	594/594
RM 13/11	507/429	598/506	494/418	715/605		715/605	715/605	624/528
RM 15/9	765/459	900/540	735/441	1125/675			1050/630	915/549
22 9/15	342/570	459/765	333/555	558/930			423/705	423/705
22 15/9	765/459	915/549	720/432	1320/792			975/585	939/563
22 16/8	1760/880	1648/824	1568/784		1552/776		1488/744	1603/802
22 17/7	1360/560	1428/588	1360/560		1394/574		1428/588	1394/574
26 15/9	1110/666	1110/666	1020/612		1065/639		1080/648	1077/646
30 12/12	468/468	552/552	468/468		444/444		504/504	487/487
30 14/10	812/580	728/520	798/570		630/450		728/520	739/528
30 15/9	1035/621	915/549	1065/639	1275/765	945/567		660/396	983/590
30 16/8	1120/560	1136/568	1040/520	1328/664	1120/560		880/440	1104/552
TOTAL	802/552	839/594	770/534	889/725	1021/573	824/958	830/605	

other temperature conditions. Time to completion of diapause development was determinted as pupation within 20 days after removal from 5°C. Diapause development required 150 days at 5°C for completion (Fig. III). Following a 50 day period at 5°C, the mortality, prepupation and pupation rates remained almost constant (Fig. IV).

(ii) Field collected larvae

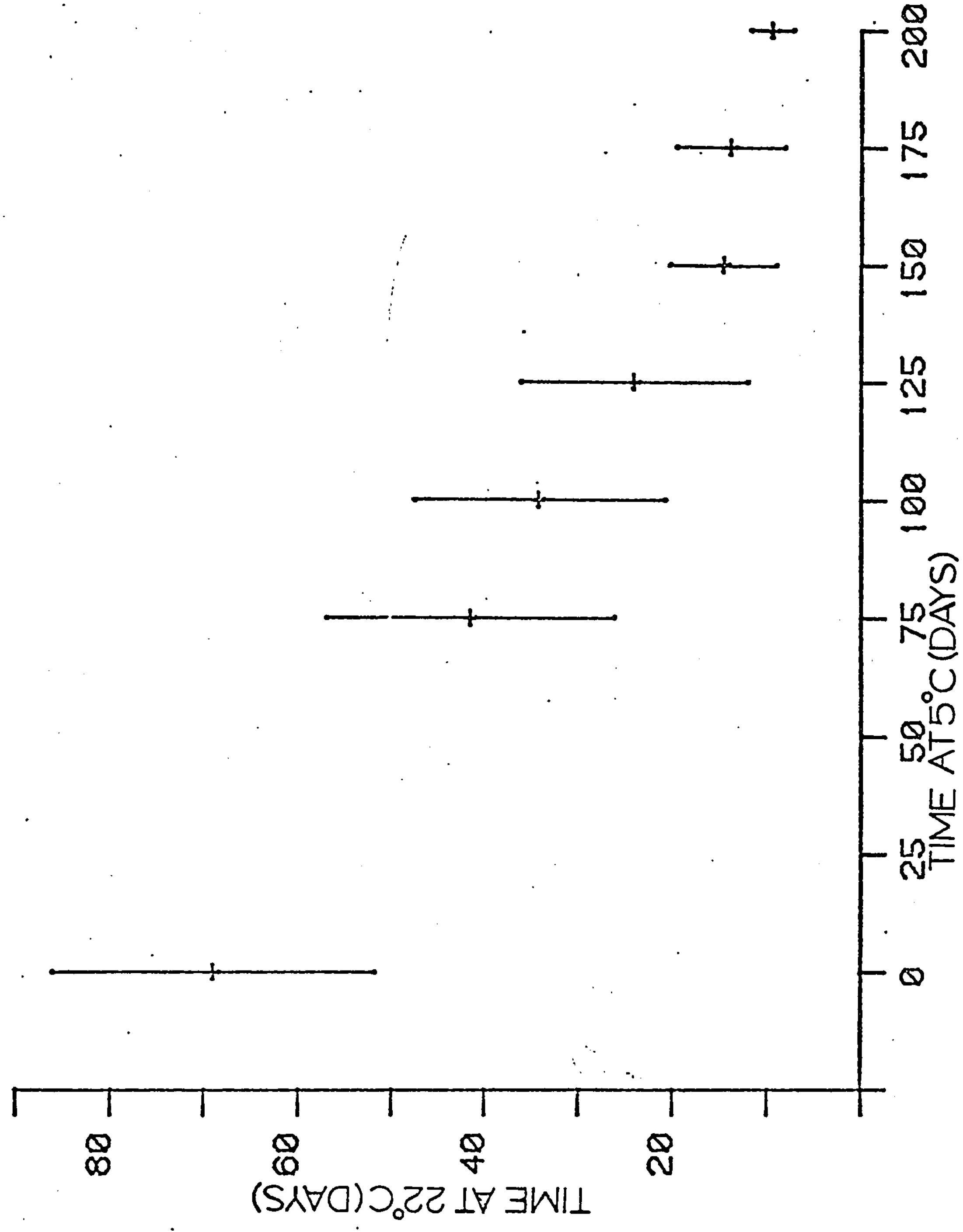
The diapausing larvae lost very little weight while at 0° and 5°C; they lost 12% under natural conditions and up to 50% at 10° or 22°C. Larval mortality was 13% at 0°C, 29% at 5°C, 80% at 10°C, 93% at 22°C and 46% under natural conditions. There was a 16% pupation rate of larvae removed from 0°C, 41% for larvae from 5°C, 11% from 10°C, 7% from 22°C and 33% from natural conditions. Because of the high mortalities, there was insufficient data to determine the amount of time needed to complete diapause development at 0°C and 10°C. At 5°C, 125 to 150 days were required before diapause development was completed (determined as pupation within 20 days of removal from 5°C) (Fig. V).

The 25 larvae placed under natural conditions were frozen solid in the sawdust and therefore were not removed until thawing. During a mid-February rain storm (Feb. 16, 1976), one larva thawed and was removed. It pupated in 16 days. The rest of the larvae were removed on March 26 and were placed at 5°C. All of the larvae which pupated (5), did so within 20 days of removal from 5°C.

f) Summary of Results

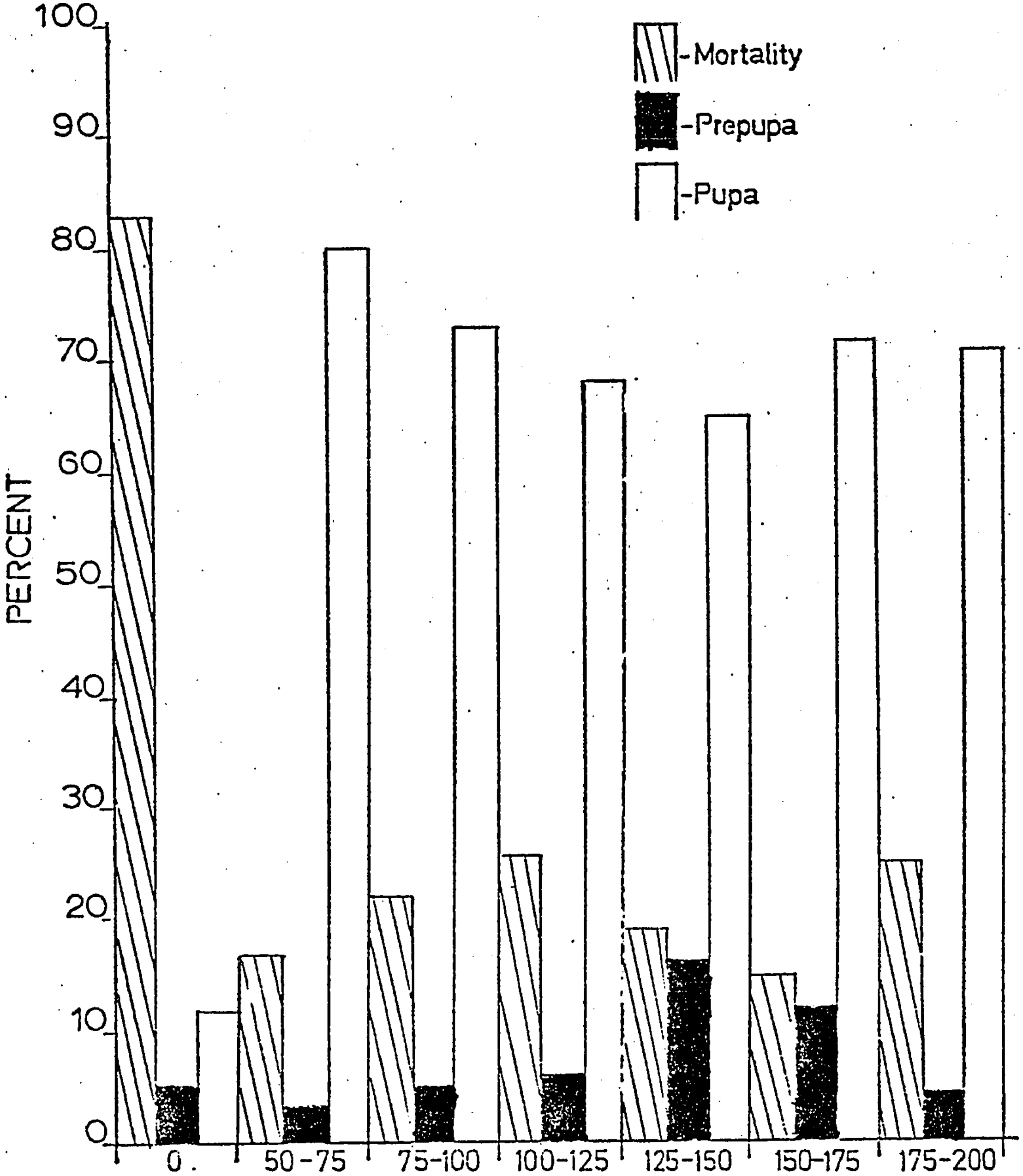
The bean, wheat germ, casein-wheat germ and fresh plantain diets were all found to be satisfactory for rearing *P. isabella* in the laboratory. The increase in temperature from 22°C to 30°C resulted in a decreased growth rate but the total amount of time from eclosion to diapause was

FIG. III: Mean number of days required for diapausing *P. isabella* larvae to pupate after removal from diapausing conditions (5°C). Bars indicate Standard Deviation. Data pooled from 20-77 laboratory reared individuals at each time period.



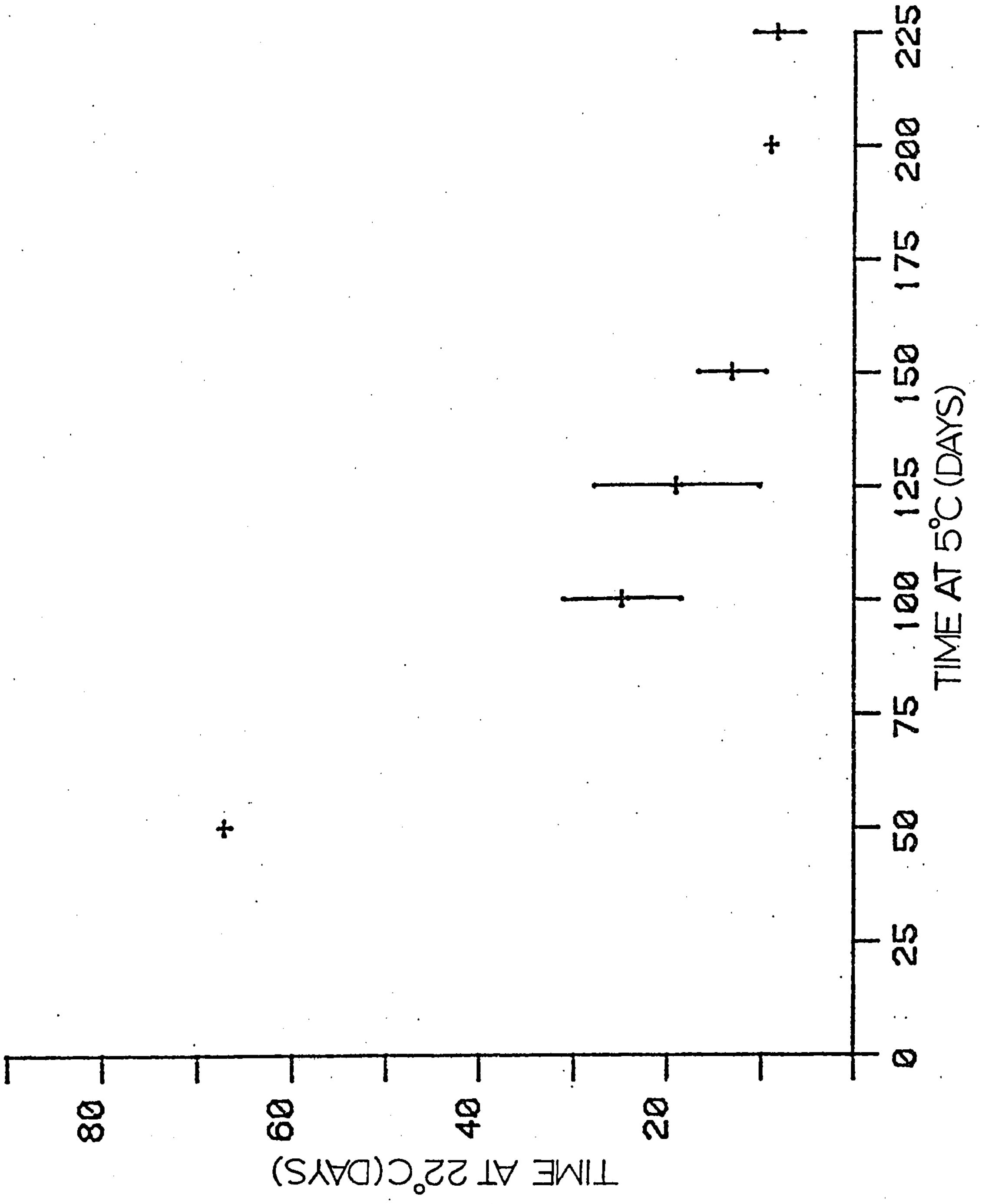
TIME AT 22°C (DAYS)
80
60
40
20
TIME AT 5°C (DAYS)
0
25
50
75
100
125
150
175
200

FIG. IV: Percent mortality, prepupation and pupation for diapausing _P. isabella_ larvae after removal from diapause conditions (5°C). Data pooled from 28 to 186 individuals at each time period from all pre-diapause photoperiods, temperatures and diets tested.



▨ -Mortality
■ -Prepupa
☐ -Pupa
PERCENT
100
90
80
70
60
50
40
30
20
10
0
0.
50-75
75-100
100-125
125-150
150-175
175-200
TIME AT 5°C (DAYS)

FIG. V: Mean number of days required for diapausing P. isabella larvae to pupate after removal from diapause conditions ($5^{o}C$). Bars indicate Standard Deviation. Data pooled from 5 to 11 field collected individuals at each time period.


TIME AT 22°C(DAYS)
20
40
60
80
TIME AT 5°C (DAYS)
0
25
50
75
100
125
150
175
200
225

not affected. Photoperiod was more important than temperature in regulating development time. As photoperiod was increased above L/D: 14/10, the developmental time also increased resulting in extra moults and a slower growth rate.

The larvae can be considered to undergo an obligatory diapause as none of the experimental conditions prevented diapause to any great extent. All of the diapausing larvae reared at 30°C died when placed at 5°C. Both the laboratory-reared and field collected larvae required 125-150 days at 5°C before diapause was terminated. Diapause was also terminated in larvae kept at 0, 10 and 22°C although mortality at 22°C was very high.

IV. DISCUSSION

a) Development of *P. isabella* on Different Diets

The banded woollybear was reared with relative ease on the bean, casein, wheat germ, casein-wheat germ and fresh plantain diets. The growth rates on all of these diets were equally comparable except for a 10 day lag, in first instar larval growth, on the casein diet (Fig. I). This lag could be due to lower palatability in the absence of wheat germ (Chippendale, 1972; Vanderzant, 1974). However, once the larvae accepted the casein diet, the growth rate compared favourably to the other diets.

The deformed wing condition found in adults from larvae fed the casein diet has been reported to be due to insufficient wheat germ oil (Fraenkel and Blewett, 1946) and more specifically, to insufficient linolenic acid (Poitout and Bues, 1974; Vanderzant, 1967). However, deformed wings were not alleviated in a hesperid by the addition of linolenic acid (J. A. George, 1976, personal communication). Because this condition previously arose on meridic diets, it was difficult to show that it was chiefly due to a fatty acid deficiency. Since deformed wings have now appeared in an insect reared on a holidic diet, a unique opportunity arises to study the deformed wing syndrome. Infertility was most likely due to the inability of the moths with deformed wings to mate.

The salt marsh caterpillar, *Estigmene acrea* (Drury), was successfully reared for 12 generations on the alfalfa diet (Vail *et al.*, 1967). It is therefore surprising that *P. isabella*, a species closely related to *E. acrea* and with similar host plants (Tietz, 1972), was not at all successful on this diet. Furthermore, when the alfalfa leaf meal was replaced by plantain, a natural host plant of *P. isabella*, development was not improved. This is a very common occurrence when using oligidic diets. Dried plant material may deteriorate during storage, thereby destroying nutrients and forming toxic products which produce an unacceptable diet (Vanderzant, 1966, 1974). Furthermore, the plantain and alfalfa diets became contaminated much sooner than the other diets, which was probably because of microbial contaminants introduced with the leaf meal. Plantain proved to be an inconvenient food for several reasons: greenhouse grown plantain was attacked by spider mites, aphids and whiteflies, because insecticides could not be used to prevent such infestations. The use of fresh plantain was therefore limited to the summer months when it was available in the field. Furthermore, additional leaves had to be added to the vials between weighings. When large quantities of plantain were added, the resulting increase in humidity caused deterioration of the leaves. Condensation within these vials was also a major cause of mortality in the first 2 instars. These problems were non-existent in the artificial diet reared individuals.

b) Head Capsule Widths and the Number of Instars of *P. isabella*

Dyar (1890) based his law on the results of successive increases in head capsule widths of 27 species of lepidoptera, one of which was *P. isabella*. According to him, *P. isabella* underwent 10 instars, and successive head capsule widths were found to be .4, .7, .9, 1.2, 1.6, 2.2, 2.6, 3.6 and 4.1 mm. The head capsule widths at each successive instar of *P. isabella* larvae found in the present study (Tables XIII a-d) were not in agreement with Dyar's results. Under all experimental conditions, the head capsule widths of the 4th instar fluctuated above and below the widths indicated by Dyar as belonging to both the fourth and fifth instars. Dyar most probably obtained his results by collecting head capsules from different individuals and then hypothesized that each successive increase in width was actually another instar. This would explain how he found 10 instars in P. isabella, while the normal number found in this study was between seven and eight.

Increase in the length of larval development in P. isabella was characterized by an increase in the number of moults. These moults should be considered as "inter-moults" rather than supernumerary ones, since the last head capsule widths were almost of equal size (Fig. II). These results support Nijhout's. (1976) theory that it is the size of the larva and not the number of instars that it has undergone, that determines time of pupation.

The 7, 8, 9 and 10 instar larvae had the same head capsule widths for each instar in the first 3 instars, but each successive instar after this number had a reduction in increment size with the increase in the total number of instars (Fig. II). The increments in the head capsule width at each successive instar as measured and analyzed in this study, therefore, do not follow Dyar's law.

c) Diapause in P. isabella

(i) Voltinism

Diapause in univoltine species has for a long time been considered as being obligatory. A diapause is obligatory when every individual in every generation enters diapause, irrespective of environmental factors (Andrewartha, 1952; Philogêne, 1975 b). These insects diapause at one and the same genetically determined developmental stage (Braune, 1973). The number of insects with truly obligatory diapause is continuously being reduced as highly specific conditions are being found to prevent diapause in these species (Wilde, 1970). Nevertheless, a certain number of individuals in populations of northern insects display an inherited tendency to obligatory diapause not regulated by photoperiod (Danilevskii et al., 1970;

Wilde, 1962). Although the majority of individuals may enter diapause, there usually is a wide range of individual variation (Mansingh and Smallman, 1967). By selection of these individuals, one can rapidly obtain a facultative strain from what may appear as an obligatory one, (Barry and Adkisson, 1966; Harvey, 1961; House, 1967 b and Hoy, 1977) or vice versa (Lees, 1955).

The genetic variability in insects would explain how obligatory and facultative strains have evolved. Through continuous natural selection, obligatory strains have evolved where the ecological conditions allow only one generation a year, and facultative strains in areas where more than one generation is possible.

The collection dates of museum specimens (Fig. VI), field observations (Appendix A) and rearing experiments indicate that P. isabella is univoltine in Canada. Since diapause was not prevented to any great degree under any of the experimental conditions tested; it must be concluded that populations in Canada undergo an obligatory diapause. A very small percentage of the individuals under the experimental conditions did avert diapause (Table XVI) showing the genetic variability of this strain. Presumably, these non-diapausing individuals would be unable to survive the winter and therefore the selection for the obligatory strain would be reinforced. Museum collection data also suggest that P. isabella is bivoltine in the more southern states (Fig. VI). There is a possibility that a seasonal influx of this facultative population to the north maintains the genetic variability of the northern population. However, this is unlikely, since the majority of the non-diapausing larvae pupated under photoperiod conditions which do not occur in the more southern latitudes of North America (Table XVI).

The critical daylength of the photoperiodic reaction of most species greatly increased from the south to the north (Danilevskii et al., 1970), and therefore, it is most likely that the Montreal-Ottawa regions are within the northern limits of a transitory region between obligatory and facultative strains of P. isabella. Other factors such as temperature might induce diapause under natural conditions in the facultative strain, for all of the individuals reared under conditions natural for the Ottawa area entered diapause. It is difficult to show that prevention of diapause in P. isabella was the result of the long photoperiods, because of the small sample size of non-diapausing individuals. To further understand this phenomenon, comparisons would have to be made with the photoperiod/diapause relationships of the more northern and southern populations of P. isabella.

(ii) Cold-hardiness

The increasing ability of an insect to survive subzero temperature is termed cold-hardening; the degree of cold-hardening which an insect undergoes is expressed as its cold-hardiness (Hanec and Beck, 1960). There has been much controversy over the relationship between cold-hardiness and diapause. Lees (1955), Salt (1961) and Ring (1972) believe that such a relationship is only coincidental while Mansingh (1971, 1974) and Mansingh and Smallman (1972), believe that there is a direct relationship.

Initially, it was assumed from the work of Payne (1926) and Sacchorov (1930) that cold-hardiness was directly related to dehydration of the insect. Payne (1927) postulated from dehydration curves of P. isabella as well as other insects, that cold-hardiness could be measured by the moisture content of the insect. At the point of inflection of the weight loss curve, he found that P. isabella could survive freezing. Unfortunately, Payne (1927) did not indicate in his paper whether the dehydration curves were determined under natural or laboratory (constant temperature) conditions. The inflection in the curve and subsequent cold-hardiness could have been due to natural temperature changes and not to a cessation of dehydration resulting from the achievement of cold-hardiness, as he had postulated. The results of this study seem to follow the former hypothesis. Diapausing P. isabella larvae kept at between 22 and 30°C constantly lost weight while those transferred to 0 and 5°C immediately stopped losing weight, much like Payne's (1927) inflection point. This would indicate that temperature and not the achievement of cold-hardiness, is critical in the maintenance of weight in diapausing P. isabella. Temperature and weight loss in diapausing P. isabella is further discussed in the section on diapause development (iv).

Dehydration does increase cold-hardiness, but the increase is negligible (Salt, 1961). In order for appreciable cold-hardiness to be achieved, the water loss must be extreme, however, most insects cannot tolerate the high electrolyte concentrations resulting from such dehydration (Salt, 1961).

Cold-hardiness may be achieved by increasing concentrations of various solutes in the haemolymph, such as polyhydric alcohols (Mansingh and Smallman, 1972, Salt, 1959; Sømme, 1967), and unsaturated fatty acids (Pantyukov, 1964). Mansingh and Smallman (1972) showed how the polyhydric alcohol levels increased in diapausing P. isabella and concluded that "development of cold-hardiness appears to be a part of the general diapause physiology".

In the present study, diapausing larvae reared at temperatures between 22 and 26°C were found to be cold-hardy while those reared at 30°C were not. Hanec and Beck (1960) found that incubating cold-hardy Pyrausta nubilalis (Hubn.) larvae at 30°C for several days tended to destroy this cold-hardiness. Furthermore, P. nubilalis larvae collected in August were not found to be cold-hardy while those collected in September were. Mansingh (1974) argued that the P. nubilalis larvae collected in August were less cold-hardy than the September collected larvae (Hanec and Beck, 1960) because complete diapause physiology was probably not yet induced. P. isabella larvae reared at 30°C were never cold-hardy, yet, some did complete diapause development at 30°C. If Mansingh's (1974) argument was valid, it means that diapause physiology was never induced, i.e.: these larvae never entered diapause.

The results of the present study with P. isabella as well as those of Hanec and Beck (1960) would indicate that diapause may serve to be a period during which cold-hardening may occur, but, that neither the weather conditions which induce diapause, nor diapause itself, produce cold-hardiness. This, therefore, supports Salt's (1961) hypothesis that the relation of cold-hardiness to diapause appears to be a coincidence arising from concurrent timing. Furthermore, it has been shown in the present study with P. isabella, and by Hanec and Beck (1960) as well as by Mansingh and Smallman (1972) that cold-hardiness is not achieved in diapausing individuals kept at high temperatures. Mansingh and Smallman (1972) concluded from their findings that "the enzyme system responsible for the lowering of supercooling points..... seems to work more efficiently at low ambient temperatures and otherwise reduced biosynthetic and metabolic activities during diapause". Because of the arguments against the direct relationship between diapause and cold-hardiness presented earlier, it would seem that lower temperatures actually induce cold-hardiness during diapause, but that the two phenomena are independent of one another.

(iii) Effects of photoperiod and temperature

Photoperiods with a photophase longer than 14 hrs. were found to slow the developmental time in P. isabella. There are only two instances in the literature where the development period was retarded by longer photoperiod. Danilevskii (1961) reported this phenomenon in the noctuid, *Agrotis triangulum* (Hufn.), while Geyspitz and Zarankina (1963) observed it in the tussock moth, *Dasychira pudibunda* L. The photoperiod affected maximum larval weight in *D. pudibunda* to a greater extent than in *P. isabella*.

The total duration of illumination that *P. isabella* larvae were exposed to before the onset of diapause varied much more than the duration of darkness (Table VI). This would indicate that the dark period is more important in controlling the development rate in the larvae of this insect. Moreover, the increase in developmental time, as indicated by the head capsule widths (Fig. II), occurred only after the 3rd instar. This may be the stage at which the larvae became light sensitive, a response which has to be further investigated.

Temperature did not affect the total larval development time in *P. isabella* as would have been expected. Increase in temperatures did not always result in a decreased developmental period. Short photoperiods and low temperatures produced intensive acceleration in developmental period in *D. pudibunda* (Geyspitz and Zarankina, 1963) while long days produced inhibition, additional moulting, and a reduction in growth rate (Geyspitz and Zarankina, 1963). Similar results were obtained with *P. isabella*. Geyspitz and Zarankina (1963) concluded that "it is practically impossible to apply the rule of heat total to *D. pudibunda*". This statement seems to be equally applicable to *P. isabella*.

There are three possible reasons why longer photoperiods increased development time and the number of instars. The banded woollybear may be primarily a nocturnal feeder and therefore its rate of development may be directly linked to the amount of dark per day. Short scotophase may result in starvation of the larvae. Starvation has been shown to induce extra moulting (McGinnis and Kasting, 1959; Nijhout, 1975; Jacobson and Blakeley, 1960). Furthermore, increased temperatures may decrease growth rates during long photoperiods because the metabolic rate is increased but the insect cannot compensate for this increase by feeding more during the short scotophase.

Another explanation is that, this phenomenon is correlated with the photoperiodic effect of diapause induction. Many authors have found that the scotophase was more important in diapause induction than the photophase (Adkisson, 1964, 1965; Beck, 1962 b; Bowen and Skopik, 1976; Danilevskii, 1961; Dickson, 1949; Lees, 1953 b, 1966), while others postulate that it is the phase of an oscillation of dark and light stimulated rhythms which induce or prevent diapause (Saunders, 1976). Nevertheless, an obligatory diapausing insect must have lost its ability to respond to the diapause preventing stimulus. Degenerate forms of photoperiod reactions are found in many univoltine insects (Danilevskii, 1961).

It is possible that in the evolution of an obligatory strain of _P. isabella_, the insect lost its photophase response and therefore depends on the scotophase for diapause induction. If this is the case, it gives us a unique opportunity to study diapause induction by comparing the photoperiodic responses in this obligatory strain, to those of a southern, facultative strain.

The third possible explanation for the photoperiod effect on growth is that it is an adaptation, in this obligatory strain, which functions to synchronize its life cycle with the season. If the growth rate was overly dependent on the temperature in _P. isabella_, larvae would mature and enter diapause well before fall during exceptionally warm summers. Since all the larvae would enter diapause, mortality would be very high because of the hot weather they would experience (as discussed previously). The slow down photoperiodic effect prevents this from happening. During hot summers when the photoperiod is long, developmental time is lengthened by the slowing of the growth rate and by the production of inter-moults, while during cool periods or towards the end of summer, when the photoperiod is shorter, the opposite effect is produced. This adaptation ensures that diapause is induced only in the early fall when the temperatures are conducive to diapause maintenance without high mortality. Geyspitz and Zarankina (1963) concluded that the delay in the development in D. pudibunda, due to photoperiod and temperature, was an "unusual case of diapause in which movement and feeding are not eliminated but merely partly reduced". A more appropriate explanation would be that this delay has developed as just a preparatory function for the proper timing of diapause induction.

Whatever the reason behind the photoperiodic regulation of the development period, it has been shown that photoperiod has a great effect on P. isabella development and that the concept of day-degree accumulation (Arnold, 1960) cannot be used with this species. More investigations will have to be performed with univoltine species to determine how widespread this phenomenon is. Possibly, greater attention will have to be paid to the photoperiod when constructing future computer models for univoltine insects.

(iv) Diapause development

Chilling is not an absolute necessity for diapause development to occur in P. isabella as diapausing larvae kept at 22, 26 and 30°C completed development. Mortality and weight loss in these larvae increased progressively as the temperature was increased from 0 to 30°C. This indicates that the cold may prevent the exhaustion of fat body reserves, thus enabling the larvae to survive the diapause development period, as postulated by Beck (1968) and McLeod and Beck (1963). Indeed, Scholander et al., (1953) demonstrated that respiration rates in overwintering Chironomus larvae were directly proportional to the temperature. Unfortunately, it is not known if diapause development had been completed in these larvae. Furthermore, diapausing pupae of the corn earworm <u>Heliothus</u> <u>armigera</u> (Hubn.) lost less weight when kept at higher humidities (Ditman <u>et</u> <u>al.</u>, 1940). It is likely that lower temperatures not only slow down the metabolic rate but also reduce the amount of dessication in diapausing insects.

Post-chilling mortality was not affected by the length of chilling time (Fig. IV), although time to pupation decreased as chilling time was increased (Figs. III, V). It would be expected that both of these parameters should be decreasing in parallel, as those larvae which terminated diapause, theoretically, should have a lower mortality than those still in diapause. The constant rate of mortality may be due to a temperature shock (transfer from 5 to 22°C) and therefore might not be a reflection of the actual post-diapause viability.

The high mortality during the diapausing period at 5°C may reflect natural diapause mortality (Appendix A), or it may indicate that this temperature is not optimal for diapause development in this species. It is unfortunate that too little data was obtained at 0 and 10°C to permit a valid comparison with the 5°C results.

V. SUMMARY AND CONCLUSIONS

Experiments on the effects of photoperiod, temperature and diet on the development of *P. isabella* revealed that:

1) The species is univoltine in the Ottawa-Montreal area and undergoes an "obligatory" diapause.

2) The larva can be easily reared on bean, wheat-germ, casein-wheat germ and fresh plantain diets.

3) Larvae reared on casein, alfalfa and plantain diets had greater variations in the number of instars, than did those on the other diets.

4) The increments in the head capsule widths at each successive instar did not follow Dyar's rule. Moreover, the measurements of the head capsules at each instar were found to be different from those reported by Dyar.

5) Development time increased at photoperiods longer than 14 hrs. This increase was characterized by extra instars that were due to "intermoults" rather than to supernumerary moults.

6) The results suggest that scotophase may be more important than photophase in influencing development.

7) Temperature did not affect overall larval developmental time, although, higher temperatures did slow initial growth rate. The day-degrees/development relationship, typical of many insects, does not hold true in this insect.

8) "Chilling" was not absolutely necessary for diapause development, although, mortality was very high at higher temperatures. Temperature seems to be critical in lowering the metabolic rate of the diapausing larvae.

9) Diapausing larvae reared at 30°C were not cold-hardy and could not withstand being transferred to 5°C.

VI. APPENDIX

a) Observations on the Life History of P. isabella

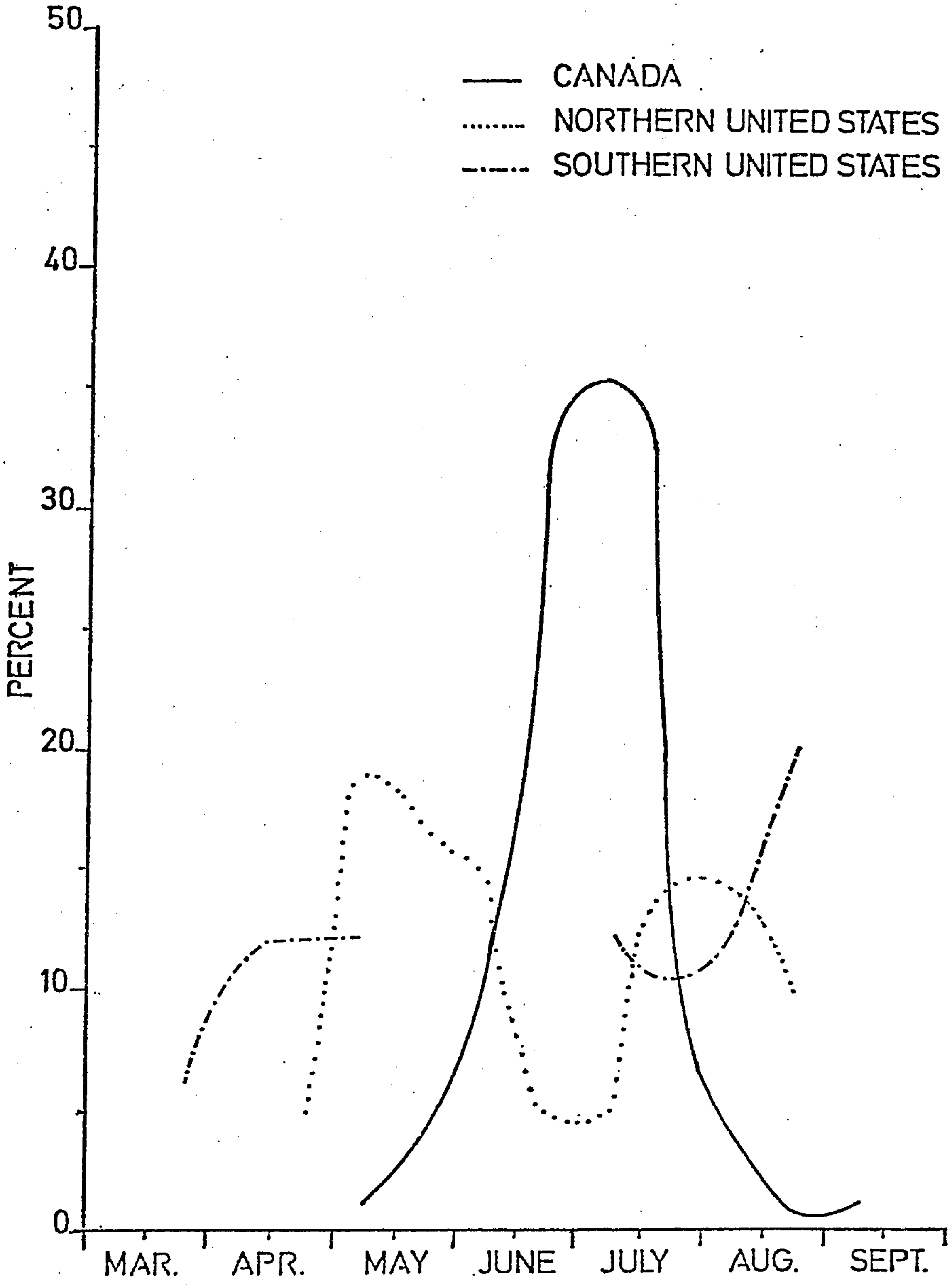
In early September, last instar larvae were found feeding mainly on plantain. Some were also feeding on clover and dandelion. When looking for the larvae, one must search around the base of the host plants as the woollybears roll into a ball and drop to the ground as soon as they are disturbed. In this rolled-up position, they are very difficult to see for they blend in with the debris on the ground. In early morning, the larvae were observed basking in the sun on the highest points of the plants.

The larvae were first seen on the move around mid-September. It was at this time that they were the easiest to collect. Woollybears were seen crossing roads, especially in areas where there were fallow fields. This travelling continued on warmer days until the end of October. Larvae were also collected while on the move in mid-May. These larvae usually pupated within five days of being collected. The head capsule widths of last instar field collected larvae ranged between 3.8 and 6 mm (mean = 4.4, Standard Deviation,=.6 and Sample Size = 12).

Pupae were collected under wooden planks in the beginning of June. Under one pile of wood, 30 dried larvae, 1 prepupa in its cocoon, 2 pupae and 1 recently emptied cocoon were found. This would indicate a high overwintering mortality.

Moths of P. isabella were collected in light traps between early June and July, but they were never very abundant. The collection dates of specimens in the Lyman Museum of McGill University and in the National Insect Collection of Canada indicate an early July flight peak in Canada (Fig. VI). This same data indicates that the species is bivoltine in the more southern states and monovoltine in Canada.

FIG. VI: Percent of P. isabella adults collected at different periods of the year. Data obtained from the Lyman Museum (McGill University) and the Canadian National Insect Collection. Collections were made between 1875 and 1975. The number of specimens were: Canada - 160, Northern United States - 21, Southern United States - 15. There is a clear indication of the univoltine nature of the species in Canada.


CANADA
NORTHERN UNITED STATES
SOUTHERN UNITED STATES
PERCENT
50
40
30
20
10
0
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.

Eggs and early instar larvae were never found in the field.

Only 3% of the 263 field collected larvae were parasitized. One of the larvae contained five *Parachaeta bicolor* (Macq.) maggots. The other parasite found was *Compsilura concinnata* (Mg.). A list of the pathogens and parasites known to affect *P. isabella* is presented in Table VII.

b) Biology of *P. isabella* in the Laboratory

Eggs

The eggs turned darker as they developed and the head capsules could be seen within the chorion approximately one day before eclosion (Plate I). Between 3 and 9 days were required for the eggs to mature. (Mean = 6.1 days, Standard Deviation = 1.1, Sample Size = 28 single egg patches.) All infertile eggs turned brown after a mean of 12 days. Some were also attacked by fungus at this time. No eggs were ever attacked by fungi or bacteria within 12 days and therefore the fertile and infertile eggs were easily distinguished. Eclosion from the fertilized egg patches was almost 100%.

Larvae

As soon as the larvae emerged, they devoured the chorion and then proceeded to devour unemerged eggs, even in the presence of fresh plantain. No cannibalism of emerged larvae was observed.

The larvae could be easily transferred after eclosion by using a soft haired brush. Care had to be taken that the larvae did not stick to the diet or to water condensation on the walls of the vial.

The exuvia, including bristles and head capsule, was usually devoured within 24 hours of moulting. Larvae completing their development sometimes excreted 2 to 5 pellets of pink frass, 3 to 7 days after attaining maximum

FUNGI		
Empusa grylli	U.S.A.	Verak,C. 1941, Insect Pest Survey Bull. Vol.21 (9) ; 721
Entomophthora aulicae	U.S.A.	Verak,C. 1941, Insect Pest Survey Bull. Vol.21 (9) ; 721
Spicaria farinosa	U.S.A.	Verak,C. 1941, Insect Pest Survey Bull. Vol.21 (9) ; 721
Cordyceps militaris (L.)	U.S.A.	Verak,C. 1941, Insect Pest Survey Bull. Vol.21 (9) ; 721
Muscardine	Illinois	Forbes,S.A. 1900, Ill. Agr. Exp. Sta. Bull. 60 ; 505
	Minnesota	Lugger 1899, Min. Agr. Exp. Sta. Bull. 61 ; 131 - 132
NEMATODA		
Hexamermis sp.	Missouri	Puttler,B.; Thewke,S.E. 1971, Ann. Ent. Soc. Am. Vol.64 (5) ; 1177 -1178
HYMENOPTERA		
Ichneumonidae		
Amblyteles centrator (Say)	U.S.A.	Schaffer ; Griswold.,1934, Rev. Appl. Ent. Series A Vol.xxii ; 688
Campoplex sp.	U.S.A.	Schaffer , Griswold.,1934, Rev. Appl. Ent. Series A Vol.xxii ; 688
Eulimneria valida (Cress)	U.S.A.	Schaffer , Griswold.,1934, Rev. Appl. Ent. Series A Vol.xxii ; 688
Pimpla pedalis (Cress)	N. Am.	Cushman.,1921, Rev. Appl. Ent. Series A Vol. ix ; 169 Schedl.,1931, Rev. Appl. Ent. Vol.xix ; 765
Ichneumon signatipes (Cress)	Illinois	Saunders, W. 1873, Ont. Ent. Soc. An. Rep.
	U.S.A.	Riley, C.V. 1880, Am. Ent. 3 ; 133
Trogus obsidianator (Brulle)	Illinois	Saundres, W. 1873, Ont. Ent. Soc. An. Rep.
	U.S.A.	Riley, C.V. 1880, Am. Ent. 3 ; 133
Ichneumon coeruleus (Cress)	U.S.A.	Riley, C.V. 1880, Am. Ent. 3 ; 133
Ophion macrurum (Linn.)	U.S.A.	Riley, C.V. 1880, Am. Ent. 3 ; 133
DIPTERA		
Tachinidae		
Exorista larvarum(L)	U.S.A.	Schaffer , Griswold.1934 , Rev. Appl. Ent. Series A Vol.xxii ; 688
		Metcalf, Flint, Metcalf. 1962, *Destructive and Useful Insects.*,4th ed. McGraw - Hill Book Co. N.Y. , 1087p.
Rileymyia adusta		Metcalf, Flint, Metcalf. 1962, *Destructive and Useful Insects.* ,4th ed. McGraw - Hill Book Co. N.Y. , 1087p.
Aplomya affinis (Fall)	U.S.A.	Schaffer, Griswold. ,1934 Rev. Appl. Ent. Series A Vol.xxii ; 688
Parachaeta bicolor (Macq)	U.S.A.	Schaffer, Griswold.,1934 , Rev. Appl. Ent. Series A Vol.xxii ; 688
	Québec	*
Winthemia datanae (Tns)	U.S.A.	Schaffer, Griswold. ,1934 Rev. Appl. Ent. Series A Vol.xxii ; 688
Zenillia futilis (O.S.)	Canada	Tothill. ,1913 Rev. Appl. Ent. Series A Vol.i ; 114
		Aldrich, Webber.,1924, Rev. Appl. Ent. Vol.xii ; 214
Compsilura concinnata (Mg)	Ontario	*

* Found in present study

TABLE VII: Pathogens and Parasites of *P. isabella*.

weight, in the case of the diapause larvae, and between 2 and 5 days before pupating, in the case of non-diapause and post-diapause larvae.

The development of the larvae under different photoperiod, temperature and diet conditions is discussed in the main text. Growth rates, percent mortality, head capsule widths and days at each instar are presented in parts d, e, f and g of the Appendix.

Pupae

Time of pupation was determined by placing the cocoon in front of a light. The prepupa or pupa can then be readily seen within the cocoon. Two to four days after pupation, the pupae were removed by carefully cutting the cocoon with a pair of scissors. Removal from the cocoon within two days of pupation can result in damage to the pupa as its cuticle is not yet fully sclerotized.

Sexing by the examination of the position of the genital pore (Villiard, 1969) was 100% accurate if the cuticle was completely sclerotized. A small number of pupae had completely sclerotized but deformed cuticle and the sexing of these was not possible.

The mean development time of the pupae at 22°C was 14.5 days for the females (Table VIII) and 15.5 days for the males (Table IX). Percent mortality was 6% (N = 389) (males = 5%, N = 184 ; females = 2%, N = 193). 50% of the dead pupae had deformed cuticles.

Moths

Upon emerging, the moths immediately climbed onto the paper towel and spread out their wings to dry (Plate II). Care had to be taken to ensure that the paper was close to the vial wall so that enough space was available for wing drying. Females confined in the vial for 3 days laid infertile eggs.

The moths oviposited readily on strips of paper towels. Eggs were deposited in patches of 25 to 350. The moths were frequently seen feeding

TABLE VIII: Mean number of days from pupation to emergence of female *P. isabella* at each combination of photoperiod, temperature, and diet.

N = Sample size, S.D. = Standard Deviation.

DIET	BEAN		CASEIN		WHEAT GERM		ALFALFA		CASEIN-WHEAT GERM		PLANTAIN (FRESH)		TOTAL	
	N	DAYS (S.D.)	N	DAYS (S.D.)	N	DAYS (S.D.)	N	DAYS (S.D.)	N	DAYS (S.D.)	N	DAYS (S.D.)	N	DAYS (S.D.)
RM 9/15	6	14.3 (0.82)	5	13.8 (1.92)	5	14.6 (0.55)	3	14.0 (1.00)			1	14.0 (——)	20	14.2 (1.08)
RM 11/13	5	14.8 (0.84)	5	12.4 (2.70)	7	14.6 (1.27)	4	15.3 (0.50)			9	15.2 (1.92)	30	14.5 (1.84)
RM 12/12	4	13.0 (1.15)	10	15.9 (3.96)	7	15.0 (1.00)	6	13.3 (1.63)			1	15.0 (——)	28	14.7 (2.69)
RM 13/11	6	14.3 (1.75)	13	14.6 (1.56)	13	16.0 (6.68)	7	14.3 (1.25)			5	12.8 (2.59)	44	14.7 (3.87)
RM 15/9	6	13.2 (2.14)	2	12.5 (4.95)	5	15.2 (0.84)	4	12.2 (0.96)			4	13.8 (2.22)	21	13.5 (2.08)
22 9/15	4	14.5 (1.00)	4	17.3 (5.19)	7	15.4 (1.62)	2	14.0 (1.41)			4	13.2 (1.71)	21	15.0 (2.64)
22 15/9	1	14.0 (——)	2	16.5 (3.54)	6	14.0 (2.10)					3	20.3 (12.86)	12	16.0 (6.12)
22 16/8					1	15.0 (——)							1	15.0 (——)
22 17/7			2	13.5 (0.71)							1	12.0 (——)	3	13.0 (0.82)
26 15/9	1	15.0 (——)											1	15.0 (——)
30 12/12					1	15.0 (——)							1	15.0 (——)
30 15/9									2	14.5 (0.71)	2	12.5 (2.12)	4	13.5 (1.50)
30 16/8	3	13.0 (1.00)							1	14.0 (——)	1	11.0 (——)	5	12.8 (1.17)
TOTAL	36	14.0 (1.40)	43	14.7 (3.13)	52	15.1 (3.44)	26	13.8 (1.40)	3	14.3 (0.47)	31	14.4 (4.29)	190	14.5 (3.06)

TABLE IX: Mean number of days from pupation to emergence of male *P. isabella* at each combination of photoperiod, temperature and diet.

N = Sample size, S.D. = Standard Deviation.

DIET	BRAN		CASEIN		WHEAT GERM		ALFALFA		CASEIN-WHEAT GERM		PLANTAIN (FRESH)		TOTAL	
	N	DAYS (S.D.)	N	DAYS (S.D.)	N	DAYS (S.D.)	N	DAYS (S.D.)	N	DAYS (S.D.)	N	DAYS (S.D.)	N	DAYS (S.D.)
RM 9/15	3	14.6 (2.51)	9	15.0 (1.66)	5	15.4 (1.52)	6	14.3 (0.82)			2	12.0 (2.83)	25	14.6 (1.72)
RM 11/13	6	14.7 (3.78)	11	16.4 (1.86)	5	15.2 (0.45)	8	14.4 (1.85)			4	15.3 (0.96)	34	15.3 (2.13)
RM 12/12	7	17.9 (8.07)	2	16.5 (0.71)	8	15.5 (2.00)	2	15.0 (0.00)			2	17.0 (2.83)	21	15.8 (6.68)
RM 13/11	7	14.4 (2.37)	5	17.2 (2.68)	5	15.8 (1.30)	1	15.0 (——)			1	16.0 (——)	19	16.0 (2.05)
RN 15/9	2	15.0 (0.00)	3	15.6 (1.15)	8	16.8 (2.25)	5	16.4 (1.52)			5	13.2 (1.64)	23	15.6 (2.10)
22 9/15	5	14.0 (3.32)	7	20.6 (13.04)	2	18.0 (4.24)					7	15.1 (1.21)	21	16.9 (7.72)
22 15/9	2	15.0 (0.00)	4	17.0 (2.71)	5	15.4 (1.14)	1	16.0 (——)			1	11.0 (——)	13	15.5 (2.10)
22 16/8	1	16.0 (——)											1	16.0 (——)
22 17/7	1	17.0 (——)	3	15.3 (2.31)	1	14.0 (——)			1	15.0 (——)	4	14.3 (0.50)	10	14.3 (4.40)
26 15/9	1	16.0 (——)	1	16.0 (——)							1	15.0 (——)	3	15.7 (0.47)
30 12/12	1	14.0 (——)			1	14.0 (——)	1	28.0 (——)					3	18.7 (6.60)
30 15/9											1	14.0 (——)	1	14.0 (——)
30 16/8											1	11.5 (——)	1	11.5 (——)
TOTAL	36	15.5 (4.13)	45	16.7 (5.34)	40	15.7 (1.81)	24	14.9 (5.29)	1	15.0 (——)	30	14.0 (3.05)	177	15.5 (4.19)

on the sucrose solution but were never seen in copula. All eggs were infertile if the moths were kept in a room above 25°C (25°C-35°C). There was no problem of fertility at temperatures below 25°C (22°C-25°C).

c) Growth of the Non-Diapause Larvae

Observations on the development of the non-diapause larvae are summarized in Table X. The development rates were much faster than for the diapause larvae (Fig. VII). Time to pupation fluctuated between 30 and 56 days (except in one case on the alfalfa diet, 30°C, L/D 12/12) while the time to diapause fluctuated between 35 and 110 days (Table XVIII). These results would indicate that the commitment to the prevention of diapause is determined in the early larval stages.

The maximum larval weights at 22°C were slightly lower than those of the diapause larvae under the same conditions. The reverse was true for the larvae at 30°C (Table XVII).

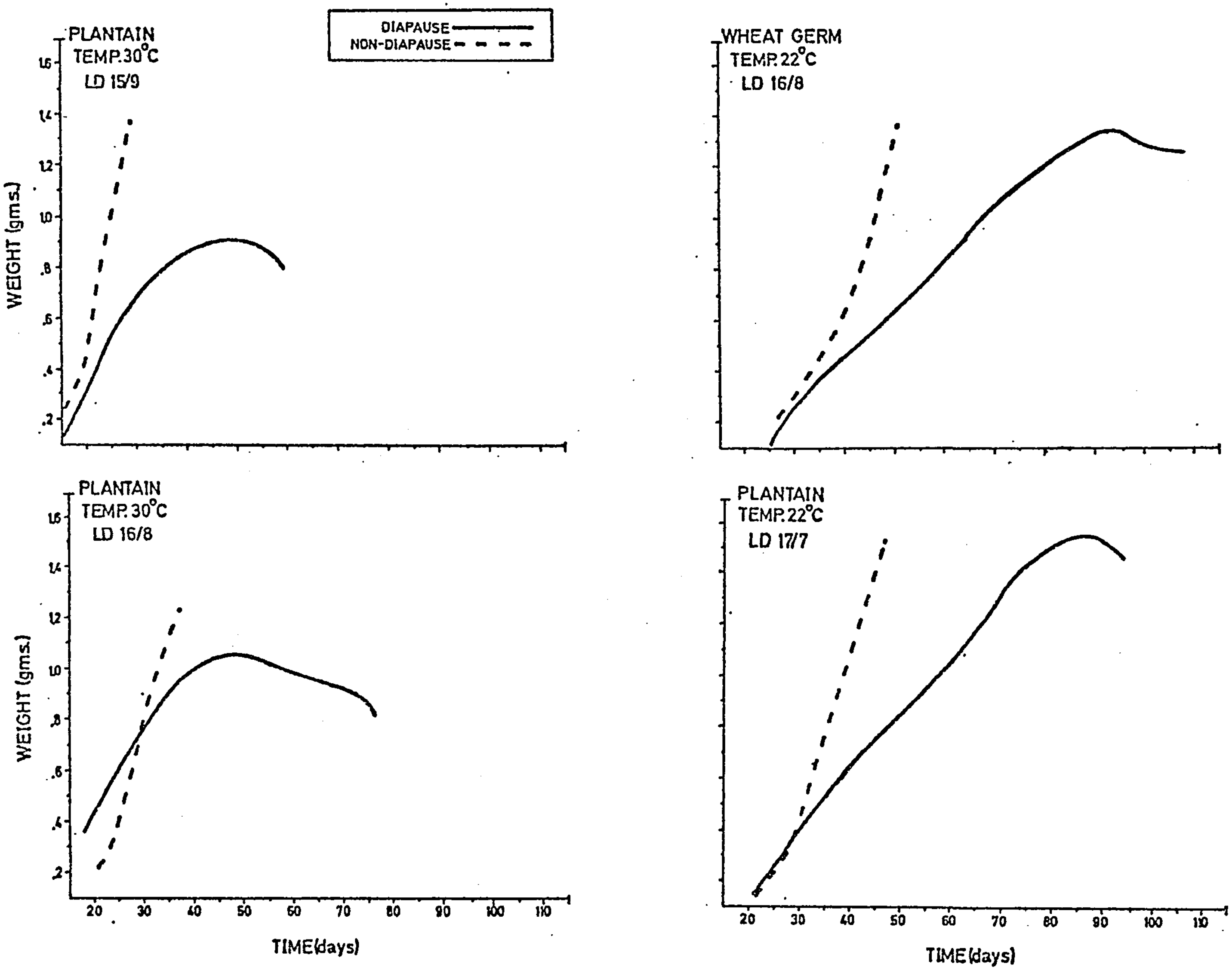
The number of instars for the non-diapause larvae fluctuated between 7 and 8. The majority of these larvae were from photoperiods of L/D 15/9 to 17/7. Only two larvae pupated without diapause at 30°C, L/D 12/12.

TABLE X: Development of non-diapausing P. isabella larvae at each combination of photoperiod, temperature and diet. Data on mean number of days from eclosion to pupation, maximum larval weight, pupal weight, range and mean number of instars. N = Sample size, S.D. = Standard Deviation.

				BEAN		WHEAT GERM		ALFALFA		CASEIN-WHEAT GERM		PLANTAIN (fresh)
22	16/8	Days to Pupation:				56						
		N (S.D.)			1	(0)						
		Maximum Weight:				1.37						
		N (S.D.)			1	(0)						
		Pupal Weight:				.689						
		N (S.D.)			1	(0)						
		# Instars:				7.0						
		N Range (S.D)			1	0 (0)						
22	17/7	Days to Pupation:		45								53.4
		N (S.D.)	1	(0)							5	(15.7)
		Maximum Weight:		1.35								1.37
		N (S.D.)	1	(0)							5	(.20)
		Pupal Weight:		–								.660
		N (S.D.)	–	–							5	(.123)
		# Instarc:		7								7.8
		N Range (S.D.)	1	0 (0)							5	7-8 (.45)
30	12/12	Days to Pupation:				41		78				
		N (S.D.)			1	(0)	1	(0)				
		Maximum Weight:				—		.71				
		N (S.D.)			1	(0)	1	(0)				
		Pupal Weight:				.780		.413				
		N (S.D)			1	(0)	1	(0)				
		# Instars:				8.0		–				
		N Range (S.D.)			1	0 (0)	1	0 (0)				
30	15/9	Days to Pupation:								32.0		36.7
		N (S.D.)							2	(4.24)	3	(4.62)
		Maximum Weight:								1.31		1.35
		N (S.D.)							2	(.243)	3	(.175)
		Pupal Weight:								.741		.727
		N (S.D.)							2	(.113)	3	(.108)
		# Instars:								7.0		7.7
		N Range (S.D.)							2	0 (0)	3	7-8 (.58)
30	16/8	Days to Pupation:		30.3						27.0		44.0
		N (S.D.)	3	(1.15)					1	(0)	3	(0)
		Maximum Weight:		1.27						1.06		1.26
		N (S.D.)	1	(0)					1	(0)	2	(.059)
		Pupal Weight:		.662						.636		.660
		N (S.D.)	3	(.061)					1	(0)	3	(.022)
		# Instars:		7.0						7.0		8.0
		N Range (S.D.)	3	0 (0)					1	0 (0)	3	0 (0)

FIG. VII: Mean growth rates of diapause and non-diapause *P. isabella* larvae at three temperature, photoperiod and diet combinations. Data pooled from 1 to 3 individuals for the non-diapause larvae and from 5 to 10 individuals for the diapause larvae.

L/D = Light/Dark hours.


DIAPAUSE
NON-DIAPAUSE
PLANTAIN
TEMP. 30°C
LD 15/9
WHEAT GERM
TEMP. 22°C
LD 16/8
PLANTAIN
TEMP. 30°C
LD 16/8
PLANTAIN
TEMP. 22°C
LD 17/7
WEIGHT (gms.)
1.6
1.4
1.2
1.0
.8
.6
.4
.2
TIME (days)
20
30
40
50
60
70
80
90
100
110

d) Mean Number of Days at Each Instar of *P. isabella* at Each Combination of Photoperiod, Temperature and Diet

TABLE XI a: Mean number of days at each instar of P. isabella at each combination of photoperiod and diet at room (Rm) temperature.

N = Sample size, S.D. = Standard Deviation

DIET	BEAN			CASEIN			WHEAT GERM			ALFALFA			PLANTAIN			PLANTAIN (fresh)		
	N	DAYS	(S.D.)	N	DAYS	(S.D.)	N	DAYS	(S.D.)	N	DAYS	(S.D.)	N	DAYS	(S.D.)	N	DAYS	(S.D.)
RM Temp. 9/15																		
INSTAR: 1	19	4.0	(.74)	20	4.6	(.67)	20	4.3	(.49)	19	4.9	(.70)	20	4.5	(.51)	13	4.5	(.52)
2	19	2.7	(.80)	18	4.7	(2.38)	19	2.4	(.76)	15	4.9	(1.44)	18	8.5	(3.82)	9	3.3	(.50)
3	16	5.1	(1.44)	16	4.6	(1.89)	14	4.8	(.86)	15	5.7	(1.72)	9	6.8	(4.12)	9	4.7	(2.00)
4	14	2.8	(1.31)	17	4.2	(.90)	14	2.4	(.85)	15	7.6	(4.70)	6	7.5	(1.97)	7	3.1	(.90)
5	16	4.1	(1.20)	19	5.0	(.94)	19	4.9	(.94)	14	6.6	(3.18)	5	11.2	(5.63)	8	6.5	(3.21)
6	16	6.9	(.57)	19	6.5	(1.58)	17	7.2	(.73)	14	10.9	(3.02)	5	8.6	(2.88)	6	11.0	(1.09)
7				6	6.3	(.52)				4	8.2	(1.89)	4	11.5	(4.43)			
8										2	9.0	(1.41)	4	12.0	(3.83)			
9													1	10.0	(0)			
10													1	9.0	(0)			
RM Temp. 12/12																		
INSTAR: 1	20	4.0	(.79)	20	4.4	(.60)	20	4.3	(.49)	20	4.8	(.77)	20	4.5	(.60)	16	4.4	(.88)
2	20	2.5	(.69)	19	4.5	(1.71)	20	2.6	(.50)	18	4.9	(1.66)	17	9.4	(2.87)	12	3.2	(1.05)
3	19	4.3	(1.20)	15	4.7	(2.22)	20	4.5	(1.00)	15	5.0	(2.48)	7	12.3	(5.06)	9	4.2	(1.42)
4	19	2.6	(1.42)	10	4.5	(.97)	20	2.5	(1.28)	11	7.7	(2.65)	2	11.5	(.71)	10	2.7	(1.16)
5	18	4.3	(.76)	14	4.8	(.66)	20	3.9	(.69)	11	5.8	(.60)	1	11.0	(0)	12	4.6	(2.23)
6	17	7.8	(.73)	15	6.1	(1.67)	20	7.4	(.76)	8	7.6	(3.20)				12	9.7	(2.00)
7				8	6.6	(1.30)				7	7.1	(2.54)				1	11.0	(0)
8										2	9.0	(2.83)						
RM Temp. 13/11																		
INSTAR: 1	20	4.4	(.76)	20	4.7	(.72)	20	4.3	(.49)	20	4.3	(.49)	20	4.5	(.61)	11	4.8	(.75)
2	18	2.7	(1.13)	17	4.1	(1.25)	19	3.0	(.85)	18	7.0	(1.80)	17	9.1	(3.31)	21	4.3	(1.39)
3	18	4.4	(1.50)	16	6.0	(2.39)	19	4.0	(.94)	16	4.9	(1.95)	9	9.2	(6.34)	9	3.8	(1.64)
4	15	2.1	(.96)	14	4.5	(1.99)	20	2.8	(1.06)	13	8.6	(3.20)	5	5.2	(3.49)	6	4.2	(2.23)
5	15	4.3	(.82)	14	6.0	(2.66)	17	4.0	(.90)	11	7.7	(3.98)	2	6.0	(1.41)	10	5.2	(1.81)
6	18	7.5	(.86)	18	6.7	(2.08)	17	7.8	(.83)	11	8.7	(2.72)	2	6.5	(3.53)	8	9.9	(1.46)
7				5	8.2	(2.28)				3	9.3	(1.53)	1	11.0	(0)			
8													1	10.0	(0)			
RM Temp. 15/9																		
INSTAR: 1	20	3.7	(.80)	20	4.6	(.74)	20	4.1	(.59)	20	4.3	(.49)	20	4.2	(.64)	15	4.0	(.92)
2	20	3.2	(1.25)	15	5.9	(2.71)	19	3.1	(.87)	15	7.1	(2.81)	18	10.4	(3.85)	14	3.5	(1.56)
3	20	4.6	(1.31)	12	4.8	(1.53)	18	4.4	(1.15)	12	6.7	(3.14)	3	9.3	(7.09)	16	4.7	(1.45)
4	19	2.4	(.96)	16	6.8	(3.23)	19	3.1	(.94)	12	8.9	(3.55)	1	11.0	(0)	14	2.9	(1.00)
5	19	5.6	(.49)	14	6.0	(1.75)	19	5.5	(.90)	12	8.8	(3.30)	1	5.0	(0)	14	5.2	(1.05)
6	20	9.3	(2.06)	15	6.3	(1.88)	19	9.9	(2.10)	14	9.9	(3.58)	1	14.0	(0)	16	11.2	(6.07)
7	5	11.6	(2.09)	16	10.7	(2.78)	4	10.0	(1.15)	14	11.4	(2.59)				16	17.3	(5.31)
8				4	12.2	(1.26)				5	14.6	(3.91)						
9										1	11.0	(0)						

TABLE XI b: Mean number of days at each instar of P. isabella at each combination of photoperiod and diet at 22°C. N = Sample size, S.D. = Standard Deviation

DIET	BEAN	CASEIN	WHEAT GERM	ALFALFA	CASEIN-WHEAT GERM	PLANTAIN (fresh)
	N DAYS (S.D.)	N DAYS (S.D.)	N DAYS (S.D.)	N DAYS (S.D.)	N DAYS (S.D.)	N DAYS (S.D.)
22°C L/D 9/15						
INSTAR: 1	18 4.5 (.78)	18 4.7 (.75)	20 4.4 (.60)	20 4.8 (,25)		20 4.9 (.97)
2	18 4.0 (1.50)	11 6.6 (.92)	19 4.1 (.91)	18 6.5 (1.50)		18 4.5 (1.29)
3	18 3.5 (1.50)	8 3.5 (1.31)	18 3.4 (1.15)	12 7.7 (3.62)		16 3.6 (1.63)
4	18 4.3 (1.33)	11 5.9 (1.58)	19 3.7 (.67)	9 8.2 (5.29)		17 3.6 (1.41)
5	12 4.8 (.94)	11 5.0 (1.70)	19 5.0 (1.10)	7 9.9 (3.24)		15 4.5 (2.23)
6	11 7.0 (.77)	12 7.5 (2.24)	19 6.5 (.96)	5 9.4 (5.86)		11 8.8 (2.60)
7		11 7.3 (1.01)	1 4.0 (0)	3 10.0 (1.73)		
8		1 8.0 (0)				
22°C L/D 15/9						
INSTAR: 1	19 4.0 (.66)	19 4.9 (.78)	20 4.2 (.64)	20 4.7 (.91)		15 4.6 (.90)
2	18 4.3 (1.33)	10 8.7 (4.24)	20 4.6 (1.35)	18 9.2 (3.17)		13 4.6 (2.18)
3	19 3.2 (1.65)	10 5.8 (2.62)	20 3.8 (3.53)	12 7.9 (2.78)		11 4.0 (1.26)
4	17 3.9 (.33)	14 5.7 (1.90)	18 4.1 (.47)	9 7.5 (2.40)		13 3.2 (.93)
5	17 5.4 (.62)	14 6.1 (2.81)	17 5.3 (.77)	9 9.0 (2.91)		18 5.2 (.94)
6	20 10.2 (1.55)	13 6.5 (1.05)	17 10.3 (1.69)	9 11.4 (6.33)		17 13.2 (5.06)
7	1 10.0 (0)	4 9.5 (1.29)		8 10.1 (2.29)		10 9.2 (2.04)
8				8 11.7 (3.15)		
9				4 14.7 (6.18)		
10				1 12.0 (0)		
22°C L/D 16/8						
INSTAR: 1	20 4.3 (.49)	18 4.8 (.62)	18 4.3 (.48)	15 5.3 (.90)	19 4.6 (.60)	17 5.5 (1.37)
2	16 2.9 (.34)	11 3.9 (.83)	12 5.2 (2.44)		13 3.8 (2.19)	2 7.0 (4.24)
3	11 5.2 (1.08)	8 5.0 (1.77)	10 5.6 (1.95)		10 4.7 (.82)	
4	13 3.6 (.87)	11 6.8 (1.25)	14 5.9 (2.61)		12 4.2 (1.29)	5 5.8 (2.17)
5	13 5.8 (1.48)	14 6.4 (1.39)	13 5.4 (1.04)		16 6.3 (1.30)	12 6.4 (2.94)
6	15 9.3 (2.32)	13 7.7 (2.39)	12 7.6 (3.39)		17 12.4 (1.90)	12 8.2 (3.41)
7	18 14.6 (4.78)	12 10.0 (3.25)	15 15.0 (8.71)		18 26.7 (13.82)	15 28.5(15.49)
8	18 28.7(10.54)	14 17.7 (8.65)	13 28.0 (8.00)		7 32.7 (9.53)	5 22.2 (7.05)
9	8 47.1(14.90)	12 20.9(10.08)	4 32.0 (2.16)		2 40.0 (12.73)	
10		5 31.2 (9.34)				
11		2 27.5 (6.36)				
22°C L/D 17/7						
INSTAR: 1	19 4.4 (.51)	14 4.5 (.52)	17 4.7 (.59)		13 4.5 (.52)	
2	19 3.4 (.60)	8 5.9 (2.10)	16 4.4 (1.30)		9 3.2 (.44)	
3	19 4.6 (.95)	11 5.0 (2.14)	16 4.8 (2.07)		12 4.6 (1.08)	4 5.5 (1.73)
4	18 4.3 (1.32)	16 6.1 (2.29)	14 5.5 (1.56)		12 5.2 (1.54)	6 5.7 (1.97)
5	17 5.0 (1.17)	17 7.8 (1.79)	15 5.5 (1.19)		14 5.2 (1.12)	6 4.2 (1.83)
6	18 8.2 (2.62)	18 8.2 (3.00)	16 9.6 (2.19)		18 10.2 (1.69)	11 8.4 (1.97)
7	15 17.1(10.72)	18 19.8(12.03)	16 22.9(10.65)		18 21.4 (14.00)	10 17.2 (8.99)
8	8 23.7(12.8)	11 23.5(10.74)	3,17.6 (2.31)		10 23.8 (6.01)	5 22.6 (9.42)

TABLE XI c: Mean number of days at each instar of P. isabella at each combination of photoperiod and diet at 30°C.

N = Sample size, S.D. = Standard Deviation

DIET	BRAN			CASEIN			WHEAT GERM			ALFALFA			CASEIN-WHEAT GERM			PLANTAIN (fresh)		
	N	DAYS	(S.D.)	N	DAYS	(S.D.)	N	DAYS	(S.D.)	N	DAYS	(S.D.)	N	DAYS	(S.D.)	N	DAYS	(S.D.)
30°C L/D 12/12																		
INSTAR: 1	19	3.4	(.76)	18	3.4	(.61)	18	3.4	(.78)	17	3.5	(.51)	18	3.4	(.70)	1	3.0	(0)
2	18	2.7	(1.19)	6	6.0	(1.55)	15	3.1	(1.68)	3	9.7	(4.04)	10	2.0	(0)			
3	11	3.0	(.30)	7	4.1	(1.07)	9	3.2	(.66)	2	13.0	(4.24)	10	2.8	(.42)	2	5.0	(1.40)
4	11	3.8	(.60)	10	5.4	(2.27)	11	3.7	(.65)	2	8.0	(2.83)	16	4.0	(.36)	1	5.0	(0)
5	16	3.7	(2.05)	8	4.2	(1.39)	13	6.4	(2.59)	1	10.0	(0)	16	3.1	(.72)	7	5.4	(3.50)
6	13	6.7	(2.87)	9	7.4	(5.57)	9	5.6	(2.22)				16	5.2	(1.48)	4	6.2	(.96)
7	2	7.5	(3.53)	3	12.0	(10.39)	6	5.5	(1.51)				6	7.5	(2.07)			
30°C L/D 14/10																		
INSTAR: 1	18	2.9	(.32)	16	3.1	(.25)	17	2.9	(.48)	19	3.2	(1.12)	14	2.6	(.50)	7	2.6	(.53)
2	13	2.8	(1.16)	7	3.7	(1.11)	8	2.7	(1.16)	3	3.7	(1.15)	11	2.3	(.65)			
3	13	3.1	(1.04)	7	5.3	(3.09)	10	3.3	(1.83)				16	3.1	(.34)			
4	13	3.2	(.44)	9	3.8	(.97)	13	4.2	(2.24)				17	3.5	(.94)	9	3.4	(1.13)
5	15	3.7	(.70)	12	6.5	(2.39)	15	4.1	(1.33)				18	4.3	(1.13)	8	4.4	(1.99)
6	19	6.6	(1.89)	14	6.8	(2.19)	16	7.9	(2.32)				17	7.0	(1.87)	12	5.5	(1.73)
7	15	11.8	(5.57)	14	8.9	(2.84)	17	11.4	(5.23)				8	15.9	(7.75)	12	11.7	(3.96)
8	4	18.0	(3.16)	10	9.5	(2.84)	3	13.7	(2.52)									
9				3	13.7	(2.31)												
30°C L/D 15/9																		
INSTAR: 1	20	2.0	(0)	18	3.2	(.71)	12	2.1	(.29)	18	2.8	(.42)	16	2.4	(.50)	3	2.3	(.58)
2	19	2.6	(1.02)	13	4.1	(1.70)	10	3.3	(.48)	8	4.1	(.99)	16	2.1	(.62)	1	3.0	(0)
3	19	3.3	(1.00)	9	3.4	(1.42)	18	3.3	(.67)	5	7.4	(1.52)	16	3.2	(.75)	3	3.0	(1.00)
4	16	3.4	(1.50)	10	3.6	(.70)	16	4.1	(1.45)	6	15.8	(6.21)	15	3.5	(1.46)	7	3.3	(1.11)
5	16	3.7	(1.06)	13	5.3	(1.75)	17	4.6	(1.42)	7	10.3	(7.09)	16	4.0	(1.55)	7	3.6	(.79)
6	19	7.3	(.87)	14	5.6	(.85)	16	7.8	(3.08)	7	15.7	(7.85)	18	7.7	(2.11)	3	5.7	(.58)
7	17	15.4	(8.17)	18	8.3	(1.84)	14	12.6	(5.17)	4	11.5	(3.70)	13	16.8	(6.56)	2	5.5	(.71)
8	3	25.3	(6.43)	8	15.8	(7.04)	5	15.0	(10.27)	1	8.0	(0)	2	34.5	(4.95)	1	15.0	(0)
9							7	19.9	(12.02)	1	22.0	(0)						
30°C L/D 16/8																		
INSTAR: 1	17	2.6	(.79)	18	3.2	(1.10)	18	2.5	(.51)	16	3.3	(1.35)	11	2.3	(.65)	7	3.3	(1.80)
2	16	2.2	(.93)	10	3.1	(.57)	18	2.9	(.80)	2	6.0	(5.66)	8	2.5	(1.07)	1	4.0	(0)
3	14	3.1	(.95)	9	6.7	(2.24)	16	4.1	(2.16)	2	12.0	(2.83)	12	3.2	(1.03)	1	3.0	(0)
4	13	3.2	(1.42)	15	4.9	(1.91)	15	2.9	(1.35)	2	7.0	(5.66)	15	3.0	(1.46)	4	3.7	(1.50)
5	15	3.3	(.80)	16	6.0	(2.03)	14	4.5	(2.38)	1	2.0	(0)	15	3.5	(1.12)	10	4.6	(.97)
6	16	7.4	(2.82)	14	6.9	(2.81)	14	6.4	(2.59)	1	23.0	(0)	15	8.1	(1.46)	12	5.9	(1.78)
7	14	13.9	(6.09)	12	9.5	(4.03)	17	9.8	(3.71)				8	14.7	(3.45)	7	12.0	(6.23)
8	5	14.8	(3.70)	11	17.6	(8.46)	5	15.8	(6.26)				1	19.0	(0)	1	14.0	(0)
9	1	23.0	(0)	1	13.0	(0)												

TABLE XI d: Mean number of days at each instar of P. isabella at each diet at 26°C, photoperiod (L/D) 15/9 and at room (Rm.) temperature, photoperiod (L/D) 11/13. N = Sample size, S.D. = Standard Deviation

DIET		BEAN			CASEIN			WHEAT GERM			ALFALFA			CASEIN-WHEAT GERM			PLANTAIN (fresh)		
		N	DAYS	(S.D.)	N	DAYS	(S.D.)	N	DAYS	(S.D.)	N	DAYS	(S.D.)	N	DAYS	(S.D.)	N	DAYS	(S.D.)
26°C L/D 15/9																			
INSTAR:	1	14	3.0	(0)	16	3.3	(.48)	20	3.0	(0)	19	3.6	(.60)	17	2.9	(.43)	4	3.0	(0)
	2	10	3.0	(0)	10	4.1	(.32)	12	3.4	(.67)	4	6.7	(.50)	9	3.0	(.50)			
	3	8	3.2	(.46)	9	5.2	(2.05)	9	5.8	(2.49)	1	21.0	(0)	6	2.8	(.75)	3	2.0	(1.00)
	4	16	3.9	(.34)	13	5.6	(3.07)	15	4.1	(1.68)				13	4.0	(.82)	4	4.5	(.58)
	5	18	4.9	(1.05)	14	5.4	(.94)	16	6.5	(1.97)				15	5.8	(1.78)	12	4.3	(1.43)
	6	17	6.9	(1.83)	16	7.6	(4.79)	17	8.8	(5.03)				16	8.8	(3.10)	13	6.5	(1.39)
	7	15	14.0	(6.21)	17	13.9	(9.42)	13	12.7	(5.48)				14	16.6	(7.78)	12	14.9	(6.84)
	8	4	20.7	(11.81)	6	18.5	(11.04)	2	26.5	(7.78)							3	23.0	(19.08)
	9				3	21.3	(6.43)										1	38.0	(0)
															PLANTAIN				
RM Temp. L/D 11/13																			
INSTAR:	1	19	3.9	(.70)	20	4.6	(.68)	20	4.3	(.58)	19	4.4	(.51)	20	4.4	(.76)	13	4.5	(2.14)
	2	19	2.6	(.61)	18	3.7	(1.36)	20	2.6	(.81)	12	5.7	(1.37)	14	8.1	(4.43)	11	3.1	(1.51)
	3	19	3.9	(1.13)	17	5.6	(2.45)	19	4.4	(1.12)	11	4.1	(1.37)	9	5.8	(1.71)	13	4.9	(.95)
	4	19	3.2	(1.26)	15	4.1	(.64)	19	2.9	(1.45)	13	7.9	(3.50)	6	7.7	(3.08)	13	3.6	(1.50)
	5	18	4.4	(.78)	15	6.1	(1.94)	19	5.0	(1.41)	13	5.8	(.99)	5	9.0	(3.81)	14	5.1	(2.73)
	6	18	7.4	(.50)	18	6.8	(1.25)	15	7.0	(.85)	15	10.9	(3.27)	5	15.6	(1.95)	13	9.5	(2.87)
	7				1	6.0	(0)				1	16.0	(0)	4	11.7	(3.86)	3	13.0	(5.57)
	8													2	10.0	(1.41)			

e) Mean Head Capsule Widths of *P. isabella* at Each Combination of Photoperiod, Temperature and Diet.

TABLE XII: Mean head capsule widths (mm) at each instar for larvae of _P. isabella_ pupating after 7, 8, 9 and 10 instars on each diet. Data pooled from 8 photoperiods and 4 temperatures tested. N = Sample size, S.D. = Standard Deviation

DIET	BEAN			CASEIN			WHEAT GERM			CASEIN-WHEAT GERM			PLANTAIN (FRESH)			TOTAL		
	N	WIDTH	(S.D.)	N	WIDTH	(S.D.)	N	WIDTH	(S.D.)	N	WIDTH	(S.D.)	N	WIDTH	(S.D.)	N	WIDTH	(S.D.)
7 INSTARS																		
INSTAR:I	99	.4	(0)	12	.4	(.04)	54	.4	(.01)	0	—	(—)	19	.4	(0)	184	.4	(.01)
II	96	.5	(.05)	1	.6	(—)	52	.5	(.04)	6	.5	(.04)	14	.5	(.19)	169	.5	(.07)
III	83	.8	(.06)	15	.9	(.10)	35	.8	(.05)	11	.9	(.13)	11	.8	(.04)	155	.8	(.07)
IV	99	1.2	(.10)	10	1.1	(.13)	51	1.3	(.13)	18	1.3	(.14)	34	1.3	(.15)	212	1.3	(.19)
V	119	1.8	(.13)	11	1.7	(.18)	53	1.9	(.12)	31	1.8	(.13)	41	1.8	(.17)	255	1.8	(.14)
VI	138	2.6	(.18)	13	2.5	(.19)	70	2.6	(.19)	32	2.4	(.28)	31	2.5	(.34)	284	2.6	(.23)
VII	82	3.7	(.25)	10	3.6	(.18)	46	3.5	(.25)	36	3.4	(.31)	28	3.5	(.29)	202	3.6	(.29)
8 INSTARS																		
INSTAR:I	4	.4	(0)	17	.4	(.02)	3	.4	(0)	3	.4	(0)	13	.4	(0)	40	.4	(.01)
II	15	.6	(.04)	14	.5	(.06)	24	.6	(.03)	16	.5	(.04)	10	.5	(.03)	82	.5	(.11)
III	23	.8	(.05)	25	.8	(.11)	27	.8	(.06)	26	.8	(.04)	22	.8	(.06)	123	.8	(.07)
IV	37	1.2	(.09)	24	1.1	(.10)	43	1.2	(.16)	43	1.2	(.15)	47	1.2	(.12)	194	1.2	(.14)
V	54	1.7	(.12)	33	1.5	(.24)	43	1.7	(.22)	44	1.7	(.16)	50	1.7	(.13)	224	1.7	(.19)
VI	54	2.3	(.21)	27	2.1	(.25)	48	2.2	(.27)	61	2.3	(.21)	65	2.3	(.18)	255	2.3	(.23)
VII	53	2.9	(.25)	42	2.8	(.29)	54	2.9	(.30)	60	3.0	(.30)	60	3.1	(.21)	269	2.9	(.28)
VIII	56	3.6	(.31)	36	3.6	(.36)	70	3.7	(.05)	65	3.7	(.27)	58	3.9	(.27)	285	3.7	(.31)
9 INSTARS																		
INSTAR:I	0	—	(—)	5	.4	(0)	0	—	(—)	0	—	(—)	0	—	(—)	5	.4	(0)
II	7	.6	(.00)	12	.6	(.04)	11	.5	(.03)	6	.5	(.04)	0	—	(—)	36	.5	(.03)
III	14	.8	(.07)	19	.7	(.07)	11	.8	(.09)	9	.8	(.05)	4	.8	(.03)	57	.8	(.08)
IV	18	1.1	(.13)	25	1.1	(.12)	10	1.2	(.18)	11	1.2	(.13)	8	1.1	(.05)	72	1.1	(.13)
V	22	1.7	(.14)	16	1.4	(.03)	14	1.6	(.19)	15	1.6	(.16)	8	1.5	(.12)	75	1.6	(.19)
VI	26	2.2	(.20)	30	1.9	(.04)	20	2.0	(.13)	15	2.2	(.11)	13	2.3	(.12)	104	2.2	(.21)
VII	22	2.6	(.23)	34	2.4	(.28)	17	2.5	(.16)	13	2.6	(.13)	11	2.7	(.19)	97	2.5	(.25)
VIII	28	3.2	(.27)	33	2.9	(.24)	18	3.1	(.20)	18	3.3	(.18)	113	3.3	(.17)	110	3.1	(.26)
IX	29	3.8	(.30)	38	3.6	(.30)	25	3.9	(.29)	19	3.9	(.18)	13	4.2	(.15)	124	3.8	(.31)
10 INSTARS																		
INSTAR:I	1	.4	(—)	0	-.-	(—)	0	—	(—)	0	—	(—)				1	.4	(—)
II	2	.5	(0)	2	.5	(0)	2	.5	(.07)	1	.5	(0)				7	.5	(.04)
III	3	.8	(.05)	4	.8	(.08)	2	.8	(.07)	1	.8	(0)				10	.8	(.06)
IV	6	1.1	(.28)	7	1.0	(.07)	4	1.2	(.08)	1	1.2	(0)				18	1.1	(.19)
V	8	1.5	(.17)	11	1.6	(.13)	5	1.5	(.18)	2	1.8	(.11)				26	1.4	(.20)
VI	10	1.8	(.16)	12	1.8	(.26)	5	2.0	(.18)	2	2.2	(.21)				29	1.9	(.24)
VII	9	2.4	(.21)	11	2.1	(.17)	5	2.3	(.27)	2	2.8	(.07)				27	2.3	(.27)
VIII	10	2.9	(.30)	7	2.8	(.17)	6	3.0	(.34)	2	3.3	(.14)				25	2.9	(.29)
IX	11	3.4	(.22)	12	3.1	(.24)	6	3.6	(.38)	2	3.7	(.14)				31	3.3	(.32)
X	11	4.0	(.20)	13	4.0	(.23)	6	3.9	(.26)	2	4.1	(.07)				32	3.9	(.22)

TABLE XIII a: Mean head capsule widths at each instar of P. isabella at each combination of photoperiod and diet at room (Rm) temperature. Underlined results designate last instar head capsule widths and do not necessarily correspond to the instar number.

N = Sample size, S.D. = Standard Deviation

DIET	BEAN			CASEIN			WHEAT GERM			ALFALFA			PLANTAIN			PLANTAIN (fresh)		
	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)
RM Temp. 9/15																		
INSTAR: I	15	.4	(0)	13	.4	(.04)	18	.4	(0)	12	.4	(.01)	10	.4	(.03)	6	.4	(0)
II	9	.6	(.05)	1	.6	(0)	12	.6	(.03)	4	.5	(.02)	7	.5	(0)	2	.6	(.07)
III	8	.9	(.05)	8	.8	(.07)	13	.8	(.04)	9	.6	(.05)	5	.7	(.09)	6	.8	(.04)
IV	12	1.3	(.09)	9	1.0	(.10)	15	1.3	(.07)	6	.9	(.12)	3	.9	(.06)	6	1.4	(.06)
V	12	1.9	(.12)	14	1.6	(.13)	12	1.9	(.14)	9	1.5	(.21)	4	1.2	(.17)	9	1.9	(.14)
VI	18	2.6	(.19)	14	2.4	(.22)	15	2.8	(.19)	12	2.7	(.12)	4	1.4	(.20)	6	2.5	(.19)
VII	10	3.6	(.19)	5	2.7	(.13)	7	3.8	(.22)	2	3.8	(.14)	2	2.1	(.14)	3	3.4	(0)
VIII				6	3.6	(.12)							2	2.3	(.49)			
IX													1	2.7	(0)			
X													1	3.2	(0)			
XI													1	3.7	(0)			
RM Temp. 12/12																		
INSTAR: I	15	.4	(0)	15	.4	(0)	17	.4	(0)	15	.4	(.02)	13	.4	(.02)	2	.4	(0)
II	17	.5	(0)	3	.6	(.11)	14	.5	(.02)	5	.5	(0)	6	.5	(0)	1	.5	(0)
III	8	.7	(.05)	10	.8	(.14)	7	.8	(.07)	6	.7	(.06)	1	.7	(0)	5	.8	(.07)
IV	11	1.1	(.05)	8	1.2	(.10)	17	1.2	(.09)	5	1.0	(.08)	1	1.8	(0)	10	1.3	(.15)
V	15	1.8	(.14)	9	1.6	(.16)	11	1.8	(.16)	3	1.2	(.06)	1	2.4	(0)	5	2.0	(.16)
VI	15	2.6	(.16)	6	2.1	(.15)	19	2.6	(.11)	7	1.7	(.17)	1	3.3	(0)	12	2.4	(.18)
VII	8	3.8	(.17)	8	2.6	(.11)	4	3.6	(.09)	8	2.6	(.27)				3	3.4	(.46)
VIII				4	3.8	(.08)				0	–	–						
RM Temp. 13/11																		
INSTAR: I	11	.4	(0)	15	.4	(.01)	15	.4	(.02)	13	.4	(.02)	19	.4	(.01)	2	.4	(0)
II	5	.5	(.05)	2	.5	(0)	12	.5	(.04)	8	.5	(.02)	7	.5	(.02)	5	.5	(.04)
III	1	.8	(0)	16	.7	(.05)	7	.8	(.08)	8	.7	(.05)	3	.6	(0)	4	.9	(.02)
IV	4	1.1	(.05)	12	1.0	(.06)	15	1.3	(.07)	7	.8	(.06)	1	.9	(0)	8	1.4	(.16)
V	11	1.7	(.14)	11	1.5	(.23)	13	1.8	(.12)	5	1.4	(.15)	0	–	–	14	1.9	(.14)
VI	17	2.6	(.11)	9	2.5	(.27)	14	2.5	(.15)	11	2.5	(.27)	1	1.3	(0)	5	2.6	(.22)
VII	4	4.0	(.11)	2	2.6	(.35)	1	3.9	(0)	3	3.4	(.53)	1	1.6	(0)	2	3.5	(.21)
VIII				0	–	–							0	–	–			
RM Temp. 15/9																		
INSTAR: I	18	.4	(0)	17	.4	(0)	16	.4	(0)	13	.4	(0)	17	.4	(0)	11	.4	(0)
II	18	.6	(.03)	7	.5	(.04)	13	.5	(.03)	9	.5	(.04)	14	.5	(.02)	6	.5	(.02)
III	13	.8	(.06)	11	.7	(.09)	9	.8	(.04)	9	.7	(.04)	1	.6	(0)	10	.7	(.04)
IV	17	1.2	(.08)	9	1.0	(.11)	15	1.2	(.07)	7	1.0	(.14)	1	.8	(0)	14	1.2	(.09)
V	16	1.8	(.10)	13	1.4	(.11)	15	1.8	(.10)	9	1.3	(.13)	1	.9	(0)	14	1.7	(.10)
VI	20	2.7	(.14)	12	2.0	(.17)	17	2.6	(.13)	13	1.9	(.18)				17	2.5	(.26)
VII	5	3.2	(.15)	17	2.8	(.18)	3	3.1	(.21)	6	2.6	(.26)				13	3.1	(.19)
VIII	10	3.9	(.18)	3	3.0	(.11)	6	3.8	(.12)	3	3.2	(.15)				8	4.1	(.16)
IX				14	3.8	(.11)				5	3.7	(.23)						

TABLE XIII b: Mean head capsule widths at each instar of *P. isabella* at each combination of photoperiod and diet at 22°C. Underlined results designate last instar head capsule widths and do not necessarily correspond to the instar number.

N = Sample size, S.D. = Standard Deviation

DIET	BEAN			CASEIN			WHEAT GERM			ALFALFA			CASEIN-WHEAT GERM			PLANTAIN (fresh)		
	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)
22°C L/D 9/15																		
INSTAR: I	11	.4	(.01)	13	.4	(0)	13	.4	(.01)	16	.4	(0)				7	.4	(0)
II	15	.5	(.03)	8	.5	(.04)	14	.6	(.03)	11	.5	(.01)				5	.6	(.08)
III	16	.8	(.08)	7	.7	(.05)	14	.8	(.05)	6	.7	(.04)				12	.9	(.05)
IV	13	1.3	(.06)	11	1.0	(.03)	11	1.3	(.09)	6	.9	(0)				12	1.3	(.14)
V	15	1.9	(.15)	2	1.5	(.03)	11	1.8	(.13)	6	1.3	(.14)				13	2.0	(.23)
VI	17	2.6	(.16)	6	2.0	(.25)	17	2.6	(.12)	3	1.8	(.15)				10	2.7	(.15)
VII	9	3.7	(.10)	13	2.7	(.20)	10	3.5	(.16)	2	2.5	(.14)				3	3.8	(.26)
VIII				3	3.7	(.17)				1	3.5	(0)						
22°C L/D 15/9																		
INSTAR: I	15	.4	(0)	10	.4	(0)	13	.4	(0)	14	.4	(0)				10	.4	(0)
II	13	.6	(.04)	5	.6	(.04)	14	.6	(.04)	11	.5	(.02)				6	.6	(.04)
III	16	.8	(.03)	6	.7	(.05)	13	.8	(.04)	5	.7	(.07)				11	.9	(.06)
IV	16	1.2	(.08)	10	1.0	(.09)	16	1.2	(.05)	5	.8	(.04)				16	1.3	(.10)
V	18	1.8	(.08)	15	1.3	(.08)	16	1.8	(.05)	9	1.2	(.10)				15	1.9	(.11)
VI	18	2.7	(.11)	12	1.9	(.21)	18	2.7	(.11)	6	1.5	(.18)				17	2.7	(.12)
VII	1	3.1	(0)	13	2.6	(.24)	8	3.7	(.10)	5	2.0	(.34)				10	3.2	(.14)
VIII	17	3.9	(.15)	2	3.0	(0)				5	2.2	(.44)				14	4.0	(.29)
IX				8	3.7	(.17)				3	2.5	(.46)						
X										8	3.3	(.65)						
22°C L/D 16/8																		
INSTAR: I	1	.4	(0)	0	–	–	0	–	–	4	.4	(0)	2	.4	(0)	2	.4	(0)
II	2	.5	(.03)	4	.5	(0)	7	.5	(.04)	1	.5	(0)	4	.5	(0)	2	.5	(0)
III	5	.8	(.05)	2	.9	(0)	7	.8	(.03)				9	.8	(.04)	4	.8	(.03)
IV	12	1.1	(.06)	6	1.0	(.10)	9	1.2	(.11)				11	1.1	(.08)	13	1.1	(.06)
V	12	1.5	(.07)	13	1.1	(.13)	13	1.5	(.21)				13	1.7	(.11)	8	1.7	(.19)
VI	16	2.0	(.24)	15	1.6	(.28)	15	2.0	(.15)				16	2.3	(.11)	17	2.3	(.14)
VII	16	2.5	(.20)	15	2.1	(.39)	14	2.5	(.34)				16	2.9	(.26)	13	3.0	(.31)
VIII	18	3.2	(.25)	14	2.7	(.34)	12	3.1	(.27)				7	3.4	(.14)	5	3.4	(.12)
IX	8	3.6	(.13)	11	3.0	(.35)	4	3.6	(.36)				2	3.7	(.14)	18	4.0	(.12)
X	17	3.9	(.20)	5	3.4	(.23)	18	3.9	(.37)				18	3.8	(.33)			
XI				2	3.8	(.07)												
XII				17	3.9	(.29)												
22°C L/D 17/7																		
INSTAR: I	0	–	–	2	.4	(0)	1	.4	(0)				0	–	–	2	.4	(0)
II	7	.5	(0)	9	.5	(.02)	13	.6	(.03)				4	.5	(.02)	2	.5	(0)
III	12	.8	(.05)	12	.7	(.04)	10	.8	(.05)				11	.8	(.02)	7	.8	(.05)
IV	11	1.0	(.18)	13	1.0	(.08)	9	1.0	(.09)				10	1.1	(.06)	6	1.3	(.21)
V	11	1.6	(.19)	11	1.5	(.32)	12	1.6	(.19)				12	1.5	(.13)	12	1.6	(.22)
VI	19	2.1	(.30)	15	1.9	(.24)	12	2.2	(.24)				17	2.2	(.11)	17	2.4	(.17)
VII	9	2.6	(.51)	16	2.7	(.45)	12	2.9	(.25)				15	2.7	(.25)	12	2.8	(.20)
VIII	8	3.0	(.41)	10	3.1	(.24)	3	3.1	(.25)				10	3.2	(.19)	5	3.3	(.23)
IX	2	3.2	(.07)	12	3.9	(.20)	18	3.8	(.17)				17	3.9	(.19)	12	4.1	(.13)
X	17	3.9	(.32)															

TABLE XIII c: Mean head capsule widths at each instar of *P. isabella* at each combination of photoperiod and diet at 30°C. Underlined results designate last instar head capsule widths and do not necessarily correspond to the instar number.

N = Sample size, S.D. = Standard Deviation

DIET	BRAN			CASEIN			WHEAT GERM			ALFALFA			CASEIN-WHEAT GERM			PLANTAIN (fresh)		
	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)
30°C L/D 12/12																		
INSTAR: I	1	.4	(0)	6	.5	(0)	0	-	-	3	.3	(0)	0	-	-	0	-	-
II	5	.56	(.02)	1	.6	(0)	4	.5	(0)	3	.65	(.05)	4	.5	(0)	0	-	-
III	8	.8	(0)	10	.87	(.10)	4	.8	(0)	4	1.02	(.05)	4	.81	(.02)	1	.92	(0)
IV	11	1.2	(.10)	5	1.1	(.05)	8	1.5	(.22)	2	1.2	(.07)	6	1.1	(.10)	4	1.1	(.06)
V	14	1.8	(.12)	5	1.7	(.28)	9	1.7	(.11)	2	1.5	(.28)	13	1.7	(.16)	5	1.7	(.24)
VI	13	2.4	(.20)	9	2.4	(.24)	10	2.3	(.31)	2	2.2	(.49)	13	2.0	(.20)	2	2.7	(.14)
VII	2	3.0	(.14)	4	2.9	(.36)	5	2.7	(.47)				8	2.7	(.29)	7	3.6	(.16)
VIII	18	3.5	(.15)	11	3.6	(.22)	16	3.4	(.41)				18	3.6	(.18)			
30°C L/D 14/10																		
INSTAR: I	0	-	-	0	-	-	1	.4	(0)	0	-	-	0	-	-	0	-	-
II	5	.55	(.05)	4	.5	(.02)	4	.6	(.03)	0	-	-	5	.6	(.04)	0	-	-
III	8	.8	(.02)	6	.9	(.10)	6	.9	(.09)				7	.8	(.06)	0	-	-
IV	9	1.2	(.11)	11	1.1	(.12)	13	1.2	(.12)				12	1.3	(.09)	10	1.3	(.18)
V	17	1.7	(.11	11	1.4	(.07)	8	1.7	(.21)				15	1.8	(.12)	9	1.8	(.07)
VI	17	2.3	(.26)	12	2.0	(.26)	11	2.2	(.37)				16	2.5	(.17)	13	2.5	(.25)
VII	12	3.0	(.24)	8	2.6	(.42)	12	2.9	(.26)				7	3.3	(.25)	12	3.1	(.23)
VIII	3	3.2	(.25)	6	3.0	(.12)	3	3.1	(.06)				18	3.6	(.31)	17	3.7	(.35)
IX	20	3.7	(.26)	3	3.0	(.15)	19	3.7	(.20)									
X				14	3.7	(.25)												
30°C L/D 15/9																		
INSTAR: I	2	.4	(0)	0	-	-	2	.4	(0)	0	-	-	1	.4	(0)	0	-	-
II	5	.55	(.03)	5	.55	(.05)	4	.6	(.02)	4	.5	(.02)	7	.6	(.11)	1	.55	(0)
III	9	.8	(.08)	9	.8	(.12)	8	.8	(.05)	2	.6	(0)	7	.8	(.06)	3	.8	(.08)
IV	11	1.3	(.09)	10	1.1	(.14)	10	1.4	(.12)	3	1.2	(.20)	13	1.3	(.10)	8	1.3	(.10)
V	17	1.8	(.10)	10	1.5	(.25)	12	1.8	(.16)	2	1.7	(.03)	17	1.8	(.13)	9	1.7	(.15)
VI	17	2.3	(.17)	16	2.1	(.16)	12	2.3	(.30)	3	2.9	(.38)	18	2.4	(.15)	13	2.4	(.17)
VII	18	2.9	(.16)	17	2.6	(.25)	10	2.8	(.27)	4	2.5	(.77)	11	2.9	(.10)	7	2.9	(.27)
VIII	3	3.2	(.23)	6	2.9	(.22)	4	3.1	(.29)	1	1.6	(0)	2	3.4	(.14)	1	3.0	(0)
IX	20	3.5	(.25)	17	3.4	(.31)	2	3.5	(.56)	1	2.7	(0)	17	3.5	(.26)	10	3.5	(.33)
X							7	3.3	(.50)									
30°C L/D 16/8																		
INSTAR: I	1	.4	(0)	1	.4	(0)	0	-	-	0	-	-	0	-	-	0	-	-
II	2	.6	(.03)	7	.5	(0)	4	.5	(.05)	2	.5	(.07)	5	.6	(.04)	1	.5	(0)
III	6	.8	(0)	9	.8	(.07)	4	.9	(.06)	2	.9	(0)	5	.9	(.05)	5	.8	(0)
IV	10	1.2	(.07)	10	1.1	(.10)	7	1.2	(.15)	2	1.0	(.21)	9	1.3	(.09)	9	1.2	(.08)
V	16	1.8	(.11)	5	1.5	(.20)	7	1.5	(.08)	1	1.8	(0)	11	1.7	(.11)	13	1.8	(.11)
VI	19	2.3	(.15)	11	1.9	(.16)	15	2.0	(.27)	1	2.9	(0)	13	2.4	(.20)	14	2.2	(.30)
VII	16	2.7	(.26)	12	2.3	(.15)	12	2.6	(.30)	1	3.3	(0)	8	2.8	(.30)	8	3.0	(.20)
VIII	4	2.9	(.25)	10	2.7	(.18)	1	2.9	(0)				2	3.2	(.21)	1	3.3	(0)
IX	1	3.0	(0)	1	3.1	(0)	18	3.4	(.24)				16	3.3	(.29)	11	3.6	(.33)
X	16	3.3	(.24)	16	3.3	(.17)												

TABLE XIII d: Mean head capsule widths at each instar of *P. isabella* at each diet, at 26^{o}C, photoperiod (L/D) 15/9 and at room (Rm.) temperature, photoperiod (L/D) 11/13.

N = Sample size, S.D. = Standard Deviation

DIET	BEAN			CASEIN			WHEAT GERM			ALFALFA			CASEIN-WHEAT GERM			PLANTAIN (fresh)		
	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)	N	WIDTH (mm)	(S.D.)
26°C L/D 15/9																		
INSTAR: I	0	-	-	0	-	-	0	-	-	1	.4	(0)	1	.4	(0)	1	.4	(0)
II	5	.6	(.02)	3	.5	(.03)	6	.6	(.02)	0	-	-	5	.6	(.02)	0	-	-
III	5	.8	(.03)	10	.7	(.08)	7	.9	(.06)	1	.8	(0)	5	.9	(.16)	2	.8	(.07)
IV	12	1.3	(.05)	10	1.0	(.06)	13	1.2	(.17)				14	1.4	(.19)	13	1.2	(.09)
V	16	1.9	(.06)	16	1.4	(.15)	14	1.7	(.24)				14	1.8	(.15)	10	1.7	(.18)
VI	13	2.3	(.12)	12	1.7	(.13)	16	2.3	(.39)				17	2.5	(.23)	16	2.4	(.17)
VII	13	3.0	(.23)	16	2.5	(.46)	11	2.8	(.32)				10	3.2	(.17)	12	3.1	(.20)
VIII	3	3.0	(.18)	5	2.9	(.28)	2	3.0	(.32)				18	3.9	(.24)	2	3.4	(.14)
IX	16	3.9	(.22)	3	3.1	(.06)	20	3.9	(.17)							1	3.5	(0)
X				17	3.9	(.27)										17	4.0	(.40)
RM Temp. 11/13														PLANTAIN				
INSTAR: I	12	.4	(0)	14	.4	(.03)	14	.4	(.02)	15	.4	(.02)	13	.4	(.01)	9	.4	(0)
II	13	.5	(.05)	2	.5	(.07)	11	.5	(.04)	6	.5	(.02)	4	.5	(.05)	11	.5	(.04)
III	13	.8	(.08)	11	.8	(.11)	11	.8	(.05)	9	.7	(.03)	6	.7	(.07)	5	.8	(.05)
IV	16	1.2	(.10)	10	1.1	(.15)	15	1.3	(.10)	5	1.0	(.06)	5	.9	(.05)	6	1.3	(.05)
V	16	1.8	(.14)	10	1.7	(.16)	12	2.0	(.16)	10	1.6	(.22)	3	1.2	(.23)	9	1.9	(.06)
VI	19	2.6	(.21)	9	2.6	(.25)	16	2.7	(.12)	11	2.6	(.18)	2	1.7	(0)	7	2.6	(.15)
VII	7	3.7	(.22)	4	3.4	(.310	7	3.6	(.22)	3	3.6	(.10)	2	1.8	(.42)	2	3.1	(.11)
VIII													4	3.9	(.29)	2	3.7	(.35)

f) Percent Larval Mortality of *P. isabella* at Each Combination of Photoperiod, Temperature and Diet

TABLE XIV: Percent pre-diapause mortality in P. isabella larvae at each combination of photoperiod, temperature and diet.

N = Sample size

*This total does not include the Alfalfa, Casein-Wheat Germ and Plantain diets.

DIET	BEAN		CASEIN		WHEAT GERM		ALFALFA		CASEIN-WHEAT GERM		PLANTAIN		PLANTAIN (FRESH)		TOTAL*	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
RM 9/15	1	5	0	0	1	5	5	25			15	85	13	65	20	25
RM 12/12	0	0	3	15	0	0	7	40			19	95	15	75	18	22
RM 13/11	2	10	2	10	0	0	6	30			19	95	9	45	13	16
RM 15/9	0	0	1	5	1	5	6	30			19	95	3	15	5	6
RM 11/13	0	0	0	0	0	0	5	25			16	80	5	25	5	6
22 9/15	2	10	5	25	0	0	17	85			20	100	4	20	11	14
22 15/9	0	0	6	30	1	5	11	55			19	55	2	10	9	11
22 16/8	2	10	3	15	4	20	20	100	3	15			3	15	12	15
22 17/7	1	5	2	10	2	10	20	100	2	10			2	10	7	9
26 15/9	1	5	3	15	0	0	20	100	3	15			4	20	8	10
30 12/12	1	5	9	45	1	5	19	95	1	5			11	55	22	27
30 14/10	0	0	6	35	1	15	20	100	1	5			4	16	11	14
30 15/9	0	0	2	10	0	0	14	70	0	0			7	35	9	11
30 16/8	3	15	3	15	2	10	19	95	3	15			7	35	7	35
TOTAL	13	5	45	16	13	5	189	67	13	9	127	91	89	32	160	14

TABLE XV a: Percent mortality at each instar in _P. isabella_ at each combination of photoperiod and diet, at room (Rm.) temperature.

N = Sample size

DIET	BEAN		CASEIN		WHEAT GERM		ALFALFA		PLANTAIN		PLANTAIN (fresh)	
	N	%	N	%	N	%	N	%	N	%	N	%
RM Temp. 9/15												
INSTAR: I	0	0	0	0	0	0	1	5	0	0	6	30
II	0	0	0	0	1	5	0	0	1	5	3	21
III	0	0	0	0	0	0	1	5	9	47	0	0
IV	1	5	0	0	0	0	2	11	4	40	0	0
V	0	0	0	0	0	0	1	6	1	17	0	0
VI	0	0	0	0	0	0	0	0	0	0	2	18
VII	0	0	0	0	0	0	0	0	0	0	2	22
TOTAL:	1	5	0	0	1	5	5	25	15	85	13	65
RM Temp. 12/12												
INSTAR: I	0	0	0	0	0	0	0	0	0	0	2	10
II	0	0	1	5	0	0	1	5	3	15	2	11
III	0	0	0	0	0	0	2	10	10	59	1	6
IV	0	0	1	5	0	0	3	18	5	71	0	0
V	0	0	0	0	0	0	0	0	1	50	0	0
VI	0	0	1	5	0	0	1	7	-	-	0	0
VII	0	0	0	0	0	0	0	0	-	-	10	67
TOTAL:	0	0	3	15	0	0	7	40	19	95	15	75
RM Temp. 13/11												
INSTAR: I	0	0	0	0	0	0	0	0	0	0	5	25
II	2	10	0	0	0	0	1	5	3	15	0	0
III	0	0	1	5	0	0	1	5	8	47	0	0
IV	0	0	1	5	0	0	2	11	5	55	0	0
V	0	0	0	0	0	0	2	12	1	33	0	0
VI	0	0	0	0	0	0	0	0	0	0	4	26
VII	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL:	2	10	2	10	0	0	6	30	19	95	9	45
RM Temp. 15/9												
INSTAR: I	0	0	0	0	0	0	0	0	0	0	2	10
II	0	0	0	0	0	0	2	10	2	10	0	0
III	0	0	1	5	1	5	1	5	15	83	1	5
IV	0	0	0	0	0	0	2	12	2	66	0	0
V	0	0	0	0	0	0	1	7	0	0	0	0
VI	0	0	0	0	0	0	0	0	0	0	0	0
VII	0	0	0	0	0	0	0	0	-	-	0	0
TOTAL:	0	0	1	5	1	5	6	30	19	95	3	15

TABLE XV b: Percent mortality at each instar in *P. isabella* at each combination of photoperiod and diet, at 22°C. N = Sample size

DIET	BEAN		CASEIN		WHEAT GERM		ALFALFA		PLANTAIN		PLANTAIN (fresh)	
	N	%	N	%	N	%	N	%	N	%	N	%
22°C L/D 9/15												
INSTAR: I	2	10	2	10	0	0	0	0	0	0	0	0
II	0	0	0	0	0	0	2	10	5	25	1	5
III	0	0	2	11	0	0	6	33	9	60	1	5
IV	0	0	1	6	0	0	2	17	6	100	0	0
V	0	0	0	0	0	0	3	30	–	–	0	0
VI	0	0	0	0	0	0	2	28	–	–	1	5
VII	0	0	0	0	0	0	1	20	–	–	1	6
VIII	–	–	0	0	–	–	1	25	–	–	–	–
TOTAL:	2	10	5	25	0	0	17	85	20	100	4	20
22°C L/D 15/9												
INSTAR: I	0	0	1	5	0	0	0	0	1	5	2	10
II	0	0	2	10	0	0	2	10	7	36	0	0
III	0	0	0	0	0	0	6	33	9	75	0	0
IV	0	0	1	6	0	0	0	0	1	33	0	0
V	0	0	1	6	1	5	1	8	0	0	0	0
VI.	0	0	0	0	0	0	1	9	0	0	0	0
VII	0	0	0	0	0	0	0	0	1	50	0	0
VIII	–	–	1	7	–	–	1	11	0	0	0	0
TOTAL:	0	0	6	30	1	5	11	55	19	55	2	10
22°C L/D 16/8									CASEIN-WHEAT GERM			
INSTAR: I	0	0	0	0	0	0	5	25	1	5	2	10
II	0	0	2	10	1	5	14	93	0	0	0	0
III	2	10	0	0	0	0	1	100	1	5	0	0
IV	0	0	0	0	0	0	–	–	0	0	0	0
V	0	0	0	0	0	0	–	–	0	0	0	0
VI	0	0	0	0	0	0	–	–	0	0	0	0
VII	0	0	0	0	0	0	–	–	0	0	0	0
VIII	0	0	0	0	3	16	–	–	1	5	1	5
IX	0	0	0	0	0	0	–	–	0	0	0	0
X	0	0	1	5	0	0	–	–	0	0	0	0
TOTAL:	2	10	3	15	4	20	20	100	3	15	3	15
22°C L/D 17/7												
INSTAR: I	0	0	0	0	0	0	0	0	1	5	1	5
II	0	0	2	10	1	5	17	85	0	0	1	5
III	0	0	0	0	0	0	2	67	0	0	0	0
IV	0	0	0	0	0	0	1	100	1	5	0	0
V	0	0	0	0	0	0	–	–	0	0	0	0
VI	0	0	0	0	0	0	–	–	0	0	0	0
VII	0	0	0	0	0	0	–	–	0	0	0	0
VIII	0	0	0	0	1	5	–	–	0	0	0	0
IX	1	5	0	0	0	0	–	–	0	0	0	0
TOTAL:	1	5	2	10	2	10	20	100	2	10	2	10

TABLE XV c: Percent mortality at each instar in *P. isabella* at each combination of photoperiod and diet at 30°C.

N = Sample size

DIET	BEAN		CASEIN		WHEAT GERM		ALFALFA		CASEIN -WHEAT GERM		PLANTAIN (fresh)	
	N	%	N	%	N	%	N	%	N	%	N	%
30°C L/D 12/12												
INSTAR: I	0	0	0	0	0	0	2	10	0	0	8	40
II	1	5	0	0	1	5	13	72	1	5	1	8
III	0	0	0	0	0	0	1	20	0	0	1	9
IV	0	0	9	45	0	0	0	0	0	0	1	10
V	0	0	0	0	0	0	1	25	0	0	0	0
VI	0	0	0	0	0	0	2	67	0	0	0	0
VII	0	0	0	0	0	0	-	-	0	0	0	0
TOTAL:	1	5	9	45	1	5	19	95	1	5	11	55
30°C L/D 14/10												
INSTAR: I	0	0	0	0	0	0	0	0	0	0	2	10
II	0	0	2	10	1	5	16	80	0	0	1	5
III	0	0	0	0	0	0	3	19	0	0	0	0
IV	0	0	1	5	0	0	0	0	0	0	0	0
V	0	0	2	12	0	0	1	100	0	0	0	0
VI	0	0	0	0	0	0	-	-	1	5	0	0
VII	0	0	0	0	0	0	-	-	0	0	0	0
VIII	0	0	1	7	0	0	-	-	0	0	1	6
IX	0	0	0	0	0	0	-	-	-	-	0	0
TOTAL:	0	0	6	35	1	15	20	100	1	5	4	16
30°C L/D 15/9												
INSTAR: I	0	0	0	0	0	0	2	10	0	0	7	35
II	0	0	2	10	0	0	7	39	0	0	0	0
III	0	0	0	0	0	0	2	18	0	0	0	0
IV	0	0	0	0	0	0	2	22	0	0	0	0
V	0	0	0	0	0	0	0	0	0	0	0	0
VI	0	0	0	0	0	0	0	0	0	0	0	0
VII	0	0	0	0	0	0	1	14	0	0	0	0
VIII	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL:	0	0	2	10	0	0	14	70	0	0	7	35
30°C L/D 16/8												
INSTAR: I	0	0	0	0	1	5	2	10	3	15	1	5
II	0	0	2	10	0	0	14	78	0	0	1	5
III	0	0	0	0	0	0	2	50	0	0	3	17
IV	0	0	0	0	0	0	0	0	0	0	0	0
V	0	0	0	0	0	0	1	50	0	0	0	0
VI	0	0	1	5	0	0	0	0	0	0	0	0
VII	1	5	0	0	1	5	-	-	0	0	0	0
VIII	2	10	0	0	0	0	-	-	0	0	1	7
IX	0	0	0	0	0	0	-	-	0	0	1	7
TOTAL	3	15	3	15	2	10	19	95	3	15	7	35

TABLE XV d: Percent mortality at each instar in P. isabella at each diet at 26°C, photoperiod (L/D) 15/9 and at room (Rm.) temperature, photoperiod (L/D) 11/13.

N = Sample size

DIET	BEAN		CASEIN		WHEAT GERM		ALFALFA		CASEIN-WHEAT GERM		PLANTAIN (fresh)	
	N	%	N	%	N	%	N	%	N	%	N	%
26°C L/D 15/9												
INSTAR: I	1	5	0	0	0	0	1	5	0	0	2	10
II	0	0	1	5	0	0	15	79	0	0	1	5
III	0	0	0	0	0	0	3	75	1	5	0	0
IV	0	0	0	0	0	0	1	100	0	0	0	0
V	0	0	1	5	0	0	-	-	1	5	0	0
VI	0	0	0	0	0	0	-	-	0	0	0	0
VII	0	0	0	0	0	0	-	-	1	5	1	6
VIII	0	0	1	5	0	0	-	-	0	0	0	0
TOTAL:	1	5	3	15	0	0	20	100	3	15	4	20
									PLANTAIN			
RM Temp. 11/13												
INSTAR: I	0	0	0	0	0	0	1	5	0	0	3	15
II	0	0	0	0	0	0	1	5	5	25	0	0
III	0	0	0	0	0	0	1	5	5	33	1	6
IV	0	0	0	0	0	0	1	6	3	30	0	0
V	0	0	0	0	0	0	0	0	1	14	0	0
VI	0	0	0	0	0	0	0	0	0	0	0	0
VII	0	0	0	0	0	0	1	6	1	16	1	6
VIII	-	-	0	0	-	-	0	0	1	20	0	0
TOTAL:	0	0	0	0	0	0	5	25	16	80	5	25

g) Mean Growth Rates of *P. isabella* Larvae at Each Combination of Photoperiod, Temperature and Diet

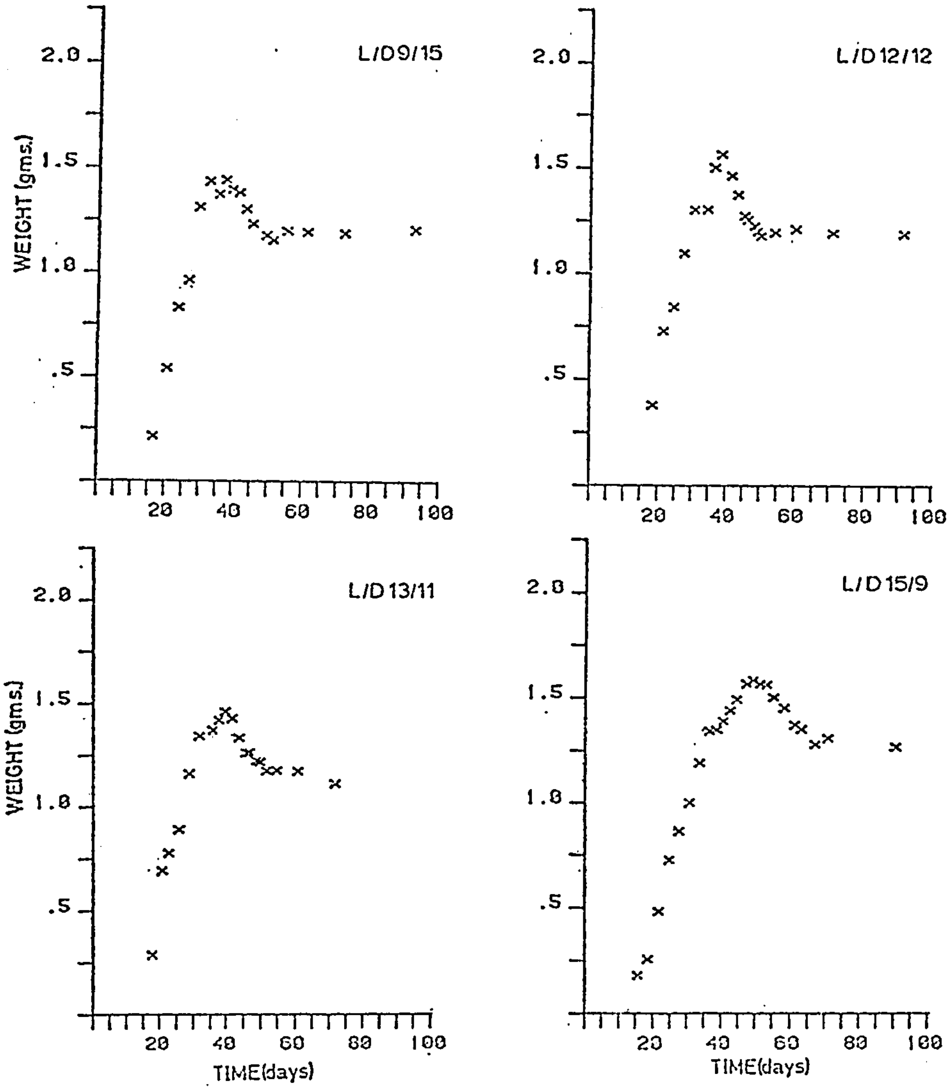


FIG. VIII a: Mean growth rates of P. isabella larvae at room temperature on Bean diet and at 4 different photoperiods. L/D = Light/Dark hrs. Data pooled from 10 to 15 individuals at each photoperiod.

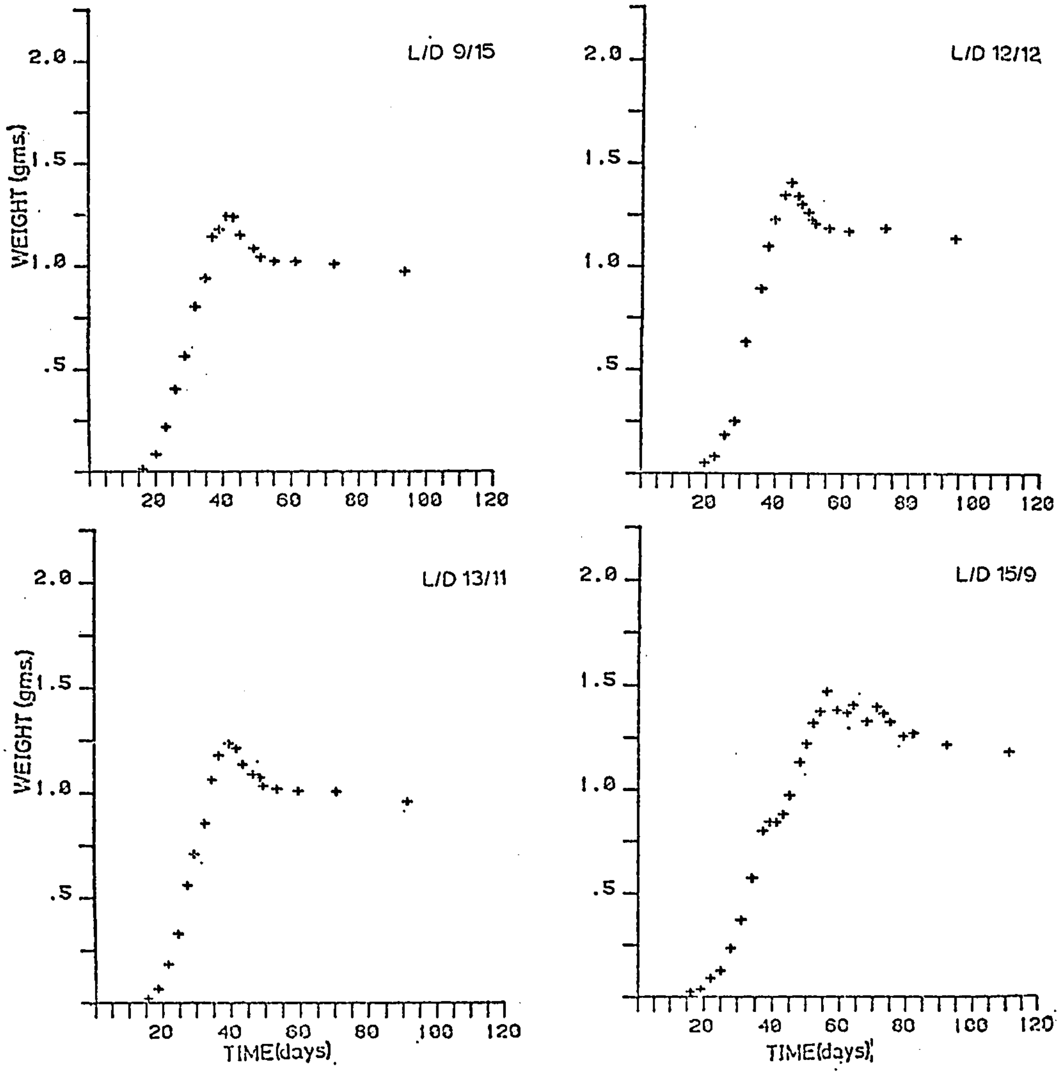


FIG. VIII b: Mean growth rates of <u>P. isabella</u> larvae at room temperature, on Casein diet, and at 4 different photoperiods. L/D = Light/Dark hrs. Data pooled from 10 to 15 individuals at each photoperiod.

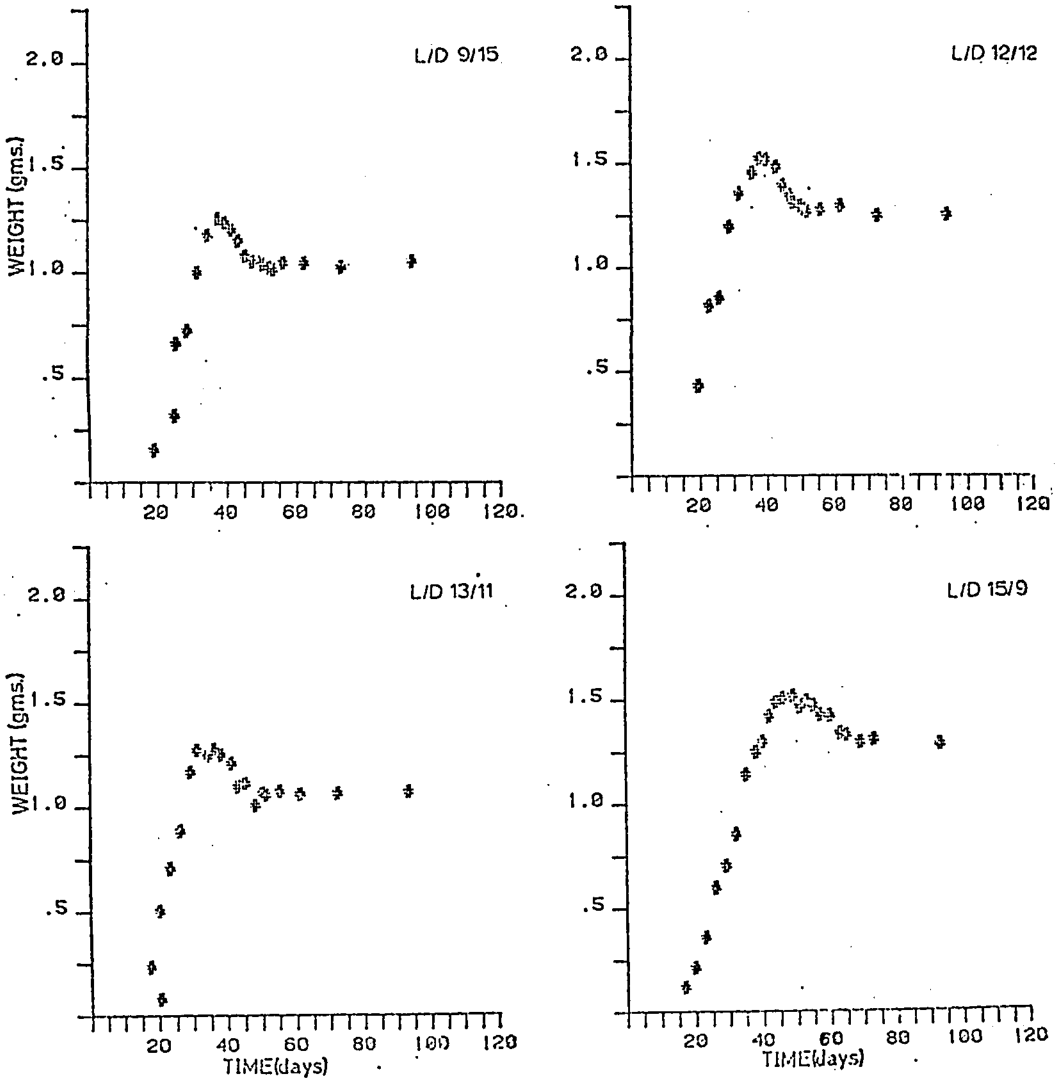


FIG. VIII c: Growth rates of P. isabella larvae at room temperature, on Wheat Germ diet, and at 4 different photoperiods. L/D = Light/Dark hrs. Data pooled from 10 to 15 individuals at each photoperiod.

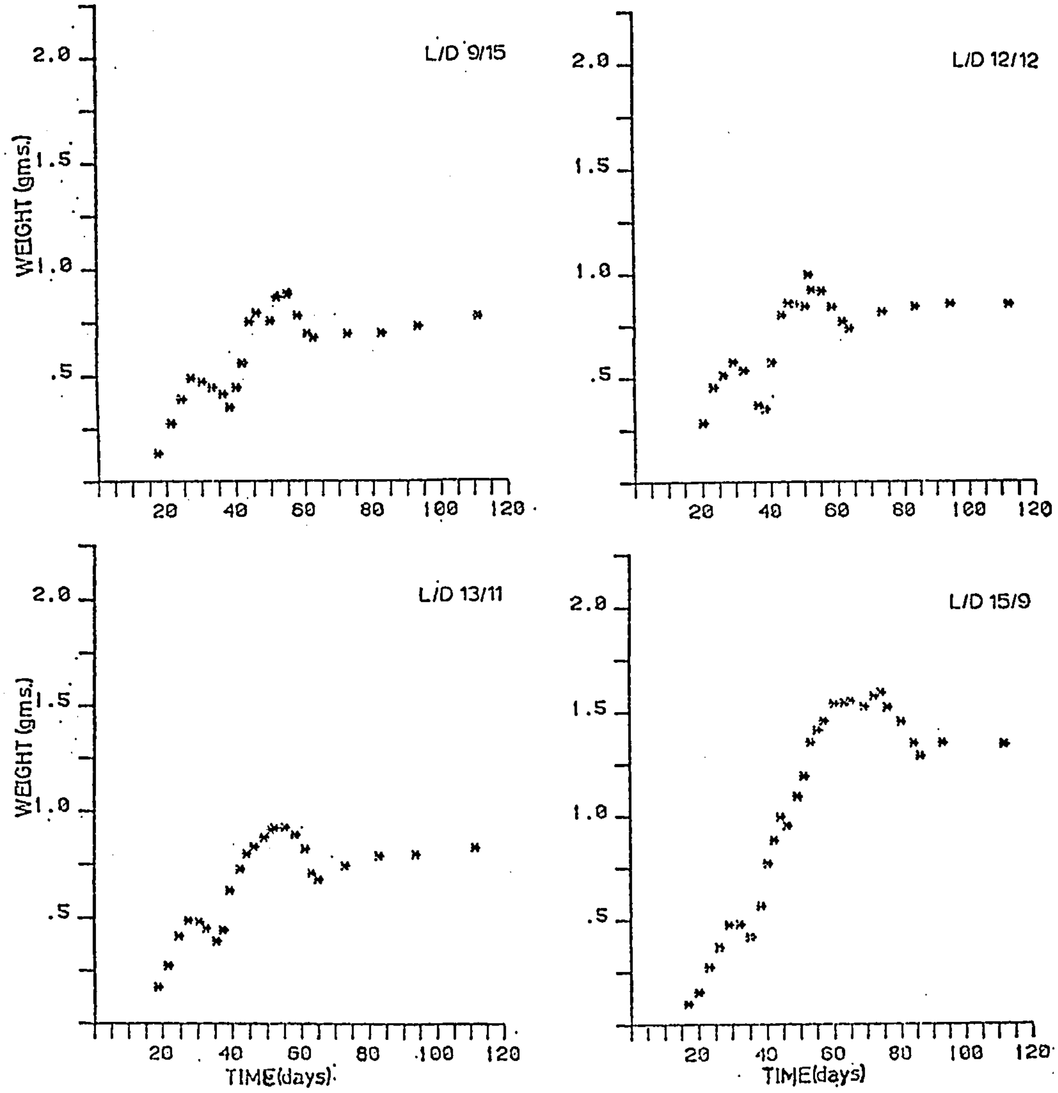


FIG. VIII d: Growth rates of P. isabella larvae at room temperature, on a fresh plantain diet, and at 4 different photoperiods. L/D = Light/Dark hrs. Data pooled from 10 to 15 individuals at each photoperiod.

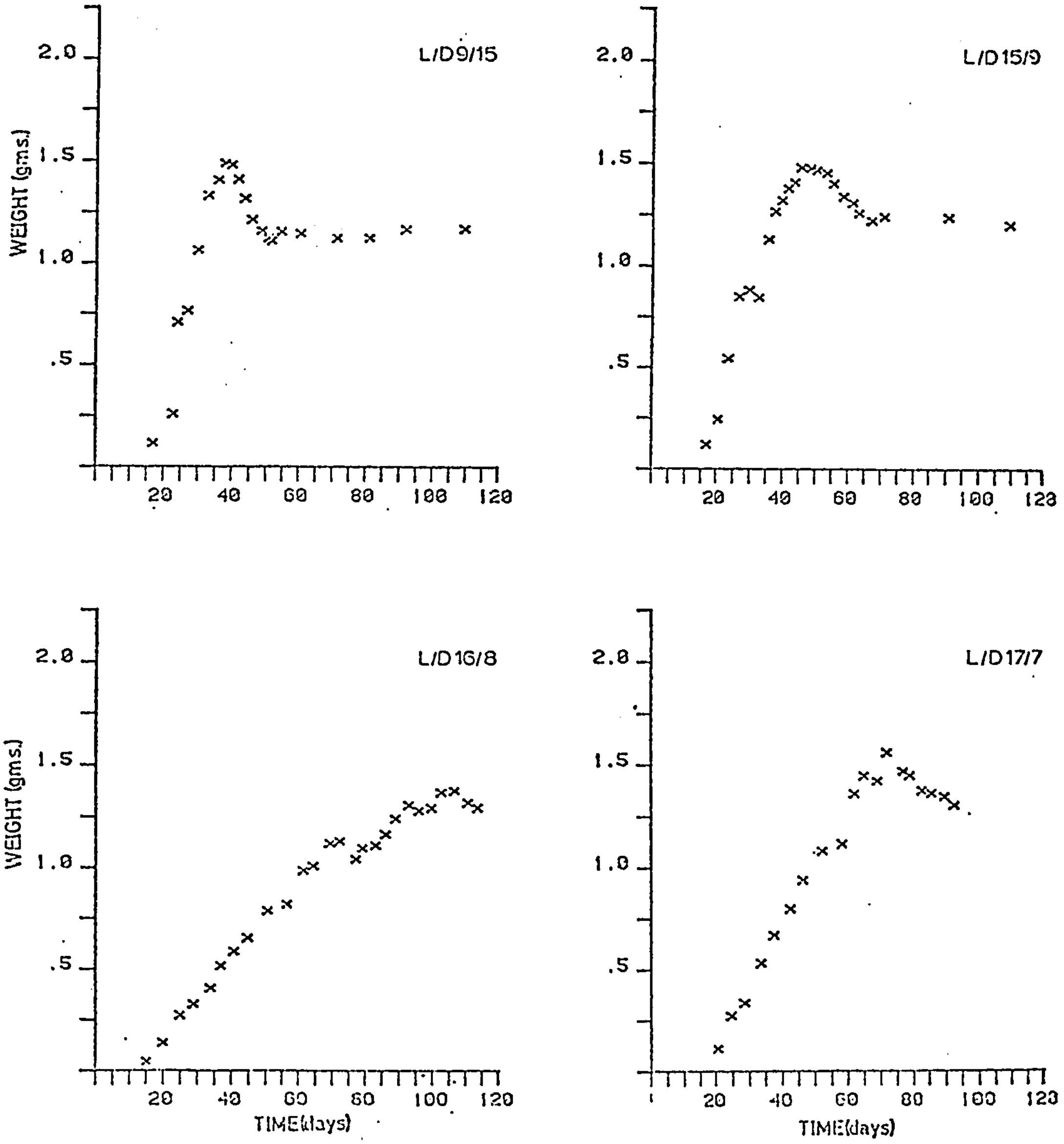


FIG. VIII e: Growth rates of <u>P. isabella</u> larvae at 22^{o}C, on Bean diet, and at 4 different photoperiods. L/D = Light/Dark hrs. Data pooled from 10 to 20 individuals at each photoperiod.

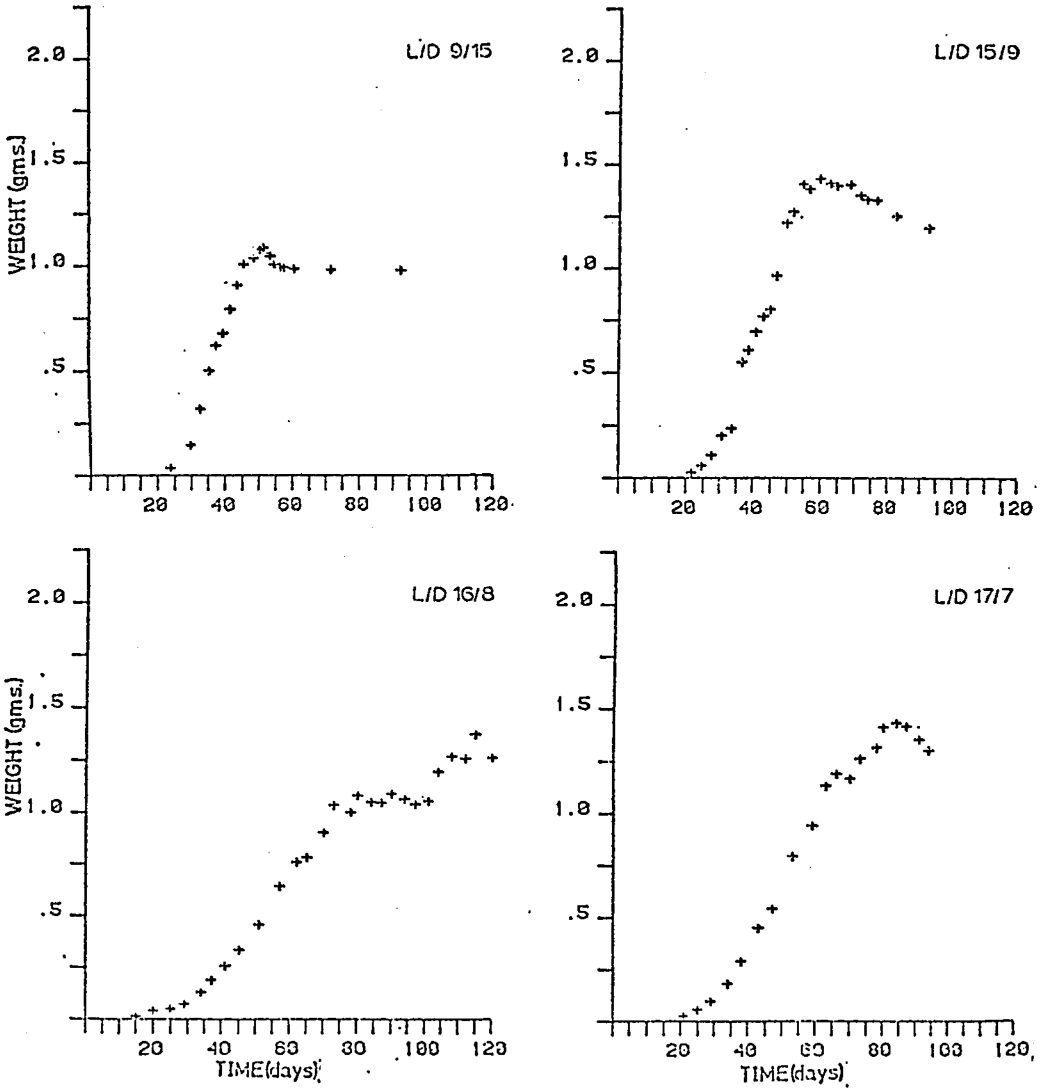


FIG. VIII f: Growth rates of P. isabella larvae at 22°C, on Casein diet, and at 4 different photoperiods. L/D = Light/Dark hrs. Data pooled from 10 to 20 individuals at each photoperiod.

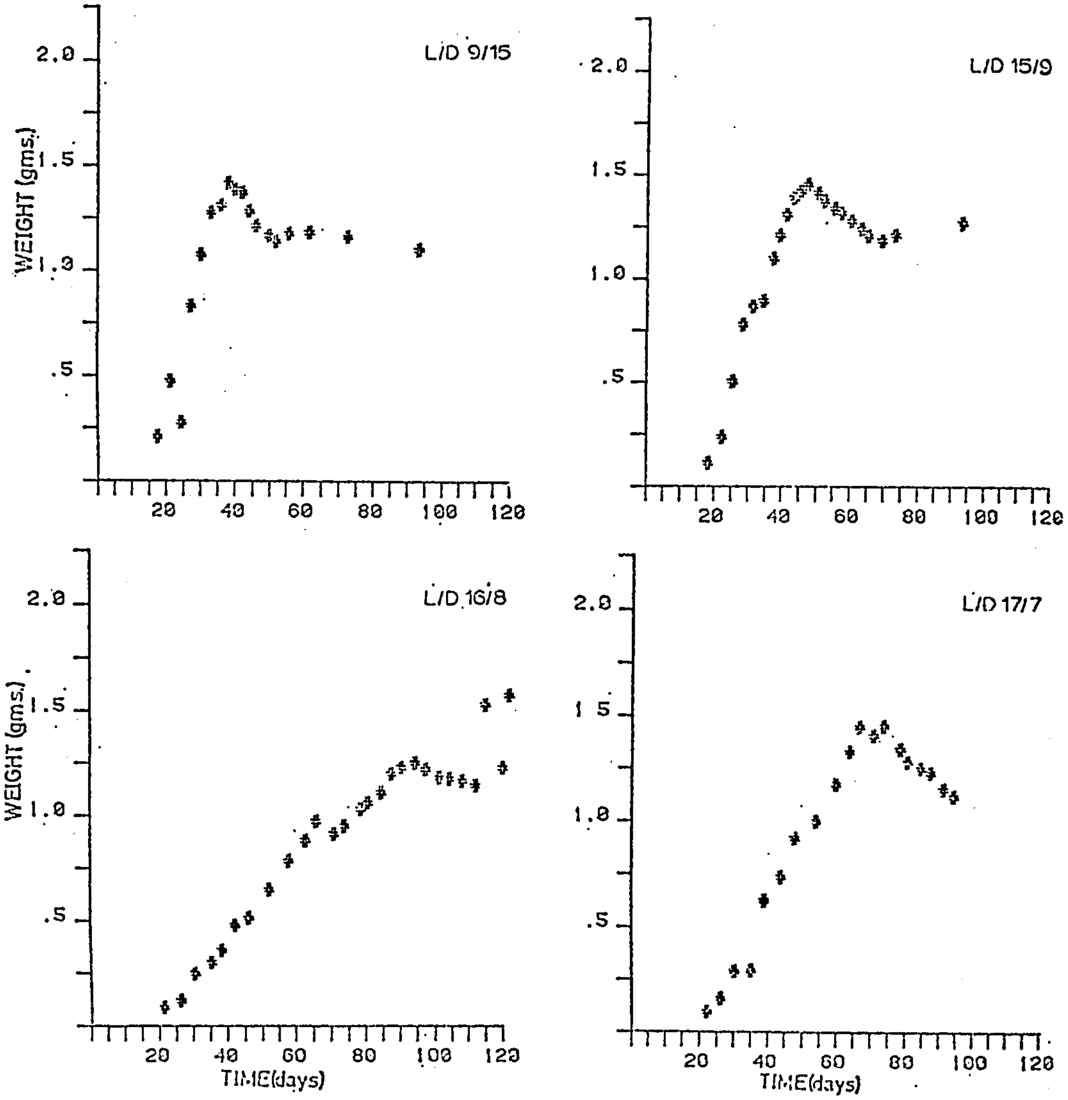


FIG. VIII g: Growth rates of <u>P. isabella</u> larvae at 22^{o}C, on Wheat Germ diet, and at 4 different photoperiods. L/D = Light/Dark hrs. Data pooled from 10 to 20 individuals at each photoperiod.

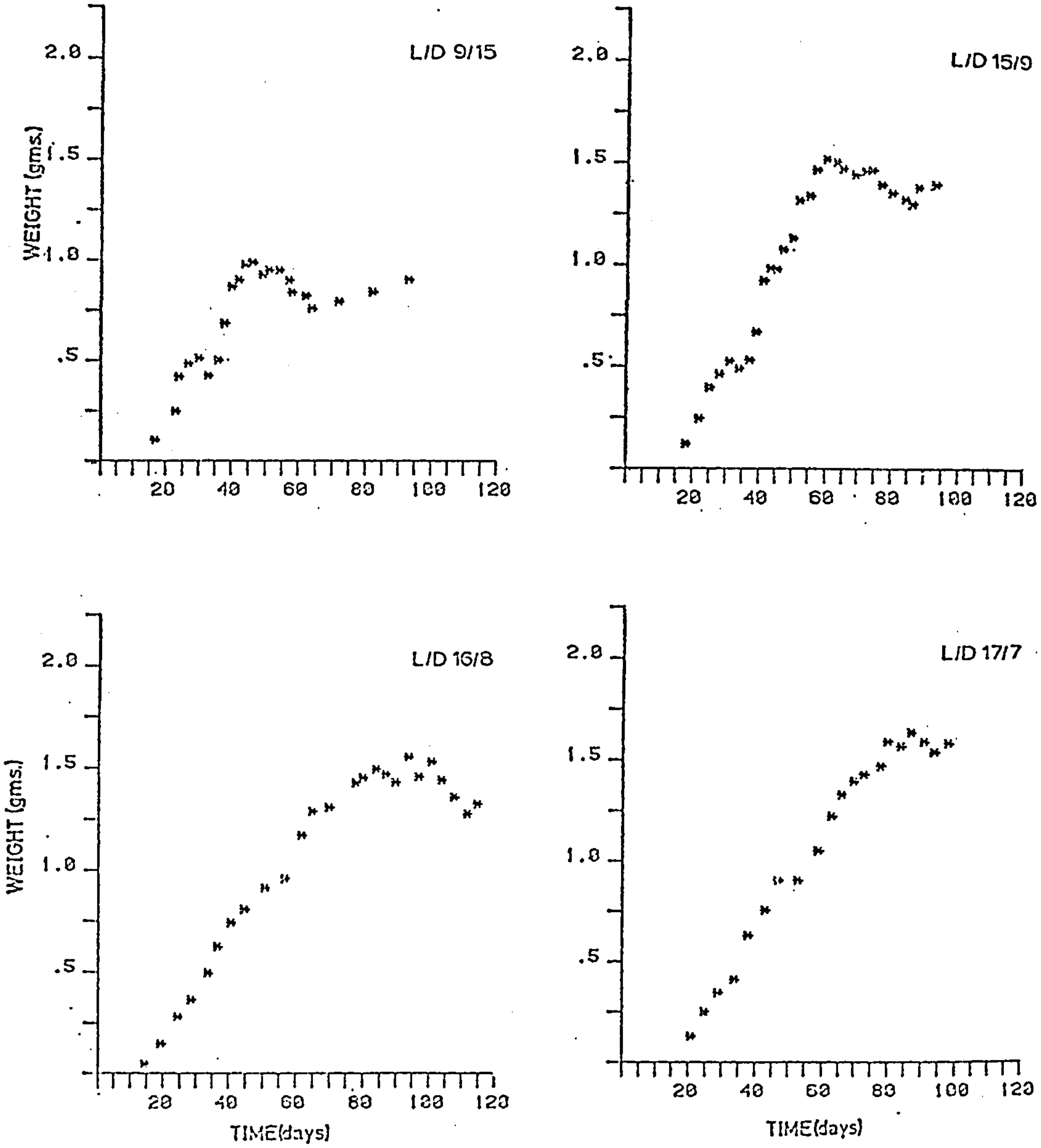


FIG. VIII h: Growth rates of P. isabella larvae at 22°C, on a fresh plantain diet, and at 4 different photoperiods. L/D = Light/Dark hrs. Data pooled from 10 to 20 individuals at each photoperiod.

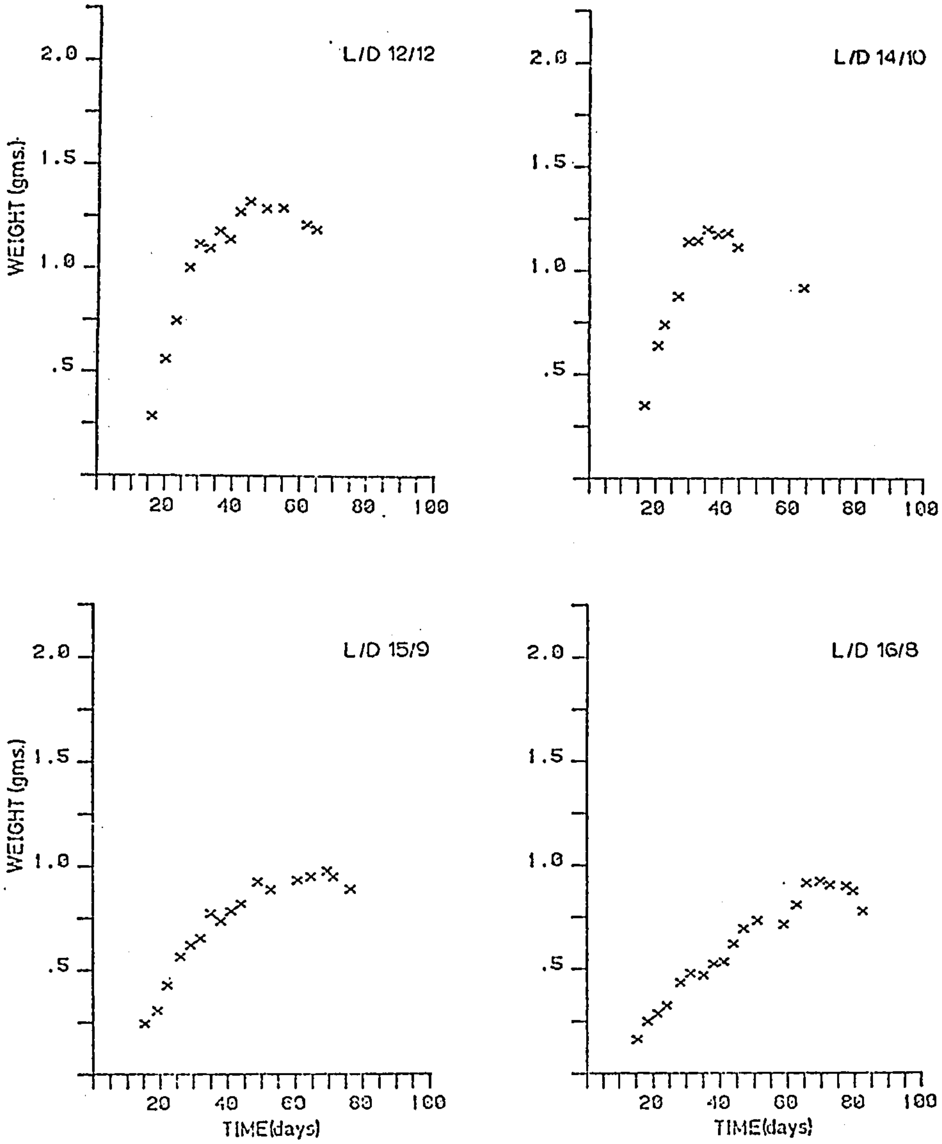


FIG. VIII i: Growth rates of P. isabella at 30^{o}C, on Bean diet, and at 4 different photoperiods. L/D = Light/Dark hrs. Data pooled from 10 to 15 individuals at each photoperiod.

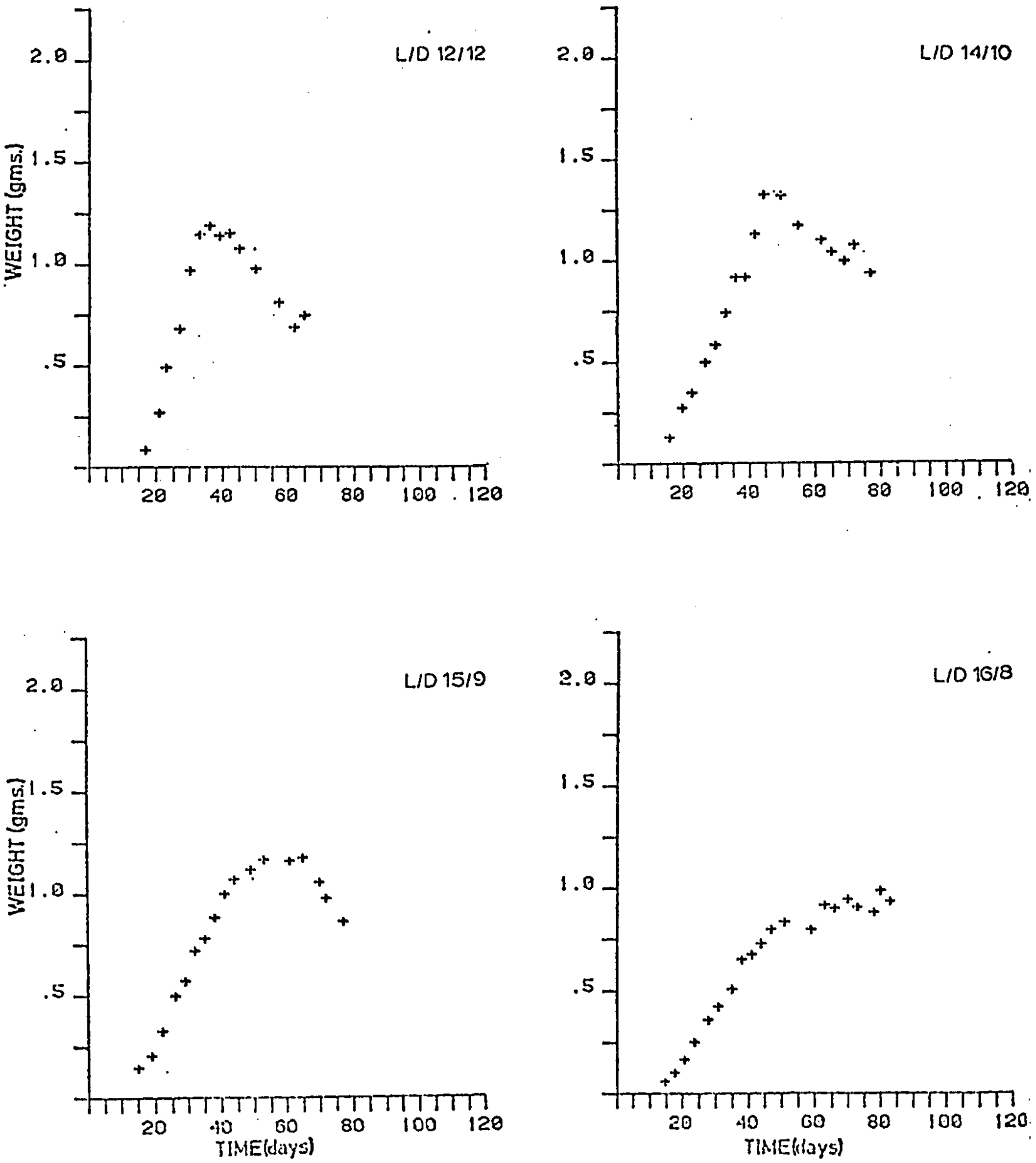


FIG. VIII j: Growth rates of P. isabella larvae at 30°C, on Casein diet, and at 4 different photoperiods. L/D = Light/Dark hrs. Data pooled from 10 to 15 individuals at each photoperiod.

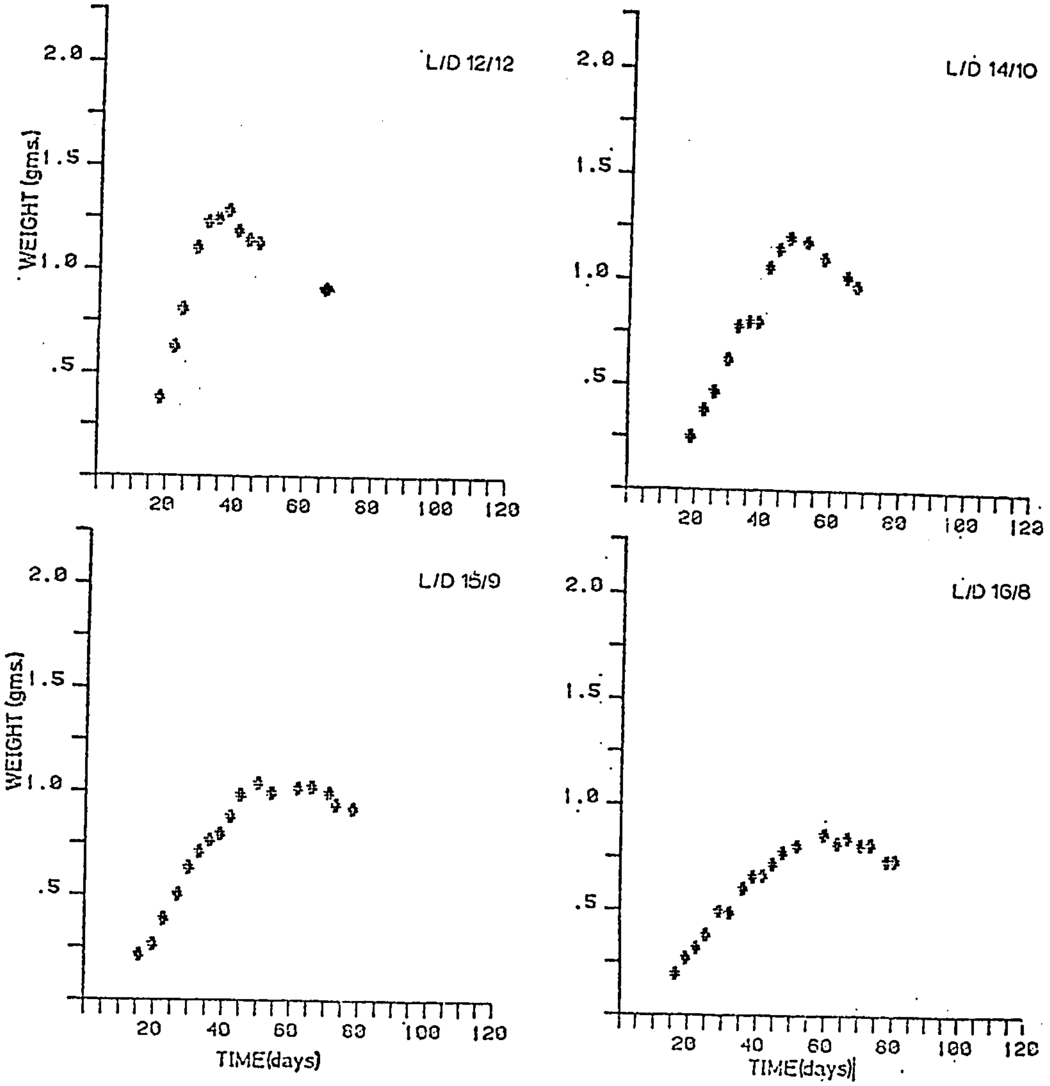


FIG. VIII k: Growth rates of P. isabella larvae at 30°C, on Wheat Germ diet, and at 4 different photoperiods. L/D = Light/Dark hrs. Data pooled from 10 to 15 individuals at each photoperiod.

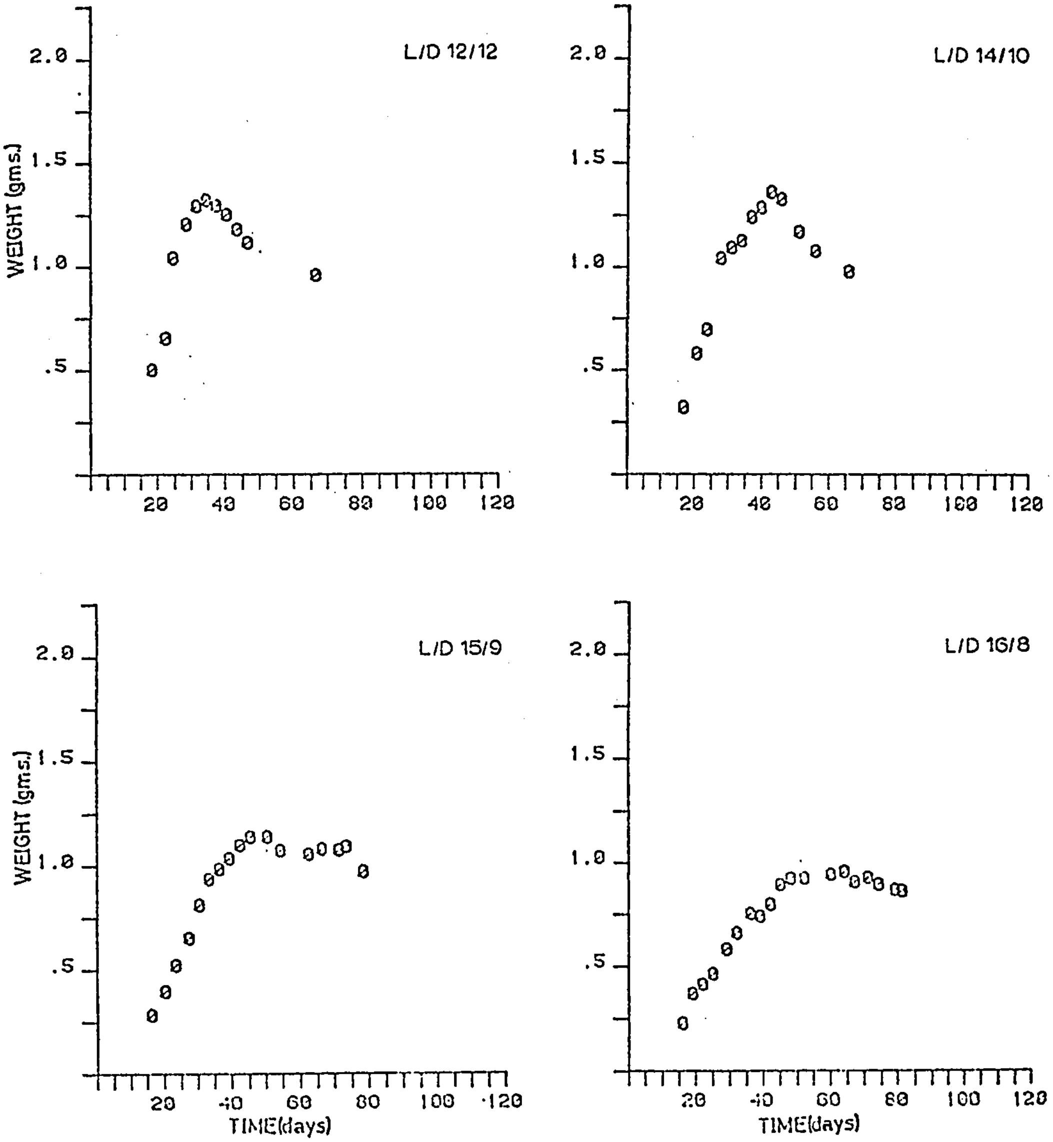


FIG. VIII 1: Growth rates of P. isabella larvae at 30°C, on Casein-Wheat Germ diet, and at 4 different photoperiods. L/D = Light/Dark hrs. Data pooled from 10 to 15 individuals at each photoperiod.

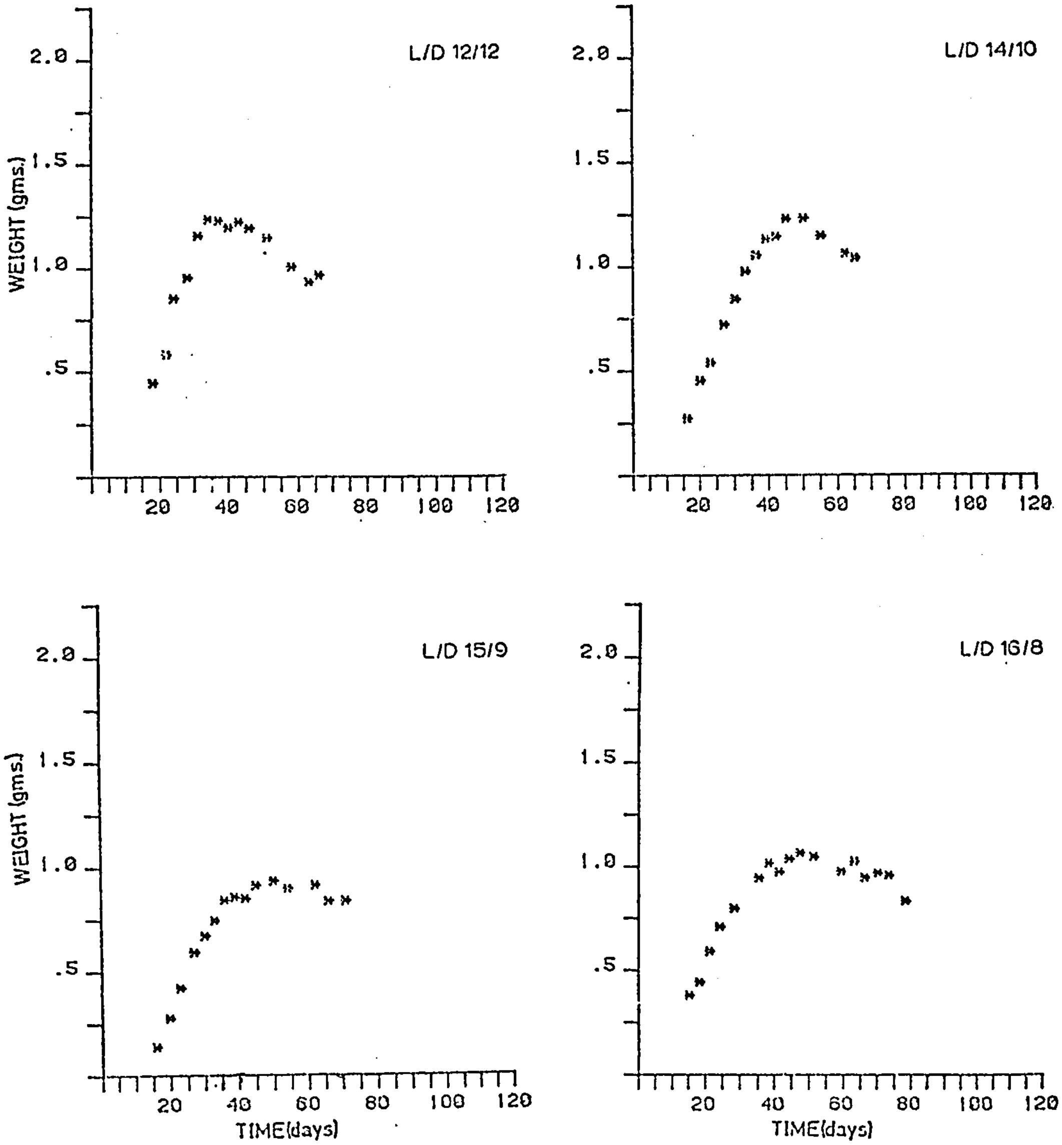


FIG. VIII m: Growth rates of P. isabella larvae at 30°C, on a fresh plantain diet, and at 4 different photoperiods. L/D = Light/Dark hrs. Data pooled from 10 to 15 individuals at each photoperiod.

h) Miscellaneous Data on the Larval Development of *P. isabella* at Each Combination of Photoperiod, Temperature and Diet

TABLE XVI: Diapause response of <u>P. isabella</u> larvae at each combination of photoperiod, temperature and diet.

DIET		BEAN		CASEIN		WHEAT GERM		ALFALFA		CASEIN-WHEAT GERM		PLANTAIN (fresh)		TOTAL			
TEMPERATURE (°C)	PHOTOPERIOD (L/D)	NUMBER PUPATED	NUMBER IN DIAPAUSE	NUMBER PUPATED	NUMBER IN DIAPAUSE	NUMBER PUPATED	NUMBER IN DIAPAUSE	NUMBER PUPATED	NUMBER IN DIAPAUSE	NUMBER PUPATED	NUMBER IN DIAPAUSE	NUMBER PUPATED	NUMBER IN DIAPAUSE	PUPATED N	PUPATED %	DIAPAUSE N	DIAPAUSE %
RM	9/15		19/20		20/20		19/20		15/20				6/20	0	-	79	100
RM	11/13		20		20		20		15				15	0	-	90	100
RM	12/12		20		15		20		12				5	0	-	72	100
RM	13/11		18		18		20		14				11	0	-	81	100
RM	15/9		20		19		19		14				17	0	-	89	100
22	9/15		18		15		20		3				16	0	-	72	100
22	15/9		20		15		19		8				18	0	-	80	100
22	16/8		18		17	1	15		0		17		17	1	1	84	99
22	17/7	1	18		18		18		0		18	5	13	6	7	85	93
26	15/9		19		17		20		0		17		16	0	-	89	100
30	12/12		19		11	1	18	1	0		19		9	2	2	95	98
30	14/10		20		14		19		0		19		16	0	-	88	100
30	15/9		20		18		20		6	2	18	3	10	5	5	92	95
30	16/8	3	14		16		19		1	1	16	3	10	7	9	76	91
TOTAL																	
N		4	263	0	233	2	266	1	88	3	124	11	179	21		1153	
%		1.4	98.6	0	100	.7	99.3	1.1	98.9	2.3	97.7	5.7	94.3	1.8		98.2	

TABLE XVII: Mean maximum weight (gm) attained by P. isabella larvae at each combination of photoperiod, temperature and diet.

*This total does not include the Alfalfa, Casein-Wheat Germ and Plantain diet results.

N = Sample size, S.D. = Standard Deviation

DIET		BEAN		CASEIN		WHEAT GERM		ALFALFA		CASEIN-WHEAT GERM		PLANTAIN		PLANTAIN (fresh)		TOTAL*	
TEMPERATURE (oC)	PHOTOPERIOD (L/D)	N	WEIGHT (S.D.)	N	WEIGHT (S.D.)	N	WEIGHT (S.D.)	N	WEIGHT (S.D.)	N	WEIGHT (S.D.)	N	WEIGHT (S.D.)	N	WEIGHT (S.D.)	N	WEIGHT (S.D.)
RM	9/15	9	1.51 (.108)	10	1.41 (.153)	10	1.60 (.119)	6	1.462 (.057)			2	.92 (.345)	4	.97 (.119)	33	1.44 (.23)
RM	11/13	10	1.54 (.135)	10	1.40 (.098)	10	1.47 (.108)	7	1.50 (.230)			3	1.25 (.249)	11	1.10 (.173)	41	1.37 (.21)
RM	12/12	10	1.59 (.061)	8	1.42 (.107)	10	1.51 (.144)	8	1.32 (.178)			1	1.09 (0)	4	1.09 (.232)	32	1.40 (.20)
RM	13/11	6	1.43 (.119)	9	1.38 (.110)	10	1.47 (.092)	7	1.44 (.084)			1	.133 (0)	7	1.18 (.331)	34	1.39 (.20)
RM	15/9	10	1.64 (.149)	17	1.59 (.112)	9	1.59 (.170)	13	1.45 (.084)			0	—	17	1.64 (.144)	53	1.61 (.14)
22	9/15	10	1.50 (.133)	10	1.33 (.149)	10	1.41 (.112)	3	1.31 (.101)			0	—	10	1.02 (.147)	40	1.31 (.22)
22	15/9	10	1.52 (.090)	7	1.51 (.142)	9	1.46 (.108)	5	.86 (.631)			0		18	1.54 (.193)	44	1.51 (.15)
22	16/8	18	1.32 (.242)	16	1.18 (.235)	15	1.46 (.211)	0	—	16	1.29 (.265)			17	1.53 (.161)	66	1.37 (.25)
22	17/7	12	1.52 (.207)	14	1.40 (.228)	11	1.53 (.313)	0	—	15	1.35 (.245)			10	1.51 (.311)	47	1.48 (.26)
26	15/9	12	1.70 (.241)	13	1.52 (.236)	11	1.49 (.147)	0	—	10	1.55 (.159)			13	1.53 (.263)	49	1.56 (.23)
30	12/12	11	1.26 (.108)	11	1.29 (.184)	11	1.36 (.186)	0	—	11	1.31 (.134)			9	1.207 (.159)	42	1.28 (.16)
30	14/10	11	1.33 (.212)	9	1.30 (.230)	12	1.41 (.201)	0	—	10	1.29 (.221)			9	1.29 (.131)	41	1.34 (.20)
30	15/9	17	1.07 (.164)	10	1.14 (.201)	16	1.04 (.158)	5	.96 (.257)	15	1.10 (.161)			5	.936 (.108)	48	1.06 (.17)
30	16/8	14	.92 (.123)	16	.92 (.061)	15	1.056 (.236)	1	.98 (0)	14	.91 (.193)			7	1.08 (.151)	52	.98 (.17)
TOTAL		162	1.39 (.28)	160	1.33 (.25)	159	1.39 (.25)	55	1.32 (.31)	91	1.30 (.27)	7	.98 (.43)	141	1.35 (.30)		

TABLE XVIII: Mean number of days from eclosion to maximum weight (diapause) of _P. isabella_ larvae at each combination of photoperiod, temperature and diet.

N = Sample size, S.D. = Standard Deviation

*This total does not include the Alfalfa, Casein-Wheat Germ and Plantain diets.

DIET Temperature (oC)	Photoperiod (L/D)	BEAN N	BEAN DAYS TO DIAPAUSE (S.D.)	CASEIN N	CASEIN DAYS TO DIAPAUSE (S.D.)	WHEAT GERM N	WHEAT GERM DAYS TO DIAPAUSE (S.D.)	ALFALFA N	ALFALFA DAYS TO DIAPAUSE (S.D.)	CASEIN-WHEAT GERM N	CASEIN-WHEAT GERM DAYS TO DIAPAUSE (S.D.)	PLANTAIN N	PLANTAIN DAYS TO DIAPAUSE (S.D.)	PLANTAIN (fresh) N	PLANTAIN (fresh) DAYS TO DIAPAUSE (S.D.)	TOTAL* N	TOTAL* DAYS TO DIAPAUSE (S.D.)
RM	9/15	9	35 (3.3)	10	41 (2.0)	10	38 (3.0)	6	52 (3.0)			2	77 (18.4)	4	53 (1.7)	33	40 (6.1)
RM	11/13	10	38 (2.4)	10	42 (1.8)	10	35 (3.7)	7	52 (5.4)			3	93 (10.6)	11	53 (4.4)	41	42 (7.7)
RM	12/12	10	38 (2.8)	8	44 (3.6)	10	38 (2.6)	8	53 (5.4)			1	72 (0)	4	52 (3.5)	32	41 (5.7)
RM	13/11	8	39 (3.2)	9	46 (2.2)	10	38 (5.4)	7	55 (3.6)			1	55 (0)	7	55 (4.3)	34	44 (7.6)
RM	15/9	9	51 (4.9)	17	60 (6.8)	9	49 (5.9)	13	75 (10.4)			0	—	17	70 (6.0)	52	60 (10.2)
22	9/15	10	38 (2.4)	10	51 (5.6)	10	37 (2.1)	3	62 (4.0)			0	—	10	47 (4.7)	40	43 (7.1)
22	15/9	10	51 (1.9)	7	61 (6.8)	9	48 (4.0)	5	88 (3.6)			0		18	65 (6.2)	44	58 (8.9)
22	16/8	18	110 (14.8)	16	103 (14.2)	15	98 (15.7)			16	97 (18.9)			17	93 (8.5)	66	101 (14.7)
22	17/7	12	80 (12.0)	14	84 (8.1)	11	80 (12.5)			15	82 (7.7)			10	84 (9.7)	47	82 (10.5)
26	15/9	11	74 (8.4)	13	74 (10.7)	11	68 (9.7)			10	71 (8.0)			13	72 (10.2)	48	72 (9.8)
30	12/12	11	39 (5.1)	11	46 (15.7)	11	39 (6.6)			11	37 (7.9)			8	42 (5.1)	41	41 (9.6)
30	14/10	11	58 (13.7)	9	52 (9.8)	12	57 (10.5)			10	45 (6.6)			9	52 (7.2)	41	55 (10.7)
30	15/9	17	69 (6.0)	10	61 (6.4)	16	71 (11.3)	5	85 (7.3)	15	63 (13.9)			5	44 (6.7)	48	65 (11.5)
30	16/8	14	70 (6.9)	15	71 (9.2)	15	65 (10.2)	1	83 (0)	14	70 (15.7)			7	55 (12.9)	51	67 (10.7)
TOTAL		160	61 (24.4)	159	63 (20.5)	159	57 (21.5)	55	65 (15.2)	91	69 (22.7)	7	80 (17.2)	140	64 (17.0)		

TABLE XIX: Range and mean number of instars of P. isabella larvae at each combination of photoperiod, temperature and diet.

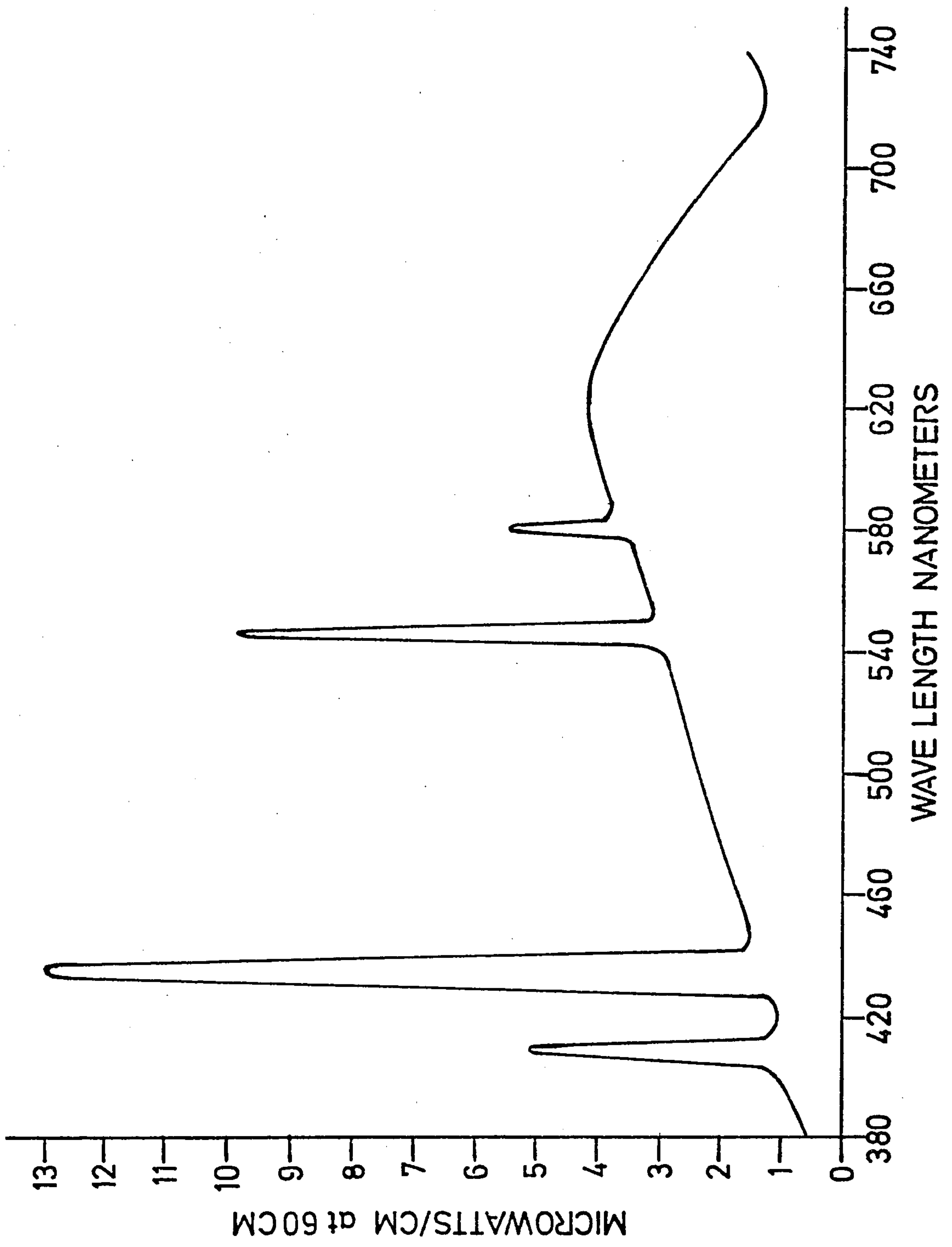
N = Sample size, S.D. = Standard Deviation

*This total does not include the Alfalfa, Casein-Wheat Germ and Plantain diet results.

DIET		BEAN		CASEIN		WHEAT GERM		ALFALFA		CASEIN-WHEAT GERM		PLANTAIN		PLANTAIN (fresh)		TOTAL*	
Temperature (°C)	Photoperiod (L/D)	N Range	# Instars (S.D.)	N Range	# Instars (S.D.)	N Range	# Instars (S.D.)	N Range	# Instars (S.D.)	N Range	# Instars (S.D.)	N Range	# Instars (S.D.)	N Range	# Instars (S.D.)	N Range	# Instars (S.D.)
RM	9/15	19 0	7.0 (0)	20 6-8	7.25 (.55)	19 6-7	6.9 (.32)	15 6-9	7.3 (.82)			5 7-11	9.0 (1.4)	9 6-7	6.7 (.44)	67 6-8	7.0 (.5)
RM	11/13	20 0	7.0 (0)	20 7-8	7.05 (.22)	20 6-7	6.8 (.41)	16 7-8	7.1 (.25)			5 7-9	8.2 (.84)	16 6-8	7.1 (.57)	76 6-8	7.0 (.2)
RM	12/12	20 6-7	6.9 (.22)	16 7-8	7.5 (.52)	20 0	7.0 (0)	12 6-9	8.2 (.39)			1 0	6.0 (0)	15 6-8	7.0 (.38)	71 6-8	7.1 (.4)
RM	13/11	18 0	7.0 (0)	17 7-8	7.3 (.47)	20 0	7.0 (0)	13 7-8	7.2 (.44)			1 0	9.0 (0)	8 0	7.0 (0)	62 7-8	7.2 (.4)
RM	15/9	20 7-8	7.3 (.44)	19 7-9	8.2 (.50)	19 7-8	7.2 (.42)	14 8-10	8.4 (.65)			1 0	7.0 (0)	17 7-8	7.9 (.24)	75 7-9	7.6 (.6)
22	9/15	18 6-7	6.9 (.24)	15 7-9	8.0 (.38)	20 7-8	7.1 (.22)	3 7-8	7.7 (.58)			0 -	- -	16 6-7	6.9 (.34)	69 6-9	7.2 (.6)
22	15/9	20 7-8	7.1 (.22)	15 6-9	8.2 (.41)	19 0	7.0 (0)	8 9-11	9.6 (.74)			2 7-9	8.0 (1.4)	18 7-8	7.6 (.50)	72 7-9	7.4 (.5)
22	16/8	18 9-10	9.4 (.51)	17 8-12	10.1 (1.09)	18 8-10	9.0 (.68)	0 -	- -	18 8-10	8.5 (.71)			18 7-9	8.2 (.62)	71 7-12	9.2 (.9)
22	17/7	19 7-10	8.3 (.95)	18 8-9	8.6 (.50)	19 7-9	8.1 (.46)	0 -	- -	18 8-9	8.6 (.51)			13 7-9	8.2 (.73)	69 7-10	8.3 (.5)
26	15/9	19 7-9	8.1 (.62)	18 8-10	8.7 (.77)	20 7-9	7.8 (.64)	0 -	- -	18 7-8	7.8 (.43)			17 7-10	8.1 (.75)	74 7-10	8.2 (.7)
30	12/12	19 6-8	6.9 (.52)	12 7-8	7.4 (.50)	18 7-8	7.3 (.46)	0 -	- -	19 7-8	7.4 (.51)			9 0	7.0 (0)	58 6-8	7.1 (.4)
30	14/10	20 7-9	8.0 (.65)	15 8-10	8.9 (.74)	19 7-9	8.0 (.52)	0 -	- -	19 7-8	7.5 (.51)			17 7-8	7.7 (.47)	71 7-10	8.3 (.8)
30	15/9	20 7-9	8.1 (.51)	18 8-9	8.4 (.51)	20 7-10	8.2 (.87)	7 7-10	7.9 (1.07)	18 7-9	7.8 (.62)			9 7-9	7.8 (.67)	67 7-10	8.2 (.7)
30	16/8	17 7-10	8.2 (.75)	17 7-10	8.5 (.87)	19 7-9	8.2 (.60)	1 0	7.0 (0)	17 7-8	7.6 (.62)			12 7-9	7.8 (.62)	65 7-10	8.2 (.8)
TOTAL		267 6-10	7.6 (.9)	237 6-12	8.1 (1.0)	270 6-10	7.5 (.8)	89 6-11	7.8 (1.0)	127 7-10	7.9 (.7)	15 7-11	8.3 (1.3)	193 6-10	7.7 (.7)		

i) Spectral Distribution of Fluorescent Lamps

FIG. IX: Spectral distribution of F40 Cool White Deluxe Westinghouse Lamp. (Taken from: A Practical Guide to Westinghouse Fluorescent Lamps, Westinghouse Canada Limited, Dorval, P.Q., publication #18ME 5/74, 31 pp.)



MICROWATS/CM at 60 CM
0
1
2
3
4
5
6
7
8
9
10
11
12
13
380
420
460
500
540
580
620
660
700
740
WAVE LENGTH NANOMETERS

VII. LITERATURE CITED

Adkisson, P. L.. 1961. Effect of larval diet on the seasonal occurence of diapause in the pink bollworm. J. Econ. Entomol. 54: 1107-1112.

Adkisson, P. L.; Bell, R. A. and Wellson, S. G.. 1963. Environmental factors controlling the induction of diapause in the pink bollworm. Pectinophora gossypiella (Saunders). J. Insect Physiol. 9: 299-310.

Adkisson, P. L.. 1964. Action of photoperiod in controlling insect diapause. Am. Naturalist 98: 357-374.

Adkisson, P. L.. 1965. Action of light in controlling insect growth and development. Electromagnetic Radiation in Agriculture Proc. 1965. pp. 30-33.

Adkisson, P. L.. 1966. Internal clocks and insect diapause. Science, Wash. 154: 234-241.

Ali, M.. 1973. Influence of photoperiod and temperature on the food consumption of the alfalfa beetle, Subcoccinella vigintiquatuorpunctata L. (Coleoptera:Coccinellidae). Acta Phytopath. Acad. Scien. Hungar. 8: 207-215.

Andrewartha, H. G.. 1952. Diapause in relation to the ecology of insects. Biol. Rev. 27: 50-107.

Arnason, A. P. and H. McDonald. 1951. Sask. Dept. Agr. R. 46: 156.

Arnold, C. Y.. 1960. Maximum-minimum temperatures as a basis for computing heat units. Proc. Am. Soc. Hort. Sci. 76: 682-92.

Barker, J, F. and W. S. Herman. 1976. Effect of photoperiod and temperature on reproduction of the monarch butterfly, Danaus plexippus. J. Insect. Physiol. 22: 1565-1568.

Barlow, C. A.. 1962. The influence of temperature on the growth of experimental populations of Myzus persicae (Sulzer) and Macrosiphum euphorbiae (Thomas) (Aphididae). Can. J. Zool. 40: 145-156.

Barlow, C. A. and W. D. Kerr. 1969. Locomotory responses to temperature in the grain weevil, Sitophilus granarius (L.) (Coleoptera: Curculionidae). Can. J. Zool. 47: 217-224.

Barnes, J. L.. 1976. Effect of temperature on development, survival, oviposition and diapause in laboratory populations of Sepedon fuscipennis (Diptera:Sciomyzidae). Environ. Entomol. 5: 1089-1098.

Barry, B. D. and P. L. Adkisson. 1966. Certain aspects of the genetic factors involved in the control of larval diapause of the pink bollworm. Ann. Entomol. Soc. Am. 59: 122-125.

Baumberger, J. P.. 1917. Hibernation: A periodical phenomenon. Ann. Entom. Soc. Amer. 10: 179-186.

Beck, S. D. and J. W. Apple. 1961. Effects of temperature and photoperiod on voltinism of geographical populations of the European corn borer, Pyrausta nubilalis (Hbn.). J. Econ. Entomol. 54: 550-558.

Beck, S. D.. 1962a. Temperature effects on insects: Relation to periodism. Proc. North Central Branch, Ent. Soc. Americ. 17.

Beck, S. D.. 1962b. Photoperiodic induction of diapause in an insect. Biol. Bull. 122: 1-12.

Beck, S. D.. 1963. Physiology and ecology of photoperiodism. Ent. Soc. Amer. Bul. 9: 8-16.

Beck, S. D.. 1968. Insect Photoperiodism. Academic Press., New York 288 pp.

Beck, S. D., Chippendale, G. M. and Swinton, D. E.. 1968. Nutrition of the European corn Borer, Ostrinia nubilalis. VI. A Larval Rearing Medium without Crude Plant Fractions. Ann. Entomol. Soc. Amer. 61: 459-462.

Bio-Serv. 1976. Diet catalog: Insect rearing supplement. Bio-Serv., Inc., Frenchtown, N. J.

Bliss, C. I. and R. I. Beard. 1954. The growth of the head capsule in individual milkweed bugs. Ann. Entomol. Soc. Am. 47: 388-92.

Bowen, M. F. and S. D. Skopik. 1976. Insect photoperiodism: The "T" Experiment" as evidence for an hourglass mechanism. Science, 192: 59-60.

Braune, H. J.. 1973. The Role of Temperature in Controlling Obligatory Diapause. In: Effects of Temperature on Ectothermic Organisms, ed.: W. Wieser, Springer-Verlag, 1973. pp. 233-238.

Bull, D. L. and P. L. Adkisson. 1962. Fat content of the larval diet as a factor influencing diapause and growth-rate of the pink bollworm. Ann. Ent. Soc. Amer. 55: 499-502.

Burges, H. D.. 1962. Diapause, pest status and control of the khapra beetle, Trogoderma granarium Everts. Ann. Appl. Biol. 50: 614-617.

Bursell, E.. 1974. Environmental aspects - Temperature. In: The Physiology of Insecta Vol. 2 ed.: M. Rockstein. Academic Press, N.Y.

Butler, G. D.,Jr. and T. J. Henneberry. 1976. Temperature-dependent rate tables for insects associated with cotton in the southwest. A.R.S., U.S.D.A. ARS W-38 Oct., 1976.

Butler, G. D., Jr. and D. R. Scott. 1976. Two models for development of the corn earworm on sweet corn in Idaho. Envir. Ent. 5: 68-72.

Byers, J. R. and C. F. Hinks. 1976. Fine structure of the midventral abdominal tracheal glands in banded woollybear caterpillars (Arctiidae:Lepidoptera). Can. J. Zool. 54: 1824-1839.

Cayrol, R. 1975. Influence de diverses combinaisons des photophases de 8 heures et de 16 heures sur les processus de developpement et de croissance chez les larves d'Amathes c.-nigrum (Lep. Noctuidae). Esquisse d'une théorie concernant un type de dormance. Ann. Zool. Ecol. Anim. 7: 321-330.

Chapman, R. F.. 1969. The Insects, Structure and Function. English Universities Press, London. 819 pp.

Chippendale, G. M.. 1972. Composition of meridic diets for rearing plant-feeding lepidopterous larvae. Proc. North Central Branch - E.S.A. 27: 114-121.

Chittenden, F. H.. 1903. The Hedgehog Caterpillar. United States Dept. Agr., Bur. Ent. Bull. 43: 44-45.

Church, N. S. 1955. Hormones and the termination and reinduction of diapause in Cephus cinctus Nort. (Hymen.:Cephidae). Can. J. Zool. 33: 339-69.

Cousin, G. 1932. Etude expérimentale de la diapause des insects. Bull. Biol. Suppl. 15: 341.

Crowder, L. A., T. F. Watson and D. T. Langston. 1975. Diapause of the pink bollworm as related to crop maturity. J. Econ. Entomol. 68: 110-112.

Danilevskii, A. S. 1961. Photoperiodism and seasonal development of insects. (English Ed.) 1965. Oliver and Boyd, Edinburgh and London.

Danilevskii, A. S., N. I. Goryshin and V. P. Tyshchenko. 1970. Biological rhythms in terrestrial arthropods. Ann. Rev. Entomol. 15: 201-244.

Denlinger, D. L. 1972. Seasonal phenology of diapause in the flesh fly Sarcophaga bullata. Ent. Soc. Amer. Ann. 65: 410-414.

Deseő, K. V. and G. Y. Sáringer. 1975. Photoperiodic regulation in the population dynamics of certain lepidopterous species. Acta. Phytopath. Acad. Scien. Hung. 10: 131-139.

Deseő, K. V. 1973. Reproductive activity of Codling Moth (Laspeyresia pomonella) during the preimaginal state. Acta. Phytopath. Acad. Sci. 8: 193-206.

Dethier, V. G. 1943. The dioptric apparatus of lateral ocelli. II: Visual capacities of the ocellus. J. Cell Comp. Physiol. 22: 115-126.

Dickson, R. C. 1949. Factors governing the induction of diapause in the oriental fruit moth. Ann. Entomol. Soc. Amer. 42: 511-537.

Dirig, R. 1975. Growing Moths. 4-H Members' Guide m-6-6, New York State College of Agriculture and Life Sciences. 39 pp.

Ditman, P. P., Weiland, G. S. and Guill, J. H. 1940. The metabolism in the corn earworm. III. Weight, water and diapause. J. Econ. Ent. 33: 282-95.

Dougherty, E. C. 1959. Axenic culture of invertebrate metazoa: A Goal. Ann. N.Y. Acad. Sci. 77: 27-54.

Drooz, A. T. 1965. Elm spanworm head capsule widths and instars. J. Econ. Entomol. 58: 629-31.

Dyar, H. G. 1890. The number of moults of lepidopterous larvae. Psyche 5: 420-2.

Fenton, F. A. 1937. The insect record for Oklahoma 1935-1936. Okla. Acad. Sci. 17: 29-31.

Fogal, W. H. and Kwain, M. J. 1972. Host plant nutritive value and variable number of instars in a sawfly, Diprion similis. Israel Journal of Ent. 7: 63-73.

Forbes, S. A. 1900. Economic entomology of the sugar beet. Illinois Agr. Exp. Sta. Bull. 60: 505.

Fraenkel, G. and M. Blewett. 1946. Linoleic acid, vitamin E and other fat-soluble substances in the nutrition of certain insects. (Ephestia kuchniella, E. elutella, E. cautella, and Plodia interpunctella (Lep.)) Jour. Exptl. Biol. 22: 172-90.

French, G. H. 1877. Illinois Dept. Agr. Trans. 15: 182.

Gaines, J. C. and F.L. Campbell. 1935. Dyar's rule as related to the number of instars of the corn earworm, Heliothis obsoleta Fab. collected in the field. Ann. Entomol. Soc. Amer. 28: 445-461.

Galichet, P. F. 1964. Diparopsis watersi, Lepidoptera, Noctuidae, ravageur du cotonnier en Afrique central. Ecologie des populations. Etude expérimentale de la diapause. Cot. Fib. trop. 19: 437-518.

Geyspitz, K. F. and A. I. Zarankina. 1963. Some features of the photoperiodic reaction of Dasychira pudibunda L. (Lepidoptera:Orgyidae). Entomol. Rev. 42: 14-19.

Gibson, A. 1905. Nature study no. XXIX.: Woollybear caterpillars. Ottawa Nat. 1905. pp. 159-162.

Greenfield, M. D. and M. G. Karandinos. 1976. Fecundity and longevity of Synanthedon pictipes under constant and fluctuating temperatures. (Lep.:Sesiidae). Environ. Ent. 5: 883-887.

Hanec, W. and S. D. Beck. 1960. Cold hardiness in the European corn borer, Pyrausta nubilalis (Hubn.). J. Insect Physiol. 5: 169-180.

Hans, H. 1961. Termination of diapause and continuous laboratory rearing of the sweet clover weevil, *Setona cylindricolis* Fahr. Ent. exp. and app. *4*: 41-46.

Harvey, G. T. 1961. Second diapause in the spruce budworm from eastern Canada. Can. Ent. *93*: 594-602.

Harvey, W. R. 1962. Metabolic aspects of insect diapause. A. Rev. Ent. *7*: 57-80.

Henneguy, L. F. 1904. *Les Insectes. Morphologie, reproduction, embryogénie* Paris.

Hinton, H. E. 1973. Neglected phases in metamorphosis: a reply to V. B. Wigglesworth. J. Ent. Ser. A. *35*: 57-68.

Hinton, H. E. 1976. Notes on neglected phases in metamorphosis, and a reply to J. M. Whitten. Ann. Entomol. Soc. Amer. *69*: 560-566.

Hinks, C. F. and J. R. Byers. 1975. A new glandular organ in some toxic caterpillars. Experientia *31*: 965-966.

Hinks, C. F. and Byers, J. R. 1976. Biosystematics of the genus *Euxoa* (Lepidoptera:Noctuidae) V. Rearing procedures and life cycles of 36 species. Can. Ent. *108*: 1345-1357.

Hoars, W. S. 1975. *General and Comparative Physiology*. Prentice-Hall, N.J. 848 pp.

Hodek, I. 1962. Experimental influencing of the imaginal diapause in *Coccinella septempunctata* L. Acta. Soc. Entomol. Cech. *59*: 297-313.

Hodek, I. 1974. Reactivation of diapausing *Aelia acuminata* adults before hibernation (Heteroptera). Acta. Ent. Bohemoslov. *71*: 65-71.

Hogan, T. W. 1960. The onset and duration of diapause in eggs of *Acheta commodus* (Walk.). Aust. J. Biol. Sci. *13*: 14-29.

House, H. L. 1967 a. Artificial diets for insects: a compilation of references with abstracts. Information Bull. 5. Research Institute, Canada Agriculture, Belleville, Ont.

House, H. L. 1967 b. The decreasing occurrence of diapause in the fly *Pseudosarcophaga affinis* through laboratory-reared generations. Can. J. Zool. *45*: 149-153.

Hoxie, R. P. and S. G, Wellso. 1974. Cereal leaf beetle instars and sex, defined by larval head capsule widths. Ann. Ent. Soc. Americ. 67: 183-186.

Hoy, M. A. 1977. Rapid Response to Selection for a Nondiapausing Gypsy Moth. Science 196: 1462-1463.

Huettel, M. D. 1976. Monitoring the quality of laboratory-reared insects: A biological and behavioral perspective. Environ. Ent. 5: 807-814.

Imms, A. D. 1964. A General Textbook of Entomology 9th ed. Methuen and Co., London. 886 pp.

Ingram, B. R. 1976. Effects of photoperiod and temperature on abnormal wing-pad development in two species of Odonata. Can. J. Zool. 54: 1103-1110.

Jacobson, L. A. and Blakeley, R. E. 1960. Survival, development and fecundity of the pale western cutworm, Agrotis orthogonia Morr. (Lepid.:Noctuidae) after starvation. Can. Ent. 92: 184-188.

Jacquemard, P. 1976. La diapause de Diparopsis watersi (Roths.) (Lepid.: Noctuidae) dans le nord du Cameroun. Cot. Fib. Trop. 31: 297-311.

Janisch, E. 1932. The influence of temperature on the life-history of insects. Trans. Entomol. Soc. London 80: 137-168.

Jenkin, P. M. and Hinton, H. E. 1966. Apolysis in arthropod moulting cycles. Nature 211: 871.

Kishaba, A. N., T. J. Henneberry, R. Pangaldan and P. H. Tsao. 1968. Effects of mold inhibitors in the larval diet on the biology of the cabbage looper. J. Econ. Ent. 61: 1189-1194.

Kishi, Y. 1971. Reconsideration of the method to measure the larval instars by the use of the frequency distribution of the head-capsule widths or lengths. Can. Ent. 103: 1011-1015.

Lees, A. D. 1950. Diapause and photoperiodism in the fruit tree red spider mite (Metatetranychus ulmi Koch.). Nature, 166: 874.

Lees, A. D. 1953 a. Environmental factors controlling diapause in the fruit tree red spider, Metatetranychus ulmi. Ann. Appl. Biol. 40: 449-486.

Lees, A. D. 1953 b. The significance of light and dark phases in the photoperiodic control of diapause in Metatetranychus ulmi (Koch). Ann. Appl. Biol. 40: 487-497.

Lees, A. D. 1955. The Physiology of Diapause in Arthropods. Cambridge University Press, London and New York.

Lees, A. D. 1956. The physiology and biochemistry of diapause. Ann. Rev. Entomol. 1: 1-16.

Lees, A. D. 1966. Photoperiodic timing mechanisms in insects. Nature 210: 986-989.

Logan, J. A., D. J. Wollkind, S. C. Hoyt and L. K. Tanigoshi. 1976. An analytic model for description of temperature dependent rate phenomena in arthropods. Environ. Ent. 5: 1133-1140.

Lugger. 1899. Wooly Bears. Minnesota Agri. Exp. Sta. Bull. 61: 131-132.

Lukefar, M. J. and Martin, D. F. 1964. The effects of various larval and adult diets on the fecundity and longevity of the bollworm, tobacco budworm and cotton leafworm. J. Econ. Ent. 57: 233-235.

Lutz. 1909. Larval Variation Due to Moisture. New York Ent. Soc. Journ. 17: 139.

Mansingh, A. and B. N. Smallman. 1967. Effect of photoperiod on the incidence and physiology of diapause in two saturniids. J. Insect Physiol. 13: 1147-1162.

Mansingh, A. 1971. Physiological classification of dormancies in insects. Can. Ent. 103: 983-1009.

Mansingh, A. and B. N. Smallman. 1972. Variation in Polyhydric Alcohol in Relation to Diapause and Cold-hardiness in the Larvae of Isia isabella. J. Insect Physiol. 18: 1565-1571.

Mansingh, A. 1974. Studies on insect dormancy. II. Relationships of cold-hardiness to diapause and quiescence in the eastern tent caterpillar, Malacosoma americanum (Fab.), (Lasiocampidae:Lepidoptera). Can. J. Zool. 52: 629-637.

Marten, J. 1880. Noxious and beneficial insects. Illinois Dept. Agric. Trans. 18: 115.

McDonald, I. A. 1976. Ecological genetics and the sampling of insect populations for laboratory colonization. Envir. Entomol. 5: 815-820.

McGinnis, A. J. and R. Kasting. 1959. Nutrition of the pale western cutworm, Agrotis orthogonia Morr. (Lepid.:Noctuidae). I. Effects of underfeeding and artificial diets on growth and development, and a comparison of wheat sprouts of Thatcher, Triticum aestivum L. and Golden Ball, T. durum Desf. as food. Can. J. Zool. 37: 259-266.

McLeod, D. G. R. and S. D. Beck. 1963. Photoperiodic termination of diapause in an insect. Biol. Bull. 124: 84-96.

McLeod, D. G. R. 1964. Diapause in Euxesta notata (Weidemann). Proc. Entomol. Soc. Ontario 94: 61-62.

McMullen, R. D. 1967. The effects of photoperiod, temperature and food supply on rate of development and diapause in Coccinella novemnotata. Can. Ent. 99: 578-586.

McPherson, J. E. 1974. Photoperiod effects in a southern Illinois population of the Euschistus tristigmus complex (Hemiptera:Pentatomidae). Ann. Ent. Soc. Am. 67: 943-952.

McPherson, J. E. 1975. Effects of developmental photoperiod on adult morphology in Euschistus tristigmus (SAY) (Hemiptera:Pentatomidae). Ann. Ent. Soc. Am. 68: 1107-1110.

McPherson, J. E. and K. W. Vangeison. 1975. Effects of photoperiod on a population of Euschistus tristigmus (Say) (Hemiptera:Pentatomidae) from Gainesville, Fla. Ann. Ent. Soc. Am. 68: 205-206.

Menaker, M. and G. Gross. 1965. Effect of fluctuating temperature on diapause induction in the pink bollworm. J. Insect Physiol. 11: 911-914.

Metcalf, C. L., W.P. Flint and R. L. Metcalf. 1962. Destructive and Useful Insects. McGraw-Hill, N.Y. 1087 pp.

Mitchell, R. T. and H. S. Zim. 1962. Butterflies and Moths. Golden Press, N.Y. 160 pp.

Moreau, J. P. 1964. A propos de la biologie d'Arctia caja L. (Lepidoptera: Arctiidae). XIIth Int. Congr. Entomol. London, 1964. p. 539.

Morris, R. F. 1967. Factors Inducing Diapause in Hyphantria cunea. Can. Ent. 99: 522-528.

Müller, H. J. 1965. Probleme der Insektendiapause. Zool. Anz. Suppl. 29: (Verh. Dtsch. Zool. Ges. 1965) 192-222.

Müller, H. J. 1970. Formen der Dormanz bei Insekten. Nova Acta Leopoldina 35: 1-27.

Nijhout, H. F. 1975. A threshold size for the metamorphosis in the tobacco hornworm, Manduca sexta (L). Biol. Bull. 149: 214-225.

Oldroyd, H. 1970. Elements of Entomology. Universe Books, N.Y. 312 pp.

Ouye, M. T. 1962. Effects of antimicrobial agents on microorganisms and pink bollworm development. J. Econ. Ent. 55: 854-857.

Pantyukov, G. A. 1964. The effect of low temperature on different populations of the brown tail moth Euproctis chrysorrhoea (L.) and the gypsy moth Lymantria dispar (L.) (Lepidoptera:Orgyidae). Ent. Rev. Wash. 43: 47-55.

Payne, N. M. 1926. Freezing and survival of insects at low temperatures. Quart. Rev. Biology 1: 279-281.

Payne, N. M. 1927. Measures of insect cold-hardiness. Biol. Bull. Mar. Biol. Lab. 52: 449-457.

Peterson, L. 1946. Can. Ins. Pest Rev. 24: 111.

Philogène, B. J. R. and D. M. Benjamin. 1971. Temperature and photoperiod effects on the immature stages and adults of Neodiprion swainei (Hymenoptera:Diprionidae). Can. Ent. 103: 1705-1715.

Philogène, B. J. R. 1975 a. Observations sur la structure des ocelles larvaires (stemmates) de certaines lepidopteres. Can. Ent. 107: 1073-1080.

Philogène, B. J. R. 1975 b. Responses of the Cinnabar Moth Hypocrita jacobaeae to various temperature/photoperiod regimes. J. Insect Physiol. 21: 1415-1417.

Philogène, B. J. R. and A. Massalski. 1976. Neurosecretory system of the brain-corpus cardiacum complex in diapausing Tyria jacobaeae L. (Lepidoptera:Arctiidae). Int. J. Insect. Morphol. and Embryol. 5: 289-299.

Pipa, R. L. 1971. Neuroendocrine involvement in the delayed pupation of space-deprived Galleria mellonella (Lepidoptera). J. Insect Physiol. 17: 2441-2450.

Pipa, R. L. 1976. Supernumerary instars produced by chilled wax moth larvae: Endocrine mechanisms. J. Insect Physiol. 22: 1641-1647.

Plantevin, G. 1975. Contribution à l'étude de la biologie de Galleria mellonella: Mues, croissance et développement. Ann. Zool. Ecol. Anim. 7: 365-398.

Poitout, S. and R. Cayrol. 1969. Action de différent facteurs sur le nombre de stades larvaires chez la noctuelle de la tomate Hèlicoverpa armigera Hbn. Ann. Soc. Entomol. Fr. (N.S.) 5: 407-427.

Poitout, S. and R. Bues. 1974. Elevage de plusieurs espèces d'Arctiidae sur milieu artificiel simple. Particularités de l'élevage selon les espèces. Ann. Zool. Anim. 6: 431-441.

Raina, A. K. and R. A. Bell. 1974. Haemocytes of the pink bollworm, Pectinophora gossypiella, during larval development and diapause. J. Insect. Physiol. 20: 2171-2180.

Raske, A. G. 1976. Complexities in the number of larval instars of the birch casebearer in Newfoundland (Lep.:Coleiphoridae). Can. Ent. 108: 401-405.

Rathore, Y. S., W. D. Guthrie and S. W. Carter. 1976. Inheritance of Decreased Survival on Field Corn of European Corn Borer Cultures Reared Continuously on a Meridic Diet. USDA-ARS-NC-45, May, 1976.

Richards, O. W. 1949. The relation between measurements of the successive instars of insects. Proc. R. Entomol. Soc. Lond. Ser. A Gen. Entomol. 24: 8-10.

Riley, C. V. 1880. Notes on our commoner insects: The Isabella Tiger-moth. Amer. Ent. 3: 133.

Ring, R. A. 1972. Relationship between diapause and supercooling in the blowfly, Lucilia sericata (Mg.) (Diptera:Calliphoridae). Can. J. Zool. 50: 1601-1605.

Saccharov, N. L. 1930. Studies in cold resistance of insects to cold. Ecology, 11: 505-517.

Salt, R. W. 1959. Role of glycerol in the cold-hardening of Bracon cephi (Gahan). Can. J. Zool. 37: 59-69.

Salt, R. W. 1961. Principles of insect cold-hardiness. A. Rev. Ent. 6: 55-74.

Sanderson, E. D. 1910. The relation of temperature to the growth of insects. J. Econ. Ent. 3: 113-139.

Saunders, W. 1873. IV.- The Isabella Tiger Moth. Can. Ent. 5: 75-77.

Saunders, D. S. 1973. Thermoperiodic Control of Diapause in an Insect Theory of Internal Coincidence. Science, 181: 358-360.

Saunders, D. S. 1976. The Biological Clock of Insects. Sci. Amer. 234: 114-121.

Scholanders, P. F., W. Flagg, R. J. Hock and L. Irving. 1953. Studies on the physiology of frozen plants and animals in the Arctic. J. Cellular Comp. Physiol. 42: Supl. 1.

Shapiro, A. M. 1968. Laboratory feeding preferances of the banded woollybear, Isia isabella. Ann. Ent. Soc. Amer. 61: 1221-1224.

Shelford, V. E. 1929. Laboratory and field ecology. Baltimore: Williams and Welkins.

Siddiqui, W. H. and Barlow, C. A. 1973. Population Growth of Anagasta kuehniella (Lepid.:Pyralidae) at Constant and Alternating Temperatures. Ann. Entomol. Soc. Am. 66: 579-585.

Singh, P. and H. L. House. 1970 a. Antimicrobials: "safe" levels in a synthetic diet of an insect, Agria affinis. J. Insect Physiol. 16: 1769-82.

Singh, P. and H. L. House. 1970 b. Antimicrobial agents: their detrimental effects on size of an insect, Agria affinis. Can. Ent. 102: 1340-44.

Singh, P. and Bucher, G. E. 1971. Efficacy of "safe" levels of antimicrobial food additives to control microbial contaminants in a synthetic diet for Agria affinis larvae. Entomol. Exp. Appl. 14: 297-309.

Singh, P. 1972. Bibliography of artificial diets for insects and mites. Bull. N.Z. Dept. Scient. Ind. Res. 209.

Smith, C. N. 1966. Insect Colonization and Mass Production. New York: Academic Press. 618 pp..

Sømme, L. 1967. The effects of temperature and anoxia on haemolymph composition and supercooling in three overwintering insects. J. Insect Physiol. 13: 805-814.

Surgeoner, G. A. and W. E. Wallner. 1975. Determination of larval instars of Heterocampa manteo and reduction of larval head capsule size by the parasitoid Diradops bethunei. Ann. Ent. Soc. Am. 68: 1061-1062.

Tauber, M. J. and Tauber, C. A. 1973 a. Insect Phenology: Critera for Analyzing Dormancy and for Forecasting Postdiapause Development and Reproduction in the Field. SEARCH: Agriculture 3: No. 12; 1-16. (Cornell University).

Tauber, M. J. and Tauber, C. A. 1973 b. Nutritional and Photoperiodic Control of the Seasonal Reproductive Cycle in Chrysopa mohave (Neuroptera). J. Insect Physiol. 19: 729-736.

Tauber, M. J. and Tauber, C. A. 1973 c. Seasonal Regulation of Dormancy in Chrysopa carnea (Neuroptera). J. Insect Physiol. 19: 1455-1463.

Tauber, M. J. and Tauber, C. A. 1974. Thermal accumulations, diapause and oviposition in a conifer-inhabiting predator, Chrysopa harrisii (Neuroptera). Can. Ent. 106: 969-978.

Tauber, M. J. and Tauber, C. A. 1976. Insect Seasonality: Diapause Maintenance, Termination and Postdiapause Development. Ann. Rev. Ent. 21: 81-107.

Thiele, H. U. 1973. Remarks about Mansingh's and Muller's classifications of dormancies in insects. Can. Ent. 105: 925-28.

Tietz, H. M. 1972. Index to the Life Histories - North American Macrolepidoptera. pp. 368-370. Allyn Museum of Entomology.

Tingle, F. C., H. C. Lane, E. E. King and E. P. Lloyd. 1971. Influence of nutrients in the adult diet on diapause in the boll weevil. J. Econ. Ent. 64: 812-814.

Trottier, R. 1971. Effect of Temperature on the Life-cycle of Anax junius Odonata:Aeshnidae) in Canada. Can. Ent. 103: 1671-1683.

Vail, P. V., Henneberry, T. J. and Pengalden, R. 1967. An artificial diet for rearing the salt marsh caterpillar Estigmene acrea (Lepid.: Arctiidae), with notes on the biology of the species. Ann. Ent. Soc. Am. 60: 134-138.

Vanderzant, E. S. 1966. Defined diets for phytophagous insects. In: Insect colonization and mass production. C. N. Smith-Ed. Academic Press, N.Y.

Vanderzant, E. S. 1967. Wheat-germ diets for insects: Rearing the boll weevil and the salt-marsh caterpillar. Ann. Ent. Soc. Am. 60: 1062-1066.

Vanderzant, E. S. 1969. Physical aspects of artificial diets. Ent. Exp. and Appl. 12: 642-650.

Vanderzant, E. S. 1974. Development, significance and application of artificial diets for insects. Ann. Rev. Ent. 19: 139-160.

Vepsäläinen, K. 1971. The role of gradually changing daylength in determination of winglength, alary dimorphism and diapause in a Gerris odontogaster (Zett) population (Gerridae, Heteroptera) in South Finland. Ann. Acad. Sci. Fenn. A, IV Biologica: 183.

Vepsäläinen, K. 1974. Determination of wing length and diapause in water-striders (Gerris Fabr., Heteroptera). Hereditas 77: 163-176.

Villiard, P. 1969. Moths and How to Rear Them. Funk and Wagnalls, N.Y. 242 pp.

Watson, T. F. and M. L. Lindsey and J. E. Slosser. 1973. Effect of temperature, moisture and photoperiod on diapause termination in the pink bollworm. Environ. Entomol. 2: 967-70.

Way, M. J., Hopkins, B. and Smith, P. M. 1949. Photoperiodism and diapause in insects. Nature, Lond. 164: 615.

Way, M. J. and Hopkins, B. A. 1950. The influence of photoperiod and temperature on the induction of diapause in Diataraxia oleracea L. (Lepidoptera). J. Exptl. Biol. 27: 365-6.

Way, M. J. 1962. Definition of diapause. Ann. Appl. Biol. 50: 595-596.

Wellington, W. G. 1960. The need for direct observation of behaviour in studies of temperature effects on light reactions. Can. Ent. 92: 438-448.

Wheeler, M. W. 1893. A contribution to insect embryology. J. Morph. 8: 1.

Whitten, J. A. 1976. Definition of Insect Instars in Terms of "Apolysis" or "Ecdysis". Ann. Entomol. Soc. Amer. 69: 556-559.

Wigglesworth, V. B. 1972. The Principles of Insect Physiology 7th ed. Chapman and Hall-London. 827 pp.

Wigglesworth, V. B. 1973. The significance of "apolysis" in the moulting of insects. J. Ent. (A) 47: 141-149.

Wilde, J. de, Duintjer, C. S. and Mook, L. 1959. Physiology of diapause in the adult Colorado beetle. I. The photoperiod as a controlling factor. J. Insect Physiol. 3: 75-85.

Wilde, J. de. 1962. Photoperiodism in insects and mites. A. Rev. Ent. 7: 1-26.

Wilde, J. de. 1969. Diapause and seasonal synchronization in the adult Colorado beetle (*Leptinotarsa decemlineata* Say). In *Dormancy and survival*. Soc. Exp. Biol. Symp. 23: 263-284.

Wilde, J. de. 1970. Hormones and Insect Diapause. Mem. Soc. Endocrinol. 18: 487-514.