HYSIOLOGICAL STUDIES ON GROWTH AND RS GOVERNING THE SPECIES SPECIFICITY OF CT PESTS IN RELATION TO THEIR HOST PLANTS

(ABSTRACT)

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DOCTOR OF PHILOSOPHY

To

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ABSTRACT

Population study of two representative species pf Pierid butterflies viz. *Pieris brassicae* (L) and *Pieris napi montana* Venity, in relation to their host plants reveals that the absolute density of eggs, larvae and adults of these butterflies varies with different environmental factors like temperature, humidity and rainfall, in the study area. Density of eggs is more in *Pieris brassicae* (L) than in *P. napi montana* Venity, since the former lay more number of eggs at a time than the latter, but the egg distribution is more in *P. napi montana* even if the adults lay their eggs singly. Larval density is also higher in case of *Pieris brassicae* than in *P. napi montana*, but adults of *P. napi montana* are uniformly more in number than that of *P. brassicae*. Both the species synchronized their life cycles with the availability of their accepted host plants in the fields. Sunny weather and open areas are preferred by adults of both the species, especially for mating and oviposition. Density of adults, larvae and eggs is always high during the winter months, i.e. October to January, and decline during the summer months, i.e. March to August in both the species.

Life cycle studies shows that *Pieris brassicae* (L) spent the shortest duration, i.e. from incubation period till adult emergence, on knol khol (*Brassicae oleracea* var. *gongylodes* L.) and longest on cabbage (*B. oleracea* var. *capitata* L.), while *P. mapi montana* spent the shortest life cycle duration on cabbage (*B. oleracea* var. *capitata* L.) and mustard (*B. campestris* var. *sarson* Prain.) and longest on cauliflower (*B. oleracea* var. *botrytis* L.).

Hymenopteran flies have been found to parasitize the larval stages of both the species of butterflies studied. In case of *Pieris*

brassicae (L) the main parasite inflicting their larval stages is *Apanteles glomeratus* (L) while in P. napi montana Venity, the larval parasite is not yet identified. Due to heavy parasitization by these hymenopteran parasites, the larvae of both the butterflies species die prematurely, hence affecting larval growth, life cycle duration and population of both the host species in general.

Rate of consumption, growth and conversion efficiencies of *Pieris brassicae* varies with different host plants on which they are fed and also during various stages of larval life.

Analysis of total organic nitrogen, total free amino acid and sugar, reveal that there exists a difference among acceptable host plants and even between different age groups of the same host plant. Mustard (*B. campestris* var. *sarson* Prain) and raddish (*Raphanus sativus* L.) contain very high amount of total organic nitrogen as compared to other larval host plants. Cabbage (*B. oleracea* var. *capitata* L.), cauliflower (*B. oleracea* var. *botrytis* L.) and knol khol (*B. oleracea* var. *gongylodes* L.) contain very high amount of total free amino acid than other acceptable host plants, while the total free sugar contents does not vary much between them.

Qualitatively, fifteen free amino acids are present in cabbage (*B. oleracea* var. *capitata* L.) and cauliflower (*B. oleracea* var. *botrytis* L.) and knol khol (*B. oleracea* var. *gongylodes* L.), fourteen in mustard (*B. campestris* var. *sarson* Prain) and thirteen in raddish (*Raphanus sativus* L.). Only two free sugars are present in all host plants viz. glucose and galactose. Ten free amino acids are present in the different larval stages of *P. brassicae* (L.) and only eight are present in the larvae of *P. napi montana* Venity. Glucose and galactose are the only two free sugars present in the larval stages of both the butterflies. Same pattern of free amino acids and sugars are present in the larval fecal matter of both the species of butterflies but the quantity differs individually.

Larval stages of *Pieris brassicae* (L) do not feed on other host plants except their known host plants, as observed by preference tests. Larval preference for selective feeding exist even among different host plants known. Mustard (*B. campestris* var. *sarson* Prain) is best preferred other than raddish (*R. sativus* L.) and cauliflower (*B. oleracea* var. *botrytis*), while cauliflower and raddish are more preferred than knol khol (*B. oleracea* var. *gongylodes* L.) or cabbage (*B. oleracea* var. *capitata*), as revealed by 'arena' choice tests experiments.

Six inorganic salts viz. sodium acetate, cadmium acetate, lead acetate, potassium nitrate, magnesium sulphate and manganous sulphate out of ten salts tested, show inhibitory effect on the feeding behaviour of *P. brassicae* larvae when tested on host plants, while the other salts do not exhibit this. Only two water soluble amino acids viz. DL-methionine and glycine from amongst the twelve amino acids tested, stimulated feeding in *P. brassicae* larvae while others are inhibitory.

Ascorbic acid only from amongst the four organic acids tested stimulated feeding in *P. brassicae* larvae, while other acids show inhibitory effects. Out of ten sugars, only galactose stimulated feeding of *P. brassicae* larvae, while others sugars are, to a great extent, inhibitory in character when tested on accepted host plants.

Cauliflower (*Brassica oleracea* var. *botrytis* L.) is the most preferred host plant for oviposition by adults of *P. brassicae* (L) followed by knol khol (*B. oleracea* var. *gongylodes* L.) and cabbage

(*B. oleracea* var. *capitata* L.), Mustard (*B. campestris* var. *sarson* Prain) is less preferred and raddish (*Raphanus sativus* L.) is the least preferred host plant for oviposition by these adults in experimental field conditions.

ECOPHYSIOLOGICAL STUDIES ON GROWTH AND FACTORS GOVERNING THE SPECIES SPECIFICITY OF SOME INSECT PESTS IN RELATION TO THEIR HOST PLANTS

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Thesis submitted in fulfilment of the requirements of the Degree of

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To

THE NORTH-EASTERN HILL UNIVERSITY
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JULY, 1983

Dedicated

to

My Father

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SUPERVISOR'S CERTIFICATE

I certify that the thesis entitled "Ecophysiological Studies on Growth and Factors Governing the Species Specificity of Some Insect Pests in Relation to their Host Plants" submitted by Besterwell Kharbuli for the Degree of Doctor of Philosophy of the North-Eastern Hill University, Shillong, embodies the record of original investigation carried out by him under my supervision. He has been duly registered and the thesis presented here is worthy of being considered for the award of the Ph.D. Degree. This work has not been submitted for any degree of any other university.

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Signature of the Supervisor

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CONTENTS

* * *

List of Tables

List of Tables

List of Tables

List of Tables

Pages

List of Tables

....

List of Figures and Plates

List of Figures and Plates

******

GENERAL INTRODUCTION

All forms of animal life need organic materials in order to exist, grow and reproduce. Some subsist on living, dead or decaying plants; others get the food they require from living or dead animals.

Many kinds including some insects live on a mixed diet of both plant and animal material. Civilized man has almost endless variety in his diet: Bacteria, yeasts, fungi, roots, berries, fruits and foliage of plants furnish vegetable food; he eats flesh of many invertebrates, although fish, birds and mammals commonly furnish his main protein requirements.

No insect selects food in such a variety but few insects are omnivorous. Most of the more specialised kinds of insects restrict their diet to a limited range only. Parasitic insects are generally very specific in the selection of their hosts. Predatory insects confine their diet to animals smaller or less active than themselves. Quite frequently they also select a particular kind of prey, hence, they are also specific in selection to some extent. Parasitic and predatory insects reduce the abundance of plant-eating insect life. Nevertheless, under the conditions that prevailed in nature, their influence has not kept the vast hordes of phytophagous insects from maintaining population at a required level. Neither has it curtailed their evolutionary differentiation because of their innumerable adaptations in structure and in habits, to their environment. Some of the most striking features in this respect relates to the instinctive behaviour that determines the selection of food plants.

There is great variation in the number and variety of food plants the insects select; but there is a fix purpose in their behaviour that is far beyond their dietary requirements.

In search for the causes underlying such selection, we shall consider mainly those species, about half of the living species of insects - which feed on flowering plants, particularly those of economic importance.

In some insects, the adult and larval stages feed on the same plants but in case of butterflies and moths the adult sucks the nectar of various flowers and the laying of its eggs on the larval food plant is not a response to its adult appetite. Any failure of the adult to select plants acceptable to its offspring would spell disaster, because the young offsprings cannot go foraging in search of plants other than those upon which they find themselves. Similar peculiarities prevail among a great variety of diverse insects that restrict their feeding to specific plants.

Insects are grouped into three categories in relation to their food habit. The first group includes those feeders that exercise little choice, depending on availability, abundance, texture of foliage, succulence and the like. Nearly all of them have preferred food plants, however. Like the gypsy moth (_Lymantria dispar_ L.) caterpillar feed on the leaves of deciduous forest trees, but it is most abundant on _Quercus_ spp. Many grasshoppers range over a wide variety of low plants, grasses and the like. Such insects are known as "polyphagous because they accept plants in considerable variety" (Mosher, 1915).

The second group include those insects which restrict their feeding to a small and discrete number of usually similar plants, hence, termed as 'oligophagous'. No clear-cut demarcation can be drawn to separate them from polyphagous forms but they obviously represent a distinct specialisation in food selection especially when their food plants have some characteristics in common, which could be demonstrate through visual observation or by laboratory methods.

The third group of insects, includes those feeders which are highly specialised and referred to as 'monophagous'; because they restrict their feeding to a single species of food plant. These insects are comparatively low in number; indeed, some entomologists believe that none exists in the strictest sense. The boll weevil, Anthonomus grandis, whose habits have been minutely studied, falls in this category.

Until a few decades ago, it was customary to attribute the unmistakeable selection of food plants by oligophagous insects to a sixth botanical sense that enable them to recognize their natural host. But such a supposition has many flaws as has been proved by experimental techniques. Some insects, especially their larvae restrict feeding to certain plants belonging to the same family, although sometimes feed on some dissimilar and unrelated plants. A Dutch entomologist, E. Verschaffelt (1910) who studied the behaviour of butterflies and caterpillars with reference to mustard oils, concluded that the presence of thse chemicals was the factor that determine their choice. Other entomologists, have extended such studies to a large number of other insects and their food plants, and found that some specific chemical or chemicals commonly forms the tie that binds them to a more constant diet.

So, we now understand that an insect's selection of food plants depend primarily on an acute and discriminating chemical sense. As the presence of such chemicals is usually confined to some group of plants or varieties, they are the ones to which the insect is attracted. When the same chemical,attractant appears sporadically in unrelated plants, they also may be chosen as host-plants. This basic conception is supported by observations of the behaviour of insects in nature and by experimental techniques. Thus it explains the puzzling 'botanical sense', and has open up a promising field for study of stimulants, attractants and repellents that have great practical implications (Dethier, 1937; 1941; Brues, 1920; 1940).

In the organic ecosystem, the interaction between animal life and plant life play a dynamic role. Shillong and its adjacent areas in the North-Eastern India, provide a typical subtropical ecosystem, in which the flora and fauna is unique, and offers ample opportunity to study the dynamics of action and reaction amongst them.

Shillong and its adjacent areas, possessed a variety of edible fruits and vegetables which are economically important to the human population in this area. Besides these, there are also, species and condimant which are profusely cultivated and used by the human population.

Such a variety of commercially important plants and vegetables are not useful only to the human population but offer a good opportunity to other animal life, especially insects and nematodes to feed upon, and infest various parts of them, hence becoming their chief insect pests. A point of interest about these insects and other commercially important plant feeders is that thay specifically attack only certain plants and portions of the plant, such as leaf, root, stem, fruit or flower and such other parts of the plant.

Another interesting phenomenon to be noted is that only certain development stages of the life cycle of such insects are infective to the plants. It is due to heavy infestations of these insects on commercially important plants, especially vegetable plants and others, that the economy of the North-Eastern Hill region suffers immensely.

There are a number of parameters both biotic and abiotic which are involved in such phenomena. In order to understand these interesting phenomena, an understanding of the ecologically important parameters in different seasons of the year which governs population dynamics, life cycle, duration of life cycle, survival, growth and other essential biological functions of such insects, is a prerequisite. Furthermore, investigations on the nutritive factors and values of various infested plants and plant parts in relation to the growth and feeding behaviour, of such insects would also be interesting.

As mentioned, it is well established that insect pests attack specifically certain parts of certain plants, this may be due to the presence of certain chemical stimuli which attracted pest insects to oviposit, feed and to perform all biological functions required, on these host plants. With regard to feeding, there must be some 'stimulants' which incite and help the insect or its young one to continue feeding and choose their feeding sites selectively. Other factors like crowding, orientation, temperature, humidity and other such physical stimuli are also responsible to a certain extent for regulating the various behavioural response of insects towards their host plants.

In the present work, the study of various possible environmental factors, which are involved in the population dynamics of pests attacking cruciferous vegetables in different seasons was investigated. Selective study of a specific pest insect which infest crucifers and the screening of various parameters like nutritional stimuli, physical stimuli, chemical factors and such other factors which influence its behaviour, selective dfeeding and feeding specificity was also worked out. Culturing of the pest species in laboratory conditions, and the study of its life cycle, growth and preference in relation to its accepted food plants was also done.

Since the research work focusses on the fundamental aspects of the biology and development of some important pest insects, as well as the role of biotic and abiotic factors on population dynamics and growth in relation to various host plants; knowledge and information obtained from this investigation would be of immense value to understand the interaction between pest and non-pest insects with their host plants, the control of such insect pests, whether biological or chemical and to grow new plants with better resistance so as to promote the economy of the cultivators and the farmers and of the whole North-Eastern Hill Region of India.

REVIEW OF LITERATURE

The subject of insect-plant relationship is not very recent and the literature survey on this field reveals that this particular subject has been worked out by many workers since the early nineteenth century. Many theories and postulations have been put forth by several workers, furthermore, many contributions have come from all sides covering several aspects of insect-plant relationship, like ecology, plant preference, life cycle studies and other biological, chemical and physical relationships between the two interdependent terrestrical communities in natural as well as in artificial conditions.

Although these aspects of insect-plant relationships are being explored by many workers, the literature surveyed will summarised the position of the subject as it is at present.

Preference or non-preference is defined as those chemical or morphological host-plant characteristics and insect responses that lead away from the selection and use of a particular plant, for food, oviposition, shelter or a combination of the three (Painter, 1969).

The morphology of the host-plant may affect the nutrition of the insect in the following ways: (a) It may limit the amount of feeding because of the texture, shape or colour which would reduce amount of nutritive material being ingested and (b) may limit the digestibility and utilization of food by the insect (Kasting et al 1958; Kasting and Mc.Ginnis, 1959).

If the morphological and physical characteristics of the plants are suitable for the insect, chemicals having nutritive characteristics may also play an important role in initial attraction, feeding and oviposition. Synthetic diets of cruciferae feeders gain in their acceptibility after adding mustard oil glucosides (Nayar and Thorsteinson, 1963). Feeding by the spotted cucumber beetle (Diabrotica undecimpunctata howardi Barber) is stimulated by cucurbitacins (Chambliss and Jones, 1966). Boll weevil feeding on artificial diet is increased by the addition of gossypol (Maxwell et al 1963).

Phagostimulant effects of sinigrin have been demonstrated in other lepidoptera (David and Gardiner, 1966), though not all brassicaceous insects require sinigrin to feed normally (Gothilf and Beck, 1967).

Plutella maculipennis larvae have responded with differing sensitivity to sinigrin, gluconapin and other glycosides and their occurrence in different proportions in various crucifers doubtless contributes to differences in acceptibility within the generally acceptable host plant group (Nayar and Thorsteinson, 1963). The point to be made here with the above examples cited is simply that these secondary plant substances added to the diet probably have little or no nutritive value in themselves, but do act as feeding stimulants to increase food intake of the insect which in most cases improves the general nutrition of the insect.

Some plant substance may play a dual role in that they stimulate as well as being essential nutritionally. Proteins, sugars, phospholipids, inorganic salts, minerals, vitamins, amino-acids etc., are exaples of materials that many times function in dual roles of acting as feeding stimulants and also being essential for proper development. Essential oils, glycosides and the other secondary substances as previously stated are usually involved more in a singular role - that of attraction and feeding stimulation and less so from a strictly nutritive standpoint.

Odours are also involved and may guide insects to possible food plants, as in grasshoppers (Haskell et al, 1962), the colorado potato beetle Leptinotarsa decemlineata (de Wilde et al, 1969) and migrant locusts Schistocerca gregaria as well show a positive anemotaxis when the vapours of their host plant are perceived (Kafka, 1971).

Jermy (1966) suggested that most insects select primarily in a negative way, i.e. they eat everything not containing particular deterrent secondary plant substances, majority of these compounds tested appear to affect food uptake negatively (Buhr et al, 1958; Fraenkel, 1959; Harley and Thorsteinson, 1967).

However, the problem is more complex, because plant species differ quantitatively in their contents of nutritive elements. It is likely, that food selection depends on more subtle information than only the presence or absence of those secondary plant substances (Schoonhoven, 1968). Inactivation of deterrent receptor cells, as has been done in the case of silkworm (Bombyx mori (L) by Ishikawa et al (1969) lead to an increased feeding upon non-host diets. As has been shown in many lepidoptera larvae, the sensory system allows for an appraisal of the levels of several nutritive compounds, such as sugars, amino-acids, sterols etc. Behavioural evidence suggests the same for other insects (Hsiao and Fraenkel, 1968; Akeson et al, 1970).

The effects of dietary components on feeding insects were also studied widely. Gothilf and Beck (1967) shown that ascorbic acid and cellulose deterred larval feeding while proteins sugars, wheat germ oil and inorganic salts promote feeding in case of the cabbage looper larvae, Trichoplusia ni. The best known example of increased feeding stimulation as a result of combined effects of different substances is that of sugars and amino-acids, as reported by Back and Hanec (1958) for the European corn borer, Ostrinia nubilalis, and by Thorsteinson (1960) for the grasshopper, Camnula pellucida.

Moore (1980) found that varied amounts of starch, sucrose and lipids, in the diet of the adult boll weevil, Anthonomus grandis (Bohem.) have a drastic effect on its fatty acid composition and synthesis. The amino-acid tyrosine was found to inhibit feeding of the pea leaf weevil, Sitona lineatus (L.) on three pea cultivars, while saccharose amongst the sugars tested was most effective for stimulation of feeding (Havlickova,1980).

Choice of food by the larvae of the fly, Agria affinis depends upon the levels of glucose and amino-acids which determined the growth and development of the fly. Nutrient balance is a prime factor determining food selection in this insect (House, 1969, 1971). The role of amino-acids in the feeding behaviour of Spodoptera littoralis (Boisd.) was also reported by Kalifa et al (1974), in which, protein, glutamic acid and alanine were highly effective in evoking feeding responses in this insect, while, leucine, histidine, serine and methionine had little effect on its feeding behaviour.

Sugar content of plants may be very important to insect pests, usually because of feeding stimulation but may be also limiting in proper growth and survival other than regulating quantitative intake. Low level of soluble sugar content in host plant of *Brevicoryne brassicae* (L) limits reproduction and development of winged forms in the aphid (Evans, 1938, 1939).

Most phytophagous insects studied so far have shown the same amino-acid requirement as the rat and other mammals. In the pea aphid, *Acrythosiphon pisum* (Harris), resistant plants of *Pisum sativum* (L.) lower concentration of amino-acids occur in resistant than susceptible lines (Auclair, 1957). Varietal resistance of the pea plant, *Pisum sativum* (L.) to the aphid, *Acyrthosiphon pisum* is correlated with the relative proportions of amino acids and glucose in the tissue of resistant and susceptible varieties of Peas (Maltais and Auclair, 1957).

Plants deficient in essential minerals needed by insects may in addition contain a typical concentrations of organic compounds than can affect the growth or reproductive capacity of the insects feeding on them. Barker and Tauber (1954) reported that pea aphid exhibit lower reproductive capacity on plants deficient in calcium, magnesium, nitrogen, phosphorus and potassium. Allen and Selman (1957) observed the oviposition rate of the mustard beetle, *Phaedon viridis* (Melsheimer) on watercross leaves (*Nasturtium* spp) decreased when nitrogen, phosphorus, potassium or iron concentrations are lowered.

Preference, susceptibility and resistance of plants to insects also depends on the plant's chemical composition, its morphophysiological condition and various other stimuli whether visual or olfactory, which are present in the plant. Varietal resistance of many plants to various insects was primarily due to its varying chemical composition (Pimentel, 1961; Way and Murdle, 1965; Mason and Baxter, 1970; Sharma, 1971; Podoler and Applebaum, 1971; Chalfant and Gaines, 1973; Sullivan and Brett, 1974; Sehgal and Ujagir, 1977).

Amino acid composition and concentration in plant leaves is very important in the host selection and preference of the larvae of colorado potato beetle, *Leptinotarsa decemlineata* as demonstrated by Mitchell (1974). The rice weevil, *Lissorhoptrus oryzophilus*, preferred young leaves of rice plant and leaves with high amount of total nitrogen, gluconsoluble proteins, hemicellulose and decreasing amount of sucrose as shown by Bang and Tugwell (1976).

Dietary amino acid have been shown to influence the feeding rate of the aphid, *Myzus persicae* (Mittler, 1970) and a higher total amino acid concentration in the diet of boll weevils, increase larval survival, growth, consumption and hatching (Lindig *et. al.* 1981). Cook (1977) reported that only L-proline and L-serine from among the amino acids tested, elicited feeding response in *Locusta migratoria* (L.), hexose and disaccharride s sugars are also highly stimulating.

Leaf age and their position on the host plant have also been found to influence the food preference of the fall webworm, Hyphantria cunea (Barbosa and Greenblatt, 1979a). Age of plant leaves and their amino acid composition affects the performance of *Brevicoryne brassicae* L.) and *Myzus persicae*. Nitrogen and elemental deficiency also influence their reproductive functions

(Van Emden, 1966; Van Emden *et al*, 1971). De Silveira Fonseca *et al* (1972a,b,c;) reported from their observation on silkworms (*Bombyx mori* L.), that age of the mulberry leaf influence their growth and development, also the feeding frequency and water, which as a result produce healthier and heavier cocoons. Younger leaves aged one months, were superior in supporting grouth and development than older leaves.

Ebbjerg (1970) found that mortality of the fifth instar of the European pine shoot moth, *Rhyacionia buolinia* (Schiff), was due to the effect of the water content of the needles of the lodgepole pine (*Pinus contorta* Loud.), while growth rate on dried shoots were very high.

One of the most important aspects of host plant in relation to phytophagous feeders, especially insects is the synchronization of their life cycle with the vegetative cycle of the host plant. Here the age of the host plant, play an important role to a certain extent, in regulating various life functions of an insect feeding on it, hence, the effect cannot be small. de Wilde *et al*, (1969) demonstrate in the colorado potato beetle, (*Leptinotarsa decemlineata*) that females fed with physiologically aged potato leaves, do not reproduce normally or dispause follows earlier; and that growing young leaves of potato, are consumed in relatively higher quantities thus leading to better reproduction and inhibition of diapause later. Parry (1974a,b; 1976; 1978) found that the aphid, *Elatobium abietinum* (W.), settled preferentially more on previous years sitka spruce needles than on current ones. Further analysis show that current year needles had initially higher levels of total and soluble nitrogen levels during shoot elongation periods, but previous year needles and higher levels for most of the remainder of the year. Quantitatively amino acid level was relatively higher in the previous year needles than in the current ones; thus as a whole affect the feeding behaviour of the aphid.

In Philaenus spumarius (L.), Horsfield (1977, 1978) found that nymphs select for feeding young leaves of Xanthium strumarium plants with higher amino acid concentration in the xylem sap which lead to lower mortality than leaves with low amino acid concentration.

Chemical components have also been shown to influence the relationship between insects and the food plants on which the insects or their immature stages feed.

The effect of increase amount of nitrogen as a result of fertilization and its influence on the behaviour, responses and life function of insects have been also worked out. Beckham (1970) reported on the abundance of cotton insects in cotton fields after fertilization and found that more aphids occurred on leaves, as the rate of nitrogen was increased. The affect of nitrogen as a factor contributing towards resistance of strawberries to mites, has been worked out by Rodriques et al, (1970) and show that mite injury to strawberries is correlated to the foliage nitrogen concentration.

Host plant deficient in nitrogen were preferred less than to those with normal nitrogen concentration as shown by Sogawa (1978), this as such lead to lower concentration in amino acid nitrogen in the plant sap which as a result effect the feeding behaviour of the brown leaf hopper. Siddhu and Kaur (1977) show that nitrogen application to the host plant of the mustard aphid (*Lipaphis erysimi* Kalt.) influence the fecundity of the aphid feeding on it.

Other workers also reported on the influence of elemental levels on various insect responses and biology (Sharma, 1970; Byers and Jung, 1979).

Parry (1978) attribute variable nitrogen levels in Douglas fir as a responsible factor affecting the population levels of *Adelges cooleyi* (Gillette.). This factor is also associated with nymphal immigration, the soluble nitrogen level of the current year needles were higher but decrease thereafter.

The effects of food plants on oocyte growth of *Oxya japonica*, have been found to be significant by Lee and Wong (1979). Out of the four plants tested, maize (*Zea mays*) was found to be the best food plant, followed by *Axonopus* and *Cyperus* and *Oryza* was the poorest. These effects are related to the nutritional protein requirement of the insect as well as the chemical composition of the host plant and the amount of food ingested.

Food quality palys an important role in the population dynamics of many insects especially the pest species. Shaw and Little (1977) obtained direct evidence for this by rearing spruce budworm larvae (*Christoneura fumiferana* Clem.) on young field grown balsam fir (*Abies balsamea* L.) trees treated to vary the foliar concentrations of nitrogen, carbohydrate and fat, and observed significant difference in larval survival and pupal weight. Harvey (1974) demonstrate with budworm reared on artificial diet that pupal weight and larval development rate were influenced by the sugar concentrations. Foliar levels of nitrogen, amino acids, sugar and fat have been shown to vary with needle age, host species and host maturity (Durzan, 1968; Durzan and Lopushanski, 1968; Little, 1970; Kimmins, 1971).

Food quality effects have also been demonstrated with other insects with regards to food uptake, longevity, mortality, survival, fertility and reproductive potential (Singh, 1970; Varshney *et al.* 1971; Pratt *et al.* 1972; Smirnoff and Bernier, 1973; Carrow and Betts, 1973; Shaw *et al.* 1978).

The role of ascorbic acid as a feeding stimulant and nutritional requirement for phytophagous insects has been investigated. Thorsteinson (1958) found that ascorbic acid acted as a feeding stimulant for three plant feeding insects, the grasshopper, *Chorthippus longicornis* (Latreille), the colorado potato beetle, *Leptinotarsa decemlineata* (Say.), and the diamond backmoth larva, *Plutella maculipennis* (Curt.). Ito (1961) suggested that ascorbic acid was both a feeding stimulant and a nutritional requirement for the silkworm, *Bombyx mori* (L.). Chippendale and Beck (1964) and Chippendale (1975) shows that ascorbic acid is necessary for normal development of the larvae of the European corn borer, *Ostrinia nubilalis* and *Diabrotica grandiosella* adults, if reared on meridic diet containing no crude plant material. Vanderzant *et al* (1962) have also shown that the boll weevil, *Anthonomus grandis* (Boh), the bollworm, *Heliothis zea* (Boddie.) and the salt marsh caterpillar, *Estigmene acrea* (Drury.) all fail to develop on synthetic diets lacking ascorbic acid.

Oxalic acid was found to inhibit sucking response of brown leafhopper (*Nilaparvata lugens*) feeding on rice plants (Yoshihara *et al*, 1980). Trans-aconitic acid was detected by Kim *et al* (1976) in barnyard grass and this substance show potent inhibitory activity for feeding in brown leafhopper, *Nilaparvata lugens* (Stal.). Numata *et al* (1978) also reported many such substances present in plants which have anti-feeding potential and coumarin present in all non-grasses, as reported by Bernays and Chapman (1975) is the sole factor responsible for the unpalatibility of *Anthoxanthum* to the grasshopper, *Chortippus parallelus*. Chang *et al* (1981) demonstrate the inhibitory interactions of methylene dioxyphenyl compounds on the southern armyworm (*Spodoptera eridania*).

Abnormal growth and development in *Manduca sexta* larvae was observed by Rosenthal *et al* (1975), this is due to the effect of diet containing canavaline-ureacycle-amino acids. Inhibitory effects of amino acid analogues on insect reproduction have been demonstrated by Hegdekar (1970).

Other factors apart from biological factors and the like which affect growth, development, life duration and other life functions of insects are, crowding and larval density (Kitamura, 1968; Salama and Salem, 1971; Zutshi and Saxena, 1978) and temperature, humidity and light effects and seasonal variation (Childs *et al*, 1970; Sachan and Bajpai, 1973; Shapiro, 1978; Twine, 1978; Wahla *et al*, 1979; Archer *et al*, 1980; Honek and Novak, 1980; Papilon *et al*, 1980; Saunders, 1980 and Cox *et al*, 1981).

Effects of host plants on insects feeding on them have also been studied by several workers. Doss (1979) reported on the effects of host plants on larval duration, pupal weights and pupal duration on *Heliothis armigera* (Hubn). Barbosa *et al.* (1979) reported the effects of host plants on development and survival of the gypsy moth (*Lymantria dispar*). Host foliage also had some influence on the development, survival, fecundity and oviposition of the spearmarked black moth, *Rheumaptera hastata* as shown by Werner (1979) and on the effect of foliage on the body weight and survival in the larval of *Lithophanini* as shown by Schweitzer (1979). The investigations of Mansour *et al* (1981) on *Heliothis armigera* and Poonia *et al* (1981) on *Diacrisia obliqua*, demonstrate that food plants influence not only the pupal weights and reproductive potential of adults but also the growth index, gain on larval weight and survival of feeding larvae on their respective host plants.

Effects and influence of various host plants, on oviposition, larval growth, adult fecundity and total duration of life cycle in insects had been investigated, Chattoraj and Yadava (1968), on the gram cutworm (*Agrotis flammatra* Shiff.); on *Thrips tabaci* (Lindman.) by Abdel-Gawaad *et al* (1970, 1971); on Choristoneura conflictana by Beckwith (1970); on sugarbeet armyworm, *Spodoptera exigua* (Hubn.) by Afify *et al* (1971); on *Agrotis ipsilon* (Hubn.) by El-kifl *et al* (1971) and El-Sayed (1975) and Thorsteinson (1972). Ichinose and Sasaki (1975) on *Anadivia peponis* Fab; and Vilkova (1976) and Chand Choudhary (1977); Tingey and Pillemer (1977) and Barbosa and Greenblatt (1979) on other insects. Many other workers have also reported on the multiple effects of host plants on reproduction, development, fecundity, etc. Nutrient status and physiology of host plants also influence the insect on feeding on them, specially their population and other biological functions (Markukla et al, 1969; Metcalfe, 1970; Grijpma and Gara, 1970a,b; Day, 1971; Drooz, 1971; Finch, 1971, 1980; Greene and Thurston, 1971; Poe, 1971; Salama et al, 1971; Salama and Tolba, 1971; Verner, 1971; Patterson et al, 1975; Wicklund, 1975; Choudhury and Bhattacharya, 1976; Claridge et al, 1977; Newman and Walker, 1977; Bale and Luff, 1978; Capinera 1978a,b; Lal and Mukherji, 1979; Mc.Farlane and Thorsteinson, 1979; Ottens and Todd, 1979; Combs et al, 1980; Holtzer and Sterling, 1980; Niemela et al, 1980; Sureja and Chand, 1980).

Patterns of relationships between insects and their food plants, repponse of insects to plants had also been investigated by various workers. Saxena et al (1974) and Saxena and Saxena (1975) worked out a variety of insect responses to various plants in leafhoppers, Empoasca devastans and Empoasca kerri motti in relation to growth, survival, egg production and oviposition on various plants. Effect of plant species and organic matter on feeding behaviour and weight gain of several insects have also been investigated by several workers; King (1977) on larvae of the black beetle, Heteronychus arator and the effects of plant species of its feeding behaviour and weight gain. Scriber and Feeny (1979) reported on the effects of growth form of food plants on hervibivorous caterpillars and that they grow faster and more efficiently on herbaceous plants than on shrubs and trees.

Nair and McEwen (1976), Nair et al (1976) in their host selection studies of the adult cabbage maggot (Hylemya brassicae), reported the effects of glucosinolates and common nutrients on oviposition of the adult fly, and that sinigrin and four other glucosinolates induced oviposition. The mustard oil, allylisothiocyanate stimulate the flight activity of the fly and attract them to their source. Glucose, sucrose, casein, wheat germ oil and B-vitamins did not influence oviposition at the tested concentrations, but casein hydrolysate inhibited oviposition.

Dethier and Goldrich (1971) demonstrated that sugars added to the food of the blowfly larvae, during their development lead to an increase sensitivity of adults to some sugars. Chang and Philogene (1978) reported the responses of Psylla pyricola to various polar and non-polar lipids of Pyrus sp. leaves and also to various phenolic compounds, furthermore, only six pollar-soluble and two lipid-soluble phenolics if present in any plant is enough to be easily accepted by the psyllid as a host.

In the host plant selection of the horse raddish flea beetle, Phyllotreta armoraciae, two flavanol glycosides are found to be the factor which stimulates feeding of the beetle in combination with glucosinolates (Neilsen et al, 1979). This agrees with the findings of Feeny et al (1970) and Hicks (1974), on mustard oil glucosides which stimulates feeding in cabbage fish beetle adults, Phyllotreta cruciferae and Phyllotreta striolata.

Feeding stimulation, responses and behaviour of insects in relation to the plant on which they feed have also been profusely investigated by many workers on various insects. Variation in the level of chemical components and presence of other chemical constituents which influence the various behavioural responses and preference of insects to their host plants has also been simultaneously investigated (Baker and Norris, 1967; 1968a,b;

Meyer and Norris, 1967; Gilbert and Norris, 1968; Baker et al, 1968; Borg and Norris, 1969; Norris, 1970; Peacock and Fisk, 1970; Nielsen, 1978; Jordens-Rottgar, 1979; Fisk, 1980; Haglund, 1980; and Albert and Jarrett, 1981).

Studies on food and feeding specificity, feeding habits and evolution of food plant preference on phytophagous insects, in natural and synthetic diets have been worked out by many workers (Dethier, 1954; 1968; Goodpasture, 1974; Pavlik, 1974; Yamamoto, 1974; Ellis and Hardman, 1975; deBoer et al, 1977; Mishra, 1977; Saxena and Schoonhoven, 1978; Smiley, 1978; Dethier and Yost, 1979; Hussain et al, 1979; Wasserman, 1979; Moser and Oertli, 1980; Powell, 1980).

Host plant extracts were usually found to be stimulating in various test with reference to feeding and behaviour and to a large extent on ovipositional responses. As shown by Meisner and Ascher (1972) and Meisner (1973) in Spodoptera littoralis and Pouzat (1976) in Acanthoscelides obtectus, these insects feed on non-host plants and oviposit on any substrate containing the host extracts. Feeding inhibition by leave extracts on insects was also demonstrated by Meisner et al (1981) on Spodoptera littoralis.

Interrelationships embracing plant-arthropod relationship as related to natural phenomena was very complex as viewed by Huffaker (1974), especially the interplay between the plant hosts and their phytophagous feeders and among the latter and their own carnivorous predators and parasites and at higher levels as well have had striking influences in the evolution of species, and in their functional, dynamic roles in explaining the population dynamics and energetics of complex communities.

Insect-plant relationships are often studied in cultivated species of economic importance while the thorough knowledge acquired in modern plant protection research is appreciable, the study of insects and plants under more natural conditions may add new data relevant to an understanding of the evolution of their relationship. Herrebout et al (1976), Schoonhoven et al (1977), shown that small ermine moths of the genus Yponomeuta (Lepidoptera) show different degrees of relationship with their host plants which results as evidence to the clue of their origin and evolution. Further works by Gerrits-Heybrock et al (1978) reveals that larvae of ermine moths can retain sensitivities to substances found in ancestral food plants, which support the hypothesis that members of this genus feed originally on celastraceous plants. Auerbach and Hendrix (1980), as a result of their study of the insect fern interaction, with regard to utilization and species area association indicate that some aspects of fern-insect associations are similar to those known for angiosperm-insect interactions. Two hypotheses are frequently presented to explain the apparent resistance of ferns to insect attack. Both hypotheses involve chemical constituents of ferns; one stresses the presence of thiaminase, the other on the occurrence of phytoecdysones. These hypotheses according to Hendrix (1977) and Jones and Firn (1978) have their own shortcomings. Moran (1980), analysed the cactophagous insect community on Opuntia hosts, and described the various specificity of the phytophagous insects on opuntias, their coevolution, life histories and the behavioural adaptation.

Hicks and Tahvanainen (1974), when working with niche differentiation by crucifer feeding flea beetles (Chysomelidae) show that six closely related flea beetle species in Central New York coexist by possessing distinct host plant and habitat preferences. Van Drongelen and Povel (1980) demonstrate by experiments the relationship between the larvae of *Yponomeuta* spp. (Lepidoptera) and their various host plants on the basis of gustatory sensitivity measured by electrical responses.

Hori (1968, 1974, 1975a) observed in the cabbage bug, *Erydema rugosum* (Motschulsky.) that adult bugs feed mainly on mesophyll and parenchymatous cells of the stem and on the pod and flower bud of the cruciferous food plants, their nymphs feed not only on mesophyll but also on vasular elements; the younger the age of the nymphs, the more they feed on the latter elements, and that on the injured tissues of cabbage the peroxidase activity increased temporarily but decreased rapidly plant tissue, the acid phosphatase activity and amount of phenol compounds decreased immediately after the injury but thereafter it was restored to the level of the uninjured plant tissue. These changes in the host tissue were not observed in the nymphal feeding but on the adult only. The chlorophyll content also decreased as a result of the feeding of the adult bug. With regard to the change in amino acid components of the host tissue, seventeen and fifteen kinds of amino acids were detected in the injured and the uninjured tissue respectively. The total amount of amino acids was significantly greater in uninjured tissue.

Hori (1971a,b; 1973; 1975b) studied the feeding habits and the injury inflicted by *Lygus disponsi* (Linnavuori.) to its host plants, sugar beet and rape, which lead to many malformation tin the host plants on which these bugs feed, and also observed that these malformations are related to the frequency, duration and the quantity of feeding of these bugs. Other important observations are that the concentration of the thirteen amino acids found originally in the host plant, i.e. sugarbeet, increase remarkably due to injury. Five kinds of sugars were originally present in the host plant and were more abundant quantitatively as a result of injury, except glucose. Phenoloxidase activity also increase as a result of injury, especially in the vein tissues but substances reacting with Salkovski reagent decrease. All these changes lead to malformation of the leaf of the host plant as a result of the feeding of the bug.

When an insect or any phytophagous organism, encounters a substrate or any plant in natural or artificial condition, it must first approach it, then have a test bite to verify whether the substrate is tasty or not, whether it is acceptable to it as food or not. Then biting, sucking, chewing or nibbling occurs accordingly, followed by consumption, digestion and ejestion. These are a chain of events occurring during the feeding process of any insect or organism, when the substrate or plant species is found suitable for consumption, thus leading to nutrition, growth and development, tissue repair, reproduction and other neccessary biological functions, in order to exist and continue life in nature.

The consumption of or feeding on any substrate or food plants should be followed by utilization of the food, conversion to tissue growth and development. Therefore, various indices like consumption, utilization, conversion should be known so that prediction and postulation for growth could be estimated. Hence, these type of studies are very important for each organism from the smallest to the largest and from the simplest to the complex forms.

Studies on food consumption, its utilization and conversion efficiencies in relation to growth and development in phytophagous feeders is not very new, especially on those species of economic importance.

An insect may eat a small or a large amount of food, and it may or may not grow or develop properly. Hence food consumption is very important in understanding the various insect responses in relation to their accepted host plants. The amount of food ingested therefore have very important influence on body growth and development of many insects. Various workers have reported the influence of food consumption on growth and development rate of insects (Jones and Thurston, 1970; Renner, 1970; Reid and Greene, 1973; DeVita, 1974; Scriber, 1978, 1979a,b; Vaish and Agarwal, 1978; Babu et al, 1979; Reddy and Alfred, 1979; Berry and Shields, 1980; Gupta and Vats, 1980; and Ottens and Todd, 1980).

In many works done on consumption or ingestion of food by insects, feeding responses and preference to various food plants or parts of the same plant and synthetic diets, were also studied, together with utilization, digestion and development rate. Comparative consumption, utilization studies are also made to understand the preference of insects or their young ones to plants and to observe the resultant effect of such behaviour on growth and development of such insects (Evans, 1939; Weismann and Podmanicka, 1970; Dale and Chandrika, 1973; Boldt et al, 1975; Erickson, 1975; Braham and Wittor, 1978; Ratan, 1978; Prem Chand, 1979; Ramdev and Rao, 1979; Capinera et al, 1981).

Studies on food consumption, utilization and conversion efficiencies, as they influence growth and development of insects have attracted the attention of nutritionists. Hence, simultaneously with these efficiency studies, investigations have also been carried out especially on nutrients, chemical components, and other important plant chemicals, and their influence on consumption, digestion, utilization and egestion rates, and their resultant effect on growth and development of insects in particular, on artificial diets or natural substrates (Baker et al, 1970; Mittler et al, 1970a,b,c; Shaver et al, 1970; Flowers et al, 1975; Gahukar, 1976, 1979; and Larsson and Tenow, 1979).

Energy relationships, balance, budgets and energy flow in relation to various indices of consumption, utilization, growth and development had also been carried out. (Erhan, 1969; Lawton, 1970; Taylor and Bardner, 1970; Wightman and Rogers, 1978; Delvi and Pandian, 1979; Kingsolver and Daniel, 1979; Llewellyn and Qureshi, 1979; and Koller and Leonard, 1981).

Influence of physical factors, like temperature, photoperiodism, humidity and other conditions, either naturally or artificially, have been studied and their effects on consumption, utilization, conversion indices and resultant effects on growth and development of insects had also been demonstrated either on natural substrates or synthetic diets. (El-Shaarawy and Gomaa, 1975; Ali and Salem, 1978; Bhat and Bhattacharya, 1978; Khalsa et al, 1979; and Singhal, 1978, 1979).

Parasitism and other pathobiological factors have also been demonstrated to influence, consumption, growth, utilization and food budget of many insects, hence affecting their growth and normal development (Cloutier and Mackauer, 1979; Brewer and King, 1980, 1981; Milstead, 1980; and Espinel, 1981).

Phytoecdysones, hormone analogues, especially juvenile and ecdysone and density have also been shown to influence food consumption, utilization and conversion efficiences of many insects, hence affect their growth and development (Shigematsu et al, 1974; Fytizas and Mourikis, 1979; and Mathavan et al, 1980).

Such investigations were done to gather some understanding about responses and relationships of insects to their host plants in artificial or natural conditions whether they are pests or beneficial in nature.

The problem of insect plant relationship as it stands at present left behind many mysteries for the applied as well as the theoretical biologists to solve. As a matter of fact, various aspects of insect plant relationship and related mechanisms involved are still open for further investigations.

CHAPTER I

Population Density of *Pieris brassicae* (L.) and *Pieris napi montana* Verity, in Cruciferous fields.

1.1. INTRODUCTION

The habitats for any species of insects are neither homogeneous nor continuous. The importance of habitat structure upon the population dynamics of insects has been pointed out by Elton (1949) and more recently by Southwood (1977). In case of insect plant relationships, the role of plants in regulating the population dynamics of insects is well known (Van Emden and Way, 1971).

Coming to the study of agro-ecosystems, where the situation is different from those of natural conditions, to a certain extent, the problem of insect plant relationship is quite different. Here the insects are closely associated with their host plants on which they oviposit, feed and grow, although this may differ in some cases. In this study of insect host plant relationship, *Pieris* butterflies together with their host plants belonging to the family Cruciferae, are taken into account. *Pieris brassicae* (L.) and *Pieris napi montana* Verity, both were selected as representative species.

The butterflies belonging to the genus *Pieris* are often known as pests of cruciferous vegetables. Among all the species of this genus, namely, *Pieris brassicae* (L.), *Pieris rapae* (L.), *Pieris napi montana* (L.), *Pieris melete* (L.), only *Pieris brassicae* and *Pieris rapae* are well known pests. These two species of *Pieris* lay eggs on cruciferous plants and their young ones feed on these vegetables, while the adults live on the nectar of various flowering plants.

Pieris brassicae (L.) or commonly called the large cabbage white butterfly (Plate 1-A,C) is very common and is found in the Indian region mainly in the North-Eastern Hills of India, the foothills of the Himalayas, the extreme northern plains of India and

Baluchistan. In Europe, it is very common in Britain and the Scandinavian countries and is also found in the Mediterranean region including North Africa, except in Egypt (Rivnay, 1962, Wynter-Blyth, 1932).

Pieris napi montana Verity commonly called the small cabbage white or dark veined butterfly (Plate 1-B,D) is also very common; it is found mainly in Burma and Sikkim, but it was also recorded from the Himalayan foothills and the hilly regions of North-East India (Wynter-Blyth, 1932).

Both these species favour hilly region and mountain site, and they may be found in areas wheresoever crucifer cultivation is common. In Shillong both these species are very common, especially before the approach of summer till the beginning of cold winter in those areas where cultivation of cruciferous crops are heavy and even in small kitchen gardens.

Population dynamics of *Pieris* spp. have been studied widely and most of the studies are carried out simultaneously with the availability of their host plants in natural conditions. Nakamura (1970) described the Pieridae community in Japan and also their ecological separation with regard to feeding sites and food plants. Ito *et al* (1975) gave the features of the population dynamics of *Pieris rapae crucivora* (Boisd.) an introduced pest in Okinawa based on yone year survey. Ohsaki (1979, 1980) represented a comparative study of three species of Pierid butterflies, *Pieris rapae*, *P. melete* and *P. napi* in relation to their oviposition plants, nectar plants and rooting sites in Aichi prefecture. Furthermore, Yamamoto (1977, 1978) reported on the number of eggs laid by *Pieris napi nesis* and *P. rapae crucivora* in Sapporo, Japan.

Explanation of PLATE NO. 1.

A - Male of *Pieris brassicae* (L.)

B - Female of *Pieris napi montana* Venity

C - Female of *Pieris brassicae* (L.)

D - Male of *Pieris napi montana* Venity

E - Feeding last stage larva of *P. n. montana* Venity

F - Feeding last stage larva of *P. brassicae* (L.)

G - Pupal cases of the larval parasite parasitizing *P. napi montana* Venity.

H - Adults of the parasite parasitizing *P. n. montana* Venity.

I - Parasitized larva of *P. brassicae* (L.) with parasitic grubs.

J - Grubs of the parasitic hymenopteran (*Apanteles glomeratus* L.)

K - Pupal cocoons of *A. glomeratus* (L.)

L - *Apanteles glomeratus* (L.) adults

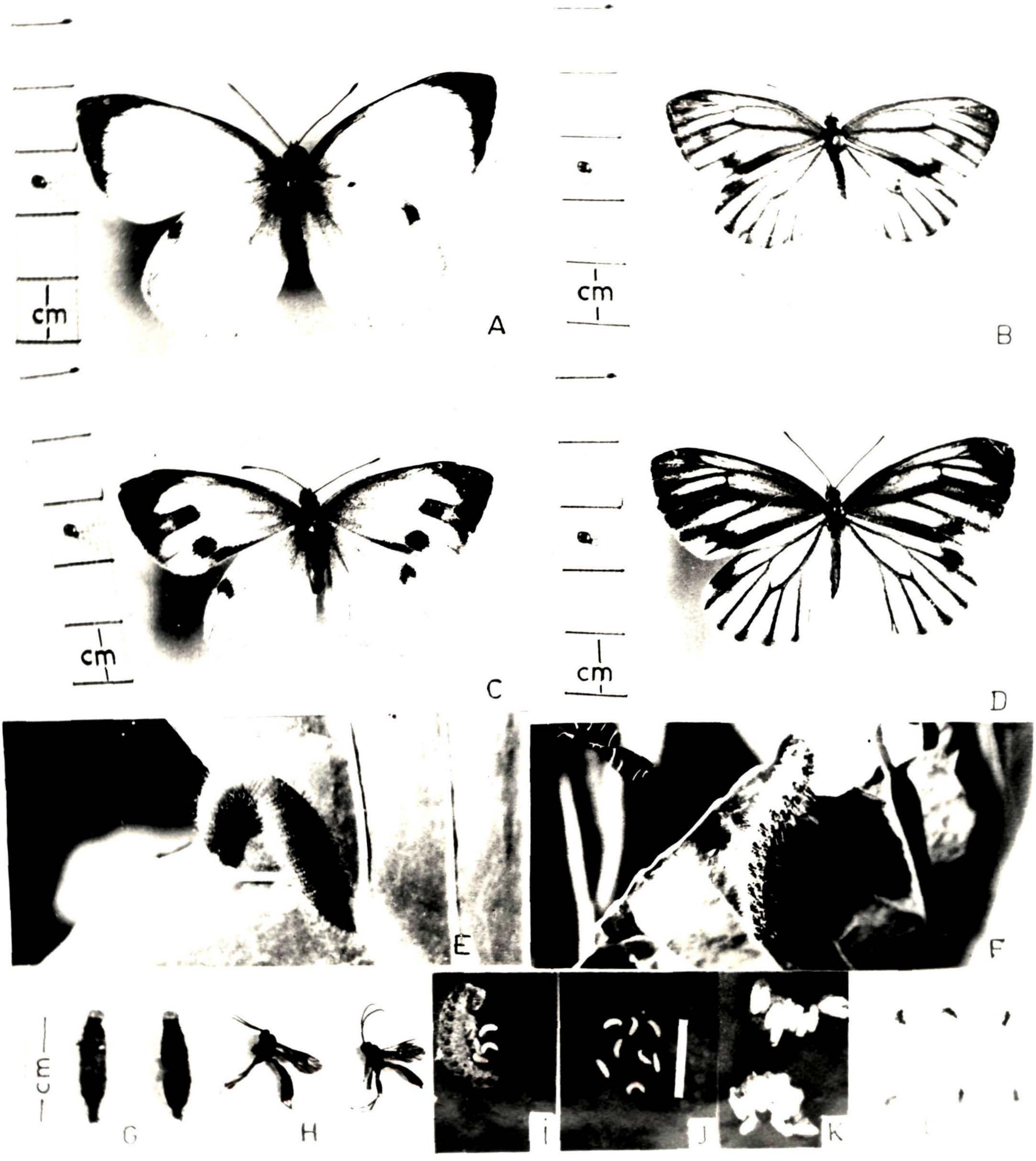


PLATE-1

Ashby and Pottinger (1974) reported the natural population regulation of *Pieris rapae* L. in New Zealand and Jones *et al* (1980) on its long distance movement in Australia. In Britain, the ecology of *Pieris napi* (L.) was worked out by Lees and Archer (1974). Emmel (1972) reported on the dispersal of *Pieris rapae* in South West Virginia, U.S.A., while the host plants of American white butterflies (Pieridae) was reported by Bowden (1971) and Shapiro (1975). Gardiner (1974) reported on the establishment of *Pieris brassicae* (L.) as a pest in Chile.

Other studies with regard to mating, host selection, flower visiting behaviour, adult longevity, reproductive potential and habitat selection of *Pieris rapae* have also been reported (Obahara, 1970; Obahara *et al*, 1974; Miyakawa, 1976; Suzuki, 1978; Jones and Ives, 1979).

Since not much work has been done on the population dynamics of *Pieris brassicae* (L.) and *P. napi montana* Verity, the present study was taken up with a view to find out population fluctuation during different months of the year in relation to physical and biological parameters in natural conditions.

1.2. MATERIALS AND METHODS

Areas around Shillong (97°7'E - 24°0'N) and its suburbs were chosen as study sites. Survey of cultivated crucifers in different sites was primarily done and those areas with heavy cultivation only were chosen for field surveys. Population study was done only at one area, that is, at Sait village, about 15 kms. from Shillong. The village is located on the south of Shillong plateau and very close to Shillong peak. Its altitude is approximately 5000-5500 ft. from sea level.

In this village, there is a large area of approximately 4 sq. km. which is use for cultivation of various cruciferous vegetables like cabbage, *Brassica oleraceae* var *capitata* (L.); cauliflower, *Brassica oleraceae* var *botrytis* (L.); mustard, *Brassica campestris* var *sarson* Prain; raddish, *Raphanus sativus* (L.); lettuce, *Latuca indica* (L.); knol khol, *Brassica oleraceae* var *gongylodes* (L.) and some other crops like rice, *Oryza sativa* (L.); maize, *Zea mays* (L.) and potato, *Solanum tuberosum* (L.). The site selected is hilly with some flat land here and there, and is thinly covered by trees such as pines, *Pinus kesiya* (L.).

Population study was carried out forthnightly. Population sampling was done only during the afternoon and sampling time was only 2 hours i.e. from 12.00 to 2.00 p.m. During this time allotted, temperature, humidity and rainfall observed in the field were recorded.

Sampling of insect population was carried out according to the method of Richards (1940), where only the larval stages and eggs were taken into account. The absolute density of larvae and eggs was recorded randomly from 50 plants in the field whether the plants are in monoculture or mixed culture plots. Larvae and eggs were directly counted *in situ* from each plant. The number of adults flying during the allotted time was estimated visually following the method of Barnes and Barnes (1954) and shaded and unshaded plots (Murray (1963) were also surveyed on the hill sides and slopes, for eggs, larvae and adults.

1.3. RESULTS

The two year population survey (September, 1979 to February, 1982) of pest insects of cruciferous crops, namely *Pieris brassicae* (L.) and *Pieris napi montana* Venity at the study area, revealed many interesting results especially in relation to physical and biological factors.

1.3.1. Population density of eggs.

The population study of eggs of both the species during the year 1979 shows that in the month of September and October, the density was in climax, but slash down in case of *P. brassicae* during the start of the following year, that is 1980. On the other hand, in case of *P. napi montana* Venity it is reversed. The population density of eggs again was at peak for both the species during the month of August and September, 1980. In case of *P. brassicae* it drops down in November and December, while this was not observed in *P. napi montana* Venity. Again in October and November, 1981, the population density of eggs of both the species was at maximum, but dropped down during the end of the year (Fig. 1A).

Comparatively the density of eggs of *P. brassicae* was uniformly higher than that of *P. napi montana* Venity. During the winter months, January-February, the density of eggs was very low in both the species and this was also observed during the summer months from June to July (Fig. 1A).

1.3.2. Population density of larvae.

The population density of larvae of both the species, was observed to vary during different months of the year. The larval density was very high during the months of September and October, 1979 in both the species studied. The larval density dropped during the months of April-August in the year 1980.

In 1980, again in the months of September-December, the larval density of both the species was at peak, this was also observed in the year 1981. During winter, the larval density was always high in both the species, but this is reversed during the summer (Fig. 1B).

1.3.3. Adult population.

The number of adults of both the species also vary during the different months of the year.

During the period August to December of both the year 1980 and 1981, the number of adults of both the species was observed to be at climax, but drops down during the early summer, during the period April-June. The adults of *P. napi montana* were observed to be always more in number than that of *P. brassicae*, but there is a uniform fluctuation of the number of both the species throughout the study period (Fig. 2).

The two year population survey of these *Pieris sp.* shows that the adults do not favour summer conditions, but preferred winter. This is correlated with the availability of food plants on which they oviposit. Host plant availability was more during the winter from October-January but during the summer, host plants were still in nurseries and not available to the adults in the open field conditions (Table-1).

1.3.4. Population density of eggs in relation to physical factors.

Average monthly records of temperature (maximum and minimum), rainfall and humidity, reveal that there is a close relation with

Fig. 1 Average absolute density of eggs (A) and larvae (B) of P. brassicae and P. napi montana Verity.

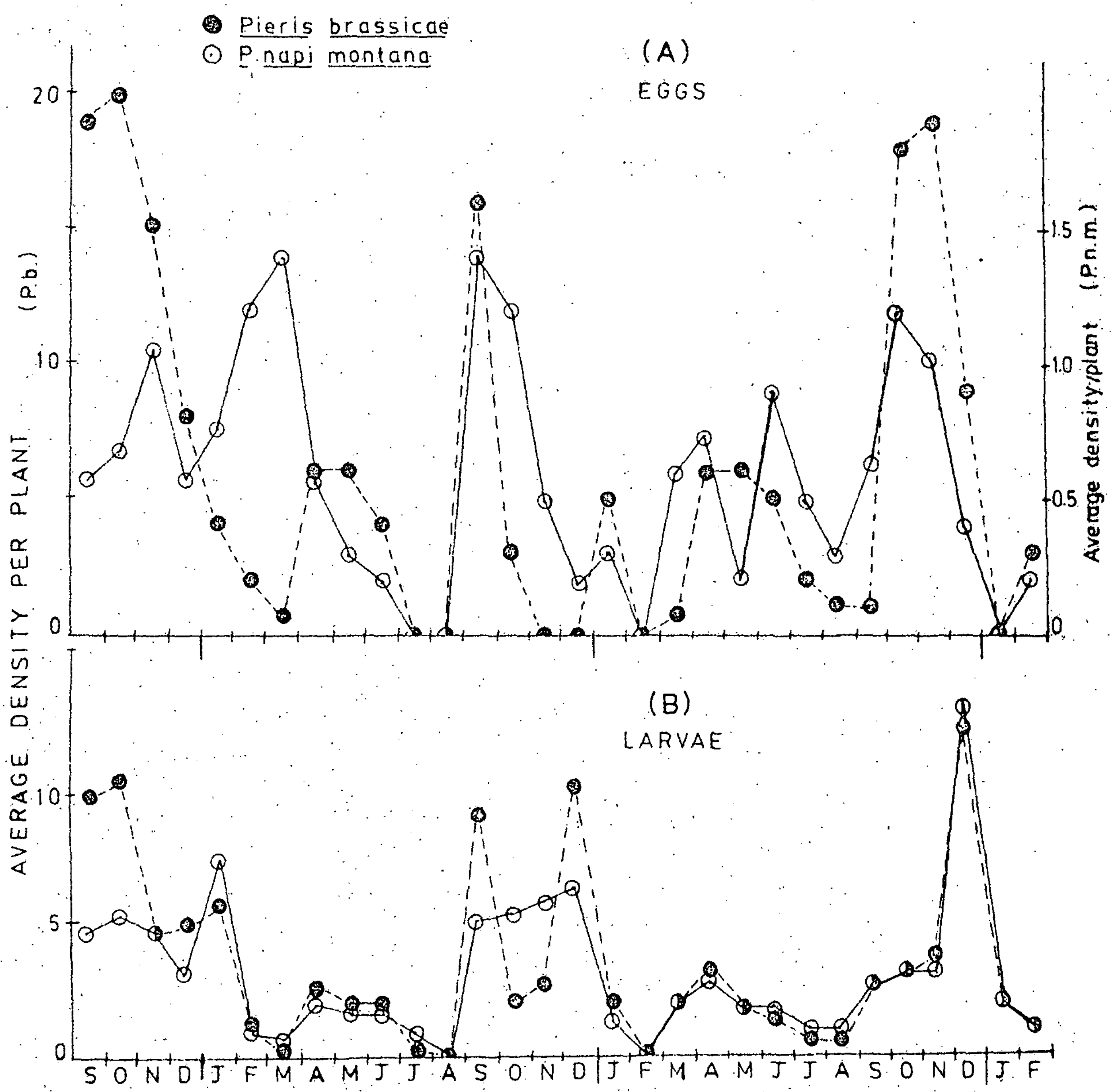
 ● Pieris brassicae
○ P. napi montana
(A)
EGGS
(B)
LARVAE
AVERAGE DENSITY PER PLANT
(P.b.)
Average density/plant (P.n.m.)
20
10
0
10
5
0
1.5
1.0
0.5
0
S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F
1979
1980
1981
1982
SAMPLING PERIOD (MONTHS.)

Fig.1.

TABLE-1

Host plant availability in the study area during different months of the year.

PLANTS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Cabbage (*Brassica oleracea* var. *capitata* L.)	+	-	-	-	$+_N$	$+_N$	+	+	+	+	+	+
Cauliflower (*Brassica oleracea* var. *botrytis* L.)	+	-	-	-	$+_N$	$+_N$	+	+	+	+	+	+
Mustard (*Brassica campestris* var. *Sarson* Prain)	+	+	-	-	-	-	$+_N$	$+_N$	+	+	+	+
Knol khol (*Brassica oleracea* var. *gongylodes* L.)	+	-	$+_N$	$+_N$	+	+	+	-	-	-	-	+
Raddish (*Raphanus sativus* L.)	+	-	-	-	$+_N$	$+_N$	+	+	+	+	+	+
Lettuce (*Latica indica* L.)	+	-	$+_N$	$+_N$	+	+	+	+	+	-	-	-

+ = Present

$+_N$ = Present in Nurseries

\- = Absent

Fig. 2 Number of *P. brassicae* (L.) and *P. napi montana* Verity adults present in a unit time.

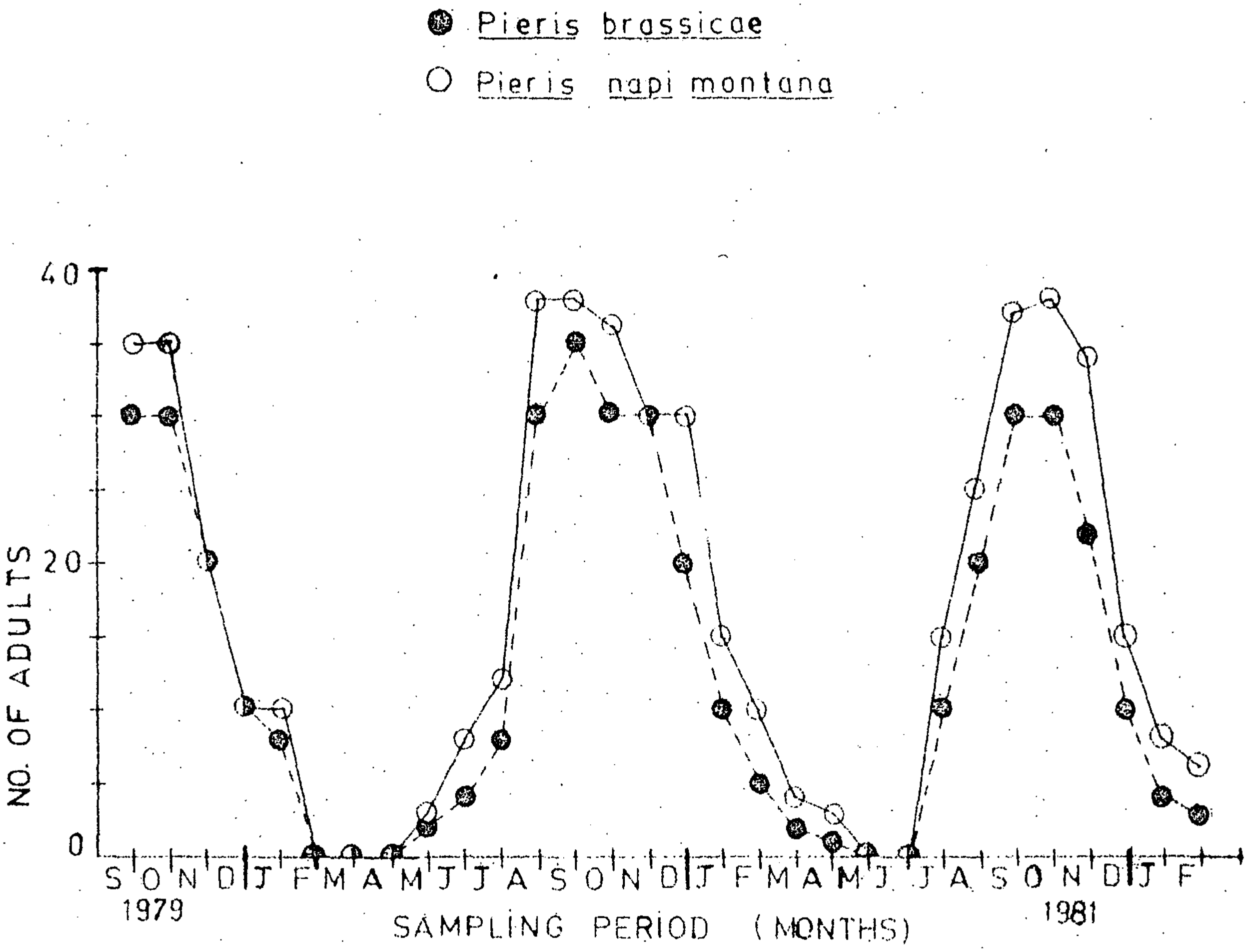

● Pieris brassicae
○ Pieris napi montana
40
20
0
NO. OF ADULTS
S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F
1979
1981
SAMPLING PERIOD (MONTHS)

Fig.2.

average egg density in the field. During the wet summer period - June-August (Fig. 3A) of both the year 1980 and 1981, the average egg density was very low in both the species, but as the winter season with low rainfall, from September to February proceeds, the egg density was very high in both the species.

With regard to humidity (Fig. 3A), when it was high during summer, average egg density was observed to be always low in both the butterflies species, but with the coming of low humidity period during the winter, the egg density was observed to be very high in both.

In relation to temperature (Fig. 3B), the average egg densit of both the species studied, bears a direct relationship. During the hot season, from May-August of the year 1980 and 1981, the density of eggs of both the species was very low in comparison to the cold season, from October to January of 1980 to 1981.

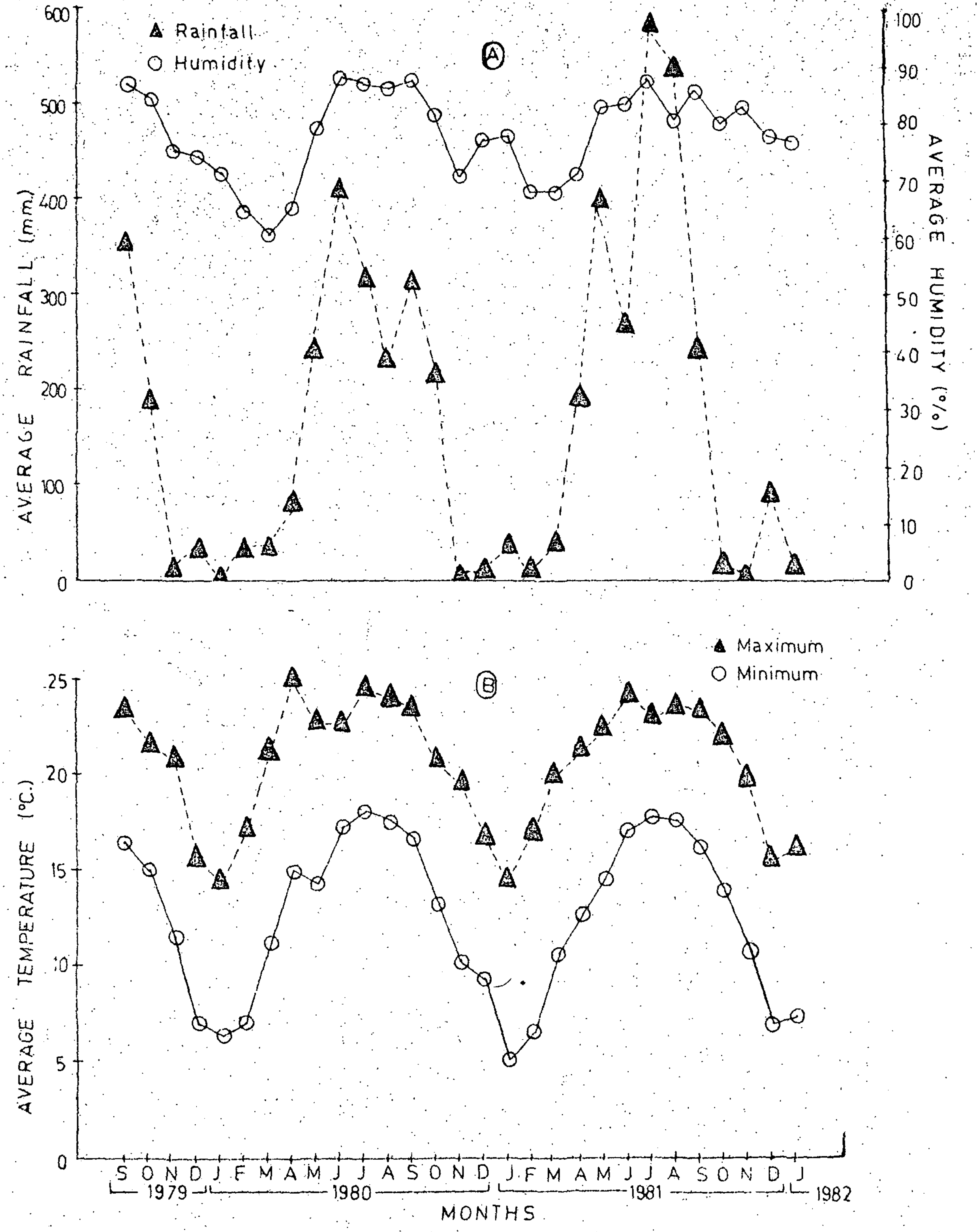
1.3.5. <u>Population density of larvae in relation to physical factors</u>

The average larval density of both the species studied reveals a direct relationship with the physical factors like rainfall and humidity. During the wet summer, May-August, the density of larvae was very low in comparison to the dry winter from October - January of both the years, 1980 and 1981.

1.3.6. <u>The number of adults in relation to physical factors.</u>

The visually estimated number of adults of both the species shows a direct relationship to physical factors like rainfall and humidity. The number of adults of both the species flying per unit time, was very high in the months of September to December of the sampling period, when physical factors like rainfall and humidity

Fig. 3 Average rainfall and humidity (A) and Temperature (B) in different months of the sampling period.



▲ Rainfall
○ Humidity
Ⓐ
AVERAGE RAINFALL (mm)
0
100
200
300
400
500
600
AVERAGE HUMIDITY (%)
0
10
20
30
40
50
60
70
80
90
100
▲ Maximum
○ Minimum
Ⓑ
AVERAGE TEMPERATURE (°C.)
0
5
10
15
20
25
S O N D J F M A M J J A S O N D J F M A M J J A S O N D J
1979
1980
1981
1982
MONTHS

Fig.3.

were comparatively low. But during the months of May to July of the sampling period, the number of adults flying is very low, when high humidity and rainfall conditions prevail in the field.

With regard to temperature, the highest number of adults flying was observed during the months of September to November of the sampling years 1979-1981, in both the species, when comparatively lower temperature prevails in the field. While during the hot summer June to August of the year 1980 and 1981, the number of adults flying was observed to be very low and sometimes came to a standstill in both the species.

1.3.7. Comparison of ovipositional preference in shaded and open areas in cabbage and cauliflower plantation.

With regard to ovipositional preference in plants of shaded and open areas in the field, both the species of butterflies, exhibited preference towards plants growing in open than in shade (Fig.4).

In case of cabbage, the adults of both species shows a tendency to oviposit on plants growing in the open than in the shaded areas. The percentage of plants oviposited was always high in the open area in comparison to the shaded ones, especially during the winter months.

The adults of both species of butterflies exhibited ovipositional preference towards cauliflower plants growing in the open than those in shade. The percentage of plants oviposited in case of cauliflower was high in the open areas than those in shaded ones, especially during the winter months.

Fig. 4 Percentage of cruciferous plants oviposited in shade and open areas.

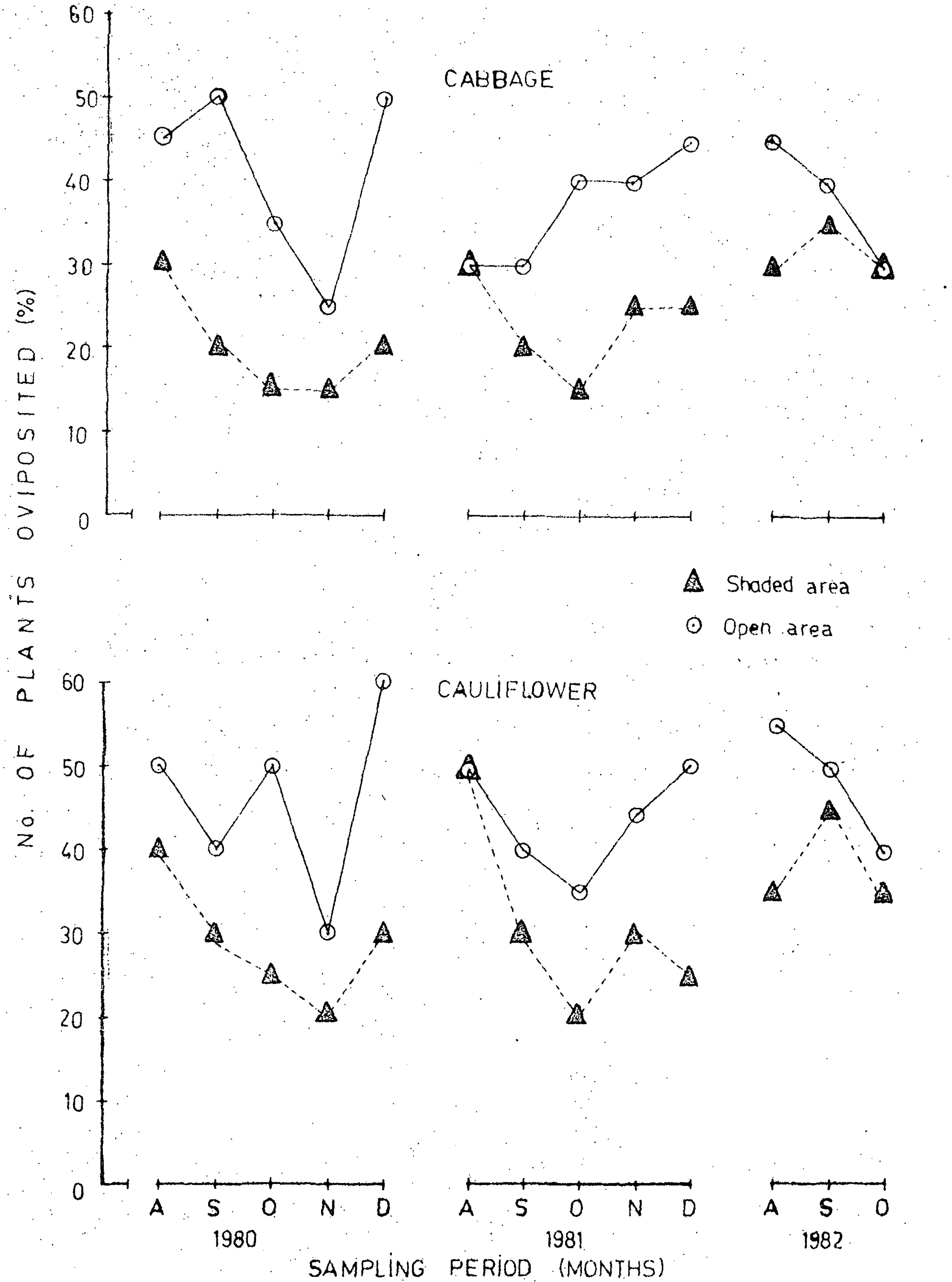

CABBAGE
CAULIFLOWER
No. OF PLANTS OVIPOSITED (%)
0
10
20
30
40
50
60
▲ Shaded area
⊙ Open area
A
S
O
N
D
1980
1981
1982
SAMPLING PERIOD (MONTHS)

Fig. 4.

1.4. DISCUSSION

In the present observation, habitats of the two Pierid butterflies studied, i.e. *Pieris brassicae* (L.) and *P. napi montana* Venity were qualified by oviposition plants, humidity, temperature and light conditions, all of which seem to correlatively influence the population structure of the adults, larvae and eggs. In both the species oviposition plants were restricted to cruciferous vegetables only, but for nectar resources adults randomly choose all the flowering plants available in and around their habitats. In case of *Pieris brassicae*, common oviposition plants cultivated are cabbage, *Brassica oleraceae* var *capitata* (L.); cauliflower, *Brassica oleraceae* var *botrytis* (L.); mustard, *Brassica campestris* var *sarson* Prain; knol khol, *Brassica oleraceae* var *gongylodes* (L.) and sometimes raddish, *Raphanus sativus* (L.). But *Pieris napi montana* Venity is found to oviposit mainly on cabbage and cauliflower only. This may be due to host plant specificity exhibited by all *Pieris* sp. Both the species of butterflies preferred sunny conditions. This corroborates with the study of Ohsaki (1979) with *P. rapae* (L.).

Pieris brassicae females lay eggs in batches or clusters which range from 30-80 eggs per batch while *P. napi montana* Venity lay their eggs singly. Thus the egg laying behaviour of both the species differ from one another, and this lead to the variation of average egg density in both the species. The number of eggs laid per female is therefore greater in *P. brassicae* than in *P. napi montana* Venity. But the distribution of eggs on a single host plant is more uniform in case of *P. napi montana* Venity than in *P. brassicae*, because eggs of *P. napi montana* Venity have been found frequently in a single host plant than those of *P. brassicae*. *P. napi montana*

Venity is more strategic in egg laying, because the females lay their eggs singly, so that the host plant on which they are laid will provide all the neccessary needs for feeding, protection from natural enemies and more shelter to the developing eggs and larvae, but in case of *P. brassicae* there is always crowding which leads to insufficient food source for their larval stages, easy preying by natural enemies and less shelter for the eggs and developing larvae. Both the species lay their eggs on the ventral side of the leaf of their host plants to give more protection to the eggs and developing young ones. This is always observed in these species and it is the female which is responsible for such protective behaviour in natural conditions.

Both the species of butterflies are commonly found during the winter and generally absent during the summer especially in the months of June and July, in the study area. This is because of the presence and absence of their host plants. Cruciferous vegetables being the winter crop in Shillong area and its suburbs, and the cultivation is also common during those months, hence these butterflies also synchronised their activities during those months only. Therefore, their number during the winter exceeds that of the summer which supports the observation of Chou (1975, 1979) in *Pieris* sp. Hence during the winter season, 4-6 generations of *P. brassicae* and 2-3 generations of *P. napi montana* Venity could be observed in the field.

The population survey of adults based on visual estimation shows that adults of *Pieris brassicae* is generally less than that of *P. napi montana* Venity. This may be attributed to the immature death of the larvae due to the cold winter season which is evident that larvae of *P. napi montana* Venity are more cold resistant than those of P. brassicae adults. In general, P. brassicae lay more eggs at a time than P. napi montana, so that the strategy will compensate the larval death in natural conditions, thus the population of adults is more or less stabilized.

Most plants planted in the open field areas are more susceptible to oviposition by both the species of butterflies, hence lead to more damage by their larvae. While plants planted in the shaded fields are less susceptible to damage by the larvae of both the species. This is because both the species preferred plants growing in the open areas especially when the area is sunny during the winter.

Many other physical and biological factors do play a role in the population dynamics of insect species. Gossard and Jones (1977) attributed age and weather as responsible factors affecting oviposition in P. rapae. Seasonal mortality and density related dispersal are also taken into account by other authors (Elsey and Rabb, 1970; Shapiro, 1970, 1979; Watt et al. 1979; Bernstein, 1980) as factors regulating population fluctuation in butterflies and their larval stages.

Parasitization by insect parasitoids (Bradleigh and Iwantsch, 1980) also affect the population dynamics of Pierid butterflies.

Varietal influence, nitrogen variations in host varieties, also is a very important factor contributing towards fluctuations in insect population (Iheagwam, 1981a,b; Moyoro, 1981).

Although information keep on flowing with regard to factors influencing insect population structure, there are many other which are yet unexplored, since an organism reacts differently to the environment it is exposed to, and this variation is observed to vary even among different individuals of the same species and from species to species.

CHAPTER II

Life Cycle studies on *Pieris brassicae* (L.) and *Pieris napi montana* Vanity, and Consumption, Growth and ecological conversion efficiencies of the larvae of *P. brassicae* (L.) in relation to their host plants.

2.1. INTRODUCTION

A great deal is known concerning the qualitative nutritional requirements of insects. The quantitative aspect of insect nutrition, however, have received little attention, and there have been few studies on the rates of intake and the efficiency of food utilization. In particular, relatively little is known about the consumption, digestibility and efficiency of conversion of defined diets. Quantitative works with artificial diets has usually received more attention, especially when it concerns certain nutrients. This defines the relationship between the requirements for particular nutrients (Sang, 1956, 1959), but contributes nothing towards food intake, absolute requirement or the efficiency of food utilization.

Insects as a group feed upon a remarkably diverse list of organic substances. At the same time most species show a high degree of specificity in their choice of food. This may be due to natural selection and competition, which drives certain species to a more specialised food supply that they can use and utilize more efficiently than its competitors (Gordon, 1959). Nevertheless, the qualitative nutritional requirement of growing insects seems to be relatively uniform (Fraenkel, 1953; House, 1962).

Measures of consumption and utilization have played little part in the classical studies of insect nutrition, although their usefulness in this aspect is obvious. For example, instances of poor growth may not be due to the lack of nutrients in the food, but may be due to a low rate of consumption. Measures of consumption and utilization can give an indication to this, since the pattern of utilization may be different although the foods are similar in their ability to support growth.

One of the major concerns of modern ecology is the elucidation of the biotic relationships within and between communities. A knowledge of the food efficiencies and energetics of insects is thus of particular importance to ecology, since in terms of either biomass or number, insects are a major component of almost all terrestrial communities (Engelmann, 1966).

It seems apparent that adaptive nutritional differences must be sought on a quantitative level and that a meaningful comparative nutrition of insects will not emerge until quantitative studies are emphasized.

An understanding of insect ecology has been hampered by an inadequate knowledge of nutritional physiology. The effects of food quality upon physiology and behaviour and at the population and ecosystem levels are too often neglected. Nutritional ecology is central to proper interpretations of life history, feeding behaviour, habitat selection, defence, growth and reproduction, both in ecological and evolutionary time. Careful consideration of the present and future information on this topic can lead to better predictive capabilities in both evolutionary theory and pest management.

Since Waldbauer's excellent review of 1968, many researchers have begun to use the quantitative nutritional approach in understanding the insects nutritional physiology and ecology. Several works have been reported by various workers on this aspect, especially on insects, belonging to Lepidoptera. Chockalingam (1979) reported on the food consumption and utilization in Pericallia ricini; Krishnan and Chockalingam (1981) reported on the influence of food quality on the food utilization and growth in Pericallia ricini. Both the studies indicate that the different food plants influence the consumption, digestion and growth of Pericallia ricini.

Similar results are reported by several workers for lepidopteran insects (Mukerji and Guppy, 1970; Perumal et al. 1972; Mathavan and Baskeran, 1975; Dhandapani and Balasubramian, 1980).

Slansky and Feeny (1977) in their work with Pieris rapae (L.) reported that the growth of the larvae of this butterfly is limited by the availability of nitrogen in their food plants and that the larvae consumed the leaves with low nitrogen, faster and utilized them more efficiently. Several authors have also reported on the influence of nutrients in the leaves of food plants, on the life cycle, growth and utilization efficiencies of lepidopteran larvae (Walbauer, 1964; Soo Hoo and Fraenkel, 1966a,b; Mathur, 1966; and Feeny, 1970).

With regard to Pieris brassicae (L.) a common pest of crucifers relatively very few works have been carried out especially in relation to the effects of host plants on its life history, growth and other conversion efficiencies. Recently, many reports have come from various fields related to Pieris brassicae L. and most of these works concern growth, consumption, assimilation, utilization, development and other varied aspects of physiology and nutrition. Various workers reported on the process of melanization, diapause and factors governing these metabolic functions (Bueckmann, 1971; Feltwell and Valadon, 1974; Kayser, 1974, 1979; Kayser and Angersbach, 1974; Turunen, 1973; Vuillaume and Bergerard, 1978; Crozier, 1979; Fourche et al, 1979; Kim and Lee, 1979; Ressin, 1980; and Smith, 1980).

Other authors have also reported on growth and factors governing growth of Pieris brassicae. Environmental factors like fluctuating temperature have been shown to influence growth of Pieris brassicae (Neumann and Heimbach, 1975). Furthermore, other workers reported on other aspects of larval establishment, rearing of larvae on artificial diets supplemented by vitamins and antibiotics, and other aspects of metabolism of certain physiological states of the pupae and larvae of Pieris brassicae, (Turunen, 1974; Mauchamp and Lafont, 1975; Junnikkala, 1980; Laakso and Junnikkala, 1980; Moreau et al, 1981).

Specific works on growth, consumption, assimilation, energetics and other physiological aspects of different stages of Pieris brassicae (L.) in relation to its host plants and other biological factors like hormone influence, have also been reported especially by Srihari and Gahukar (1975), Vats et al, (1977) and Yadava et al, (1979).

With regard to the effect of host plant chemicals on the life, growth, consumption and utilization efficiencies of the larval stages of Pieris brassicae (L.) not much work has been done, especially the effect of host plant chemicals like nitrogen, free sugars and free amino-acids, on these life functions. Samersaw and Garavaya (1973) reported on the mechanism by which mineral fertilizers affect the life cycle of Pieris brassicae larvae, where high concentration of phosphorus and calcium and low nitrogen content inhibit larval development. Furthermore, the reduction of nutritive quality of potato leaves fed, due to low protein and carbohydrates content added more to the inhibition of larval development. Apart from this work, there has been an inadequate knowledge on the effect of host plant chemicals on the various life functions of *Pieris brassicae* although a [illegible] isects including [illegible]

This investigation was taken up with a view to find out the role played by various host plants in regulating the life cycle duration of *Pieris brassicae* (L.) and also the various ecological efficiencies like consumption, growth, digestion and utilization of chemical components of various host plants on which the larvae feed together with the chemical analyses of those host plants selected by the feeding larval stages of the butterfly. *Pieris napi montana* Verity, also was selected as another representative species to study the comparative effects of host plants, accepted by *P. brassicae*, on its life cycle only.

2.2. MATERIALS AND METHODS

2.2.1. Life cycle studies.

Freshly laid eggs of Pieris brassicae (L.) (Plate 3-C) and Pieris napi montana Venity, were collected from the field with part of the host plant on which they are oviposited. These eggs were kept in rearing white coloured glass bottles (9.00 cm diameter X 18.00 cm high), lined with wet filter paper to maintain humid atmosphere. The rearing units were covered with nylon mesh to allow air to enter inside and kept under laboratory conditions. Time, in days, taken by the eggs to hatch is recorded.

Groups of newly hatched larvae of both species were separated from their original host plants by means of a soft hair brush, and transferred to the food plants cabbage (Brassicae oleraceae var capitata L.); cauliflower (B. oleraceae var botrytis L.); knol khol (B. oleraceae var gongylodes L.) and mustard (B.campestris var sarson Prain.), on which they will be reared till pupation and were kept in the same type of rearing units as above. Fresh leaves of specific host plants (Plate 3-A,B) were given each day to these larvae. Their fecal matter and food remains from the rearing unit were clean daily. Larval duration, in days, of both species on their specific host plants were noted till the pupating period; and the time from pupation (Plate 2-B) till adult emergence was also recorded.

All these rearings were conducted under laboratory conditions and a photoperiod of 14 : 10 hours, light and dark period respectively. Field observations were also made.

2.2.2. Studies on Consumption, Growth and Other Ecological efficiencies.

Pieris brassicae (L.) larvae only were selected for growth and ecological efficiency experiments and different larval stages (Plate 2-A) were used for this purpose.

Fresh laboratory hatched larvae of Pieris brassicae and larvae collected from the field (Plate 3-D,E,F,G,H) were separated to determine their stage using headwidth measurements. Larvae having the same headwidths are classed as belonging to the same age groups.

A group of active and healthy, larvae belonging to the same age as determined, were starved for one day (24 hrs.) under laboratory conditions, and a required number of larvae from this group were killed by exposing to chloroform vapour and then dried in an oven (80-85°C) to get the initial dry weight of the group. With the other set of larvae, the experiment on growth and other efficiencies was carried out. A required number of larvae belonging to the same age, were taken from the starved sample and transferred to petridisihes (1.9 cm high X 14.00 cm diameter), where humidity is maintained by wet filter paper lining.

Fresh host plants leaves were given to these larvae separately. Before feeding many discs (5.00-5.5 cm diameter) were out from the specific host plant (Plate 2-E) and some control discs were dried in an oven, as done to the larvae, to get the initial dry weight of food offerred. To eliminate the error in dry weight of the food offerred, discs were cut off from both the halves of the folded leaves taking their midribs as the middle line. One disc is dried for initial weight and the other is fed to the larvae.

Explanation of PLATE NO. 2.

A - Different larval stage of *Pieris brassicae* (L.)

B - Pupal of *P. brassicae* (L.)

C - Undamage leaf of a host plant

D - Damaged leaf.

E - Discs cut out from leaves of host-plants for feeding.

F - Actively feeding last stage larva of *P. brassicae* (L.) in natural condition.

PLATE-2

Explanation of PLATE NO. 3.

A - Heathy but damaged host plant (<u>Brassica</u> <u>Oleracea</u> Var gongylodes L.)

B - Healthy, undamage host plant (<u>Brassica</u> <u>Oleracea</u> Var botrytis L.)

C - Eggs of <u>P</u>. <u>brassicae</u> (L.) on the ventral side of the leaf

D - First stage larvae of <u>P</u>. <u>brassicae</u> (L.)

E - Second stage larvae of <u>P</u>. <u>brassicae</u> (L.)

F - Third stage larvae of <u>P</u>. <u>brassicae</u> (L.)

G - Fourth stage larvae of <u>P</u>. <u>brassicae</u> (L.)

H - Last stage larva of <u>P</u>. <u>brassicae</u> (L.)

PLATE-3

After a fixed time period of feeding (24 hrs.), larvae were separated from their food and some of them were killed by chloroform and dried in the oven to get the final weight. Amount of food left and excreta were also separated and dried as above, to get the dry weight of ejesta and final food left.

In case of experiments involving wet weights, the larvae and food offerred were weighed before the experiment to get the initial observations and after a fixed feeding period, the larvae, the amount of food left and the excreta were weighed separately to get the final observation. The larvae in this case were not killed, but anaesthesized by chloroform.

These experiments were repeated and conducted on all stages of P. brassicae (L.) using different food plants. Weighing was carried out on a monopan electric balance (K-Roy K-16) for dry weight experiments and in an ordinary double plan balance (K-Roy Pvt.) for wet weight experiments. Photoperiod, temperature and humidity in the laboratory were all recorded.

Indices of growth and consumption for each larval stage, and other ecological efficiencies of conversion were calculated as follows following the method of Waldbauer (1968).

Relative consumption rate (RCR)

$RCR = \frac{F}{TA}$ where F = fresh or dry weight of food eaten (mg)
T = duration of feeding period (days)
A = mean fresh or dry weight of larva during feeding period (mg)

Relative growth rate (RGR)

$RGR = \frac{G}{TA}$ where G = fresh or dry weight of larvae during feeding period (mg)
T = duration of feeding period (days)
A = mean fresh or dry weight of larvae during feeding period (mg)

Efficiency of conversion of ingested food to body substance (ECI)

ECI is calculated as : $$ECI = \frac{\text{Weight gained (mg)}}{\text{weight of food ingested (mg)}} \times 100$$

Coefficient of approximate digestibility (CAD)

CAD is calculated as :

$$CAD = \frac{\text{Weight of food ingested (mg)} - \text{Weight of faeces (mg)}}{\text{Weight of food ingested (mg)}} \times 100$$

Efficiency with which digested food is converted to body substance

ECD is calculated as :-

$$ECD = \frac{\text{Weight gained (mg)}}{\text{Weight of food ingested (mg)} - \text{Weight of faeces (mg)}} \times 100$$

2.2.3. Analyses of chemical components of various host plants.

Samples of leaves of various host plants were freshly collected from the field and brought to the laboratory in plastic bags.

Quantitative analysis of total organic nitrogen - Leaves of a host plant and different larval stages of *P. brassicae* were dried in the oven at 80-85°C for 1 day and powdered. Total organic nitrogen was estimated by Micro-Kjeldahl procedures following the method of Humphries (1956) from triplicate samples.

Analyses of free sugar and free amino acid - Required amount of fresh growing leaves from the same host plants and larval stages of *P. brassicae* were crushed with 85% ethanol, using a pestle and mortar, then centrifuged at 1000-1200 rpm. for 4-5 mins. The supernatant is used for qualitative and quantitative analysis of total free sugar and total free amino acid content

Total free sugar was estimated quantitatively following the method of Roberts (1979) using glucose as the standard. Total free amino acid was estimated quantitatively by the method of Spies

(1957), using leucine as the standard. Proline [illegible] hydroxyproline were not taken into account. Beckman Spectrophotometer (Model J26) was used for both analyses.

For qualitative estimation of free sugars and free amino acids, ascending and horizontal paper-chromatographic procedures are used following the methods of Giri and Rao (1952) for amino acids and Giri and Nigam (1954) for sugars. Whatman's No.1 chromatographic paper was used for both analysis. Reference amino acids and sugars used, were obtain from BDH Suppliers.

These estimation were done either simultaneously with the feeding experiments or later if the extracted samples are kept in a refrigerator.

The same procedures are also used for analyses of excreta and feeding fifth larval stages of *P. napi montana Venity*.

2.3. RESULTS

2.3.1. Life cycle studies.

Life cycle studies of insects and the effects of host plants on them are reported by various workers. But in the case of *Pieris brassicae* (L.) and *Pieris napi montana* Venity both belonging to Pieridae, very few reports are there with regard to such studies. Mukherji (1961) found that *Pieris brassicae* (L.) complete its life cycle in fifty days if reared on cabbage.

The present study shows that *Pieris brassicae* (L.) exhibit a variation in its life cycle if reared on different host plants. The duration of larval and pupal stages differs from one host plant to another, although the incubation period remains more or less same on all accepted host plants as shown in Table-2. The incubation period of *Pieris brassicae* is generally four days whether in the field of laboratory conditions on all host plants.

The larval duration is shortest when reared on cauliflower (12.154 ± 2.66), followed by knol khol (12.3 ± 1.487) and raddish (13.625 ± 2.69). It is longer on mustard (14.1 ± 1.921) and longest on cabbage (16.2 ± 2.44).

The pupal duration is shortest on knol khol (16.8 ± 5.636) followed by mustard (18.7 ± 3.976). The duration is longer in case of cauliflower (21.231 ± 5.833) followed by raddish (22.5 ± 1.5) but longest in cabbage (26.6 ± 14.242).

If the total duration is taken into consideration, *Pieris brassicae* complete its life cycle, very fast on knol khol (33.33 ± 4.755) from the egg stage till adult emergence, followed by mustard (36.8 ± 4.069) and cauliflower (37.462 ± 6.629). The total duration is longer when reared on raddish (40.5 ± 2.121) and longest

TABLE - 2

Life cycle duration of *Pieris brassicae* (L.) from the egg stage till adult emergence on different host plants.

Host Plant	EGG - Ist STAGE (M ± SD)	Ist - Vth STAGE (M ± SD)	PUPA - ADULT (M ± SD)	TOTAL DURATION (M ± SD)	NO. OF OBSERVATION
A	4.0 ± 0.392	12.154 ± 2.66	21.231 ± 5.833	37.462 ± 6.629	13
B	4.1 ± 0.3	16.2 ± 2.44	26.6 ± 14.242	46.9 ± 15.852	10
C	4.2 ± 0.4	12.3 ± 1.487	16.8 ± 5.636	33.33 ± 4.755	10
D	4.0 ± 0.0	14.1 ± 1.921	18.7 ± 3.976	36.8 ± 4.069	10
E	4.375 ± 0.484	13.625 ± 2.69	22.5 ± 1.5	40.5 ± 2.121	8

A = Cauliflower (*Brassica oleracea* var. *botrytis* L.)
B = Cabbage (*Brassica oleracea* var. *capitata* L.)
C = Knol khol (*Brassica oleracea* var. *gongylodes* L.)
D = Mustard (*Brassica campestris* var. *sarson* Prain)
E = Raddish (*Raphanus sativus* L.)

Number of days are represented as mean and standard deviation (M±SD).

on cabbage (46.9 ± 15.582).

The life cycle duration from the egg stage till adult emergence of Pieris napi montana Venity, does not show much variation as revealed by Pieris brassicae (L.). The incubation period of Pieris napi montana Venity, is more or less as in P. brassicae i.e. four days if reared in laboratory or in field conditions on all host plants.

The larval duration is also very stable on all host plants reared i.e. cabbage, cauliflower and mustard as shown in Table-3.

The total life cycle duration if taken into account, Pieris napi montana Venity, spent the shortest on cabbage and mustard with 33.83 ± 4.88 and 34.0 ± 1.42 days respectively, but it is longer on cauliflower with 36.167 ± 5.398 days. But over all the total life cycle duration is more or less stable on all host plants tested.

2.3.2. Consumption and growth of Pieris brassicae (L.) on various host plants.

From dry weight experiments :- The larval stages of Pieris brassicae (L.) exhibit a series of variation in their relative consumption rates with regard to different accepted food plants. Even in the same food plant, there is a difference in food intake by different stages of the feeding larvae. Summarized here are the different rates of consumption (RCR), growth (RGR) and other ecological efficiency of conversion of ingested food to body substance (ECI), the coefficient of approximate digestibility (CAD) and the efficiency with which digested food is converted to body substance (ECD), which are all represented as mean values.

Different larval stages of P. brassicae (L.) exhibit different consumption rates even if the larvae feed on the same host

TABLE - 3

Life cycle duration of *Pieris napi montana* Venity from the egg stage till adult emergence on different host plants at 18-23°C Temperature and 70-75% Humidity.

HOST PLANT	EGG - Ist STAGE (M ± SD)	Ist - Vth STAGE (M ± SD)	PUPA - ADULT STAGE (M ± SD)	TOTAL DURATION (M ± SD)	NO. OF OBSERVATION
A	4.67 ± 0.471	12.5 ± 1.61	19.0 ± 3.83	36.167 ± 5.398	6
B	4.33 ± 0.471	13.33 ± 1.491	16.167 ± 3.625	33.83 ± 4.88	6
C	4.0 ± 0.0	13.00 ± 0.707	17.0 ± 1.58	34.0 ± 1.42	4

A = Cauliflower (*Brassica oleracea* var. *botrytis* L.)
B = Knol khol (*Brassica oleracea* var. *gongylodes* L.)
C = Mustard (*Brassica campestris* var. *sarson* Prain.)

Number of days are represented as mean and standard deviation (M ± SD).

plant. When fed on cabbage (*Brassica oleraceae* var *capitata* L.), the highest consumption rate is exhibited by the fifth stage larvae (2.28 ± 1.65) followed by the second stage larvae (1.8209 ± 0.1439) and the third stage larvae (1.357 ± 0.075), but the least is exhibited by the fourth stage larvae (1.0286 ± 0.645). In response to the relative consumption rates, the fourth stage larvae of *Pieris brassicae* exhibited the highest relative growth (0.758 ± 0.494), followed by the fifth (0.5282 ± 0.3415) and third stages (0.4625 ± 0.0047) which have lower relative growth rate values. But in the second stage larvae, least growth rate (0.292 ± 0.0338) is observed although the consumption rate is high (Table-4.1).

When the larvae of *P. brassicae* are fed with cauliflower (Brassicae oleraceae var botrytis L.), the highest consumption rate is observed in second stage larvae (13.626 ± 6.641), the rate decreases in the third stage (0.8153 ± 0.6357) and the fourth stage larvae (1.368 ± 0.9043), but there is a slight increase in the last stage larvae i.e. fifth stage (2.076 ± 1.78).

In response to the relative consumption rates, the second stage larvae of *P. brassicae* exhibited the highest relative growth rate (0.6743 ± 0.115), the rate decreases in the third stage larvae (0.2985 ± 0.1349) and decreases further in the fourth stage larvae (0.1833 ± 0.0972). In the fifth stage larvae, there is an increase in the growth rate (0.526 ± 0.0604) which is more or less equivalent to the second stage larvae as shown in Table-4.2.

When fed on mustard (*Brassica campestris* var *sarson* Prain), the second stage larvae of *P. brassicae* shows high relative consumption rate (4.87 ± 3.689), the rate increases further in the third stage larvae (6.021 ± 1.265). Relative consumption rate decreases in

TABLE - 4.1

Relative consumption and growth rates of different larval stages of *Pieris brassicae* (L.) on cabbage - *Brassica oleracea* var. *capitata* (L.) at 18-24°C and 70-75% temperature and humidity respectively.

FOOD PLANT	LARVAL STAGES	RELATIVE CONSUMPTION RATE (RCR) (mg/mg/day/dry weight)	RELATIVE GROWTH RATE (RGR) (mg/mg/day/dry weight)
Cabbage *Brassica oleracea* var. *capitata* L.	II	1.8209 ± 0.1439	0.292 ± 0.338 (3)
	III	1.3575 ± 0.0075	0.4625 ± 0.0047(3)
	IV	1.0286 ± 0.645	0.758 ± 0.494 (4)
	V	2.283 ± 1.652	0.5282 ± 0.3415(6)

Figure in parenthesis represented number of observations.

TABLE - 4.2

Relative consumption and growth rates of the different larval stages of *Pieris brassicae* (L.) on cauliflower -*Brassica oleracea* var. *botrytis* (L.) at 15-24°C temperature and 70-72% humidity.

FOOD PLANT	LARVAL STAGES	RELATIVE CONSUMPTION RATE (RCR) (mg/mg/day/dry wt.)	RELATIVE GROWTH RATE (RGR) (mg/mg/day/dry weight)
Cauliflower *Brassica oleracea* var. *botrytis* L.	II	13.626 ± 6.641	0.674 ± 0.115 (5)
	III	0.8153 ± 0.6357	0.2985 ± 0.1349 (6)
	IV	1.368 ± 0.9043	0.1833 ± 0.0972 (4)
	V	2.076 ± 1.782	0.526 ± 0.06044 (5)

Figure in parenthesis represented number of observations.

the fourth stage larvae (1.00 ± 0.764), but there is a little increases in the fifth stage (2.641 ± 1.305). In response to the various relative consumption rates, the larvae shows high relative growth rate in the second stage (0.791 ± 0.168) and the rate increases in the third stages (1.54 ± 0.418). Relative growth rate is very low in the fourth stage larvae (0.185 ± 0.008) while the rate further increases in the fifth stage larvae (0.837 ± 0.096) as shown in Table-4.3.

In the case of raddish (Raphanus sativus L.) the consumption rates of Pieris brassicae (L.) larvae is high in the second larval stages (0.918 ± 0.056), but the rate is highest in the third stages (1.366 ± 0.145). The consumption rate declined in the later stages, in the fourth larvae stages (0.198 ± 0.043) and the fifth stages (0.218 ± 0.001), as shown in Table-4.4.

In response to the variation in rates of consumption, the larvae of Pieris brassicae exhibit a variation in their growth rates at different larval stages when reared on raddish (R. sativus). The second larval stages exhibit high growth rates (0.472 ± 0.086), but it is higher in the third larval stages (0.577 ± 0.076). The growth rates decline in the later stages as shown by the fourth stages (0.021 ± 0.004) and are higher in the fifth stages (0.187 ± 0.009) as shown in Table-4.4.

When reared on knol khol (Brassicae oleraceae var gongylodes L.), the larvae of P. brassicae exhibited very little variation in consumption rates as shown by the second stage (13.12 ± 0.468) and the fifth stage larvae (12.48 ± 2.13). In response to the more or less uniform consumption rates the larvae stages of P. brassicae also show uniform growth rates. The second stages (0.156 ± 0.029)

TABLE - 4.3

Relative consumption and growth rate of different larval stages of *Pieris brassicae* (L.) on mustard - *Brassicae campestris* var. *Sarson* Prain at 15-22°C Temperature and 68-70% Humidity.

FOOD PLANT	LARVAL STAGES	RELATIVE CONSUMPTION RATE (RCR) (mg/mg/day/dry weight)	RELATIVE GROWTH RATE (RGR) (mg/mg/day/dry weight)	
Mustard *Brassicae campestris* var. *Sarson* Prain	II	4.87 ± 3.685	0.791 ± 0.168	(3)
	III	6.021 ± 1.265	1.54 ± 0.418	(4)
	IV	1.001 ± 0.764	0.1857 ± 0.008	(3)
	V	2.641 ± 1.305	0.837 ± 0.096	(3)

Figure in parenthesis represents number of observations.

TABLE - 4.4

Relative consumption and growth rate of different larval stages of *Pieris brassicae* (L.) on Raddish - *Raphanus sativus* (L.) and Knol khol - *Brassicae oleracea* var. *gongylodes* (L.) at 15-24 °C Temperature and 70-72% Humidity.

FOOD PLANT	LARVAL STAGES	RELATIVE CONSUMPTION RATE (RCR) (mg/mg/day/dry weight)	RELATIVE GROWTH RATE (RGR)(mg/mg/day/dry weight)	
Raddish	II	0.918 ± 0.056	0.472 ± 0.086	(3)
Raphanus	III	1.366 ± 0.145	0.577 ± 0.076	(4)
sativus (L.)	IV	0.198 ± 0.043	0.021 ± 0.004	(4)
	V	0.218 ± 0.001	0.187 ± 0.009	(4)
Knol khol				
B.oleracea	II	13.12 ± 0.468	0.156 ± 0.029	(4)
var. *gongylodes* (L.)	V	12.48 ± 2.13	0.060 ± 0.005	(5)

Figure in parenthesis represents number of observations.

and the fifth stages (0.060 ± 0.005) does not show much variation in their growth values as shown in Table-4.4.

2.3.3. Consumption and growth of Pieris brassicae (L.) of various host plants.

From wet weight experiments : When the larvae of Pieris brassicae (L.) are reared on different host plants they exhibited differences in their consumption and growth patterns.

Summarized below are the different consumption and growth rates of the larvae of Pieris brassicae (L.) in relation to different accepted food plants. As in dry weight experiments, the different larval stages of P. brassicae exhibited a series of variation in the rates of consumption and growth.

Pieris brassicae larvae consume the largest amount of cabbage leaves (3.89 ± 1.06) when they are in the second larval stage. In the third stages, the consumption rate is lower (1.874 ± 0.837). The consumption rate is again higher in the fourth stage larvae (3.701 ± 0.115), while the rate decreases in the fifth larval stage (1.291 ± 0.20) as shown in Table-5.1.

In response to the various rates of consumption, the second larval stage of Pieris brassicae show the highest growth rate (0.672 ± 0.36). The third larval stage shows a lower growth rate (0.325 ± 0.084). The growth rate again is very high in the fourth stage larval (0.526 ± 0.035), but it declines in the last larval stage i.e. fifth stage (0.398 ± 0.093) as shown in Table-5.1.

When fed on cauliflower (B. oleraceae var botrytis L.) the second stage larvae show the highest rate of consumption (3.14 ± 1.69). The rate is lower in the third stage (2.67 ± 1.41) and the fourth stage larvae (2.507 ± 1.358) but lowest in the last stage (fifth) larvae (1.389 ± 0.866) as shown in Table-5.2.

In response to the different consumption rates, Pieris brassicae larvae show a series of variation in their growth rates when reared on cauliflower. The second stage larvae exhibit a growth rate of 0.412 ± 0.135, but the rate is higher in the third stage larvae (0.606 ± 0.537) while it decreases again in the fourth stage (0.585 ± 0.437) and lowest in the fifth stage (0.346 ± 0.126) as shown in Table-5.2.

When fed on mustard (B. campestris var sarson Prain) and raddish (R. sativus L.), the fifth stage larvae shows more or less the same consumption rates (0.637 ± 0.507) and (0.634 ± 0.403) respectively as shown in Table-5.3.

The growth rates of P. brassicae in the last stages were more or less the same when reared on mustard and raddish with growth rates of 0.187 ± 0.023 and 0.233 ± 0.08 respectively (Table-5.3).

When fed on knol khol (B. oleraceae var gongylodes L.) the second stages larvae of P. brassicae shows the highest consumption rate (8.546 ± 4.59). While in the third stage larvae, the rate is much lower (3.069 ± 0.344). The consumption rate is again higher in the fourth stage larvae (5.099 ± 0.143) as shown in Table-5.3.

In response to the different consumption rates, P. brassicae larvae exhibited a difference in their growth rates. The second stage larvae show a higher growth rate (0.450 ± 0.054), but the rate is higher in the third stage larvae (0.483 ± 0.073) and highest in the fourth stage larvae (0.653 ± 0.098) as in Table-5.3.

2.3.4. Digestibility and efficiency of conversion of Pieris brassicae (L.) on different host plants.

From dry weight experiments : The efficiency of conversion ingested food to body substances (ECI) is an over-all measure of an

TABLE - 5.1

Relative consumption and growth rates of different larval stages of *Pieris brassicae* (L.) on cabbage - *Brassica oleracea* var. *capitata* (L.) at 18-23°C Temperature and 70-75% Humidity.

FOOD PLANT	LARVAL STAGES	RELATIVE CONSUMPTION RATE (RCR) (mg/mg/day/dry weight)	RELATIVE GROWTH RATE (RGR) (mg/mg/day/dry weight)	
Cabbage *B. oleracea* var. *capitata* (L.)	II	3.89 ± 1.06	0.672 ± 0.36	(4)
	III	1.874 ± 0.837	0.325 ± 0.084	(5)
	IV	3.710 ± 0.115	0.526 ± 0.035	(5)
	V	1.299 ± 0.20	0.398 ± 0.093	(4)

Figure in parenthesis represents number of observations.

TABLE - 5.2

Relative consumption and growth rates of different larval stages of *Pieris brassicae* (L.) on cauliflower - *Brassica oleracea* var. *botrytis* (L.) at 18-23°C Temperature and 70-75% Humidity.

FOOD PLANT	LARVAL STAGES	RELATIVE CONSUMPTION RATE (RCR) (mg/mg/day/wet weight)	RELATIVE GROWTH RATE (RGR) (mg/mg/day/wet weight)	
Cauliflower *B. oleracea* var. *botrytis* (L.)	II	3.14 ± 1.69	0.412 ± 0.135	(4)
	III	2.67 ± 1.41	0.606 ± 0.537	(7)
	IV	2.507 ± 1.358	0.585 ± 0.437	(4)
	V	1.389 ± 0.866	0.346 ± 0.126	(4)

Figure in parenthesis represents number of observations.

TABLE - 5.3

Relative consumption and growth rates of different larval stages of *Pieris brassicae* (L.) on mustard (*Brassica campestris* var. *sarson* Prain), raddish (*Raphanus sativus* L.) and knol khol (*Brassica oleracea* var. *gongylodes* L.) at 18-23°C Temperature and 70-75% Humidity.

FOOD PLANTS	LARVAL STAGES	RELATIVE CONSUMPTION RATE (RCR) (mg/mg/day/wet weight)	RELATIVE GROWTH RATE (RGR) (mg/mg/day/wet weight)	
Mustard *B. campestris var. sarson* (Prain)	V	0.637 ± 0.507	0.187 ± 0.023	(5)
Raddish *Raphanus sativus* L.	V	0.634 ± 0.403	0.233 ± 0.08	(5)
Knol khol *B. oleracea* var. *gongylodes* (L)	II	8.546 ± 4.59	0.450 ± 0.054	(5)
	III	3.069 ± 0.344	0.483 ± 0.073	(4)
	IV	5.099 ± 0.143	0.653 ± 0.098	(4)

Figure in parenthesis represents number of observations.

insect's ability to utilise for growth the food which it ingests, expressed as percentage. *Pieris brassicae* (L.) larvae exhibit a series of variation in this efficiency which differ from one particular stage to another. Experiments conducted on *P. brassicae* larvae fed with cabbage (*Brassica oleraceae* var *capitata* L.) shows that the second stage larvae have the least efficiency (13.102 ± 0.037), the efficiency is higher in the third stage larvae (34.228 ± 0.329). The efficiency is highest in the fourth stage larvae (39.059 ± 4.673), but it decline in the fifth stage larvae (36.303 ± 22.821) as shown in Table-6.1.

The efficiency with which digested food is converted to body substances (ECD) is another measure of the insect's ability to metabolise the ingested food substances for energy requirements, expressed as percentage. In the case of *Pieris brassicae* (L.), this efficiency is lowest in the second stage larvae (30.438 ± 0.451) if reared on cabbage. The efficiency is higher in the third stage larvae (44.10 ± 0.416) but highest in the fourth stage larvae (58.45 ± 11.77), it again decreases in the last stage larvae (44.229 ± 27.4) as shown in Table-6.1.

The coefficient of approximate digestibility (CAD) is a measure of the insects ability to digest the food substance and it also measures fecal matter excreted during the digestion process. It is also expressed as percentage. In case of *Pieris brassicae* (L.) larvae fed with cabbage, this digestibility coefficient is very low in the second stage larvae (42.844 ± 0.311), while it is slightly higher in the third stage larvae (74.145 ± 1.99), but decreases a little in the fourth stages larvae (68.03 ± 6.28). The digestibility coefficient is highest in the fifth stage larvae (84.09 ± 10.783) as shown in Table-6.1.

TABLE - 6.1

Digestibility and conversion efficiencies of different larval stages of *Pieris brassicae* (L.) on cabbage - *Brassica oleracea* var. *capitata* (L.) measured on dry-weight basis at 18-24°C Temperature and 70-75% Humidity.

LARVAL STAGES	EFFICIENCY OF CONVERSION OF INGESTED FOOD TO BODY SUBSTANCE	COEFFICIENT OF APPROXIMATE DIGESTIBILITY.	EFFICIENCY OF CONVERSION OF DIGESTED FOOD TO BODY SUBSTANCE	
II	13.102 ± 0.037	42.844 ± 0.311	30.438 ± 0.451	(7)
III	34.228 ± 0.329	74.145 ± 1.995	44.1035 ± 0.4165	(3)
IV	39.059 ± 4.673	68.038 ± 6.261	58.458 ± 11.775	(4)
V	36.303 ± 22.821	84.096 ± 10.783	44.229 ± 27.486	(6)

Figure in parenthesis represents number of observations.

All calculated in percentage (%). Mean and Standard Deviation (M ± SE) are given here in all cases.

The ECI (efficiency of conversion ingested food) of *Pieris brassicae* (L.) larvae fed on cauliflower (*Brassica oleraceae* var *botrytis* L.) is lowest in the second stage larvae (11.55 ± 6.43) but it increased in the third stage larvae (43.921 ± 16.867), while in the fourth stage larvae the efficiency decreases (23.697 ± 13.867). The ECI increases in the fifth stage larvae (40.686 ± 30.597) as in Table-6.2.

The ECD of *Pieris brassicae* (L.) larvae fed on cauliflower is again lowest in the second stage larvae (14.66 ± 7.96) and is maximum in the third stage larvae (53.940 ± 21.252). The efficiency again decreases in the fourth stage larvae (37.066 ± 24.48) and increases a little in the fifth stage larvae (45.477 ± 32.458) as shown in Table-6.2.

The coefficient of approximate digestibility (CAD) of *Pieris brassicae* (L.) larvae fed on cauliflower is high in the case of the second stage larvae (78.39 ± 2.86), but higher in the third stage larvae (82.45 ± 7.82). CAD is lowest in the case of the fourth stage larvae (73.183 ± 18.031), but it is maximum in the fifth stage larvae (85.857 ± 6.527) as shown in Table-6.2.

The ECI of *Pieris brassicae* (L.) larvae fed on mustard (*Brassicae campestris* var *sarson* Prain.) is high in the second stage larvae (33.739 ± 26.30), but the efficiency is higher in the third stage larvae (43.393 ± 18.434). The ECI is maximum in the fourth stage larvae (45.924 ± 35.9) but is minimum in the fifth stage larvae (29.97 ± 22.5) as shown in Table-6.3.

The ECD of *Pieris brassicae* (L.) fed on mustard is very high in the second stage larvae (53.797 ± 35.17) while it is very low in the third stage larvae (21.66 ± 11.822). The ECD is maximum in the

TABLE - 6.2

Digestibility and conversion efficiencies of different larval stages of *Pieris brassicae* (L.) on cauliflower - *Brassica oleracea* var. *botrytis* (L.) measured on dry weight basis at 15-24°C Temperature and 70-72% Humidity.

LARVAL STAGES	EFFICIENCY OF CONVERSION OF INGESTED FOOD TO BODY SUBSTANCE	COEFFICIENT OF APPROXIMATE DIGESTIBILITY	EFFICIENCY OF CONVERSION OF DIGESTED FOOD TO BODY SUBSTANCE	
II	11.554 ± 6.435	78.395 ± 2.865	14.662 ± 7.962	(5)
III	43.921 ± 16.867	82.454 ± 7.821	53.94 ± 21.252	(6)
IV	23.699 ± 13.867	73.183 ± 18.031	37.066 ± 24.485	(4)
V	40.686 ± 30.597	85.657 ± 6.527	45.477 ± 32.458	(5)

All calculated in percentages (%); Mean and Standard deviation (M ± SE) are given here in all cases. The figure in parenthesis represents number of observations.

TABLE - 6.3

Digestibility and conversion efficiencies of different larval stages of *Pieris brassicae* (L.) on mustard - *Brassica campestris* var. *sarson* (Prain) measured on dry weight basis at 15-22°C Temperature and 68-70% Humidity.

LARVAL STAGES	EFFICIENCY OF CONVERSION OF INGESTED FOOD TO BODY SUBSTANCE	COEFFICIENT OF APPROXIMATE DIGESTIBILITY	EFFICIENCY OF CONVERSION OF DIGESTED FOOD TO BODY SUBSTANCE
II	33.739 ± 26.3	71.843 ± 23.98	53.797 ± 35.17 (3)
III	43.393 ± 18.434	63.357 ± 8.072	21.664 ± 11.822 (4)
IV	45.924 ± 35.9	78.88 ± 7.47	54.391 ± 40.36 (3)
V	29.979 ± 22.5	77.629 ± 12.87	35.049 ± 25.8 (3)

All calculated in percentages (%); Mean and Standard deviations (M ± SE) are given here in all cases. The figure in parenthesis represents number of observations.

fourth stage larvae (54.39 ± 40.36) and decreases in the fifth stage larvae (35.04 ± 25.8) as shown in Table-6.3.

The CAD of P. brassicae (L.) larvae is very high in the second stage larvae (71.84 ± 23.98) when fed on mustard. The CAD is lowered a little in the third stage larvae (63.35 ± 8.072) while it is maximum in the fourth stage larvae (78.88 ± 7.47). The efficiency in the fifth stage larvae does not differ much from the fourth stage, it decreases slightly from it (77.629 ± 12.87) as shown in Table-6.3.

The ECI of the larvae of P. brassicae (L.) on raddish (Raphanus sativus L.) is very high in the second stage larvae (45.5 ± 5.01) but the efficiency decreases in the third stage larvae (36.74 ± 1.201). The ECI is very low in the fourth stage larvae (8.65 ± 0.521) but it is maximum in the fifth stage larvae (83.69 ± 2.06) as shown in Table-6.4.

The ECD of the larvae of P. brassicae when fed on raddish is very low in the second stage larvae (18.17 ± 2.2) but the efficiency increases in the third stage larvae (45.18 ± 1.46). The ECD again is very low in the fourth stage larvae (18.17 ± 0.83) and it is maximum in the fifth stage larvae (91.54 ± 1.48) as shown in Table-6.4.

CAD of the larvae of P. brassicae (L.) when fed on raddish leaves, is very high in both the second stage (78.276 ± 2.708) and the third stage larvae (83.704 ± 4.16). The coefficient of approximate digestibility decreased in the fourth stage larvae (56.521 ± 1.91) but it is maximum in the fifth stage larvae (87.36 ± 0.388) as shown in Table-6.4.

ECI of the larvae of P. brassicae (L.) when fed on knol khol (B. oleracea var. gongylodes L.) is very low in both the second and

TABLE - 6.4

Digestibility and conversion efficiencies of the different larval stages of *Pieris brassicae* (L.) on Raddish - *Raphanus sativus* (L.) and Knol khol - *Brassica oleracea* var. *gongylodes* (L.) measured on dry weight basis at 15-24°C Temperature and 70-72% Humidity.

LARVAL STAGES	EFFICIENCY OF CONVERSION OF INGESTED FOOD TO BODY SUBSTANCE	COEFFICIENT OF APPROXIMATE DIGESTIBILITY	EFFICIENCY OF CONVERSION OF DIGESTED FOOD TO BODY SUBSTANCE	
Raddish - *Raphanus sativus* (L.)				
II	45.56 ± 5.01	78.276 ± 2.708	18.174 ± 2.2	(3)
III	36.74 ± 1.201	83.704 ± 4.16	45.188 ± 1.46	(4)
IV	8.65 ± 0.521	56.521 ± 1.91	18.172 ± 0.836	(4)
V	83.69 ± 2.06	87.36 ± 0.388	91.54 ± 1.48	(4)
Knol khol - *Brassica oleracea* var. *gongylodes* (L.)				
II	2.34 ± 0.708	89.23 ± 3.71	1.87 ± 0.256	(4)
IV	0.541 ± 0.043	96.10 ± 0.779	0.557 ± 0.041	(5)

the fifth stage larvae. In the second stage larvae, the efficiency is low (2.34 ± 0.708), but it is lower in the fifth stage (0.541 ± 0.043) as shown in Table-6.4.

ECD of the larvae of *P. brassicae* (L.) on knol khol is low in the second stage larvae (1.87 ± 0.296) and lower in the fifth stage larvae (0.557 ± 0.041) (Table-6.4).

CAD of the larvae of *P. brassicae* (L.) on knol khol is high in the second stage larvae (89.23 ± 3.71), but it is higher in the fifth stage larvae (96.10 ± 0.779) (Table-6.4).

2.3.5. Digestibility and efficiency of conversion of *Pieris brassicae* (L.) on different host plants.

From wet weight experiments : The efficiency of conversion of ingested food to body substance (ECI) of *Pieris brassicae* (L.) larvae when fed on cabbage leaves (*B. oleraceae* var *capitata* L.) is very high in the second stage (29.22 ± 16.39) but decreases in the third stage larvae (23.84 ± 18.44). This efficiency is very low in the fourth stage larvae (15.31 ± 0.64), while it increases in the fifth stage larvae (27.99 ± 0.159) (Table-7.1).

The efficiency with which digested food is converted to body substance (ECD) of *P. brassicae* (L.) larvae is low in the second stage larvae (33.525 ± 19.23), but it increases in the third stage larvae (42.61 ± 26.45) to maximum. The ECD is very low in the fourth stage larvae (21.836 ± 1.66) but it again increases in the fifth stage larvae (40.653 ± 0.461) (Table-7.1).

The coefficient of approximate digestibility (CAD) of the larvae of *P. brassicae* (L.) fed on cabbage leaves is maximum in the second stage larvae (88.02 ± 2.56) but it decreases in the third stage larvae (62.166) ± 0.414). The CAD is again increasing in the

TABLE - 7.1

Digestibility and conversion efficiencies of different larval stages of *Pieris brassicae* (L.) on Cabbage - *Brassica oleracea* var. *capitata* (L.) measured on wet weight basis at 18-23°C Temperature and 70-75% Humidity.

LARVAL STAGES	EFFICIENCY OF CONVERSION OF INGESTED FOOD TO BODY SUBSTANCE	COEFFICIENT OF APPROXIMATE DIGESTIBILITY	EFFICIENCY OF CONVERSION OF DIGESTED FOOD TO BODY SUBSTANCE	
II	29.22 ± 16.39	88.02 ± 2.56	33.525 ± 19.23	(4)
III	23.84 ± 18.44	52.82 ± 14.38	42.61 ± 26.45	(5)
IV	15.31 ± 0.64	62.166 ± 0.414	21.836 ± 1.66	(5)
V	27.99 ± 0.159	71.954 ± 4.24	40.653 ± 0.461	(4)

All calculated in percentage (%); Mean and Standard deviation (M ± SE) are given here in all cases. The figure in parenthesis represents number of observations.

fourth stage larvae (62.166 ± 0.414) and further increases in the fifth stage larvae (71.954 ± 4.24) (Table-7.1).

The ECI of the larvae of P. brassicae (L.) when fed on cauliflower (B. oleraceae var. botrytis L.) is very low in the second stage larvae (15.08 ± 4.67). The efficiency is more or less stabilised in the third stage (21.68 ± 12.96) and the fourth stage (20.82 ± 8.7) larvae, while it is rising in case of the fifth stage larvae (30.497 ± 12.65) (Table-7.2).

The ECD of the larvae fed on cauliflower is very low in the second stage (19.99 ±4.73) and it is higher as the larvae reached the third stage (39.20 ± 2.029). The ECD decreases a little as the larvae reaches the fourth stage (30.25 ± 8.33) while the fifth stage there is maximum increase (62.13 ± 19.63) (Table-7.2).

CAD of the larvae fed on cauliflower is maximum in the second stage larvae (74.27 ± 5.04). In the third stage, the CAD is much lower (53.84 ± 9.72) but it increase as the larvae reach the fourth stage (64.833 ± 16.05). As the larvae reach the last stage, the CAD again decreases (53.32 ± 22.22) (Table-7.2).

ECI of the fifth stage larvae of P. brassicae (L.) when fed on mustard (B. campestris var sarson Prain) leaves is 24.032 ± 0.976%. Since not much data could be collected comparison could not be made with other larvae stages of life cycle (Table-7.3).

ECD of the fifth stage larvae of P. brassicae on mustard is 28.568 ± 1.028%.

Its CAD in mustard is very high, it reaches upto 85.585 ± 1.354% (Table-7.3).

The eECI of the fifth stage larvae of P. brassicae (L.) when

TABLE - 7.2

Digestibility and conversion efficiencies of different larval stages of *Pieris brassicae* (L.) on Cauliflower - *Brassica oleracea* var. *botrytis* (L.) measured on wet weight basis at 18-23°C Temperature and 70-75% Humidity.

LARVAL STAGES	EFFICIENCY OF CONVERSION OF INGESTED FOOD TO BODY SUBSTANCE	COEFFICIENT OF APPROXIMATE DIGESTIBILITY	EFFICIENCY OF CONVERSION OF DIGESTED FOOD TO BODY SUBSTANCE	
II	15.08 ± 4.67	74.27 ± 5.04	19.99 ± 4.73	(4)
III	21.68 ± 12.96	53.84 ± 9.72	39.20 ± 2.029	(7)
IV	20.82 ± 8.70	64.88 ± 16.05	30.25 ± 8.33	(4)
V	30.497 ± 12.65	53.32 ± 22.22	62.13 ± 19.63	(4)

All calculated in percentage (%); Mean and Standard deviation (M ± SE) are given here in all cases. The figure in parenthesis represents number of observations.

fed on raddish (Raphanus sativus L.) is 29.665 ± 0.545%. Its ECD is 34.79 ± 6.749% and its CAD is 71.328 ± 9.92%. As not much data could be obtained comparisons between the different larval stages could not be made (Table-7.3).

The ECI of the larvae of P. brassicae (L.) when fed on knol khol (B. oleracoae var gongylodes L.) is very low in the second stage (11.336 ± 5.69). The ECI increases as the larvae reach the third stage (20.641 ± 0.756) but again decreases in the fourth stage (10.752 ± 0.808) (Table-7.3).

The ECD of the larvae of P. brassicae (L.) when fed on knol khol leaves, is low in the second stage larvae (15.446 ± 9.13), but it is higher in the third stage (31.978 ± 1.464). The ECD decreases as the larvae reaches the fourth stage (19.26 ± 0.915) (Table-7.3).

CAD of P. brassicae (L.) larvae fed on knol khol is very high in the second stage of the life cycle (75.81 ± 8.42). The CAD decreases as the larvae reached the third stage (61.449 ± 0.624) and decreases further in the fourth stage (51.2 ± 4.77) of the life cycle.

2.3.6. Total organic Nitrogen content of the host plants, fecal matter and larvae of Pieris brassicae (L.).

Total organic nitrogen (N) content of various host plants of Pieris brassicae (L.) and P. napi montana Venity, vary among themselves and also between the different age groups even in the same variety of species. All measurements have been made on dry weight basis expressed as mg N/g of biomass. Mean values and standard deviations are represented here.

Fig. 5 summarise the total organic nitrogen content of various host plants and the difference between their age groups and the fecal matter of larvae of P. brassicae (L.) fed on these host plants.

TABLE - 7.3

Digestibility and conversion efficiencies of different larval stages of Pieris brassicae (L.) on Mustard - Brassica campestris var. sarson (Prain); Raddish - Raphanus sativus (L.) and Knol khol - Brassica oleracea var. gongylodes (L.) measured on wet weight basis at 18-23°C Temperature and 70-75% Humidity.

LARVAL STAGES	EFFICIENCY OF CONVERSION OF INGESTED FOOD TO BODY SUBSTANCE	COEFFICIENT OF APPROXIMATE DIGESTIBILITY	EFFICIENCY OF CONVERSION OF DIGESTED FOOD TO BODY SUBSTANCE	
Mustard - Brassica campestris var. sarson (Prain.)				
V	24.032 ± 0.976	85.585 ± 1.354	28.568 ± 1.028	(5)
Raddish - Raphanus sativus (L.)				
V	29.665 ± 0.545	71.328 ± 9.92	34.794 ± 6.749	(5)
Knol khob- Brassica oleracea var. gongylodes (L.)				
II	11.336 ± 5.69	75.810 ± 8.42	15.446 ± 9.13	(5)
III	20.641 ± 0.756	61.449 ± 0.624	31.978 ± 1.464	(4)
IV	10.752 ± 0.808	51.2 ± 4.727	19.261 ± 0.915	(4)

All calculated in percentage (%); Mean and Standard deviation (M ± SE) are given here in all cases. The figure in parenthesis represents number of observations.

Fig. 5 Total nitrogen content of young and old leaves of cruciferous plants, larval fecal matter and larvae of *P. brassicae*.

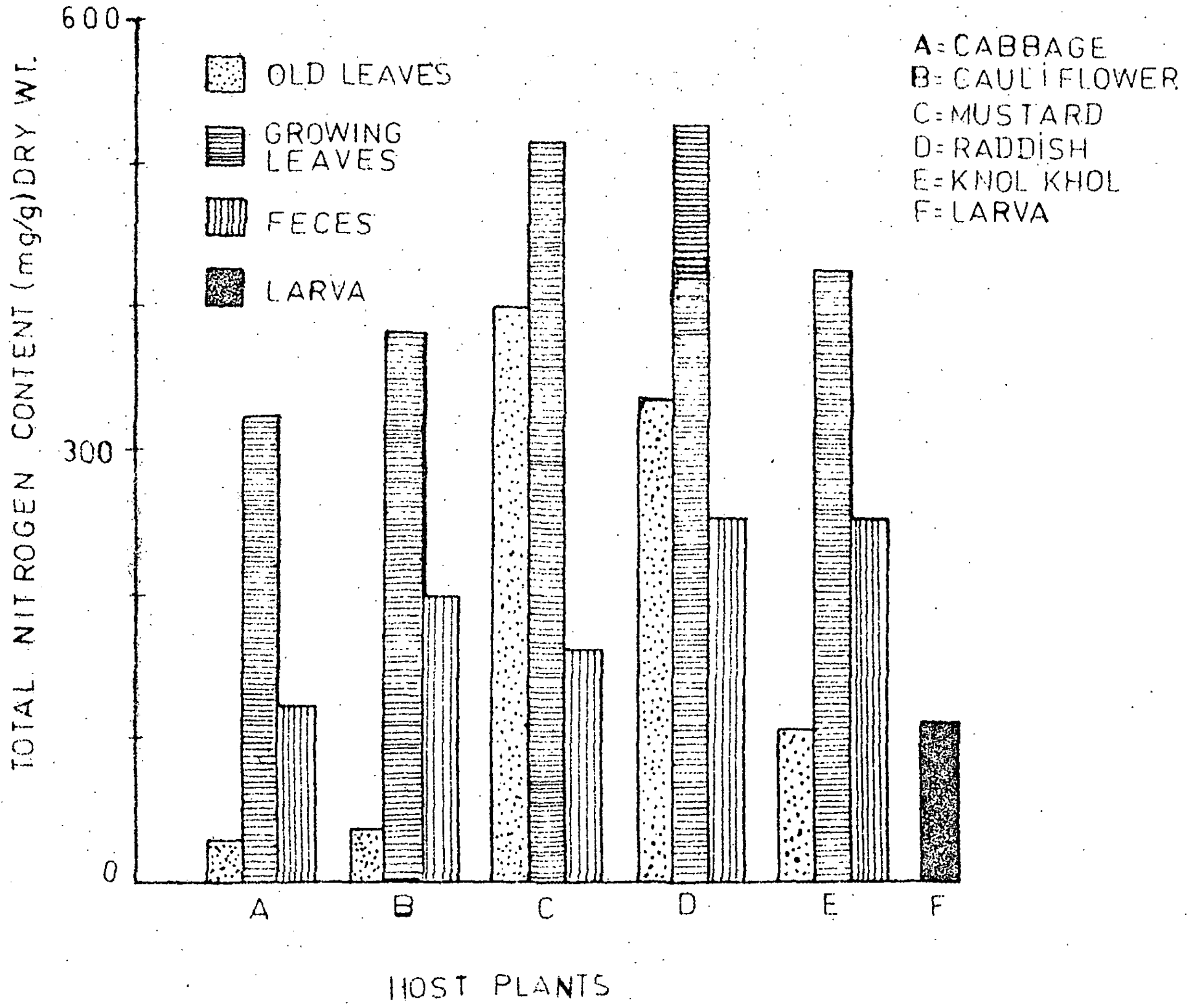

TOTAL NITROGEN CONTENT (mg/g) DRY WT.
600
300
0
OLD LEAVES
GROWING LEAVES
FECES
LARVA
A=CABBAGE
B=CAULIFLOWER
C=MUSTARD
D=RADDISH
E=KNOL KHOL
F=LARVA
A
B
C
D
E
F
HOST PLANTS

FIG. 5

In case of cabbage (*B. oleraceae* var *capitata* L.) the total organic nitrogen content is very low in the old leaves (29.905 ± 1.03) as compared to the leaves of growing young plants (324.378 ± 3.4605). The fecal matter of the pooled sample of different larval stages of *P. brassicae* (L.) show a very high total organic nitrogen content (124.38 ± 6.64) when fed on cabbage.

The total organic nitrogen content of young growing cauliflower (*B. oleraceae* var *botrytis* L.) leaves is very high (386.375 ± 7.359), while it is very low in case of old leaves (38.749 ± 1.135). The pooled fecal matter of different larval stages of *P. brassicae* (L.) shows a high total organic nitrogen content (198.13 ± 2.58) when fed on this plant.

In case of mustard (*B. campestris* var *sarson* Prain) the young growing leaves shows a very high total nitrogen content (516.25 ± 7.07) in comparison to the old leaves which have nitrogen content (399.375 ± 20.396), hence there is not much difference in the nitrogen content as shown by other host plant varieties. The pooled sample of fecal matter from different larval stages of *P. brassicae* (L.) fed on mustard show a very high nitrogen content (162.19 ± 7.67).

The total nitrogen content of raddish (*Raphanus sativus* L.) in case of young growing leaves is very high (527.5 ± 2.169) but it declined in the old leaves (336.75 ± 4.97). The pooled fecal matter, of different larval stages of *P. brassicae* (L.) fed on raddish also exhibit very high total nitrogen content (255.94 ± 8.94).

In case of knol khol (*B. oleraceae* var *gongylodes* L.) the young growing leaves contain more total organic nitrogen (426.24 ± 6.37) than the older leaves (108.75 ± 9.56). The fecal matter of the pooled sample of various larval stages of *P. brassicae* (L.) fed on knol khol shows a high total organic nitrogen content (257.25 ± 3.82).

In the different larval stages of P. brassicae (L.) i.e. from the first to the last stage, it is observed that the total organic nitrogen content is more or less stabilised. In the earlier stages of life cycle, the nitrogen content is lower (104.53 ± 4.37) but it increases a little in the late stages (107.5 ± 1.76), hence there is not much difference and the overall nitrogen content was 106.01 ± 3.06.

It is observed that the young growing leaves of all host plants of P. brassicae (L.) contain more nitrogen than the old leaves. Raddish was found to contain the highest amount of total organic nitrogen followed by mustard, knol khol, cauliflower and cabbage in case of young and growing leaves. Among the old leaves, mustard was observed to contain the highest amount of total organic nitrogen, followed by raddish and knol khol, while cauliflower and cabbage contain the least amount of total organic nitrogen.

2.3.7. Total free amino acid content of host plants, larvae and fecal matter of Pieris brassicae (L.).

Total free amino acid content of different host plants of P. brassicae and P. napi montana Venity, show a variation among themselves. Total free amino acid content was expressed as mg/g wet weight of the plant leaves (Fig. 6A).

Cauliflower (B. oleraceae var. botrytis L.) show a very high free amino acid content, followed by knol khol (B. oleraceae var. gongylodes L.) and cabbage (B. oleraceae var. capitata L.). Mustard (B. campestris var. sarson Prain) and raddish (Raphanus sativus L.) exhibit low free amino acid content.

The fecal matter of different larval stages of P. brassicae (L.) fed on each host plant also exhibited the same pattern of total free amino acid content as their host plants. The larval stages of P. brassicae (L.) show a very high total free amino acid content, which is usually more than their host plants. The pooled sample of the different larval stages of P. brassicae does not show much difference from their earlier and late stage of life cycle, when fed on any of the accepted host plants.

2.3.8. Total free sugar content of host plants, larvae and fecal matter of P. brassicae (L.).

Total free sugar content of the host plants of Pieris brassicae (L.) and P. napi montana Venity does not show much difference although a variation among them exists. Total free sugar content is expressed as mg/g wet weight of the plant leaves (Fig. 68).

Raddish (Raphanus sativus L.) and knol khol (B. oleraceae var. gongylodes L.) show a very high free sugar content than cauliflower (B. oleraceae var. botrytis L.) and mustard (B. campestris var. sarson Prain). Cabbage (B. oleraceae var. capitata L.) amongst all show the least amount of free sugar content. The fecal matter of all stages of P. brassicae (L.) larvae is observed to vary in its free sugar content when the larvae is fed on various foodplants. In case of larvae fed on cauliflower, the free sugar content of the feces is highest, followed by mustard, raddish and knol khol. The free sugar content of the feces is very low ehen larvae is fed on cabbage.

In the larval stages of P. brassicae (L.) an exceedingly high amount of free sugar content is observed. There is not much difference in the various stages of the life cycle with regard to this factor, even when the larval stages are fed on different host plants.

Fig. 6 Total free amino acid (A) and sugar (B) content of leaves of cruciferous plants, larval fecal matter and larvae of *P. brassicae*.

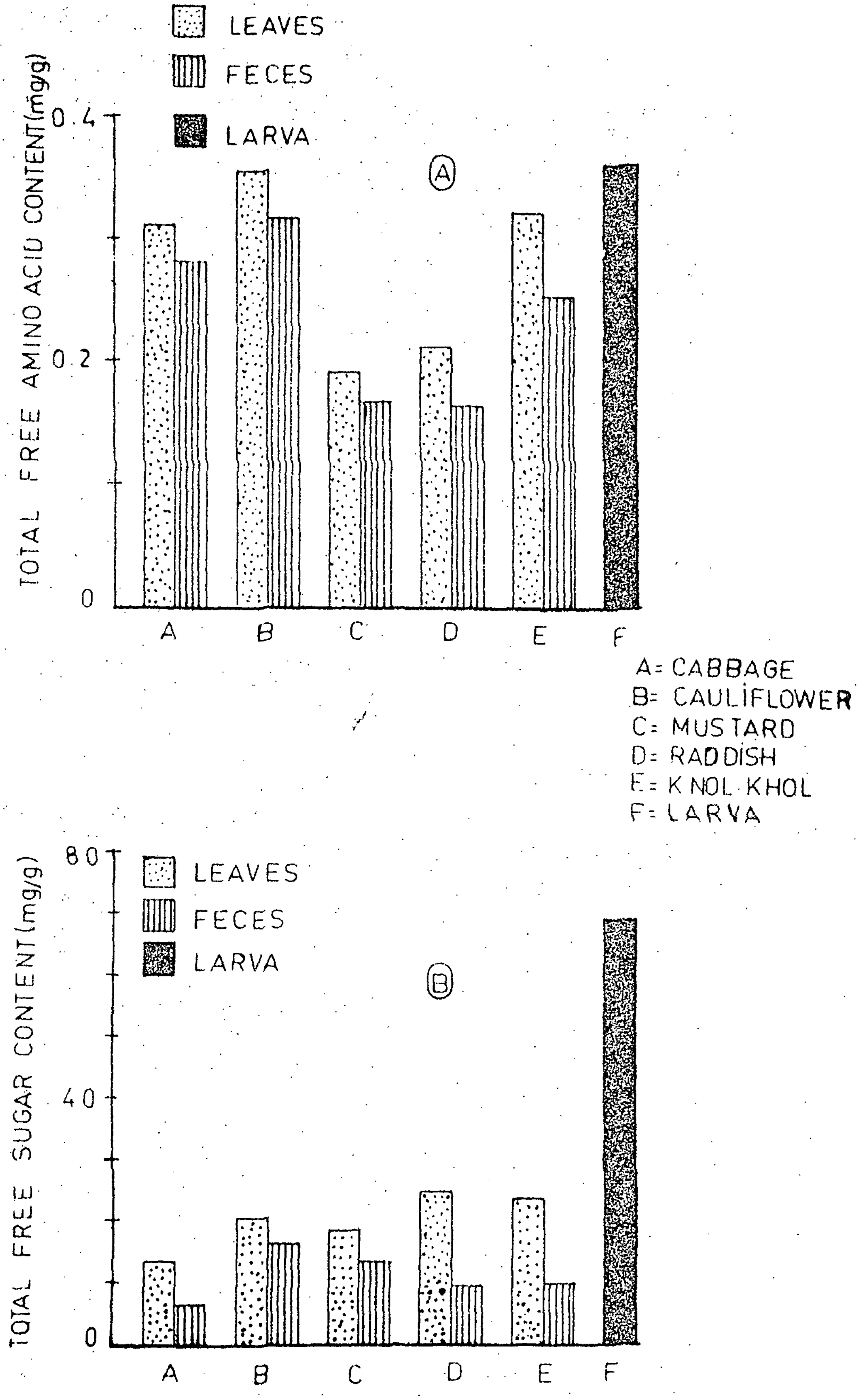

LEAVES
FECES
LARVA
Ⓐ
TOTAL FREE AMINO ACID CONTENT (mg/g)
0.4
0.2
0
A
B
C
D
E
F
A= CABBAGE
B= CAULIFLOWER
C= MUSTARD
D= RADDISH
E= KNOL KHOL
F= LARVA
80
40
0
LEAVES
FECES
LARVA
Ⓑ
TOTAL FREE SUGAR CONTENT (mg/g)
A
B
C
D
E
F

Fig 6

2.3.9. Qualitative free amino acid and free sugar composition of different host plants.

Free amino acids : Qualitative analyses of free forms of amino acids and sugar present in the various host plants of *Pieris brassicae* (L.) and *Pieris napi montana* Verity, has been carried out by simple paper chromatographic methods. Result of the qualitative chromatographic analyses is given in Table-8.1.

Fifteen free amino acids are detected in case of cabbage (*B. oleraceae* var. *capitata* L.). These are Dl-alanine, Dl-2, Amino butyric acid, L-arginine monohydrochloride, Dl-aspartic acid, DL-3,4-dihydroxyphenyl-alanine, L-glutamic acid, glycine, L-histidine monohydrochloride, L-hydroxyproline, Dl-nor-leucine, L-lysine monohydrochloride, L-proline, Dl-serine, Dl-threonine and Dl-valine.

In case of cauliflower (*B. oleraceae* var. *botrytis* L.), L-lysine monohydrochloride is not detected, but another free amino acid L-tyrosine is present. The total number of free amino acids detected in this host plant is also fifteen, representing the same type of free amino acids present in cabbage.

Fourteen free amino acids are detected in case of mustard (*B. campestris* var. *sarson* Prain), which again follow the series of amino acids present in cabbage and cauliflower (Table-8.1). The only difference is that L-hydroxyproline and L-tyrosine are not detected in case of mustard.

The series of free amino acids detected in knol khol (*B. oleraceae* var. *gongylodes* L.) very much resemble those present in cauliflower, their total number is fifteen, L-lysine monohydrochloride is not detected in knol khol as it is in cauliflower.

In raddish (*Raphanus sativus* L.), thirteen free amino acids have been detected, which again the series are very much similar to those present in cabbage, cauliflower, mustard and knol khol. Three amino acids from the series are not detected in raddish, these are, L-hydroxyproline, Dl-norleucine and L-tyrosine.

Taking into consideration the series of free amino acids detected in all the host plants of P. brassicae and P. napi montana Venity, L-hydroxyproline is not detected in case of two host plants, these are mustard and raddish. Dl-norleucine was not detected only in the case of raddish. L-lysine monohydrochloride is not detected in the case of cauliflower and knol khol. L-tyrosine was absent in cabbage, mustard and raddish. All other free amino acids are detected on all host plants and follow the same series as detected on cabbage, cauliflower, mustard, knol khol and raddish. In total, fifteen free amino acids are detected in cabbage, fifteen in cauliflower, fourteen in mustard, fifteen in knol khol and thirteen in raddish.

Free sugars : Generally, two types of free sugars are commonly detected in the host plants of P. brassicae (L.) and P. napi montana Venity (Table-8.1).

In cabbage (B. oleraceae var. capitata L.), glucose and galactose are clearly present, glucose being always in higher amount than galactose. These same free sugars were also clearly identified in cauliflower (B. oleraceae var. botrytis L.).

In case of mustard (B. oleraceae var. sarson Prain), glucose was detected all alone while galactose is not observed. In raddish (Raphanus sativus L.), the same result is observed ias in mustard, glucose being predominantly present while galactose is not detected.

TABLE - 8.1

Qualitative free amino acid and free sugar composition of the different host plants of *Pieris brassicae* (L.) and *Pieris napi montana* Venity.

AMINO ACID	CABBAGE 1	CAULI-FLOWER 2	MUSTARD 3	KNOL KHOL 4	RADDISH 5
1. Dl-alanine	+	+	+	+	+
2. Dl-2,amino-n-butyric acid	+	+	+	+	+
3. L-arginine mono-hydrochloride	+	+	+	+	+
4. Dl-aspartic acid	+	+	+	+	+
5. Dl-3,4-dihydroxy phenylalanine	+	+	+	+	+
6. L-glutamic acid	+	+	+	+	+
7. Glycine	+	+	+	+	+
8. L-histidine mono-hydrochloride	+	+	+	+	+
9. L-hydroxyproline	+	+	-	+	-
10. Dl-norleucine	+	+	+	+	-
11. L-lysine monohy-drochloride	+	-	+	-	+
12. L-proline	+	+	+	+	+
13. Dl-serine	+	+	+	+	+
14. Dl-Threonine	+	+	+	+	+
15. L-Tyrosine	-	+	-	+	-
16. Dl-valine	+	+	+	+	+
SUGAR					
1. Glucose	+	+	+	+	+
2. Galactose	+	+	-	+	-

1 = *Brassica oleracea* var. *capitata* (L.)
2 = *Brassica oleracea* var. *botrytis* (L.)
3 = *Brassica campestris* var. *sarson* (Prain)
4 = *Brassica oleracea* var. *gongylodes* (L.)
5 = *Raphanus sativus* (L.)

+ = presence and - = absence

In knol khol (B. oleracease var. gongylodes L.) again both the free sugars are present. Glucose is more intensely detected than galactose, as observed in cabbage and cauliflower plants.

2.3.10. Qualitative free amino acid and free sugar composition of different larval stages of *Pieris brassicae* (L.) and their fecal matter.

Free amino acids of different larval stages : Qualitative analyses of free forms of amino acids in different larval stages of P. brassicae (L.) as carried out by simple chromatographic procedures is presented in Table-8.2. Ten free amino acids are detected in all the five stages of P. brassicae larvae. These free amino acids are, Dl-alanine, Dl-aspartic acid, L-glutamic acid, L-leucine, Dl-isoleucine, Dl-serine, Dl-threonine, Dl-tryptophan, L-hydroxy-proline and L-proline. These amino acids are quantitatively different from each other even if the series is similar. The quantity also differ from one larval stage to another. The free amino acid composition is similar from one larval stage to another, but there is a difference in the quantity of each only.

Free sugars of different larval stages : Glucose and galactose are the only two free sugars detected in all the five stages of P. brassicae larvae. Glucose is observed to be predominantly present than galactose. The quantity of glucose again, show a variation among the different larval stages, which is also exhibited by galactose (Table-8.2). Quantitatively, glucose is higher in amount than galactose as observed.

Free amino acid and free sugar composition of larval fecal matter when fed on cabbage : When the larvae of Pieris brassicae (L.) especially the last stage (fifth stage) is fed with cabbage (B. oleraceae var. capitata L.) and the fecal matter was studied by simple chromatographic analyses. The result show that only eight free amino acids have been detected in this case. These amino acids are, Dl-aspartic acid, L-leucine, Dl-isoleucine, L-hydroxyproline, Dl-serine, Dl-3,4, dihydroxy-phenylalanine, L-histidine monohydrochloride and Dl-valine (Table-8.2).

The series of amino acids are to a certain extent similar to those present in the host plant, i.e. cabbage (Table-8.1). Five free amino acids which are present in the larval stages are absent (not detected) in the feces of the last stage larvae, these are, Dl-alanine, L-glutamic acid, Dl-threonine, Dl-tryptophan and L-proline.

These free amino acids which are present in the fecal matter are quantitatively very low in comparison to the amount present in the original host plant i.e. cabbage.

Free sugars like glucose and galactose, present in the host plant i.e. cabbage, in detectable quantity are no more observed in the fecal matter (Table-8.2).

<u>Free amino acid and free sugar composition of larval fecal matter.</u>

<u>When fed on cauliflower</u> : When the larvae of <u>Pieris brassicae</u> (L.) especially the fifth (last) stage is fed on cauliflower (<u>B. oleraceae</u> var. <u>botrytis</u> L.) and the fecal matter is studied by simple chromatographic procedures, the analysis shows that five free amino acids, namely L-leucine, Dl-isoleucine, Dl-threonine, Dl-3-4, dehydroxyphenylalanine and L-histidine mono-hydrochloride are present (Table-8.2).

Seven free amino acids present in the various larval stages of life cycle out of ten are not detected in the fecal matter of those last stage larvae fed on cauliflower. Two amino acids, i.e. Dl-3-4, dihydroxyphenyl alanine and L-histidine monohydrochloride are detected in the fecal matter as they are originating from the host plant.

Quantitatively, these free amino acids detected in the larval fecal matter are present in small amounts as compared to the original host plant. The quantity even vary among themselves.

Free sugars, viz., glucose and galactose, which are intensely detected in the host plant i.e. cauliflower, are not observed any more in the fecal matter of the feeding larvae, that is, the fifth (last) stage larvae (Table-8.2).

2.3.11. Qualitative free amino acid and free sugar composition of the larval stage of *Pieris napi montana* Venity and their fecal matter.

Free amino acids of the larval stage : Qualitative free amino acid and free sugar composition of the last stage larvae of, *P. napi montana* Venity, as analysed by simple chromatographic procedures shows that, eight free amino acids are present, i.e. Dl-aspartic acid, L-glutamic acid, Dl-alanine, L-hydroxyproline, L-proline, L-leucine, Dl-serine and Dl-threonine (Table-8.3). Quantitatively, these free amino acids are different from each other in their amount. All these above named free amino acids are present in detectable amounts, especially in the last stage of larval life.

Free sugars of the larval stage : Two free sugars are intensely detected in the last larval stage of *P. napi montana* Venity, as analysed by simple chromatographic procedures, these are, glucose and galactose (Table-8.3). Quantitatively, the amount of glucose is observed to be higher than that of galactose.

TABLE - 8.2

Qualitative free amino acid and free sugar composition of the different larval stages of *Pieris brassicae* (L.) and fecal matter.

AMINO ACID	LARVAL STAGES					FECAL MATTER LARVAE FED WITH CABBAGE	FECAL MATTER LARVAE FED WITH CAULIFLOWER
	I	II	III	IV	V		
1. Dl-alanine	+	+	+	+	+	±	±
2. Dl-aspartic acid	+	+	+	+	+	+	±
3. L-glutamic acid	+	+	+	+	+	±	±
4. L-leucine	+	+	+	+	+	+	+
5. Dl-isoleucine	+	+	+	+	+	+	+
6. Dl-serine	+	+	+	+	+	+	±
7. Dl-threonine	+	+	+	+	+	±	+
8. Dl-tryptophan	+	+	+	+	+	±	±
9. L-hydroxyproline	+	+	+	+	+	+	±
10. L-proline	+	+	+	+	+	±	±
11. Dl-3,4-dihydroxyphenylalanine	±	±	±	±	±	+	+
12. L-histidine mono hydrochloride	±	±	±	±	±	+	+
13. Dl-valine	±	±	±	±	±	+	±
SUGARS							
1. Glucose	+	+	+	+	+	±	±
2. Galactose	+	+	+	+	+	±	±

+ = denotes presence

± = undetected

Free amino acid and free sugar composition of the larval fecal matter.

When fed on cabbage : When the larvae of *P. napi montana* Venity is fed on cabbage (*B. oleraceae* var. *capitata* L.) and the fecal matter is studied, by simple chromatographic procedures, six free amino acids, namely, Dl-aspartic acid, L-hydroxyproline, L-proline, Dl-threonine, L-arginine mono-hydrochloride and L-histidine monohydrochloride are present (Table-8.3).

Four amino acids generally present during the last larval stage, namely, L-glutamic acid, Dl-alanine, L-leucine and Dl-serine, are not detected in the fecal matter (Table-8.3). The quantity of free amino acids detected in the larval fecal matter are present in very low amount as compared to the higher quantity observed in the host plant.

L-arginine monohydrochloride and L-histidine monohycerochloride are detected in the larval fecal matter as they are originally present in the host plant.

The six free amino acids present in the fecal matter of the larvae of *P. napi montana* Venity are quantitatively different among themselves.

Glucose and galactose, the only two free sugars present in the host plant and larvae of *P. napi montana* Venity, are not observed any more in the fecal matter of the last larval stage when fed on cabbage (Table-8.3).

Free amino acid and free sugar composition of the larval fecal matter.

When fed on cauliflower : When the last stage larvae of *P. napi montana* Venity is fed on cauliflower (*B. oleraceae* var.

botrytis L.) and the fecal matter excreted is studied, seven free amino acids, namely Dl-aspartic acid, L-hydroxyproline, L-proline, Dl-threonine, L-arginine monohydrochloride, L-tyrosine and L-histidine monohydrochloride are present (Table-8.3).

The quantity of these free amino acids detected is very low in comparison to those originally present in the host plant (Table-8.2). The four amino acids, namely Dl-aspartic acid, L-hydroxyproline, L-proline and Dl-threonine which are detected in the last larval stage, are present in very low quantity as observed. Four amino acids, generally observed in the last larval stages are absent, in the fecal matter, these are L-glutamic acid, Dl-alanine, L-leucine and Dl-serine. Three amino acids, namely L-arginine monohydrochloride, L-tyrosine and L-histidine monohydrochloride are detected in the fecal matter of the last stage larvae, as they originated from the host plant, i.e. cauliflower. Their quantities are very low in comparison to the host plant.

Glucose and galactose, the free sugars present in the host plant are not detected in the fecal matter of the last larval stage of P. napi montana Venity (Table-8.3).

It is generally observed in all analyses that the host plants analysed contain more free amino acids quantitatively. The quantity declines in the larval stages of both the butterflies studied. In the fecal matter, the quantity further decrease and sometime becoming negligible. The same observation has been made in the case of free sugars.

TABLE - 8.3

Qualitative free amino acid and free sugar composition of the larval stages of Pieris napi montana Venity and their fecal matter.

AMINO ACID	LAST LARVAL STAGES	FECAL MATTER COLLECTED FROM LARVAE FED WITH CABBAGE	FECAL MATTER COLLECTED FROM LARVAE FED WITH CAULIFLOWER
Dl-aspartic acid	+	+	+
L-glutamic acid	+	±	±
Dl-alanine	+	±	±
L-hydroxyproline	+	+	+
L-proline	+	+	+
L-leucine	+	±	±
Dl-serine	+	±	±
Dl-threonine	+	+	+
L-arginine mono hydrochloride	±	+	+
L-tyrosine	±	±	+
L-histidine mono-hydrochloride	±	+	+
SUGAR			
Glucose	+	±	±
Galactose	+	±	±

+ = denotes presence

± = denotes not detected

2.4. DISCUSSION

Life cycle duration of the butterflies studied viz., *Pieris brassicae* (L.) and *Pieris napi montana* Venity, vary greatly with the types of host plants on which their larval stages are reared on. This is generally observed in Lepidoptera, especially in the oligophagous and polyphagous types of feeders.

As has been observed from the life cycle studies, the developmental cycle of *Pieris brassicae* (L.) from the egg stage till adult emergence, is shortest when the larvae are reared on knol khol (*Brassica oleraceae* var. *gongylodes* L.) followed by mustard (*B. campestris* var. *sarson* Prain) and cauliflower (*B. oleraceae* var. *botrytis* L.). In raddish (*Raphanus sativus* L.) also the duration is longer but it is longest on cabbage (*B. oleraceae* var. *capitata* L.).

Pupal duration of *P. brassicae* (L.) is observed to be shortest on knol khol (*B. oleraceae* var. *gongylodes* L.) followed by mustard (*B. campestris* var. *sarson* Prain), then cauliflower (*B. oleraceae* var. *botrytis* L.) and raddish (*Raphanus sativus* L.) and last longer in cabbage (*B. oleraceae* var. *capitata* L.).

Larval duration of *P. brassicae* (L.) is observed to be shortest on cauliflower (*B. oleraceae* var. *botrytis* L.) then raddish (*Raphanus sativus* L.) followed by mustard (*B. campestris* var. *sarson* Prain) andlalest longer in cabbage (*B. oleraceae* var. *capitata* L.).

The incubation period of the eggs of *Pieris brassicae* (L.) is generally observed to be same on all host plants on which they are laid. This is also observed by Mukerji (1961).

In comparison to *Pieris brassicae* (L.) the life cycle duration of *Pieris napi montana* Venity, is very short on cabbage (*B. oleraceae* var. *capitata* L.) followed by mustard (*B. campestris* var. *sarson* Prain) and last longer in cauliflower (*B. oleraceae* var. *botrytis* L.). The pupal period also follow the same mode as shown by the life cycle duration since not much difference is observed.

The larval period of *P. napi montana* Verity, is observed to be shortest on cauliflower (*B. oleraceae* var. *bortytis* L.). In cabbage (*B. oleraceae* var. *capitata* L.) and mustard (*B. campestris* var. *sarson* Prain) the duration of larval period is more or less same and longer than in cauliflower.

The incubation period in *P. napi montana* Verity is also generally observed to be same on all host plants on which the eggs are laid.

But as such, host plants do not singly affect the variation of the life cycle of any species of insect. Numerous other physical, biochemical and biological factors are also responsible for these changes. It is observed in the species studied that, temperature play a very important role in controlling the developmental time period of the species. Below 14°C (room temperature) and above 26°C the developmental period of the species studied is affected drastically. As observed in certain host plants, the development period is very long especially during the winter months - December to January, due to the diapausing pupal stages. Other cases of photoperiodic induction of pupal diapause have also been reported in the small cabbage butterfly, *Pieris rapae* (L.) (Kono, 1970). Quality of light, especially ultra violet (UV) have been observed to reduce the development time in this species (Thoms and Philogene, 1979).

In hotter areas of India like Bihar and Uttar Pradesh, the life cycle duration of *P. brassicae* (L.) generally is longer

(Mukherji, 1961; Gupta, 1981) while in Shillong and its adjacent areas which are relatively cold, the life cycle duration from incubation till adult emergence is much shorter as observed.

There are other factors and controlling mechanisms which regulate the life cycle duration of the species of butterfly studied, viz., *Pieris brassicae* (L.) and *P. napi montana* Venity. The aggregating behaviour as observed in the field, especially in *P. brassicae* larvae, may often lead to suppression of faster development, because of competition for food resources, which further lead to slower development and growth in general. As observed in other species of butterflies and moths (Smith, 1969) and other insects (Park, 1938; Sang, 1949, 1959), that crowding affects the general growth and life cycle duration of such species. In case of *P. napi montana* Venity, not much of larval crowding behaviour is observed because the eggs are laid singly but the opposite is observed in *P. brassicae*.

Age of the host plants on which the larvae of *P. brassicae* (L.) and *P. napi montana* Venity, feed also may affect the life cycle duration, especially the feeding stages, hence contributing to the total life cycle, either shortened or prolonged it. This factor was not studied during this investigation but biochemical factors like organic nitrogen, free amino acids and free sugars were considered in relation to life cycle duration and other ecological efficiences like consumption, growth and conversion aspects. As it is a known fact that the host plant composition does affects the life cycle of the insects feeding on them. Protein and leaf resin composition of the food plant (*Diplacus aurantiacus*) of the checkerspot butterfly (*Euphydryas chalcedona*) affects the larval life duration and responses due to this factor (Lincoln *et al.*,1982).

Leaf nitrogen and water content variation in the host plants of Colias butterfly larvae also affect the larval responses and life cycle (Tabashnik, 1982).

But not only life cycle and the larval responses are affected, but also their choices due to the host plant quality, as in the case of beetles (Messina, 1982) and other forest insects (Lunderstaedt, 1981).

Nitrogen content in the diet of P. brassicae and Barathra brassicae regulates the development of these species (Gorovaya and Samarsov, 1976) as has been also reported in some other insects. Nitrogen i.e. organic nitrogen, does really regulate the life cycle of many insects. In case of P. brassicae and P. napi montana Venity, it is observed, that in mustard and raddish where the organic nitrogen is high, the total duration of life cycle of P. brassicae is short in comparison to cabbage and cauliflower where the total organic nitrogen is lower. Hence, the total life cycle duration of the species takes much longer, pointing out that nitrogen is one of the factors regulating the life cycle of the species. But this is not so convincing in Pieris napi montana Venity.

Total free amino acid and total free sugar composition of the various host plants of P. brassicae and P. napi montana Venity, singly do not affect the life cycle duration of both the species when compared to the effects observed in the case of nitrogen. In general, the host plant is the sole factor on which the life cycle of any species is dependent on, as attributed by other workers (Cates, 1980; Gupta, 1982; Prestidge, 1982; Lederhouse et al, 1982) especially in chewing types of insects.

The effects of host plants on various developmental aspects of P. brassicae has also been reported (Gupta, 1981) as well as the different consumption and utilisation efficiencies of the larvae on various host plants (Gupta and Malayvar, 1981). Yadava et al (1979) described the various consumption, assimillation is positively correlated.

Generally consumption and growth are not correlated distinctly in P. brassicae as observed from the experiments performed. A series of variations could be seen whether in consumption or growth performances of different larval stages on different host plants.

Cauliflower (B. oleracae var. botrytis L.) and knol khol (B. oleracae var. gongylodes L.) are the host plants where consumption rate is high while the growth rate is not satisfactory so as to attribute these two host plants as most preferred. In cabbage (B. oleracae var. capitata L.) there is a uniform rate of consumption in all larval stages of Pieris brassicae and there also exists a uniform growth rate among them. Therefore, from this point of view, cabbage could be attributed to be the most preferred host plant, if consumption and growth is considered. Hence the host plants of P. brassicae show intraspecific variation with respect to host favourability as suggested in other phytophagous insects (Journet, 1980; Tabashnik, 1982).

Digestibility and conversion efficiencies vary in P.brassicae (L.) from stage to stage of larval life, on all host plants tested. As calculated from consumption and growth parameters, efficiencies like ECI, ECD and CAD are very high in almost all the host plants and in all the larval stages tested. Low efficiencies of conversion and digestibility is observed in certain cases of experiments, which may be attributed to parasitisation, diseases and age of the parasites. As in previous reports, evidences have been brought forth to support this phenomena (Fuehrer, 1980). Growth as well as consumption may also be affected by such phenomena.

Utilisation of nitrogen, in the organic form, in P.brassicae is observed to be stabilised on all host plants as calculated from dry weight measurements. Nitrogen utilisation, as observed from the nitrogen content of host plants fed and feces excreted by the larvae of P. brassicae, tends to fluctuate round 30-60% (Fig. 7A). Nitrogen utilisation, again, as other efficiencies depend on host of factors, like parasitisation and disease of larval stages.

Amino acid and sugar utilisation as seen from wet weight analyses of host plants fed and feces excreted by the larval stages of P. brassicae show a tendency which is more or less similar in both cases.

Amino acid utilisation ranges from 70-90%, this factor is very stable as observed in P. brassicae larvae (Fig. 7B). Amino acids are well known as far as their function is concerned, especially as building blocks of various proteins required for development and growth in general (House, 1974), hence their utilisation is very high.

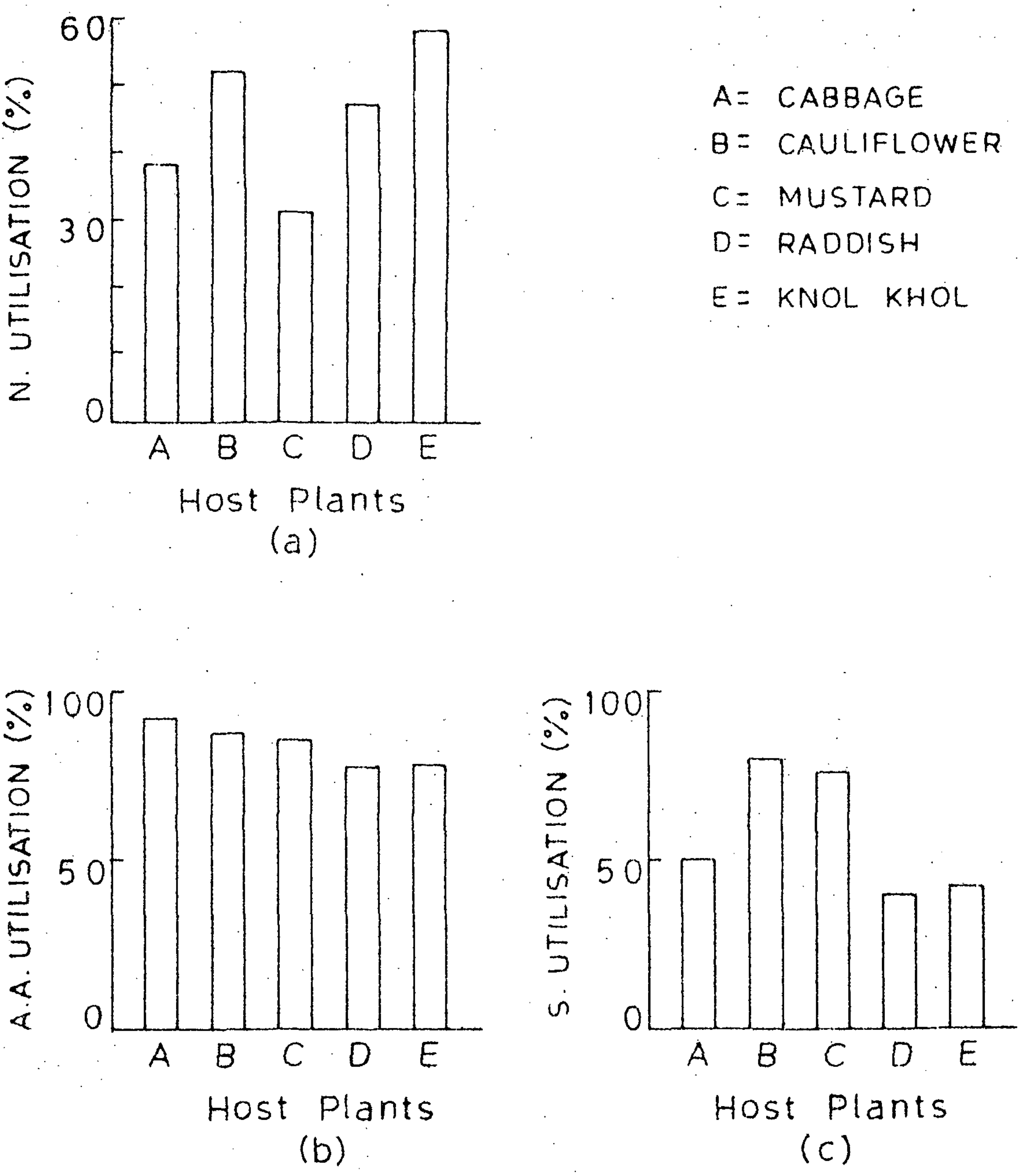
Utilisation of sugar in P. brassicae larvae is also more or less stable on all host plants fed. The utilisation of sugar ranges from 40-80% (Fig. 7C). Sugars, especially glucose is well known for its biological function as an energy producing molecule, which is very much essential for proper growth and development (Wigglesworth, 1972) hence its high utilisation as observed in P. rapae crucivora (Boisd) (Kusano and Nishida, 1978).

Fig. 7 Utilization of different chemical components in percentage of various host plants by the larvae of *P. brassicae*.

a) Nitrogen

b) Amino acid

c) Sugar.


N. UTILISATION (%)
60
30
0
A
B
C
D
E
Host Plants
A= CABBAGE
B= CAULIFLOWER
C= MUSTARD
D= RADDISH
E= KNOL KHOL
A.A. UTILISATION (%)
100
50
0
A
B
C
D
E
Host Plants
S. UTILISATION (%)
100
50
0
A
B
C
D
E
Host Plants

(a)

(b)

(c)

Fig. 7

These deductions have been made only on P. brassicae (L.) larvae in relation to their feeding, on young and growing host plants. The utilisation of different chemical components by the larvae of this species is again governed by factors like larval parasitisation and diseases together with the age of the host plants on which they feed.

Amino acids and sugars detected in the feces of larval stages of Pieris brassicae (L.) are quantitatively low, that by simple paper chromatographic procedures, they could not be detected as such, while by spectrophotometric methods (as has been carried out), they could be easily quantified. This is the basis on which the utilisation measurements have been facilitated.

CHAPTER III

Larval feeding and adult oviposition preferences and effect of chemicals on larval feeding behaviour in *Pieris brassicae* (L.)

3.1. INTRODUCTION

Most if not all plant species may satisfy the food requirements of certain insects. Some of the insects will thrive on several plant species, which botanically can be quite unrelated. Others have a more limited appetite and relish only a few related or even one single plant species. Food selection behaviour which has been more subtly developed in insects than in any other major group of animals, may focus on three basic questions (Schoonhoven, 1972a) :- (i) in which way does a phytophagous insect select its host plant in an environment in which a multitude of plant species usually occur? (ii) what is the function of this behaviour in physiological and ecological terms? (iii) how did the food selection behaviour developed during evolution?

Many specialised insect hervibores choose as food, plants which contain 'specific plant secondary compounds'. For *Pieris* spp. only plants which contain glucosinolates are recognise as potential food plants and adults of *Pieris brassicae* (L.) always choose such plants only, for oviposition (Verschaffelt, 1910). David and Gardiner (1962) tested the action of mustard oil glucosides as feeding stimulants of *Pieris brassicae* larvae in semisynthetic diets with positive results. Mitchell (1977) found that gravid *Pieris brassicae* usually select *Brassica oleracea* var. *oleraceae* as hosts, with strong positive reaction to Grignard's picrate test. This is attributed to the presence of allyl-nitrile, the specific attractant for oviposition.

Adults of oligophagous lepidoptera utilise specific contact chemical stimuli to discriminate host from non-host plants. The stimuli appeared to be perceived by chemoreceptors located on the tarsi and the effect leads to oviposition. In its absence eggs are not normally laid. The ovipositional stimuli for Pieris butterflies are sinigrin and related mustard oil glycosides (David and Gardiner, 1962; Hovanitz and Chang, 1963; Schoonhoven, 1967; Ma and Schoohhoven, 1973).

Fox (1974) reported that in the case of Pieris rapae (L), ovipositional preference ranges from Brussels sprout to cabbage. But for natural oviposition the cabbage-worm adults prefer Brussels sprouts more than cauliflower and cauliflower more than cabbage. This shows that even among the cruciferous plants also, Pieris spp. exhibit discrimination, but so far this behaviour has been reported only in Pieris rapae (L.).

Insects, aided by their chemical senses are able to select their food, to a large extent base on chemical characteristics. Various compounds present in their food may serve as attractants and phagostimulants, thus promote feeding. On the other hand, insects are alterted for feeding deterrent compounds in their environment which signal nutritionally suboptimal or toxic food stuffs. In case of Pieris brassicae (L), once the adults lay their eggs on a selected plant the larvae is exposed to inevitable situation and has to adapt themselves to whatever the conditions are, be physical or chemical. After the incubation period, the larvae hatches and beginning from this period only, they are exposed to such unpredictable environmental conditions (Schoonhoven and Dethier, 1966; Schoonhoven, 1969b).

The larvae search for food and started chewing its food plant. At this stage the larvae are subjected to many host plant chemicals, which lead to more feeding or cessation of feeding. Here, the host plant chemicals like sugars, aminoacids, soluble proteins and other such compounds present in the sap, play a very important role in limiting and delimiting feeding (Jermy et al. 1968).

From the behaviour point of view, the nervous system attract special attention in such analyses. While studying food selection in phytophagous insects many questions arise, as whether the different behavioural reactions towards certain food plants by different insect species are due to the fact that they receive different sensory information from the same plant or whether in different species identical sensory messages are processed in a different way within their central nervous systems and therefore lead to different behavioural reactions.

When a natural stimulus, such as plant sap, is applied to the two maxillary sensilla stylonica of a Pieris caterpillar, the resulting impulse pattern in the form of chemoreceptory cells present, is often variable when different individuals are compared, it also varies when different chemicals are tested, especially in terms of behavioural reactions. The different reactions to chemical stimuli in experimental conditions has already been studied by Schoonhoven (1976a,b; 1977a,b) using electroantennographic methods but only certain group of chemicals like deterrents and attractants were analysed.

In the present study, ovipositional and feeding, preferences between selected host and non-host plants, and the effects of various organic and inorganic chemicals on the larval feeding behaviour of Pieris brassicae (L.) was investigated.

3.2. MATERIALS AND METHODS

Fresh host and non-host plants were collected from the field and brought to the laboratory in plastic bags.

3.2.1. Test for food plant preference.

Leaf discs of uniform sizes (2.0 cm. diameter) were cut out from healthy and growing host and non-host leaves. Arena choice tests were conducted in glass petridishes (21.0 cm. diameter X 1.5 cm. high) which are quarterly filled with paraffin wax (BDH) (Fig.8). Humidity inside was maintained by wet filter paper lining (Whatman No.1) with a pencil mark at the centre and the four peripheral sites to indicate the position for the leaf discs to be tested. To avoid positional effects in the area and possible directional stimuli, the position of leaf discs were randomized following the method of Chew (1980). Leaf discs were pinned to the periphery of the arena at the centres leaving a small space (approximately 0.4 - 0.5 cm. high) from the base. <u>Pieris brassicae</u> (L.) larvae used in these tests, were either laboratory reared or collected from the field. In both cases, larvae are starved for 10-12 hrs. before the experiment and only healthy and active larvae are selected for choice tests. The last stage larvae are used in most of the tests. Larval behaviour was recorded as touching, attacking and chosen depending on the time the larvae spend on any leaf disc.

In another set of experiment, a required number of larvae were selected and choice tests experiment were conducted only with selected plants. Larvae were released in the centre of the arena and observed under a fixed time period. The number of larvae found feeding on any leaf disc was noted, percentage of feeding larvae was calculated from the observations. A non-host plant disc is used as a control in all experiments.

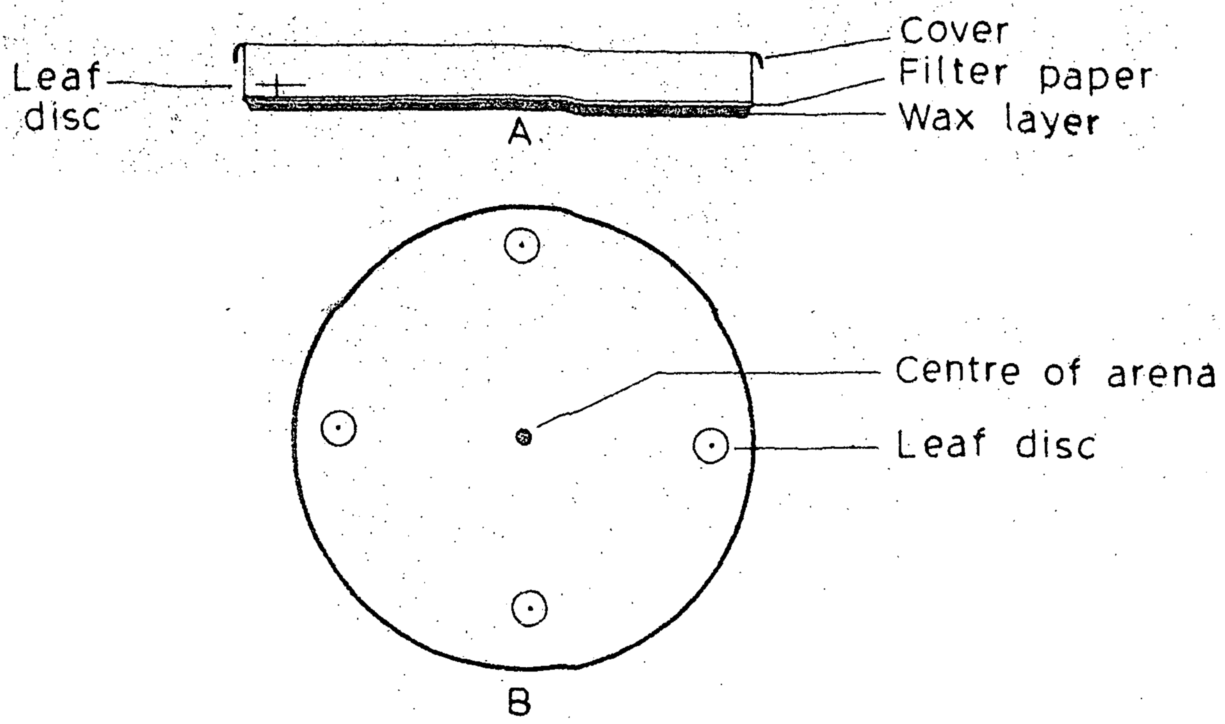


Fig. 8. Diagrammatic representation of Arena ▭ and disc positions for choice test.

A= Sectional view B= Top view

3.2.2. Effect of chemicals on the feeding behaviour.

Active feeding fifth stage larvae of *Pieris brassicae* (L.) (Plate-2 F) were used for assaying the effects of known chemicals upon the feeding behaviour. Various known chemicals were dissolved in distilled water separately and their 5% solutions were used for experimentation.

Four hour starved larvae were fed with different host leaves under laboratory conditions inside a glass container, usually in a small petridish (9.0 cm diameter X 1.5 cm high). When a larva is actively feeding and chewing its host plant, a known chemical solution is administered by means of glass micropipette on that part of the host plant where the larva is actively feeding, and its behavioural response is observed directly and scored according to the degree of reaction, such as escaping, regurgitating, active feeding, and cessation of feeding. In this case, one larva is used for one solution test to avoid error of response, according to the method of Schoonhoven and Jermy (1977). A series of chemical solutions were screened by this method to find out stimulatory and deterency effects on the feeding of these larvae on their accepted host plants. Water is used as a control solution.

3.2.3. Ovipositional preferences.

These experiments were conducted in a net house (4.6 m X 2.8 m X 2.1 m). Saplings (1-2 months old) of various host plants of *Pieris brassicae* (L.) were purchased from Barabazar market, Shillong, and planted in plastic buckets (22 X 22 cm) inside the net house. Cauliflower *Brassica oleracea* var. *botrytis* (L.), cabbage- *Brassica oleracea* var. *capitata* (L.), mustard- *Brassica campestris* var. *Sarson* Prain, raddish- *Raphanus sativus* L.) and knol khol- *Brassica* *oleracea* var. *gongylodes* L.) were arranged in group of 5(five) serially and randomly numbering to 40 plants in a net house.

Freshly emerged adults of *Pieris brassicae* (L.) (4-5 pairs) reared in the laboratory were released in this net house and their ovipositional behaviour were observed daily by counting the number of plants oviposited. Percentage of oviposition was calculated on the basis of the number of batches of eggs, laid on a specific host plant. This was observed daily with the records of humidity and temperature. Dead butterflies were replaced by new ones. Healthy plants were used for this experiment and saplings showing signs of witting are removed and new ones are introduced. Part of the leaf on which oviposition has occurred, were cut off and washed with water.

3.3. RESULTS

3.3.1. Food plant preference.

The last stage larvae of Pieris brassicae (L), exhibited a series of behavioural response towards their accepted host and non-host plants. Results of behavioural studies on food plant preference by the larvae, is tabulated in Table-9.

Out of ten plants tested for larval preferences, five are well known host plants of P. brassicae. All these five host plants, viz. cabbage, cauliflower, knol khol, mustard and raddish exhibited same larval responses. In all these host plants, the larval behaviour is observed to be in three distinct phases. The first phase, is that the larva moves to the site where the host plant's disc is located and beging to 'touch' it. The second phase follows immediately after touching, where the larvae 'attack' the leaf disc by its anterior parts and the third phase follows by which the larva starts 'feeding' or 'chewing' at the disc vigorously, generally without cessation till it is satiated.

In case of non-host leaf disc, viz. Pea, Beetroot, Potato and Lettuce, a different type of larval behaviour is observed. In all these behavioural responses, the larva exhibited only the first phase of action, i.e. touching. While the other responses are not performed by it. Only in case of Lettuce (Latuca indica L.) it is observed that the second phase i.e. attacking, is performed but it does not last long as seen in preferred hosts plants. In Pea (Pisum sativum L), Beetroot (Beta vulgaris L) and Potato (Solanum tuberosum L) only the first phase of behaviour is observed. After 'touching' the larva retreat from the leaf disc of these plants.

TABLE - 9

Behavioural responses of V (last) stage larvae of P. brassicae (L.) to various plants.

PLANTS TESTED	TOUCHING	ATTACKING	FEEDING
Cabbage (*Brassica oleracea* var. *capitata* L.)	+	+	+
Cauliflower (*B. oleracea* var. *botrytis* L.)	+	+	+
Knol khol (*B. oleracea* var. *gongylodes* L.)	+	+	+
Mustard (*B. campestris* var. *sarson* Prain)	+	+	+
Raddish (*Raphanus sativus* L.)	+	+	+
Pea (*Pisum sativum* L.)	+	-	-
Beet root (*Beta vulgaris* L.)	+	-	-
Potato (*Solanum tuberosum* L.)	+	-	-
Castor (*Ricinus communis* L.)	-	-	-
Lettuce (*Latuca indica* L.)	+	+	-

+ = positive response

- = negative response

On Castor (*Ricinus communis*) leaf disc from among all the plants, negative response was exhibited by the larva of *P. brassicae*.

3.3.2. Differential feeding preference towards host plants.

Results of preference tests among various host plants of the larvae of *P. brassicae* (L) revealed that even within accepted food plants, there exist a differential feeding preference among them as shown in Fig. 9.

Various choice tests were conducted and results show that the larvae of *Pieris brassicae* exhibited a series of host plant preference in a 'choice' situation.

Tests, using host plants, viz. cabbage, cauliflower and mustard, indicate that the larvae preferred to feed on mustard primarily. But given a choice, the second most preferred plant is cauliflower and last is cabbage.

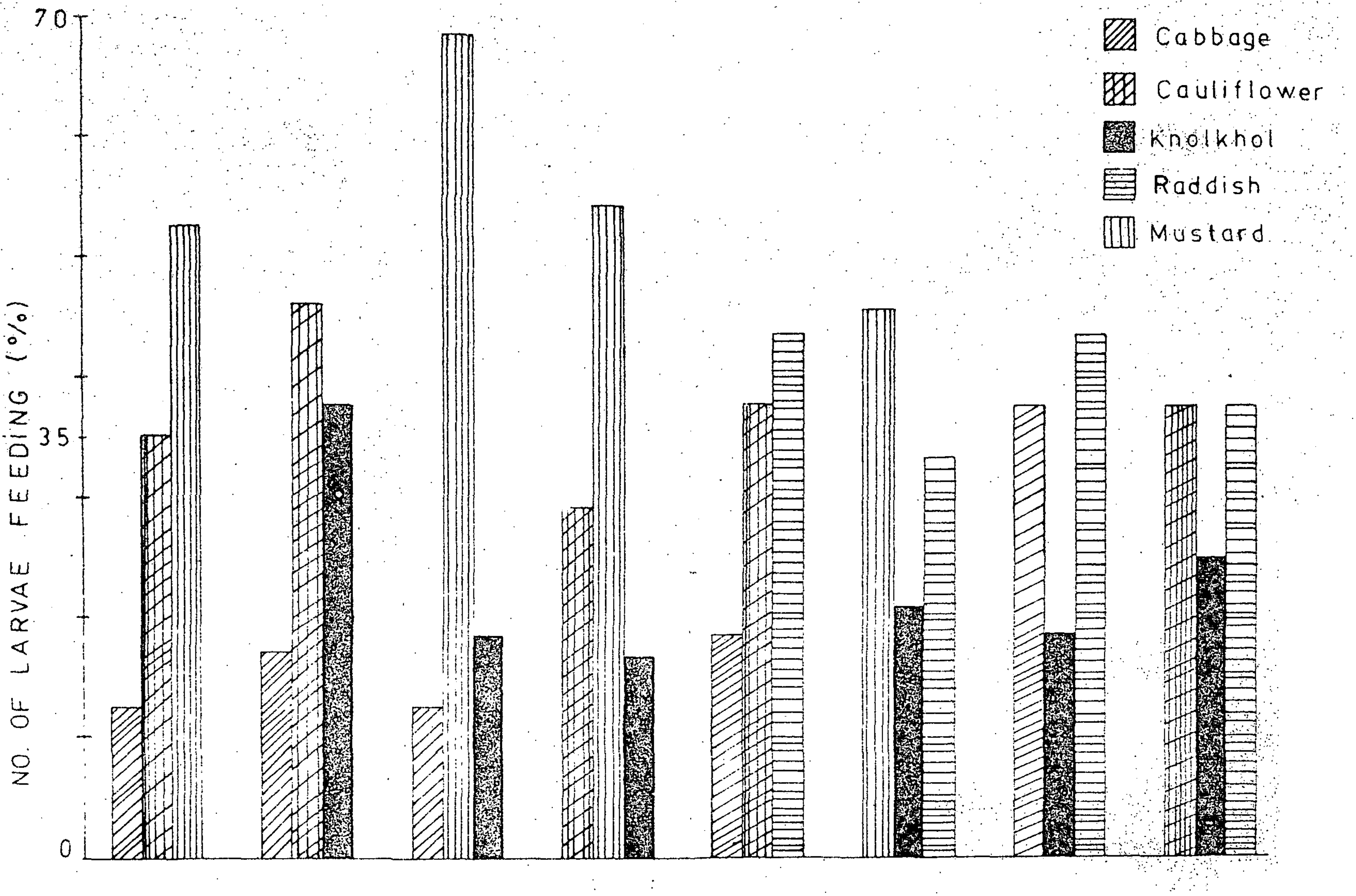
In tests where host plants, viz. cabbage, cauliflower and knol khol are present, a high percentage of larvae chooses to feed on cauliflower first, which a lower percentage feed on knol khol and the least on cabbage.

When cabbage, mustard and knol khol were tested, maximum number of larvae preferred to feed on mustard. Minimum number of larvae feed on knol khol and cabbage.

In the other tests, mustard was most preferred by a maximum number of larvae. Although in cauliflower, the number is not very less than when compared to knol khol.

Other tests show that in raddish, there is a high percentage of larvae feeding, while in cauliflower also preference is not low, but in case of cabbage a very low number of larvae are feeding.

Fig. 9 Percentage of *P. brassicae* larvae feeding on a certain host plant's disc in various 'Arena. Choice Test' experiments.



HOST PLANTS

FIG.9

The other test revealed that on mustard there occurs a high percentage of larvae feeding, than on raddish and knol khol.

Raddish was observed to be the most preferred host plant, due to a high percentage of larvae feeding, while on cabbage also a very high number of larvae are feeding in comparison to knol khol as revealed by choice tests.

Other tests, show that in raddish and cauliflower there exist an equal number of larvae feeding on them, but on knol khol the number is quite low.

In all preference experiments conducted on the larvae of *P. brassicae*, mustard proves to be the most preferred plant in a 'choice' situation, where some of the host plants are also present. Cauliflower and raddish are also well preferred 'than' the other host plants, viz. cabbage and knol khol.

Effects of chemicals on the feeding behaviour of *P.* brassicae (L).

Active feeding last stage larvae of *P. brassicae* (L) are exposed to many types of chemicals present in the sap of the host plant. *P. brassicae* being an oligophagous feeder, is faced with many such plant chemicals which tends to inhibit or promote its feeding.

3.3.3. Inorganic salts.

Ten inorganic chemical compounds have been tested with regard to their ability to inhibit or promote feeding in the actively feeding last stage larvae of *P. brassicae* (L). The various behavioural responses, exhibited by a larva when fed on certain host leaf, due in administration of a known inorganic salt, is recorded in Table-10.1.

TABLE - 10.1

Behavioural responses of feeding Vth (last) stage larvae of *P. brassicae* (L.) towards various organic chemicals.

INORGANIC SALTS	REGURGITATING				ESCAPING				CESSATION OF FEEDING			
	C_1	C_2	M	K	C_1	C_2	M	K	C_1	C_2	M	K
Sodium acetate	+	+	+	+	+	+	+	+	+	+	+	+
Sodium nitrate	+	+	+	+	-	-	-	-	-	-	-	-
Di-Sodium hydrogen phosphate	+	+	+	+	+	+	+	+	-	-	-	-
Ammonium Chloride	+	+	+	+	+	+	+	+	-	-	-	-
Ammonium Sulphate	+	+	+	+	+	+	+	+	-	-	-	-
Cadmium acetate	+	+	+	+	+	+	+	+	+	+	+	+
Potassium Nitrate	+	+	+	+	+	+	+	+	+	+	+	+
Lead Acetate	+	+	+	+	+	+	+	+	+	+	+	+
Magnesium Sulphate	+	+	+	+	+	+	+	+	+	+	+	+
Manganous Sulphate	+	+	+	+	+	+	+	+	+	+	+	+

C_1 = Cabbage (*Brassica oleracea* var. *capitata* L.)

C_2 = Cauliflower (*B. oleracea* var. *botrytis* L.)

M = Mustard (*B. campestris* var. *sarson* Prain)

K = Knol khol (*B. olerace* var. *gongylodes* L.)

\+ = positive response

\- = negative response

Six inorganic salts tested out of ten, exhibited inhibitory effects on the feeding larva of P. brassicae. Sodium acetate, Cadmium acetate, Potassium nitrate, Lead acetate, magnesium sulphate and Manganous sulphate, exhibited intense inhibitory responses on the feeding larva. Regurgitating of saliva, is followed by another phase of behavioural response, i.e. escaping. After there two responses, there is cessation of feeding, which lasted for longer period and the larva switch over to another part of the host leaf where there exist a 'free chemical zone'.

Sodium nitrate, lead to regurgitation only when larva is fed on leaf administered with it. The other responses, escaping and cessation of feeding of the larva are not observed.

When di-Sodium hydrogen phosphate is administered to the site of active feeding by a larva, its behavioural responses consists of two phases only, regurgitating and escaping. The third phase of response is not observed, the larvae continues to feed undisturbed. The same observation has been made, when ammonium chloride and ammonium sulphate are tested.

3.3.4. Water soluble amino-acids.

Twelve water soluble amino acids have been screened to assess their ability to inhibit or promote feeding in the last stage larvae of P. brassicae (L). Behavioural responses exhibited by a larva feeding on a certain host plant leaf, due to the administration of a known amino acid is recorded in Table-10.2.

Amongst all water soluble amino acids tested, only Dl-methionine and glycine does not exhibited any sign of provoking in the larva during feeding on selected host plants. There is no regurgitating, escaping or cessation of feeding responses in the feeding larvae.

TABLE - 10.2

Behavioural responses of feeding V (last) stage larvae of *Pieris brassicae* (L.) towards water soluble amino acids.

AMINO ACIDS	REGURGITATING				ESCAPING				CESSATION OF FEEDING			
	C_1	C_2	M	K	C_1	C_2	M	K	C_1	C_2	M	K
Dl-alanine	+	+	+	+	-	-	-	-	-	-	-	-
L-arginine monohydrochloride	+	+	+	+	-	-	-	-	+	+	+	+
L-hydroxy proline	+	+	+	+	-	-	-	-	+	+	+	+
L-leucine	+	+	+	+	-	-	-	-	-	-	-	-
Dl-isoleucine	+	+	+	+	+	+	+	+	-	-	-	-
Dl-B-phenylalanine	-	-	-	-	+	+	+	+	+	+	+	+
Glycine	-	-	-	-	-	-	-	-	-	-	-	-
L-proline	+	+	+	+	-	-	-	-	+	+	+	+
L-serine	-	-	-	-	-	-	-	-	+	+	+	+
Dl-threonine	+	+	+	+	+	+	+	+	+	+	+	+
Dl-valine	+	+	+	+	-	-	-	-	+	+	+	+
Dl-methionine	-	-	-	-	-	-	-	-	-	-	-	-

C_1 = Cabbage (*Brassica oleracea* var. *capitata* L.)
C_2 = Cauliflower (*B. oleracea* var. *botrytis* L.)
M = Mustard (*B. campestris* var. *sarson* Prain.)
K = Knol khol (*B. oleracea* var. *gongylodes* L.)

- = negative responses
+ = positive responses

When Dl-alanine is administered on the feeding site, the larva reacts by regurgitating only, but escaping and cessation of feeding is not inhibited. The same behavioural responses have been observed when L-leucine is administered on the feeding site.

Regurgitating and cessation of feeding have been observed in the feeding larva, when L-arginine monohydrochloride, L-hydroxy proline, L-proline and Dl-valine is administered on the feeding site on all accepted host plants. Escaping behaviour is not observed when these amino acids are tested.

When Dl-isoleucine is administered on the feeding site, regurgitating and escaping responses have been observed in the actively chewing larva of P. brassicae, when it feeds on any of its accepted food plants. After a short period of relaxation, the larva starts chewing again on the same part of the host leaf as if undisturbed.

No regurgitating reaction have been observed in the active feed larva of P. brassicae, when Dl-Beta-phenylalanine is applied to the site of feeding on all its host plants. Intense response of escaping and cessation of feeding is observed instead.

When L-serine is applied to the feeding sites of the larva of P. brassicae, no regurgitating and escaping reactions are exhibited, when fed on any of the accepted host plants. But there is cessation of feeding for a very long period and the larva does not sometimes, feed at all.

All three phases of behavioural responses have been observed in the larva of P. brassicae, viz. regurgitating, escaping and cessation of feeding, when Dl-threonine is administered on the feeding site of the larva, on all accepted host plants.

3.3.5. Organic acids.

Four organic acids have been tested with regard to their ability to promote or inhibit, feeding in the last stage larvae of *P. brassicae* (L). Behavioural reactions and responses of the feeding larva, when fed on a certain host plant leaf, due to the administration of a known organic acid is recorded in Table-10.3.

Ascorbic acid, does not inhibit the feeding of the chewing larva, since regurgitating, escaping and cessation of feeding responses are not exhibited. This is observed on all accepted host plants.

When citric acid is applied to the feeding site of the larva, while chewing on any of the host plants, violent regurgitating reaction is observed. This also has been observed when succinic acid is administered on the feeding site of the larva. Escaping and cessation of feeding does not occur.

Oxalic acid, inhibited feeding in the larvae of *P. brassicae* when administered on the feeding sites. Regurgitating and escaping responses are observed which were followed by a long phase of feeding cessation. This is observed on all host plants.

3.3.6. Sugars.

Ten sugars have been screened to assess their ability to suppress or promote feeding in the last larval stage of *P. brassicae* feeding on its accepted host plants. Behavioural responses towards these sugars, by the larva of *P. brassicae* is recorded in Table-10.3.

Glucose when applied on the feeding site of the actively chewing larva of *P. brassicae* generate intense regurgitating responses, but the other behavioural phases are not observed. The

TABLE - 10.3

Behavioural responses of feeding V(last) stage larvae of *Pieris brassicae* (L) towards various organic acids and sugars.

CHEMICAL COMPOUNDS	REGURGITATING				ESCAPING				CESSATION of FEEDING			
	C_1	C_2	M	K	C_1	C_2	M	K	C_1	C_2	M	K
Ascorbic acid	-	-	-	-	-	-	-	-	-	-	-	-
Citric acid	+	+	+	+	-	-	-	-	-	-	-	-
Oxalic acid	+	+	+	+	+	+	+	+	+	+	+	+
Succinic acid	+	+	+	+	-	-	-	-	-	-	-	-
D-glucose	+	+	+	+	-	-	-	-	-	-	-	-
Sucrose	+	+	+	+	-	-	-	-	-	-	-	-
Galactose	-	-	-	-	-	-	-	-	-	-	-	-
Dextrose	+	+	+	+	-	-	-	-	-	-	-	-
Maltose	+	+	+	+	-	-	-	-	+	+	+	+
Xylose	+	+	+	+	-	-	-	-	+	+	+	+
Ribose	+	+	+	+	-	-	-	-	+	+	+	+
Rhamnose	+	+	+	+	-	-	-	-	-	-	-	-
Mannose	+	+	+	+	-	-	-	-	+	+	+	+
Arabinose	+	+	+	+	-	-	-	-	-	-	-	-

C_1 = Cabbage (*Brassica oleracea* var. *capitata* L.
C_2 = Cauliflower (*B. oleracea* var. *botrytis* L.)
M = Mustard (*B. campestris* var. *sarson* Prain)
K = Knol khol (*B. oleracea* var. *gongylodes* L.)

\+ = Positive response
\- = Negative response

larva chew its food actively as if undisturbed. This is also observed when dextrose, rhamnose, sucrose and arabinose are administered on the feeding site of the larvae, on all accepted host plants.

Regurgitating and cessation of feeding responses habe been observed in the larvae of P. brassicae (L) when maltose is applied to its feeding site, on any accepted host plants. Escaping reaction is not observed. These responses have also been recorded in the active feeding P. brassicae (L) larvae, when xylose, ribose and mannose were administered to its feeding site.

From amongst all sugars tested, only galactose does not inhibit the feeding of P. brassicae larvae. This is observed when it is applied to the feeding sites of the larvae on all host plants.

3.3.7. Ovipositional preference.

P. brassicae (L) adults are known to oviposit only on plants whose tissues contain mustard oil glycosides or glucosinolates. Therefore, all host plants accepted by the adults for oviposition and larvae for feeding are contain these special class of secondary substances, which are specific to cruciferae.

Adults of P. brassicae show ovipositional variation toward their accepted host plants even if all of them belong to cruciferae, therefore, containing glucosinolates. Ovipositional preference of P. brassicae adults in net house conditions, towards their food plants differed from one host plant to another (Figure 10-8).

Generally, 1-2 day old P. brassicae adults show no sign of ovipositional behaviour unless released in the field. Under net house conditions, it is observed that amongst all host plants tested for oviposition, cauliflower (Brassicae oleraceae var. botrytis L.)

proves to be the most preferred. Various ten day experiments exhibited that from the third till the tenth day, maximum cauliflower plants are oviposited.

Raddish (*Raphanus sativus* L.) from amongst the host plants tested proves to be the least preferred host for oviposition by adults of *P. brassicae*. Very few raddish plants were observed to contain egg batches.

In cabbage (*B. oleracea* var. *capitata* L.) it is observed that uniform oviposition exists from the second to the eight day of the experimental period. Egg batches were also uniform in number. This was also observed in case of knol khol (*B. oleracea* var. *gongylodes* L.), where oviposition existed from second to the eight day.

Oviposition of *P. brassicae* adults in case of mustard (*B. campestris* var. *sarson* Prain), started from the third day of their exposure to host plants. Oviposition on mustard existed till the sixth day, but sometime on the eight day also, adults still lay eggs on large number of mustard plants. The number of egg batches were not large as observed in other host plants.

In the ninth and tenth day of the experimental period, oviposition by adults of *P. brassicae* is negligible as in the first day. Random oviposition occurs and egg batches were observed on cauliflower only.

The resulting ovipositional preference towards their host plants as observed in *P. brassicae* (L) could be classified as follows : cauliflower > cabbage or knol khol > mustard > raddish.

Environmental factors like humidity and temperature do not fluctuate much during the experimental period as observed (Fig.10-A).

Fig. 10 (A) Daily fluctuation of temperature and humidity.

(B) Percentage of different host plants oviposited per day by *P. brassicae* adults in net house condition.

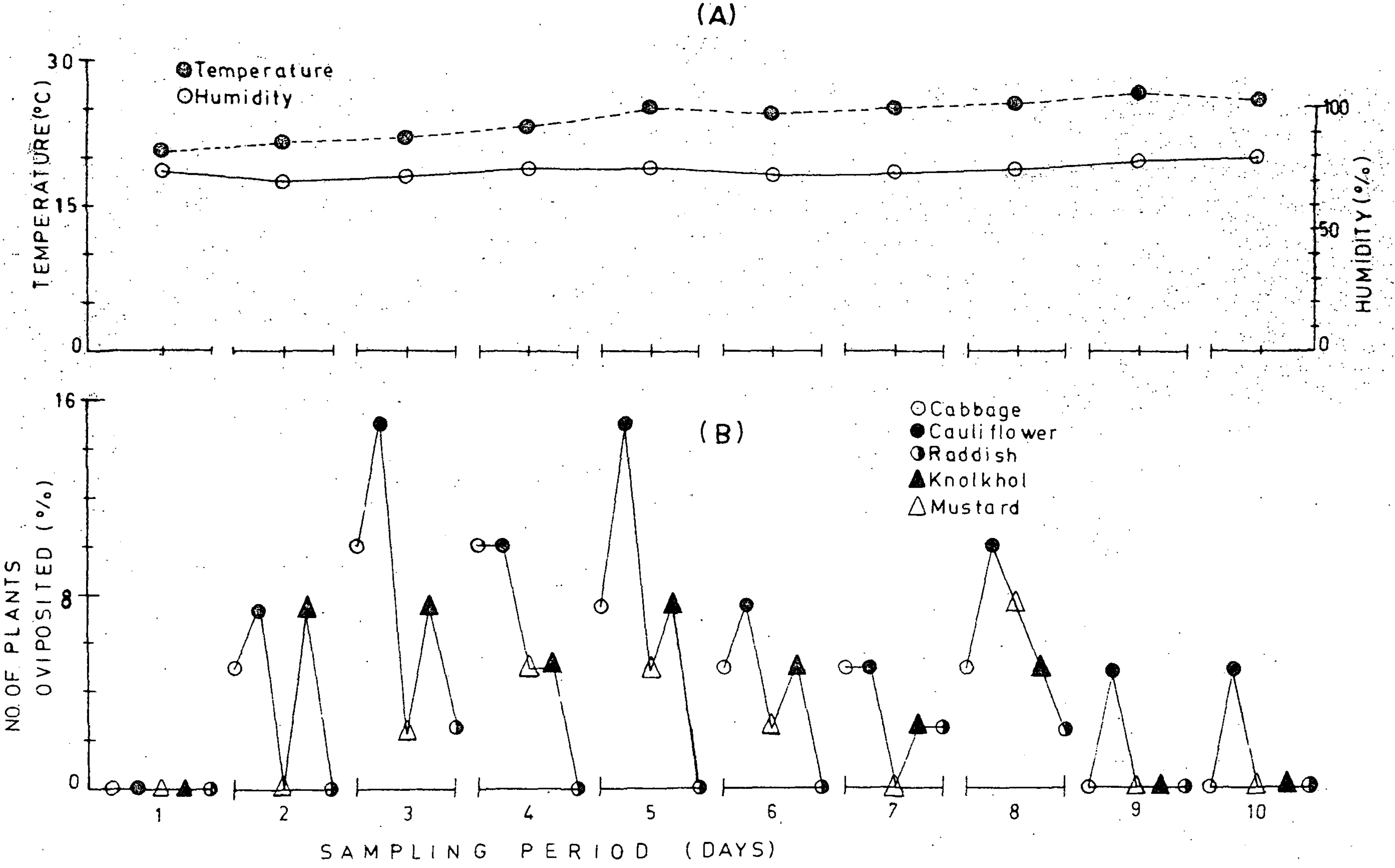

(A)
30
15
0
TEMPERATURE (°C)
Temperature
Humidity
100
50
0
HUMIDITY (%)
(B)
16
8
0
NO. OF PLANTS OVIPOSITED (%)
Cabbage
Cauliflower
Raddish
Knolkhol
Mustard
1
2
3
4
5
6
7
8
9
10
SAMPLING PERIOD (DAYS)

FIG.10

3.4. DISCUSSION

Insects depend to a large extent on their chemosensory system to locate their food sources, oviposition sites and mating partners. The behavioural physiologist seeks to explain animal behaviour patterns in terms of physiological processes and activities. Here, the nervous system attracts special attention in such analyses. In *Pieris brassicae* (L) emphasis had been given to antennal and maxillary receptors which effect the nervous system and lead to intricate mechanisms, involved in plant preference in the larvae or ovipositional selection in adults.

The larval stages of *P. brassicae* (L) show discrimination in the choice of a plant on which to feed. The investigation reveals that the larvae could easily differentiate between host and non-host plants. The chemical sense well developed in these larvae are unmistakably involved not only in guiding them to their host plants, but also in discriminating host from non-host plants. Schoonhoven (1972b) specified the location of these chemical receptors on the antennae and some on the mouth parts, as it is with *P. brassicae* and other lepidopterous insects.

Apart from being able to discriminate host from non-host plants, the *P. brassicae* (L) larvae could also selectively differentiate between various acceptable host plants. Arena choice tests experiments indicated that the feeding larvae selectively choose a single host plant from among the rest of the acceptable host range for feeding. Mustard (*B. campestris* var. *sarson* Prain) as observed by 'choice' tests is the most preferred host plant for the feeding larvae of *P. brassicae*. The larval preference could be classified as mustard more preferred than cauliflower or raddish and cauliflower or raddish more preferred than knol khol or cabbage.

Arena 'choice test' experiments proved that mustard is the most preferred host plant for larval feeding, under such close circumstances, which is indicative that mustard contains more glucosinolates than other host plants. In all observations, cut leaves were used which as a result lead to production of more volatile glycosides due to cutting. These volatile compounds produced, triggered the sensory system of the larva to react to them, hence, resulting to selection of that particular source from where these "signals" originate.

The analyses of environmental cues which elicit behavioural responses in animals has revealed that often a stimulus situation is characterized by one or a few simple factors. The concept of sign stimuli or key stimuli has also been applied to the analysis of feeding behaviour of insects (Tinbergen, 1951; Eibl-Eibesfeld, 1970). Sensitive cells present in the mouth parts of the larva of P. brassicae, which perceived the volatile glycoside, generate a certain pattern of nerve impulses which are transmitted to the brain. Translation of these messages then lead to induction of feeding, if other physiological factor does not interfere in the process. Host plants having low content of such volatile substances do not generally, therefore, generate feeding behaviour.

Chemoreceptors of insects, in general, are located on several strategic parts of the body. The antennae bear olfactory receptors, but also contact chemoreceptors. Gustatory receptors as well as olfactory, are also located on various mouth parts in many insect species, as established by morphologic, electrophysiologic and behavioural methods. Distinction between olfactory and gustatory receptors made on morphologic bases are not absolute. Sensory physiologists, taking advantage of the specific reaction insects show to some chemicals at low concentration, have in several cases successfully located the receptors involved.

In case of P. brassicae (L), the larvae process specific taste cells for sugars, amino acids, salts and mustard oil glycosides (Schoonhoven, 1969), which together translate the chemical composition of its host plants into nerve impulses leading to feeding behaviour.

In P. brassicae, among all salts tested, acetates of lead, sodium and cadmium and sulphates of magnesium and manganese are observed to have deterrent properties. Other salt possessing similar property is potassium nitrate. All these salts deterred larval feeding and the larvae response aggressively to them. Salts having slight detterrent effects on P. brassicae larvae are ammonium sulphate, ammonium chloride and di-sodium hydrogen phosphate. Nitrate of sodium is observed to have least detterent effect on the feeding of P. brassicae larvae.

Copper sulphate ions at 0.004 M concentration, deterred feeding, in the larvae of P. brassicae (Schoonhoven and Jermy, 1977). Calcium ions for instance, reduce the sensitivity of sugar taste cells in P. brassicae larvae and by this effect depress food uptake (Ma, 1972).

Most amino acids tested prove to possess feeding deterrent effects on the larvae of P. brassicae. L-arginine, L-hydroxyproline, Dl-Betaphenylalamine, L-proline, L-serine, Dl-threonine and L-valine from amongst the water soluble amino acids tested, possess slight to very high deterrent properties on the feeding larvae. Dl-alanine, L-leucine, Dl-isoleucine, glycine and Dl-methionine are observed to stimulate feeding in P. brassicae larvae. Glycine and Dl-methionine are remarkably stimulating the feeding behaviour of the larvae, but other amino acids show lesser stimulating effect. Proline enhances food intake in P. brassicae (Ma, 1969), as well as other amino acids (Schoonhoven, 1969b) but marked effect have been observed with leucine and iso-leucine. Similar effects have been described in other lepidopterous insects as well. Glycine and Dl-methionine promote larval feeding, but no reports are available relating to P. brassicae.

Ascrobic acid is observed to stimulate feeding in the larvae of P. brassicae, while citric acid and succinic acid exert lesser stimulatory effects. Oxalic acid only, from among the organic acids tested proved to possess deterrent properties.

From among sugars tested, D-glucose, sucrose, dextrose, rhamnose and arabinose exhibited stimulatory effects on the feeding of P. brassicae larvae. Galactose show very high stimulating effect. Maltose, Xylose, ribose and mannose show very high feeding deterrent activity on P. brassicae larvae. Sucrose, is the best known phagostimulant in case of P. brassicae (Schoonhoven, 1977a). Behavioural observations revealed that a sucrose receptor is present in all lepidopterous species. Glucose like sucrose stimulated larval feeding in P. brassicae, which indicated that a glucose receptor is also present in these larvae. Glucose receptors are also revealed by behavioural and electrophysiological tests in case of other lepidoptera viz. Philosamia cynthia (Dru) and Bombyx mori (Ishikawa et al. 1969).

But as such, salts, sugars and amino acids singly do not effect the feeding behaviour of P. brassicae larvae. Combined effects of many interacting ions may have greater deterrent or stimulatory action on P. brassicae larvae, as observed in other insects. Dethier and Kuch (1971) proved that sucrose receptor responses may be increase by the presence of some amino acids whereas salts decrease the reaction of this receptor. Sinigrin, a mustard oil glucoside, stimulating a certain receptor cell, when tested alone does not positively effect food intake in P.brassicae larvae, but combined with sucrose, it strongly promoted larval feeding activity, within a permissible concentration range (Schoonhoven, 1976b). Thus some amino acids also, may enhance or decrease the reaction to sugar or to sugar alcohols e.g. inositol and some salts (Dethier, 1971; 1972). In many cases sodium and copper salts, decrease the responsiveness of sugar receptors in P. brassicae.

It is generally observed that the chemosensory system of an insect varies in its sensitivity because of a number of factors which as a result, affect its general feeding behaviour. Age and feeding history have been attributed as factors contributing towards variable chemosensory responses and behaviour. Other factors like effect of food starvation or deprivation, adaptation rate to taste and ionic concentration, and most of all individual variability do affect the insect's general behaviour, especially food uptake. These are the few factors which are responsible for feeding behaviour, but other factors, such as chemical and physical should also be present simultaneously to ensure normal feeding.

In Pierid butterflies, adults lay eggs and larvae feed only on plants containing gluconicolates or mustard oil glucosides, but not all glucosinolate containing plants support larval development of these butterflies (Bowden, 1971; Chew, 1977, 1978; Slansky and Feeny, 1977). Mature females of Pieris brassicae hence must choose selectively for a host plant on which to lay eggs to enable larval development and complete life cycle. Apart from choosing cruciferae plants, gravid Pieris brassicae butterflies also prefer plants or leaves of plants, containing no conspecific eggs or larvae for oviposition (Rothschild and Schoonhoven, 1977), since there is evidence that a volatile deterrent associated with their eggs, which is detected by the approaching gravid female butterfly.

Net house oviposition experiments conducted and field observations on P. brassicae adults, show that females highly prefer cauliflower (Brassicae oleracea var. botrytis L.) plants for oviposition, in the presence of other accepted food plants. Cabbage (B. oleracea var. capitata L.) and knol khol (B. oleracea var. gongylodes L) are less preferred than cauliflower. Mustard (B. campestris var. sarson Prain) is least preferred and Raddish (Raphanus sativus L) is last in the choice of oviposition plants by P.brassicae. Therefore, even amongst accepted host plants, there exist a range of preference for oviposition by the adult female P. brassicae butterfly.

Certain factors like size of the plant leaf, its physical characteristics and colour may play an important role in attracting P. brassicae butterflies for oviposition, other than chemical cues attributed. Cauliflower leaves among all host plants, have certain physical characteristics which permit the adult females to choose them as oviposition sites. Their sizes are large, with a larger leaf area for the young larvae to feed and complete development. The plant size is conspicuously large, with a large area for production of volatile oviposition attractants, which may attract the females to oviposit. Cabbage and knol khol have these characteristics, but less in mustard and least in raddish. The colour of the leaf is very intensely green in cauliflower, but the colour decreases, as observed in other host plants. This is another characteristic which leads to its preference by the gravid females. All these physical characteristics in the host plants contributed to adult preference for oviposition in _P. brassicae_ (Ilse, 1937; Terofal, 1965; Lundgren, 1975; Behan and Schoonhoven, 1978) as well as in _P. rapae_ (Latheef and Irwin, 1979).

In case of raddish (_R. sativus_) dense presence of epidermal hairs, may be an obstruction to egg laying by _P. brassicae_; hence, it is not preferred. Cases of ovipositional mistakes have been also reported on other lepidopterous insects, when females oviposition plants toxic to their larvae or on plants too small to support full larval development (Dethier, 1959; Straatman, 1962; Sevastopoulo, 1964; Douwes, 1968; White, 1974; Chew, 1977; 1978; 1979; Singer and Mandracchia, 1982).

Oviposition deterrent associated with frass has been also reported in _Trichoplusia ni_ (Renwick and Radke, 1980), this factor may also operate in field conditions in _P. brassicae_, especially in plants where frass is present. Oviposition is not observed in host plants where larvae present. Oviposition is not observed in host plants where larvae is feeding and where ever there is frass collection at the base of the plant. In other butterflies, size and age of host plant do qualify in ovipositional choice (Courtney, 1982; Courtney and Courtney, 1982), host plant distribution (Sharp _et al._ 1974; Mackay and Singer, 1982) and other ecological determinants (Singer, 1982; Holdren and Ehrlich, 1982).

As it is generally known, different insect species have different feeding habits. The question arises whether these differences are due to different decisions taken by the brain after receiving information from chemoreceptors, which have common characteristics in different insect or alternatively, whether the different species are equipped with different receptor systems. It is also known that insects show pronounced individual variations with regard to feeding behaviour, this feature again points to the fact that they are known for their plasticity which identify them as a group.

The fact that feeding behaviour and ovipositional strategy can be modified by experience, opens new experimental approaches in the analyses of physiology of learning in invertebrates. The relationship between behaviour and physiological processes, an almost unexplored field in the domain of insect nutrition, offers new lights into the functional coherence of the organism.

In view of the fact that different insects have different chemosensory systems, with their interspecific differences in the degree of tolerance towards various plant chemicals, there could be no way out to find a link between molecular structure of a compound and its feeding deterrent capacity, hence the design of feeding deterrent is not possible. They have to be sought at by empirical methods. Since polyphagous species tolerate a wide range of plant compounds, possibility of finding deterrents is more in oligophagous ones. Pest insects are generally oligophagous in habit, thus may appear to be susceptible to feeding deterrents.

GENERAL DISCUSSION

Insect plant relationship in agroecosystems does not differ much from non-agroecosystem, when viewed from population dynamics, feeding behaviour and ecological efficiency parameters. Pierid butterflies studied in relation to their cruciferae host plants exhibited that, population dynamics of eggs, larvae and adults depend largely on the population of their host plants especially in cultivated ecosystems. Population dynamics of butterflies is directly related to the density of their host plants and to a greater extent, the dynamics of host plants also, is dependent on their phytophagous consumers. Apart from reducing the effective photosynthetic area of the host plants thereby affecting its general growth, insects play a role in changing various biochemical systems in their hosts. This is reciprocated by plants towards their phytophagous consumers, which could be seen in their changing life cycles, variable growth and affecting behaviour in general.

P. brassicae and P. napi montana Verity, both voracious cruciferous leaf feeders show that their life cycle duration from the egg stage till adult emergence, depends on their host plants to a large extent. In these species studied, only the larval forms are restricting for food to their cruciferous hosts. Hence, an effective change in the larval life span lead to a resulting change in their total life duration. Both the species studied vary in their life duration accordingly when they are reared on different hosts. This is one of the many cases where the host plants plated a dramatic role in regulating the life cycles of the phytophagous insects which feed on them.

Not only life cycle of the species considered is affected by various host plants, but also growth and behaviour in general. When a certain host is preferred for feeding by the larvae of these butterflies, consumption follow and the result is exhibited in growth. Hence growth, to a great extent, is governed by the host plant on which the larvae primarily feed. P. brassicae larvae show a variation in consumption and growth patterns when fed on various host plants which results in their different efficiencies of conversion.

Voracious feeders like the larvae of P. brassicae (L.) and to a lesser extent, P. napi montana Verity, directly eliminate their preferred host plants by their intense feeding behaviour. It is observed that P. brassicae larvae consumed more food than P. napi montana. Apart from this difference, there are also others by which these two species distinguished themselves as pest and non-pest insects. P. brassicae lay large number of eggs and the larval density is much higher than P. napi montana, hence the damage done to the host plants (Plate-2C,D) is much more by their larvae. Another feeding behaviour difference which is observed in the field is that growing larvae of P. brassicae feed specifically on the leaf margin (Plate-1F), while P. napi montana does not do so (Plate-1E). This may be due to host texture, quality and chemical composition.

Apart from insects regulating the population of their host plants, life cycle duration and growth, vice versa, many other ecological parameters in the environment like temperature and humidity also play dynamic roles in such activities.

While studying the life cycle duration of P. brassicae and P. napi montana observations have been made that there are parasitoids parasitizing their larval stages. Apanteles glomeratus (L) is observed to parasitized *P. brassicae* (Plate-1 I,J,K,L), while in case of *P. napi montana*, the parasitoid is not yet identified (Plate-1 G,H). These parasitoids apart from growth reducing function in the host larvae, do also regulate the population dynamics of both larval and adult stages of these butterflies.

In case of *P. brassicae* larvae, it is seen that various known chemical compounds tested do affect their feeding behaviour in all host plant selected. These compounds may also be present in varying amounts in the host plants of *P. brassicae* larvae, but do not generally effect their feeding behaviour in natural conditions.

Larvae of *P. brassicae* show a range of preference for feeding even among cruciferous plant varieties, which indicate that resistance has already developed among them towards the damage done by larval feeding. This preference was also seen even in ovipositing female butterflies. The plants resistance towards phytophagous consumers is a well known phenomenon in nature.

P. brassicae (L.) being a pest in agroecosystems where large cultivation of cruciferous crops exist, hence its control is very much essential. *P. napi montana* is generally observed to be a non-pest insect in such ecosystems. Control of *P. brassicae* has been tried employing various methods like biological, using parasites and pathogenic bacteria (Creighton *et al*, 1970; Ashby, 1974; Rataul, 1975; Tatchell, 1981). Parasitoids have also been effective in control of the larvae of this species (Lal and Chandra, 1976; Maisyeyeva, 1980) in field and laboratory conditions.

Apart from these control methods utilised, other biological control systems have also been employed especially resistance breeding through genetic manipulation of preferred host plants (Dickson and Eckenrode, 1980).

In *P. rapae* (L) various methods of control were used for reducing its population by employing pathogens, parasites and chemicals (Dempster, 1967, 1968; Soliman *et al.* 1970; Parker *et al.* 1971; Siever and Wilkinson, 1978; and Levin *et al.* 1981).

Since the investigation on any pest insect is usually basic to future understanding of its biology and control, several ideas could be utilised from such knowledge. As seen in case of *P. brassicae*, several methods of control could also be used especially in agroecosystems. The first and most feasible method is by using parasites. Since in both the species of butterflies larval parasitisation is very specific by specific organisms i.e. Hymenopterans; mass culture of such parasites will be required and their release in the field resulting in population decline in adult butterflies. Hence to some extent control the damage done by the larvae to field crops.

Another method would also be mentioned here, that is, a detailed study of nitrogen variation (Mattson, 1981), in the host plant varieties which led to preferred larval feeding and a biochemical method to alter this change. Nitrogen fertilizers could be employed in variable amounts to cruciferous fields so as to create nitrogen fluctuations in host plants, thereby creating a bottleneck effect on larval feeding; since *Pieris* spp. studied reacts violently to nitrogen differences in their host plants. This could be achieved only by extra loading or subtracting of nitrogen containing fertilizers before applying, but simultaneously the yield should not be effected.

Mixed culture of different cruciferous plant varieties could also be employed as one of the control methods, since adult butterflies of *Pieris* spp. oviposit selectively on their host plants.

Therefore, monoculture should not be encouraged because only one plant variety is affected, hence the damage is more than in mixed culture.

Another method i.e. doping of 'trace' elements, like cadmium, cobalt, manganese etc. in their complex salt form, together with fertilizers as they are being employed simultaneously in the field, may have drastic effect on larval feeding of these Pieris butterflies, when these ions are allocated in the sap of the host plant leaf. Calcium and copper salts can also be used as they deterred larval feeding in low concentration when present in the sap. These salts could be 'dope' in common fertilizers used and at the same time yield, and toxicity side effects should be taken into account.

The above mentioned methods of control, if taken into account, may not affect larval feeding or adult oviposition in general, but in certain cases may prove to be drastic, when fertility, oviposition, reproduction, general life span and growth are considered, without neglecting the environment of the ecosystem in particular.

In conclusion, it can be said that the evolutionary path of the phytophagous insect has not been an easy one; pollen feeding often seems to represent 'the first step' and feeding in or on foliage is a full success. Relatively few orders have achieved this, although those that have, does reaped a rich reward, both in number of species and often in abundance of individuals. Plants have responded to insect attack, and thus insects and plants must be viewed as two co-evolving, competing and often mutually dependent biochemical systems: the balance between them is often very delicate and relatively small biochemical changes may have large ecological effects.

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