INTRODUCTION
The insect fat body or adipose tissue is an organ of exceptional interest for the study of the regulation of differentiated cell function (Wyatt 1980). As has long been known the fat body cells are responsible for a wide range of roles. Whereas the chief function of the fat body is as a storage site for lipids and also carbohydrates and protein reserves, in reality it constitutes the principal tissue for intermediary metabolism. Thus it furnishes a diversity of roles that may be unequalled in any other metazoan cell. The fat body cell can switch its activity pattern in response to nutritional, hormonal and developmental signals, to provide the successive needs of the growing metamorphosing, migrating and reproducing insect. Kilby (1963) has emphasised its conduit of intermediary metabolism in a review of biochemistry of the insect fat body and has similarised it with mammalian liver, since both the tissues store excess nutrients, detoxify foreign chemicals and serve as the biosynthetic source for circulating metabolites. One of the first studies showing the importance of the fat body in intermediary metabolism was undertaken by Wigglesworth (1942b) on the fat body of mosquito. The rapid increase in the knowledge of this area depended on the application of histological and histochemical techniques, electrophoretic and immunological techniques and an improved understanding of insect endocrinology and cell biology.
It is now known that the fat body function for metabolism of carbohydrates, lipids and nitrogenous compounds, the synthesis and regulation of blood sugar, storage of glycogen, fat and protein and synthesis of the major blood proteins. However, the exact role of this tissue in metabolism is not very clear. According to Pemrick and Butz (1970) there are three possibilities for intermediary metabolism by the fat body, one of which is that it responds to changes in the nutritional and hormonal environment which regulates the balance between synthesis, release and sequestration specially of proteins. The synthesis of blood proteins in some insects has been shown by Hill (1962) and Thomsen and Möller (1963). It is postulated that these proteins may be used in developing oocytes during vitellogenesis (Telfer 1961, '65; Highnam et al., 1963; Prabhu et al., 1967; Mellius and Telfer, 1969; Laughton, 1969) and are synthesized in the fat body (Lauffer 1960; Shigmatsu 1960; Coles 1965; Hill 1965; Price and Bosman 1966; Wyss-Huber and Lüscher 1967; Bodnaryk and Morrison 1968; Pan et al., 1969; Brookes 1969; Dutkowski and Cymborowski 1971; Highnam, 1975; Wyatt and Pan 1973, 1980; Sahai and Banerjee 1984).

In recent years information on the endocrine systems of several insects has established more than one fact which has a direct bearing on oogenesis and folliculogenesis in adult females. This may be extended to the fat body metabolism. In pterygote insects the thoracic glands
disappear during or soon after the last moult, consequently, of the organised endocrine system only the cerebral neurosecretory cells and corpora allata remain as possible sources of hormones, controlling the reproductive development which is a very closely associated process with that of the fat body metabolism. The corpora cardiaca, the fourth major component (the other three mentioned above) of the neuroendocrine system, produce their own intrinsic hormones but their major function in most insects is to store and release neurosecretory hormones from the brain i.e. to act as major neurohaemal organs.

As the central tissue for intermediary metabolism, the fat body is thus the focus attention for all the endocrine controls. Insect hormones are usually viewed from the aspect of their morphogenetic effects. However, it is increasingly apparent that like other highly integrated and complex animals, insects (male) also have a variety of hormones that influence intermediary metabolism. Metabolic activity includes both basal metabolism and metabolism related to special physiological functions (Keeley 1978). Both types of metabolism may be influenced by hormones. Studies with *Nauphoeta cinerea* have shown that corpora allata influences fat body metabolism (Luscher 1968). Decapitation of this cockroach has indicated arrest of oocyte growth and reduced fat body respiration and protein synthesis. Implantation of corpus allatum restores oocyte growth, respiratory activity and protein synthesis in this
insect. Similar effects were also shown in male Nauphaeta cinera indicating the regulatory activity of the glands independent of the ovaries.

Relationship between hormones and fat body have been worked out and discussed by Kilby (1963, '65); Steele (1965, '76, '80); Price (1973); Goldsworthy and Mordue (1974); Engelmann (1974); Wyatt (1974); Highnam and Hill (1976); Banerjee (1977, '79); Keeley (1978) etc. Numerous studies have been carried out on the effects of corpus allatum and also the neurosecretory cells and corpora cardiaca on fat body metabolism. The most significant perhaps, have been studies by (Pfeiffer 1945); Hill (1962, '65); Bowers and Friedmann (1963); Steele (1963); Orr (1964); Slama (1964); Gilbert (1964); Luscher and Leuthold (1965); Wiens and Gilbert (1965, '67); Gilbert (1965, '67); Odhiambo (1966); Keeley (1967); Müllcr and Engelmann (1968); Osborne et al. (1968); Dutkowski and Cimborowski (1971); Walker and Bailey (1971); Banerjee (1977, '78, '79); Couble (1979); Nair, Chen and Wyatt (1981) etc. The studies on neuroendocrine effects have shown regulation of the capacity for fat body protein synthesis, release of diglycerides from the fat body i.e. for lipid metabolism etc.

Neuroendocrine regulation with special reference to protein synthesis by the fat body has been studied by Bodenstein (1957); Hill (1962, '65); Thomsen and Møller (1963); Orr (1964); Coles (1964, '65); Locke and Collins
(1965); Minks (1965, '67, '70); Engelmann (1965); Engelmann and Penney (1966); Osborne (1968); Scheurer and Lüscher (1968); Scheurer (1969); Collins (1974); Highnam and Hill (1976). However the protein synthesis processes with oocyte maturation are not in all insects dependent on an active pars-intercerebralis-cardiaca system (Highnam 1964). In *Rhodnius* normal oocyte maturation occurs in brainless animals as shown by Wigglesworth (1936, 1966) and the corpora allata stimulates RNA synthesis (Vanderberg 1963a, b) and the synthesis of at least two haemolymph proteins (Coles 1964, '65). In *Rhodnius* and *Nauphoeta* as mentioned before, protein synthesis appears to be under the control of the corpus allatum alone.

Thus it seems that the synthesis of haemolymph proteins is controlling by different hormones in different insects. However, sometimes the results of different authors on a single species are also conflicting e.g. according to Engelmann and Penney (1966). The synthesis of at least two haemolymph proteins in *Leucophaea maderae* is stimulated by corpus allatum hormone but no such stimulation could be demonstrated in the fat body in vitro. Which clearly responds with increased protein synthesis and release to corpora cardiaca (Wyss-Huber and Lüscher, 1967; Lüscher *et al.*, 1969). The seemingly opposed results can be brought into agreement if it is assumed that each hormone stimulates the synthesis of specific proteins (Luscher 1968).
The fat body of the insects also plays an important role in carbohydrate and lipid metabolism, comparable to liver and adipose tissue in mammals. Since the pioneering work of Wigglesworth (1942b) on the fat body of mosquito a number of hormones have been found to alter the level of glycogen and lipid in fat body. The source of such hormones controlling glycogen and lipid metabolism are mainly the corpora cardiaca (Steele, 1980) which have received very little attention until recently (Müller and Engelmann 1968; Jones et al., 1977). The periodic shedding of the cuticle and its replacement in the course of development has probably received more intensive study than any other aspect of insect life (Steele 1980). These events are of considerable importance in carbohydrate metabolism because chitin is the major component of cuticle. However the carbohydrate reserves of the fat body are not restricted to a role in cuticle formation as also mentioned by Wyatt (1980) but are also major source of energy for flight and other purposes like development of gonads in both sexes (Banerjee 1977, '81, '83; Sahai and Banerjee 1984), as a precursor for trehalose and other metabolites (Wyatt 1980) etc. Obviously the synthesis and transport of this metabolite requires a sophisticated set of controls. Thus, as Steele (1980) has stated, "hormones profoundly influence carbohydrate metabolism is therefore hardly surprising". The corpora cardiaca of the neuroendocrine system produces the two main hormones associated with the carbohydrate and lipid metabolism
of the fat body, i.e. trehalogen and adipokinetic hormone respectively. Nevertheless, the most important function of corpora cardiaca as mentioned already, is to act as the major neurohaemal organ, storing the neurosecretory hormones.

In most insects, glycogen is an abundant reserve carbohydrate, and the one which remains in tissues after fixation and dehydration of tissue as in other animals. Large amounts of glycogen are found in the fat body in which it accumulates especially just prior to metamorphosis (Wyatt 1967). Studies with special reference to endocrine effects on carbohydrate metabolism in insects have been performed by Steele (1961, '63, '64); Bowers and Friedman (1963); Van Haendel (1965); Odhiambo (1966); Friedman (1967); Goldsworthy (1969, '70); Shepard and Keeley (1972) etc. as reviewed by Keeley (1978) and critically examined by Steele (1980). However according to Goldsworthy (1969) glycogen degradation in the Locust fat body is insensitive to hormonal stimulation at most adult stages.

Endocrine control of lipid metabolism in insects has been studied by Pfeiffer (1945); Thomsen (1952); Orr (1964); Vroman and Kaplanis (1965); Mayer and Candy (1969); El-Ibrashy and Boeter (1970); Walker and Bailey (1971); Gilbert (1971); Downer (1972); Goldsworthy et al. (1972); Downer and Steele (1972); Goldsworthy and Coupland (1974); Spencer and Candy (1976); Highnam (1977); Goldsworthy et al. (1977); Dalhman and Herman (1978); Steele (1980) etc.
The relationship between the corpora allata and fat body lipids is one of oldest recognised endocrine effects on fat body metabolism. Pfeiffer (1945) posed an important problem concerning the metabolic effects of the corpora allata hormone when he demonstrated that allatectomy of Melanoplus leads to massive accumulation of lipids and glycogen in the fat body. A number of later studies confirmed that allatectomy caused lipid accumulation and fat body hypertrophy in many species of adult insects (Thomson 1952; Bodenstein 1953; Orr 1964; Vroman and Kaplanis 1965; Minks 1967; Banerjee 1969; Banerjee and Sahai 1983). The fat body lipids are normally mobilised and deposited in the developing oocytes or yolk material. However, the means by which the corpora allata affect the production and the transfer of the lipids from the fat body to the ovaries still remains unknown. One possibility is that corpora allata directly regulates lipid metabolism and allatectomy causes an imbalance in the synthesis and release (Pfeiffer 1945; Orr 1964a, b; Vroman and Kaplanis 1965).

Alternatively, the corpora allata increases the permeability of the ovaries to haemolymph metabolites. In the absence of the corpora allata, therefore, the ovaries do not sequester the metabolites which accumulate in the fat body (Highnam 1964; Highnam et al., 1967; Dailey and Huebner 1974; Kambsells 1974; Keeley and Davenport 1976; Banerjee 1977). Thus, this problem has not yet been satisfactorily settled and needs further investigations.
It is now well known that the dipterous fat body is also capable of extensive metabolic activity involving the synthesis and degradation of carbohydrates, lipids, proteins and nucleic acids. In this order of insects the adult fat body continues from pupal fat body which is formed from the larval fat body. During the 3rd larval instar of Drosophila (Butterworth et al., 1965) and Sarcophaga (Benson 1965) deposition of protein granules occurs within the cells of the fat body. Transplantation experiments by Butterworth et al. (1965) and Butterworth and Bodenstein (1967) have shown that this process is under the control of a secretion from the larval ring gland. These experiments as well as the work by Neufeld et al. (1968) and Arking and Shaya (1969) have shown that in Calliphora and Drosophila. Certain aspects of protein metabolism are under hormonal control. These two along with other dipterans possess similar patterns of RNA and DNA metabolism according to a comparative data drawn by Church and Robertson (1966). However there is a conflicting evidence on the control of uptake and storage of proteins by the fat body cells of larvae and pharate pupae by the hormonal milieu prevailing at the time of pupal development (Butterworth and Bodenstein 1967; Thomassen and Mitchell 1972; Collins 1974). In calpodes (Collins 1974) cells of larval fat body do not initiate storage of blood proteins except in the hormonal milieu appropriate for pupation.
During the larval pupal transformation of holometabolous insects, the fat body diminishes in internal metabolism and protein synthesis and changes to function chiefly in storing material for adult development. The mitochondria and endoplasmic reticulum degenerate and the cytoplasm become loaded with various types of storage organelles (Price 1973; Thomson 1975). The change in function of fat body cells has been shown by the fluctuations in storage proteins, 1 and 2 in Hyalophora cecropia (Tojo et al., 1978) and Bombyx mori (Nagata and Kobayshi 1980). The two processes in the fat body, the synthesis and uptake of the storage proteins, may be hormonally controlled for the latter process the sequestration and the formation of intracellular storage granules according to Riddiford and Truman (1973); Truman (1974); Dean (1978) etc. who suggest that these may be induced by ecdysteroids. Metamorphosis in holometabolous insects provides unique opportunities for studies of the action of the moulting hormone at the cellular level. The storage proteins are synthesised in the life cycle of each holometabolous species only during a limited period of the last larval instar. Regulation by changing endocrine balance seems possible but the available evidence does not present a consistent picture (Wyatt 1980). In Calliphora the synthesis of calliphorin and other haemolymph proteins is inhibited by ecdysterone added to cultured larval fat body while juvenile hormone has no effect (Pan et al., 1969). In Bombyx on the other hand the
synthesis of storage proteins is repressed by juvenile hormone (Tojo et al., 1980b). The resorption of proteins and deposition in granules both in *C. pipodes* and in *Drosophila* are stimulated by ecdysterone although not entirely dependent on this hormone (Collins 1974; Butterworth et al., 1979). Similarly in *Drosophila* (Bowers 1982) 20-hydroxyecdysone stimulates synthesis of yolk-polypeptides, even in the male fat body although the female fat body can produce these metabolites without the requirement for added hormone. Almost the same results have been shown by Stoppie et al. (1981) for *Sarcophaga bullata* using ecdysterone. On the other hand, the uptake of haemolymph proteins by the ovaries is stimulated by juvenile hormone as shown *in vivo* by Kambysellis (1974). The synthesis of fat body lipids in dipterans is suppressed by active juvenile hormone (Keeley 1978) which is of course true for fat body of other insects too as mentioned earlier. The hormonal control of fat body metabolism, specially synthesis of vitellogenic proteins is being debated (Raikhel and Lea 1983). In dipterans like mosquitoes the neuroendocrine control of fat body metabolism is thus quite conflicting as mentioned above and needs explorations. It is unclear as yet whether the sex and age of the insect also affect all the processes mentioned above. Studies on endocrine regulation of fat body metabolism of male insects have been quite scanty until recently. The previous significant work done on male insect fat body have been those by Odhiambo (1966); Walker and Bailey (1970, '71);
Banerjee (1977, '81 a,b,c, '83); Stoppie et al. (1981); Irvine and Brasch (1981); Nair et al. (1981) and Bowers (1982), so far as the author is aware. Before this, Gilbert and Schneiderman (1961) showed that allatotomy of adult male insects resulted in hypertrophy of fat body due to accumulation of lipids. This was later confirmed by Odhiambo (1966), Strong (1968a, b) and Banerjee (1977, '81c) who showed accumulation also of glycogen. The fat body cells of males are never as specialized for protein synthesis as those of the females and they never produce vitellogenins even in the correct endocrine milieu (Keeley 1978). The assumptions that there must be a feedback mechanism through the ovaries (and also testes as mentioned by Banerjee 1977a, b, 1979, 1981c) to the neurosecretory cells and corpora allata in the control of fat body metabolism can be tested by studying endocrine control of fat body metabolism in male insects i.e. in the absence of the ovarian factors.

**Significance of the work envisaged:**

The insect fat body is an organ of exceptional interest for differentiated cell function and as a central tissue for intermediary metabolism, it must be the focus attention for the endocrine controls.

From the review of literature as given above, the author deduced that

(i) The fat body protein granules, their formation,
functional significance and regulation bear on the question of protein conservation in insects, thus they warrant further investigations. Furthermore, the exact nature of the effects of juvenile hormone (JH) on fat body as well as the role of eddysone in causing storage of proteins remains unclear. The question of endocrine regulation of protein granule formation is again complicated by the situation found in adult insects as described by Keeley (1978). The same problem remains in holometabolous insects as well.

(ii) The control of carbohydrate and lipid deposition in an release from the fat body is little studied and needs explorations.

(iii) Metamorphosis in holometabolous insects provides unique opportunity for studies of the action of the moulting hormone at the cellular level, particularly when it is also known that in dipterans, control of fat body metabolism is quite conflicting (as concluded from the review of the literature).

(iv) It is still unclear whether the age and sex of insects affect the endocrine regulations in the insect fat body since studies on endocrine control of fat body metabolism of males have been quite scanty.

(v) Corpora cardiaca (CC) exerts differential effects in different insects as described above. This must be due to different physiological differences between them, and the effect of CC could be further explored in some other insects.
Considering all the above and then the research facilities available to the author, she has focussed mainly on describing the fat body metabolism in some insects under various endocrine environments introduced experimentally in chemical terms, using simple histochemical techniques for nucleic acids, proteins, glycogen and lipids. The histochemistry of the pathological conditions of the fat body resulting from various experiments in relation to the normal conditions have been thus explored. The effect of induced experimental environments of the neuroendocrine system on the growth of the fat body i.e. changes in sizes of cells, nuclei and nucleoli were also studied.

It was proposed to study insects from two diverse groups (hemimetabolous and holometabolous) to arrive at a better understanding of the results. Moreover, two types of fat bodies in fact were studied, the adult fat body from the first group and the larval from the second, and different types of experiments designed to come to the conclusions of the role played by the neuroendocrine system.

The experiments in the adult fat body were also performed with the male insects in order to test the control mechanisms in the absence of ovarian environment.
since the ovaries have widely been accepted to serve as rendering some feedback between the endocrine organs and the fat body of insects.