Chapter 1

Introductory Chapter: Lepidoptera

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Additional information is available at the end of the chapter

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1. Lepidoptera

The word Lepidoptera comes from the Latin word, equivalent to lepido- and from the ancient Greek words lepis and pteron mean scales and wings, respectively. Therefore, it stands for insects with scaly wings. It is the second largest, diverse, widespread, and widely recognized insect's order in the class Insecta of phylum Arthropoda. Linnaeus (1707–1778) divides it into three groups: (1) butterflies, (2) skippers, and (3) micro- and macro-moths. It consists of 126 families and 46 superfamilies (**Table 1**). They can be differentiated on morphological, anatomical, behavioral, and ecological characteristics [1]. Further, 500,250 species of Lepidoptera are described, with 70,820 species of butterflies [2, 3] and 3700 species of skippers globally [4–6]. Furthermore, about 165,000 species of moths, including micro- and macro-moths, are found up to now [6–9]. In nature, Lepidoptera regard as the symbol of beauty and grace. They are very beautiful creatures of nature (**Figure 1A**) [10–12].

1.1. Morphology

The group Rhopalocera is related to butterflies and skippers; however, Heterocera is to micro- and macro-moths. The Lepidoptera show a great diversity in forms, size, structure, and other distinctiveness (**Figure 1A** and **B**) [13, 14].

1.1.1. Head segment

Lepidoptera's head capsule is the feeding and sensory center. It is small, round, or elliptical and sclerotizes organization. The upper-middle portion of the head is called the frons; below is the clypeus, and below it is the labrum, to both sides of which the edges of the mandibles with different aspects of the maxillary palps may expand beyond and/or underneath, even when view them from front [15]. As a whole, the shape and size of the head capsule, color patterns, and location of hairs on the head are supportive in identifying species of caterpillars with aid of a microscope (**Figure 1C**).

Kingdom: Animalia
Subkingdom: Invertebrata
Super-division: Eumetazoa
Division: Bilateria
Subdivision: Ecdysozoa
Superphylum: Tactopoda
Phylum: Arthropoda von Siebold, 1848
Subphylum: Atelocerata
Superclass: Hexapoda
Class: Insecta
Infraclass: Neoptera
Subclass: Pterygota
Superorder: Endopterygota
Unranked: Amphiesmenoptera
Unranked: Holometabola
Order: Lepidoptera Linnaeus, 1758
Examples:

- Butterflies
- Skippers
- Micro-moths
- Macro-moths

Table 1. The taxonomic position of the order Lepidoptera [13].

1.1.1.1. Mouthparts

The siphoning-type mouthparts are found in the imago. They are transformed into a long flexible hollow structure, in which the formation of the suctorial proboscis encompasses a fluid-tight food tube. Lepidoptera feed on nectar, and their proboscis length may increase almost 100-folds. Usually, when they do not use them, they keep coil under the head with the help of small muscles present there. In all Lepidoptera, the basic structure of mouthparts is the same, which include each one labium, labrum, hypopharynx, or tongue with pairs of mandibles and maxillae (**Figure 1C**) [16, 17].

1.1.1.2. Antennae

The antennae show a wide variation in forms, size, structure, and other characteristics among species and even between different sexes. The basic structure of antennae of Lepidoptera is usually filiform, which is altered into the capitates of antenna, which are club shaped with a long shaft and a bulb at the end. In the skippers, most of the antennae's tips are changed

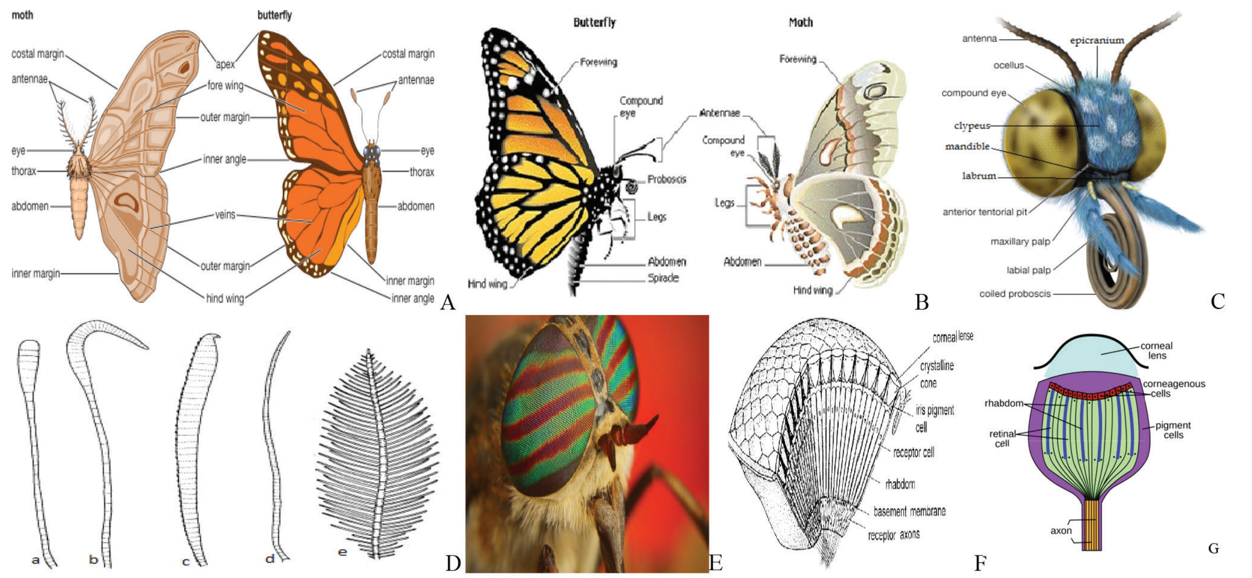

Figure 1. Parts of Lepidoptera body: (A and B) butterfly and moth; (C) generalize mouth parts; (D) generalize antennae of order Lepidoptera: butterflies; (a) skippers; (b) micro- and macro- moths (c, d, e) [18, 19]; (E) compound eye of Lepidoptera; (F) unit and basic structure, ommatidium of a compound eye, showing its construction; (G) simple eye or ocellus [22].

into a narrow hook-like projection. A moth's antennae are feathery or saw edged. They also act as the balancing organ. The shapes of antennae are assisting in identifying species of Lepidoptera (**Figure 1D**) [20].

1.1.1.3. Compound eyes

The eyes are usually paired, golden brown, or even red as in some skipper species. They built quite differently from the vertebrate eye, but like Arthropod, it is made up of repeating units up to 17,000, the ommatidia, each function as a separate visual receptor, which in combination provide a broad mosaic view of the image, such type of the eye is a compound eye. Each is connected to a lens, which is attached to a nerve leading to the brain (**Figure 1E** and **F**) [21].

1.1.1.4. Simple eyes or ocelli

In all Lepidoptera, in addition compound eyes, simple eyes, or ocelli (singular: ocellus; simple photoreceptors) are also present. They made with a single lens and several sensory cells. Only two ocelli are present in imago, excluding a few moths, one on each side of compound eyes. In some species, a type of sense organs, which called chaetosemata, is found near the ocelli. In caterpillars, three pairs of simple eyes are found, which are not homologous to ocelli of imago. Simple eyes of caterpillars are differently named as stemmata. Lepidoptera are able to perceive ultraviolet (UV) light and observe wing colors and patterns by ocelli (**Figure 1G**) [22].

1.1.2. Thorax

The thorax is the second part of the body, which composed of three jointed segments, the prothorax, mesothorax, and metathorax, each derives from a primitive segment. They are covered dorsally with tergites, ventrally with sternites, and laterally with pleurites (chitinous plates) [23]. The characteristic like the presence or absence and shape of sclerotized plates; location of primary setae; and location, color, and shape of the prothoracic spiracle assists in identification of caterpillar and imago species [24].

1.1.2.1. Jointed legs

Lepidoptera have three pairs of well-developed jointed legs. They are located in each segment of the thorax and covered with scales. Each leg consists of nine segments, that is, coxa, trochanter, femur, tibia; five tarsal segments with a pretarsus; and a pair of articulated curved claws on the fifth segment. Morphology of the legs also aids in identifying caterpillar and imago species (**Figure 2a** and **b**) [25]. The aroliar pad (a pad extending between the tarsal claws) and pulvillus (plural: pulvilli, pads beneath each tarsal claw) are short or absent in some families. The tibia of each leg contains a subgenual organ, which detects and amplifies small vibrations (**Figure 2a** and **b**) [26].

1.1.2.2. Wings

The mysterious flight of Lepidoptera depends on their wings, which accomplished several kinds of difficult tasks like diving, circling, parachuting, equilibrium, etc. all because of their lightness in nature. Their wings are subjected to considerable variations in shape, size, markings, spots, and vein patterns, thus reflecting their specific functional differences. Strong muscles in the thorax move the wings up and down in a digit 8 pattern during the flight. Both pairs of wings are covered with thousands of bright, colorful, and dull scales. Due to the presence of scales on the wings, the term for order Lepidoptera has been coined (**Figure 2f** and **g**). Wing scales adapt

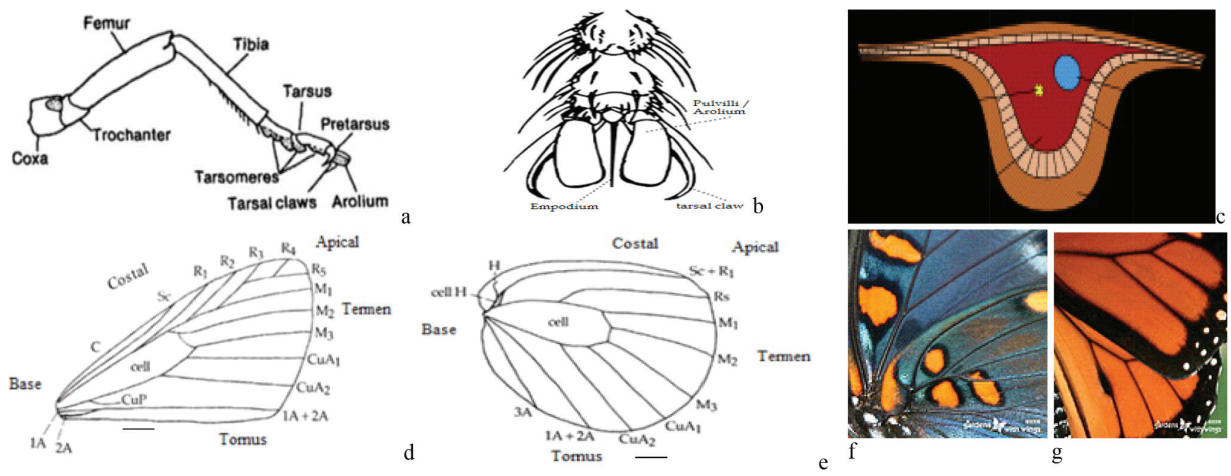

Figure 2. (a) Generalize structure of Lepidoptera Leg; (b) generalize structure of tarsus; (c) TS of vein from wing generalized wings venation: (d) forewing; (e) hindwing; with names of different veins with their abbreviations are: C: Costal; Sc: subcostal vein; R1: 1st radius vein; R2: 2nd radius vein; R3: 3rd radius vein; R4: 4th radius vein; R5: 5th radius vein; M1: 1st median vein; M2: 2nd median vein; M3: 3rd median vein; Cu1: 1st cubitus vein; CuA1: 1st cubitus anterior; CuP2: 2nd cubitus posterior; 1A: 1st anal vein; 2A: 2nd anal vein; 3A: 3rd anal vein; H: humeral 2012; bars in photographs indicate 30 mm; (f) wing color of black and white; (g) wing of a male the monarch butterfly, *Danaus plexippus* (Linnaeus, 1758) (Nymphalidae: Nymphalinae) [23–26].

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to different environmental conditions affecting flights. They are also found to influence by the time factor, which affects speed, foraging, calling, finding places for spawning, avoiding predators, etc. Wing pattern is successful in establishing the correlation in adaptation and adaptive change. Both changes in morphology of wings and the pattern of flight are closely associated with the genetic material. Similarly, the relationship has been established between wing venation and wing pattern in the genus *Micropterix* Hubner, 1825 (Family: Micropterigidae). Such type of studies plays a major role in understanding its evolutionary status and highlights its significance in taxonomical analysis. They are chitinous membranes, nourished and supported by tubular veins (**Figure 2c–e**). These veins also function in exchange of oxygen. Further, venation has aerodynamic importance, plays specific role in flight system, and adapts to different surroundings [26]. Bashar et al. [27] prepared pictorial key for identification of the local nymphalid butterflies of Bangladesh, based on the wing venation of the butterflies. It has also observed that venation is an important trait in Lepidoptera phylogenetic development [28].

1.1.3. Abdomen

The abdomen is third part of the body. It consists of 10–11 segments tapering to the end. Each segment provides membranes in between allowing for articulation and movement. In Lepidoptera systematic, they have been one of the most important sources of character information [20]. In some caterpillar, four pairs of prolegs normally located on the third to sixth segments, and a separate pair of prolegs by the anus, which has a pair of tiny hooks called crotchets, helps in gripping and walking [29].

1.1.4. Scales

The name of this order Lepidoptera is due to the presence of the scales. The head, thorax, abdomen, wings, and legs are covered with minute scales, are lamellar or blade-like, and are attached with a pedicel, while other forms may be hair-like or specialized as the secondary sexual characteristics. Either, they give color, by color pigments they contain or through structural coloration with mechanism that include photonic crystal and diffraction grating. They are functioned as aiding gliding flight, insulation, producing pheromone, thermoregulation, etc. The most important is the large diversity of their bright or indistinguishable pattern, which aids the organisms to protect itself by camouflage or mimicry including rival and potential mate (**Figure 2f** and **g**) [4].

1.1.5. Sound-producing organs

The sounds of some Lepidoptera are clearly audible, for example, members of Sphingidae and Pyralidae. Many moths have developed ears on their wings or thorax, which are called as tympanal organ, which can make them aware of thread, predator, etc. The Neotropical tiger moth, *Bertholdia trigona* (Grote, 1879) (Noctuoidea: Erebidae), actively makes out of function of the bat radar by creating its own ultrasound and by vibrating its tympanum present on its metathorax. Males of the moth, *Symmoracma minoralis* (Snellen) (Pyralidae: Nymphulinae), produce a high-intensity calling song from tymbals like structure found in the genital segment [30–32].

1.2. Endocrine control

In Lepidoptera, the growth and metamorphosis are under control by interacting sets of hormones. Ecdysis is initiated by ecdysiotropin, or prothoracicotropic hormone (PTTH) or brain hormone (BH) is secreted by protocerebrum which acts on ecdysial glands. Eclosion hormone is secreted by brain median neurosecretory cells; it is stored in the corpora cardiac and is released into the hemolymph during switchover from pupa to imago. Within the abdominal ganglia, it acts on neurons to begin the pre-eclosion behavior. The corpora allata secret juvenile hormone (JH). It is liable to bring juvenile progress and variable species to species. The molting hormone (MT) or ecdysone hormone (EH) is secreted by the ecdysial gland. Distinctively, all hormones and neurohormones are involved in management of circadian rhythms, growth, development of the nervous system, diapause, mating, metabolism, oviposition, pheromone biosynthesis, regulation of dormancy, regulation of migratory behavior, and other physiological functions in the body. The EH is responsible for several activities of pupal-imago conversion, with respect to the behavior associated with ecdysis, following deterioration of abdominal intersegmental muscles. Ecdysis-triggering hormone which is the most newly discovered hormone shows a significant role in ecdysis. Bursicon (tanning hormone) is usually synthesized in neurohemal organs related with the ventral chain ganglia. Its functions are to stimulate sclerotization and tanning of the cuticle during the course of ecdysis (**Figure 3**) [33–36].

1.3. Polymorphism

Existence of the morphologically different individuals in the life cycle of the same species is termed as polymorphism. The sexual dimorphism is very common, in which male and female are structurally different and are found in families Pieridae, Nymphalidae, Papilionidae, and Psychidae. The other types are geographical, seasonal, genetic, and environmental polymorphism. In some species, the polymorphism is limited to one sex, typically the female [33–36].

1.4. Pheromones

They are biochemicals, meant of communication, secreted into the surroundings, and affect the activities or functioning in others species. Such communication systems have provided challenges to scientists in different disciplines including behavior, biochemistry, chemistry, ecology, genetics, and physiology. They produce in greater varieties. As a result, the great numbers of researches are conducted focusing on butterflies and moths. Pheromone systems are species specific for attracting mates. Sex pheromones are used for long-distance biochemical communication [37, 38].

1.5. Migration

Lepidoptera contribute an essential part as the environmental indicators. If any minute dangerous variations occur in the surroundings, they may affect acutely. Due to unfavorable environmental affects, they migrate rapidly in long distances, from locations to the area, which are more suitable for any part of the seasons. Their destination may be tropical and subtropical areas and all continents, excluding Antarctica. They stay away from undesirable

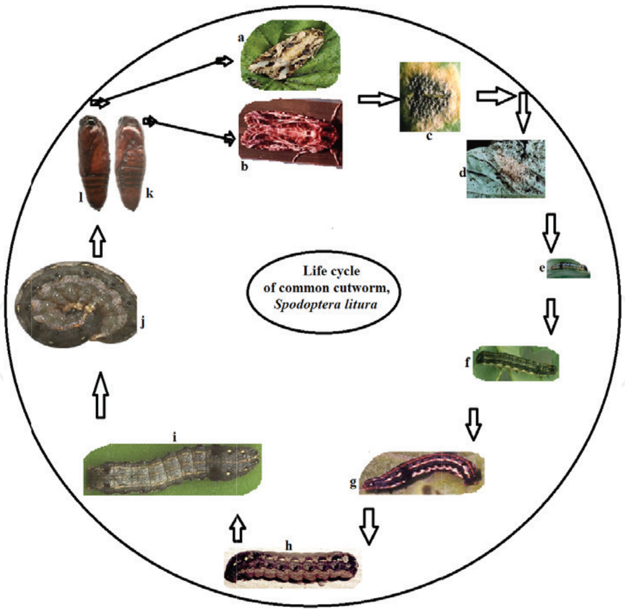

Figure 3. Life-cycle of Lepidoptera, the common cutworm, *Spodoptera litura* (Fabricius, 1775): (a) imago male; (b) imago female; (c) bunch of egg; (d) newly hatched 1st instar caterpillar; (e) 2nd instar caterpillar; (f) 3rd instar caterpillar; (g) 4th instar caterpillar; (h) 5th instar caterpillar; (i) 6th instar caterpillar; (j) defensive posture of 6th instar caterpillar; (k) female cocoon; (l) male cocoon [19].

circumstances, including adverse climate, food shortage, overpopulation, weather, etc. In some conditions, few members migrate, and in other conditions, all migrate [39–41].

1.6. Internal anatomy

1.6.1. Digestive system

In Lepidoptera, the foregut is started from the mouth; the pharynx may be highly modified into a pump. Posterior to it is the esophagus which opens into a crop or storage organ. Immediately, posterior to it is the proventriculus, a structure that contains sclerotized toothlike denticles, aiding in grinding the food. Some fluid-feeding Lepidoptera lack a proventriculus. The stomodael valve (foregut valve) regulates the flow of materials from the foregut-midgut. The former is lined with chitinous protective layer called the intima. It prohibits absorption of nutrients. In many Lepidoptera, the foregut valve has associated with gastric caeca that produce digestive enzymes and increase surface area. The intima is absent in the midgut, and most of the absorption of nutrients occurs here. The Malpighian tubules attach to the pylorus region of the hindgut. Posterior to them is the anterior intestine and the highly muscularized rectum that terminates in the anus. It functions in removing water from the fecal materials; therefore, Lepidoptera produce very dry excrements (**Figure 4**) [42–45].

1.6.2. Circulatory system

Lepidoptera have open circulatory system. The major portion of the hemolymph is found in open cavities. It bathes the organs within the body cavity, the hemocoel. Hemolymph enters

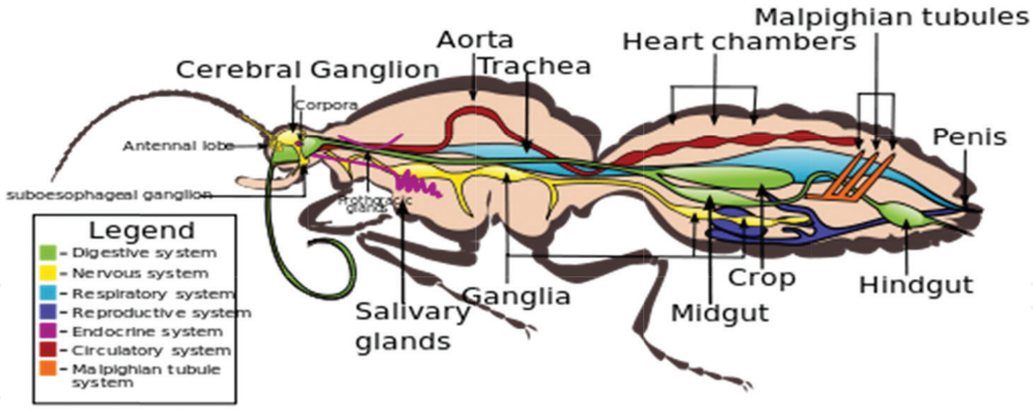

Figure 4. Internal anatomy of Lepidoptera viewing imago male (family: Nymphalidae), showing the most of the major organ systems, with characteristic reduced forelegs of that family and the corpora include the corpus allatum and the corpus cardiac [41].

the dorsal vessel or heart via small openings called the ostia. It is then pumped toward the head, where it then returns to the hemocoel. It serves as a lubricant for the movement of internal structures. It is a hydraulic medium for applying pressure for molting, eversible glands are extruded via pressure changes, and some muscular contraction is opposed by hydrostatic pressure within the hemocoel. Hemolymph transports various substances from one tissue to another (**Figure 4**) [42–45].

1.6.3. Respiratory or tracheal system

Tracheal system consists of a system of branching tubes (tracheae) and openings to the outside called spiracles. Atria spiracles have mechanisms that allow Lepidoptera to close the opening. It prevents water loss and prevents the entry of pathogens and parasites. Tubes begin rather large and branch to become successively smaller and smaller as they penetrate deep within the tissues of the insect. The smallest branches of the tracheae are the tracheoles, and gaseous exchange occurs here. Air sacs have many potential functions, all rather speculative, including increasing the volume of air in the body for exchange, lowering the specific gravity for flight, and providing room for the growth of internal organs. Usually, the first pair of spiracles is found on the mesothorax. Lepidoptera may control the flow by opening and closing the spiracles (**Figure 4**) [42–45].

1.6.4. Excretory system

The function of the excretory system is to maintain chemical homeostasis. By this system, hemolymph is cleaned with metabolic wastes including nitrogenous waste products created during digestion of food. As well as toxins, concentration of salts, and water are also regulated in hemolymph by the same. Malpighian tubules and the hindgut comprise the excretory system. Malpighian tubules, attached to the gut, float freely within the hemocoel and are bathed in hemolymph. They vary in number from 2 to 250 or more. Their functions are removing toxins, nitrogenous wastes, and ions to maintain ionic concentrations within the hemolymph. Water and other small ions are removed from the gut by the rectum (**Figure 4**) [42–50].

1.6.5. Nervous system

In Lepidoptera, the central nervous system is composed of a double chain of ganglia joined by longitudinal connectives. The anterior ganglion is the brain. The brain connects to the ventral chain of ganglia via two connectives that travel around the pharynx. The brain connects to the eyes, ocelli, and antennae. The subesophageal ganglion is highly complex and innervates the sense organs and muscles associated with the mouthparts, salivary glands, and neck region. The subesophageal ganglion is the primary excitatory or inhibitory influence on motor activity of the whole Lepidoptera. The frontal ganglion connects the brain to the stomatogastric subsystem. The hypocerebral ganglion is associated with two endocrine glands one of which is the corpus allatum that produces JH. The thoracic ganglia contain the sensory and motor centers for their respective segments. More derived taxa show a reduction in the number of abdominal ganglia. In visceral nervous system, nerves associated with the brain, salivary glands, and foregut are the stomatogastric subsystem. The caudal visceral subsystem is associated with the posterior segments of the abdomen including the reproductive system. In peripheral nervous system, all of the nerves are with synapses to the central and the visceral nervous systems. These nerves are associated with sensory structures (**Figure 4**) [51–59].

1.6.6. Reproduction

The adult male Lepidoptera reproductive tract is composed of a pair of testes, vas deferens, accessory glands, ejaculatory duct, and aedeagus. In testes, sperm begin to mature during the third and fourth larval instars. These divisions take place during the larval and pupal stages. Sperm are matured through spermiogenesis. All butterflies and moths produce two kinds of sperm: eupyrene sperm have a nucleus and can fertilize eggs, while apyrene sperm do not have a nucleus, and they facilitate the eupyrene sperm. Matured sperm are transferred within a protein-rich ejaculate called a spermatophore. It forms within the male's aedeagus and is transferred with sperm at the very end of copulation into the bursa copulatrix of female which can take up to 16 hours. The adult female Lepidoptera reproductive tract is composed of the bursa copulatrix, sperm duct, spermatheca, ovaries with ovarioles, and common oviduct. The end of the ovarioles is called the germarium, where oocytes are produced from the original germ cells. This process begins during the larval stage and continues in imago. Oocytes are covered with chorion, which forms in the last stage of oogenesis. However, male genitals include a valva, which is usually large, as it is used to grasp the female during mating. In female genitalia, there are three basic arrangements of openings for copulation, fertilization, and egg-laying. Firstly, in exoporian, an external opening that carries sperm from the copulatory opening of gonopore to the ovipore is found in Hepialidae and its related families. Secondly, in monotrysian, a single genital aperture near the end of the abdomen through which both copulation and egg-laying occur is found in primitive groups. Thirdly, in ditrysian, an internal duct that carries sperm with two distinct openings each for copulation and egg-laying is found in all the remaining groups (98%). As the egg passes down the common oviduct, few sperm are released from the spermatheca [33, 46]. Fertilization occurs just before an egg is about to be laid. High levels of JH circulating in adult butterflies cause eggs to mature in females and cause the male reproductive tract to develop. Diapause Lepidoptera, which reach sexual maturity after the overwintering period, have low levels of JH in their hemolymph (**Figure 5a–c**) [60–67].

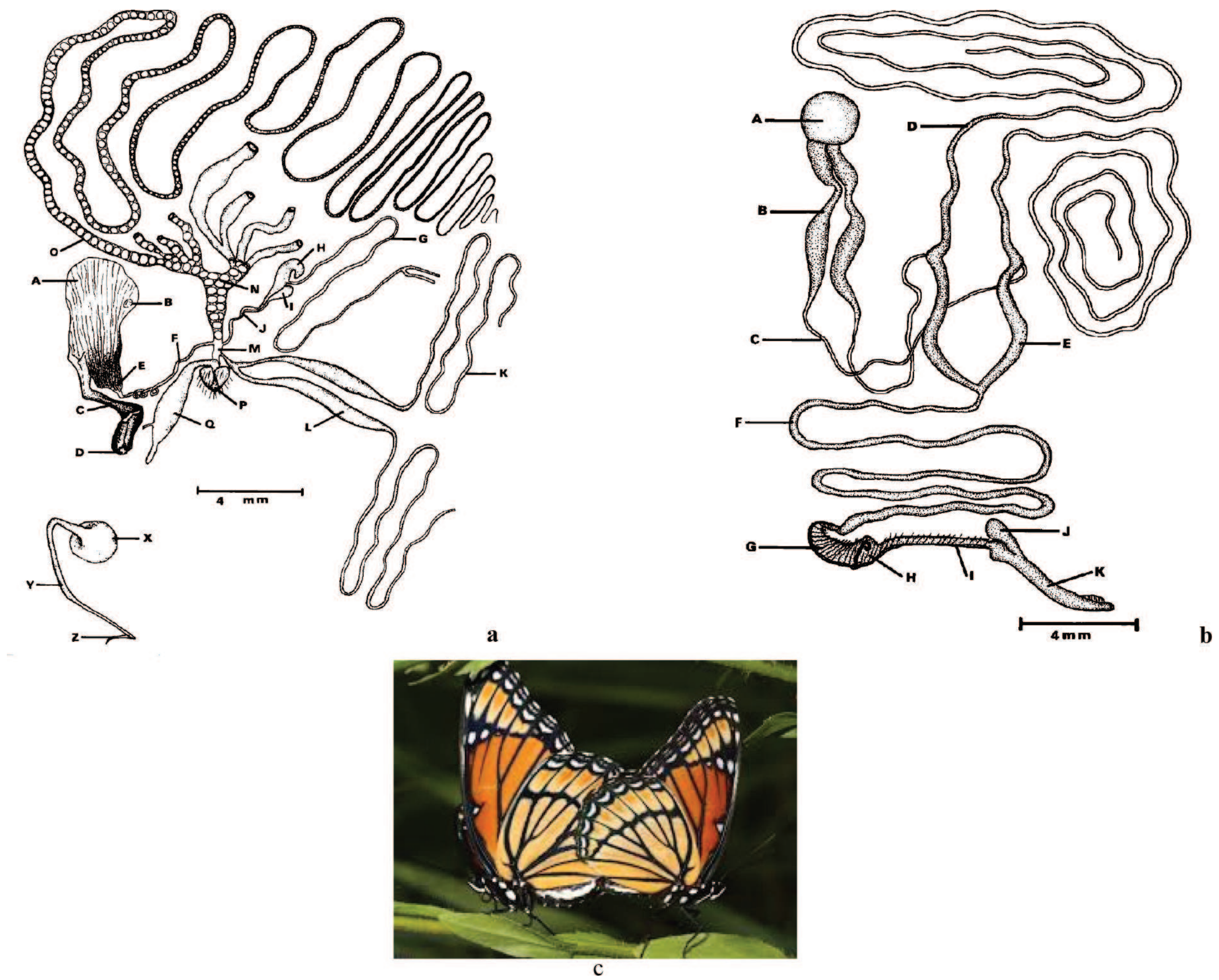

Figure 5. Anatomy of reproductive system of Lepidotera: (a) the female imago reproductive system: A: corpus bursae; B: signum, C: ductus bursae; D: ostium bursae; and E: diverticulum of bursa copulatrix; F: ductis seminalis; G: spermathecal gland; H: utriculus I: lagena of spermatheca; J: ductus receptaculi; K: accessory gland (paired); L: accessory gland reservoir (paired); M: vestibulum; N: calyx of the unpaired oviductus communis; O: one of four ovarioles of ovary (paired); P: papillae anales; Q: rectum; X: corpus, Y: collum, and Z: frenum of spermatophore; (b) the male imago reproductive system: A: testis; B: seminal vesicle (paired); C: vas deferens (paired); D: accessory glands (paired); E: ductus ejaculatorious duplex; F: primary segment of ductus ejaculatorious simplex; G: muascular area; H: area of frenum formation; and I: area of collum formation of the cuticular secondary segment of the ductus ejaculatorious simplex; J: caecum of aedeagus; K: aedeagus (After Etman and Hooper, 1979); (c) the mating pair of the the monarch butterfly, *Danaus plexippus* (Linnaeus, 1758) (Nymphalidae: Nymphalinae) [48, 49].

2. Lepidoptera as model taxon

Lepidoptera are ideal for to increase awareness toward environmental issues and educational purposes. They produce a more positive perspective of the invertebrates to the public, mostly due to their esthetic value. As Lepidoptera are the most well-known insects, they have become flagship organisms for the divulgation of invertebrate conservation plans. Their ecological significance is massive, not only because of the greatest percentage of species and biomass they account for in ecosystems, although they act as herbivores, pollinators, and food for insectivores. For researchers, scientists, and students, they offer a model taxon for precious to cram of biodiversity, conservation studies, environmental impact estimates, monitoring of animal populations, ecology, ethnology, evolution, genetics, systematic, and many other ecological and genetic studies. They open doors to establishment of chemical ecology as a scientific discipline for study and research.

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