Chapter

Introductory Chapter: Diptera

Farzana Perveen and Anzela Khan

1. Introduction

Diptera is an order of single pair winged insects commonly known as flies/ true flies. The 2nd pair of wings are modified into halteres. They are mostly small to medium-size. Biologically, it is very vast order with greatly diversified insects. Many have co-evolved in association with plants and animals and most successful groups of organisms on this universe (**Figure 1**; **Table 1**) [2].

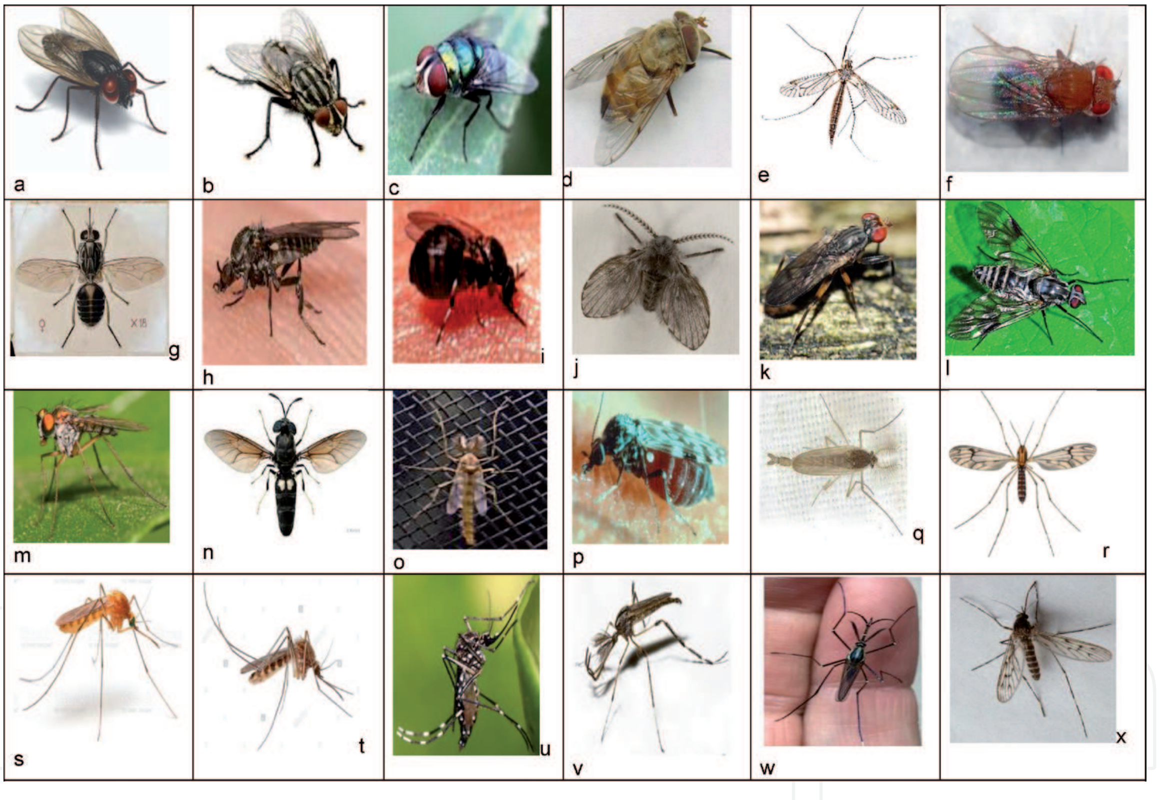

Figure 1.
Members of order Diptera: **Flies:** *a):* Housefly, Musca domestica *(Muscidae); b): Flesh fly,* Sarcophga carnaria *(Sarcophagidae); c): Blowfly,* Chrysomya megacephala *(Calliphoridae); d): Horse-fly,* Tabanus bovinus *(Tabanidae); e): Crane-flies,* Tipula oleracea *(Tiulidae); f): Fruit-fly,* D. melanogaster *(Drosophilidae); g): Tsetse-fly,* Glossina gambiensis *(Glossinidae);* **tinny-flies:** *h): Sand-fly,* Austrosimulium australense *(Simuliidae); i): Black-fly,* Parasimulium furcatum *(Simuliidae); j): Moth-fly,* Clogmia albipunctata *(Psychodidae); k): Marsh-flies,* Pherbellia annulipes *(Sciomyzidae); l): Watersnipe-fly,* Ibisia marginata *(Athericidae); m): Aquatic long-legged-fly,* Chrysosoma adoptatum *(Dolichopodidae); n): Soldier-fly,* Hermetia illucens *(Stratiomyidae);* **midges:** *o): Non-biting midge,* Chironomus *(Chironomidae); p): Biting midge,* Culicoides sonorensis *(Ceratopogonidae); q): Phantom-midge,* C. punctipennis *(Chaoboridae); r): Dixid midge,* Dixa nebulosa *(Dixidae);* **mosquitoes:** *Mucidae): s): African malaria mosquito,* A. gambiae*; t): Common-house-mosquito,* C. pipiens*; u): Yellow-fever-mosquito,* A. aegypti*; v): Shaggy-legged-gallinipper,* Psorophora ciliate*; w): Elephant mosquito,* Toxorhynchites rutilus*; x): Banded-house-mosquito,* C. annulata *[1].*

Domains: **Eukaryota**
Super-kingdom: **Opisthokonta**
Kingdom: **Animalia** Linnaeus, 1758
Sub-kingdom: **Invertebrata**
Clade 1: **Metazoa** Haeckel, 1874
Super-Division: **Eumetazoa**
Division: **Bilateria**
Sister-clade: **Protostomia**
Sub-division: **Ecdysozoa**
Super-phylum: **Tactopoda**
Group: **Panarthropoda**
Phylum: **Arthropoda** Von Siebold, 1848
Clade 2: **Mandibulata**
Sub-phylum: **Atelocerata**
Super-class: **Hexapoda**
Class: **Insecta**
Infra-class: **Neoptera**
Sub-class: **Pterygota**
Unranked: **Endopterygota**
Ranked: **Holometabolous**
Super-order: **Panorpida**
Order: **Diptera** Linnaeus, 1758

Table 1.
Taxonomic position of order: Diptera [1].

2. History of Diptera

First true dipterans were found in middle Triassic, and widely spread during middle and late Triassic [3]. The basal clades in Diptera include Deuterophlebiid and mysterious Nymphomyiid [1]. Based on fossil record, 3 episodes of evolutionary radiation are thought to have happened. Numerous novel kinds of subordinate Diptera established in the Triassic, nearby 220 million years back. Several inferior Brachycera seemed about 180 million ages back in Jurassic. A 3rd radiation acquired mid Schizophora at commence of Paleogene, 66 million years past [4].

3. Classification

About 150,000 species are described in 150 families (**Figure 1**; **Table 1**) [2].

4. Morphology

4.1 Head segment

Head is distinct from thorax, with a marked narrowing at neck. The suture separates 2 regions, upper one is the frontal region, which has continuity with apex, orbital region and gena; lower one, the clypeus, contains the insertion of the antennae and ends with epitomal edge, which comprises the upper lip [3]. They have filiform, stylate or aristate antennae. All fly antennae consist of 3 parts: scape, pedicel, and flagellum [2]. They have prominent compound eyes on a mobile head. They grow to occupy most of the side of the head. The morphology of the compound eye is characterized by a significant number of ommatidia. The ocelli, when present are located in the top of the head, arranged at the corners of a triangle in an area called stemmaticum or ocellar triangle [2].

4.2 Mouthparts

They are adapted and joint into a sucking proboscis, which is extremely different in construction. The inherited state was the piercing and sucking sort of proboscis. There are more improved proboscis arrangements multifariously rasp or sponge fluids. The labellum is modified into sponge structure. Non-functional adult mouthparts are also found in several Diptera. In some species the mouthparts of the females are adapted for piercing the skin of hosts and feed on blood as ectoparasites [2].

4.3 Thoracic characteristics

Thorax is 2nd morphological region of the body in Diptera and it bears the locomotion organs, represented by 3 pairs of legs. In all Insects, it is composed by morphological and structural organization of the first 3 post-cephalic segments, named pro-, meso-, and metathorax, in order antero-posterior [2].

4.4 Wings: flying organs

They have one pair of functional and membranous wings are attached to the complex mesothorax [2]. Flies are capable of great maneuverability during flight due to the presence of 2nd pair of wings on the metathorax, are reduced to halteres. They provide fast response to the wing-steering tissues, therefore, they function as a balancing and controlling organs for the body. Flies are without of the halteres are not able to fly. The wings and halteres move simultaneously but the strength of individual wing strike is self-regulating, permitting the fly to try slanted [5]. The wings of the fly are connected with 2 types of fibrous tissues (FT), one is used to supply them with mechanical or electrical energy and second is used for well regulator [6]. Flies have an ability to fly in an upright direction, however, they rapidly diverge in different straight-line paths. Particularly, the change of directions encompasses a slant of 90° and accomplish within 50 milliseconds, it is known as saccades. They originate by optical impulse as the fly perceives an item, nerves then activate FT in the thorax that responsible a minor change in wing stroke, which produce enough rotation. It can be detected within 4–5 wing-beats; therefore, the halteres trigger a counter-turn and the fly heads off in a new direction [7].

4.5 Abdominal characteristics

The abdomen is 3rd part of the body of Diptera. It composed of 11 abdominal segments, called urites, the newest of which are compact and distinguished with sexual structures. A sole urite seems as a circle with dorsal sclerite, named as tergite or tergum. However, a ventral one, termed as sternite or sternum. They are connected by a pleural membrane. Each urite is connected to adjoin by an inter-segmental membrane. Morphology of the abdomen is substantially determined by morpho-anatomic adaptation, in both sexes, as a function of the reproduction. In feminine, the primordial urites grow delicately and elastically, they form a capricious enlarging ovipositor. This structural transformation frequently follows by sclerotization of 8th (last) urite, therefore, the ovipositor enters through the tissues of the host-organism, to house the eggs and larvae. In masculine, the same passes a complicated alteration to make an organ, united with genitalia titled the hypopygium [2].

4.6 Locomotion

Diptera have 3 pairs of legs, one pair on each of 3 segments of the thorax and are generally called the fore, mid-, and hind-legs. Diptera larva is apodous (without legs), but sometimes, especially in aquatic larva has appendages similar to pseudopodia. If fly is walking on the wall or ceiling, then it was observed that other portions of the tarsi in action. The bottom of the housefly's feet boasts tiny, gripping claws and moist suction pads called pulvilli, which allow the fly to land almost anywhere [3].

4.7 Development

They have complete metamorphosis (holometabolous) [3] (for detail concern Chapter: Characteristics of Dipteran Insects).

4.8 Habits

Food habits of some species are unknown but most of Diptera may feed wide varieties of materials. They are detritivores (common fly, *Dryomyza anilis* and housefly, *Musca domestica*), flower feeders [Acalyptratae, Bibionidae, Conopidae] and nectar feeders [Nemestrinidae, Bombyliidae and Tabanidae]. Adults Brachycera feed on flowers, Syrphidae, which obtain all their protein requirements by feeding on pollen. Both male and female mosquitoes feed on nectar and plant juices, but in many females suck the blood of mammals, birds, amphibians or reptiles to obtain proteins as materials for maturation of eggs and oviposition. Many Diptera are obligatory blood-feeders [Muscidae, Phlebotominae, and Rhagionidae] [2].

Their larvae feed on diverse nutrients, different from those of adults. They feed on leaf-litters, leaves, stems, roots, flowers and seed heads, mosses, fungi, rotting woods, fruits; other organic matters such as slime, flowing sap, rotting cacti, carrions, dungs, detritus in mammals, birds or wasp nests; fine organic materials including insect frasses and micro-organisms. Tachinidae larvae parasitise on insects. Endoparasites larvae of Conopidae feed on bees, wasps, cockroaches and calyptrates, however, Pyrgotidae feed on adult scarab beetles. Sciomyzidae larvae are exclusively associated with freshwater and terrestrial snails or slugs. Odiniidae larvae feed in the tunnels of wood-boring larvae of Coleoptera, Lepidoptera, and other Diptera. *Oedoparena* [a small genus of Dryomyzidae] feed on barnacles [2].

4.9 Habitats

Diptera occur all over the world except in regions with permanent ice-cover. They are abundant throughout the world and occupy virtually every terrestrial niche, in tropics, subarctic, at sea level, and high on mountains. They colonize on beaches to low-tide level, they also found into deeper water, and only 1–2 midges are truly marine. *Pontomyianatans* are found in the Pacific as well as in freshwater. On the other hand, migrating flies have been found far out to sea. They are found in most land-biomes, including caves, deserts, and tundra. Palearctic habitats

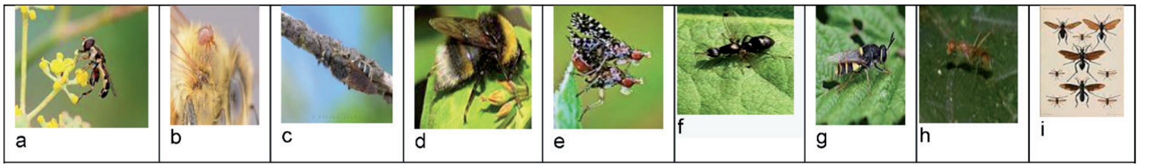

Figure 2.
Camouflage in Diptera: a): Hover-fly, Syritta pipienns *(Braulidae); b): Bee-louse,* B. coeca *(Braulidae); c): Soldier-fly,* Lasiopa villosa *(Stratiomyidae); mimicry in Diptera: d): European-hover-fly,* Pocota personata *(Syrphidae) with a bumble-bee (Hymenoptera); e): Gepunktete-hornfliege,* Trypetoptera punctulata *(Tephritidae) with spider (arachnids: Araneae); f): Members of Sepsidae with ant (Formicidae); g): Members of Stratiomyidae with wasp (Hymenoptera); h): Micropezid (Micropezidae) with green-tree-ant,* Oecophylla smaragdina*; i): Large-robust-flies,* Pantophthalmus rothschildi *(Pantophthalmidae) and giant-fly,* Mydas praegrandis *(Mydidae) with members of Pompilidae (Hymenoptera) [5].*

include meadows, prairies, mountain passes, forests, desert oases, seashores, sandy beaches, coastal lagoons, lakes, streams, rivers, bogs, and fens. They also found in areas polluted-water by rotting waste, industrial emissions, urban areas, cattle, horse and poultry farms [2].

4.10 Association

Stylogastrinae are obligatory associated with Formicides and Orthoptera and other Diptera. They typically use ground-dwelling Orthoptera and army ants (Formicidae) for raiding columns to flush out their prey. Phoridae are specialists parasitoids on ants, but tropical species are parasitoids on stingless bees (Hymenoptera). They are often host to more than one or 12 fly-larvae. More than 400 species of hoverflies (Syrphidae: Microdontinae) are myrmecophiles, they live in the nests of ants as scavengers or predators. Adults of many *Bengalia* (Calliphoridae: Bengaliinae) are kleptoparasites on ants and snatch foods and pupae being carried by ants or feed on winged termites [4].

4.11 Camouflage or mimicry

Camouflage is common in Diptera. Hover-flies, *Syritta pipienns* (Braulidae) use motion camouflage to approach females. Bee-louse, *B. coeca* (Diptera) uses chemical camouflage to survive within honeybee colonies. Soldier-fly, *Lasiopa villosa* (Diptera, Stratiomyidae) male shows camouflaged by hiding on a dry elm twig (**Figure 2a**–**c**) [6].

Many Diptera exhibit batesian mimicry. Syrphidae often are brightly colored, with spots, stripes, and bands of yellow or brown covering their bodies. Due to this coloring, and sometimes behavior patterns, they are often mistaken for wasps or bees (Hymenoptera). Wing pattern of *Trypetoptera punctulata* (Sciomyzidae) is very similar to some Tephritidae, therefore, they mimic the color pattern of some spiders (Arachnidae) [5]. Several fly species are look like an ant. Sepsisoma spp. (Richardiidae) mimic ants particularly with formicinae, *C. crassus*. Species of stilt-legged flies especially the wingless and haltere-less, *Badisis ambulans* (Micropezidae) resemble ants, as do species in *Strongylophthalmyia* and *Syringogaster spp*. Mydidae are mimics of stinging Hymenoptera (**Figure 2d**–**i**) [6].

5. Reproductive performance

Fly gives optical signals as diverse from biochemical or other signs throughout their sexual life.

5.1 Sexual-selection and courtship

Diptera show sexual-selection and numerous designs of sexual-dimorphism, such as stretching of male-body, eye-stalks, or addition of exoskeleton have changed frequently in flies. Fruit fly, *Phytalmia mouldsi* McAlpine and Schneider (Tephritidae) uses a resource defense mating-system. Mountain midges, *Deuterophlebia* Edwards males have extremely long antennae, which they employ when contesting territories over running water, waiting for females to mate. Acalyptratae (sub-section of Diptera) exhibit morphological development associated with agonistic behavior include: Clusiidae, Diopsidae, Drosophilidae, Platystomatidae, Tephritidae, and Ulidiidae [8].

5.2 Swarms

Swarm-based mating systems typically involve males flying in swarms to attract patrolling females. Such swarms are often of gigantic size. Smaller swarms may be around a fixed point called a swarm marker. Swarming occurs in Chronomidae, Bibionidae, Platypezidae, Limoniidae, Fanniidae, Chloropidae, Coelopidae, Milichiidae, and Trichoceridae. Chaoboridae form larval as well as adult swarms [8].

5.3 Bioluminescence

Keroplatidae and glow-worm, *Orfelia fultoni* (Mycetophilidae) display bioluminescence. In some, it is restricted to immature stages, but in others, this character is kept by pupae and adults. Ability to produce their own-light is used by some predatory-larvae as a bait for potential-prey, but it makes them more vulnerable to predation or parasitism [9].

6. Economic importance

Dipterans are an important group of insects with economic importance and have a considerable impact on the environment [10].

6.1 Useful Diptera

They are also use as bioindicator for environment, and biological control agents, some Diptera produce useful products, they are foods for other animals, they participate as pollinators, dispersal of seeds, and symbionts. They are extraordinary important insects in the putrefaction and deterioration of materials of plant and animal. They remain instrument for the disintegration and permit the nutrients mix into the humus to increase fertility of soil. The immature stages are supplementary diet for higher agrarian organisms. In food chains, they are also a significant constituent. Many larvae function as predators, parasitoids, or scavengers of the host larvae. The larvae of Acroceridae and some Bombyliidae are hypermetamorphic. Diptera are very advantageous to men. Houseflies, blowflies and fungus gnats (Mycetophilidae) are scavengers and assistance in decay. Robber (Asilidae and Tachinidae), dagger and balloon flies (Empididae) are predators and parasitoids. They control a diversified pest. Bee-flies (Bombyliidae) and hoverflies (Syrphidae) are pollinators of crops [11]. The following are special uses of Diptera:

1. Fruit-fly, *D. melanogaster* has long been used as a model organism in genetical researches, because it is easy to bred and reared in the laboratory (**Figure 3a**) [13].

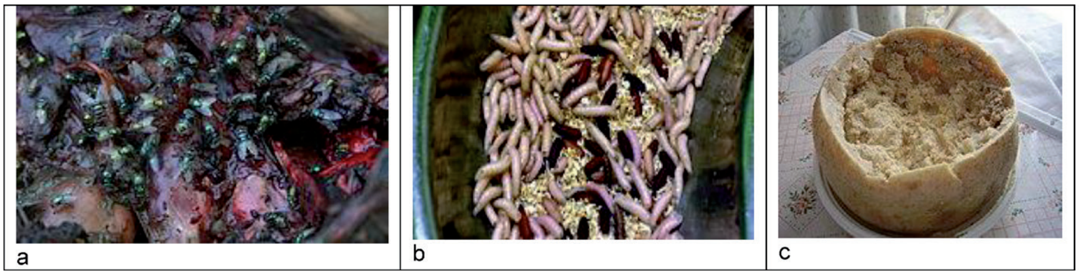

Figure 3.
Useful Diptera: a): Techniques and on molecular sequences in phylogenetics; b): Maggots are useful to forensic entomology; c): Sardinian cheese, casu marzu is exposed to cheese skippers such as Piophila casei *(Piophilidae); [12].*

2. They are also use for investigations in physiology, microbial pathogenesis and development among other research topics [14].

3. Maggots (Diptera larvae) can be used as a biomedical-tool for chronic wound-care as they are safe and effective. Eradicating dead tissues promote cell-growth and healthy-wound-healing. They have biochemical properties such as antibacterial activity found in their secretions [15].

4. Studies on dipteran by Willi Hennig used in the development of cladistics techniques that he applied to morphological characters, but now adapted for use with molecular sequences in phylogenetics [16].

5. Maggots found on corpses are useful to forensic entomology. They visit corpses and carcases at fairly well-defined times after the death of victim (**Figure 3b**) [17].

6. Maggots used as animal feed at zoological gardens and safari parks. Blow-fly larvae (gentles) and bluebottle larvae (casters) are produced commercially. They use as bait for fish, and as food for carnivorous, kept as pets, in zoos, or for research. They also use as large-scale food for farmed chickens, pigs, and fish [18].

7. Sardinian cheese, casu marzu is exposed to flies cheese skippers such as *Piophila casei* (Piophilidae). Digestive activities of the fly larvae soften the cheese and change the odor as fragment of course of ripening (**Figure 3c**) [19].

6.2 Harmful Diptera

The applied significance of the Diptera is as disease vectors, and agricultural pests. Many Diptera larvae are predatory. Some Tephritidae are leaf miners or gall formers. They are obligate parasites of mammals (Oestridae). There are roughly 150 known species worldwide those cause myiasis in animals. They are members of related families, such as the Calliphoridae [20].

6.3 Diptera as pests

Some leaf-miner flies (Agromyzidae), fruit flies (Tephritidae and Drosophilidae) and gall midges (Cecidomyiidae) are pests of agricultural crops; others such as tsetse flies, screwworm and botflies (Oestridae) attack livestock, causing wounds, spreading disease, and creating significant economic harm [20].

6.4 Diptera as medical importance

Mosquitoes (Culicidae), black-flies (Simuliidae) and drain-flies (Psychodidae) have great impact on human health as vectors of major tropical diseases. *Anopheles* mosquitoes transmit malaria, filariasis, and arboviruses; *A. aegypti* mosquitoes carry dengue-fever and Zika-virus; black-flies carry river blindness; sand-flies carry leishmaniasis. Other dipterans irritate to humans, when present in large numbers. These include house-flies, which pollute foods and feast food-borne diseases such as biting midges and sand-flies (Ceratopogonidae) and the house-flies and stable-flies (Muscidae). In tropical regions, eye-flies (Chloropidae), which visit the eye in search of tears irritate in some seasons [20].

6.5 Emblematic Diptera

In different cultures, flies play a variety of symbolic roles. They have both good and bad impacts on faith. In the traditional Navajo religion, big-fly is an important spirit-being. In Christian, demonology, Beelzebub is a demonic-fly, Lord of the flies, and God of the Philistines. They have appeared in literature since ancient Sumer [21]. In 1962, the biologist Vincent Dethier describes the characteristics of flies in his book titled to know a fly. Design of miniature-flying-robots has been made due to inspiration from flies [22]. In 1993, Steven Spielberg's film Jurassic Park trusted on the idea that DNA could be preserved in the stomach contents of a blood-sucking-fly fossilized in amber, though the mechanism has been discounted by scientists [23].

7. Communication

Sex pheromones are known for many dipteran species and play an important role in courtship behavior, together with visual, tactile, acoustic and other factors. Pheromones for a number of dipterans have been recently identified. In the Nematocera pheromones are volatile components, which act at a distance [24].

7.1 Parthenogenesis and viviparity

Hippoboscidae (louse flies, sheep keds), Streblidae and Nycteribiidae (together known as bat flies) and tsetse flies (*Glossina* spp.: vectors of African trypanosomes) are distinguished by their specialized reproductive biology, defined by adenotrophic viviparity (maternal nourishment of progeny by glandular secretions followed by live birth) is unique reproductive mechanism [25]. A study of chromosomal variability in the diploid parthenogenetic species *Lonchoptera dubia* (Lonchopteridae, Brachycera, Diptera) is based on an analysis of 272 females from 32 widely separated areas, chiefly in eastern North America. *L. dubia* is almost entirely nearctic and northern in distribution, occurring in the northern United States and southern Canada. Selection studies on the automictic (normally bisexual) tychoparthenogenetic species *DrosophiIa parthenogenetica* indicate that continued selection for parthenogenesis within a unisexual line for 62 generations results in selective improvement in parthenogenesis during the first 17 generations, and thereafter no change in rate of parthenogenesis [26].

7.2 Hibernation and diapause

Eastern tree hole mosquito, *A. triseriatus* 4th-instar larvae pupate only under constant increased daylength (longer day in photoperiodism). In common house mosquito, *C. pipiens*, females normally digest blood meal (trypsin and a chymotrypsin pathway), as the females then enter diapause. In *C. pipiens*, there are about 40 genes which are upregulated and downregulated during diapause, these genes code for functions like regulatory functions, metabolic functions, digestion, endocrine functions, cytoskeletal genes, ribosomal genes, transposable elements, and other with unknown functions. Asian tiger mosquito, *A. albopictus* collection was least during winter in Hanoi, Northern Vietnam, as it undergoes diapause. Hibernation mostly occurs in insects living in polar regions. *Parous Cx. p. pipiens* females from region of the northeastern US enter hibernacula during winter [27].

8. Internal anatomy and physiology

8.1 Nervous system

The nervous system of Diptera can be divided into a brain and a ventral nerve cord. The head capsule is made up of 6 fused segments. The first 3 pairs of ganglia are fused into the brain, while the three following pairs are fused into a structure of 3 pairs of ganglia under the insect's esophagus, called the subesophageal ganglion. *Musca domestica*, have all the body ganglia fused into a single large thoracic ganglion. At least a few insects have nociceptors, cells that detect and transmit sensations of pain (**Figure 4**) [29].

8.2 Digestive system

An insect uses its digestive system for all steps in food processing: digestion, absorption, and feces delivery and elimination. Main structure of Diptera's digestive system is a long enclosed tube called alimentary canal (or gut), which runs lengthwise through the body and directs food in one direction: from the mouth to the anus. It can be divided into 3 sections: the foregut, midgut and hindgut, each of which performs a different process of digestion (**Figure 4**) [29].

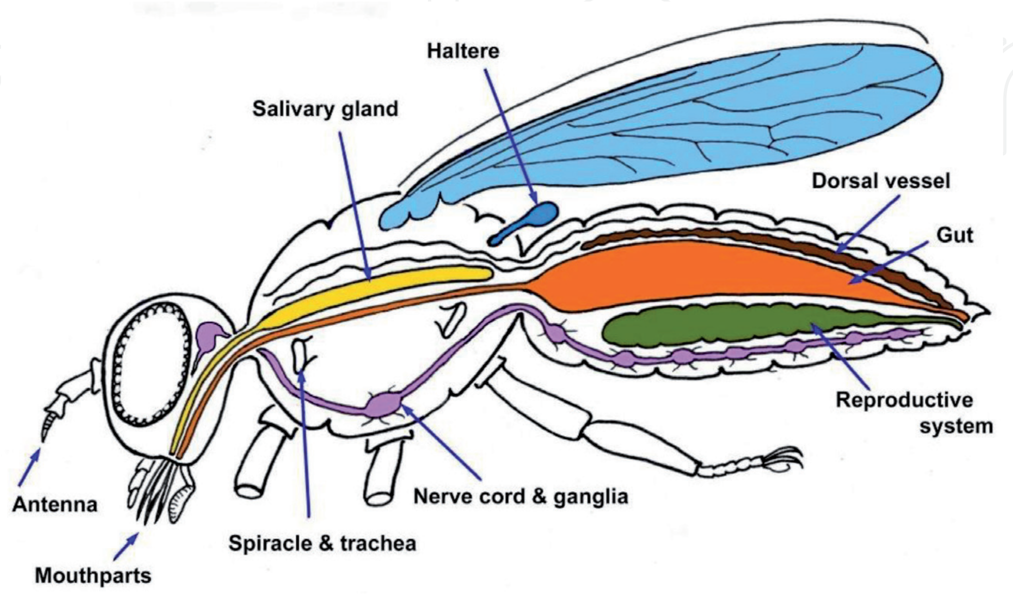

Figure 4.
Morphology and physiology of Diptera: Nervous system, digestive system, excretory system, respiratory systems, circulatory system, endocrine system, and reproductive system [28].

8.3 Excretory system

In the hindgut, undigested food particles are joined by uric acid to form fecal pellets. The rectum absorbs 90% of the water in these fecal pellets, and dry pellet is then eliminated through anus. Uric acid is formed from haemolymph waste products diffused from the Malpighian tubules at the junction between mid- and hindgut ranging from only 2 to over 100 tubules (**Figure 4**) [29].

8.4 Respiratory systems

Diptera respiratory system composed of internal tubes and sacs through which gases either diffuse or are actively pumped directly to tissues that are trachea. Since oxygen is delivered directly, the circulatory system is not used to carry oxygen (**Figure 4**) [29].

8.5 Circulatory system

A single, perforated dorsal tube that pulses peristaltically, toward the thorax, the dorsal tube divides into chambers and acts like the insect's heart. The opposite end of the dorsal tube is like the aorta circulating the haemolymph, inside the body cavity. Air is taken in through openings on the sides of the abdomen called spiracles. Haemolymph's main function is that of transport and it bathes the insect's body organs. It transports hormones, nutrients and wastes and has a role in, osmoregulation, temperature control, immunity, storage (water, carbohydrates and fats) and skeletal function. It also plays an essential part in the molting process. Body fluids enter through one-way valved ostia, which are openings situated along the length of the combined aorta and heart organ. Movement of haemolymph is particularly important for thermoregulation in Diptera (**Figure 4**) [29].

8.6 Endocrine system

Endocrine system of Diptera composed of neurosecretory cells, corpora cardiaca, prothoracic glands, and corpora allata (**Figure 4**) [29].

8.7 Reproductive system

Female insects are able make eggs. The ovaries are made up of a number of egg tubes, called ovarioles, which vary in size and number by species. The number of eggs that the insect is able to make vary by the number of ovarioles. Accessory glands or glandular parts of the oviducts produce a variety of substances for sperm maintenance, transport, and fertilization, as well as for protection of eggs. Spermathecae are tubes or sacs in which sperm can be stored between the time of mating and the time an egg is fertilized (**Figure 4**) [29].

Main male reproductive organ is the testis. However, most male Diptera have a pair of testes, inside of which are sperm tubes or follicles that are enclosed within a membranous sac. The follicles connect to the vas deferens by the vas efferens, and 2 tubular vasa deferentia connect to a median ejaculatory duct that open outside. A portion of the vas deferens is often enlarged to form the seminal vesicle, which stores the sperm before they are discharged into the female. The ejaculatory duct is derived from an invagination of the epidermal cells. The terminal portion of it may be sclerotized to form the intromittent organ, the aedeagus. The aedeagus can be quite pronounced or de minimis (**Figure 4**) [29].

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