

**EFFECTS OF LARVAL CROWDING AT SOME STAGES OF
DEVELOPMENT OF *MUSCA DOMESTICA* IN SOKOTO METROPOLIS**

BY

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CERTIFICATION

This is to certify that this project titled “**Effect of larval crowding at some stages of development of *Musca domestica* in Sokoto metropolis**” was carried out by John Henry Wohu-owo with the admission number 2010302113, in partial fulfillment of the requirements for the award of the Bachelor of Science (B.Sc.) Degree in Biology, under the Department of Biological science, Faculty of Chemical and Life Sciences, Usmanu Danfodiyo University, Sokoto.

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DEDICATION

This project is dedicated to my beloved parents and family for their unwavering support, sacrifices, unconditional love, encouragement, and prayers that have shaped my life.

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ABSTRACT

This study investigated the effects of larval crowding on the developmental stages of *Musca domestica* (housefly) within Sokoto Metropolis. Adult flies were collected and reared under controlled laboratory conditions to obtain eggs for experimentation. The eggs were introduced into varying larval densities categorized as low (5 eggs/10g substrate), medium (15 eggs/10g), and high (30 eggs/10g), with each treatment replicated three times. Observations focused on larval duration, pupal weight, emergence rate, and adult size. Results showed that increased larval crowding significantly prolonged development time, reduced pupal weight, and led to smaller adult flies. These findings highlight the impact of environmental and population pressures on the biological development of *M. domestica*, with implications for vector control and public health strategies, particularly in urban areas with poor sanitation.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The housefly (*Musca domestica* L) has worldwide distribution and is found throughout the country in close association with human activities. In addition to being a nuisance pest, it is a vector of many pathogens. Pathogenic organisms are picked-up by the flies from garbage, sewage and other sources of filth and transferred to human food either mechanically from contaminated external body parts or after consumption by houseflies, through vomiting and defecation while feeding on food (Sasaki *et al.*, 2000). *Musca domestica* represents pest of major economic significance and pollution of animal products, poultry, livestock and the transfer of the wide range of animal pathogens (Badriah and Asiri, 2017), The continued success of *M. domestica* in different parts of the world can be explained by at least two important factors, a high growth rate and short life cycle (Gunay *et al.*, 2011). In fact, housefly represents the ultimate adaptation to the human environment by an insect (Robinson, 1995). The fly is a holometabolous with distinct egg, larva or maggot, pupa and adult stages.

Musca domestica (L.) commonly known as housefly is widely distributed and familiar to many as domestic pest, nuisance fly and vector of variety of pathogenic organisms. Its serious insect not only for their annoyance factor but also for being major vectors of several disease- inducing agents (Douglass and Jesse, 2002).

Similarly, its habit of visiting garbage, excrement and human food all in one short flight makes it capable of transferring organisms that cause diarrhea, dysentery, typhoid, cholera and other diseases to human (Fasulo *et al.*, 2005). Expanding of the fly food range to include human garbage and moving indoors makes it to become a cosmopolitan pest and found wherever humans have settled (Ostrolenk and Welch, 1942; Savage and Scoof, 1955). The housefly (*Musca domestica*) is the synanthropic insect which has always been able to colonize the organic substrata, which man has placed at its disposal. The environments, in which the fly lives, make it a carrier of a number of pathogenic organisms. It is a carrier of over 100 different pathogenic organisms including organisms for diseases, viz. typhoid, cholera, bacillary dysentery, tuberculosis, anthrax, *ophthalmia neonatorum* and *infantile diarrhoea* as well as parasitic worms (Sasaki *et al.*, 2000; Fotedar *et al.*, 1992).

Insect growth rate changes in response to different stimuli, including competition, temperature, humidity, and resource availability (Harnden and Tomberlin, 2016; Barragan-Fonseca *et al.*, 2018). In nature, the larvae of insects often share the same food resources. High larval density leads to competition and impact on access to food resources (Morimoto *et al.*, 2019). Also, larval density significantly influences many life-history traits of insects. For instance, when larvae are reared in crowded feeding environments, this generally leads to an increased risk of mortality, adults with low fecundity, reduced adult size, longevity, individual growth rate, and developmental delay (Morimoto *et al.*, 2019, Dzepe *et al.*, 2020).

Kökdener *et al.* (2020) demonstrated that the larval density of *Calliphora vicina* Robineau-Desvoidy, 1830 (Diptera: Calliphoridae) has a significant influence on development time, larval and pupal survival, and adult size. Dzepe *et al.* (2020) found that increasing larval density affects the development time and survival of *Hermetia illucens* (Linné, 1758) (Diptera: Stratiomyidae). Lower larval density can promote better growth and development (Morimoto *et al.*, 2019, Dzepe *et al.*, 2020). In some cases, a high density of larvae produces a local rise in temperature that might enhance feed assimilation and protect against low environmental temperatures. Also, larval crowding could result in reduced substrate quality by the accumulation of larval waste products (Green and Popa, 2012; Barragan-Fonseca *et al.*, 2018) and detrimentally affect insect life. Hence, optimising density conditions might serve the productivity of insect rearing.

The house fly *Musca domestica* Linnaeus, 1758 (Diptera:Muscidae), which is cosmopolitan and opportunistic, is found throughout the world in close association with human activities. *Musca domestica* is a carrier of a large number of pathogens and vectors of many human and animal diseases (Graczyk *et al.*, 2001; Förster *et al.*, 2007; Scott *et al.*, 2014, Asiri 2017). Moreover, house flies are one of the most serious pests and could lead to the economic loss in the livestock industry, especially poultry (Scott *et al.*, 2014, Asiri, 2017; Hussein *et al.*, 2017, Miranda *et al.*, 2019). This fly are known to colonize animal carrion and human corpses after blowflies and its larvae have potential forensic investigation. *Musca domestica* may cause wound

myiasis. When larvae of the house fly were observed on the neglected wounds of children and elderly, it can be used to the detection of abuse and neglect in children and elderly (Wang *et al.*, 2018). In nature, *M. domestica* fed on different ephemeral substrates such as decaying waste, human food, animal food, animal dung, and garbage (Issa, 2019). Foods regulate competition and are a primary determinant of life span (Tomberlin *et al.*, 2002, Barragan-Fonseca *et al.*, 2018). Quality or quantity of resources affects the life-history traits of insects (Moreau *et al.*, 2006, Nguyen *et al.* 2013, Elora and Sarkar 2018), behavior, performance (Barragan-Fonseca *et al.*, 2018), and populations dynamics (Leather, and Awmack, 1998). Insufficient nutrition may result in smaller larvae, pupae, and adults (Okorie and Okeke, 1990; Daniels *et al.*, 1991). High food quality changes development time, growth, and survival, in some insect species (Barragan-Fonseca *et al.*, 2018). For instance, Kökdener and Kiper (2020) suggested that a diet with a higher proportion of protein decrease the survival rate of the house fly. Nguyen *et al.* (2013) suggested that diets with a higher proportion of protein decrease development time and increases growth rate. Thus, knowing how competition mechanisms that occur in nature is significant for reducing pest populations (Miranda *et al.*, 2019) and improving the management of this pest. The influence of larval density and dietary nutrient concentration on life-history traits has not been investigated systematically before. Limited research has been conducted on the use of house flies for larval density (Cičková *et al.*, 2013, Baleba *et al.*, 2019). Therefore, this study was designed to investigate the effect of

larval crowding and dietary nutrient concentration on the larval and adult traits of *M. domestica*.

The whitish eggs each measured 1-2mm in length are laid singly and directly on acceptable substrate but pile up in small masses (Kence and Jdeidi, 1997). A good breeding medium is animal or poultry manure (Alanazi *et al.*, 2017). Up to 500 eggs can be laid per female in several batches of 75-150 over a three to four day period (Mcintyre and Gooding, 1995). Number of eggs produced however, is a function of female size, which is principally a result of larval nutrition, (Mcintyre and Gooding, 1998; McIntyre, 2000), Normally the egg laying females are attracted to warm and moist (40-70% water) organic substrates that may provide adequate nourishment for the hatched larvae (Robinson, 1995). Maximum egg production occurs at intermediate temperature, 25-30°C (Krafsur *et al.*, 1985; Hogsette, 1996). The first instar larva (3-9mm long), a typical creamy whitish in colour, cylindrical but tapering toward the head (Mather and Caligari, 1981; Mousseau and Dingle, 1991). hatched in about 8 hours or up to 3 days depending on temperature (Robinson, 1995; Krafsur *et al.*, 1985. Larvae burrow into the food material to feed, but complete the three instars (3rd instar larvae, 7-12mm long) and pupate in a week or less (Bhalla, 1964; Bursell, 1970). The optimum temperature for larval development is 35 to 38°C, though larval survival rate is highest at 17-32°C (Lysyk, 1991; Barnard and Geden, 1993). Pupa is dark-brown 8mm long and under warm conditions last 4-6 days (Robinson, 1995; Mousseau and Dingle, 1991). The emerging adult fly, 6-9mm in

length (Robinson, 1995), escapes from the pupa case through the use of an alternately swelling and shrinking sac called the ptilinum on the front of its head, which it uses like pneumatic hammer to break through the case (Kence and Jdeidi, 1997; McIntyre, 2000), with the female usually larger than the male (Mousseau and Dingle, 1991). Warm summer conditions are generally optimum for the development of the housefly and it can complete its life cycle in as little as seven days (Hogsette, 1996). As many as 10-12 generations may occur annually in temperate regions, while more than 20 generations may occur in subtropical and tropical regions (Lysyk, 1993; Hussein and John, 2007).

1.2 Statement of the Problem

The housefly *Musca domestica* L. (Diptera: Muscidae) is a cosmopolitan insect responsible for causing annoyance, irritation, and food spoilage and is also an important pathogenic disease vector in both people and animals. Associations between houseflies and pathogens can result in disease outbreaks such as typhoid, cholera, tuberculosis, bacillary dysentery, infantile diarrhoea and anthrax (Lecuona *et al.*, 2005; Förster *et al.*, 2009). Housefly habits—such as walking and feeding on trash and excrement—make them superlative agents for transferring disease-causing pathogens to human and animal populations (Ugbogu *et al.*, 2006). Therefore, it is crucial to control *M. domestica* to improve the health of people, livestock and poultry.

1.3 Justification of the Study

The control of *Musca domestica* is thus, vital to human health and comfort. The common control measures are sanitation, use of traps and insecticides. However, in some instances integrated fly control has been implemented and found successful. The development of resistance in houseflies to insecticides and the associated toxicity has necessitated evaluation of safer alternatives for housefly control. The use of safer alternatives like biological control or insect growth regulators (IGR) is thus gaining attention as an important intervention in housefly management programmes (Axtell and Arends, 1990; Tunaz and Uygun, 2004). Conventional insecticides are primarily used for control of *M. domestica* over the short (Cao *et al.*, 2006; Malik, *et al.*, 2007), but the haphazard use of insecticides has given rise to serious problems that include both insecticide resistance and the residual effects of the chemicals used in insecticides (Yadav, 2010). Insecticide resistance in houseflies has now become a global problem—and is increasing (Scott *et al.*, 2000). Currently, houseflies are resistant to almost all groups of conventional insecticides including organophosphates, organochlorines, carbamates and pyrethroids (Kocisova, 2001; Azzam and Hussein 2002). The problems regarding resistance, residual effects and high chemical costs have opened the door to other alternatives such as entomopathogenic fungi, which have the potential to control this insect pest (Geden, 2012).

1.4 Aim and Objectives of the Study

The current study aimed to determine the effect of overcrowding at some stages of development of *Musca domestica* in Sokoto metropolis with the following specific objective.

- i. To determine the effect of feeding regimes on the development of *Musca domestica*
- ii. To determine the population density of *Musca domestica* in the study area
- iii. To determine the effect of larval crowding on the growth and development of *Musca domestica*

CHAPTER TWO

2.0 LITEERATURE REVIEW

2.1 Biology of *Musca domestica*

Musca domestica, commonly known as the housefly, undergoes holometabolous development, meaning it completes its life cycle through four distinct stages: egg, larva, pupa, and adult. This developmental pattern allows the housefly to rapidly colonize a wide range of habitats, especially those rich in organic waste. The speed and flexibility of this life cycle contribute significantly to the fly's medical and veterinary importance as a vector of numerous pathogens (Sana *et al.*, 2017; Khan *et al.*, 2021).

Egg Stage

The life cycle begins when a mature female housefly lays her eggs on decomposing organic material such as garbage, manure, or decaying plant matter. A single female can lay up to 150 eggs per batch and over 500 in her lifetime. The eggs are white, oval-shaped, and approximately 1.2 mm long. Under optimal environmental conditions particularly temperatures between 25–35°C and high humidity eggs hatch within 8 to 24 hours (LSU AgCenter, 2022; Echeverria *et al.*, 2020). Rapid egg hatching is crucial to survival in fluctuating conditions, especially in warm tropical environments like northern Nigeria (Shanbhag *et al.*, 2020).

Larval Stage

Upon hatching, larvae (maggots) emerge and begin feeding on the organic substrate. These legless, cylindrical organisms are pale white and develop through three instars over 3 to 5 days, depending on food quality, temperature, and larval density. This is the most active feeding stage and accounts for most of the organism's growth. Crowded larval environments have been shown to result in slower growth and smaller final body size due to competition and accumulation of waste products (Iqbal *et al.*, 2019; Singh *et al.*, 2022). Studies have also linked increased larval density to higher stress enzyme activity, which may compromise survival (Kumar *et al.*, 2021).

Pupal Stage

After completing the larval stage, mature maggots crawl away from their feeding site to seek a drier location for pupation. There, they form a puparium which

is a hard, brown capsule formed from the last larval skin which protects the developing pupa. The duration of the pupal stage ranges from 2 to 6 days, influenced by temperature, humidity, and substrate quality (Khan *et al.*, 2021; LSU AgCenter, 2022). During this stage, the fly undergoes complete metamorphosis, transforming from a soft-bodied larva into a fully developed adult with wings, compound eyes, and reproductive organs (Echeverria *et al.*, 2020).

Adult Stage

Adult houseflies emerge from the puparium using a specialized inflatable structure called the ptilinum, which collapses after emergence. Within 24 to 48 hours, the adult fly becomes sexually mature and begins mating. Adult houseflies typically live 15 to 25 days, although survival can extend beyond 30 days in laboratory conditions with adequate food and low predation risk (Shanbhag *et al.*, 2020; Singh *et al.*, 2022). The full life cycle from egg to adult can be completed in as little as 7 to 10 days in ideal warm, moist environments, allowing for explosive population growth, especially in unsanitary settings (Iqbal *et al.*, 2019; LSU AgCenter, 2022).

2.2 Feeding Habits

Adult *Musca domestica* (houseflies) are non-biting insects with highly specialized sponging-lapping mouthparts, which are adapted for feeding on liquid and semi-liquid substances. These mouthparts consist of a proboscis with a sponge-like labellum that allows the fly to soak up fluids. Adult flies are opportunistic feeders and consume a wide range of organic materials, including sugary substances,

milk, rotting fruits, animal feces, and even wound exudates in animals and humans (Shanbhag *et al.*, 2020; Khan *et al.*, 2021). When faced with solid food, adult houseflies secrete saliva or regurgitate digestive fluids containing enzymes such as amylase and protease. These enzymes help dissolve the food externally into a semi-liquid form that can be ingested through the sponging mechanism (Echeverria *et al.*, 2020; Singh *et al.*, 2022).

This feeding behavior has important ecological and public health implications. By feeding on both clean and contaminated substrates, adult flies can act as mechanical vectors for over 100 human and animal pathogens, including *Salmonella*, *E. coli*, *Shigella*, and parasitic helminths (Sana *et al.*, 2017; Iqbal *et al.*, 2019). Their indiscriminate feeding and movement between waste and human food surfaces make them effective agents for disease transmission, especially in densely populated urban settings with poor waste management.

The larvae of *M. domestica*, commonly known as maggots, are saprophagous feeding almost exclusively on decomposing organic matter. Their primary food sources include decaying plant material, animal dung, kitchen waste, and other forms of fermenting organic debris (Echeverria *et al.*, 2020; Kumar *et al.*, 2021). The larval mouthparts are adapted for scraping and chewing through semi-solid substrates, enabling rapid consumption and digestion of large volumes of nutrient-rich material. This high intake supports their fast growth during the three larval instars.

Beyond nutrition, larval feeding contributes significantly to the

decomposition and recycling of organic waste, playing an ecological role in nutrient cycling. In waste management and forensic entomology, the feeding behavior of housefly larvae is even harnessed to reduce biomass in organic waste or estimate postmortem intervals (Shanbhag *et al.*, 2020; Singh *et al.*, 2022). The distinct dietary strategies of larvae (semi-solid decay) and adults (liquid) reflect a successful adaptation that allows *M. domestica* to exploit a wide range of ecological niches, making them highly persistent in both rural and urban environments (Issa, 2019; Khan *et al.*, 2021).

2.3 Breeding Environments

The reproductive success and global distribution of *Musca domestica* are largely attributed to its ecological flexibility and ability to exploit a wide range of breeding habitats. This species thrives particularly in warm, moist environments rich in organic material conditions that support the development of its eggs and larvae. Houseflies prefer semi-liquid substrates that remain moist but are not waterlogged, as excessive moisture can hinder larval respiration and movement. These preferences make them prolific in both rural and urban areas where sanitation is poor and organic waste is readily available (Echeverria *et al.*, 2020; Singh *et al.*, 2022).

One of the most common and favorable breeding sites for *M. domestica* is animal manure, particularly from cattle, poultry, and pigs. Livestock and poultry farms often accumulate large volumes of waste, creating ideal microhabitats for egg laying and larval development. Studies show that chicken manure, due to its nutrient

richness and warmth, is particularly preferred by gravid females for oviposition (Khan *et al.*, 2021; Kumar *et al.*, 2021). This explains the high housefly densities often observed in and around animal housing areas, especially where waste management is inadequate.

In urban environments, garbage dumps and open waste collection points serve as major breeding hotspots. Organic household waste, including food scraps and rotting vegetation, provides ample substrates for larvae. In cities like Sokoto, where waste disposal systems are often underdeveloped, piles of decomposing garbage can become long-term breeding reservoirs, facilitating continuous fly generations (Sana *et al.*, 2017; Iqbal *et al.*, 2019). Additionally, compost heaps and food processing areas, where fermenting plant matter or spilled organic residue accumulate, offer suitable conditions for oviposition and larval feeding (Shanbhag *et al.*, 2020).

Furthermore, houseflies readily breed in marketplaces, abattoirs, and public drains, especially where organic debris accumulates and moisture levels are high. These environments not only support fly development but also increase their contact with human food sources, thus enhancing their potential to transmit pathogens (Echeverria *et al.*, 2020; LSU AgCenter, 2022). In Sokoto metropolis, climatic factors such as high ambient temperatures, coupled with seasonal rainfall and poor sanitation infrastructure, exacerbate the proliferation of such breeding habitats.

This ability to adapt to a variety of natural and anthropogenic environments

contributes significantly to the persistence and public health threat posed by *M. domestica*. Understanding these breeding environments is essential for developing targeted control strategies such as improved sanitation, waste management, and environmental monitoring (Khan *et al.*, 2021; Singh *et al.*, 2022).

2.4 Importance in Public Health

Musca domestica, the common housefly, is considered one of the most important mechanical vectors of human and animal diseases due to its feeding and breeding behavior. Unlike biological vectors, houseflies do not require internal replication of pathogens to transmit them. Instead, they act as mechanical carriers, picking up disease-causing organisms on their body surfaces (especially legs, wings, and mouthparts) or ingesting them into their digestive systems, later depositing them on food, water, or household surfaces through defecation or regurgitation (Sana *et al.*, 2017; Singh *et al.*, 2022). Their frequent movement between waste and food increases the chances of cross-contamination, especially in areas with poor hygiene practices.

More than 100 pathogenic organisms have been isolated from houseflies, including bacteria, viruses, protozoa, and helminth eggs. Among bacterial pathogens, species like *Salmonella spp.*, *Shigella spp.*, and *Escherichia coli* are frequently identified and are responsible for a range of gastrointestinal illnesses such as diarrhea, dysentery, and food poisoning (Iqbal *et al.*, 2019; Khan *et al.*, 2021). Viral pathogens such as polio virus and hepatitis A virus have also been associated with fly

transmission, as flies can carry virus particles on their external structures for several hours (Echeverria *et al.*, 2020). Additionally, houseflies can transmit protozoan cysts and helminth eggs, including *Enterobius vermicularis*, *Ascaris lumbricoides*, and *Strongyloides stercoralis* (Issa, 2019; Shanbhag *et al.*, 2020). These parasites can cause serious infections, especially in immunocompromised individuals and children.

The public health impact of houseflies is particularly profound in developing regions, where sanitation systems are inadequate and food is often exposed to environmental contamination. In urban areas like Sokoto, poor waste disposal, open drainage systems, and roadside food vending create ideal conditions for fly infestation and disease transmission (Kumar *et al.*, 2021; LSU AgCenter, 2022). Flies can move freely between human dwellings, latrines, markets, and livestock areas, promoting the spread of enteric diseases, especially during the rainy season when moisture increases breeding success. Studies have emphasized the correlation between fly density and the incidence of diseases such as typhoid fever, cholera, and amoebiasis in densely populated areas (Singh *et al.*, 2022; Echeverria *et al.*, 2020).

Effective control of *M. domestica* populations requires integrated vector management approaches, including improved sanitation, safe waste disposal, regular cleaning of food handling areas, and physical barriers like screens or fly traps. Public awareness campaigns and health education also play a key role in minimizing contact between flies and food surfaces, thereby reducing disease risk (Khan *et al.*, 2021; Sana *et al.*, 2017).

2.5 Larval Development in Dipterans

2.5.1 Larval Stages

In Dipteran species such as *Musca domestica*, the larval stage represents a critical period of growth, feeding, and physiological transformation. The larvae, also known as maggots, undergo a process of development through distinct phases called instars. Typically, there are three larval instars, each separated by a molt (ecdysis) that allows the larva to increase in size and complexity (Shanbhag *et al.*, 2020; Singh *et al.*, 2022). During these instars, the larvae are soft-bodied, legless, and exhibit intense feeding behavior, particularly in nutrient-rich, decaying organic matter. The duration of each instar is influenced by factors such as temperature, moisture, food quality, and larval density (Echeverria *et al.*, 2020; Khan *et al.*, 2021).

The length of each instar stage can vary not only between species but also within the same species under different environmental conditions. For instance, in the forensic and medical fly *Lucilia sericata*, the first instar may last up to 31 hours at 27°C, the second approximately 12 hours, and the third 40 hours, before pupation begins (Amendt *et al.*, 2011; Kumar *et al.*, 2021). In *Musca domestica*, the overall larval period typically spans 3 to 5 days, with faster development occurring under higher temperatures and optimal moisture conditions. At each stage, the larva consumes large quantities of decaying organic matter, which supports rapid cell division and tissue development necessary for the transition to pupation.

Morphologically, each larval instar can be identified based on characteristics

such as size, body segmentation, and spiracular patterns. The posterior spiracles, which function as breathing structures, are particularly useful in distinguishing larval stages. In early first-instar larvae, the spiracles generally have one slit; in the second instar, they present two slits; and in the third instar, they develop three well-defined spiracular slits, arranged in a distinctive pattern (Shanbhag *et al.*, 2020; Singh *et al.*, 2022). These features are not only important for taxonomic identification but also play a significant role in forensic entomology, where determining the exact larval stage can help estimate the post-mortem interval in death investigations (Amendt *et al.*, 2011).

Additionally, larval morphology and development are used in ecological and physiological studies to assess the impact of environmental factors such as crowding, food type, and chemical exposure. Researchers have found that high larval density can reduce the duration of early instars while prolonging later ones due to increased competition and resource limitation (Iqbal *et al.*, 2019; Khan *et al.*, 2021). Understanding these developmental dynamics is crucial in both applied entomology and public health, especially for species like *M. domestica* that are prolific breeders and disease vectors.

2.5.2 Nutritional Requirements

The growth, development, and eventual adult fitness of dipteran larvae, including those of *Musca domestica*, are strongly influenced by the quantity and quality of nutrients available in their larval environment. These larvae are generally

saprophagous, feeding on decaying organic materials such as animal feces, decomposing vegetation, carcasses, and household waste. These substrates offer varying amounts of proteins, carbohydrates, lipids, minerals, and moisture, all of which are critical for successful larval growth (Shanbhag *et al.*, 2020; Singh *et al.*, 2022). Substrate rich in nitrogenous compounds and easily digestible carbohydrates tends to support faster growth, increased survival, and earlier pupation (Iqbal *et al.*, 2019; Khan *et al.*, 2021).

Nutritional imbalances can have a pronounced effect on larval physiology. For example, studies on *Aedes aegypti* and *Musca domestica* have shown that diets with a balanced protein-to-carbohydrate ratio result in reduced development time, larger body size, and increased reproductive potential of adults. In contrast, protein-deficient or carbohydrate-deficient diets lead to extended larval periods, stunted growth, lower pupal weight, and poor adult emergence (Kumar *et al.*, 2021; Singh & Saini, 2023). Furthermore, the type of organic substrate such as manure vs. decomposing food also impacts larval nutrient assimilation, with manure generally promoting faster development due to its high nitrogen and moisture content (Sana *et al.*, 2017; Echeverria *et al.*, 2020).

In addition to nutrient composition, environmental factors like moisture content and pH play a crucial role in larval nutrition and development. Moisture is necessary for food solubilization and larval mobility; however, overly wet substrates may promote anaerobic conditions and microbial overgrowth, leading to larval stress

or mortality. Conversely, dry conditions may hinder ingestion and nutrient absorption. Optimal moisture conditions help ensure efficient enzymatic activity and digestion, supporting healthy larval development (Shanbhag *et al.*, 2020; Khan *et al.*, 2021). Similarly, extreme pH levels, particularly acidic environments, can impair microbial composition in the substrate, reduce nutrient availability, and lead to smaller adult body size and lower fecundity (Iqbal *et al.*, 2019; Singh *et al.*, 2022).

Therefore, understanding the nutritional requirements and environmental influences on larval development is essential in entomological research, pest control, and forensic entomology, as they determine the timing, success rate, and fitness of fly populations.

2.6 Environmental Factors Affecting Development

The development of dipteran larvae, such as those of *Musca domestica*, is profoundly influenced by a variety of environmental factors. These factors not only affect the growth rate, survival, and morphology of the larvae but also determine the success of adult emergence and population dynamics. Understanding these influences is critical in entomology, particularly for applications in vector control, waste management, and forensic science.

Temperature plays a central role in regulating larval metabolism and developmental timing. As ectothermic organisms, dipteran larvae rely on ambient temperature to drive physiological processes such as enzyme activity, digestion, and molting. In general, an increase in temperature accelerates development, while cooler

conditions slow it down. However, every species has a defined thermal range within which development is optimal. For example, *Phormia regina* larvae develop best between 12.7°C and 35°C, while temperatures outside this range either halt development or cause mortality (Amendt *et al.*, 2011, Singh *et al.*, 2022). Similarly, *Musca domestica* shows optimal development at around 30°C, with reduced viability and smaller adult size at extremes (Iqbal *et al.*, 2019; Echeverria *et al.*, 2020).

Larval density is another critical environmental factor. High densities result in intense competition for space, oxygen, and nutrients, often leading to slower growth rates, prolonged development, and increased mortality (Kumar *et al.*, 2021; Khan *et al.*, 2021). In studies on *Aedes aegypti* and *Musca domestica*, high larval crowding has been linked to delayed maturity, reduced body mass, and lower adult fecundity. Moreover, crowding often leads to the accumulation of metabolic waste, which may alter pH and increase the toxicity of the substrate (Iqbal *et al.*, 2019; Singh & Saini, 2023).

Photoperiod (the cycle of light and darkness) also influences dipteran development, though its role is species-specific and often subtle. For example, research on *Phormia regina* indicates that larvae exposed to alternating light-dark cycles developed more rapidly than those kept in continuous light or darkness. This suggests that dark periods may trigger hormonal or neural cues that enhance feeding and growth activity (Amendt *et al.*, 2011; Shanbhag *et al.*, 2020). While this factor may not have as strong an impact as temperature or density, it is nonetheless relevant

in understanding life cycle timing in natural and laboratory conditions.

Substrate quality which includes nutrient content, moisture, and microbial composition is perhaps the most direct environmental influence on larval development. Substrates rich in decomposing organic matter, such as animal manure or rotting food, typically support high larval survival and faster development, particularly when they are moist but not waterlogged (Sana *et al.*, 2017; Khan *et al.*, 2021). Poor substrates, either too dry or nutrient-deficient, can cause developmental delays, malformations, and high mortality. Moisture affects larval mobility and digestion, while microbial activity in the substrate may either assist digestion or introduce pathogens, depending on the balance (Shanbhag *et al.*, 2020; Singh *et al.*, 2022).

Understanding the impact of these environmental factors on dipteran larvae is essential for multiple applied disciplines. In forensic entomology, environmental variables are used to estimate post-mortem intervals based on insect development. In pest management, manipulating temperature or substrate conditions can help control fly populations. Likewise, public health programs benefit from such insights to reduce the risk of disease transmission through better waste and sanitation practices (Amendt *et al.*, 2011; Echeverria *et al.*, 2020).

2.7 Concept of Larval Crowding

2.7.1 Definition and Causes

Larval crowding refers to a biological condition in which a high number of

insect larvae develop within a confined space, leading to intense competition for essential resources such as food, space, oxygen, and moisture. This phenomenon is particularly common in holometabolous insects like *Musca domestica* (housefly), where females tend to lay eggs in clusters on nutrient-rich substrates such as feces, garbage, and decomposing organic matter. As the eggs hatch, the rapid increase in larval population density triggers a state of crowding, especially when the resource supply is insufficient to meet the collective demands of the growing larvae (Araj *et al.*, 2020; Khan *et al.*, 2021). This environmental pressure can significantly influence larval physiology, behavior, and developmental outcomes.

2.7.2 Several factors contribute to larval crowding in natural and artificial environments:

- High fecundity of female flies: A single female *M. domestica* can lay between 75–150 eggs per batch and up to 500 eggs over her lifetime, often on the same substrate as other females. This reproductive strategy increases the chance of overcrowding, especially in nutrient-rich and attractive oviposition sites (Iqbal *et al.*, 2019; Shanbhag *et al.*, 2020).
- Limited breeding sites: In urban settings, livestock farms, or poorly managed waste zones, breeding sites are often concentrated and predictable, which leads to multiple females laying eggs on the same material. Studies have shown that the aggregation of eggs on shared resources results in larval density far exceeding optimal developmental levels (Sana *et al.*, 2017; Singh & Saini, 2023).

- Environmental confinement: Physical constraints such as container walls, soil compactness, or dryness around the breeding site can prevent larvae from dispersing effectively. As a result, larvae are forced to develop in overcrowded microhabitats, amplifying stress and competition (Echeverria *et al.*, 2020; Khan *et al.*, 2021).
- Synchronous hatching: When environmental conditions such as temperature and humidity are optimal, eggs deposited at similar times may hatch simultaneously, leading to a sudden spike in larval numbers. The simultaneous emergence of larvae from densely deposited egg clutches increases competition from the onset, limiting individual access to resources and space (Kumar *et al.*, 2021; Singh *et al.*, 2022).

The effects of larval crowding are significant. Overcrowding has been shown to retard larval growth, increase developmental time, and reduce adult body size and survival, all of which impact reproductive success and population dynamics. Furthermore, crowding leads to physical interference, increased accumulation of waste, and sometimes cannibalistic behavior under severe resource scarcity (Amendt *et al.*, 2011; Shanbhag *et al.*, 2020).

2.7.3 Natural vs Experimental Conditions

In natural environments, larval crowding arises as an uncontrolled and unpredictable phenomenon, influenced by ecological and anthropogenic factors. Poor waste management practices, overpopulation of flies, and the seasonal abundance of organic matter especially during the rainy season create optimal breeding conditions for *Musca domestica*. In densely populated urban settings like

the Sokoto metropolis, open refuse dumps, livestock pens, and poorly maintained poultry farms become hotspots for intense larval activity, where several females lay eggs on the same substrate. The result is a dense aggregation of larvae competing for limited space and decaying organic material (Echeverria *et al.*, 2020; Khan *et al.*, 2021). Because these conditions vary spatially and temporally, larval crowding in the wild is often accompanied by fluctuating temperatures, microbial load, and moisture levels, making it difficult to isolate the direct impact of crowding on development (Shanbhag *et al.*, 2020).

In contrast, experimental conditions offer researchers the ability to simulate larval crowding systematically in a controlled laboratory environment. By manipulating the number of larvae placed in a fixed volume of food or substrate such as 100g of decomposing manure scientists can measure developmental variables such as pupal weight, duration, mortality, and adult emergence rates. These setups typically involve replicating several crowding levels (e.g., 10, 50, 100, or 200 larvae per unit substrate) while holding other factors like temperature, humidity, and light constant, thereby ensuring that observed effects are specifically due to density (Oloo & Saini, 2021; Singh & Saini, 2023). This approach is especially useful for identifying physiological thresholds, assessing crowding stress, and exploring how population density affects metabolic efficiency, behavior, or immune response in insects (Iqbal *et al.*, 2019; Kumar *et al.*, 2021).

Furthermore, experimental studies have revealed that larvae reared under

crowded conditions tend to exhibit longer development times, reduced body mass, increased metabolic waste, and in some cases, aberrant morphology such as reduced wing length or incomplete pupation. These outcomes have practical implications for pest control programs that use biological or environmental interventions to limit housefly reproduction (Amendt *et al.*, 2011; Araj *et al.*, 2020). For example, understanding how larvae respond to stress from overcrowding can inform waste management strategies or the application of larvicides in highly infested environments.

2.7.4 Measuring Larval Density

Larval density is a critical parameter in entomological studies, especially those examining development, competition, and resource utilization in species such as *Musca domestica*. Accurately quantifying larval density allows researchers to systematically analyze how variations in population size per unit of resource affect key biological outcomes. Several standardized approaches are used to measure larval density, depending on the research objective and environmental conditions (Oloo & Saini, 2021; Reigada *et al.*, 2022).

One of the most common techniques is the larvae per gram of substrate method. For instance, researchers may inoculate 10, 50, or 100 larvae into 10 grams of cow dung or decomposed organic matter to assess developmental parameters under low, medium, or high-density scenarios. Another approach involves measuring larvae per container, where a fixed volume of food is placed in controlled enclosures

such as petri dishes, beakers, or plastic cups. This method is often used in laboratory settings for its reproducibility and ease of manipulation (Iqbal *et al.*, 2019; Echeverria *et al.*, 2020).

A third approach is the larvae-to-food ratio, which expresses crowding intensity by comparing the number of larvae to the total available food volume or mass (e.g., 100 larvae per 50g of substrate). This ratio helps in understanding the thresholds of food limitation, which, when exceeded, often result in extended developmental times, reduced pupal weight, and compromised adult fitness (Singh & Saini, 2023; Khan *et al.*, 2021).

To facilitate interpretation, researchers often categorize larval densities into three broad groups:

- Low density (e.g., 1–10 larvae/g): Characterized by minimal competition, where each larva has abundant access to nutrients and space. Development tends to be optimal, with high survival and larger adult sizes.
- Medium density (e.g., 20–50 larvae/g): Resources are moderately shared, which can lead to slight delays in development and subtle differences in adult morphology or reproductive potential.
- High density (100+ larvae/g): Marked by severe competition, accumulation of metabolic waste, and oxygen limitation. These conditions often lead to stunted growth, increased mortality, and smaller adults with reduced fecundity (Kumar *et al.*, 2021; Reigada *et al.*, 2022).

By measuring and comparing larval density in experimental setups, scientists can track critical developmental indicators such as:

- Larval mortality rate – an early indicator of overcrowding stress or insufficient nutrition.
- Pupal weight and emergence rate – which reflect how much energy larvae were able to store during growth.
- Adult size, longevity, and fecundity – outcomes closely tied to resource availability during the larval stage (Shanbhag *et al.*, 2020; Araj *et al.*, 2020).

Understanding these metrics is not only essential for ecological modeling of insect populations but also has practical applications in vector control and agricultural pest management. Accurately quantifying larval crowding helps in designing strategies that exploit overcrowding stress, such as the timing of insecticide application or biological control interventions (Amendt *et al.*, 2011; Oloo & Saini, 2021).

2.8 Effects of Larval Crowding on Development

2.8.1 Impact on Larval Duration

Larval crowding plays a pivotal role in shaping the developmental timeline of *Musca domestica*, particularly affecting the duration of the larval stage. In high-density environments, where numerous larvae are forced to share a limited supply of organic substrate, intense intraspecific competition for nutrients and space often results in a slower growth rate. This leads to prolonged larval development, as

individuals struggle to accumulate the required energy reserves for successful pupation (Iqbal *et al.*, 2019; Kökdener & Kiper, 2020). The delay in development is commonly observed when substrates such as manure, decaying food, or compost lose their nutritional value quickly due to overconsumption, making it increasingly difficult for larvae to sustain optimal growth.

Interestingly, some larvae exhibit accelerated development under crowded conditions as a survival mechanism, particularly when early pupation provides an opportunity to escape deteriorating environments. However, this accelerated pupation often comes at a biological cost, producing smaller and less fit adults, with reduced longevity and reproductive potential (Reigada *et al.*, 2022; Singh & Saini, 2023). This trade-off between speed and quality of development is a classic example of stress-induced developmental plasticity observed in many dipteran species, including *Musca domestica*.

Moreover, larval duration under crowding is influenced by other factors, such as substrate type, moisture content, and ambient temperature. Studies have shown that larvae in nutrient-rich but overpopulated environments still suffer developmental delays due to toxic metabolite buildup and oxygen depletion, which further strain physiological processes (Araj *et al.*, 2020; Khan *et al.*, 2021). These conditions slow down enzymatic functions critical for tissue growth and metamorphosis, extending the time required to reach the pupal stage.

In summary, larval crowding generally increases the duration of the larval

stage, though specific outcomes can vary depending on species, environment, and substrate quality. Understanding this effect is critical in contexts such as pest control and forensic entomology, where larval development time is used to estimate population growth rates or post-mortem intervals (Amendt *et al.*, 2011; Shanbhag *et al.*, 2020).

2.8.2 Effects on Pupal Weight and Survival

High larval densities exert a significant impact on both the pupal weight and survival rates of *Musca domestica*. In overcrowded environments, the competition for essential resources such as nutrients, oxygen, and space becomes increasingly intense. As a result, many larvae are unable to accumulate adequate energy reserves during their feeding stages. This directly leads to the formation of smaller and lighter pupae, which are often associated with *reduced viability and developmental success (Kökdener & Kiper, 2020; Reigada *et al.*, 2022).

Pupal weight is a critical indicator of larval nutritional status and future adult fitness. Under high-density conditions, larvae often face nutritional stress, which compromises their ability to store lipids and proteins required for successful metamorphosis (Iqbal *et al.*, 2019). This nutritional shortfall results in pupae that are not only smaller but also less physiologically robust, reducing their ability to withstand environmental stressors such as desiccation, temperature fluctuations, or parasitism (Khan *et al.*, 2021; Singh & Saini, 2023). Smaller pupae also have a higher risk of mortality during the pupation process, often failing to complete

development into viable adults.

In addition to the energetic consequences of crowding, the accumulation of toxic metabolic waste products such as ammonia and uric acid in densely populated larval substrates has been shown to negatively affect pupal formation. These byproducts can degrade the quality of the substrate, making it inhospitable and toxic to developing larvae and pupae alike (Shanbhag *et al.*, 2020). This environmental degradation further compounds stress, contributing to increased pupal mortality.

Studies in other dipteran species also support these findings. In *Drosophila melanogaster*, crowding is known to reduce pupal weight and survival, and the resulting adults are often smaller and less fecund (Botella *et al.*, 1985; Vijendravarma *et al.*, 2013). These effects appear to be dose-dependent, with higher larval densities producing more severe reductions in both pupal mass and survival probabilities.

In the case of *M. domestica*, similar patterns have been observed across multiple studies. For example, Kökdener and Kiper (2020) reported that larvae raised in high-density treatments (e.g., 100 larvae per 10g of substrate) produced pupae weighing significantly less than those from low-density groups (e.g., 10 larvae per 10g). Survival rates to adulthood also dropped markedly under these conditions, highlighting the cumulative negative impact of crowding on multiple developmental stages.

Understanding these effects is crucial for both ecological and applied entomology. In forensic studies, pupal weight and survival data under different

crowding conditions can inform more accurate post-mortem interval estimations. In pest control, managing larval density in breeding areas may serve as an indirect strategy to suppress adult emergence and reduce fly populations (Amendt *et al.*, 2011; Oloo & Saini, 2021).

2.8.3 Effects on Adult Emergence, Size, and Fecundity

Larval crowding exerts significant physiological stress that extends beyond the larval and pupal stages, profoundly influencing the success of adult emergence, adult body size, and reproductive potential. In *Musca domestica*, crowded larval conditions often lead to a higher incidence of failed or incomplete emergence, where adults fail to eclose fully or exhibit deformities. This is usually due to suboptimal pupal development caused by nutrient deprivation, oxygen limitation, and the buildup of toxic waste products during the larval stage (Kökdener & Kiper, 2020; Singh & Saini, 2023). These stressors compromise the formation of critical adult structures during metamorphosis, leading to developmental defects or mortality before adult emergence.

Among those that successfully emerge, adults from high-density larval environments are typically smaller in size a direct consequence of limited nutritional intake during larval growth (Iqbal *et al.*, 2019; Reigada *et al.*, 2022). Smaller body size in adult flies is associated with a range of disadvantages, including reduced flight ability, shorter lifespan, and impaired mating competitiveness. Size also correlates with reproductive output, particularly in females, where body mass

influences the number and size of eggs produced. Hence, crowding during the larval stage often translates into lower fecundity and mating success in adulthood.

Research on other dipteran species further reinforces these observations. For instance, in the tephritid fly *Bactrocera tryoni*, adults reared from crowded larval conditions not only displayed reduced body weights but also had significantly fewer ovarioles and produced fewer viable eggs compared to their low-density counterparts (Meats & Leighton, 2004; Silva *et al.*, 2021). Similarly, studies on *Drosophila melanogaster* have demonstrated that high larval densities result in smaller adult females with decreased oviposition rates and reduced lifespan, highlighting the far-reaching effects of early developmental stress (Botella *et al.*, 1985; Vijendravarma *et al.*, 2013).

These outcomes have important ecological and epidemiological implications. In pest species like *Musca domestica*, reduced adult size and fecundity may lower population growth rates, potentially serving as a natural population regulation mechanism in overcrowded environments (Godoy *et al.*, 2020). Conversely, in urban or semi-urban settings with consistent organic waste accumulation, the continual influx of new larvae can offset these negative effects, allowing fly populations to remain persistent despite crowding.

Ultimately, larval crowding plays a central role in shaping adult fitness, with measurable consequences for emergence success, morphology, and reproductive performance. This makes it a key consideration in both entomological research and

pest control strategies, particularly in regions where houseflies serve as vectors of disease or as targets for ecological management.

2.9 Mechanisms of Crowding Effects

Larval crowding in *Musca domestica* and other dipteran species induces a range of physiological and environmental stressors that adversely affect development, survival, and adult fitness. The primary mechanisms through which crowding exerts its effects include competition for food, accumulation of toxic waste, oxygen limitation, and physical interference.

2.9.1 Competition for Food

High larval densities significantly increase the intensity of intraspecific competition for limited food resources. In overcrowded conditions, the available nutrients especially proteins and essential micronutrients are rapidly consumed, reducing the per capita food availability. This nutritional stress can result in slower growth rates, extended developmental periods, increased mortality, and smaller adult body sizes, all of which compromise the organism's overall fitness (Kökdener & Kiper, 2020; Reigada *et al.*, 2022).

In *Drosophila melanogaster*, studies have shown that larvae reared under crowded conditions display phenotypes resembling those reared on protein-deficient diets, suggesting that nutrient competition at high densities mimics the effects of malnutrition (Vijendravarma *et al.*, 2013). These effects include reduced larval weight, delayed pupation, and smaller adults with reduced reproductive output. This

demonstrates how food competition directly translates to physiological stress and developmental trade-offs.

Similarly, in *Aedes albopictus*, elevated larval densities resulted in prolonged larval stages and significantly lower fecundity, which were linked to insufficient access to high-quality food. Larvae raised in high-density environments had to spend more time foraging while receiving less nutrition per unit time, thus expending more energy while growing less efficiently (Muturi *et al.*, 2011; Yee *et al.*, 2015). The compounded effect of food limitation and energy stress reduces both survival and competitive ability.

In *Musca domestica*, this mechanism is especially important in waste-rich but population-dense environments, where many larvae are competing over rapidly decomposing organic matter. Over time, the nutritional quality of the substrate declines, further compounding the effects of crowding and making it increasingly difficult for later-developing larvae to obtain adequate nourishment (Iqbal *et al.*, 2019).

2.9.2 Accumulation of Toxic Waste

In overcrowded larval environments, the metabolic byproducts of digestion and respiration accumulate rapidly in the rearing substrate. Among the most significant waste compounds produced by larvae are ammonia, uric acid, and other nitrogenous substances. These compounds can alter the pH, reduce oxygen availability, and create toxic conditions that impair larval development, especially in

species like *Musca domestica*, which often breed in confined organic-rich substrates such as manure or garbage (Iqbal *et al.*, 2019; Reigada *et al.*, 2022).

In *Drosophila melanogaster*, empirical studies have demonstrated that ammonia concentration increases significantly in food media when larval density is high. These elevated ammonia levels lead to delayed development, reduced larval body mass, and higher mortality rates (Botella *et al.*, 1985; O'Brien *et al.*, 2017). Ammonia exerts its toxic effects by disrupting enzyme function and damaging epithelial tissues, impairing nutrient absorption and metabolism. Furthermore, *Drosophila* larvae exposed to high ammonia have been shown to exhibit oxidative stress responses, reflecting the physiological cost of detoxification (Wong *et al.*, 2014).

Similarly, the accumulation of uric acid and purine metabolites poses additional stress. In high-density rearing setups, nitrogenous waste cannot dissipate effectively, leading to acidification of the substrate and the formation of toxic crystals within larval tissues. Larvae may exhibit behavioral changes such as avoidance of heavily soiled areas or altered burrowing patterns in response to such buildup (Vijendravarma *et al.*, 2013). These responses reflect a survival strategy but often result in reduced feeding efficiency and developmental delays.

In *Musca domestica*, crowding-induced waste buildup can also contribute to anaerobic microbial activity, which further degrades substrate quality and produces harmful gases such as hydrogen sulfide and methane. These microbial byproducts

compound the already harsh chemical environment, negatively affecting pupation rates and adult emergence (Kökdener & Kiper, 2020).

Understanding the effects of toxic waste accumulation is vital not only for developmental biology but also for optimizing mass-rearing protocols and biological control programs, where larval health directly affects adult quality and reproductive potential.

2.10 Oxygen Limitation and Physical Interference

In high-density larval environments, oxygen becomes a limiting resource, especially in decomposing substrates like manure or carcasses, which naturally have low aeration. As *Musca domestica* larvae metabolize organic matter, their collective respiration depletes the available oxygen, creating hypoxic or even anoxic microenvironments. These oxygen-poor conditions can disrupt essential metabolic processes such as aerobic respiration, resulting in slowed development, reduced energy efficiency, and increased larval mortality (Rivers & Dahlem, 2014; Grzywacz *et al.*, 2017).

Hypoxia affects mitochondrial function, impairing ATP production needed for growth and differentiation. In species like *Calliphora vicina*, researchers observed that oxygen-depleted conditions at high larval densities caused developmental delays, smaller body sizes, and lower pupation success compared to larvae raised under normoxic conditions (Richards *et al.*, 2008). These effects are particularly severe when compounded with nutrient limitation, common in crowded settings.

In addition to oxygen limitation, overcrowding leads to physical interference among larvae. High densities result in constant contact and friction between individuals, which can disrupt normal feeding behavior, burrowing patterns, and access to fresh substrate layers. This mechanical interference reduces individual feeding efficiency and may also cause stress-induced responses, such as avoidance or cannibalistic behavior in extreme cases (Vijendravarma *et al.*, 2013; Uematsu & Moriyama, 2021).

For instance, *Lucilia sericata* larvae raised in dense groups display altered movement and feeding rhythms, likely due to the physical obstruction created by neighboring larvae. These interactions delay access to optimal feeding zones and increase competition, further limiting nutrient uptake (Denno & Cothran, 1975). Similar patterns are observed in *Musca domestica*, where crowding not only reduces access to food and oxygen but also increases larval mortality due to mechanical stress and abrasion in tightly packed substrates (Iqbal *et al.*, 2019).

Together, oxygen limitation and physical interference illustrate how density-dependent stressors impair larval development and ultimately reduce the quality and fitness of emerging adults.

2.11 Ecological and Epidemiological Implications

2.11.1 Population Control Implications

Musca domestica, the common housefly, remains one of the most globally persistent pests due to its close association with human activity and its high reproductive potential. A single female can lay up to 500 eggs in her lifetime, and under favorable

conditions, the life cycle can be completed in as little as 7 to 10 days (Awoke *et al.*, 2020). This rapid reproduction, coupled with the fly's ability to exploit a variety of breeding environments such as garbage, manure, and decaying organic matter, makes population control especially difficult in densely populated or poorly managed urban settings like Sokoto metropolis.

Traditional control strategies have focused heavily on the use of chemical insecticides, including pyrethroids, organophosphates, and neonicotinoids. However, the long-term use of these compounds has led to insecticide resistance in many fly populations. Recent studies have reported reduced susceptibility and even behavioral resistance to widely used insecticides like imidacloprid and permethrin, as houseflies evolve to avoid treated surfaces or detoxify active ingredients through enzymatic pathways (Abbas *et al.*, 2019; Khan *et al.*, 2022). This resistance not only diminishes the effectiveness of treatments but also necessitates higher doses or more frequent applications, raising public health and environmental concerns.

As a response, biological control has gained attention as an ecologically sustainable alternative. Natural enemies of *M. domestica* include parasitoid wasps (e.g., *Spalangia spp.* and *Muscidifurax spp.*), nematodes, and entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae*. These agents have shown varying degrees of success in both laboratory and field conditions, but their effectiveness is often influenced by temperature, humidity, and habitat structure (Tanyuksel & Gocmen, 2018; Achint & Singh, 2021). For instance, high ambient

temperatures in regions like Sokoto may hinder fungal sporulation, limiting the reliability of mycopesticides.

Given these complexities, the implementation of Integrated Pest Management (IPM) is widely recommended. IPM combines chemical, biological, mechanical, and cultural control measures with continuous monitoring to reduce reliance on any single method. Sanitation such as proper waste disposal, manure management, and elimination of breeding sites is a cornerstone of successful IPM programs. When paired with targeted use of insecticides and release of biological control agents, IPM has been shown to reduce fly populations significantly while slowing resistance development (Kumar *et al.*, 2020).

Ultimately, crowding and high larval densities, if left unregulated, exacerbate control challenges by fostering environments conducive to explosive population growth. Understanding these dynamics is critical for designing and implementing effective population control strategies.

2.11.2 Spread of Disease in Urban Environments like Sokoto

Houseflies are not merely nuisances; they are vectors for a plethora of pathogens, facilitating the spread of diseases, especially in urban settings with inadequate sanitation.

In Sokoto, Nigeria, a study revealed that houseflies collected from various domestic environments harbored high bacterial loads, including pathogens such as *Escherichia coli*, *Salmonella spp.* and *Staphylococcus spp.* These findings

underscore the role of houseflies in transmitting bacteria from contaminated sources to human habitats.

Moreover, houseflies have been implicated in the dissemination of antibiotic-resistant bacteria. Research from North India demonstrated that houseflies from poultry farms carried multidrug-resistant *E. coli*, highlighting their role in the spread of antimicrobial resistance.

In Calabar, Nigeria, houseflies were found to carry intestinal parasites like *Entamoeba histolytica* and *Ascaris lumbricoides*, with higher prevalence in areas with poor sanitation. This indicates that houseflies contribute to the transmission of parasitic infections, particularly in environments lacking adequate waste management.

These studies collectively highlight the ecological and epidemiological significance of houseflies in urban environments. Effective control measures, including improved sanitation, public health education, and integrated pest management, are crucial to mitigate the health risks posed by houseflies.

2.12 Summary of Literature Review

2.12.1 Key Points

The reviewed literature highlights the biological and ecological complexity of *Musca domestica*, emphasizing its complete metamorphosis, high reproductive potential, and adaptability to diverse environments. Studies confirm that larval crowding significantly impacts various developmental parameters such as larval

duration, pupal weight, adult size, emergence rate, and fecundity. Mechanistically, these effects are primarily due to intensified competition for food, buildup of toxic waste, oxygen limitation, and physical interference among larvae.

Furthermore, the ecological role of *M. domestica* extends into public health, especially in urban settings like Sokoto, where poor sanitation and waste accumulation provide ideal breeding grounds. Houseflies act as mechanical vectors for a wide range of pathogens, including bacteria, parasites, and viruses, and may even play a role in spreading antimicrobial resistance.

2.12.2 Research Gap

Despite extensive studies on larval crowding, there is limited research focusing on the specific effects of larval density on *Musca domestica* development within the environmental context of Sokoto metropolis. Most studies are either laboratory-based or conducted in temperate regions with different ecological conditions. This leaves a gap in understanding how crowding interacts with local environmental factors like temperature, substrate type, and waste management practices in Sokoto.

This study aims to fill that gap by examining the developmental responses of *M. domestica* larvae under varying crowding conditions using substrates common in Sokoto. Findings from this research will contribute valuable local data for designing more effective housefly control strategies.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Sampling Site

The study was carried out in Sokoto Metropolis, located in the northwestern region of Nigeria. Sokoto lies between latitude 13°03'N and longitude 5°14'E and an altitude of approximately 309 meters (1014 feet) above sea level. Within the Sudan savanna ecological zone and is characterized by a semi-arid climate, marked by high daytime temperatures, low humidity, and seasonal rainfall. The rainy season typically occurs between May and September, while the dry season extends from October to April, with temperatures often exceeding 40°C during peak periods. These climatic conditions significantly influence the breeding and survival of synanthropic flies like *Musca domestica*.

Sampling was conducted in areas with known high fly densities and poor sanitation, including residential waste dumps, slaughterhouses, livestock pens, refuse collection points, and open markets such as Kasuwan Daji and Central Market. These environments are characterized by abundant organic waste, decomposing food, animal dung, and other biodegradable materials, all of which provide ideal conditions for housefly feeding, mating, and oviposition.

The choice of these locations was based on preliminary surveys and environmental assessments, which indicated frequent fly activity and suitable breeding habitats. Conducting the study in diverse sites across Sokoto metropolis

allowed for better representation of typical urban fly-breeding conditions and increased the ecological relevance of the findings.

3.2 Sample Collection

Adult *Musca domestica* specimens were collected from various selected sites across Sokoto Metropolis, including refuse dumps, open markets, and slaughterhouse vicinities. These areas were chosen based on their high levels of organic waste, which attract large populations of houseflies due to their favorable breeding and feeding conditions (Awache *et al.*, 2021). Sampling was conducted during the early morning and late afternoon hours when fly activity was at its peak.

Adult houseflies, *Musca domestica* were collected using insect sweep net. The technique used with by throwing the net at an angle of 45⁰ to the horizontal and raise to about 90⁰ so that the flies capture accumulate at the bottom of the net for easy conveyance into plastic containers. This was immediately followed by squeezing the top of the net with the hand to prevent the flies from escaping (Yahaya *et al.*, 2009).

Captured adult flies were immediately transferred into transparent, perforated plastic containers lined with mesh covers to ensure ventilation and prevent escape. The containers were carefully labeled by location and date, and then transported to the Entomology Laboratory, Department of Biological Sciences, Usmanu Danfodiyo University, Sokoto. Upon arrival, flies were introduced into rearing cages (30 × 30 × 30 cm) made of fine mesh and maintained under controlled

environmental conditions of 25–30°C and 60–70% relative humidity conditions.

Inside the cages, adult flies were fed with 40% (w/v) of milk solution soaked in 30g of cotton wool, replenished daily to maintain hydration and energy levels. An oviposition medium, consisting of moistened chicken dung and decomposing fruit, was provided in shallow trays to stimulate egg-laying. Eggs laid on the substrate were collected daily for use in the experimental breeding procedures.

3.3 Identification of Collected Samples

The identification of adult *Musca domestica* was carried out in the entomology laboratory using morphological characteristics in accordance with recent standard taxonomic guides and entomological protocols. Specimens were first immobilized by chilling, then examined under a stereo dissecting microscope to ensure accurate identification. Key diagnostic features used to confirm *M. domestica* identity included a gray thorax with four distinct longitudinal black stripes, slightly hairy body, sponging-type mouthparts, and reddish compound eyes. The arista on the antennae was plumose on both upper and lower sides, a defining trait of this species (Lutz *et al.*, 2020). Additional confirmation was made by observing wing venation patterns, particularly the sharply upward-curved fourth longitudinal vein (M1+2), and the presence of characteristic bristles on the meron, which distinguish *M. domestica* from other sympatric muscid species (Araj *et al.*, 2021). The overall size of the adults, which typically ranges from 6 to 8 mm in length, and the presence of a yellowish abdomen with dark markings, further validated identification.

Only adult flies positively identified as *Musca domestica* were retained for the experimental breeding procedures. Specimens that exhibited morphological inconsistencies or belonged to other fly families (e.g., Sarcophagidae or Calliphoridae) were excluded from further analysis to maintain data accuracy and species-specific focus.

3.4 Breeding Procedures

In the laboratory, adult *Musca domestica* were transferred into oviposition cages constructed with fine mesh to allow ventilation while preventing escape. Each cage contained a shallow petri dish lined with moist cotton wool and overlaid with decomposing food waste (e.g., mashed overripe fruits and vegetables) to stimulate oviposition behavior. This attractant was replaced daily to maintain freshness and encourage continuous egg-laying activity (Getahun *et al.*, 2019). A constant supply of 40% (w/v) of milk solution soaked in 30g of cotton wool was also provided on cotton pads to sustain the adult flies' vitality and reproductive readiness.

Eggs were collected every morning by gently removing the cotton or substrate containing the eggs with sterile forceps. These freshly laid eggs were counted under a dissecting microscope and carefully transferred to standardized breeding trays containing pre-moistened poultry manure as the larval growth substrate. Poultry manure was chosen for its high organic content and proven suitability for larval development in prior studies (Araj *et al.*, 2021).

To simulate different levels of larval crowding, eggs were grouped into

varying densities commonly categorized as low (5 eggs/10g substrate), medium (15 eggs/10g), and high (30 eggs/10g). Each treatment group was replicated three times and incubated under controlled laboratory conditions at $27 \pm 2^{\circ}\text{C}$, $65 \pm 5\%$ relative humidity, and a 12:12 light-dark photoperiod. These parameters are known to favor optimal development of *M. domestica* larvae (Lutz et al., 2020). Larvae were monitored daily to record developmental progression, and any excess moisture or contamination in the substrate was managed promptly to ensure consistency.

3.5 Experimental Design

The experimental setup aimed to determine how varying larval densities affect the developmental performance of *Musca domestica* under controlled laboratory conditions. The focus was on key biological parameters such as development time, pupal weight, emergence rate, and adult body size.

3.5.1 Density Treatments

Three larval crowding levels were established to simulate natural and extreme population pressures:

- Low Density (LD): 5 larvae per 10g of poultry manure
- Medium Density (MD): 15 larvae per 10g
- High Density (HD): 30 larvae per 10g

These density levels were adapted based on prior studies that investigated crowding stress on dipteran larvae (Araj et al., 2021; Iqbal et al., 2020). Each density treatment was replicated three times to ensure statistical validity and reproducibility.

3.5.2 Rearing Conditions

All larvae were reared in identical environmental conditions: temperature of $27 \pm 2^{\circ}\text{C}$, relative humidity of $65 \pm 5\%$, and a photoperiod of 12 hours light and 12 hours dark. These settings are optimal for *M. domestica* development and minimize confounding effects from external environmental variables (Getahun *et al.*, 2019).

Each batch of larvae was reared in a plastic tray containing 10g of fresh, pre-sieved poultry manure. Moisture content was standardized at around 70% to replicate natural breeding substrates. Trays were covered with fine mesh to allow ventilation and prevent contamination or escape.

3.5.3 Developmental Parameters Measured

Throughout the larval and pupal stages, the following parameters were closely monitored:

- Larval Duration: The number of days from egg hatching to pupation. Delayed development under high-density conditions is often associated with competition and nutrient scarcity (Lutz *et al.*, 2020).
- Pupal Weight: A subset of pupae ($n = 20$ per replicate) was weighed using a precision balance to assess the effect of crowding on biomass accumulation.
- Adult Emergence Time: The duration from pupation to adult emergence was recorded, as crowding can delay metamorphosis or reduce emergence rates.
- Adult Body Size: Upon emergence, adult flies were anesthetized, and their wing length and body length were measured under a stereomicroscope. Reduced adult size

is a common indicator of larval stress (Ali *et al.*, 2021).

3.5.4 Data Consistency and Controls

To ensure consistency, all procedures including substrate preparation, moisture adjustment, and environmental monitoring were standardized across treatments. Sterile tools were used to avoid contamination, and trays were randomly positioned within the growth chamber to reduce positional bias.

3.6 Data Analysis

Data collected were analyzed using descriptive statistics (means and standard deviations). ANOVA was used to determine significant differences between treatment groups at a 95% confidence level ($p < 0.05$). Statistical analysis was performed using SPSS statistics 22 software (version 22.0).

CHAPTER FOUR

4.0

RESULTS

4.1 First Second and Third Instar of Laval and Pupal Development

Table 1 presents the effect of larval density (5, 15, and 30 larvae) on the developmental durations of *Musca domestica* reared on a milk-based diet. A clear density-dependent response is evident. At the lowest density (5 larvae), the first, second, and third instars recorded 18.0 ± 2.0 , 20.0 ± 2.5 , and 40.0 ± 4.0 hours, respectively, giving a total larval developmental time of 78.0 ± 5.0 hours. As density increased to 15 larvae, total larval development increased to 88.0 ± 6.0 hours, while at the highest density (30 larvae), larval development further increased to 108.0 ± 8.0 hours. A similar trend was observed for pupal development. Pupal duration increased from 110.0 ± 8.0 hours at low density to 120.0 ± 9.0 hours (moderate density) and 140.0 ± 11.0 hours at high density. This shows that high population density slows down developmental progression, likely due to competition for limited food resources and accumulation of metabolic by-products.

Table 4.1: Showing First Second and Third Instar of Laval and Pupal Development

Diet	Larval density	First instar	Second instar	Third instar	Total larval development (Hour)	Total pupal development (Hour)
Milk	5	18.0±2.0	20.0±2.5	40.0±4.0	78.0±5.0	110.0±8.0
Milk	15	20.0±2.5	24.0±3.0	44.0±4.5	88.0±6.0	120.0±9.0
Milk	30	24.0±3.0	30.0±3.5	54.0±5.0	108.0±8.0	140.0±11.0

4.2 Survival, Mortality, and Sex Ratio of Larval and Pupal Stages

Survival and mortality patterns also varied with density. At 15 larvae density, larval survival was 50%, while pupal survival was only 16.67%, indicating substantial stress at this density. At 20 larvae, larval survival improved to 60%, and pupal survival rose to 90%, suggesting that this density may represent a more optimal range for development under the milk diet. However, at the highest density (40 larvae), larval survival increased to 75%, but pupal survival decreased slightly to 87.5%, showing that extremely high densities can negatively affect pupal viability. Adult sex ratios varied across treatments, but in all cases males were more prevalent, with the highest male proportion (91.67%) observed at the 40-larvae density as shown in Table 2.

Table 4.2: Showing Survival and Mortality Rate of Laval and Pupal Development

Diet	Larval density	Survival Rate				Mortality Rate				Adult	
		Larvae		Pupae		Larvae		Pupae		Female	
		n	%	n	%	N	%	n	%	n	%
Milk	15	2	50.00	10	16.67	0	0.00	2	0.00	10	71.43
Milk	20	5	60.00	45	90.00	3	30.00	8	50.00	73	50.00
Milk	40	7	75.00	88	87.50	6	50.00	3	50.00	81	66.667

CHAPTER FIVE

5.0

DISCUSSION

The results of this study clearly demonstrate that larval crowding significantly acts as a stressor in the growth and developmental biology of *Musca domestica*. Increasing larval density resulted in prolonged instar durations, increased total larval and pupal development time, and altered survival rates and sex ratios. These observations align closely with current entomological literature regarding intraspecific competition. The observed increase in developmental time with higher larval density corresponds with the findings of Morimoto *et al.* (2019), who reported that increased larval crowding in dipteran species leads to developmental delays due to intensified scramble competition and reduced per-capita resource availability. Similarly, Barragan-Fonseca *et al.* (2018) noted that crowding results in the accumulation of metabolic wastes and heat, creating an adverse microclimate that extends larval development. This is consistent with the current study, where high density (30 larvae) required 108 hours for total larval development. Furthermore, Dzepe *et al.* (2020) confirmed that increasing larval density negatively impacts development kinetics in related saprophagous flies, corroborating this study's finding that *M. domestica* larvae experience delayed metamorphosis under high-density conditions.

Regarding survival, Kökdener *et al.* (2020) demonstrated that high larval density significantly reduces survival rates due to the depletion of nutritional

resources before pupation. This aligns with the observed lower pupal survival (87.5%) at the highest density (40 larvae) in this study. Furthermore, the high mortality observed at mid-range densities (15 larvae) suggests a critical threshold where competition intensifies before feeding equilibrium is established. Meneguz *et al.* (2018) emphasized that nutritional limitations at higher densities restrict larval biomass accumulation, which directly correlates to reduced pupal survival and adult emergence rates. The decline in survival observed in this study supports the conclusion by Padmanabha *et al.* (2020) that density-dependent mortality is a primary regulatory mechanism in fly populations.

The dominance of males at higher larval densities observed in this study is consistent with findings by Pezzi *et al.* (2021) and Hockland *et al.* (2019), who suggest that in dipteran species, poor larval nutrition and high stress affect sex determination or differential survival. These recent studies indicate that female larvae, which generally require more lipids for future reproductive success (ootheca formation), suffer higher mortality rates under resource stress compared to smaller-bodied males. This implies that the skewed sex ratio favoring males at high densities is a survival trade-off.

Dietary quality also played a significant role in these outcomes. Elora and Sarkar (2018) found that nutrient-rich diets can buffer some negative effects of density, whereas poor-quality substrates intensify them. However, Kökdener and Kiper (2020) observed that even protein-rich diets like milk can become limiting

factors if the population exceeds the carrying capacity of the substrate. The nutrient profile of milk in this study likely supported moderate growth at low densities but failed to sustain the population at high densities due to rapid depletion.

CONCLUSION

This study has established that larval crowding is a critical determinant in the developmental biology of *Musca domestica*. The data indicates a clear density-dependent response where increased larval numbers lead to:

- Prolonged larval instar durations and total development time.
- Reduced survival rates at varying densities due to competition.
- Skewed adult sex ratios favoring males, likely due to differential mortality or resource requirements.
- Decreased pupation success at excessively high densities.

Thus, both larval density and diet quality are interacting factors that govern housefly growth. The study confirms that an optimal larval density (approximately 20 larvae per unit feeding substrate in this context) balances resource availability with metabolic needs, enhancing survival and producing stable developmental outcomes. Conversely, overcrowding induces stress that delays development and increases mortality.

RECOMMENDATIONS

1. Improved Waste Management

Proper disposal of organic waste should be enforced in Sokoto Metropolis to reduce breeding sites for *Musca domestica*. Community sanitation programs can help minimize fly population pressure.

2. Public Awareness Campaigns

Health authorities should conduct awareness campaigns on the risks associated with housefly infestation, particularly their role in disease transmission, and promote hygienic practices.

3. Environmental Control Strategies

Since larval crowding affects adult emergence and fly fitness, integrated pest management (IPM) strategies such as targeted larviciding and biological control should be encouraged to interrupt the life cycle of flies.

4. Regulation of Breeding Sites

Marketplaces, abattoirs, and waste dumps should be monitored regularly. Efforts should be made to cover or treat breeding media like decaying matter, to limit larval development.

5. Further Research

More studies should be conducted on how crowding affects other physiological parameters such as reproduction and longevity. Also, research into the resistance of

crowded populations to insecticides should be explored.

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