Influence of Seasonal Variation on Drug Detection in Necrophagous Insects and Its Implications for Postmortem Interval Estimation

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***Abstract*—Forensic entomology has become an indispensable discipline in criminal investigations by employing insects associated with decomposing remains to estimate the postmortem interval (PMI). An important extension of this field is entomotoxicology, which examines the presence of drugs and toxic substances in necrophagous insects feeding on human remains. In situations where conventional biological specimens are unavailable because of advanced decomposition, insect larvae serve as valuable alternative samples for toxicological analysis. However, environmental conditions, particularly seasonal variation, significantly influence insect colonisation, development, and drug metabolism. Factors such as temperature, humidity, rainfall, and photoperiod affect both insect life cycles and the persistence of xenobiotics within insect tissues, thereby influencing the accuracy of PMI estimation. This review discusses the role of necrophagous insects in forensic investigations, examines how seasonal changes affect drug detection, highlights the challenges encountered in entomotoxicological analysis, and explores recent technological advances that improve forensic accuracy. The study concludes that incorporating seasonal environmental data with toxicological and entomological evidence enhances the reliability of forensic investigations.**

***Index Terms*—Forensic Entomology, Entomotoxicology, Necrophagous Insects, Postmortem Interval, Seasonal Variation, Toxicology.**

I. INTRODUCTION

Forensic entomology is the application of insect biology to legal investigations, particularly in determining the postmortem interval (PMI), or the time elapsed since death. Necrophagous insects, which feed on decomposing tissues, colonise a corpse in predictable succession and provide valuable biological evidence. Their developmental stages allow forensic scientists to estimate PMI even when traditional pathological methods are no longer reliable.

The emergence of entomotoxicology has further expanded the scope of forensic entomology. This branch investigates drugs and poisons present within insects that have fed on decomposing tissues. When blood, urine, or internal organs are no longer available due to advanced decomposition, larvae and pupae can be analysed for toxic substances. However, the accuracy of entomotoxicological investigations depends heavily on environmental conditions. Seasonal factors influence insect activity, decomposition rates, and drug metabolism, making them essential considerations in forensic interpretation.

II. NECROPHAGOUS INSECTS AND THEIR FORENSIC IMPORTANCE

Necrophagous insects are among the earliest organisms to colonise decomposing remains. The most important groups include blowflies (Calliphoridae), flesh flies (Sarcophagidae), house flies (Muscidae), carrion beetles (Silphidae), cheese skippers (Piophilidae), and dermestid beetles (Dermestidae).

Blowflies are the primary forensic indicators because they often arrive within minutes after death and lay eggs in natural body openings or wounds. Their larvae develop through predictable stages that are influenced mainly by environmental temperature. Forensic investigators estimate PMI by comparing larval

development with local weather records using Accumulated Degree Hours (ADH) or Accumulated Degree Days (ADD). Besides estimating PMI, necrophagous insects can indicate body movement, concealment, environmental conditions, and the presence of drugs or toxins within decomposing tissues.

III. ENTOMOTOXICOLOGY AND DRUG DETECTION

Entomotoxicology examines the transfer of drugs and toxic substances from decomposing tissues into insects. Larvae feeding on contaminated tissues ingest these compounds, which may remain detectable throughout larval, pupal, and adult stages.

Common substances detected in necrophagous insects include morphine, heroin metabolites, cocaine, methamphetamine, diazepam, amitriptyline, phenobarbital, pesticides, heavy metals, and ethanol. These compounds may alter insect development, directly influencing PMI estimation.

Modern analytical techniques such as Gas Chromatography–Mass Spectrometry (GC–MS), Liquid Chromatography–Tandem Mass Spectrometry (LC–MS/MS), High-Performance Liquid Chromatography (HPLC), Fourier Transform Infrared Spectroscopy (FTIR), and immunoassays enable accurate identification of drugs in insect specimens even when human tissues have decomposed extensively.

IV. SEASONAL VARIATION AND DRUG DETECTION

Seasonal variation is one of the most significant environmental factors affecting forensic entomology. Temperature, humidity, rainfall, and photoperiod influence insect behaviour, decomposition, and drug metabolism.

During spring, moderate temperatures promote rapid insect colonisation and consistent larval development. Blowflies become highly active, and drug detection is generally reliable because insect metabolism remains relatively stable.

In summer, high temperatures and humidity accelerate decomposition and insect development. Blowflies colonise corpses rapidly, and larval growth is significantly faster. However, increased metabolic activity may accelerate the degradation of certain drugs, reducing their detectable concentrations within insect tissues. Consequently, investigators must apply temperature corrections when estimating PMI.

During autumn, cooler temperatures slow insect activity and larval development. Colonisation may be delayed, but drugs often remain detectable for longer periods because metabolic degradation occurs more slowly. Decomposition also progresses at a reduced rate, extending insect succession.

Winter presents the greatest challenges for forensic investigations. Low temperatures reduce insect activity, delay colonisation, and may induce diapause in certain species. Although slower metabolism increases drug persistence, delayed insect arrival can complicate PMI estimation if seasonal conditions are not considered

V. ENVIRONMENTAL FACTORS AFFECTING DRUG DETECTION

Among environmental variables, temperature exerts the greatest influence on insect physiology. High temperatures increase metabolic rate, digestive enzyme activity, larval growth, and xenobiotic metabolism, resulting in faster degradation of drugs. In contrast, lower temperatures slow metabolism and preserve drugs within insect tissues for longer periods.

Humidity also plays a vital role in decomposition. High humidity promotes microbial growth and larval survival, accelerating tissue decomposition. Conversely, dry conditions cause tissue desiccation, reduce insect colonisation, and may preserve certain drug residues despite lower insect abundance.

Rainfall influences insect access to remains. Heavy rain can wash away eggs and larvae, delay colonisation, and reduce insect diversity. Moderate rainfall, however, maintains tissue moisture and supports larval development. Severe storms may disperse larvae from the body, complicating evidence collection and PMI estimation.

VI. DRUG EFFECTS ON INSECT DEVELOPMENT AND PMI

Certain drugs alter insect development independently of environmental conditions, increasing the complexity of forensic interpretation. Cocaine accelerates larval development, potentially causing

underestimation of PMI. Morphine slows larval growth, leading to overestimation. Amitriptyline delays pupation, while methamphetamine stimulates feeding behaviour and accelerates tissue consumption. When seasonal environmental factors interact with drug-induced developmental changes, estimation errors become even greater. Therefore, forensic investigators must integrate toxicological findings with insect developmental data, local weather records, and regional insect succession patterns to improve accuracy.

VII. CHALLENGES AND EMERGING TECHNOLOGIES

Several limitations continue to affect entomotoxicological investigations. Geographic variation influences insect species distribution, making developmental data from one region unsuitable for another. Different insect species also metabolise drugs at different rates, and environmental degradation caused by ultraviolet radiation, rainfall, or microbial activity can alter drug concentrations before specimen collection.

Recent technological developments have substantially improved forensic accuracy. DNA barcoding enables precise insect identification, while next-generation sequencing enhances species analysis. Artificial intelligence and machine learning algorithms integrate climatic data, insect developmental information, and toxicological findings to generate more accurate PMI predictions. Metabolomics, proteomics, and portable mass spectrometry further improve the detection and interpretation of drugs within insect specimens.

VIII. CONCLUSION

Seasonal variation significantly influences both drug detection in necrophagous insects and the estimation of the postmortem interval. Environmental factors such as temperature, humidity, rainfall, and seasonal insect diversity affect insect colonisation, larval development, and the metabolism of xenobiotics, thereby influencing forensic interpretations. Ignoring these variables may lead to inaccurate toxicological conclusions and erroneous PMI estimates.

The interaction between drugs and insect development further complicates forensic investigations. Substances such as cocaine, morphine, methamphetamine, and antidepressants may alter larval growth independently of environmental conditions, making it essential to interpret toxicological findings alongside seasonal climatic data and species-specific developmental models.

Recent advances in analytical chemistry, molecular biology, and artificial intelligence have considerably strengthened forensic entomology. The integration of DNA-based species identification, advanced toxicological techniques, and computational modelling has enhanced the precision of both drug detection and PMI estimation. Continued research focusing on regional developmental databases, climate change, and standardised entomotoxicological protocols will further improve the scientific reliability of forensic investigations.

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