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A REVIEW ON *Aerodramus* SPP. IN TROPICAL ECOSYSTEMS: EMPHASIS ON FOOD SOURCES FOR EDIBLE BIRD NEST (EBN) PRODUCTION

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Abstract: Edible Bird Nests (EBNs) are highly coveted commercial products of saliva secretions from swiftlets, particularly *Aerodramus* spp. These nests are renowned for their nutritional value and medicinal properties, contributing significantly to human health. The architects of these nests, the primary source of sustenance for swiftlets is insects. However, habitat degradation due to the conversion of landscapes is declining the insect populations. This review delves into the fundamental food sources of *Aerodramus* spp. in tropical ecosystems, with a particular focus on how these elements impact the production and sustainability of premium EBNs. Recent research has shed light on the key dietary resources for *Aerodramus* spp., encompassing eight distinct insect orders: *Blattodea*, *Coleoptera*, *Diptera*, *Ephemeroptera*, *Hemiptera*, *Hymenoptera*, *Isoptera*, and *Lepidoptera*. This comprehensive review provides updated challenges and suggests potential directions for future investigations within the realm of EBN research.

Keywords: Edible Bird Nests (EBNs), *Aerodramus* spp., swiftlet, food source, sustainable management.

Introduction

Swiftlets are gregarious and colonial nesters that belong to the family Apodidae. There are four known genera: *Aerodramus*, *Hydrochous*, *Schoutedenapus*, and *Collocalia* (Jamalluddin *et al*., 2019). Swiftlets, members of the *Aerodramus* genus play a crucial role in ecosystem dynamics and inhabit various tropical ecosystems.

Countries like Malaysia, Indonesia, and Thailand are examples of tropical countries interested in studying *Aerodramus fuciphagus*, commonly known as the Edible Bird Nest (EBN) swiftlet. This particular species is highly valued for producing EBNs, a delicacy with cultural and economic significance in these regions. The other prevalent contributor species to the EBN sector is the black nest (*A. maximum*) (Hao *et al*., 2019). Both *A. fuciphagus* and *A. maximum* are typically harvested for human consumption in other tropical countries in Southeast Asia, including Myanmar, Vietnam, Cambodia, and the Philippines (Chok *et al*., 2021). However, local communities in Malaysia widely breed *A. fuciphagus* for commercial purposes.

The group *Aerodramus* spp. is widely recognised for its ability to build an edible bird's nest of massive salivary secretions from specialised sublingual salivary glands, which are generally considered safe to consume (Shah & Aziz, 2014). As swiftlets consume insects, the nutrients from their prey are metabolised and incorporated into the saliva used to build their nests (Chua & Zukefli, 2016; Daud *et al*., 2021; Aguilar-Toalá *et al*., 2022). Research indicates that the nutritional content of EBN, including proteins, amino acids, and minerals is directly influenced by the diet of the swiftlets (Ahmad *et al*., 2019). EBN from different sources such as swiftlet premises versus natural caves, shows variations in chemical composition and nutrient levels, suggesting that the diet influences the EBN's nutritional profile (Chok *et al*., 2021).

For instance, protein content in EBN samples ranges from 57.9 g to 65.2 g/100 g, with the highest levels recorded during the wet season when insect prey is more abundant. This variation highlights the impact of seasonal changes in insect availability on the nutritional quality of EBN. The primary nutrient in EBN is an 80% to 90% glycoprotein, which is unique compared to other protein sources like chicken, fish, or soy (Daud *et al*., 2021). This glycoprotein is likely derived from the swiftlets' saliva used in nest building (Hui *et al*., 2021).

In its role as an exotic functional food, EBN holds immense value, particularly in Traditional Chinese Medicine (TCM) and modern medical medicine, for its ability to enhance overall health quality (Idris *et al*., 2013). Its consumption offers advantages such as reducing hypersensitivity, antioxidant properties, boosting immunity, supporting neurobiological development, and stimulating cell growth (Tan *et al*., 2021). This solidified salivary secretions of *A. fuciphagus* hold immense value in Chinese medicine and form the cornerstone of a multimillion-dollar industry (Daud *et al*., 2021; Lim *et al*., 2021).

EBN is often considered the world's most costly animal by-product, with a price ranging from US$2,000 to US$10,000 per kilogram, which is highly promoted due to its exceptional nutritional and medicinal properties (Babji *et al*., 2015; Chok *et al*., 2021). The growing demand for EBN has led to an increase in its economic value, ranging from US$1000 to US$10,000 per kilogram, with variations based on factors such as grade, shape, species, and origin (Idris *et al*., 2013; Looi & Abdul, 2016). Thus, the global practice of harvesting primarily centres around cultivating *A. fuciphagus* EBN-produced nests.

The EBN industry primarily caters to the demand from nations such as Taiwan, China, and Hong Kong (Jamalludin *et al*., 2019). The Malaysian EBN Industry has achieved total export volumes of 962 metric tonnes, valued at RM714 million in 2021 (Kevser *et al*., 2022). Almost 99% of swiftlet farms are dedicated to producing white EBNs in Malaysia (Syed-Ab-Rahman *et al*., 2016). Commencing from June 2021, there were a total of 12,954 EBN establishments officially registered with the Department of Veterinary Services (DVS) Malaysia (Kevser *et al*., 2022). In conjunction with other esteemed Eastern delicacies like sea cucumber and Asian pearls, the EBN gained acknowledgement from the Ministry of Agriculture and Food Industries Malaysia in 2021. It was included in the High Value Commodities (HVC) foods list. In short, EBN products categorised as having higher market value or premium products from Asia offer one of the crucial economic sources to many countries.

The EBN emerges as a crucial commodity for tropical countries like Malaysia, Indonesia, Thailand, and many more, particularly due to its association with the insectivorous species *A. fuciphagus*. This review contends that focusing on the preservation and sustainable production of EBN is imperative, given the vital role of tropical ecosystems as a primary food source for the thriving swiftlet population. The increasing demand for EBN, coupled with a growing spotlight on its importance, necessitates a concentrated effort to sustain production. This review delves into the intricate interplay of swiftlet habitat, distribution, foraging behaviour, and diet preferences across diverse countries. Furthermore, it critically examines challenges in maintaining EBN production and provides insightful recommendations to address current research gaps, thereby shaping the future trajectory of EBN production.

Habitat and Distributional Pattern of *Aerodramus* Spp.

Aerodramus spp. is distributed across diverse tropical habitats encompassing tropical islands, caves, and forested areas (Lourie & Tompkins, 2000; Valdez *et al*., 2011; Tarburton, 2017). These birds are commonly sighted in diverse tropical ecosystems across Southeast Asian regions, including some remote islands of the

Bay of Bengal, Myanmar, Thailand, Indochina, Hainan, the Malay Peninsula, Borneo, Java, and the Philippines (Lim & Cranbrook, 2002; Thorburn, 2015; Looi *et al*., 2015; Syed-Ab-Rahman *et al*., 2016). Given their strong habitat preferences, most swiftlets exhibit colonial nesting behaviour (Sadanandan *et al*., 2023).

One prominent member of the *Aerodramus* spp. is the *A. fuciphagus*, a grey-brown swiftlet characterised by blackish-brown upper parts and a rump that varies from whitish to brown. This particular swiftlet boasts a lifespan spanning 15 to 18 years and is famed for creating white nests. The EBN production of this species is particularly pronounced during periods of optimal rainfall and abundant food resources, as saliva production is influenced by various factors, including seasonal shifts, climate variations, and food availability (Langham, 1980).

Meanwhile, limestone caves are often considered swiftlets' natural nesting sites. They have exhibited remarkable adaptability to roosts and nests in man-made artificial houses resembling cave-like environments (Ford & Cullingford, 1976; Looi & Abdul, 2016). This adaptation has led to exclusive swiftlet farming in purpose-built structures designed to attract these birds (Rahman *et al*., 2016). These man-made nesting structures go by various names, including EBN houses, man-made houses, purpose-built houses, or artificial buildings. Existing townhouses in sub-urban areas were also renovated for this purpose. EBN houses are strategically situated in diverse settings, encompassing coastal, forested, and urban areas (Yaacob *et al*., 2021).

The distribution of swiftlets in areas hosting EBN houses can be influenced by the unique habitat landscape (Idris & Hasmawati, 2002; Adams, 2020). The availability of insects, which are vital for the survival of *Aerodramus* spp., varies significantly across different landscape patterns. Insects are particularly sensitive to environmental changes as they can experience substantial impacts resulting from shifts in climate and land use patterns within their natural surroundings (King *et al*., 2021). For example, in urban areas or areas near cities, where human habitation and pollutants are prevalent, the positioning of artificial EBN houses can impact the availability of insects (Elkins *et al*., 2004). The presence of pollutants and disturbances associated with urban environments may influence the diversity and abundance of insects in these areas, subsequently affecting the dietary options for swiftlets. Conversely, forested areas have been identified as particularly favourable and productive sites for swiftlet ranching. The forested landscape often offers a more pristine environment with a higher prevalence of natural insect populations, making it an attractive choice for swiftlets searching for abundant food resources (Yaacob *et al*., 2021).

The distribution of insect orders varies significantly across different ecosystems and can influence the dietary preferences of insectivorous birds such as swiftlets (Tong *et al*., 2021). Diptera and Hymenoptera were the primary insect orders within the coastal and inland forest ecosystems of Perhentian Island, Terengganu, Malaysia (Abdullah *et al*., 2021). Meanwhile, Coleoptera, Hymenoptera, Diptera, and Orthoptera were mostly observed in reserved forests such as the Kota Damansara Forest Reserved in Selangor, Malaysia (Rahman *et al*., 2013). Kota Damansara Reserved Forest is characterised by limited human interference, creating favourable conditions for sustaining a wide array of terrestrial insects. Similarly, national parks, exemplified by Gunung Salak in West Java, recorded high numbers of Diptera and Hymenoptera compared with other insect orders (Sutrisno, 2010). These national parks are known for maintaining natural habitats, providing an environment that sustains various insect species. In short, varying landscapes have the potential to lead to different insect diversity and abundance.

Understanding the distribution of these insects is crucial for swiftlets, which rely heavily on insect availability for their dietary needs. Swiftlets primarily feed on aerial insects and the abundance and diversity of available insects in different habitats can directly influence their dietary preferences. Therefore, the variation in insect distribution across different landscapes can impact swiftlet foraging behaviour and nutritional intake.

In instances where swiftlets are reared, plentiful food sources significantly influence their inclination to inhabit the artificial swiftlet houses erected by farmers (Ibrahim *et al*., 2009; Idris *et al*., 2014; Yaacob *et al*., 2021). Hence, it is important to note the strategic positioning of swiftlet houses as indicates the correlation between the availability of insects for swiftlets, highlighting a mutually beneficial connection with the distributional pattern of *Aerodramus* spp. and the overall quality of the EBN house's habitat landscape.

Foraging Behaviour and Dietary Preferences of *Aerodramus* Spp.

Swiftlets primarily engage in foraging for insects, which is a behaviour that is intricately linked to the presence and quality of habitats where these insects thrive (Oliver *et al*., 2014; Mursidah *et al*., 2021; Yaacob *et al*., 2021). Their foraging journeys take them through a spectrum of landscapes, including forested areas, young oil palm plantations, rubber plantations, paddy fields, rice fields, orchards, and open waters (Syed-Ab-Rahman *et al*., 2016; Burhanuddin & Noor, 2017; Petkliang *et al*., 2017; Ahmad *et al*., 2019).

Research has unveiled variations in the spatial patterns of *Aerodramus* spp. These patterns include an average core area spanning approximately 17 square kilometres, a home range encompassing about 64 square kilometres, and an average flight distance from man-made structures ranging from 2 to 6 kilometres (Burhanuddin & Noor, 2017). These findings underscore the dynamic nature of *Aerodramus* spp. spatial navigation, providing valuable insights into their foraging behaviour and their remarkable ability to adapt to human-made environments.

The foraging behaviour of *Aerodramus* spp. becomes notably intensified during the breeding season. The breeding season is a critical period when they require protein-rich prey to sustain their nestlings (Nyffeler *et al*., 2018). In Malaysia, the breeding season of *A. fuciphagus* is typically observed between October and February (Langham, 1980). Meanwhile, January to May and July to October were observed as the breeding seasons for *A. inexpectatus germani* in Southern Thailand (Petkliang *et al*., 2017). This timing aligns with the favourable environmental conditions of a wet season as it provides ample resources for swiftlets to find food and nourish their young during this critical reproduction period (Langham, 1980; Petkliang *et al*., 2017).

The foraging behaviour of swiftlets is further influenced by weather conditions, the cyclical progression of the insect life cycle across different seasons, and the specific feeding locations chosen by these agile birds. These birds can remarkably modify their foraging activities in response to various climatic variables such as temperature, humidity, and wind patterns (Syed-Ab-Rahman *et al*., 2016). Note that certain insects may be more or less active depending on weather conditions, directly impacting prey availability for swiftlets (Petkliang *et al*., 2017). In tropical climate countries such as South India and Madagascar, some insects, including litter insects, appear more abundant during wetter periods (Anu *et al*., 2009; van Dijk *et al*., 2024). Swiftlets adeptly adjust their foraging strategies to align with prevailing weather conditions (Fujita & Leh, 2019; Chok *et al*., 2021). This highlights their ability to capitalise on opportunities presented by changing environmental factors.

The seasonal progression of the insect life cycle represents another significant influence on swiftlet foraging. Insects undergo distinct developmental phases that can vary in prevalence throughout the year (Syed-Ab-Rahman *et al*., 2016). On the other hand, swiftlets are known to adapt their foraging strategies to target specific stages of the insect life cycle that are more abundant during particular seasons (Chok *et al*., 2021; Aranda *et al*., 2021). This foraging behaviour allows them to efficiently exploit the seasonal fluctuations in insect populations to ensure a consistent food supply for themselves and their nestlings.

Moreover, the strategic selection of feeding locations ensures a consistent and abundant supply of prey for these birds. This is evidenced by the discerning choices of swiftlets based on factors such as vegetation types and proximity to water sources (Janzen, 1973; Manchi *et al*., 2010; Petkliang *et al*., 2017). The adaptability of foraging behaviour is further highlighted in studies revealing that swiftlets display intriguing feeding patterns depending on their habitat, whether natural limestone caves or man-made birdhouses. This indicates their ability to thrive in diverse environments (Hao *et al*., 2015; Petkliang *et al*., 2017; Johnson *et al*., 2018). For example, those inhabiting natural limestone caves were observed foraging in proximity to nearby forest reserves, which are rich in insect life (Lourie & Tompkins, 2000; Lim & Cranbrook, 2002).

In contrast, swiftlets residing in man-made birdhouses displayed distinct foraging patterns. The dietary preferences are influenced by their choice of foraging areas and their proximity to urban environments (Langham, 1980; Chan *et al*., 2019). For instance, swiftlets were observed foraging in rural settings above nearby gardens and oil palm plantations (Syed-Ab-Rahman *et al*., 2016). Meanwhile, in urban areas, *Aerodramus* spp. showcased their adaptability to human-altered landscapes when they were seen foraging over abandoned greenbelts surrounding the vicinity (Hao *et al*., 2015).

Since swiftlets are predominantly insectivorous, their foraging behaviour clearly indicates their dietary preferences, encompassing a broad spectrum of insect orders. Notably, a profound discovery was uncovered in a Penang shophouse. This investigation disclosed that the food bolus of *A. fuciphagus* predominantly consists of a diverse array of insects, with Hymenoptera, Ephemoptera, Homoptera, and Diptera identified as major diet preferences as documented by Langham in 1980.

In 2000, Lourie and Tompkins conducted a study on swiftlet species (*A. fuciphagus*, *A. maximus*, and *A. salangana*) in Niah Forest and Penang Forest, revealing their preference for ants, fig wasps (Hymenoptera), Nematocera, and Brachycera (Diptera). This aligns with a report on swiftlets' diet in Sabah, emphasising Diptera and Hymenoptera (Lim & Cranbrook, 2002).

In 2011, Mariana swiftlets in New Mexico preferred Hymenopterans (Valdez *et al*., 2011). Conversely, Malaysian oil palm plantations revealed Dipterans, Hymenopterans, and Homopterans as the favoured prey (Syed-Ab-Rahman *et al*., 2016). Additionally, research conducted on Atiu swiftlets in the South Pacific highlighted their dietary reliance on Hymenoptera, Lepidoptera, and Blattodea despite their lack of EBN production (Tarburton, 2017). In Perak, Malaysia, a DNA analysis study unveiled *A. fuciphagus* feeding on a varied diet comprising Diptera, Hemiptera, Coleoptera, Hymenoptera, Blattodea, and Odonata across urban, agricultural, and mixed-use landscapes (Chan *et al*., 2019).

Based on previous reports, Table 1 compares swiftlet diets across different countries and land use patterns or habitats. There are several different species of swiftlets compiled from various studies, which include White-nest swiftlet (*A. fuciphagus*), Black-nest swiftlet (*A. maximus*), Mossy-nest swiftlet (*A. salangana*), Mariana swiftlet (*A. bartschi*), and Atiu swiftlet (*A. sawtelli*) (Table 1).

Swiftlets' dietary preferences are closely tied to the food resources available in their specific environments (Hao *et al*., 2015; Chan *et al*., 2019; Tong *et al*., 2021). Previous reports recorded that these swiftlets tend to favour two specific insect orders, Diptera and Hymenoptera, as their primary prey (Table 1). However, this preference is not fixed. It reflects their inclination to consume what is most abundant and accessible in their immediate environment (Manchi *et al*., 2010; Petkliang *et al*., 2017; Tong *et al*., 2021).

Table 1: Comparison of swiftlet diets across different countries and land use patterns or habitats

Country	Swiftlet Species	Land Use Patterns/Habitat	Man-made/ Natural	Diets	References
Malaysia	*Aerodramus fuciphagus*	Sub-urban	Man-made	Hymenoptera, Ephemeroptera, Homoptera, Diptera	Langham (1980)
Malaysia	*Aerodramus fuciphagus*	Forest area of a cave	Natural	Hymenoptera, Diptera	Lourie & Tompkins (2000)
Malaysia	*Aerodramus maximus*	Forest area	Natural	Hymenoptera, Diptera	Lourie & Tompkins (2000)
Malaysia	*Aerodramus salangana*	Forest area of a cave	Natural	Hymenoptera, Diptera	Lourie & Tompkins (2000)
Malaysia	*Aerodramus* spp.	Forest/wild area	Natural	Diptera, Hymenoptera	Lim & Cranbrook (2002)
Malaysia	*Aerodramus fucihagus*	The rural area of oil plantations	Man-made	Diptera, Hymenoptera, Homoptera	Syed-Ab-Rahman *et al*. (2016)
Malaysia	*Aerodramus fuciphagus*	Urban, mono-crop, and mixed-use	Man-made	Diptera, Hemiptera, Coleoptera	Chan *et al*. (2019)
New Mexico	*Aerodramus bartschi*	Tropical island	Natural	Hymenoptera	Valdez *et al*. (2011)
New Zealand	*Aerodramus sawtelli*	Coastal of an island	Natural	Hymenoptera, Lepidoptera, Blattodea	Tarburton (2017)

Challenges and Future Direction of EBN Production

The EBN industry faces considerable challenges as environmental changes continue to disrupt the delicate balance between *Aerodramus* spp., their habitats, and the availability of insects. Swiftlets primarily consume flying insects, which provide essential nutrients for growth and reproduction (Mursidah *et al*., 2021). These insects are rich in proteins and essential fatty acids, both crucial for swiftlet health, particularly in supporting their immune system and reproductive success (Looi & Omar, 2016; Mursidah *et al*., 2021).

Recent studies have underscored the global decline of insect populations, reporting a 40% reduction in key species including *Lepidoptera*, *Hymenoptera*, and *Coleoptera*, primarily due to habitat loss, agrochemical pollution, and invasive species (Sánchez-Bayo & Wyckhuys, 2019). Such declines in insect availability directly threaten swiftlet nutrition. Insects are a critical source of nutrients including proteins and lipids, vital for nest-building and reproduction. Poor nutrition weakens swiftlets' immune systems, making them more susceptible to diseases, reducing reproductive success, and ultimately impacting the quality as well as quantity of EBNs (Langham, 2008; Looi & Rahman, 2016).

The ongoing destruction of natural habitats—due to deforestation, agriculture, urbanisation, and mining—exacerbates this problem (Mantyka-Pringle *et al*., 2015; Sasaki *et al*., 2021). As the availability of insect-rich habitats decreases, swiftlets are forced to travel greater distances to forage. Studies have shown that swiftlets roosting in man-made houses travel up to 30 kilometres to reach forested areas, where insect biodiversity is more abundant (Fujita & Leh, 2019). However, this long-distance commuting increases energy expenditure and reduces the energy available for reproduction and nest construction, which leads to lower nest quality (Burhanuddin & Noor, 2017; Ahmad *et al*., 2019; Alpandi *et al*., 2022). When swiftlets expend excessive energy commuting, they have fewer resources to invest in critical activities like reproduction and nest maintenance, resulting in lower reproductive rates and poorer nest quality (Ahmad *et al*., 2019; Alpandi *et al*., 2022). Additionally, swiftlets may struggle to meet their nutritional needs if commuting distances increase without a corresponding increase in food availability. This nutritional shortfall can further reduce their reproductive success and diminish the quality of the nests they produce (Costa *et al*., 2015).

Habitat degradation also alters the landscape in secondary areas near human settlements where swiftlets may be forced to forage. These secondary habitats typically offer lower insect diversity and quality, further straining the nutritional health of swiftlets (Mursidah *et al*., 2021). As a result, the dietary deficits encountered by swiftlets in such environments can negatively affect their reproductive output, clutch size, and overall population density (Johnson *et al*., 2018).

The decline in insect populations and the degradation of natural habitats are part of a broader ecological imbalance that threatens the sustainability of the EBN industry. The dependence of swiftlets on diverse, insect-rich habitats means that any further destruction or pollution of these environments will reduce their food sources, and by extension, their ability to thrive. Consequently, swiftlet populations may dwindle, and EBN production could decline significantly.

In addition, the EBN industry's ongoing expansion often involves replacing traditional nesting sites with man-made houses, which may not be sustainable if it continues to encroach upon or degrade these vital forest habitats. Rather than expanding the number of EBN houses, focusing on maintaining existing houses with proper practices and ensuring habitat conservation is crucial. Hence, implementing sustainable management practices in existing EBN houses and restoring natural habitats will support the diverse insect populations that swiftlets rely on. This investigation of the impact of habitat loss on EBN production reveals significant challenges. Note that addressing these issues requires filling critical gaps in understanding through comprehensive assessments of habitat impacts, long-term monitoring of swiftlet populations, and evaluation of economic and ecological trade-offs between EBN production and habitat conservation efforts.

Besides, swiftlets demonstrate remarkable navigational abilities across diverse landscapes critical for their foraging behaviour and nesting habits (Syed-Ab-Rahman *et al*., 2016; Burhanuddin & Noor, 2017; Petkliang *et al*., 2017; Ahmad *et al*., 2019; Montiani-Ferreira *et al*., 2022). Meanwhile, studies on their specific foraging strategies in varied landscapes are limited. Their capability to segregate prey species through niche breadth remains a significant area of research interest. For example, understanding swiftlets' efficient prey segregation can guide habitat management strategies around EBN houses by optimising their placement to maximise foraging efficiency while minimising ecological impact. Other than that, stakeholders can develop sustainable practices that support swiftlet populations and enhance EBN production by gaining insights into swiftlets' adaptive behaviours and home range dynamics in response to human-altered environments. This dual approach promotes sustainable EBN production and contributes to habitat conservation efforts. This can further ensure the long-term viability of swiftlet populations and the ecosystems they rely on.

Furthermore, the challenge of accurately identifying swiftlets' diet is a significant consideration. Common methods such as collecting guano samples and food boluses have been employed to determine swiftlets' diets. Another technique involves the gentle agitation of birds to obtain their food bolus, known as tartar emetic, which utilises diluted Antimony Potassium Tartrate (APT) (Sing-tyan *et al*., 2017). It is crucial to highlight that obtaining ethical approval is imperative before applying this method as it involves live, healthy swiftlets.

A significant limitation arises, although these techniques are favoured for their reliability. These methods primarily enable identification only up to the order level due to the fragmented or partially digested insect components in retrieved samples. Consequently, addressing this research gap and advocating for adopting more advanced methods becomes essential.

To surmount this challenge and achieve higher precision in insect identification, a potential avenue involves employing DNA molecular analysis. This approach holds promise in identifying insects down to the genus level, offering a solution to enhance the accuracy and depth of dietary analysis for swiftlets. As a case in point, a study has approached this technique by utilising high-throughput sequencing, an analysis of total DNA extracted from faecal samples. However, the result was shown to be at the order level (Chan *et al*., 2019). This highlights the need for further refinement and development of DNA-based methods to unlock their full potential. Suppose it is possible to precisely identify the specific insects that swiftlets prefer. In that case, it opens the possibility of mass-rearing those insects, thereby supporting the dietary needs of swiftlets in natural and artificial habitats. This advancement would improve the understanding of swiftlet ecology and contribute to more sustainable and effective management practices within the EBN industry.

In considering the future direction of EBN solutions, a holistic approach is necessary to ensure the sustainability of swiftlet populations and their vital food sources. The well-being of *Aerodramus* spp., their habitat, distribution patterns, foraging behaviour, and dietary preferences are closely intertwined with the availability of suitable food sources in tropical ecosystems. One key strategy is the implementation of regulations that set harvest limits for EBN. These limits are crucial to prevent overexploitation, as swiftlet populations are highly sensitive to disturbances and excessive harvesting (Benjakul & Chantakun, 2022). Therefore, establishing legal restrictions on the number of nests harvested annually can mitigate the risk of depleting swiftlet populations and their essential insect food sources.

A suggestion can be made around utilising existing EBN structures to create a comprehensive and efficient swiftlet ranching protocol. A practical implementation of this idea could involve DVS Malaysia taking the lead in formulating meticulous guidelines for ranchers. By guaranteeing sustainable and high-quality production of EBN from these current structures, this approach maintains the integrity of habitats and deters the construction of unnecessary houses that may not greatly benefit the EBN industry. Thus, it adheres to the principles of responsible resource management and industry sustainability.

Next, sustainable farming practices also play a pivotal role in the future of EBN production. Encouraging controlled swiftlet farms that replicate natural habitats can alleviate the pressure on wild swiftlet populations. These farms should adhere to ethical guidelines and prioritise eco-conscious methods. This can ensure that swiftlets can access abundant and diverse insect populations (Ibrahim *et al*., 2009; Fujita, 2012; Alpandi *et al*., 2022).

In addition, a concentrated effort directed toward investigating the preferred land use patterns of swiftlets for their food sources while also understanding the abundance of their diet could present a significant avenue of exploration (Ahmad *et al*., 2019; Outhwaite *et al*., 2022). Such investigations can unlock new opportunities within the EBN industry and carry the profound potential to raise awareness about the importance of environmental preservation. Protecting natural swiftlet habitats such as coastal areas, reserved forests, and national parks is essential for maintaining ecological balance.

Moreover, these ecosystems provide diverse niches for various insect species to thrive, sustaining swiftlet populations (Forister *et al*., 2019; Mckenna *et al*., 2019). Conservation efforts should focus on minimising human disturbances and preserving these critical habitats. Consequently, this could enhance the flourishing trade of EBN for exportation and serve as a compelling reminder of the urgency of safeguarding our planet's delicate ecosystems.

Last but not least, public education plays a vital role in shaping the future of EBN sustainability. Raising awareness about the importance of sustainable sourcing is crucial. Public education campaigns can inform consumers about the ecological significance of swiftlets and the need for responsible harvesting practices. An informed consumer base can drive demand for sustainably sourced EBN to encourage a shift toward environmentally conscious choices.

Conclusions

In conclusion, the dietary preferences of *Aerodramus* spp. are intricately tied to their habitat, distribution patterns, foraging behaviour, and the broader tropical ecosystems they inhabit. These swiftlets showcase impressive adaptability upon revealing the diverse dietary compositions influenced by varied land use patterns and nesting locations. This adaptability is crucial as it directly impacts the production of the highly esteemed EBN, recognised for its medicinal value. Despite the importance, challenges exist in sustainable EBN production. Addressing these challenges becomes paramount for the continued coexistence of swiftlets, their tropical ecosystems, and the prised EBN they produce. Future endeavours should prioritise understanding and managing these aspects since it underscores the critical role of food sources in maintaining this delicate ecological balance.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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