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Swiftlets and Edible Bird's Nest Industry in Asia

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Abstract – Swiftlets are small insectivorous birds which breed throughout Southeast Asia and the South Pacific. Among many swiftlet species, only a few are notable to produce edible bird's nests (EBN) from the secreted saliva during breeding seasons. The taxonomy of swiftlets remains one of the most controversial in the avian species due to the high similarity in morphological characteristics among the species. Over the last few decades, researchers have studied the taxonomy of swiftlets based on the morphological trade, behavior, and genetic traits. However, despite all the efforts, the swiftlet taxonomy remains unsolved. The EBN is one of the most expensive animal products and frequently being referred to as the "Caviar of the East". The EBN market value varies from US$1000.00 to US$10,000.00 per kilogram depending on its grade, shape, type and origin. Hence, bird's nest harvesting is considered a lucrative industry in many countries in Southeast Asia. However, the industry faced several challenges over the decades such as the authenticity of the EBN, the quality assurance and the depletion of swiftlet population. Furthermore, there is limited scientific evidence regarding EBN's medical benefits as claimed by manufacturers. This paper reviews the taxonomy of swiftlets, its morphological characteristics, the challenges currently encountered by the industry, and finally the composition and medical benefits of EBN.

Keywords: Edible bird's nests (EBN), swiftlets, swiftlet farming industry, taxonomy

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Introduction

Palaeotropical swiftlets including the genera of *Aerodramus*, *Collocalia* and *Hydrochous* are small insectivorous birds which can be found throughout Southeast Asia and the South Pacific. Swiftlets generally form large colonies in dark caves or cave-like environments due to its ability to navigate in darkness using echolocation (Chantler & Driessens, 2000; Medway, 1962). Selected species are notable for their ability to produce edible nests which primarily comprise mucin-like glycoproteins that comefrom the cemented salivary secretion. White-nest swiftlets (*Aerodramus fuciphagus*) and black-nest swiftlets (*Aerodramus maximus*) are highly prized as the premium grade nests as both are formed entirely or mainly from the saliva secretion with non-incorporation of other materials such as grass, mud and feather (Lim, Cranbrook & Zoologist, 2002). Hence, bird's nest harvesting is considered as a lucrative industry in many countries in Southeast Asia (Gausset, 2004).

Malaysia is currently the third largest EBN production country, which contributes approximately 9% of the global supply in 2006, after Indonesia (60%) and Thailand (20%). However, the swiftlet farming in Malaysia has a long and illustrious history where it started as a cottage style operation at a natural cave area (Gausset, 2004). As the swiftlet farming industry continued to expand, the suppliers started to build artificial man-made habitats which resemble the natural cave environment for swiftlets in order to maintain the supply chains (Tan et al., 2014). The swiftlet farming industry in Malaysia has been growing drastically over the last decade. Before 1998, 900 swiftlet houses or farms were estimated in Malaysia. However, by the end of 2013, the numbers of active swiftlet farms in Malaysia were estimated to be 60,000 units (Malaysia Economic Transformation Programme Annual Report, 2013). However, the overall value of Malaysia's EBN is generally unstable and is mainly determined by the quality of raw bird's nests which is based on various factors such as size, shape (half-cup , stripe, or biscuit), type (white, black, or grass), origin (man-made house or natural cave) and colour (white, yellow, or red).

Despite many efforts done by various agencies, swiftlet ranching and EBN industry still face several major drawbacks which hinder the development of the swiftlet industry. These drawbacks lead to the unstable market price of raw and processed EBN in both local and international tradings. Such challenges include the adulteration of EBN, the depletion of the swiftlet population, and poorly traceable and undefined quality standards of raw and processed EBN from different sources.

Over the years, the method of EBN grading and authentication changed drastically due to the technology development and availability. Previously, EBN manufacturers used to grade EBN and detect adulteration by observation based on colour and texture. Such a method was somewhat subjective and based on the experience of individuals. Since then, researchers have developed various methods based on the analysis of EBN's composition, microscopic observation and genetic analysis for EBN grading, and to identify fake or adulterated EBN (Ma & Liu 2012; Marcone, 2005; Wu et al., 2010). However, each method has its own advantages and disadvantages, and no single method is able to define the quality of EBN.

In order to establish a sustainable swiftlet ranching and EBN industry, various agencies from both the government and industrial sectors have to cooperate in establishing the best practices in swiftlet husbandry and management as well as the complete value chain processes in producing EBN as value-added products in meeting the requirements of local and overseas markets.

Swiftlet taxonomy

The classification of swifts (Apodidae) and swiftlets (Apodidae: Collocaliini) have been controversial in terms of phylogeny and taxonomy. The genera of swifts and swiftlets have been shuffled several times based on various parameters such as the archaeological evidence, the nest morphological characteristics, the ability to echolocate, the nesting area and the molecular evidence (Brooke, 1970; Goh et al., 2001; Lee, Clayton, Griffiths & Page, 1996; Mayr, 1940; Medway 1962; Thomassen et al., 2003). Originally, swift (*Apodi*) was classified under the same order with hummingbirds (*Trochili*). However, the ability to use saliva as the sticking material for swiftlet's nest and its enlarged salivary glands in both sexes during breeding seasons distinguished swiftlets from swifts (Clark, 1906; Lowe, 1939). Despite the high morphological similarities between the swift and swiftlet families, some of the morphological characteristics such as the toes, feathering and nesting habit, do act as a distinguishing characteristics (Sick, 1948).

A swiftlet is a small insectivorous bird which forms the *Collocaliini* tribe within the swift family (*Apodidae*). The swiftlet family is among the complicated groups in bird taxonomy due to the lack of differences in morphological characteristics (Chantler & Driessens, 2000). Originally, Gray (1841) proposed that all swiftlet species be placed into a single genus, *Collocalia*, and such a taxonomy classification system was used for over a century. In 1957, the ability of echolocation was discovered in certain swiftlet species by Medway (1957). Subsequently, Brooke (1970 & 1972) suggested that the ability of several swiftlet species to echolocate as a distinctive characteristic should be considered in the swiftlet taxonomy. Brooke (1970 & 1972) split the genus *Collocalia* into three different genera which are non-echolocating swiftlets (*Collocalia*), non-echolocating giant swiftlets (*Hydrochous*) and echolocating swiftlets (*Aerodramus*). However, subsequent studies proposed that these three genera should either be combined into a single genus, *Collocalia,* (Chantler & Driessens, 2000; Salomonsen,

1983) or split into several genera by incorporating new sister groups such as *Chaeturini* and *Apodini* to the pre-existing genus based on various morphological and behavioral characteristics (Sibley, 1990).

Due to the limitation of morphological identification, Lee et al. (1996) sequenced the cytochrome-b mitochondria DNA of swiftlets in order to rearrange the swiftlet taxonomy based on molecular evidence. However, the authors only sequenced a limited portion (406 bp) of the complete cytochrome-b DNA, leaving many unanswered questions. Thomassen et al. (2003) further sequenced the complete cytochrome-b gene and the data generated support swiftlet monophyly. However, the placement of Hydrochous within the swiftlet phylogenetic tree was poorly explained in the study due to the high amount of variation in cytochrome-b gene of the *Hydrochous* species. In another study, Jordan, Johnson and Clayton (2004) incorporated more swifts and swiftlet species and used an additional of NADH dehydrogenase subunit-2 gene (ND2) in the analysis to generate better and more comprehensive taxonomy arrangement compared to previous results. The study supported the findings of swiftlet monophyly and subdivided the swiftlets into two tribes, *Aerodramus* and *Collocalia*, which were thought to be impossible in echolocating until recently. In contrast to previous publications, Jordan et al. (2004) proposed that the echolocation ability is no longer attributed to a single genus since the pygmy swiftlet (*Collocalia troglodytes*) is also able to echolocate that was previously grouped under non-echolocating *Collocalia*. Hence, echolocation is not an accurate parameter for the swiftlet taxonomy classification. In another study, Thomassen, Den Tex, De Bakker and Povel (2005) incorporated two additional sequences 2S rRNA (12S) and nuclear non-coding b-fibrinogen intron 7 (Fib7) into the pre-established cytochrome-b sequence data set in order to investigate the phylogenetic relationships of *Hydrochous gigas* with other members of the swiftlets. The findings from the study indicated that *Hydrochous gigas* is the sister group of *Aerodramus* and classified the swiftlets into a single genus *Collocalia* as proposed earlier by Gray (1841). Based on current information, the taxonomy and the naming of swiftlet species still remain unclear where the monophyly grouping of these birds requires further study.

Swiftlet morphology

Most swiftlet species in Malaysia are greatly alike and difficult to be identified based on their morphological characteristics. Sims (1961) reported that seven swiftlet species were found within Malaysia, namely *Aerodramus francica*, *Aerodramus vestita*, *Aerodrames brevirustis*, *Aerodramus fuciphaga*, *Aerodramus maximus*, *Collocalia esculenta* and *Hydrochous gigas*. Only the last two species can be readily identified; *C. esculenta* is based on the unique colour pattern and *Hydrochous gigas* is generally greater in body size compared to other species. The remaining five species are superficially alike and occasionally colonized at similar habitats.

In Malaysia, nests of white-nest swiftlets (*Aerodramus fuciphagus*) and black-nest swiftlets (*Aerodramus maximus*) which are solely or mainly constructed out of saliva, are harvested for commercial purposes (Viruhpintu, Thirakhupt, Pradatsundarasar & Poonswad, 2002). Other swiftlet species produce nests constructed largely out of vegetation such as grass, feather and mud which lack economic value. *Aerodramus fuciphagus* and *Aerodramus maximus* are almost identical in morphological characteristics, apart from the glossiness of the feather and tarsal feathering which require close observation that is rather subjective (Oberholser, 1906). A swiftlet's eyes are large, dark and short, and the hooked bills of all swiftlets are black like the legs and feet. These birds lost the ability to perch and mostly hang from the nests or stand on the hock joints which do not involve the use of metatarsal (Lim et al., 2002).

The white-nest swiftlet (*Aerodramus fuciphagus)* is small with blackish brown upper part, and the rump colour ranging from whitish to brownish. Generally, a white-nest swiftlet has shorter wings, a deeper tail-notch, and a darker underpart compared to its close homolog, black-nest swiftlet. *Aerodramus fuciphagus* and *Aerodramus maximus* have body length of 10.619 cm and 10.937 cm, outer tail length of 4.214 cm and 4.405 cm, wing cord of 11.889 cm and 12.963 cm, tarsus length of 0.997 cm and 1.147 cm, and lastly an expanded wing length of 27.217 cm and 29.695 cm, respectively (Looi, Aini, Zuki & Omar, 2015).

Swiftlet behavior characteristics

Swiftlet life cycles

The life cycles and behaviors of swiftlets in various habitats have been observed and studied in detail over the century. Swiftlets are known as monogamous and breeders with high nest site fidelity (Viruhpintu et al., 2002). Swiftlets start to breed at the age of one-year-old (Nguyen, Quang & Voisin, 2002). However, breeding seasons and the period of breeding activities such as the nest-building, egg laying, egg incubation and young rearing vary across different species and geological regions. These variations may be influenced by climatic effects such as the amount of rainfall, air humidity, and food availability (Langham, 1980). In general, the breeding cycle of a swiftlet species is approximately 92–120 days with a clutch size of two eggs **(**Langham, 1980; Lim et al., 2002; Viruhpintu et al., 2002). *A. maximus* produces a single egg clutch with an approximate egg size of 16-25 mm; while *A. fuciphagus* normally lays two eggs per clutch with approximate egg size of 10-15mm. The incubation and fledging periods for both *Aerodramus fuciphagus* and *Aerodramus maximus* were 23±3 days and 43±6 days, respectively (Langham, 1980; Lim et al., 2002; Medway, 1962). Swiftlets breed throughout the year but mostly from October to February (Langham, 1980). Swiftlets take approximately 30-45 days to complete a single nest during the breeding season and about 60-80 days in non-breeding season (Aowphol, Voris, Feldheim, Harnyuttanakorn & Thirakhupt, 2008). According to Marcone (2005), nests are built almost exclusively by male swiftlets in approximately 35 days; however Lim et al (2002) reported that both male and female participate in the nest building.

Growth

Based on Reichel, Collins, Stinson and Camacho (2007), the observation on Mariana swiftlets at Saipan area showed that newly hatched nestlings were pink skinned and naked, devoid of any natal down. Starting from day 4-6, pin feathers appeared as dots beneath the skin on the dorsum and wings. By day 9, pin feathers were visible on all tracts and by day 13, the pin feathers start to erupt through the skin. By day 17-19, feathers began to emerge. Swiftlet nestlings started to open their eyes by Day 20 and flight feathers were approximately 50% grown by Day 37. Nestlings are fully feathered and capable of flying short distances by Day 45-47. On average, swiftlet species fledged by Day 39.8-53.3 but this varies among different species and geological areas. The wing of a newly hatched nestling was measured to be approximately 6 mm long and it grew slowly until the primary pin feathers erupted on Day 12-13. A swiftlet's wing length developed in a linear fashion from Day 13 to 45. Similar to wing development, the tail length increases linearly from Day 15 to 45. Nestlings on Day 1 weigh 1.11±0.06g. Thereafter, the nestlings grew slowly to reach approximately 8.21 g at Day 29. However, the incubation period, the age of fledging, the clutch size and the growth rate may vary among species and geographical areas (*Table 1*).

Table 1: Growth rate of various swiftlet species

Reproductive parameters of different swiftlet species					
Species	Incubation period (days)	Age at fledging (days)	Clutch size	Source and location	Reference
Mariana Swiftlet (*Aerodramus bartschi*)	22.95	47	1	Saipan	Reichel et al. (2007)
White-nest Swiftlet (*Aerodramus fuciphagus*)	25.1 ± 0.3	39.8 ± 2.6	2	Singapore	Lee and Kang (1994)

White-nest Swiftlet (*Aerodramus fuciphagus*)	23.0 ± 3.0	43.0 ± 6.0	2	Malaysia	Langham (1980)
Black-nest Swiftlet (*Aerodramus maximus*)	25.5 ± 2.2	45.9 ± 2.6	1	Singapore	Lee and Kang (1994)
Black-nest Swiftlet (*Aerodramus maximus*)	28.0	58.5	1	Sarawak	Medway (1962)
Mossy-nest Swiftlet (*Aerodramus vanikorensis*)	23.0	48.5	1-2	Sarawak	Medway (1962)
White-rumped Swiftlet (*Aerodramus spodiopygius*)	23.0	46.0	2	Fiji	Turburton (1986)
Mountain Swiftlet (*Aerodramus hirundinaceus*)	NA	53.3 ± 1.2	1	New Guinea	Turburton (2003)
Clossy Swiftlet (*Collocalia esculenta*)	21.5	42	2	Sarawak	Medway (1962)

Habitat

Natural habitat

Swiftlets breed naturally inside limestone caves and they cling to the surface of the walls and ceilings (Ford & Cullingford, 1976; Langham, 1980; Lim et al., 2002). Several researchers have studied the influence of various nest-site characters and the relationships between nesting success and environmental factors (Jehle, Yackel Adams, Savidge & Skagen, 2004; Phach & Voisin 1998; Sankaran 2001; Viruhpintu et al., 2002). For example, Jehle et al. (2004) investigated the nesting success based on daily observations from the date of egg laying at various environments. Viruhpintu et al. (2002) reported that both *Aerodramus fuciphagus* and *Aerodramus maximus* constructed their nests at different areas of the cave wall to avoid interspecific competition for nestling space, and both species selected nestling areas by unique characteristics and not randomly. However, *Aerodramus fuciphagus* is commonly distributed at low altitude natural cave up to 1280 m highland or building while *Aerodramus maximus* normally roosts from sea level to a height of 1830 m (Lim et al., 2002). Researchers speculated that *A. maximus* is able to fly and live at higher altitude due to its larger body and larger wings.

Among the selection criteria of a nestling site that may influence the breeding success are: a) the texture of the rock surface at the nest-site: rough, slightly rough and smooth rock surface; b) the presence and absence of the nest support at the nest site; c) the inclination of the cave wall at the nest-site location: flat, inwardly inclined and outwardly inclined wall; e) micrometeorological conditions such as the mean temperature (°C) and the relative humidity (%) (Sankaran, 2001). In general, a nesting area on a higher, inward-inclining, smooth and concave surface is preferred over a low and rough cave wall. A smooth and concave surface provides better support to nest building and higher nestling success, while higher and inward-inclining areas prevent eggs and nestlings from predators (Viruhpintu et al., 2002). Nguyen et al. (2002) stated that the optimum temperature for nestling success is between 26°C and 35°C. High temperature will cause damages to the egg, while low temperature affects the health of young featherless swiftlets. A humidity of 80%-90% provides the best nesting environment (Jehle et al., 2004). If the cave is too humid, fungus will build up and prevent the birds from nesting. However, if the humidity is too low, the nest will not adhere to the surface of the wall, and will probably crack and fall to the ground (Medway, 1962).

Man-made habitat

In swiftlet farming industry, man created an artificial house that resembles the natural habitat for swiftlets to roost. Studies on swiftlet nesting behaviors in natural habitat provide important information to improve the breeding environment of swiftlet houses. Man-made swiftlet houses are cave-like environments that allow the swiftlets to construct nests. Swiftlet houses can be found all over Malaysia, Indonesia and Thailand due to the active swiftlet farming industry of both white-nest and black-nest swiftlets (Lim et al., 2002). Generally, swiftlet houses are normally built close to the coast or far inland to create suitable conditions for swiftlet farming. Several elements such as light intensity, temperature, air velocity and humidity were controlled and optimized in order to replicate a suitable living environment for the swiftlets. The main entrance hole of a swiftlet house is usually designed near the top of the structure in order to avoid direct sunlight and to limit the light intensity of the structure (Sankaran, 2001). Normally, the building is constructed as a closed structure with only a limited number of ventilation holes. Air movement will cause evaporation to reduce the humidity level and air temperature inside the building. The temperature is controlled by the air ventilation while humidity is controlled by the installed humidifiers and the pools of water provided inside the structure. Temperature and humidity are important to ensure nestling success and produce good quality nests. Deformed nests do not only cause economic loss (Lau & Melville, 1994) but will also affect young swiftlets and eggs as shrieked nests cannot support the young and will fall to the ground easily (Jehle et al., 2004).

Economic value of EBN

Lim et al. (2002) defined EBN as one of the most valuable animal by-products due to its high market value. The 2011 Malaysia Economic Transformation Programme (ETP) Annual Report identified the EBN swiftlet farming industry as one of the major contributors to Malaysia Gross National Income (GNI) with a total value of RM (Malaysia Ringgit) 4.5 billion. Malaysia is currently the world's third largest supplier of EBN after Thailand and Indonesia. In 2004, Indonesia supplied approximately 84% of the global EBN production, while Malaysia contributed 9% and the rest are from other South East Asian countries mainly from Thailand (Lau & Melville, 1994). In 2006, Hong Kong was the world’s largest export market for EBN where Hong Kong consumed 50% of the global EBN production, followed by China (8%), Taiwan (4%) and Macau (3%) (Tan et al., 2014). The export quantity of Malaysia’s EBN increased over 92 % from 9503 MT (Metric ton) in 2009 to 121677 MT by 2011. In the early 90s, a kilogram of white-nest could cost up to US$8,000 (Lau & Melville 1994), but the price of Malaysia’s EBN dropped drastically to approximately US$1,900 in 2012 due to the detection of high-level nitrate and nitrite in raw EBN (*Table 2*).

Table 2: Value of EBN from Niah, in US$/kg from year 1845 to 2012
(Converted at exchange rate of RM3.8 = US$ 1) (Hobbs, 2004)

Year	Black nest	White nest
	US$/kg	US$/kg
1845	1.05	11.32
1947-1949	1.18	NA
1950-1954	1.45	21.05
1955-1959	1.61	NA
1960-1964	2.24	NA
1965-1969	2.71	NA
1970-1974	4.61	NA
1975-1979	9.61	157-196
1980-1984	19.08	NA
1990	105-210	210-447
1994	273	NA
1996-2002	158-316	1316-1789
2006-2008	NA	3400
2008-2011	NA	2900
2011-2012	NA	1900

The price of EBN began to surge around 1985, mainly due to the decline of nest supplies and rising affluence of emerging consumer society in China and Hong Kong who consume EBN for medical benefits (Lau & Melville, 1994). Since 2008, the prices of EBN declined drastically as EBN from Indonesia were banned from entering China due to high nitrite content, and later EBN from Malaysia too get banned for the similar reason in 2012. Malaysia bird's nest industry had been affected greatly due to China's ban. The demand for Malaysia EBN has dropped approximately 20% to 30%, while prices have fallen by 20% (Ramli & Azmi, 2012). To deal with such problems, the Chinese authorities have taken stringent measures such as educating the public frequently via media to not purchase EBN from unknown sources. In addition, they requested the Malaysian government to implement radio frequency identification (RFIP) technology to trace the entire supply chains from harvesting to storage before the EBN are exported to China for quality assurance including source, origin and weight of each individual piece of EBN (Thorburn, 2015).

According to Food and Agriculture Organization of the United Nations (FAO) and World Health Organization (WHO), the acceptable daily intake (ADI) of nitrite and nitrate in EBN are 30µg/g and 5µg/g, respectively. Recently, Quek, Chin, Yusof, Tan and Law (2015) investigated the nitrite and nitrate contents of eight types of Malaysia's EBN using an ion chromatography system, and the results showed that the nitrite content obtained is about 5.7 µg/g for the house nests and 843.8 µg/g for the cave nests. The nitrate content for the house and cave nests was 98.2 µg/g and 36,999.4 µg/g, respectively. Although the level of nitrate and nitrite in Malaysia's EBN exceeded the recommended ADI by FAO and WHO, studies have showed that up to 98% of nitrite and nitrate were able to be removed through soaking the raw EBN in water (Chan, 2013). Furthermore, Paydar et al. (2013) suggested that the sources of nitrite and nitrate could have been derived from ammonia through anaerobic fermentation by the bacteria itself and may not be related to any food processing methods.

The ban on Malaysia's EBN was lifted by December 2013. However, the processing facilities must be inspected by the Certification and Accreditation Administration of the People's Republic of China (CNCA) and the processing facilities are also required to procure the bird's nests from birdhouses registered with the Department of Veterinary Services (DVS), Malaysia. Following the lifting of the ban, eight Malaysian companies were given permission to export processed EBN to mainland China and up to January 2015, another batch of 15 companies went through the inspection. Under the directive of DVS Malaysia through the implementation of Economic Transformation Programme, the DVS strives to increase the upstream production of EBN by building additional 2,000 new farms and 6 collection centres annually while guiding the industry towards developing downstream, and value-added EBN related products by collaborating with universities and research centres (Economic Transformation Programme (ETP) Annual Report 2013).

Challenges in swiftlet industry

Authentic EBN

Due to the high economic value of EBN, irresponsible manufacturers often incorporated adulterants such as tremella fungus (*Tremella fuciformisis*), karaya gum (*Sterculia urens*), red seaweed, pig skin, egg white and vermicelli rice to increase the overall nett weight and size of the EBN. These compounds are used as adulterants due to the similarities in colour, taste and texture with the genuine bird's nest salivary cement which is difficult to be detected by naked eyes (Marcone, 2005). Therefore, a variety of instruments and analysis methods for EBN authentication have been established based on empirical measures, composition analysis, microscopic examination and molecular biology-based technology (*Table 3*). However, there is no single method officially established as all methods that are currently available are too time-consuming, less dynamic, not specific or require high technical skills to operate.

Table 3: Authentic EBN detection methods

Method	Content	Problem of detection methods	References
Empirical measures	Visual examination	Subjective and non-measureable	Liu and Zhang (1995). Leh (2000),; Wu, Chen, Wu, Zhao and Ge (2007)
Composition analysis	Composition of lipids, proteins, hormones, carbohydrate etc.	These constitutes are commonly found in most mammalian cells. The composition can be adulterated by materials that contain the same chemical compound, making this method nonspecific.	Marcone (2005); Ma and Liu (2012)
Optical microscopy	Characterization of feathers, nest powder and nest texture	Relies on operator experience and require specific operation technique	Liu and Zhang (1995); Wu et al. (2007)
Scanning electron microscopy	Fibre array		Sam, Tan and Lim (1991); Marcone (2005)
Fluorescence method	EBN give out blue-green fluorescence at ultraviolet light at 365 nm	Although there was a significant difference of chemical fingerprint determined between the EBN and other materials, there is still very limited information on the EBN collected from different geographical areas which makes these methods operate under a small dynamic range.	Deng, Sun, Zhou and Li (2006)
Modified xanthoproteic nitric acid test	Protein analysis		Marcone (2005)
Gas chromatography (GC)	Oligosaccharides composition		Yu-Qin et al. (2000); Marcone (2005); Yang et al. (2014)
Capillary Gas chromatography (GC)	Amino acids composition		Wang and Wang (2006)
Infrared spectrometry (IR) and Fourier transform infrared spectroscopy (FTIR)	Characteristics of protein, amino acid and carbohydrates.	Carbohydrates and amino acids exist in most adulterants and are not specific characteristic ingredients in EBN, making these methods prone to inaccurate results.	Sun, Leung and Yeung (2001); Deng et al. (2006)
High performance thin layer chromatography (HPTLC)	Amino acids composition		Teo, Ma, and Liu (2013)

SDS-PAGE	Number and characteristics of protein bands	Adulterants in EBN samples cannot be determined unless the protein band or point is specific and identifiable.	Hu and Lai (1999); Lin et al. (2009); Wu et al. (2007)
Atomic absorption	Analysis of minerals	The minerals of EBN may be varied due to the geological factors which cause complication in developing the detection standard.	Marcone (2005); Lee et al. (1996)
Molecular biological technology	Detection of fibrinogen gene and cytochrome *b* gene	The detection of specific genes may be an efficient method to identify far homolog adulterant. However, it is not able to detect close homolog adulterant due to gene conservation. Generally, molecular detection method such as real-time PCR may require specific operation skill.	Thomassen et al. (2003); Lin et al. (2009); Wu et al. (2010)

Depletion of swiftlet population

In Malaysia, government authorities have ensured EBN farming to operate in a balanced model for sustainable use of natural resources through the implementation of various laws and regulations. The Malaysian government only allows licensed harvesters to collect two or in certain circumstances maximum of three nests per pair of birds annually. Licensed harvesters may take the first nest as soon as it is complete and allow the swiftlet to build its second nest, incubate the eggs and see the chicks to fledge (requiring approximately 120 days) before the collection of the second nest. This approach allows the nest harvesters to collect two or three nests with tolerable inconvenience to the birds, meaning that the birds are able to raise some of its young and maintain a stable swiftlet population. However, such a system may collapse as the demand for EBN has grown drastically over the years and illegal harvesters no longer practice such an approach (Gausset, 2004; Hobbs, 2004; Tompkins, 1999).

Apart from the over-exploitation of the nests as the main contributor to the reduction of swiftlet population, various other factors have been identified as factors to the reduction of swiftlet population. Leh and Hall (1996) proposed that the disruption of cave ecology due to the collection of guano in caves may reduce the population and diversity of insects which swiftlets feed on, resulting in the reduction of the swiftlet population. Later, Sim (1997) proposed that the usage of pesticides implied a negative effect on the swiftlet population. The continuity of deforestation activity including forest fire and smoke also contributes to the reduction of swiftlet population. Lastly, researchers have also speculated that green algae that contaminates the swiftlet reproduction grounds can also reduce the swiftlet's reproduction rate (Leh, 2000).

Quality surveillance and assessment standards

Quality surveillance and assessment of EBN products are always a challenge in swiftlet ranching industry as no method has been established for such purposes. The EBN quality standards are poorly defined and vary across different countries. Standards developed by EBN production countries such as Malaysia, Indonesia and Thailand mainly focused on sensory indexes, water content, microbial and nitrite limit, while the EBN quality assurance standards in China focused on sensory index, size, moisture, protein, and sialic acid contents (ChangXing, Song, & LiQiu, 2015). Without proper surveillance and assessment standards, poor management and contaminations of bacteria or chemical compounds may affect swiftlets and EBN with possible threats, thus influencing the market value of EBN. As of today, the Department of Standard Malaysia has developed several Malaysia Standards (MS) for the EBN sector, while the Department of Veterinary Services (DVS) has embarked on the GAHP (Good Animal Husbandry Practices) and Veterinary Health Mark (VHM) quality assurance schemes for swiftlet farms and EBN processing plants to define the basic principles of animal management. Such standards serve as a guide for the EBN farming to provide a balance between the swiftlet sustainability, the EBN production and the disease control. Besides DVS, a monitoring programme for raw clean EBN is being implemented in line with the requirements set by the Ministry of Health Malaysia (MOH) and Certification and Accreditation Administration of the People's Republic of China (CNCA). The monitoring programme ensures the safety of Malaysian raw and processed EBN as consumable food products before being exported to China. Although the standards for swiftlet industry management, animal welfare, identification and traceability have been established, the standards regarding the quality of EBN still remains unclear.

As of today, the EBN grading is based on shape, size and weight as it is hard to grade the EBN products based on its content and components. Exporters have been grading EBN based on human judgment which is often inconsistent and tedious. Bird's nests are naturally found in oval shape or V-shape (corner nest). There are 4 grades of oval-shaped nests and 3 grades for V-shaped nests based on shapes and sizes (Syahir et al., 2012). The shape of an EBN is not a suitable grading measurement as the quality inspection and surveillance require assessment criteria based on measurable parameters. The quality assessment of EBN should be based on the content and composition of the EBN products. Previous studies revealed that EBN of different swiftlet species, various habitats, geological areas, and EBN harvested at distinct seasons showed variation in the composition of EBN including carbohydrates, protein, fat, and bioactivity profiles. Such findings suggested that the composition of EBN could be further studied, analyzed, optimized and developed into a measurable standard for EBN gradings among genuine EBN (Ma & Liu, 2012).

Composition and medical values of EBN

Since the 16th century, EBN soup is known as a delicacy in Chinese cuisine as well as an important health supplement (Medway, 1969). Traditional Chinese medical (TCM) practitioners have consistently indicated that consuming EBN is beneficial for a variety of health problems (Lim et al., 2002). Traditionally, EBN is used to strengthen the immune system, boost metabolism, improve skin complexion and for anti-aging effect (Hobbs, 2004; Kong et al., 1987; Leh, 2001; Lim et al., 2002). Despite many health benefits claimed to the EBN consumption, there are limited scientific evidence to support such claims. To study the medical benefits of EBN, researchers have studied the composition of EBN thoroughly over the decades in order to identify the bioactive compounds to understand the fundamental mechanism involved. EBN is revealed to be rich in protein and essential amino acids as well as a wider variety of monosaccharides than most food items (Chua et al., 2014). The composition of EBN from the genus *Aerodramus* normally consists of lipid (0.14-1.28%), ash (2.1%), carbohydrate (25.62-27.26%), and protein (62.0-63.0%) (*Table 4*). The most abundant amino acids found in EBN are serine, threonine, aspartic acid, glutamic acid, proline and valine (Kathan & Weeks, 1969), while essential elements traced include calcium (1298 ppm), sodium (650 ppm), magnesium (330 ppm), potassium (110 ppm), phosphorous (40 ppm), zinc and iron (30 ppm) (Marcone, 2005). Aswir and Wan (2011) showed that EBN contains 7 out of 8 essential sugars for human biological functions. N-acetylneuraminic acid (sialic acid) is one of the major essential sugars in EBN accounting for 9% of total essential sugars (Colombo, Garcia-Rodenas, Guesry & Rey, 2003). The majority of the sialic acid exists as gangliosides (65%) and glycoproteins (32%), while the remaining 3% can be found as free sialic acid (Brunngraber, Witting, Haberl & Brown, 1972). Sialic acid is often associated with neurological enhancement, brain development and intellectual advantages in infants as a functional component of brain gangliosides (Chau et al., 2003; Colombo et al., 2003; Wang & Brand-Miller, 2003). Oligosaccharide sequences such as sialic acid on soluble glycoconjugates are able to shed cells from microorganisms and parasites (Newburg, 1999; Rosenberg, 1995). Therefore, sialic acid is also often being referred to as an immune system moderator by affecting the flow resistance of mucus (Lehmann, Tiralongo & Tiralongo, 2006).

An early study by Howe, Lee and Rose (1960) suggested that the EBN extract has enhanced the haemagglutination-inhibiting action against the influenza virus. Ng, Chan and Kong (1986) reported on the ability of EBN to potentiate the mitogenic response of human peripheral blood monocytes to stimulate the immune responses by proliferative agents such as concanavalin A and phytohemagglutinin A. Other benefits of sialic acid include decreasing the low-density lipoprotein (LDL), increasing fertility and controlling blood coagulation (Rosen, 2004). Other glyconutrients found in EBN include 7.2% N-acetylgalactosamine (galNAc), 5.3% N-acetylglucosamine (glcNAc), 16.9% galactose and 0.7% fucose (Dhawan & Kuhad, 2002). GalNAc involves in the function of synapses between the nerve cells and its deficiency may lead to severe memory problems (Argüeso et al., 2003). GlcNAc is an amino acid and its function is as a prominent precursor for glycosaminoglycans, a major component of joint cartilage. The deficiency of glucosamine is frequently related to arthritis and cartilage degeneration (Pasztoi et al., 2009). In this respect, Matsukawa found that oral administration of EBN extract improved bone strength and calcium concentration (Matsukawa et al., 2011). The discovery by Nakagawa et al. (2007) also showed that *Collocalia* glycoproteins isolated from EBN are rich in proteoglycan (PG) which gives the cartilage elasticity. Kong et al. (1987) also discovered that partially purified EBN extract has been shown to stimulate epidermal growth factor (EGF) such as the activity in cellular process and mitogenic effect.

Table 4: Summary of EBN composition

Component	Content	Reference
Proximate analysis (%)		Yu-Qin et al., 2000; Marcone, 2005
Moisture	7.5-12.9	
Ash	2.1-7.3	
Fat	0.14-1.28	
Protein	42-63	
Carbohydrate	10.63-27.26	
Total nitrogen	25.62-27.26	
Amino acid (molar percent basis)		Yu-Qin et al., 2000; Marcone, 2005
Aspartic + asparagines	2.8-10.0	
Threonine	2.7-5.3	
Serine	2.8-15.9	
Glutamic + glutamine	2.9-7.0	
Glycine	1.2-5.9	
Alanine	0.6-4.7	
Valine	1.9-11.1	
Methionine	0-0.8	
Isoleucine	1.2-10.1	
Leucine	2.6-3.8	
Tyrosine	2.0-10.1	
Phenylalanine	1.8-6.8	
Lysine	1.4-3.5	
Histidine	1.0-3.3	
Arginine	1.4-6.1	
Tryptophan	0.02-0.08	
Cysteine	2.44	
Proline	2.0-3.5	
Fatty acid analysis (%)		Marcone, 2005
(P) Palmitric C16:0	23-26	
(O) Steric C18:0	26-29	
(L) Linoleic C18:1	22	
(Ln) Linolenic C18:2	26	
Triacylglycerol (%)		Marcone, 2005
PPO	14-16	
OOL	13-15	
PLnLn	18-19	
Monoglycerides	27-31	
Diglycerides	21-26	
Vitamin		Yu-Qin et al., 2000
Vitamin A (IU/mg)	2.57-30.40	
Vitamin D (IU/mg)	60.00-1280.00	
Vitamin C (mg/100g)	0.12-29.30	
Elemental analysis (ppm)		Yu-Qin et al., 2000; Marcone, 2005
Sodium (Na)	330-20554	
Potassium (K)	110-2645	
Calcium (Ca)	798-14850	
Magnesium (Mg)	330-2980	

Phosphorus (P)	40-1080	
Iron (Fe)	30-1860	
Sulfur (S)	6244-8840	
Barium (Ba)	4.79-41.09	
Strontium (Sr)	4.25-21.90	
Silicon (Si)	8.34-62.02	
Aluminium (Al)	15-2368	
Manganese (Mn)	3.58-12210	
Zinc (zn)	19.95-72.40	
Copper (Cu)	4.68-110.65	
Molybdenum (Mo)	0-0.94	
Cobalt (Co)	0-0.63	
Germanium (Ge)	0.05-0.97	
Selenium (Se)	0.12-0.77	
Nickel (Ni)	0-0.47	
Vanadium (V)	0.03-2.84	
Chromium (Cr)	0-7.45	
Lead (Pb)	0.50-4.08	
Cadmium (Cd)	0-0.83	
Mercury (Hg)	0.001-0.160	
Hormone determination		Ma and Liu, 2012
Testostrone (T) (ng/g)	4.293-12.148	
Estradiol (E_2) (pg/g)	802.333-906.086	
Progesterone (P) (ng/g)	24.966-37.724	
Luteinizing hormone (LH) (mIU/g)	1.420-11.167	
Follicle-stimulating hormone (FSH) (mIU/g)	0-0.149	
Prolactin (PRL) (ng/g)	0-0.392	

Conclusion

Swiftlet farming has high potentials to expand further into a multi-billion industry in all over Asia or even globally. However, over the last few decades, the industry has been unstable due to several unsolved challenges. Swiftlet farming and EBN industry which involve birds' nest harvesting, raw nest processing and product manufacturing are complex affairs, involving the interplay of various factors. Ideally, a proper and comprehensive management system should involve the entire process flow from nest harvesting until the marketing of the EBN which involves both private sectors and government agencies. This is the best approach to overcome the challenges in the industry. Unfortunately, the set of recommendations for management cannot be made by any party since each farming area is unique in terms of geographical, swiftlet's population, food source and microenvironment which require special scrutiny and suitable actions, whether the farming areas are man-made or natural habitats. Therefore, further research on swiftlet biology and ecological behaviors including the genetic characteristics, life cycle, growth rate, nesting and habitat behaviors, EBN's composition, bioactive compounds and new downstream applications of EBN may provide valuable information for the industry to grow in a sustainable manner.

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