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ARTICLE

Historical account of entomophagy among the Apatani tribe of Arunachal Pradesh: Current status and future trends

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Abstract
This review focuses on tracing the history of entomophagy practice since the time of ancient archaic humans and the development of this practice that persisted until today among ethnic communities, with particular reference to the Apatani tribe of Arunachal Pradesh, India. Insects as food is a trending research topic due to their potential as a future sustainable food. Until the mid-nineteenth century, the tribal population of Arunachal Pradesh was largely isolated, though the practice of eating insects prevailed among the majority of its tribal groups. Only in recent times has the need for alternative food resources, due to the impact of globalization, climatic crisis, and resource depletion worldwide, pushed for scientific exploration, which is gaining momentum. The history of anthropo-entomophagy and its sociocultural significance is explored in this study. The present paper also describes the ongoing scientific exploration toward the value of edible insects as neutraceutical, entomoceutical, and pest control tools historically being used by Apatanese and the prospect of these edible insects for the tribe in the future.

Keywords Apatani · Anthropo-entomology · Culture · History · Sino-Tibetan · Traditional

1 Introduction to anthropo-entomophagy

Since the beginning of human history, men have been dining on various insect delicacies such as sweet honeybees, honeypot ants, savoury ants, termites, and other scrumptious insect delights. The word entomophagy (insect as food by humans) is derived from the Greek words "éntomon" or "insect," and "phagein" "to eat" (Evans et al., 2015). Edible bugs and beetles were not just a preferred diet of the early archaic hominids. Still, entomophagy continued into the days of the earliest stages of civilization, and it has persisted even today. As humans advanced through history, the custom of eating insects as food continued to be a staple in ancient European and Chinese civilizations. Later, during the Middle Ages and Early Modern era, eating insects was mostly restricted to tropical regions, probably due to lesser insect diversity in temperate and tundra regions. Being both kosher and halāl, it was also recognized as a practice in the sacred writings of Christianity, Judaism, and Islam.

Insect-eating is an old alimentary habit that dates back to the Paleolithic era, as depicted by evidence in the shape of ancient images, sculptures, totems, or deities that have subsisted to this day (Hernández-Pacheco, 1921). According to Valadez (2003), humans were initially known to be scavengers before hunting and then turned omnivores during evolution. Ramos-Elorduy (2009) believed that humans started using insects as food first due to their abundant availability, and only with subsequent evolution came fruits, vegetables, and meat in their food chart. Furthermore, Hunter (2021) reported that our most recent common ancestor supposedly consumed insects as food 6 million years ago. All these indications led us to speculate what and how life was like for our half-human–half-ape brethren by comparing the dietary habits of modern chimpanzees, which have many similarities in their environmental niche and intelligent quote. Primeval primates often feasted on termite mounds and ants for nutritional sources, among which termites appear more critical in ancient diets (Quin, 1959).

Two million years later, the more advanced Australopithecines species emerged in the evolutionary tree. They walked on two legs, made tools, and depended profoundly

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on insects as an essential food source. For over a million years, perhaps *Australopithecus robustus* or other *Homo* spp., in southern Africa utilized bones as tools to collect termites from their nests (Backwell & d'Errico, 2001). The wear patterns of the supposed bone implements led to this conclusion. The termites were compelled to emerge when the bone tools were lowered into the termite hills so that they could be gathered. However, it can also be captured by destroying the termite hill. According to Joulian and Roulon-Doko (1994), the Gbaya in the Central African Republic and the chimpanzees (*Pan troglodytes*) in Tanzania employ more advanced strategies for such termite collection.

Then, *Homo erectus* manifested in the evolutionary tree around 1.9 million years ago and could utilize fire and prepare food. They possibly chose to forage for insects since they needed more protein to sustain their greater brain capacities. In Europe, the Neanderthal existed around 250,000 years ago during the Ice Age. They preferred to live on big game and hunted larger animals. Due to extreme cold conditions, there were few insects to forage for, and those that were there were not large enough to be worthwhile gathering. Consequently, this might be a reason that the practice of eating insects never evolved in Europe.

The modern *Homo sapiens* evolved around 1.6 million years ago (Stringer, 2002). *Homo sapiens* migrated out of Africa and replaced other ancient human species in many parts of the world (Stringer & Andrews, 1988). The existence of an ancient ice bridge between Siberia and North America enhanced larger population settlement in more tropical regions. Mainly, South American, African, and Asian continents that are located within tropical areas are where the practice of eating insects is found abundant and prevalent until now. In those days, when *H. sapiens* first discovered agriculture 12,000 years ago, it became a more popular method of food production. It was increasingly preferred because harvesting insects was more difficult in comparison to growing crops because insects are generally small and hard to find, plus the increasing populations of these modern humans and their sustenance depended on larger agriculture yields.

Additionally, domesticating animals improved the efficiency of producing much-needed protein. Thus, the practice of eating insects became less critical as compared to agriculture and animal husbandry. However, it continued to play a subsidiary diet component and remains a popular delicacy for many communities worldwide, such as roasted tarantulas in South America, fried termites in Africa, and boiled dragonfly larvae in Asian nations. Ledger (1971) discovered that termites and bees might have served as a dietary source for humans from 100,000 BCE to the present in the Melville koppies in South Africa. He mentioned two types of termite species, *Trinivitermes trinervoides* and *Hodotermes mossambicus*, and the wild honeybee *Apis mellifera unicolor*. The propensity to eat insects likely lasted during the time of the earliest *H. sapiens* expansion and then persisted or existed until the beginning of the first human civilization.

Following the development of the oldest human civilization, the earliest written evidence of insect-eating can be found in the 1st century BCE by Greek historian Diodorus, who wrote of a colony of Ethiopian acridophagi (locust eaters). He recalled that this tribe made an effort to preserve the locusts in salt for times of famine (Brothwell & Brothwell, 1998). Famous Greek philosopher Aristotle was also a keen proponent of insect-eating. He compiled a diverse array of insect recipes and ponderings in his *Historia Animalum* in the 4th century BCE. His book features an entire section devoted to an insect's life stages and the best times to consume it. He mentioned eating mature females after copulation due to good egg flavour (In *Historia Animalum*, Akhtar & Isman, 2018). Locusts on sticks were served at feasts held in the palace of the Assyrian king Ashurbanipal (668 BCE–approximately 627 BCE) (van Huis et al., 2013). In Asia, the earliest documents of entomophagy are found in China in a Tang Dynasty cookbook, written sometime between 618 and 907 CE, which reported the uses of wasp larvae and pupae in cuisine (Feng et al., 2010). Pliny the Elder stated in *Natural History* in 77 CE that the larvae of the giant Capricorn beetle (*Cerambyx cerdo*) were extremely popular in the Roman empire, which suggests that ancient Romans also consumed insects (In *Natural History*, van Huis et al., 2013). Anthropo-entomophagy has long been contested and seen as a religious taboo, yet in reality, eating insects is extensively documented in the religious writings of the ancient Jews and relatively modern religions like Christianity and Islam. Amar (2003) suggested that few kosher locusts were broadly accepted for consumption among Jews in ancient times. However, a sizable portion of the Jewish diaspora stopped engaging in the activity as a result of ignorance of the numerous kinds of "winged swarming things" mentioned in the Torah. Only Yemeni Jews and certain Jews in northern Africa kept the custom alive. Jews who used to eat locusts allegedly changed their behaviour as a result of Westernization, according to Amar (2003). The Bible mentioned the consumption of insects as food in the book of Leviticus as well as in the New Testament. There are several references to insect-eating in Islamic tradition, including locusts, bees, ants, lice, and termites (El-Mallakh & El-Mallakh, 1994). The large majority of Islamic references concern locusts, specifically mentioning permission to consume the creatures. Thus, insect consumption has been significant across many historical civilizations, and this practice has been carried down through history to many different cultures and geographic areas.

1.1 Speculation and postulation of origin and progress of entomophagy

The unavailability of written evidence regarding what led to the initial start of consuming edible insects gave out a few assumptions: (i) Since insects are consumed as dietary items by a vast diversity of vertebrates (Gardner, 1977), ancient archaic human species such as *Australopithecus* might have learned to eat insects by observing what other animals ate. (ii) The insects containing sugar were the first to make their way into prehistoric man's diet, followed by those laden with fats and lipids, and ultimately those mainly composed of protein (Meyer Rochow & Changkija, 1997). Perhaps the initial consumption of insects for food was driven by the sweet taste and umami flavours. (iii) During evolution, the development of larger brain sizes of *Homo* spp. might have pushed them for more protein sources, which edible insects might have substantiated to a certain extent. (iv) During initial agricultural development by *H. sapiens*, pest devastation might also have prompted the progression of entomophagy. On the one hand, the abundance of the insect population might have attracted them, and on the other hand, they might have found it comparatively easier to gather insects for consumption than to tame or kill larger vertebrates. (v) Additionally, evidence also presented that feeding on wild silkworm larvae and pupae in northeast India might have led to the domestication of the silkworm and the usage of its byproduct, silk.

2 Ancient origins of Apatani and other *Tanii* tribes

Apatani is a prominent distinctive *Tanii* Tribe (also known as *Tani*) residing primarily in the Ziro Valley, Lower Subansiri District of Arunachal Pradesh, a state situated in the easternmost Himalayan region of India. It is filled with various tribal populations, which are mongoloid in the natural race (Haimendorf, 1982). Most of them practice eating various insects and other traditional food habits. Arunachal Pradesh is home to around 26 major tribes. The demographic structure of the tribes of Arunachal consists of eastern tribes such as Khamti, Mishmi, Singpho, Wancho, Nocte, Lisa/Yobin, Singpho, Tangsa, etc.; western tribes such as Monpa, Miji, Sherdukpen etc., which are exclusively Buddhist and the middle belt comprised of *Tanii* tribes group, which are of the significant six tribes, Adi, Apatani, Nyishi, Galo, Tagin, Mishing which claim to have a common ancestor "*Abotani*".

Apatani identity is rooted in their cultures, beliefs, rituals, festivals, social relations, etc. These aspects constitute the ideological and practical domain of Apatani's life and identity. All the *Tanii* tribes speak the Tibeto-Burman language, which lacks written script (Blackburn, 2008) and genealogy records, so the historical narrative is passed down orally. The oral tradition associated with sociocultural life has actively contributed to the identification of the Apatani society. Essentially, the stories represent the entire backdrop, including the social evolution, change, and orally transmitted sociocultural behaviour and history, all of which are essential components of the Apatani civilization (Modang & Mibang, 2015). The Apatanese have their own oral historical background of origin and migration. Most of their folktales and myths are purely rustics, apart from a few with recognized facts.

The oral histories of the Apatani are many and intricate. *Migung* and *Miji*, the two main oral genres, both have historical content. *Miji* is the chant that priests sing when they sacrifice animals. Sung in a priestly language, these ceremonial performances last anywhere from one hour to twelve hours and narrate earlier encounters with the spirits or gods (*wii/wi*) as well as debunk creation myths. *Migung* is more historically based, narrated in prose. These tales describe the Apatani people's ancestry, migration, and relationships to other tribes. Both the ritual chants and the prose narrations mention the figure of *Abotani*, the apical ancestor of not only Apatanese/Apatanis but of all tribes in central Arunachal Pradesh, who form the *Tanii* tribe group (including Adi, Apatani, Nyishi, Galo, Tagin, Mishing) (Blackburn, 2003).

Apatanese are of Mongoloid origin. According to the mythology, their ancestors come from a place in the north or northeast known as *iipyo lembyang*, this place stands for Mongolia (Modang & Mibang, 2015). The *Tanii* tribes migrated through the Tibetan plateau to the present-day central Arunachal region and settled along the Siang River and Subansiri River valleys. As far as the myth of the Apatani is concerned, *Abotani* was the first being on the earth to be transformed into the perfect shape of a human being, and thus, he is also the first ancestor of the Apatanese. The priest chanted the creation of *Abotani*, how the earth and the sky conjugated with the rays of sun and water, and gave birth to gods, *Chantung and Chankha.* They conjugated with goddesses *Chankangrima and Dokarimang*, who gave birth to *Abotani.*

2.1 Societal structure of Apatani tribe

The Apatani people traditionally practice a form of agriculture known as paddy-cum-fish cultivation, which is unique to their culture. They developed a complex irrigation system to grow rice on wet fields, which helped them sustain their livelihoods (Rai, 2005). One significant aspect of Apatani culture is its traditional architectural style. The native Apatani houses are built on stilts with a characteristic cone-shaped bamboo roof, distinctive from other tribes in the region (Fig. 1). Apatani men are largely responsible for hunting and bringing firewood, while women primarily work

Fig. 1 Earliest picture of a native Apatani village with traditional houses (Courtesy: Haimendorf, 1982)

Fig. 2 Apatani women working in paddy field (Courtesy: Haimendorf, 1982)

in rice fields, also gathering edible insects (Fig. 2). One of the most well-known cultural practices of the Apatani people is facial tattooing and large nose plugs of women (Sen et al., 2023) (Fig. 3). This practice, known as *Tipe*, was performed on girls at a young age and was believed to enhance their beauty. However, this tradition has declined recently due to changing societal norms. The Apatani people also maintained a unique land and property ownership system, known as the *buliang* (Mibang, 2013). Under this system, each family had exclusive ownership over a piece of land transferred from one generation to another. This land system played a crucial role in the stability and sustainability of their agricultural practices. The Apatani people remained largely isolated from the outside world until the British Raj in the early nineteenth century. Robert Wilcox, the first European officer to explore the remote regions of Eastern Himalaya between 1825 and 1828, was the one who initially exposed the Apatanese to the British (Ghosh, 2019). With the advent of British colonial rule, the Apatani people came

Fig. 3 Apatani woman belonging to the last generation with facial tattoo and bamboo nose plug (Photo by Nending Muni)

into contact with outsiders for the first time. They faced several cultural and social changes during this period, influenced by the British administration and the introduction of Christianity. The first significant ethnographic work on the Apatanese was provided by Christopher Von Furer Haimendorf, an Austrian anthropologist, in 1944. After an extensive survey, he prepared a report entitled "Ethnographic Notes on the Tribes of Subansiri" (1947) on the hill tribes inhabiting the Subansiri region of the then North East Frontier. This report provided some basic details about Apatani, Nyishi, Hill Miris, and other tribes (Dabi, 2017). In recent years, the Apatani people have witnessed significant development and changes in their traditional way of life. The Ziro Valley, their homeland, has become a major tourist destination, attracting visitors from around the world. This has not only brought economic opportunities, but also impacted their culture and environment. Efforts are being made to preserve and promote Apatani culture and traditions. The Apatani Cultural and Literary Society (ACLS) was founded in 1966 to safeguard and propagate their language, customs, and heritage. Additionally, various government initiatives have been implemented to protect the natural resources and maintain the ecological balance of the Ziro Valley. Overall, the history of the Apatani people is characterized by their unique agricultural practices, distinct cultural traditions, and their ability to adapt and evolve over time. Despite the challenges faced in a changing world, they strive to preserve their ancestral land and traditional practices and quest for recognition inherited from their ancestors.

2.2 Historical and traditional roots of eating insects among Sino-Tibetan ethnic groups

Central Arunachal's *Tanii* tribes are a Sino-Tibetan ethnic group of people who migrated to and settled in the States

of Arunachal Pradesh, Assam, and the Tibet Autonomous Region of China. They share common beliefs, language (*Tanii language/dialect*) and ancestry with the Abotani (Riba, 2013). In Tibetan and Mongolian cultures, the consumption of insects as food is not reported, but for medicinal purposes, they include many insects. Lac insects and honey bees are extensively found in many Tibetan medicine ingredients. Edible insects such as honey bees, ants, cicadas, grasshoppers and beetles are mentioned in Tibetan medical medicaments, one compiled by Tendzin Püntsok, and two by Karma Ngedön Tendzin Trinlé Rapgyé with their healing potentials they are said to possess (Czaja, 2019). The insect terminology mentioned is mostly identified based on Tibetan and Chinese *materia medica*, but the exact species authenticity is uncertain. It is known that many similar insects are used for medicinal purposes in regions adjacent to Tibet, such as Mongolia and China (Costa-Neto, 2005; Ding, et al., 1997; Narsu, 1988). Similarly, many related tribes in the Indian subcontinent have also reported insect usage for therapeutic purposes (Devi et al., 2023, 2024).

The *Tanii* tribes are undoubtedly linked to Tibetans, although the introduction of Buddhism in the 7th century CE altered the Tibetan plateau's cultural environment. Thonmi Sambhota introduced the Tibetan script in the first part of the seventh century, primarily for the codification of sacred Buddhist literature (Gyatso et al., 1984). Prior to then, they also practiced a system of shamanistic and animistic rites carried out by priests known as *gshen* or *Bon-po* (Mizuno & Tenpa, 2015). It is certain that the migration of Arunachal *Tanii* tribes through/from Tibet occurred considerably earlier than that period, resulting in the preservation of the ancient animatism religion as well as the oral language that is being used today by all the *Tanii* tribes of Arunachal. It is challenging to pinpoint the precise time period of their migration and settlement since they lack written records. However, on the basis of archaeological evidence, it can be stated that the inhabitants of Lower Subansiri had a connection with the Stone Age settlement (Ashraf, 1990). The Chinese have an undoubtedly long history of ethno-entomophagy mentioned as early as the Tang Dynasty and is widely practiced in the present time. It should also be noted that ancient Tibetans and Mongols might have practiced entomophagy too since its culture and history are closely tied with Chinese. Perhaps, it got lost in the evolution of culture due to the influence of Buddhism and other relatively modern religions.

Nevertheless, the *Tanii* tribes still retain strong entomophagy practices both for food and medicine. The traditional practice of consuming insects has been a part of Apatani culture throughout history and is still practiced extensively in villages. Since time immemorial this *Tanii* tribes also might have followed one or the other speculation as mentioned earlier in this article about adopting varied insects as food e.g., measure to control pest or observing other animals eating insects or taste and flavour in insects itself or felt their physiological need for something like protein. What so ever may be the reason insects are set up in their various dishes and recipes. Some of the distinct Apatani insect cuisine dishes are *Tayu piike* (Hornet dish), and *Koha pannii* (Grasshopper cooked in Bamboo), *Jojer khenni* (Roasted Beetle). About the collections of insects, the women folk are mostly engaged themselves in their daily gathering activity as commonly found from other records also. Sutton (1990) posed a question that why do females in groups of humans and higher apes consume more insects than males? He contends that early hominid males were in charge of hunting for vertebrate flesh. Females compensated for their lack of availability to vertebrate protein and their need for it due to their parental obligations by gathering edible insects as part of their regular gathering practices. A similar pattern of practice has been observed in Apatani and other neighbouring tribes, where men are reputedly hunters and women work in paddy fields and frequently engage in edible insect gathering as an additional job for dietary sources as a delicacy. A number of insect species are cherished ingredients in other traditional dishes. They are often celebrated for their unique flavours and textures, contributing to the unique culinary heritage of these regions. Even youth are embracing entomophagy, thus not only preserving cultural identity but also opening doors to culinary innovation and the exchange of gastronomic traditions on a larger scale. Despite exposure to modernity, it has managed to preserve and maintain its cultural identity and traditions in its original state. Apatanese considered culture to be the main factor for the sustainable evergreen ecology of Ziro-Valley, which is reflected in human interaction with nature. However, cultural diffusion and the transition from traditional to modernity are unavoidable, too. Even the most conservative cultures were swept away by the wave of globalization. The growing influence of globalization is evident among the Apatanese too. The immediate effect of transition is reflected in the modern lifestyle and dietary patterns of Apatanese.

2.3 Anthropo-entomophagy and ethno-entomology among the Apatanese

Anthropo-entomophagy practices have a great deal of importance and history in the practiced regions of the world; however, the consumption of insect species and their traditional value differs from community to community. Apatanese are reported to consume 52 species of 21 families and eight orders (Chakravorty et al., 2019), a few of which are presented in Fig. 4. The Apatanese highly appreciate Odonata and other aquatic insects. An Apatani's life is very well-oriented to their agricultural field being a non-nomadic tribe. They collect almost all their edible aquatic insect from their wet paddy fields using handpicking or

Fig. 4 Few edible insects consumed by the Apatani tribe

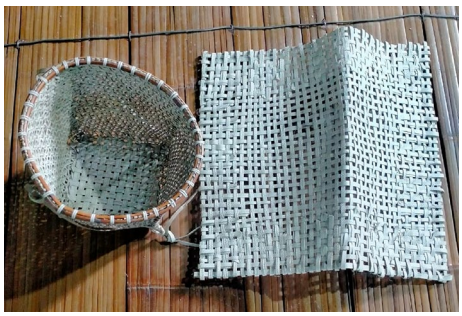

Fig. 5 Tasing-Piiah (left) and Ngyi-Pakkeh (right) used in aquatic edible insect collection by Apatanese

traditional strainer methods using *tasing-piiah* and *pakkeh* (Fig. 5). Adult dragonflies are collected using gum (*payu*) extracted from wild plants which is spread in long bamboo twigs. Meanwhile, edible beetles are collected using net and handpicking methods (Fig. 6). Collecting edible insect species from their paddy field and vegetable gardens reduces losses due to pests and improves their harvests while gathering food rich in protein and minerals. It was noted that Apatani acquired an in-depth understanding of ethno-taxonomy. Almost invariably, locals could give the vernacular names of the insects. Apatanese frequently even gave specific names to the various stages of insect life and identified species that belonged to the same family or different insect orders. The identification and naming are based on an insect's distinguishing characteristics, such as morphology, colour, and habitat. In the case of dragonflies, they primarily evaluate size and coloring and can even tell which adult a larva will become. To provide some instances, *simbo-tasing* larvae become *apang-khemu* adults, *sinta-tasing* larvae become *yaju-pokho* adults, *sinya-tasing* larvae become *byabo-takho*, *butakhe* larvae become *byamintayi* adults, and *miite*

Fig. 6 Apatani women hand-picking edible beetles from a net which are shaken down from the host tree

larvae become *etu-konchi* dragonfly adults (Chakravorty et al., 2019). Most beetle species are named solely based on their color; for example, the *Lepidiota* beetle is called *Sanko-Tapu*, meaning white patches upon the dark body in the Apatani dialect because it has white scales and a blackish body. An example of naming based on morphology is *Atractomorpha* sp., called *Taru-umyu*, meaning pointy head. The documentation of the modern ethno-entomology relation of Apatani has also unveiled the concept of "edible insect pest management" via the practice of entomology in Ziro Valley (Muni et al., 2023a). Notably, Apatani's anthropo-entomophagy and entomo-pest management might have been enhanced through an ethno-taxonomic understanding

of the insects that are common to their region and also how they traditionally utilized throughout history till date.

3 Current status of entomophagy among Apatani and their scientific substantiation

It is interesting to ponder how intelligent our ancestors were to discover, practice, and maintain the entomophagy culture. Despite this fact, we can only scientifically evaluate a small number of them in the current decade. Around 52 species of edible insects among Apatanese are documented (Chakravorty et al., 2019; Muni et al., 2023a). In addition, a significant number of edible insect species that Apatani consumes are still undetermined, and no scientific research has yet been conducted on them. The list of the edible insects consumed by the Apatani Tribe, on which the scientific validation is done exclusively so far in the Biochemical and Nutritional Laboratory, Rajiv Gandhi University Arunachal Pradesh, is given in Table 1 along with their order, vernacular name(s), and scientific exploration.

Chondacris rosea and *Brachytrupes orientalis* are known as *Koha* and *Tapu-yarii,* respectively, by the Apatanese, and they like to gather them from paddy fields and nearby nooks. According to Chakravorty et al. (2014), these species are a good source of protein and minerals like iron, copper, and zinc, and few of their amino acid content exceeds FAO recommendations. Other desired edible insects eaten by Apatani that are found to contain respectable nutritional value are dragonflies, *Laccotrephes ruber*, *Cybister* sp., and *Mimela* sp. (Jugli, 2018). Another popular species, *Aspongopus* species, is typically absent from Ziro Valley. It is purchased there from nearby tribes whose markets obtained it from riverside rock beds due to its good nutritional content (Chakravorty et al., 2011). Additionally, *Aspongopus* sp., *Mimela* sp., and other species have been found to have strong antioxidant capacity (Jugli, 2018; Raza et al., 2020; Tukshipa et al., 2022).

Furthermore, along with nutritional research, considerable work has been done from other important perspectives, such as evaluating toxicological and immunomodulatory investigations. In the case of *Mimela* sp., in-depth exploration showed no toxicological consequences in consuming it as food (Yashung et al., 2020), but rather has immunomodulatory effects (Tukshipa et al., 2022). It is also vital to determine which chemical compounds are present in insects that are contributing to nutritional, antioxidant, and immunomodulatory effects. According to Tukshipa et al. (2023), several therapeutically active components are present in *Mimela* insects. Overall, many insects may be consumed safely, and as was mentioned above, the habit of eating insects may have been influenced by the presence of pest species during the early stages of agricultural development in human history. Edible pest species like locusts cause huge devastation to agricultural crops, so it might have encouraged humans to consume them for management as well as dietary supplementation. In the Apatani Ziro Valley, similar edible insect pest control methods are practiced in the Kiwi agro-ecosystem, which gives positive local output (Muni et al., 2023a). Edible insect pest *Anomala dimidiata* is found to respond positively to its host plant's volatile compounds thus showing possible allelochemical interaction, which is important from an agricultural perspective (Muni et al., 2023b). Similar to all studies above, the inclusion of additional edible species under such inquiry by younger generations of researchers is imperative for the future toward nutraceuticals, medicinal, and agricultural dimensions.

Table 1 Few species of edible insects consumed by the Apatani tribe

Scientific name	Orders	Vernacular name(s) (Apatani)	Scientific exploration
Chondacris rosea	Orthoptera	*Koha*	Nutrient composition
Brachytrupes orientalis	Orthoptera	*Tapu-yarii*	Nutrient composition
Aspongopus sinensis	Hemiptera	*Naru-tiyoh*	Nutritional content and in vitro antioxidant activity
Dragonfly (Adult and larvae)	Odonata	*Konchii*	Nutritional content and antioxidant potential
Laccotrephes ruber	Hemiptera	*Hangeh-hangeh*	Nutritional content and antioxidant potential
Cybister sp.	Coleoptera	*Yasii-Anii*	Nutritional content and antioxidant potential
Mimela sp.	Coleoptera	*Jojer (small)*	Nutritional content, toxicological assessment, in vivo antioxidant, immunomodulatory, therapeutic potential
Anomala dimidiata	Coleoptera	*Jojer (Big)*	Its management in important crops via entomophagy, plant–insect interaction
Phyllophaga sp.	Coleoptera	*Dikang-Diilang*	Its management in important crops via entomophagy
Lepidiota sp.	Coleoptera	*Sanko-Tapu*	Its management in important crops via entomophagy

4 Future prospects of entomophagy for Apatani

The collective research exploration revealed that the insect species, which humans have historically used as food or medicine, are not only healthier but are also the product of the generation of harmonious co-existence between tribe and environmental resources and human–insect interaction that, most of the time, is overlooked. In general, future prospects regarding entomology lie in developing insect culture systems and commercializing insect products, which creates economic output in the food industry. For the Apatani and other tribes of the Northeast Indian region, it can enhance the value of this region, which is acknowledged as the poorest region of India due to its steep topographical location where conventional large-scale agriculture and animal husbandry face huge challenges. Recently, the European Union has specified new regulations on insect-based food to be accepted if their safe consumption for longer than 25 years in developing countries is demonstrated (Baiano, 2020). Thus, edible insect production and commercialization can offer revenue opportunities in developing countries and the northeast Indian region, including the Apatani tribe. Work progress regarding edible insect culture system development is gaining momentum. Although entire edible insects can be eaten, they can also be treated into an unrecognizable form to boost their attractiveness (Osimani et al., 2018). So, developing various processing techniques and creating insect-based cuisine is also key to attracting more consumers.

Insects have been designated as the priority option with the fewest environmental risks by the FAO, which is currently actively pursuing a program to identify alternative sources of food to feed the world's still-growing human population (FAO, 2010). Global demand for animal-based protein is skyrocketing, and as developing countries develop and industrialize, this demand will only continue to grow. And farm animals are already raised on 30% of all land and 70% of all agricultural land (FAO, 2017). However, insects present a highly appealing alternative to it, and it is becoming obvious that mass-producing insects require considerably less energy and other resources. Insect farming requires minimal investment and can be pursued on a small scale, enabling local communities to generate income and improve their livelihoods. Concerning the indoor mass-rearing of edible insects, not all species can be bred because of their different needs for ambient environmental management (temperature, relative humidity, photoperiod) and avoidance of parasites and illnesses. Another important factor that hinders the raising and production of insects is the lack of understanding of nutritional needs. According to Hanboonsong et al. (2013), around 20,000 medium- and large-scale businesses in Thailand successfully raise crickets, grasshoppers, and other insects. The future trend lies in developing more cultural systems for promising species to be mass-reared according to their geographical availability and practice. On the other hand, the producers are looking for polyphagous insects that could be managed with several host plants in different vegetation.

While entomophagy has significant advantages, there are also numerous challenges that need to be addressed. Insect rearing is not merely a technological application, as some obstinate decision-makers in research institutes believe, but it is also a genuine basic research subject that should be prioritized. Both academic and applied studies are necessary to guarantee success in edible insect rearing and contribute to the development of future food prospects. Moreover, ensuring the safety and hygiene of insect farming practices is crucial to prevent contamination and maintain food security standards. Insects can be considered safe from a microbiological point of view (Mézes, 2018) but can contain residues of pesticides (Sánchez-Bayo, 2021) and heavy metals (Handley, 2007). The cross-reactions between allergens present in some insect species must be considered. For quality control of edible insects produced, biochemical assays need to be extended by chemical analyses or immunoassays. The development of new quality control parameters could be suggested. Extensive investigations about the host plant–insect relationships and their subsequent effects on nutrition, reproduction, and quality parameters would be expected. Furthermore, large-scale insect farming can also be accomplished by taking a number of important steps, including increasing consumer demand and awareness, giving farmers adequate training, granting access to financial services, and educating the public and policymakers about the social, economic, and environmental advantages of insect farming as well as the effects it has on a circular economy. The development of marketplaces and the strengthening of value is also critical.

5 Conclusion

Eating insects seems to be a culturally universal practice, with very minor regional, ethnic, and insect-specific variations. A review of the literature and facts shows that entomophagy dates back to ancient archaic humans. However, it is difficult to presume how exactly insects that are not readily apparent as edible became sustenance for humans. The tradition of eating various edible insects is well known in Northeast India, especially Arunachal Pradesh, which has the greatest recorded number of edible species to date. The Apatani and other *Tanii* tribes of Arunachal Pradesh readily practice entomophagy, which may be traced back to ancient Mongolia and the Tibetan region. Although this practice has been forgotten in the current Tibetan region,

historical evidence indicates that China, Mongolia, and Tibet have interacted culturally throughout history. Therefore, it is likely that this practice originated in or was influenced by Chinese civilization, which is still highly prevalent. Nevertheless, ancient entomophagy methods of the Apatani tribe have yielded about 52 species, a few whose scientific validation has been reviewed in this study. The existing scientific evidence makes a compelling case that the data may support the traditional usage of dietary supplements and treating different illnesses with edible insects. This not only strengthens the case for traditional use but also raises the possibility that edible insects may serve as a source of a variety of crucial nutrients and cutting-edge medications. The current research is anticipated to provide possibilities for the scientific confirmation of the many additional edible insects consumed in tribal areas for their potential as food and medicine in the future.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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