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Research article

Entomophagy and allergies: a study of the prevalence of entomophagy and related allergies in a population living in North-Eastern Thailand

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As the population of the world grows, so does the need for sustainable food. Insect farming and consumption can help ease the burden of supply from other more conventional food sources. This article investigates the prevalence of allergic reactions caused by consuming edible insects. The investigation was conducted in the North-Eastern or the Isan region of Thailand, in an area where insect consumption or entomophagy is a common practice. Information concerning insect consumption and allergic reactions were gathered from multiple sources in four locations: Nongki, Nang Rong, Nong Bun Mak and Nakhon Ratchasima. The survey included questions about eating habits in relation to insects, other known food allergies and presented a list of symptoms the participants may have experienced. The results from 2500 respondents were surprising in that the prevalence of allergic reactions caused by consuming edible insects was much higher than expected. In the Isan region approximately 7.4% of people experienced an adverse reaction indicative of an edible-insect allergy and 14.7% of people experienced multiple adverse reactions indicative of an edible-insect allergy. Furthermore, approximately 46.2% of people that already suffer from a known food-based allergy also experienced symptoms indicative of an allergic reaction after insect consumption. The most common symptoms appear to be gastro-intestinal (diarrhoea and vomiting). In conclusion, the allergy aspect of entomophagy is a serious issue and has the potential to adversely affect the future of entomophagy, especially in introducing the concept to western cultures. Although preliminary in its findings, this article hopes to ignite further research into the topic in order to fully understand the implications and role that edible insects can have on the immune system.

Key words: entomophagy, allergy, insect, grasshopper—*Valanga nigricornis*, crickets—*Gryllus bimaculatus*, silk worms—*Bombyx mori caterpillar*, bamboo worms—*Omphisa fuscidentalis caterpillar*, water bugs—*Lethocerus indicus*, scorpions—*Heterometrus Longimanus*, red ants—*Oecophylla smaragdina*, red ant eggs—*Oecophylla smaragdina larvae*

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Introduction

Insects like many protein-containing foods (milk, shellfish and soy) can cause an allergic reaction in sensitive individuals (Reese *et al*., 1999; Chen *et al*., 1998). These reactions may include rash, nausea, diarrhoea, eczema and anaphylactic shock among many others. While some people have a history of allergies, it is possible to develop an allergy through long-term exposure. Allergic reactions to bug bites and stings are common within any group of humans but allergic reaction to insect consumption is still a new area of study with less complete understanding.

The nature of the allergen, their cross reactivity and the forms of exposure might be important parameters in this complex picture. For instance, some environmentally sensitive individuals allergic to house dust mites after prolonged exposure to the mite antigen have shown to become allergic to seafood tropomyosins. Tropomyosin is a protein found in cockroaches, mites and shrimps has been reported to be allergenic. These observations suggest that particular individuals with shrimp allergy for instance could be expected to experience a reaction by consuming insect proteins (Reese, Ayuso and Lehrer, 1999). Furthermore, there is evidence that allergies can be induced via the direct ingestion of insects or proteins carried by them. An example of this is the larvae of the *Apis cerana indica* (Indian honeybee) which contains pollen, thus people allergic to pollen are advised not to eat them (Chen *et al*., 1998). In a study conducted in the republic of Laos (Van Itterbeeck and van Huis, 2012) has reported that one respondent with a history of consuming insects developed an allergy to water bugs (*Lethocerus indicus*) and another have developed an allergy to all edible insects along with shrimps. These examples suggest that it is possible to develop allergies triggered by consuming edible insects. It is unlikely that processing the insects possibly via boiling will have any effect on the allergenic component of the insect. However, this remains to be demonstrated.

Allergies can also be triggered by a compound known as Chitin, which is the second most common polysaccharide in nature. Chitin is commonly found in lower organisms such as fungi, crustaceans or insects but not in mammals. Although antiviral and anti-tumour properties have been attributed to chitin, their effect on the innate and adaptive immune system has only recently been demonstrated (Lee, Simpson and Wilson, 2008). Chitosan, which is a derivative of chitin, has been shown to have properties that could modulate immune responses in specific groups of individuals (Goodman, 1989; Muzzarelli, 2010). By inducing non-specific host resistances against infections by pathogens, it has been suggested that chitin may reduce some allergic responses or work as alternative to antibiotics currently used in livestock (Muzzarelli, 2010). It is hypothesized that the difference in exposure levels to chitin and to intestinal parasites may be critical in explaining the differing prevalence of allergies on the population. The presence of chitinases in human gastric juice has been linked with responses to parasitic infections and linked to allergenic conditions. Furthermore, a review of the immunological response to chitin and its role in inducing allergies showed that the responses were dependent on the particle size of the chitin substance. This means that while medium sized chitin particles may cause an allergic response, smaller sized chitin particles may have the opposite effect of reducing the allergic response (Brinchmann *et al*., 2011).

Why is it important?

It is widely acknowledged that by 2050 the population of the world could rise to nine billion people (Un.org, 2013). The current level of food production would either have to double in the near future or alternative food sources would have to be introduced. Land is scarce and farming land even more so. There are approximately 1 billion people worldwide that suffer from chronic hunger or undernourishment, this issue must be addressed urgently (Penner, 2009). Insect proteins may be the solution or may help reduce the burden of demand from more conventional foods. The practice of eating insects, also known as entomophagy, is quite common throughout the world with approximately 2 billion people consuming insects on a regular basis especially in Asia, Southern America and Africa (Van Huis *et al*., 2013). This practice has been known to have been occurring since prehistoric times until modern times with over 1900 documented edible insect species (Van Huis *et al*., 2013). Although the majority of edible insects are gathered from forest habitats, innovation in mass-rearing systems have been implemented in multiple countries (Van Huis *et al*., 2013). Growing concerns over unsustainable and environmentally harmful modern farming techniques means that as the population grows the food supply becomes insufficient and the environment may become damaged beyond repair. With this revelation farming and eating insects may be the wiser, and necessary, choice.

While entomophagy is uncommon in western nations there has been an increase in awareness concerning its benefits and hopefully, this could lead to a growth in consumption. While many cultures around the world prize insects as a rare culinary treat. A Food and Agriculture Organization report stated that from ants to beetle larvae, eaten by tribes in Africa and Australia as part of their subsistent diets to the popular, crispy-fried locust and beetle enjoyed in Thailand, it is estimated that insect-eating is practiced regularly by at least 2 billion people worldwide (Van Huis *et al*., 2013).

The objective of this study is to determine the prevalence of insect consumption in the Isan region of Thailand. The methods applied will also hope to determine the effects that insect consumption may have on the person in relation to allergies. This is done in order to address the safety aspect of insect consumption and to determine if insects would be a viable food source. While there are many aspects of safety that must be considered to determine the viability of insect consumption, this article will mainly focus on the possibility of insects as allergens.

Materials and Methods

The main survey material was a questionnaire which included a set of questions that aimed to determine the insect eating habits of the target population along with any allergy symptoms that they may have experienced. The questionnaire was initially written in English but was required to be translated into Thai in order to accommodate the target population. Approximately 4000 questionnaires were printed and distributed to teachers at schools (Nongki Pittayakom, the local high school; Nang Rong Pitayakom and Saint Joseph's school in Nang Rong) and nursing staff in hospitals (Nongki general hospital; Nong Bun Mak Pittayakom, Saint Mary's hospital in Nakhon Ratchasima) prior to patient consent with a small number being distributed at neighbourhood community centres (Nongki Community Spaces). Government permission was required and granted prior to distribution of questionnaires to public school and hospitals.

The distribution was carried out twice, this was done both for convenience and to accommodate the bank holiday season in Thailand. The initial distribution phase included distribution of 2500 questionnaires in Nakhon Ratchasima, Nongki and Nong Bun Mak. This was carried out from 16 to 17 December 2016. While the second stage of distribution involved distribution of 1500 questionnaires in Nang Rong and this was carried out on the 22 December 2016.

The study was conducted in an area with relatively high rates of insect consumption and low levels of stigma placed on insect consumption. The Isan region of Thailand has arguably the highest rate of insect consumption of the country due to a habitat of edible insects and high number of immigrants from Laos and Myanmar, countries that also regularly consume insects. While this study was carried out in Isan, the focus was further away from the border in order to target more Thai nationals. The study also compares areas of residence of the participants, this was to determine the difference in both insects in diet and prevalence of allergy. Questionnaire design: The study involved questionnaires that aimed to determine quantitative data. The questionnaires looked for correlations between a number of variables with a focus on differences in gender, location of residence, variety of insect consumption and variety of symptoms experienced. The questions included in the questionnaire are as follows:

- □ Gender
  - ○ Male
  - ○ Female
- □ Ethnicity
  - ○ How would you describe your ethnicity?
- □ Age
  - ○ 5–10
  - ○ 10–18
  - ○ 19–30
  - ○ 30–45
  - ○ 45+
- □ Monthly income in Thai Baht
  - ○ Less than 10 000
  - ○ 10 000–30 000
  - ○ 30 000–50 000
  - ○ 50 000–100 000
  - ○ More than 100 000
- □ Level of education (either currently studying or completed)
  - ○ No formal education
  - ○ Primary
  - ○ Secondary
  - ○ Sixth form (A levels, International Baccalaureate)
  - ○ Technical College
  - ○ Bachelor's Degree
  - ○ Master's Degree
  - ○ Doctorate Degree
- □ Location of residence
  - ○ City (population of over 2000)
  - ○ Large village (population of between 1000 and 2000)
  - ○ Small village (population of between 300 and 1000)
  - ○ Suburbs (Persons living on the outskirts of a city)
  - ○ Rural areas, e.g. farms (population of under 300)
- □ Pre-existing food allergies
  - ○ Milk
  - ○ Eggs
  - ○ Peanuts
  - ○ Shellfish
  - ○ Soya
  - ○ Other
- □ Amount of insect consumption
  - ○ Never
  - ○ Rarely (less than once a week)
  - ○ Modestly (approximately once a week)
  - ○ Often (more than twice a week)
- □ Type of insect consumed
  - ○ Grasshopper
  - ○ Crickets
  - ○ Silk worms
  - ○ Bamboo worms
  - ○ Water bugs
  - ○ Scorpions
  - ○ Red ants
  - ○ Red ant eggs
  - ○ Other
- □ Any pre-existing medical conditions
  - ○ E.g. diabetes, asthma etc.
- □ Have you ever experienced any of these symptoms after a meal?
  - ○ Asthma (difficulty breathing)
  - ○ Wheezing
  - ○ Breathing difficulties
  - ○ Swelling of the lips, mouth, tongue, face and/or throat
  - ○ Urticaria (hives)
  - ○ Rashes or redness
  - ○ Itching (pruritus)
  - ○ Eczema
  - ○ Abdominal cramps
  - ○ Diarrhoea
  - ○ Nausea
  - ○ Vomiting
  - ○ Anaphylactic shock (severe generalized shock)
- □ How soon after the meal did these symptoms appear?
  - ○ During or directly after the meal
  - ○ Several hours after the meal
  - ○ The day after the meal
  - ○ Several days after the meal

Results

From the initial 4000 questionnaires randomly distributed to Schools, hospitals and community centres within the Isan region 2529 or 63% have been filled and are tabulated here. It is worth mentioning that the adherence to the questionnaire was totally on a volunteering basis and not intentionally target towards the insect eating group. However, it is well possible the non-insect eaters refrained from participating. Out of 2529 participants that responded the questionnaires, 1959 people have consumed insects, which amounts to a total of 77%.

There are differences in the amount of insect consumed by each participant, with some consuming multiple servings on a regular basis to some consuming less than one serving a week. However, there are only minor differences in amount of consumption between the genders. Figure 1 shows consumption levels and a comparison between genders.

The significant differences between amounts of insect consumed can be attributed to varying availability and personal preferences. Whereas, the consumption amounts between males and females are similar, this means that the same factors influencing insect consumption is equally applicable to both genders.

The variety of the insects consumed must also be considered due to differing nutritive values and mainly the amount of chitin. Therefore, it is important to determine which insects are being consumed. Figure 2 shows the comparison of insect consumed by species in percentage. Grasshopper (*Valanga nigricornis*) seems to be the highest consumed insect followed by silkworms (*Bombyx mori*) and cricket (*Gryllus bimaculatus*).

Due to the nature of chitin and its effects on the immune system, evidence suggests that chitin could improve immune system functioning of specific people (Goodman, 1989). The most commonly consumed insects all contain chitin but it is most highly concentrated in the exoskeleton of the insect. Insects which do not have a hard exoskeleton, such as the silk worms, bamboo worms and red ants' eggs, contain a smaller dose of chitin.

According to Fig. 3, approximately 21% of insect consumers surveyed reported at least one reaction that could indicate an allergic response, with 5% reporting multiple symptoms after consuming insects:

While the presence of a single symptom could identify an allergy, the presence of multiple symptoms would provide better evidence of an allergy and could rule out other explanations for the symptoms.

Out of 2529 people surveyed 90 people had known allergies with the most common allergy being Seafood and Shellfish. Of those 90 responders, 65 or 72% were insect consumers. Furthermore, 19 of those suffering from either seafood or shellfish allergies reported at least one symptom of an allergic reaction and 19 reported multiple symptoms indicative of an allergic reaction and 10 participants reported no reaction at all. Also, three participants reported being allergic to edible insects.

The most common symptoms reported after insect consumption (Fig. 4) are diarrhoea and vomiting, followed by nausea and dizziness.

While these symptoms are concurrent with an allergic reaction, they can also be explained by a variety of other causes including food poisoning. Symptoms such as anaphylactic shock and breathing difficulties are strong indicators of a severe allergic reaction especially if experienced during or immediately after consuming insects. A total of 150 (7.6%) insect consuming participants reported a severe allergic reaction, 25 of those or 17% have known allergies to shellfish and other seafood.

It is interesting to observe that atopic individuals do tend to show multiple symptoms further reinforcing the expected cross-reactivity between specifies.

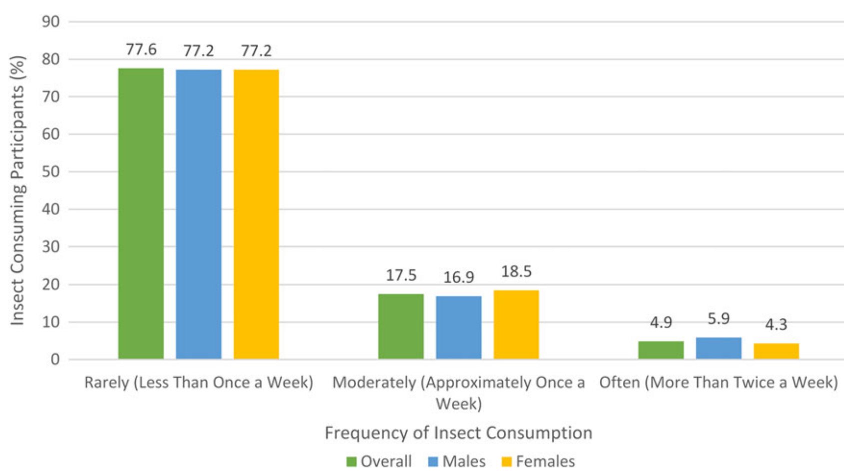

Figure 1. Comparison of insect consumption levels with a comparison between males and females in percentage.

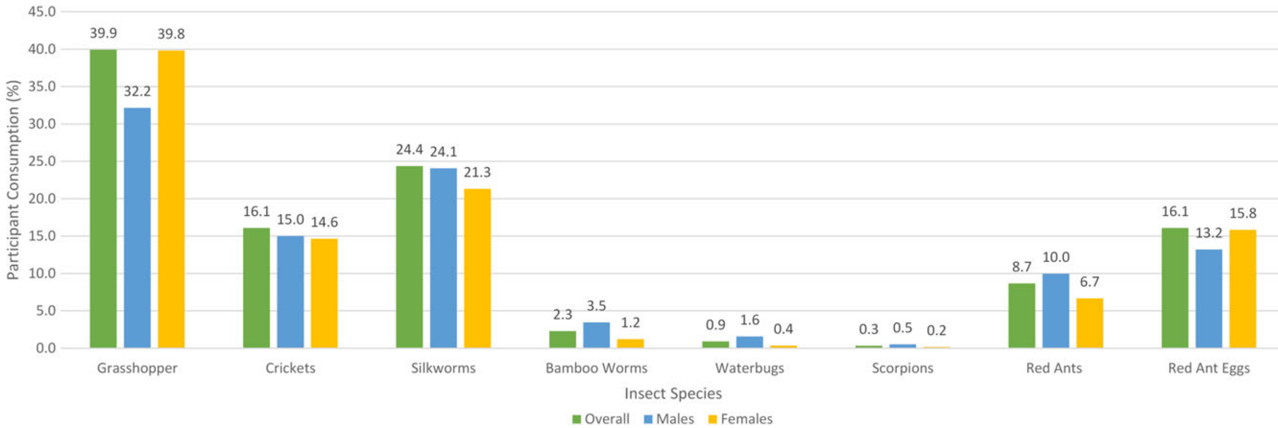

Figure 2. Comparison of insect consumption by species in percentage. Grasshopper—*Valanga nigricornis*, crickets—*Gryllus bimaculatus*, silk worms—*Bombyx mori caterpillar*, bamboo worms—*Omphisa fuscidentalis caterpillar*, water bugs—*Lethocerus indicus*, Scorpions—*Heterometrus Longimanus*, red ants—*Oecophylla smaragdina*, red ant eggs—*Oecophylla smaragdina larvae*.

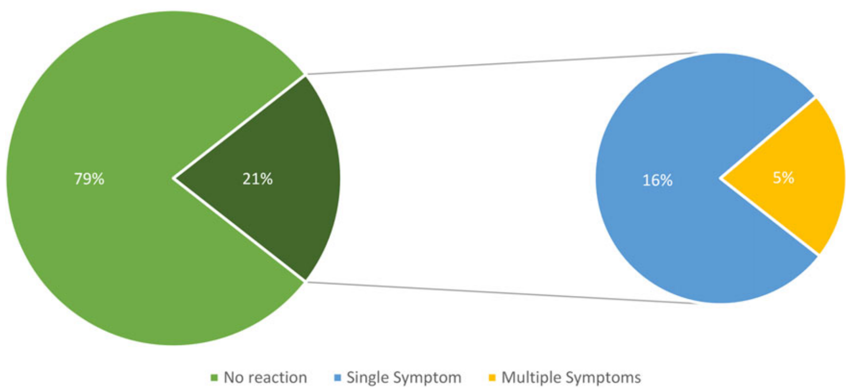

Figure 3. Prevalence of allergic reactions in insect consumer participants in percentage.

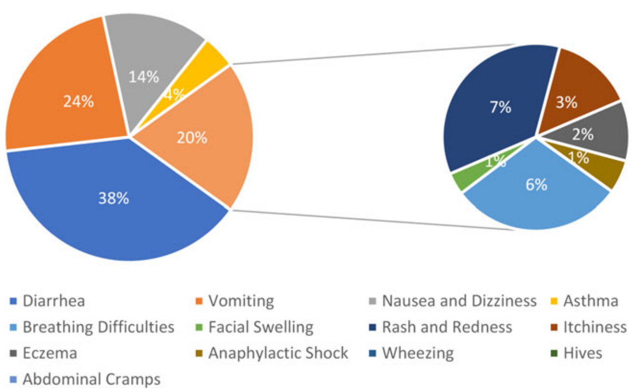

Figure 4. Symptoms experienced by the participant after insect consumption in percentage, each section represents a percentage of participant that reported the corresponding symptom.

All participants that reported known allergies also reported that they experienced symptoms indicative of an allergic reaction either immediately after consuming insects or within an hour after consumption. According to Fig. 5 the water bug appears to be the insect which is most likely to cause an allergic reaction in consumers. However, 94% of participants that reported having prior allergies, also reported symptoms indicative of an allergic reaction after consuming grasshoppers.

Discussion and Conclusion

The rates of insect allergies were found to be high relative to the average rates for other allergies. Approximately 4% of people in the USA suffer from food-based allergies. A survey found that the estimated prevalence of seafood allergies

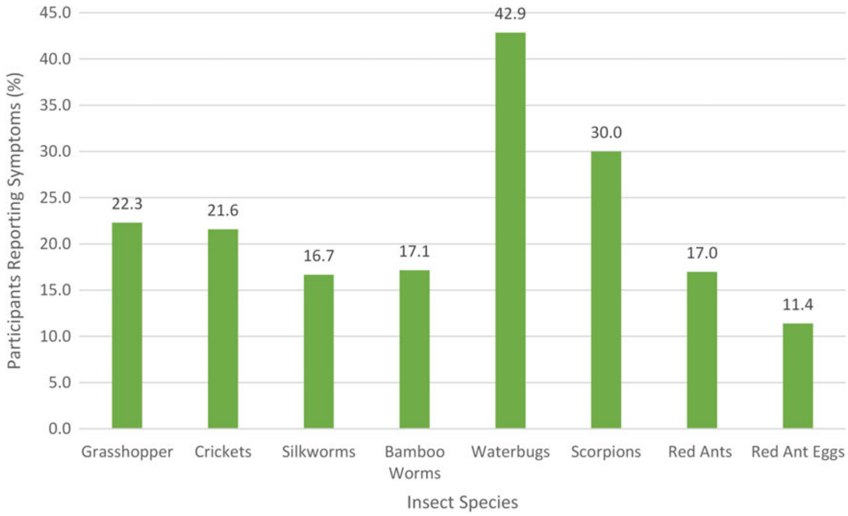

Figure 5. Allergic reactions caused by insect consumption in percentage.

amounted to 1.9% with shrimp and 0.4% with fish. This means that 2.3% of food allergies are accounted for by seafood in the USA (Sicherer, Munoz-Furlong and Sampson *et al.*, 2004). While Entomophagy is very common in Thailand, especially in the Isan Region, 77% is a significant number. To explain this the survey methodology must be considered. The survey targeted specific areas of the region where insect consumption was very common, cheap and readily available. The survey also targeted areas of lower than average economic status, this was done in order to assure the maximum number of insect consumers and does not represent the rest of the nation. The vast majority of participants were students currently in their last year of high school equivalent to year 11. The questionnaire was also written using layman's terms for symptoms associated with an allergic reaction. While the full description of anaphylactic shock was not described in English, there is no direct Thai translation, therefore anaphylactic shock was described as an array of symptoms including severe swelling of the face, difficulty breathing, dizziness and followed by loss of consciousness. Furthermore, a comparison between insect consumption and location of residence revealed that participants from big villages were most likely to consume insects on a regular basis (86%) and participants from suburban areas (69%) were least likely. The difference is due to a variety of factors including preferences, lifestyle but mainly availability. In villages multiple times a week, a local market will be held and at these market is where the majority of people purchase and consume insects either as a snack or for a later meal. Whereas, in cities or suburban areas these markets may be less common and may be less likely to have insects for sale.

However, while this figure may seem high when compared to western perceptions, studies have shown it to be comparatively low compared to nearby regions. For example, as of 2015 approximately 96.8% of people in Laos are insect consumers while only 2% of people claiming to have never consumed any insects (Barennes, Phimmasane and Rajaonarivo, 2015).

The choice of population used in this study meant that the majority of participants would be insect consumers and these participants would regularly be exposed to insect matter along with believing entomophagy to be the cultural norm. This would cause problems when trying to extrapolate the data to a wider population, especially to countries where entomophagy is still considered taboo. The lower or lack of exposure to insect products could affect the immune system and possibly cause people with lower exposure levels to be more susceptible to developing an allergy. Another factor is the social classes of the participants, higher economic status families are more likely to live in larger communities where supermarkets and convenience stores are more common and often have a larger and different selection of food. While lower income families live in smaller communities where they would purchase food from fresh food markets where hygiene standards are noticeably lower and risk of contamination is relatively high compared to supermarket foods.

Furthermore, cooking procedures must be taken into consideration. This is particularly significant when combined with the statistics for insect that is most likely to cause an allergic reaction. Water bugs stand apart from the other edible insects due to how they are most commonly consumed, especially in the Isan region. Most insects are air dried and then deep fried prior to consumption but the water bugs are often cooked by having their wings removed and eaten fresh or used in a variety of sauces. This can lead to an increased risk of food poisoning and increases the risk of toxic chemicals being present in the insect, possibly leading to conditions that have similar symptoms to an allergic reaction such as diarrhoea and vomiting which were the most common

Table 1. Percentage of participants that reported reaction after insect consumption. Shows relationship between pre-existing food allergies and increase risk of allergic reaction due to consumption of insects

Allergy rates	All participants	Insect consuming participants including those with and without pre-existing food allergies	Insect consuming participants with pre-existing food allergies
No symptoms	2095 (82.8%)	1522 (77.7%)	18 (27.7%)
Single symptom	288 (11.4%)	288 (14.7%)	17 (26.1%)
Multiple symptoms	146 (5.7%)	146 (7.4%)	30 (46.2%)

symptoms experienced. Also, other insects while they are properly cooked are often left on a large flat basket on sale and can remain for hours before consumed which can lead to contamination especially at markets where other foods are on sale and a lot of dust is in the air.

A surprising realization was the lack of differences in consumption between males and females. The choices of insect and amount of consumption were similar. The main difference came to reporting symptoms experienced after insect consumption. However, the difference came when reporting symptoms, males were much more likely to report gastrointestinal problems such as diarrhoea or vomiting while females were more likely to report symptoms such as nausea and dizziness. This could be attributed to cultural gender stereotypes, such as it would be impolite for a woman to mention intestinal distress.

Insect as nutrition sources of food

Insects are a highly nutritious and healthy source of food with high macronutrient content, high micronutrient content and a variety of minerals (Rumpold and Schlüter, 2013). The nutritious value of insects can vary quite greatly due to the wide range of edible insect species. Within the same species of insect, the nutritive value can vary quite markedly due to the multiple stages of metamorphosis and each in each stage the insect may be consuming different foods which enhances the causes for variance. This effect can be seen in ants, beetles and bees. As shown here in Thailand both the red ants and their eggs are commonly consumed.

Different species of insect can have a noticeable difference in the nutritive value. For example, 100 g of silk worms may contain 10–17 g of protein. While 100 g of crickets contain 8–25 g of protein (Van Huis *et al*., 2013).

Insect farming can also have a large impact on the environment. A project conducted in Kenya successfully linked forest conservation with livelihood improvement (Raina *et al.*, 2009). By commercializing insects such as the silkworm, communities living near forests were able to sell the silk produced, thus creating an alternative source of income. Leftover pupae were also fed to chickens. These benefits gave the local communities an incentive to manage their surrounding forest habitat. Entomophagy and by extension insect farms can also be economically beneficial to the local populations. For example, the pupae of the domesticated silk worm (*Bombyx mori*) which is considered a by-product of silk production can be used as a food source for human consumption with approximately 1.2–1.4 million silkworm cocoons per ha of mulberry bushes and a single pupa weighing 0.33 g, the average pupal by-product is an estimated 400–460 kg per ha (DeFoliart, 1989). In addition, the silkworms produce a waste product known as Frass which can be used as a fertilizer or can be used to feed fish. As of 2012 Thailand has approximately 20 000 cricket farmers with crickets being one of the most commonly consumed insects (Van Huis *et al*., 2013).

Although the overall methodology employed in this study could certainly be improved the results of this survey certainly suggest that a non-controlled introduction of entomophagy to new market will inevitably face potential safety concerns. Due to the observed high rates of allergies in a population that regularly consumes insects, the rates of allergies would be even higher in populations in which exposure is rare. The potential cross-reactivity with well know food and environmental allergens would be of further concern. Overall this presents a safety concern when trying to promote entomophagy as a possible food source for western civilization. The importance of this is two-fold, firstly in relation to the nutritive benefits of entomophagy and secondly is its impact on the environment. Both of these benefits of entomophagy are heavily reliant on consumer safety. If the product is harmful to the consumer, which is suggests here, the benefits may never be realized.

While the results of this investigation further confirmed the background information that edible insect allergies are common in some regions in Thailand, it stresses the need to a responsible discussion regarding entomophagy safety and its implementation regardless of the apparent potential benefits. Economically, environmentally, nutritionally entomophagy makes sense and will continue to be a way of helping relieve many burden places on the world and its population from hunger and starvation. The extension of the technology to other parts of the world needs however to be responsibly carried out (Table 1).

Author Biography

Geoffrey Taylor wrote this article and has responsibility for final content. He is a third-year nutrition student in 2017. Growing up in Thailand sparked an interest in insects which lead to him choosing to study insect consumption and the safety of insect consumption. Geoffrey plans on continuing his studies but is unsure of the field he would like to study. Outside of school, he enjoys boxing and is an avid music and film fan. Nanxi Wang contributions include aid in writing of article and quality checking.

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References

Barennes, H., Phimmasane, M. and Rajaonarivo, C. (2015) Insect consumption to address undernutrition, a National Survey on the Prevalence of Insect Consumption among Adults and Vendors in Laos, *PLoS One*, 10 (8), e0136458.

Brinchmann, B. C., Bayat, M., Brøgger, T. et al. (2011) A possible role of chitin in the pathogenesis of asthma and allergy, *Annals of Agricultural and Environmental Medicine*, 18, 7–12.

Chen, P. P., Wongsiri, S., Jamyanya, T. et al. (1998) Honey bees and other edible insects used as human food in Thailand, *American Entomologist*, 44 (1), 24–28.

DeFoliart, G. R. (1989) The human use of insects as food and as animal feed, *Bulletin of the Entomological Society of America*, 35, 22–35.

Goodman, W. G. (1989) Chitin: a magic bullet? *The Food Insects Newsletter*, 2 (3), 1. , 6–7.

Lee, K. P., Simpson, S. J. and Wilson, K. (2008) Dietary protein-quality influences melanization and immune function in an insect, *Functional Ecology*, 22 (6), 1052–1061.

Muzzarelli, R. A. A. (2010) Chitins and chitosans as immunoadjuvants and non-allergenic drug carriers, *Marine Drugs*, 8 (2), 292–312.

Penner, M. (2009) UN World Food Programme, [online] *Wfp.org*, accessed at: http://www.wfp.org/stories/number-world-hungry-tops-billion (26 June 2017).

Raina, S. K., Kioko, E. N., Gordon, I. et al. (2009) *Commercial Insects and Forest Conservation: Improving Forest Conservation and Community Livelihoods Through Income Generation From Commercial Insects in Three Kenyan Forests*, Science Press, Nairobi.

Reese, G., Ayuso, R. and Lehrer, S. B. (1999) Tropomyosin: an invertebrate pan-allergen, *International Archives of Allergy and Immunology*, 119 (4), 247–258.

Rumpold, B. A. and Schlüter, O. K. (2013) Nutritional composition and safety aspects of edible insects, *Molecular Nutrition & Food Research*, 57 (5), 802–823. 10.1002/mnfr.201200735.

Sicherer, S. H., Munoz-Furlong, A. and Sampson, H. A. (2004) Prevalence of seafood allergy in the United States determined by a random telephone survey, *Journal of Allergy Clinical Immunology*, 114 (1), 159–165.

Un.org. (2013) World population projected to reach 9.6 billion by 2050 | UN DESA | United Nations Department of Economic and Social Affairs, [online] accessed at: http://www.un.org/en/development/desa/news/population/un-report-world-population-projected-to-reach-9-6-billion-by-2050.html (26 June 2017).

Van Itterbeeck, J. and van Huis, A. (2012) Environmental manipulation for edible insect procurement: a historical perspective, *Journal of Ethnobiology and Ethnomedicine*, 8 (3), 1–19.

Van Huis, A., Van Itterbeeck, J., Klunder, H. et al. (2013) *Edible Insects: Future Prospects for Food and Feed Security*. Food and Agriculture Organization of the United Nations, FAO Forestry paper 171, Rome, ISBN 978-92-5-107595.