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REVIEW

Edible insects in China: Utilization and prospects

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Abstract The use of edible insects has a long history in China, where they have been consumed for more than two thousand years. In general, the level of acceptance is high for the consumption of insects in China. Many studies on edible insects have been conducted in the last twenty years, and the scope of the research includes the culture of entomophagy and the identification, nutritional value, farming and breeding of edible insects, in addition to food production and safety. Currently, 324 species of insects from 11 orders are documented that are either edible or associated with entomophagy in China, which include the common edible species, some less commonly consumed species, and some medicinal insects. However, only approximately 10 to 20 types of insects are consumed regularly. The nutritional values for 174 species are available in China, including edible, feed and medicinal species. Although the nutritional values vary among species, all the insects examined contain protein, fat, vitamins and minerals at levels that meet human nutritional requirements. Edible insects were, and continue to be, consumed by different ethnic groups in many parts of China. People directly consume insects or food products made from insects. The processing of products from insect protein powder, oil, and chitin and the development of health care foods has been studied in China. People also consume insects indirectly by eating livestock that

were fed insects, which may be a more acceptable pathway to use insects in human diets. Although limited, the data on the food safety of insects indicate that insects are safe for food or feed. Incidences of allergic reactions after consuming silkworm pupae, cicades and crickets have been reported in China. Insect farming is a unique breeding industry in rural China and is a source of income for local people. Insects are reared and bred for human food, medicine and animal feed using two approaches in China: the insects are either fully domesticated and reared completely in captivity or are partially raised in captivity, and the insect habitat is manipulated to increase production. Depending on the type of relationship the insect has with humans, plants, and the environment, different farming strategies are used. The social and scientific communities must work together to promote the use of insects as food and feed.

Key words edible insects; entomophagy; nutritive value; insect food safety; insect farming

Introduction

Insects are commonly used as a source of food by people in many parts of the world. As of 2012, over 1900 species have been recorded as food in Asia, Africa, Oceania, and North and South America (van Huis, 2013). In many regions, a large biomass of insects can be obtained as food; in part, this is because of the high diversity of insects associated with different environments, but it is also because of the ability of many species to breed quickly. According to previous research, many species of insects are highly nutritious and a healthy food source for people (Chen *et al.*, 2008; van Huis *et al.*, 2013; Ramos-Elorduy, 2005). Insects are efficient in converting their food into protein, and some species can be reared on organic waste. Compared with conventional meat-producing animals such as cattle, pigs, and poultry, insects can provide the equivalent amount of animal protein using less land and water, in addition to producing much lower levels of greenhouse gases (Dennis *et al.*, 2010). With the increasing global population and the decreasing availability of arable land, selecting and developing additional food and feed resources are essential, and insects are an important potential source of food and feed (van Huis *et al.*, 2013). The Food and Agriculture Organization of the United Nations regards insects as a potential sustainable food source

with which to respond to global food security concerns and encourages a greater use of insects in our diets (Vantomme, 2015). The potential of insect food has generated global interest to develop and use insect-food products and has promoted more research and development on edible insects. Many countries have a history of using insects as food, and this traditional knowledge should be an important contribution to the future development of insects as a food ingredient worldwide.

China has over two thousand years of history with the use of edible insects. The history dates even further back to when the ancient Chinese reared silkworms and consumed silkworm pupae (Zhou, 1982; Zhou, 1980). Despite global changes in the diets of people, the culture of insect consumption remains viable in China. Edible insects were, and continue to be, consumed in many areas of China by different ethnic groups (Luo, 2005). Many examples of ancient Chinese literature describe in detail the common types of edible insects and the techniques for collecting and cooking insects (Liu, 1991). Since the 1980s, scientific research on food insects has expanded to include the identification of species, evaluation of nutrition, new approaches to farming, and explorations of the culture associated with human entomophagy. In recent years, the research on using insects as human food and feed has

accelerated further with the recognition of insect nutritional benefits and the potential of insects to ensure food security. As a result of this effort, the number of published scientific papers and books on edible insects has increased. Therefore, the aim of this paper is to review briefly the use and the prospects for future use of edible insects in China, based on the results of scientific research that the authors have conducted over 20 years and that of other published references.

Edible insect resource

An accurate estimate of the number edible insect species worldwide has not yet been determined for several reasons. According to literature published in different regions of the world, more than 1900 edible species is an acceptable number. Most insects that are consumed are species in the orders Coleoptera (31%), Lepidoptera (18%) and Hymenoptera (14%), with others in Orthoptera (13%), Hemiptera (10%), Isoptera (3%), Odonata (3%), Diptera (2%) and other orders (5%) (van Huis *et al.*, 2013). In China, the count of edible insect species is also incomplete. In 1999, 177 edible insect species were recorded in China

(Feng *et al.*, 1999), but in 2010, 283 species were listed as food insects (Hu & Zha, 2009). However, less than 100 species are commonly consumed, and only 10 to 20 types are consumed often, which include several species of bees and wasps, silkworms, crickets, bamboo caterpillars, dragonflies and beetles. The number of edible insects continues to increase as more scientific papers are published. Based on the published literature until 2014, 324 documented species are related to food and feed in China, which include the common edible insect species, some less commonly consumed species and some medicinal insects (Feng *et al.*, 2016). The 324 species are in 11 insect orders, with Lepidoptera (37.65%), Coleoptera (18.21%) and Hymenoptera (15.43%) contributing 71.30% of the total numbers. The other orders are Orthoptera (13.27%), Hemiptera (6.17%), Isoptera (4.94%), Odonata (1.54%), and Megaloptera, Ephemeroptera, Diptera and Blattaria (four orders with a total of 2.78%; Fig. 1) (Feng *et al.*, 2016). These orders are discussed below in order from high to low percentages of edible species of the total number.

Order Lepidoptera

In Lepidoptera, 253 species are recorded as human food worldwide as of 2005 (Ramos-Elorduy, 2005). In China, 122 species of lepidopterans are documented, and the nutrient content of 34 species has been analyzed (Feng *et al.*, 2016). The host insects of Chinese caterpillar fungus and the moths that produce insect tea are a large portion of the edible lepidopteran species recorded and make Lepidoptera the largest group of edible insects in China. The famous Chinese caterpillar fungus has been traditionally used as both a medicine and a health food for a long time. Many aspects of the Chinese caterpillar fungus, such as the host insects, medicinal and health care functions, and farming technology, among others, are well studied in China (Dong *et al.*, 2016; Zhang *et al.*, 2013). However, based on considerations of food safety, the Chinese caterpillar fungus is not currently recommended as a common food for consumption according to the China Food and Drug Administration (CFDA, 2016). Eighty-six lepidopteran species are recorded as hosts of the Chinese caterpillar fungus and other fungi, and among them, the larvae and pupae of some species are edible. Insect tea is from feces excreted by several caterpillars eating certain species of plants and is a special drink in some areas of southern China. Eleven species produce insect tea but only two species are bred to produce insect tea commercially (Yang &

Yi, 2011). In addition to Chinese caterpillar fungus and insect tea, a few other larvae of moths and butterflies are also edible. The stages of moths and butterflies usually eaten by people are the larvae and pupae. Silkworms (*Bombyx mori* L.) and tussah silkworms (*Antheraea pernyi* Guérin-Méneville) have long been domesticated in China (Zhou, 1982), because humans obtain silk for textiles from their cocoons. Pupae of the two silk-producing moths are edible and can be used as material to produce health care foods. The larvae and adults of the two silkworms are food material in some places, such as Henan Province. A well-known edible insect is the bamboo caterpillar in southern China and southern Asian countries (Boulidam, 2010; Feng & Chen, 2000; Hanboonsong, 2010). The nutritive content data for some butterflies are available (Shi *et al.*, 2015), but the larvae of butterflies are less common as edible species in China.

Order Coleoptera

Beetles are one of the largest groups of edible insects worldwide, with 468 species recorded in 2005 (Ramos-Elorduy, 2005). Many beetles, particularly their larvae, are also

edible in China, including long-horned beetles, grubs, dung beetles and aquatic beetles. People usually eat beetle larvae; however, adult diving beetles are also consumed (Cong, 2007; Guo *et al*, 2003). Fifty-nine recorded species of beetle are used in China as food, feed or medicine. The nutritive data of 39 species, including for medicinal species, are available (Feng *et al.*, 2016). Mealworms (*Tenebrio molitor* L.) are well known, although these larvae were previously typically reared for bird feed. Mealworms are currently easily reared in captivity and then used to produce products such as snacks and those made from insect protein, oil and chitin (Liu *et al.*, 2010). The beetles of Meloidae and *Blaps* are important folk medicinal insects in China (Yang, 2015).

Order Hymenoptera

Bees, wasps and ants are consumed in many regions of the world, particularly in southern Asia, with 351 edible species (Ramos-Elorduy, 2005). Fifty species are recorded for food and medicine in China, and among these species, the nutrient contents have been analyzed for 35 (Feng *et al.*, 2016). The larvae and pupae of wasps are the most common edible insects in

many regions of China, and the production of honey and other products by honeybees is well developed and widely used. In addition to harvesting honey, people also collect bee larvae and pupae to eat. Local people cook the larvae and pupae of bees and wasps in several ways, such as boiling, frying, and roasting. Uncooked, raw larvae are also consumed in some areas. In summer and early autumn, several species of wasps are commonly found in local markets in Yunnan Province and other regions in southern China (Chen *et al.*, 2009). Wasps and wild bees are primarily collected from the wild. Skilled collectors wear protective coats to avoid the sting of adult wasps and collect combs with larvae and pupae for sale and their own consumption. Several species of ants are edible and are also used as traditional Chinese medicine (Liu *et al.*, 2006; Wu & Wang, 1995). *Polyrhachis dives* Smith has been well studied in China and is used as raw material to make health food and medicine for the treatment of rheumatic disease (Wang & Wang, 2010).

Order Orthoptera

Grasshoppers, locusts, katydids and crickets are common edible insects worldwide, particularly in Japan and Thailand (van Huis *et al.*, 2013). In Orthoptera, 43 species have edible value in China. The nutritional data of 37 species are available, although some of these species are not commonly used as human food (Feng *et al.*, 2016). Orthopterans are easily collected because of their large body size. Fried nymph and adult grasshoppers, locusts and crickets are common dishes in many regions of China. Locusts are also used as bird feed, and *Locusta migratoria manilensis* (Meyen) are bred in plastic houses to produce human food and pet bird feed. Some species of locusts, crickets and katydids have medicinal value (Li *et al.*, 2013).

Order Hemiptera

Hemipterans are popular edible insects in many regions of the world, with more than 190 edible species identified (Ramos-Elorduy, 2005). In Hemiptera, cicadas, scale insects and stinkbugs are the three groups frequently consumed. Currently, 20 edible species are recorded in China. Among them, the nutritive elements have been analyzed for 13 species

(Feng *et al.*, 2016). The cicada slough of some species and the adult *Aspongopus chinensis* Dalla have been used in traditional Chinese medicine (Yang, 2015). Cicadas and stinkbugs were also used as food in ancient China, with the collecting and cooking methods for these bugs recorded in the ancient literature (Liu, 1991). Fried and roasted cicadas are consumed in both southern and northern China.

Order Isoptera

Termites are common edible insects in many regions of the world, and 61 scientifically recognized species of edible termites have been identified (Ramos-Elorduy, 2005). Termites are often consumed in southern China. Local people collect the termites when they swarm from their nests after rains to start new colonies and also attempt to dig out termite hills to collect the queen, solider termites and worker termites for consumption. Termites are also used as poultry feed. The estimates are that more than 30 types of termites are edible in China, although only 16 species have been scientifically named and nutritional data are available for only five species (Feng *et al.*, 2016). Since ancient times, termites and their

nests have been used as traditional Chinese medicines (Li *et al.*, 2013). Termites *Odontotermes formosanus* (Shiraki) have been used as an ingredient in health foods, and Zhang (1999) demonstrated that termites might boost immune system function and possess anti-fatigue properties.

Order Odonata

Dragonfly nymphs are an accepted food in many regions of the world, with 29 edible species recorded (Ramos-Elorduy, 2005). Dragonfly nymphs and adults are often consumed by local people in the provinces of Yunnan, Sichuan and Guizhou in China. Because dragonfly nymphs live in fresh and clean water, they are often collected and sold with small fish and shrimps. Chicken egg fried with dragonfly nymphs, soup of dragonfly nymphs mixed with vegetables, and roasted dragonfly adults and nymphs are popular dishes. China is estimated to have 10 edible species but only five of these species are identified, and nutritional data are available for only three species (Feng *et al.*, 2001). Among the species of dragonfly, *Anax parthennope* (Selys) is the most common edible species.

Orders Diptera and Blattaria

Flies and cockroaches are not typical foods for people, although both types of insects were eaten in ancient times (Liu, 1991), but these insects are used as animal feed. Different species of flies that feed on organic matter, such as the housefly and the black soldier fly, can be used to convert organic wastes into fertilizers. Moreover, the bodies of insects are rich in protein and are therefore good feed for livestock (Wang *et al.*, 2013; Yu *et al.*, 2009). Therefore, humans benefit indirectly from the use of flies in the treatment of waste and as feed. The nutrient contents of four fly larvae were analyzed (Huang *et al.*, 2007). Because flies are reared easily in massive numbers, some researchers are attempting to use these flies to produce food products for humans that include proteins, oils, and chitin (Zhang *et al.*, 2009). However, before human use as food, scientific research on the food safety is required. Cockroaches *Periplaneta americana* (L.), which are used as medicinal material in traditional Chinese medicine and in the modern pharmaceutical industry (Hu *et al.*, 2008; Luo *et al.*, 2012), are successfully reared in completely artificial conditions in China (Feng *et al.*, 2016).

In addition to their use in medicine, cockroaches are also used as animal feed and as human food in some regions on a small scale (Yang *et al.*, 2010; Zhou *et al.*, 2007).

Orders Ephemeroptera and Megaloptera

Mayfly and alderfly nymphs are edible aquatic species. Nineteen species of mayflies are consumed worldwide (Ramos-Elorduy, 2005). Mayflies were used as food in ancient China (Liu, 1991); however, currently, edible mayflies are less common in China. The only species of edible mayfly, *Ephemeterella jianghongensis* Xu *et al.*, is found in Yunnan Province (Feng *et al.*, 1999). Of the Megaloptera, the nymphs of two species *Acanthacorydalis orientalis* (McLachlan) and *Noeochauliodes sparsus* Liu et Yang contain high levels of protein and are commonly eaten in Yunnan and Sichuan provinces (Feng *et al.*, 1999; Wang & Liu, 2011). Alderflies are often regarded as a delicious and nutritious food. Local people prepare alderfly larvae with chicken eggs to serve as a remedy food for ill children and sick patients. The collecting of alderflies in the wild and the cooking methods are well developed by local people in southwestern China (Feng *et al.*, 2016).

Nutritional and health benefits of edible insects

The nutritional composition of many insects has been studied both in China and other countries. In the analysis of insects, the primary nutritional values are those for protein, fat, amino acids, fatty acids, minerals and vitamins (Chen *et al.*, 2009; Chen *et al.*, 2008; van Huis *et al.*, 2013). The International Network of Food Data Systems (INFOODS) included data for 514 insect entries in the second edition in 2012, with only four entries cited from China. However, the nutritional values of insects have been studied for many years in China before 2012. The nutritional values for 174 species, including edible, feed and medicinal species, are available in China, according to our statistics based on published literature to 2014 (Feng *et al.*, 2016). Although the nutritional values are variable, the values for insects demonstrate that levels of protein, fats, vitamins and minerals are sufficient to meet human nutritional requirements (Tables 1 and 2). The data on nutrition show that the level of good quality protein is high in insects, at approximately 50 percent of total insect weight. Insects also have high contents of the essential amino acids in their proteins. Some insects store large amounts of fat, often with high levels of unsaturated fatty acids (Lian *et al.*, 2008). Thus, based on

scientific research, the nutritional quality of insects is high and meets human requirements; therefore, insects are potentially a good source of protein for human food and animal feed (Chen *et al.*, 2008; Ji *et al.*, 2012; Li *et al.*, 2010; Wang *et al.*, 2006; Zhou *et al.*, 2009). Moreover, some insects tested show high nutritional values; however, they are not often consumed because most of these species are not part of the traditional diet and people are less familiar with the insect. Additionally, some species are poisonous to humans or are used for medicinal purposes only, such as the beetles of Meloidae and *Blaps* (Yang, 2015). Therefore, the nutritional analysis of a large selection of insects remains to be conducted. In addition to nutritional benefits, the results of some studies demonstrate that insects provide many health benefits and can be developed into health foods. Scientific research has confirmed that some insects and their extracts function in immune regulation and contain anti-fatigue and antioxidant compounds (Liu & Wei, 2002). The precise functions of insect chitin and other polysaccharides in human physiology continue to be investigated, although some promising results with water-soluble insect polysaccharides indicate benefits for immune regulation and antioxidant and anticancer functions (Feng *et al.*, 2016).

Edible insect use

Humans use edible insects in two ways: insects are consumed as food directly or are used to produce food ingredients, and insects are used as animal feedstuff for livestock and other animals to indirectly meet the different requirements of humans.

Since ancient times, insects have been a food resource for humans in many regions of China (Liu, 1991; Luo, 2005). Traditional customs of consuming insects are well maintained in some communities, particularly in regions in which different ethnic groups live, such as in Yunnan and Guizhou provinces in southwestern China. Ethnic groups such as the Dai, Hani, Yi, and Gelao people and other people living in these regions have always used wasps, ants, cicadas, dragonflies, bamboo caterpillars and other insects in their traditional diets. The “Bug Eating Festival” is held annually in these regions (Yang, 1999; Ye, 2011). Insects were, and continue to be, an important nutritional source for local people. From their long experience of collecting, local people have summarized how to gather insects in sustainable and environmentally friendly ways. For example, locals do not gather all the insects but leave part of a colony to reproduce new generations, and they also protect colonies in the winter. Many different ways to cook and prepare insect dishes have been developed by local people, such

as steaming, roasting, frying and stewing. To make vinegar, some local inhabitants in Yunnan use one type of ant (Feng *et al.*, 2016). Insect dishes are common in the restaurants of both urban and rural regions. Silkworm pupae are commonly consumed in southern and northern China, and tussah silkworm pupae are often consumed in northern China. In Zhejiang, people enjoy eating cicadas; in Guangdong, they use aquatic beetles to cook soup; and in some regions of southern China, people drink insect tea (Yang & Yi, 2011).

Insects are not a primary food source and are a small portion of the total food produced compared with other conventional food sources such as pork, beef and poultry. The reason, at least in part, is that the large output of conventional food production is easy to obtain using advanced agricultural techniques. Additionally, currently, edible insects are typically recognized and accepted as unique, local foods and the food of minorities. Edible insects are often prepared by roasting or frying in oil and are served as dishes with wine or as snacks or barbecue. The acceptance level of insects as food varies in different areas. Therefore, to promote insects as a food resource in ordinary diets, it is essential that insects be used in a variety of utility patterns. Humans use insects either directly or indirectly. People directly consume insects or consume products made from insects. In some regions in which edible

insects are consumed often, the common edible insects, such as the silkworm, bamboo insect, crickets, and wasps, are consumed directly. Good methods to cook these insects can promote popularization of insects as food. Some insect menus and cookbooks published in China and other countries are now available and serve as (Feng *et al.*, 2016) a conduit to teach more people to cook and eat insects. Compared with the direct consumption of insects, consuming products made from insects is easier to accept. Research on mealworms, silkworms, termites and other insects has led to the development of health foods. Some food products using insects as ingredients have also been tested (Li *et al.*, 2005; Liu & Xiang, 2006; Peng *et al.*, 2003). Because mealworms grow rapidly and feed on the organic residues of human consumption, such as the outer leaves and the skin of vegetables and fruits, and are rich in proteins with a reasonable ratio of amino acids, they were selected to test their possible use as one type of protein source for people in space travel and on space stations (Fu, 2014).

People indirectly consume insects by eating livestock, such as chickens and fish, that are fed insects, which is an easier and more acceptable way to use insects in human diets. Insects are fed to poultry, pigs, fish and other animals consumed by humans (Guo & Xiong,

2008; Li *et al.*, 2007; Wang *et al.*, 2006), and insects are a natural food for poultry and fish, which are products easily accepted by humans. Research on the use of feedstuff with added insects for poultry, fish and other livestock has led to small-scale implementation in China. The quality of animals fed on feed with the additions of insects is approximately the same as that of conventional animals fed on fishmeal and may even be better because insects contain abundant protein. The unique antimicrobial peptides and other substances in insect feed may not only enrich the diet of livestock but also increase their resistance to disease (Wang *et al.*, 2006). Based on research, insects are a good livestock meal and could be a supplement to the fishmeal used in poultry, fish and other livestock breeding (van Huis *et al.*, 2013). Currently, mealworms hold the greatest promise as a feed additive, because they feed on a variety of agricultural residues, grow rapidly and can be reared in large numbers under artificial conditions (De Marco *et al.*, 2015). Grasshoppers and cockroaches are also used to feed poultry (Yao & Yao, 2006; Liu *et al.*, 2009; Yang *et al.*, 2014). Because housefly and black soldier fly larvae feed on manure and other organic waste, they can be applied to organic waste treatment for environmental protection. Additionally, these same larvae may provide valuable feedstuff for breeding livestock (Yu *et al.*, 2009; An *et al.*, 2010; Pastor *et al.*,

2015); however, a safety evaluation is required before implementing the large-scale use of these flies in feed.

Insects are also used as feed and feed additives for pets, snakes, frogs, minks, foxes, soft-shelled turtles and geckos, which are valued as special economic animals in China because they are sources of fur or feathers or the animals are raw materials for medicines (Zhou *et al.*, 2002; Bai & Cheng, 2003; Liu *et al.*, 2010; Zhang *et al.*, 2014). The usage of insects as feed and feed additives for these animals may also reduce their demand for other sources of protein feedstuff, which benefits humans indirectly.

Recently, the use of insects as food and feed has developed very rapidly in China. For example, Chinese applied for 1086 patents associated with mealworms in China from 1989 to 2016, according to the data searched from the State Intellectual Property Office of the People's Republic of China (SIPO), and the number of patent applications concerning mealworms increased sharply from 2010 to 2015, as numbers jumped from over 30 to almost 300 applications (Fig. 2). In the technical field component for patent applications concerning mealworms in China, nearly 80% of patent applications were to section A (human necessities) of the International Patent Classification (IPC) system. Among these,

applications to A23 (Foods or foodstuffs; their treatment, not covered by other classes) and A01 (Agriculture; Forestry; Animal husbandry; Hunting; Trapping; Fishing) reached 51.82% and 27.65%, respectively, which demonstrates that most patent applications involving mealworms were concerned with food and feed.

The food safety of insects and insect allergies

The food safety of insects and possible allergic reactions associated with eating insects are concerns for both scientists and consumers, because safety is a vital factor in food quality and is essential to build confidence in the consumption of edible insects (Kong, 2013; Zhang & Jiang, 2010).

Food safety is not yet a significant concern at the current rate of insect consumption. Edible insects are gathered from their natural habitats, sold in open markets and consumed only occasionally and seasonally. However, with the introduction of more insects as a part of people's daily diet, concerns with the food safety of insects will increase. Similar to other food sources, the food safety of insects is affected by collecting, processing, storage and

transportation. For food safety, four areas warrant attention: food toxicology, harmful microorganisms, toxic metal elements, and pesticide residues (Zhang, 2009; Zhao, 2009). Insects fly or creep in some areas and can feed on many different organic substances, including straw biomass, organic waste, animal bodies, plants and other insects. Both on the surface and internally as a natural property, insect bodies carry microbes and contain pesticides or other toxic substances. Currently, the information on food safety of edible insects is limited in China and other countries. The safety of insects concerning microbial contamination has been studied in some countries. When insect bodies for consumption are properly processed and stored, insects are generally safe to consume (van Huis *et al.*, 2013). In an analysis for chemical safety, the concentrations of chemical contaminants in four fly larvae used as animal feed were below the recommended maximum concentrations suggested by the European Commission, the World Health Organization and Codex. However, a high level of the toxic heavy metal cadmium was found in three of the housefly samples analyzed (Charlton *et al.*, 2015). In China, regulations and laws address these four aspects of food safety (Wang, 2010) and provide methods for evaluation and determination of indexes of food safety. Food toxicology evaluations are time consuming and require

resources, and as of 2014, only 12 species of insects and two types of insect product had been evaluated according to the Procedures for Toxicological Assessment of Food in China, according to published references. The species of insect are *B. mori* L., *A. pernyi* Guérin-Méneville (Zhou & Han, 2006), *Dendrolimus punctatus* (Walker)(Liu & Wei, 2008), *Ericerus pela* Chavannes (Feng *et al.*, 2001), *T. molitor* L. (Chen & Wang, 1997), *Massicus raddei* Blessig (Li *et al.*, 2011), *Polyrhachis dives* Smith (Wang *et al.*, 2007), *Formica sanguinea* Lat., *Musca domestica* L. (Li *et al.*, 2010; 2011), *Periplaneta americana* (L.) (Zhou *et al.*, 2007), *Macrotermes barneyi* Ligh and *Odontotermes formosanus* (Shiraki) (Zhang, 1999). Honey products and insect teas were also evaluated. Based on this limited data set, insects and products made from insects have tested safe as food or feed (Feng *et al.*, 2016). Although insects are generally safe to consume, further research is required to evaluate relative factors such as different species of insects and those fed on different feeds and reared in different conditions.

With contact, inhalation or oral consumption, insects can be a source of allergens for some sensitive people (Belluco *et al.*, 2013; Pener, 2014; Srinroch *et al.*, 2015). Twelve orders of insects are associated with human allergies (Dan, 2002). Insects are a source of inhaled

allergies and can cause asthma and coryza (Sun *et al*., 1998), and some workers and farmers on rearing farms suffer from these inhalation allergies. Allergies caused by insect bites and toxins are reported every year in China, particularly during summer and autumn. Allergies caused by eating silkworm pupae, cicadas, crickets, wasps, grasshoppers and stinkbugs are also reported in China. The allergic reactions include skin itch, urticaria, dizziness, and shock, among others. In a review of case reports of allergies caused by food consumption in China from 1980 to 2007, insects were the fourth most common allergenic offenders after pineapple, soft-shelled turtle and crab. The insects that have caused anaphylactic shock are locusts (27 cases), grasshoppers (27 cases), silkworm pupae (5 cases), a cicada (1 case), a bee pupa (1 case), a bee larva (1 case) and *Clanis bilineata tsingtauica* Mell (1 case). No deaths caused by insects were reported (Ji *et al*, 2009). Similar to other protein-rich foods, such as milk, seafood and peanuts, insects can induce allergic reactions in some people. However, compared with the allergic reactions induced by other common protein-rich foods such as fish and seafood, insects do not cause more serious allergic reactions, although the reactions remain a concern and require further research.

Insect farming

Currently, approximately 92% of edible insects are harvested and gathered from the wild worldwide (Yen, 2015a). Even in Asian and Pacific regions in which entomophagy is highly accepted among inhabitants, only a few species of edible insects have been reared for food, such as locusts and the palm weevil in Thailand (Hanboonsong *et al.*, 2013; Durst & Hanboonsong, 2015;). Although gathering pests for food in forests can reduce pest populations to some extent, the quantity harvested is limited and varies over time and by season. The quality and food safety of insects harvested from the wild are also not guaranteed. Moreover, the overharvest of insects from the wild may threaten the natural biodiversity, with some species facing the possibility of extinction (Yen, 2015b). Therefore, farming insects for food and feed, similar to that for other conventional livestock, is essential to ensure that insects are a stable part of the human diet. A few insect species have been domesticated for human use because of their commercial value, with silkworms and honeybees the best-known examples. White wax scale and Chinese gallnut aphids in China and Lac scale in China and southeastern Asia have also been farmed (Chen & Feng, 2009). The farming of these insects has provided good experience, and this type of farming has

become one type of special breeding industry in rural areas and a source of income for local people.

The farming of insects has several advantages. To produce the identical amount of protein, insects require less feed, water and living space than other farmed animals. Insects also emit less greenhouse gases and cause less environmental problems than conventional livestock (Dennis *et al.*, 2010). Because insects typically grow rapidly and can reproduce many generations in a year, humans can obtain a large biomass for food in a short time (Premalatha *et al.*, 2011). A challenge to insect farming is that not every type of insect can be raised completely in artificial conditions. Two primary approaches are used to rear and breed insects for human food and medicine and animal feed in China. In one approach, insects are fully domesticated and reared completely in captivity, which includes mealworms, cockroaches, and some beetles. In the other approach, insects are only partially raised in captivity or the habitat of the insect is manipulated to increase production, which includes locusts, wasps, bamboo caterpillars, and dragonflies. Mealworms, initially brought to China from other countries as bird feed, are reared successfully in many regions of China, and dry mealworms have been exported to Europe and other places worldwide as feed for pets and

birds, according to newspaper reports. In 2013, 29 batches of mealworms weighing 176 400 kg that were worth 1.06 million US dollars were exported from Baoding, Hebei. The export weight and value increased by 383.3% and 409.6%, respectively (Anonymous, 2014). Additionally, 554 000 kg of dried mealworms worth 3.319 million US dollars were exported from Weihai City, Shandong, in the first three quarters of 2013. The export weight and value increased by 140.1% and 130.6%, respectively (Anonymous, 2013). From the port of Weihai from January to October of 2014, 702 600 kg of dry mealworms worth 4.992 million US dollars were exported (Li, 2014), and from January to November of 2014 from Nanyang, 553 000 kg of dry mealworms worth 3.75 million US dollars were exported (Meng, 2014). Cockroaches *Periplaneta americana* (L.), the raw material of some medicines produced in China, are also successfully domesticated and are reared artificially to meet the production requirements of medical companies for medicines (Mao *et al.*, 2002; Zhang & Wu, 2006). The rearing facilities and conditions for mealworms and cockroaches have been the focus of intense research, and these insects can be reared at the scale of home or factory with large yields. According to a newspaper report, one cockroach farm in Shandong produced 20 000 kg of dry cockroaches annually (Lu, 2015). Some other medicinal insects are also

domesticated and reared in China, but the scale of rearing is usually small (Xiang, 2009). When fed on fresh plants supplied regularly, *L. migratoria manilensis* (Meyen) can be reared in a plastic greenhouse, and the food plants for the locusts can be grown outside the greenhouse for easy harvest. Wasps, bamboo caterpillars, and dragonflies are not currently fully domesticated; however, some means and techniques have been attempted to increase biomass production of these insects for human consumption (Guo, 2009; 2012; Guo & Huang, 2013; Guo *et al.*, 2013). For example, locals protect overwintering wasps, build nests for some wasps, and maintain wasp combs to harvest wasps in late summer and autumn. Additionally, when gathering edible insects, locals typically leave some individuals and parts of colonies for future reproduction. People also try to build semi-artificial habitats and then supply feed for those insects that they want to collect. As we learn more about the biological characters of these insects, more advanced methods to raise these edible insects can be developed.

Many interactions occur among insects, humans and their environments. Insects play vital roles in healthy, functioning environments, because in ecosystems, insects are decomposers of organic matter, pollinators, predators and prey. Insects are food for other animals but are

also important natural enemies of agricultural and forest plant pests. Some insects are detrimental to human welfare as vectors of disease and as pests of crops and forest trees (Gullan & Cranston, 2005). The farming of edible insects may affect humans and the environment, particularly when insect populations increase rapidly in a specific space and in a short time. For example, wasps sting humans, and locusts and grasshoppers are pests that damage crops. Some insects emit greenhouse gases and other gases that cause people discomfort. Therefore, we must evaluate the potential effects of farming insects on public health, forestry, agriculture, and the environment in general. We divided the candidate insects for farming into three types. The strict-control type includes those insects with strong flying or migrating ability, pests that harm crops and forests, and those that mechanically spread human disease microbes. The farming of this type of insect requires strict management. The second type is the general-control insect, which has no strong flying or migrating ability and is not a serious or harmful pest. The third type includes harmless insects that are not plant pests or a danger to health. Safety control regulations for these three types of insect must be established based on their impact on humans and the environment. Apart from the concerns discussed above, several other aspects of the farming of insects should also be considered.

Insect farms or factories should be built away from human living districts. The facilities for protection must be built according to insect characteristics and the relationships among insects and humans, crops, and forests. Excreta of reared insects also require management to reduce pollution of the environment. For example, in China, the excreta of mealworms are used as feed for freshwater fish or as fertilizer (Gao, 2012). The feed selected for insects should be low-priced material, such as agricultural residues and organic wastes.

Conclusions and recommendations

Insects are a source of food for humans and a potential resource to assure global food security. China has a long history of consuming insects, and the culture of eating insects is well maintained in many parts of China by different ethnic groups. Many species of insects are consumed often in different regions of China, and the level of acceptance for the consumption of insects is high in China in general. The renewed interest in consuming insects has promoted an increase in the willingness to now consume edible insects. Although edible insects are not presently a primary food source, a great deal of research on edible

insects has been conducted in recent years. The scope of study includes the culture of entomophagy and the identification, nutritive value, farming and breeding of edible insects, in addition to food safety and processing. Several species of insects, such as mealworms, locusts, and grasshoppers, are farmed for food and feed. For some well-known edible insects, including wasps, bamboo caterpillars, and dragonflies, semi-domestication has been attempted. Some food and health food products are made from processed insects. All of these factors provide good conditions for the development and use of edible insects in China. Therefore, edible insects are predicted to gradually become a supplementary source of human food and animal feed and to have a certain role in assuring food and feed security.

The social and scientific communities must work together to promote the use of insects as food and feed. For the social concerns, policies and regulations must be established to ensure that the development and use of food and feed from insects does not affect human health, harm agriculture and forest plants, or pollute the environment. To inform the public and increase consumption, publicity and education must provide accurate information on edible insects. Rather than seeing insects as a nuisance or a food source for the poor and unsophisticated, the attitudes of people toward insects must change, and we must see

insects as a healthy, nutritious and environmentally friendly food source for all people worldwide. Four primary areas of scientific research on edible insects require further investigation. First, research on the basic biology of edible insects will build a strong theoretical background for the transfer of information to other areas of research. More than 300 species of insects are recorded for human consumption in China, and among them, some species are not suitable as a food source but are used as medicinal insects. Moreover, some types of insects that are consumed by local people have not been studied and scientifically identified, and after research and evaluation, suitable species for food and feed could be selected. Understanding the basic biological characteristics will benefit the farming and domestication of edible insects. Second, the health value and food safety of insects require further evaluation. Currently, the information available on the health value of insects primarily include a listing of protein, amino acid, fat, and fatty acid contents and comparisons of nutritive content between insects and other conventional animal foods. The data on digestibility of insects in humans continue to be lacking. Additionally, the food safety of insects has not been intensively researched. With accurate information on the food safety of edible insects, the mass production and consumption of insect products are possible. Third,

the development of more effective large-scale farming methods for different insects is required, because advanced methods are necessary to satisfy the quantity and quality requirements for the processing and use of edible insects. Fourth, the technology for the processing of insect foods requires innovation to produce more high quality processed products that are easily accepted by humans. Progress in addressing the social and scientific concerns will accelerate the effective use and industrialization of edible insects.

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Table 1 Nutrient composition of insects from 11 orders (%).

Order	Name (species number)	Crude protein	Crude fat	Total sugar	Ash	Total amino acids	Essential amino acids content	Proportion of essential amino acids	Unsaturated fatty acids	Proportion of unsaturated fatty acids

Lepidoptera	Caterpillar fungi (2)	27.51	10.91	18.98	–	20.70	6.76	31.91	–	–
	Cordyceps militaris (3)	68.01	4.69	10.86	–	34.12	12.36	36.50	–	–
	Insect tea (6)	9.00–28.00	0.80–3.00	0.31–16.27	4.47–63.20	5.80–16.70	2.20–5.75	26.00–43.00	51.04	51.57
	Moths and butterflies (43)	52.82	28.34	5.96	3.81	46.75	17.72	37.90	69.29	69.63
Coleoptera	Beetles (16)	34.00–60.00	17.00–54.00	1.00–8.00	1.00–2.60	41.71	15.74	37.74	70.32	70.32
Hymenoptera	Bees (21)	53.45	19.73	13.99	3.71	45.83	16.96	33.55	59.10	59.85
	Ants (17)	50.52	24.02	3.09	4.42	37.29	13.09	35.70	79.05	79.99
Orthoptera	Grasshoppers, locusts, crickets (18)	63.78	10.00	1.50	5.00	66.54	24.78	37.44	77.50	77.50
Hemiptera	Bugs (13)	20.00–60.00	2.00–50.00	1.00–6.00	1.00–7.00	46.89	18.24	38.90	55.62	60.52

Isoptera	Termites (5)	–	–	–	–	42.01	15.91	37.87	74.19	74.19
Odonata	Dragonflies (3)	58.82	25.37	3.75	4.49	46.17	16.41	35.55	–	–
Megaloptera	Alderflies (2)	62.13	10.40	1.59	7.05	56.02	25.39	45.32	–	–
Ephemeroptera	Mayflies (1)	66.26	–	–	–	65.36	23.81	36.43	–	–
Diptera	Flies (4)	61.06	17.78	–	10.26	55.47	21.25	38.29	62.06	64.13
Blattaria	American cockroaches (1)	63.10	17.20	–	5.68	55.33	21.00	37.95	71.87	71.87

–: Data not available.

Table 2 Mineral element contents in insects (mg/kg).

Order	Name (species numbers)	Common elements					Trace elements						
		Na	K	Ca	Mg	P	Fe	Zn	Se	Cu	Cr	Mn	Mo
Lepidoptera	Caterpillar fungi (3)	547.30	12895.00	1849.70	3840.70	9882.00	142.70	91.30	0.36	12.90	1.95	23.20	0.27

	Insect tea (5)	383.90	16836.30	6239.10	3841.50	1731.00	20688.60	413.20	0.13	–	–	616.70	–
	Moths and butterflies (23)	407.35	10946.61	989.51	1933.18	5588.86	89.27	10.7.61	10.09	14.11	–	12.88	–
Coleoptera	Beetles (28)	546.50	5473.50	769.30	777.30	3806.40	278.80	88.60	0.60	15.60	0.06	17.70	6.10
Hymenoptera	Bees (8)	–	2469.10	228.90	197.70	4082.00	25.00	18.80	0.38	4.10	0.10	12.30	–
	Ants (14)	–	6360.20	2226.90	2191.10	6334.40	560.40	222.80	0.84	19.60	32.50	326.20	8.00

Orthoptera	Grasshoppers, locusts, crickets (12)	1716.00	–	773.30	928.30	4245.30	184.20	146.60	8.10	49.50	–	37.04	16.83
Hemiptera	Bugs (9)	586.00	1688.80	698.00	631.40	4172.50	216.20	78.60	–	46.30	1.96	32.10	–
Isoptera	Termites (3)	1103.00	6564.50	1015.50	1363.30	5734.00	101	167.70	0.28	23.20	0.15	–	–
Odonata	Dragonflies (3)	–	–	–	–	–	796	125.43	–	59.90	–	–	–
Diptera	Flies (4)	2700.00	7924.60	19595.90	6734.30	11100.00	2	298.70	–	33.30	1.33	215.80	–

Blattaria	American cockroaches (1)	–	14 826.70	320 .00	446.70	532 3.30	1 0 3 . 2 0	9 6 . 1 0	0. 0 5	14. 39	–	3.1 7	–

–: Data not available.

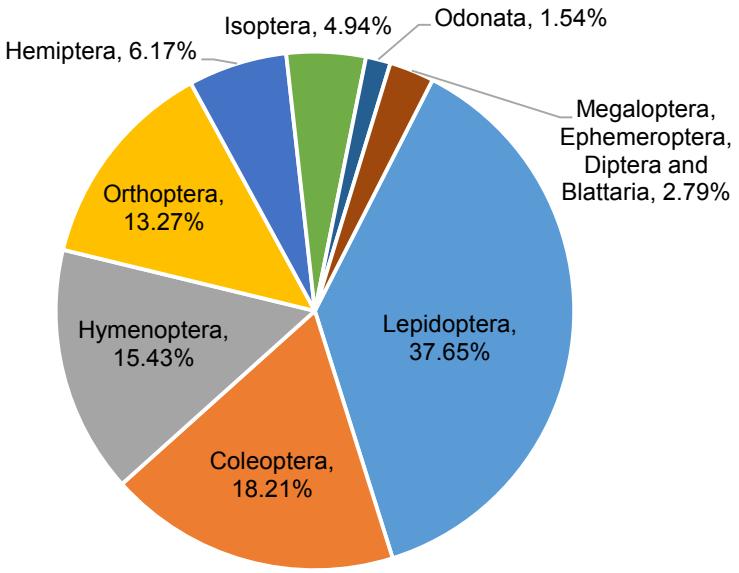

Fig. 1 Percentages of 324 species of insects in 11 orders associated with food and feed in China

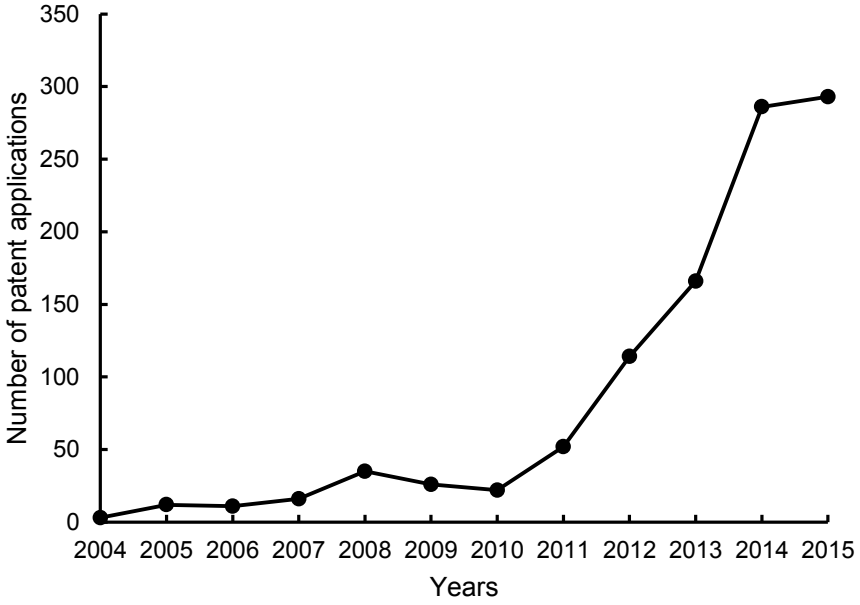

Fig. 2 Number of patent applications associated with mealworms from 1989 to 2015 in China.

Note: The data are from a general website patent search and analysis of the State Intellectual Property Office of the P.R. of China (www.pss-system.gov.cn). Only data for patent applications from Chinese were included.