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Review

Clanis bilineata tsingtauica: A Sustainable Edible Insect Resource

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Abstract: Insects provide a series of ecological services vital to human survival. Over 1000 insect species have been used for human consumption in Asia, Latin America, and Africa for more than 2000 years. Among them, the soybean hawkmoth, *Clanis bilineata tsingtauica* (CBT), is a traditional edible insect. CBT, known for its high nutritional value, is considered safe with a long consumption history in East Asia. The present review provides an overview of the rearing technology and utilization prospects of CBT. It has been extensively cultivated on live soybean plants under field and glasshouse conditions. However, an efficient rearing technology has not been reported. The mass production of CBT is still under investigation, and more advanced technology is required to develop high-quality food ingredients to meet consumer needs on a large scale. In addition, food derived from the soybean hawkmoth is prevalent in the farm product market. It is used as freeze-dried, fried, fresh meat, and canned meat. CBT-derived food, a potential dietary supplement used to retard aging in humans, would be a novel and emerging product in the food industry. The development of CBT-derived food will generate more economic and social value if the market demand can be met. This review will provide an insight into CBT mass production and its potential application in the food industry.

Keywords: *Clanis bilineata tsingtauica*; insect farming; insect use; entomophagy; biotic resource

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1. Introduction

Insects (Arthropoda: Insecta) are organisms that largely contribute to the biodiversity on Earth [1]. Insects provide various ecological services vital to human survival. They play essential roles in plant reproduction, pest control, waste biodegradation, novel food and feed production, and inspiring technology and engineering methods [2]. With the implementation of the United Nations' Sustainable Development Goals (SDGs), 'Transforming Our World: The 2030 Agenda for Sustainable Development' [3], insects can provide several benefits to humans and the environment. In particular, insects can become an important component of sustainable circular agriculture by closing nutrient and energy cycles, fostering food security, and minimizing climate change and biodiversity losses, thereby contributing to SDGs (i.e., SDG 2, 6, 9, 12, 13, 15, and 16) [4]. In addition, edible insects are gaining interest as alternative food resources for humans [5,6]. The Food and Agriculture Organization of the United Nations (FAO) and the European Food Safety Agency (EFSA) recognized the significant role of edible insects in improving global food and nutrition security; they also represent an option that most closely meets the necessary food requirements [7,8]. Until now, over 2000 insect species have been documented as edible in at least 113 countries [9]. The most commonly consumed insects include silkworms, caterpillars, mealworms, crickets, grasshopper, beetles, bees, ants, and termites [10]. Most of them are not only agricultural and forestry pests but also edible insect resources.

Soybean hawkmoth, *Clanis bilineata tsingtauica* Mell, 1922 (*Lepidoptera*: *Sphingidae*) (hereafter referred to as CBT) is widely distributed in China, Japan, India, and the Korean Peninsula [10–12]. The common host plants of CBT are leguminous crops (i.e., soybean, mung bean, pea, cowpea, velvet bean, locust tree, and Chinese wistaria) [13,14]. CBT mainly feeds on soybean, resulting in many holes or damaged leaves. In severe cases, the leaves are consumed, which in turn affects podding. Since the 1950s, intermittent outbreaks of CBT have been reported almost every several years on soybean in the Huang-Huai River Basin of China, causing significant economic losses [15,16]. Soybean is an important raw material for the food industry, and therefore, CBT has received wide attention [17]. CBT has been a traditional edible insect of East Asia for quite some time and a popular insect food with a long history of consumption in north China [12,15,18]. CBT has been gradually developed into a new insect food resource that can improve economic benefits. Therefore, this review provides an overview of the rearing technology and utilization prospect of CBT, a sustainable edible insect resource, for further utilizing the sustainable resources.

2. Rearing Protocols

In the past, CBT larvae were collected directly from farmland. However, due to planting structure adjustment and the increased CBT demand, the field population gradually decreased. Currently, it is challenging to collect CBT from the wild. Therefore, there is an urgent need to develop mass rearing technology to meet people's demands. In addition, insect farming can offer a new sustainable food resource to meet the future food demand [19,20]. At present, CBT rearing occurs mainly on family-operated farms, which implies its collection in crops. Therefore, to meet the huge demand, industrial farms are necessary for CBT cultivation and sustainable development [21]. In the existing CBT rearing method, overwintering larvae are collected from soybean farmland in the spring and stored in a glasshouse (Figure 1). Then, the CBT is grown and developed under indoor artificial conditions until next summer. The newly hatched larvae are transferred onto soybean plants, and the mature larvae are harvested next autumn [22]. The rearing protocols based on the *Technical regulation for artificial rearing of Doudan* (Larva of *Clanis bilineata*) standard of Jiangsu Province with the practical experience are reviewed for reference [23].

Figure 1. Sketch map of rearing process of *Clanis bilineata tsingtauica*.

2.1. Farm Site and Preparation

A suitable soybean field with good irrigation and no water logging should be selected as the farm site for CBT. The field should be far from where pesticides are often applied and heavy dust polluted areas, such as rice fields, vineyards, cement factories, and mixing stations. The soil is deeply plowed before the frost season in the first year to regulate the soil moisture, and then decomposed organic fertilizer is applied in the next year to maintain soil fertility.

2.2. Soybean Planting

It has been suggested to select soybean varieties that are tall, with many branches, oval and large leaves, and high protein content to prolong the growth period and increase the leaf area [23]. Soybean is planted at a row and column spacing of 50 cm and 30 cm, respectively, convenient for field management. At the time of 3–5 euphylla development, the seedlings are thinned out with 2–3 plants per sowing point. Intertillage, weeding, irrigation, and other field management practices are carried out in soybean planting.

2.3. CBT Production

The mature diapause larvae are generally obtained from the ground in November of each year. Individuals with 9 g body weight and without black spots or tachinid (*Diptera*: *Tachinidae*) eggs on the surface are selected and used for rearing. Rooms with good thermal insulation are arranged. The selected individuals are stored in the medium on the indoor shelf. The preservation medium is made of an equal proportion of sand and sawdust (1:1, volume ratio). The medium can be held into a mass and loosened to split into 2–3 petals at a moderate moisture content. The moisture should be regulated according to the medium condition during the winter.

In early March of the second year, the temperature of the warming larvae reaches 29 to 30 °C. During this period, the temperature is regulated according to soybean growth. At appropriate temperatures, mature larvae develop into pupae and moths. From 8:00 p.m. to 6:00 a.m. every day, the mating pairs are kept in the mating tube and left for mating in the dark. Then, two female moths with two-thirds of the wings and cut-off tarsus are laid in a wooden frame with an 80-g wood pulp kraft paper under it. The wooden frame is 10 cm high and divided into several small grids of 10 cm × 10 cm. After 3 days of oviposition, female moths are removed from the wooden frame. The kraft paper with CBT eggs attached is taken for disinfection.

The hanging of eggs is an important part of rearing, and this occurs from branching to the initial flowering of soybean. Egg cards should be first prepared before hanging. The egg paper (2–3 cm wide and 4–5 cm long) is soaked in a small amount of water, and 10–40 eggs are placed on each egg card. The egg card is attached at the back of soybean leaves using a stapler, maintaining a density of 20 eggs/m^2. CBT feeds by itself after hatching and transfers to other leaves at the third instar and to the neighboring plants after the fifth instar. When larvae enter the fourth instar stage, 112.5 kg urea is used per hectare, and water is poured through once. If the density of the local population is too high and the leaves are not enough to consume, the branches are cut manually and transferred to the sparsely populated area.

Furthermore, it is important to find a suitable population and optimum temperature for rearing. Previous studies on the effect of temperature on the growth and development of CBT indicated that the CBT development rate increased with increasing temperature [24–26]. The most prolonged development duration was 101 d at 19 °C, and the shortest was 47 d at 31 °C. The highest population index of 74 was recorded at 25.6 °C [24]. The most optimal temperature for CBT development ranges between 25 and 30 °C. The pupa's developmental periods in the Hainan population ranged from 19 d to 33 d, while the Jiangsu population ranged from 126 d to 318 d [25]. For both populations, the maximum survival rate was recorded at 25 °C (Hainan population: 71.4%, Jiangsu population: 90%). Within the range of 19–28 °C, the developmental rate of 3–5 instar larvae increased with increasing temperature but decreased at 31 ± 1 °C. The total feed intakes of 3rd–5th instar larvae were 10.7, 10.4, 10.8, 11.1, and 10.7 g at 19 °C, 22 °C, 25 °C, 28 °C, and 31 °C, respectively. Total and daily intake increased with rising temperature but decreased at 31 ± 1 °C [26].

In addition, researchers have analyzed the effect of temperature on overwintering. Xiao et al. (2010) investigated the preservation period and low-temperature treatment using various durations and gradient cooling for overwintering CBT larvae at 0−4 °C in sawdust soil [27]. The results showed that the death rate was low within 60 d and 31.7% after 80 d, and it reached 33% after 100 d. The mortality rate significantly increased after 20 days at low-temperature conditions, and CBT larvae pupated ahead of time. CBT larvae, which were subjected to gradient warming after gradient cooling, pupated ahead of time and showed a lower death rate. In addition, studies have shown the effect of organic content of rearing dust on CBT's pupate rate and death rate. CBT preferred to overwinter in the medium containing high organic matter [28]. This provides a basis for improving CBT rearing technology.

Meanwhile, diseases and insect pests of CBT are to be prevented and managed well in the field. The common natural opponents of CBT are *Trichogramma confusum* Viggiani (*Hymenoptera*: *Trichogrammatidae*), *Trichogramma dendrolimi* Matsumura, *Trichogramma closterae* Pang et Chen, *Telenomus (Aholeus) lebedae* Chen et Tong (*Hymenoptera*: *Scelionidae*), *Telenomus Tetratomus* Thomson, and *Telenomus angustatus* Thomson in the egg stage; *Bacillus thuringiensis* Berliner (*Bacillales*: *Bacillaceae*), *Bacillus cereus* Frankland and Frankland, nuclear polyhedrosis virus, mantis, spiders, frogs in the larval stage; and finches and bats in the adult stage [10,29,30]. Natural enemies should be strictly prevented from entering the rearing areas and diseases and insect pests should be controlled on time using integrated management measures. Moreover, CBT is sensitive to the commonly used insecticides and should be avoided during rearing.

2.4. Harvest and Storage

Harvesting of CBT usually requires an extensive understanding of its biology and ecology. At the end of the 5th instar, mature larvae stop feeding and can be captured for sale 2–3 days before penetrating the soil to overwinter. Thus, to prevent the CBT larvae from escaping, the leaves or petioles should be harvested together. Furthermore, to ensure the next rearing cycle and prevent the increase in harmful organisms, the net and film on the sheds and the sundries inside, outside, and around the shed should be removed, which is not conducive to rearing. However, frozen storage technology can be adopted to regulate the regional and seasonal supply to a certain extent to address the seasonal shortage of fresh CBT in the market. Wu and Xia (2008) found that the 5th instar larvae can be preserved well at 2−4 °C for eight months, followed by 3rd−4th instar larvae, and the optimum storage temperature is 2 to 4 °C [31]. However, the common frozen storage technology leads to poor quality and allows temporary storage. Moreover, vacuum freeze-drying technology can be used in CBT storage, retaining original shape, color, and maximum food nutrition. Li et al. (2018) reported that the eutectic point of CBT was –19.9 °C, the blanching temperature was 65 °C, pre-freezing was 4 h at –28 °C, and the drying chamber pressure at 57 Pa [32]. Under these conditions, the actual measured rehydration rate was 81.3% in 9.4 h, the shrinkage rate was only 5%, the protein retention rate was 96.3%, and the coloration change value was 9.5. Larvae stored using vacuum freeze-drying treatment can be of high quality. The application of new technology using vacuum freezing provides fine and deep processing of CBT. Myofibrillar proteins from CBT alter their texture during cold storage, which could be inhibited with pullulan [33]. Glutathione also suppresses lipid oxidation of CBT during frozen storage via antioxidation [34]. Therefore, deep processing may be used in the CBT food enterprises, broadening their market prospects.

CBT is an obligatory diapause insect. Insects belonging to this group have a strict generation per year and a fixed diapause stage. Irrespective of the external environmental conditions, it can enter diapause on schedule, which is a genetic feature of the species. CBT overwinters with mature larvae diving into the ground in September every year. Then, CBT pupates and emerges into adults around May of the following year and completes its life cycle after mating and oviposition. Thus, due to the biology of the organism, its production is seasonal. In addition, CBT rearing is relatively at the preliminary phase. Moreover, innovative rearing technologies have not been reported, which leads to low yield. No effective methods have been developed to disrupt the diapause of CBT. Therefore, CBT has long been raised by living soybean plants in the field till now, and no suitable artificial diet of CBT has been reported.

2.5. Expected Economic Benefits of Rearing

The relationship between the rate of shriveled soybean pods, plot yield, hundred-grain weight, and insect inoculation rates was determined using field experiments to obtain better economic benefits [35]. According to the natural occurrence patterns of one generation in north China (North of 32° N area) and two generations in Hubei and Jiangxi Province (South of 31° N area), Yan (2001) simulated the natural living environment conditions of

CBT and improved the production of CBT by setting up a room for larval rearing and a pool for the larvae with leaves [36]. Furthermore, Wang et al. (2002) measured and calculated the suitable rearing amount of CBT by rearing larvae in a covered cage in a soybean field [37]. When CBT amount was 10–15 per square meter, the rate of podding loss was 19–20.6%, and the loss of pod setting was about 20%. A significant correlation was found between the amount of insect inoculation and yield loss ($y = 1.57 + 0.425x$; $R^2 = 0.9946$). The profit obtained via soybean harvest and CBT by-products is CNY 473.6 per 667 m^2 more than the conventional soybean field [37]. To improve the CBT yield, Wu and Xia (2008) developed batch soybean planting in a glasshouse and designed a new rearing mode for harvesting soybean (annually) and CBT (bi-annually) [32]. Two emergence peaks were observed because the occurrence of CBT changed from one generation to two generations under glasshouse conditions. The eclosion rate was 97.2% under glasshouse conditions but only 62.8% under field conditions. This change can effectively increase the income of CBT farmers. Furthermore, Wu and Xia (2008) found that the monthly yield was 460, 620, 830, 510, 430, and 230 kg/hm^2, the market price for CBT was about CNY 180, 160, 80, 30, 20, and 30 per kg, and the gross profit was CNY 82,800, 99,200, 66,400, 15,300, 8600, and 6900 from May to October, respectively [31].

3. Utilization Ways and Prospects

After immense research and development, CBT has been considered and used as common food, a functional food, an animal feed additive, an alternative fungus host, a bionic research object, and biochar raw material (Figure 2).

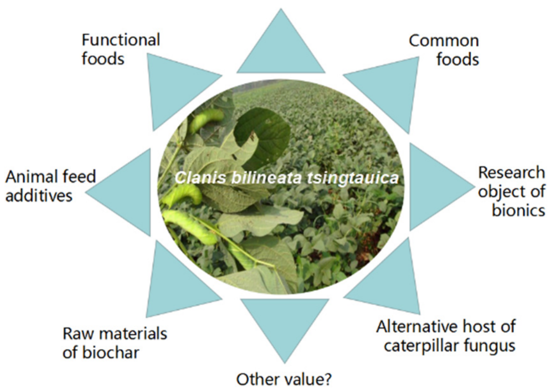

Figure 2. Utilization ways of *Clanis bilineata tsingtauica*.

3.1. Common Foods

CBT is edible at the whole larval stage from the first to the fifth instar. CBT is rich in various nutrients, such as proteins and fats [38]. CBT is an insect food with regional characteristics that represent the harmony and balance of nature, satisfy a gourmet appetite, and preserve human health. At present, the most common processing method used to process before consumption is to cook the fresh larvae using traditional Chinese techniques, such as stir-frying, deep-frying, steaming, stewing, braising, boiling, roasting, and pan-frying. The processing methods, such as boiling, frying, and roasting, make it safe for consumption [39]. People demand and expect convenience in cooking, safety, and recreation, emphasizing its nutrition, function, and safe use. In addition to being consumed after cooking, CBT can also be processed into different forms. Freeze-dried, fried, fresh meat, and canned fresh meat CBT foods are quite common. In addition, more advanced technology is expected to obtain high-quality food to meet various consumer needs and extend CBT use to a wider population. CBT protein powder is absorbed easier than other animal protein powders and is in a form better accepted by customers than in the form of the insect. For instance, fish tofu is a high-protein food, which is similar to tofu but made of fish surimi. CBT addition in fish tofu can improve the taste and highlight the tofu characteristics. Thus, fish tofu supplemented with CBT was developed as a new product with high nutritional value. In the process, raw fish is rinsed, dewatered, minced with the CBT addition, cooked, and stored. An optimum of 10% CBT provided significant protein uniformity for the fish tofu gel matrix and resulted in the closest gel structure [40]. However, further research is required to assess the effect of CBT on the qualitative properties of fish tofu.

3.2. Functional Foods

Studies have reported anti-aging [41], anti-fatigue [42,43], antioxidation [44], and other functional properties of CBT [45]. These features provided an important foundation for CBT to be used as a raw material of functional food [18]. Here, we focus on the application of CBT in functional foods. Functional components need to be optimized to obtain maximum active substances for the best use of resources. Thus, products with better edibility and added value can be generated.

3.2.1. CBT Peptide

In general, calcium chelating peptides are formed by N-terminal amino group, C-terminal end group, amino acid side chain, and chelating group and imine in skin chain. The CBT peptide chelated with calcium is easy to absorb and has good nutritional value as it stays longer in the small intestine, resulting in better absorption. Xia et al. (2020) found that CBT peptides chelated with calcium increased bone mineral density and calcium content in rats [46]. In addition, enzymatic hydrolysis can improve the processing performance of protein and obtain several bioactive peptides with different physiological activities. However, research on peptide products is still less reported. Predictably, new deep processing food products of CBT, such as jams, beverages, vinegars, and wine with powder, capsules, and tablets, would be available in the market.

3.2.2. CBT Oil

Several methods have been developed for extracting oil from vegetable and animal resources, such as conventional non-polar solvent or aqueous extraction. Because of safety, quality, and environmental issues, aqueous extraction has been industrially applied to extract animal fat and vegetable oils. However, the main disadvantage associated with the aqueous process is relatively low efficiency. Instead, ultrasonic treatment on CBT could be used to enhance the extraction yield and reduce the extraction time due to the mass transfer, heating, and cavitation effects. Sun (2018) optimized the extraction process using a response surface methodology (RSM) and obtained the highest oil yield (19.5%) under the optimal conditions of ultrasonic power, extraction temperature, extraction time, and ultrasonic interval time (400 W, 40 °C, 50 min, and 2 s, respectively) [47]. The oil obtained via ultrasound-assisted aqueous extraction showed a higher polyunsaturated fatty acid content and thermal stability than other methods. CBT can be developed as a functional oil resource. CBT oil has good oxidation resistance and thus can be processed as edible oil after refining. However, fewer products are available in the market. CBT is being transformed into powder, cake, or various other food forms. Thus, CBT products are being improved for portability and diversification with a rich taste.

3.2.3. CBT Polysaccharide

By repeatedly washing polysaccharide CBP_3 with ethanol, the precipitate was obtained, and the final product CBP_3 was obtained after deproteinization. CBP_3 is composed of seminose, glucose, and galactose (27.89: 1: 3.16); it has maximum absorption around 190−210 nm, with no absorption at 260 nm or 280 nm, which indicates the absence of nucleic acids or proteins in CBP_3 [48]. CBP_3 that inhibits free radicals in vitro has a strong antioxidant ability; therefore, it can be used as a nutritional fortifier.

3.2.4. CBT Chitosan

Chitosan, a polymer composed primarily of β−(1→4)−2−amino−2−deoxy−D−glucose (D-glucosamine) monomers, is derived by deacetylation of naturally occurring biopolymer, which can be prepared from CBT larvae skin by heating, protein removal through flavorsome hydrolysis, salt removal with HCl, NaOH deacetylation, washing, and drying. Wu (2011) reported that the optimal hydrolyzing conditions were pH 6.5 and 50 °C, and deacetylation conditions were 55% NaOH (*w*/*w*), 120 °C, and 4 h. The resulting chitosan was a white, crystalline, and water-insoluble powder produced at a yield of 31.4% (*w*/*w*) [49]. Furthermore, water-soluble chitosan (a type of chitosan) was prepared by hydrolyzing chitosan using a-amylase. The extracted chitosan was then dissolved in 1% (*v*/*v*) aqueous acetic acid (HAc) to obtain a solution at 1% (*w*/*v*) concentration. Then, 6000 U/g of thermostable α-amylase was added (pH 5). After keeping it in a water bath at 95 °C for 4 h, thermostable α-amylase was inactivated by incubation at 120 °C in a sterilizer for 15 min. The proteins in the resultant product were separated using the Sevag method. The supernatant was precipitated with six volumes of absolute ethanol, filtered through a Whatman GF/A filter paper, and freeze-dried to obtain water-soluble chitosan of CBT larval skin [41]. This water-soluble chitosan from CBT exhibits high antioxidant activity and can be developed as a potential dietary supplement to retard aging in humans.

Meanwhile, chitooligosaccharide is another kind of water-soluble chitosan, composed of oligomers of β-1,4-linked 2-amino-2-deoxy-d-glucopyranose and 2-acetamido-2-deoxy-d-glucopyranose. It is prepared by hydrolyzing chitosan from CBT larva skin using commercial α-amylase under the optimal conditions of pH 5.5, temperature 55 °C, and 40 mg/(g chitosan) α-amylase, thereby achieving the maximum dextrose equivalent. Aliquots of the reaction mixture were periodically withdrawn, filtered, and heated to 95 °C for 15 min to terminate the reaction [45]. The functional properties of active substances (Polysaccharide CBP_3, Chitosan, oil) have been partly verified with the advancement in the extraction methods. Therefore, more CBD functional food products are expected in the future.

3.3. Animal Feed Additives

The addition of CBT in some animal feed formulations is beneficial to the growth and development of poultry and livestock. CBT provides more comprehensive and rich nutrients [18,22]. During the early 1980s, CBT was used to improve egg production by 30.8% and 13.7% in Leghorn chickens and Australorps chickens, respectively. Currently, CBT is also used in new feed formulations. A polysaccharide amino acid was developed with wheat bran, corn, soybean meal, sweet potato straw powder, vegetable oil, fish meal, and animal-derived amino acid powder as the raw materials. The animal-derived amino acid powder was prepared using CBT larvae, cicada (Hemiptera: Cicadellidae), and maggot (*Diptera*: *Muscidae*) and dried and mixed evenly after grinding into powder, followed by the addition of water and proteinase [50]. The mixture was heated and stirred until enzymolysis was achieved. Then, the animal-derived amino acid powder was obtained after centrifugation and vacuum drying of the supernatant fluid. This polysaccharide amino acid feed improves the immunity of laying hens and increases egg production. In addition, CBT added to pig feed promoted sow production in the second trimester of pregnancy and ensured the normal development of fetuses in some parts of China [51]. Thus, CBT is a promising protein resource for animal feeds that can be used as a potential alternative to the existing feed.

3.4. Alternative Host of Chinese Caterpillar Fungus

Caterpillar fungus is a complex consisting of the insect carcass and larval body parasitized by the fungus *Cordyceps* (family Hypocreaceae). It is better known as Chinese caterpillar fungus, 'summer grass, winter worm'. Various caterpillar fungi, such as *Cordyceps sinensis* (Berk.) Sacc., *Cordyceps taishanensis* Liu, Yuan *et* Cao, *Cordyceps militaris* (L. ex Fr.) Link, and *Cordyceps kyushuensis* Kob., have been proven to be cultivable in CBT larvae [52–54]. Studies have compared the active components in some *Cordyceps* species. For example, the content of cordycepin and the activity of superoxide dismutase in *Cordyceps militaris* (cultured in CBT) was 35 and 1.5 times that of *Cordyceps sinensis*. Similarly, the content of polysaccharides in *Cordyceps militaris* (cultured in CBT) was two times that in *Cordyceps sinensis* [54]. *Cordyceps kyushuensis* showed immunomodulatory and antioxidant effects of polysaccharides from the parasitic fungus *Cordyceps kyushuensis*, which is a potential candidate for functional foods and therapeutic agents [55]. Thus, the CBT larvae act as promising alternative hosts for Chinese caterpillar fungus.

3.5. Research Object of Bionics

The body wall structure of CBT larvae exhibits strong stability under bending stress. Researchers have analyzed the connection between the body wall and nearby muscle tissues and the distribution of these tissues using tissue section techniques. The CBT larva was described as a telescopic cylinder with folds and depressions. Then, the reinforced inflatable tube with reinforcing ribs was designed according to its characteristics. The results indicated that the ultimate load of inflatable tubes linearly increased with the increase in pressure. The bending characteristics of the tube can be improved with reinforcing ribs. The bending capacity of the inflatable tube with reinforcing ribs was more robust at a 45° loading angle than that at a 0° angle, which was higher than that without the reinforcing ribs [56]. Under different axial pressure levels, the ultimate load of the inflatable tube with reinforcing ribs was about 1.34 N higher than that without reinforcing ribs. In addition, the maximum compression power increased by 31% to 68% compared to that without ribs [57]. The inflatable tube structure has been widely used in aerospace and construction industries due to its small folding volume, lightweight, and fast shaping [56]. This shows that CBT is a good research material in the field of bionics.

3.6. New Raw Materials of Biochar

The feasibility of using CBT larval-skin-derived biochars for immobilization of lead (Pb) in contaminated soils was evaluated by Yan and colleagues [58,59]. They found that CBT larval skin effectively improved Pb sorption and higher pyrolysis temperature favored the sorption. The addition of CBT larval skin significantly enhanced the conversion of acid-soluble Pb to stable forms. This approach proved the potential application of CBT larval skin in developing new biochar for the remediation of Pb-contaminated soils. Studies have reported that ~10 kilotons of CBT larvae are consumed in China each year, and ~2 kilotons of larval skin are used as a raw material of biochar [41,59]. This development provides technical and economic advantages in soil protection and remediation. CBT is expected to become a new raw material of biochar.

4. The Patents Filing for *Clanis bilineata tsingtauica*

The patent filing for CBT started in 1995. So far, 105 patents have been published, with the maximum filed in 2016; the maximum number of patent applications (18) was filed that year (Figure 3). At present, the patent applications in the CBT field are mainly focused on A23 (Foods or foodstuffs; their treatment, not covered by other classes) and A01K 67 (Rearing or breeding animals, not otherwise provided for, and new breeds of animals). However, the patent applications for A21 (Baking; equipment for making or processing doughs; doughs for baking) and A22 (Butchering; meat treatment; processing poultry or fish) are relatively less, indicating slightly weak innovation strategies (Figure 4). The number of patent applications in China is the highest, indicating a high level of technological innovation and fierce market competition. A growing number of patents would be filed worldwide, with CBT gaining more attention.

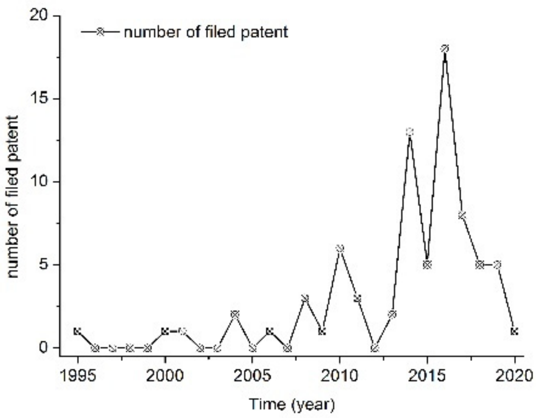

Figure 3. Number of filed patents on *Clanis bilineata tsingtauica*.

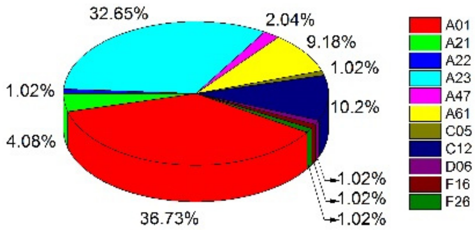

Figure 4. Categories of filed patents on *Clanis bilineata tsingtauica*.

5. Conclusions

CBT is used as a novel food component, leading to the emergence of a new field of the food industry. CBT may also be developed as alternative resources for human consumption and widely used in food, feed, bionic engineering, and environmental restoration fields. Farming or large-scale rearing is necessary to boost the supply of CBT insects. However, the key step to be developed is to overcome or disrupt the diapause that the moth presents to improve CBT rearing gradually and progressively. In addition, good agricultural practices need to be established and employed by insect farmers to prevent food or environmental security-related issues. This review's overview of traditional rearing practices and utilization is only a small step towards a promising ecological circular agricultural approach to develop edible insects as a sustainable resource.

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References

1. Scudder, G.G.E. *The Importance of Insects in Insect Biodiversity: Science and Society*; Foottit, R.G., Adler, P.H., Eds.; Wiley Blackwell: Hoboken, NJ, USA, 2009.
2. Franco, A.; Scieuzo, C.; Salvia, R.; Petrone, A.M.; Tafi, E.; Moretta, A.; Schmitt, E.; Falabella, P. Lipids from *Hermetia illucens*, an innovative and sustainable source. *Sustainability* **2021**, *13*, 10198. [CrossRef]
3. United Nations. Transforming Our World: The 2030 Agenda for Sustainable Development. Available online: https://sdgs.un.org/2030agenda (accessed on 6 April 2021).
4. Moruzzo, R.; Mancini, S.; Guidi, A. Edible insects and sustainable development goals. *Insects* **2021**, *12*, 557. [CrossRef]
5. Baiano, A. Edible insects: An overview on nutritional characteristics, safety, farming, production technologies, regulatory framework, and socio-economic and ethical implications. *Trends. Food. Sci. Technol.* **2020**, *100*, 35–50. [CrossRef]
6. Kim, T.-K.; Yong, H.I.; Chun, H.H.; Lee, M.-A.; Kim, Y.-B.; Choi, Y.-S. Changes of amino acid composition and protein technical functionality of edible insects by extracting steps. *J. Asia Pac. Entomol.* **2020**, *23*, 298–305. [CrossRef]
7. Verneau, F.; Amato, M.; La Barbera, F. Edible insects and global food security. *Insects* **2021**, *12*, 472. [CrossRef] [PubMed]
8. van Huis, A.; van Itterbeeck, J.; Klunder, H.; Mertens, E.; Halloran, A.; Muir, G.; Vantomme, P. *Edible Insects: Future Prospects for Food and Feed Security*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2013.
9. Jongema, Y. List of Edible Insects of the World (April 1, 2017)—WUR. Available online: www.wur.nl/en/Expertise-Services/Chair-groups/Plant-Sciences/Laboratory-of-Entomology/Edible-insects/Worldwide-species-list.htm (accessed on 1 September 2017).
10. Pittaway, T.; Kitching, I. Notes on selected species of hawkmoths (*Lepidoptera*: *Sphingidae*) from China, Mongolia and the Korean Peninsula. *Tinea* **2000**, *16*, 170–211.
11. Ghosh, S.; Lee, S.M.; Jung, C.; Meyer-Rochow, V.B. Nutritional composition of five commercial edible insects in South Korea. *J. Asia-Pac. Entomol.* **2017**, *20*, 686–694. [CrossRef]
12. Chen, X.; Feng, Y.; Chen, Z. Common edible insects and their utilization in China. *Entomol. Res.* **2009**, *39*, 299–303. [CrossRef]
13. Hua, Y.N. Observation and control of *Clanis bilineata* in Shandong province. *Chin. Bull. Entomol.* **1958**, *4*, 74–78. (In Chinese)
14. Zhu, H.F.; Wang, L.Y. *Fauna of Economic Insects in China (Lepidoptera: Spliingidae)*; Science Press: Beijing, China, 1980. (In Chinese)
15. Hou, Y.H.; Chen, Q.; Fan, Z.Y.; Shen, H.L.; Liu, D.; Shi, X.H.; Li, S.M. Sphingidae species under lamp in farmland and light-trapped population dynamics in recent 30 years. *J. Shanxi Agric. Sci.* **2018**, *46*, 104–107. (In Chinese) [CrossRef]
16. Tian, H. Integrated control measures to the harms of soybean pest *Clanis bilineata tsingtauica* Mell. *J. Nanyang Normal Univ.* **2009**, *8*, 58–60. (In Chinese) [CrossRef]
17. Gao, Y.; Shi, S.S.; Xu, M.L.; Cui, J. Current research on soybean pest management in China. *Oil Crop Sci.* **2018**, *3*, 215–227. [CrossRef]
18. Gao, Y.; Zhao, Y.J.; Xu, M.L.; Shi, S.S. Soybean hawkmoth (*Clanis bilineata tsingtauica*) as food ingredients: A review. *CyTA J. Food* **2021**, *19*, 341–348. [CrossRef]
19. Raheem, D.; Carrascosa, C.; Oluwole, O.B.; Nieuwland, M.; Raposo, A. Traditional consumption of and rearing edible insects in Africa, Asia and Europe. *Crit. Rev. Food. Sci.* **2019**, *59*, 2169–2188. [CrossRef]
20. Köhler, R.; Kariuki, L.; Lambert, C.; Biesalski, H.K. Protein, amino acid and mineral composition of some edible insects from Thailand. *J. Asia Pac. Entomol.* **2019**, *22*, 372–378. [CrossRef]
21. Yi, C.H.; He, Q.J.; Lin, W.; Kuang, R.P. The utilization of insect-resources in Chinese rural area. *J. Agric. Sci.* **2010**, *2*, 146–154. [CrossRef]
22. Tian, H.; Zhang, Y.M. Advances of integrated utilization on resource insect *Clanis bilineata tsingtauica*. *Guizhou Agric. Sci.* **2009**, *37*, 111–113. (In Chinese) [CrossRef]
23. Jiangsu Provincial Bureau of Market Supervision. *Technical Regulation for Artificial Rearing of 'Doudan' (Larva of Clanis bilineata) (DB 32/T 3528–2019)*; Local Standard of Jiangsu Province; Jiangsu Provincial Bureau of Market Supervision: Nanjing, China, 2019. (In Chinese)
24. Feng, Y.Y.; Ma, G.C.; Jin, Q.A.; Lv, B.Q.; Peng, Z.Q.; Jin, T.; Wen, H.B. Developmental duration and life table of the laboratory populations of *Clanis bilineata tsingtauica* (*Lepidoptera*: *Sphingidae*) at different temperatures. *Plant Prot.* **2014**, *40*, 80–83. (In Chinese) [CrossRef]
25. Feng, Y.Y.; Ma, G.C.; Lv, B.Q.; Jin, Q.A.; Peng, Z.Q.; Wang, X.N.; Jin, T.; Wen, H.B. Life table of *Clanis bilineata tsingtauica* (*Lepidoptera*: *Sphingidae*) populations from two geographical zones using jackknife technique. *Chin. J. Trop. Crops* **2014**, *35*, 2274–2277. (In Chinese) [CrossRef]
26. Feng, Y.Y.; Ma, G.C.; Jin, Q.A.; Lv, B.Q.; Peng, Z.Q.; Jin, T.; Wen, H.B. Effect of temperature on developmental duration and feeding amount of *Clanis bilineata tsingtauica*. *Chin. J. Trop. Crops* **2014**, *35*, 2442–2444. (In Chinese) [CrossRef]
27. Xiao, T.; Guo, J.; Chen, H.Z.; Wu, Q.Y.; Zhu, G.M.; Yang, J.H.; Pan, Y.L. Effect of low temperature on overwintering and pupation of *Clanis bilineata*. *J. Econ. Anim.* **2010**, *14*, 49–51. (In Chinese) [CrossRef]
28. Lin, H.F.; Wu, F.Z.; Li, S.G.; Liu, Z.H.; Gao, Y.B.; Yang, X.J.; Zhang, S.Y.; Xia, S.A.; Wu, S.X. Study on effect of different breeding dusts upon overwintering of *Clanis bilineata* (Walker). *J. Econ. Anim.* **2006**, *10*, 161–163. (In Chinese) [CrossRef]
29. Tian, K.F.; Zhao, Q.C. A preliminary report on the investigation of parasitic natural enemies of *Clanis bilineata* in Huaibei Area. *Chin. Bull. Entomol.* **2001**, *38*, 65–66. (In Chinese) [CrossRef]

30. Wang, L.Q.; Yi, J.P.; Zhu, S.Y.; Li, B.; Chen, Y.; Shen, W.D.; Wang, W.B. Identification of a single-nucleocapsid baculovirus isolated from *Clanis bilineata tsingtauica* (*Lepidoptera*: *Sphingidae*). *Arch. Virol.* **2008**, *153*, 1557–1561. [CrossRef]
31. Wu, S.J.; Xia, Z.Q. Study on preservation of *Clanis bilineata* Walker larva. *Agric. Sci. Technol.* **2008**, *9*, 155–156. [CrossRef]
32. Li, J.L.; Wang, T.T.; Chen, K.J. Effect of blanching temperature and drying chamber pressure on quality of bean worm with vacuum freeze-drying. *J. Food Sci. Biotechnol.* **2018**, *37*, 747–753. (In Chinese) [CrossRef]
33. Pan, S.K.; Jiang, L.F.; Meng, X.; Wu, S.J. Myofibrillar protein denaturation in frozen and stored *Clanis bilineata* larvae as affected by pullulan. *Int. J. Food Prop.* **2018**, *20*, S2342–S2348. [CrossRef]
34. Wu, S.J. Glutathione suppresses lipid oxidation of *Clanis bilineata* larvae meat during frozen storage. *Entomol. Res.* **2018**, *48*, 451–454. [CrossRef]
35. Ren, C.G.; Li, H.Q.; Chen, F.Q. Study on yield loss of soybean caused by *Clanis bilineata*. *Chin. Bull. Entomol.* **1991**, *28*, 276–279. (In Chinese)
36. Yan, M.H. Clanis bilineata tsingtauica-feed. *J. Biol.* **2001**, *18*, 33. (In Chinese) [CrossRef]
37. Wang, X.Q.; Chen, C.Q.; Zhao, H.; Zhang, Y.Q. Rearing *Clanis bilineata* in soybean field and its profit. *Chin. Bull. Entomol.* **2002**, *39*, 30–33. (In Chinese) [CrossRef]
38. Xia, Z.Q.; Wu, S.J.; Pan, S.K.; Kim, J.M. Nutritional evaluation of protein from *Clanis bilineata* (*Lepidoptera*), an edible insect. *J. Sci. Food Agric.* **2012**, *92*, 1479–1482. [CrossRef] [PubMed]
39. Murefu, T.R.; Macheka, L.; Musundire, R.; Manditseraa, F.A. Safety of wild harvested and reared edible insects: A review. *Food Control* **2019**, *101*, 209–224. [CrossRef]
40. Cao, J.J.; Qiu, C.J.; Guo, Y. Effect of the addition of *Clanis bilineata tsingtauica* on qualitative properties of fish tofu. *Food Res. Dev.* **2019**, *40*, 133–138. (In Chinese) [CrossRef]
41. Wu, S.J.; Lu, M.S.; Wang, S.J. Antiageing activities of water-soluble chitosan from *Clanis bilineata* larvae. *Int. J. Biol. Macromol.* **2017**, *102*, 376–379. [CrossRef]
42. Liu, X.W.; Chen, X.L.; Zhang, Y.; Li, Y.J.; Chen, F.L.; Wang, J.; Li, L.; Li, J.; Ding, H. Studies on anti-fatigue effect of alcohol extract of *Clanis bilineata* walker. *Sci. Technol. Food Ind.* **2014**, *35*, 362–368. (In Chinese) [CrossRef]
43. Xu, L.; Kong, D.Y.; Li, Y.J.; Li, L.; Chen, F.L.; Wang, J. Effects of *Clanis bilineata tsingtauica* mell on anti-fatigue in aged mice. *Food Sci. Technol.* **2014**, *39*, 64–67. (In Chinese) [CrossRef]
44. Sun, M.M.; Xu, X.; Zhang, Q.Q.; Rui, X.; Wu, J.J.; Dong, M.S. Ultrasonic-assisted aqueous extraction and physicochemical characterization of oil from *Clanis bilineata*. *J. Oleo Sci.* **2018**, *67*, 151–165. [CrossRef]
45. Wu, S.J. Preparation of chitooligosaccharides from *Clanis bilineata* larvae skin and their antibacterial activity. *Int. J. Biol. Macromol.* **2012**, *51*, 1147–1150. [CrossRef]
46. Xia, X.D.; Zhou, J.Z.; Shan, C.J.; Liu, X.L.; Wang, Y.; Li, Y.; Zhang, L.X.; Huang, Z.S. A Preparation Method of the Peptide Chelated Calcium of *Clanis bilineata tsingtauica*. China Patent 106520873B, 7 April 2020.
47. Sun, M.M. Ultrasound-Assisted Aqueous Extraction of *Clanis bilineata* Oil and Oxidation Protective Effect on Nerve Cells. Master's Thesis, Nanjing Agricultural University, Nanjing, China, 2018.
48. Tian, H. Structure characterizations of polysaccharide CBP_3 from *Clanis bilineata tsingtauica* Mell. *Sci. Technol. Food Ind.* **2016**, *37*, 97–105. (In Chinese) [CrossRef]
49. Wu, S.J. Preparation of chitosan from *Clanis bilineata* larvae skin using enzymatic methods. *Carbohydr. Polym.* **2011**, *83*, 1008–1010. [CrossRef]
50. Luo, S.Y. A Polysaccharide Amino Acid Feed for Laying Hens. China Patent 201810762470.X, 23 November 2018.
51. Liu, J.H. A Sow Feed the Second Trimester of Pregnancy and Its Fabrication Methods. China Patent 201410428602.7, 27 August 2014.
52. Guo, Y.L.; Li, C.Y. *Cordyceps kyushuensis* new to China. *Mycosystema* **2000**, *19*, 296. (In Chinese) [CrossRef]
53. Chen, C.; Li, Y.; Luo, S.; Sun, Y.J.; Zhang, C.K. Effects of *Cordyceps kyushuensis* on fruit fly's longevity. *Shanghai J. Tradit. Chin. Med.* **2005**, *39*, 56–57. (In Chinese) [CrossRef]
54. Hua, C.; Wen, L. Determination of active components in *Cordyceps militaris* (*Clanis bilineata*). *J. Huaiyin Ind. Coll.* **2005**, *14*, 55–56. (In Chinese)
55. Su, J.J.; Sun, J.; Jian, T.T.; Zhang, G.Y.; Ling, J.Y. Immunomodulatory and antioxidant effects of polysaccharides from the parasitic fungus *Cordyceps kyushuensis*. *Biomed. Res. Int.* **2020**, *8257847*, 1–10. [CrossRef]
56. Chen, D.H.; Liu, W.; Lv, J.H.; Chang, Z.Y.; Tong, J. Bending characteristics of inflatable tube bioinspired from *Clanis bilineata* larva. *Trans. Chin. Soc. Agric. Mach.* **2017**, *48*, 399–404. (In Chinese) [CrossRef]
57. Chen, D.H.; Lv, J.H.; Liu, W.; Chang, Z.Y. Stability performance of inflatable tube imitating *Clanis bilineata* larva under axial pressure. *J. Mech. Med. Biol.* **2017**, *17*, 1740028. (In Chinese) [CrossRef]
58. Yan, Y.B.; Zhang, L.; Wang, Y.H.; Wang, X.Z.; Wang, S.Y.; Li, Q.; Liu, X.Y.; Xu, Y.G.; Yang, J.J.; Bolan, N. *Clanis bilineata* larvae skin-derived biochars for immobilization of lead: Sorption isotherm and molecular mechanism. *Sci. Total Environ.* **2019**, *704*, 135251. [CrossRef]
59. Yan, Y.B.; Sarkar, B.; Zhou, L.; Zhang, L.; Li, Q.; Yang, J.J.; Bolan, N. Phosphorus-rich biochar produced through bean-worm skin waste pyrolysis enhances the adsorption of aqueous lead. *Environ. Pollut.* **2020**, *266*, 115177. [CrossRef]