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Insect-derived materials for food packaging-A review

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ABSTRACT

Due to the increasing global population and the serious environmental pollution, human beings face increased demand for high-quality nutritious food and are showing increased willingness to adopt green materials. Edible insects are considered to be a core source of nutrition for the future. Insect ingredients as edible food packaging will be a help to solve human nutritional needs and augment green environmental protection. Insect-derived films are basically at the level of small-scale research in the laboratory, and the order Orthoptera are the current research focus. Chitin extracted from insects to make packaging films has natural antibacterial advantages. In terms of mechanical properties, the chitin films can have a tensile stress of up to 89.6 MPa. In terms of light transmittance, insect protein films have a greater shading rate, 6.168 %. Generally, insect-derived food packaging films still need more exploration and research to enrich the basis of practical operation and theoretical research.

1. Introduction

It is undeniable that traditional plastic packaging is functionally successful; however, the production of petroleum-based plastics and the incineration degradation process both increase carbon emissions due to a lack of collection or proper disposal (Ncube, Ude, Ogunmuyiwa, Zulkifli, & Beas, 2021). Plastic is usually buried in landfills and geological processes can lead to it eventually polluting the oceans. At least 14 million tons of plastic finds its way into the ocean every year. Plastic debris is currently the most abundant type of litter in the ocean, making up 80 % of all marine debris found from surface waters to deep-sea sediments (2021), and one of the main sources of this class of pollution has been identified as food and beverage packaging (Ncube, Ude, Ogunmuyiwa, Zulkifli, & Beas, 2021). The manufacture of traditional plastic packaging is mainly based on the use of fossil fuels as the raw material, and in 2018, 4–8 % of global oil production was used for plastic production (Organisation for Economic Co-operation and, 2018). 40 % of this is used to make single-use plastics, whose use is primarily driven by increasing food and beverage consumption. Most food packaging plastics create a waste stream shortly after purchase, especially in single-use packaging applications for short-lived goods (Sundqvist-Andberg & Åkerman, 2021). In addition, due to the impact of the COVID-19 epidemic, the growth of the global takeaway industry has increased the consumption of foam takeaway containers such as food wrapping paper and food bags (Oliveira, Azeredo, Neri-Numa, & Pastore, 2021). The accumulation of microplastics (MPs) and their contamination of food has become a global threat to the environment and human health. It is estimated that human consumption of microplastics through takeaway food is about 2977 microplastics per person per year (Jadhav, Sankhla, Bhat, & Bhagat, 2021). Food packaging manufacturers and the food industry have been working to replace traditional, non-renewable petroleum sources with abundant, low-cost, renewable and biodegradable alternatives (Chaudhary, Bangar, Thaku, & Trif, 2022). Growing public awareness of the environmental challenges associated with traditional plastic materials, and consumer pressure to improve sustainability, has led to the development of bio-based, biodegradable, edible food packaging materials (Sundqvist-Andberg & Åkerman, 2021). Although some researchers currently predict that biodegradable or edible films will not completely replace traditional packaging materials, they can prolong the stability of food and improve the efficiency of food packaging by reducing the exchange of moisture, lipids, volatiles and gases between the food and the surrounding environment (Ivanković, Zeljko, Talić, Martinović Bevanda, & Lasić, 2017), which reduces the need for petroleum-derived polymers.

These bioplastics are commonly considered for use as primary packaging materials, some of which may be consumed together with the food they contain. In addition to increasing the shelf life of food by physically preventing contact between the food and environmental microorganisms and contaminants, these films can play an active role, since many are capable of carrying antimicrobial agents, nutrients, anti-

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browning compounds, and colouring agents, which can prevent pathogenic microorganisms from growing on food surfaces (Das, Panesar, Saini, & Kennedy, 2022). Although some of these bioplastics can be prepared using non-edible polyesters, such as polylactic acid or polyhydroxyalkanoates, others can be prepared using edible biopolymers, such as carbohydrates, lipids and proteins (Han, 2013), and these compounds can be extracted from many different natural sources. One of these possible sources of edible biopolymers, insects, have attracted the interest of the research community in recent years, since insects can be eaten directly, which is very convenient considering the growing world population. Moreover, their biopolymers can be extracted and used to prepare bioplastics that may also be edible.

1.1. Insects as food

At present, the most common system of protein production for human consumption is the intensive raising of livestock, although protein production from animal husbandry generates important ecological concerns because of its environmental impact, as it requires large quantities of water, energy and land (Godfray et al., 2018). As human food production becomes a major driver of global environmental change, there is growing recognition of the importance of shifting to more sustainable dietary patterns (Cottrell et al., 2021). At the same time, combined with the current population pressure and socio-economic growth trends, it is necessary to introduce alternatives to traditional animal protein (Fasolin et al., 2019).

In this sense, insects have received attention as an alternative protein source due to their favourable environmental impact (Churchward-Venne et al., 2017). Insects are considered one of the most environmentally friendly sources of animal protein because of their very low carbon footprint and high protein content (Van Huis & Oonincx, 2017; Ros-Baró et al., 2022). Edible insects are still a novelty in Western culture, and they also represent a challenging concept for many people around the world. Regulations allowing insects to be sold commercially for use and consumption in the EU only came into effect in 2018 (Halloran, Flore, Vantomme, & Roos, 2018), but in some African, Asian and South America countries edible insects already have a high market value, sometimes similar to that of traditional livestock, or even higher (Raheem et al., 2019; Abril, Pinzón, Hernández-Carrión, & Sánchez-Camargo, 2022). Therefore, insects are a commodity with an existing market. The global edible insect market is expected to grow to USD 9.6 billion by 2030 (Wood, 2022). In addition to the consumption of insects as potential providers of protein nutrients, natural active products derived from insects for antimicrobial, antifungal, antiviral, anticancer, antioxidant, anti-inflammatory and immunomodulatory effects (e.g. chitin, antimicrobial peptides or specific fatty acids) also have excellent prospects (Wang, Qian, & Ding, 2018; Kaya et al., 2019).

1.2. Insects as a source of biopolymers for preparing edible films and coatings

As insects are a source of valuable biopolymers, such as proteins and carbohydrates, they can be processed to produce not only foodstuffs but also bioplastics (Barbi, Messori, Manfredini, Pini, & Montorsi, 2019). The use of insects or their derivatives as raw materials to allow the substitution of petroleum packaging materials, whilst simultaneously taking advantage of their protein content as a nutrient source, is a biotechnological solution presented a few years ago. Several insect species feed naturally on organic waste, and by digesting organic matter within their bodies, they make it possible to reduce the amount of waste while producing more homogeneous and valuable biomass for a variety of purposes (e.g., for feed/food ingredients, cosmetics, pharmaceuticals, bioplastics, etc.) (Franco et al., 2022). Caligiani et al., 2018 were the first to propose the potential feasibility of producing bioplastics from insect proteins. In particular, the protein obtained by alkaline extraction from *Hermetia illucens* has been proposed for the production of bioplastics because the protein is of low quality and is not suitable for nutritional requirements (Leni, Caligiani, & Sforza, 2021). These insect-derived films are a promising source for some types of biocompostable plastics, with the added value of using proteins produced by insects digesting waste, and thus contributing to the prospect of a circular economy. Sanandiya, Vijay, Dimopoulou, Dritsas, & Fernandez, 2018 extracted chitin from *Hermetia illucens*, deacetylated it and mixed cellulose to produce packaging materials. The introduction of insect-based materials for the production of bioplastics not only represents a way to add value to food waste and by-products that are used as growth substrates for insects, but is also an effective alternative to unsustainable plastic packaging. Fig. 1 shows an abstracted process of forming a simple edible insect-derived food packaging film. The first step is to obtain insects by natural capture or artificial breeding. Then, the edible insects with high nutritional value undergo an extraction process by means of physical separation and chemical extraction to obtain biological organic macromolecular materials such as proteins, polysaccharides, and lipids. Among these, the first two are the most widely used to prepare environmentally friendly food packaging materials.

Therefore, considering that the use of biopolymers extracted from insects to create edible films and coatings for food packaging is a topic of increasing interest, this review aims to summarize recent scientific research on this subject, describing the current state of development and future trends in this field.

2. Insects as a source of biopolymers to prepare bioplastics

The main biopolymers found in insects that can be used to prepare edible films and coatings are proteins, carbohydrates and lipids. Table 1 shows the basic nutritional composition of some edible insects that can be consumed by humans or livestock as food or feed, including crude protein, fat, carbohydrates and other nutrients found in relevant studies in recent years.

Protein is the main macromolecule found in insects and the reason why these insects have attracted the attention of the international community of food researchers. Protein content in insects has been reported to be as high as 21–76 % of dry biomass in different insect types (Kouřimská & Adámková, 2016). Because insects have considerable differences in the expression of their internal structures between species, generally related to their behaviour and ecology, the sources and

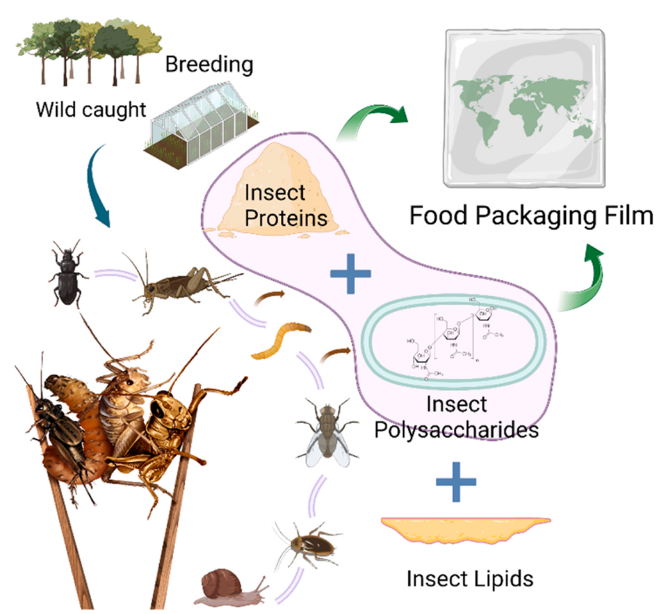

Fig. 1. Scheme of the preparation of edible insects packaging films.

structures of insect proteins vary widely. There are also differences between species in terms of the distribution of proteins of different molecular weights, and of many other components such as fats and carbohydrates (Mishyna, Keppler, & Chen, 2021). Furthermore, production techniques and feed composition in larval rearing also affect protein quality (Tschirner & Simon, 2015). In terms of amino acid content, Coleoptera, Hymenoptera, Lepidoptera and Orthoptera averaged or exceeded the IAA (indispensable amino acid) requirement for human adults (Churchward-Venne et al., 2017). The first limiting amino acid, methionine, is present in relatively low quantities in insects in general. In addition, in the study of Shikha Ojha, Bekhit, Grune, & Schlüter, 2021, the BV value is the biological value of the protein, which is used to indicate the degree to which the protein is utilized by the organism. Insects such as crickets (*G. assimilis*) have higher BV values (85.49–93.02 %) than casein (73.45 %). In a nutritional study of the epidermis and meat of *Clanis bilineata tsingtauica* larvae by Ying Su et al. (2021), four proteins were identified, including albumin, globulin, glutenin, and prolamin, which had different concentrations in larval flesh and epidermis. In Table 1, the proportion of protein to total mass of Lepidoptera and Orthoptera is seen to be higher than that of Hemiptera and Blattella and, furthermore, in the column of Coleoptera, we find that the protein ratio of aquatic insects is nearly half that of terrestrial species.

After proteins, the second bulk component of insects is lipids. The lipid content of insects varies with individual species, but also with their growth stage, environmental conditions and dietary specifications (Lorrette & Sanchez, 2022). Lipids can typically represent 10–25 % of insect dry matter, similar to the data presented in Table 1. Some species such as Odontotermes and *Ruspolia differens* shown in Table 1 can even approach 50 %. Therefore, lipids have also become one of the main by-products of the insect industry. The composition of insect fat may vary in the quantity and composition of the fatty acid distribution (Lorrette & Sanchez, 2022). Insect species, growth stage and extraction technique are some of the parameters that affect fat quality. Insect lipids are mainly composed of triacylglycerols. Other types of lipids present in small amounts include cholesterol, partial glycerides, free fatty acids (FFAs), phospholipids and wax esters. (D.A. Tzompa-Sosa, Yi, van Valenberg, & Lakemond, 2019) As insect lipids for human consumption, this raw material may be an alternative to the resource-intensive and more expensive soybean oil, palm kernel oil, coconut oil, and fish oil (Franco et al., 2021). Although some studies suggest that insect lipids function well in food, crude fats and oils have an aftertaste that requires refining to improve their organoleptic properties (Lorrette & Sanchez, 2022).

In addition, in the data collected in Table 1, the proportion of fat in cockroaches is significantly better than that of insects of other orders, while the proportion of fat in Odontotermes even accounts for half of the dry weight.

Regarding insect carbohydrates, the insect exoskeleton contains a lot of fibre. For example, in *Oecophylla smaragdina* (Kim, Yong, Kim, Kim, & Choi, 2019), the research data showed that about 19.84 % of the dry matter is fibre, which contains functional dietary fibre and this has effects related to regulating host intestinal health and improving glucose and lipid metabolism disorders (Cronin, Joyce, O'toole, & O'connor, 2021). Measured as crude fibre, acid detergent fibre, or neutral detergent fibre, the composition of these fibre fractions is unknown (Finke, 2007), but includes hardened proteins, minerals and other compounds that bind to chitin. Chitin, an N-acetyl-β-D-glucosamine polymer, provides rigidity to the insect's exoskeleton (Doucet & Retnakaran, 2012). It is present in the epidermis of the insect exoskeleton, the two innermost layers of the epidermis, and its content depends on the insect species and developmental stage (Oonincx & Finke, 2021). The chitin content of some insects listed in Table 1 ranges from the 4.72 % of *Tenebrio molitor* to 7.34 % of Crickets to the highest content, 14.1 %, of black soldier fly larvae. Another polysaccharide substance is called chitosan, with the chemical name polyglucosamine (1−4)−2-amino-B-D glucose, which can be obtained by deacetylation of chitin. The extracted chitosan has antibacterial, antioxidant, anti-cancer, anti-inflammatory properties and wastewater treatment capacity (Cronin, Joyce, O'toole, & O'connor, 2021), and is a valuable research direction. It is a new research trend to develop high value-added products such as chitosan by means of comprehensive utilization of insect resources.

3. Characterization of insect-derived packaging films

It can be seen from Table 2 that most of the studies are in the early stages of research, using laboratory-scale fabrication and solvent casting methods, with only one case involving hot-press and cold-press fabrication. The main reason is most likely that insect-derived materials are currently a new direction in edible packaging. Researchers mainly focus on research into the properties of the materials themselves and have not yet become involved in the development of industrial production and large-scale manufacturing processes. Therefore, solution casting is the most popular low-cost film-forming method in the laboratory. In recent years, researchers have been investigating the extraction of protein and chitin from insects to make edible films. The chitin or chitosan materials derived from insects have been reported to have advantages over those from marine crustaceans (Triunfo et al., 2022). For example, chitosan extracted from cicada slough, silkworm pupae, mealworms and grasshopper species showed higher potential water-holding capacity (594–795 %) and fat-binding capacity (275–645 %) compared to shrimp shell chitosan (Mohan et al., 2020). This is a promising property for food applications. Scientists today generally regard environmental protection as a major consideration and one of the main purposes of making biopolymer materials is to reduce the carbon footprint (Chandran et al., 2021). For example, *Hermetia illucens* is used as a farmed insect which can use organic waste (food waste) to complete low-carbon consumption. This concept unites the issues of organic waste management and insect rearing as well as alternative sources of protein and chitin.

The studies in Table 2 suggest that insects of the order Orthoptera are popular experimental subjects, probably because Orthoptera insects, such as grasshoppers, crickets, and locusts, are widely distributed around the world, most of them being considered as herbivorous agricultural pests. These insects are eaten in many parts of the world. They have a short life cycle (4–8 weeks for adulthood), a fast reproduction rate, a protein content of up to 76 %, and the shells of Orthoptera are also a good source of chitin (Blásquez, Moreno, & Camacho, 2012; Paul et al., 2016). On the other hand, in order to develop treatment methods for pests, the harm done by the American cockroach (Chen et al., 2021) to the public environment and the destruction of forests by weevil (Kaya et al., 2019) are the main reasons why scientists use them as research subjects. Table 2 also shows that the current research into insect resources for food packaging is more directly using insects to produce source materials, and there is less research conducted on insect metabolites as source materials. In the preparation process, in addition to the addition of active substances with functional purposes, the film-forming liquid is additivated with plasticizers such as glycerin to help the film attain better structural characteristics. Unfortunately, researchers are more inclined to study the proportion of insect extracts contained in the film-forming fluid, and there is not much research into the impact of additives such as plasticizers. After the film form is made, the physical performance properties of the film, such as the optical properties, solubility, mechanical strength, and other properties of the film, are measured to provide the numerical data necessary for an objective evaluation of the degree of excellence of the film, and to judge whether it is suitable for food packaging.

3.1. Optical and colour properties

The optical properties (colour and clarity) of food packaging play a crucial role in the appearance and acceptance of packaging by consumers (Khalid & Arif, 2022). Sensory evaluation of biopolymer-based

Table 1
Major nutrient composition of Insects (g/100 g of dried sample).

Insect		Protein	Fats	Carbohydrate	Reference
Orthoptera	Grasshopper (*Arphia fallax* S., *Sphenarium histrio* G., *Sphenarium purpurascens* Ch. *Ruspolia differens*. etc.)	43.9 ± 1.5–77.1 ± 2.8	4.22 ± 0.5–34.2 ± 1.9	0.001 ± 0.100–22.64 ± 2.90 Fibre:3.00 ± 0.90–12.17 ± 2.80	(Siulapwa, Mwambungu, Lungu, & Sichilima, 2014; Blásquez, Moreno, & Camacho, 2012; Paul et al., 2016; Montowska, Kowalczewski, Rybicka, & Fornal, 2019; Rodríguez-Miranda, Alcántar-Vázquez, Zúñiga-Marroquín, & Juárez-Barrientos, 2019)
	Cricket (*Acheta domesticus*, *Teleogryllus emma*，*Gryllus bimaculatus*，*Gryllodes sigillatus*.etc.)	55.65 ± 0.28–72.45 ± 1.30	11.88 ± 0.21–25.14 ± 0.11	0.1 ± 0.0–6.64 ± 0.15 Chitin:7.34 ± 0.73	(Blásquez, Moreno, & Camacho, 2012; Brogan, Park, Matak, & Jaczynski, 2021; Psarianos et al., 2022)
	Locust (*Locusta migratoria*, *Schistocerca gregaria* etc.)	53.80 ± 0.50–76.0 ± 0.9	11.42 ± 1.11–35.66 ± 2.15	0.018 ± 0.004–2.08 ± 0.31	(Khalil, 2013; Ochiai, Inada, & Horiguchi, 2020; Brogan, Park, Matak, & Jaczynski, 2021)
Diptera	Black Soldier Fly (*Hermetia illucens*)	29.9 ± 0.75–45.7 ± 0.07	9.50 ± 0.36–49.0 ± 0.22	Chitin: 2.9–14.1	(Caligiani et al., 2018;Huang et al., 2019; Abd El-Hack et al., 2020; Bessa, Pieterse, Marais, & Hoffman, 2020)
Coleoptera	Scarabs (*Allomyrina dichotoma* larvae, *Protaetia brevitarsis* larvae, *Zophobas morio* larvae)	44.23 ± 0.25–54.18 ± 1.50	15.36 ± 0.40–20.24 ± 0.25	Chitin:4.60 ± 0.05–10.53 ± 0.75	(Ghosh, Lee, Jung, & Meyer-Rochow, 2017; Kim, Yong, Kim, Kim, & Choi, 2019; Shin, Kim, & Shin, 2019; Hahn et al., 2020; Kulma et al., 2020;Meyer-Rochow, Gahukar, Ghosh, & Jung, 2021;Oonincx & Finke, 2021)
	Tenebrio molitor larvae & adult	52.35 ± 1.1–53.22 ± 0.32	24.7 ± 1.5–34.54 ± 0.87	2.2 ± 0.3–11.45 ± 0.38 Chitin:4.72 ± 0.21	(Zielińska, Baraniak, Karaś, Rybczyńska, & Jakubczyk, 2015; Shin, Kim, & Shin, 2019; Son, Hwang, Nho, Kim, & Kim, 2021)
	Water beetle (*Hydrophilus olilivaceous*, *Cybister tripunctatus*)	22.64 ± 0.17 –25.08 ± 0.09	6.94 ± 0.70–21.57 ± 1.61	1.67 ± 0.33–2.39 ± 0.38 Fibre:14.25 ± 0.46 to15.13 ± 0.57	(Shantibala, Lokeshwari, & Debaraj, 2014)
Hemiptera	*Lethocerus indicus*	22.67 ± 0.36	13.75 ± 0.09	15.40 ± 0.20 Fibre: 11.71 ± 0.25	(Shantibala, Lokeshwari, & Debaraj, 2014; Meyer-Rochow, Gahukar, Ghosh, & Jung, 2021)
Lepidoptera	Caterpillars (*Gonimbrasia belina*, *Gynanisa maja* and *Clanis bilineata tsingtauica*)	55.92 ± 0.04–71.85 ± 3.18	10.0 ± 0.2– 12.1 ± 0.2	8.4 ± 0.4–10.7 ± 0.3	(Siulapwa, Mwambungu, Lungu, & Sichilima, 2014; Churchward-Venne et al., 2017; Hahn et al., 2020;Gao, Zhao, Xu, & Shi, 2021; Meyer-Rochow, Gahukar, Ghosh, & Jung, 2021; Oonincx & Finke, 2021; Su et al., 2021)
	Silkworm (*Bombyx mori, pupae of muga and eri silkworm)*	53.07 ± 0.10–72.48	16.66–33.30 ± 16.00	1.24–1.62 Fibre: 3.06–3.25	(Churchward-Venne et al., 2017; Brogan, Park, Matak, & Jaczynski, 2021;Sharma, Gupta, Sharma, & Attri, 2022)
Blattaria	Odontotermes	33.672 ± 0.329	50.930 ± 1.097	Fibre: 6.298 ± 0.088	(Chakravorty, Ghosh, Megu, Jung, & Meyer-Rochow, 2016)
	Macrotermes falciger	43.26 ± 0.03	43.0 ± 0.2	32.8 ± 0.6	(Siulapwa, Mwambungu, Lungu, & Sichilima, 2014)
Hymenoptera	*Oecophylla smaragdina*	55.279 ± 1.024	14.993 ± 0.136	Fibre: 19.840 ± 0.259	(Chakravorty, Ghosh, Megu, Jung, & Meyer-Rochow, 2016)
	Laccotrephes maculatus	41.56 ± 0.52	5.16 ± 0.57	0.06 ± 0.01 Fibre: 7.31 ± 0.28	(Shantibala, Lokeshwari, & Debaraj, 2014)
Odonata	*Crocothemis servilia*	70.48 ± 0.43	4.93 ± 0.17	1.18 ± 0.09 Fibre: 9.62 ± 0.24	(Shantibala, Lokeshwari, & Debaraj, 2014)

films is critical to success in the market and it is well known that the addition of bioactive compounds to foods can significantly alter sensory acceptance (Trajkovska Petkoska, Daniloski, D'Cunha, Naumovski, & Broach, 2021). The colorimeter test is the most common test method in the laboratory and the test gives the results "L*" for brightness, "a*" and "b*" for: "red/green" and "blue/ yellow" respectively. Table 3 below summarizes the results of the CIELAB colour space test and the light transmittance of the food packaging film made from insect-derived materials.

In a study using locust protein powder as film material, researchers (Zhang, Fang, et al., 2022) found that the pigmentation increased with increasing protein content, giving the film a dark brown colour, and that the increase in glycerol content resulted in an increase in the a* and b* values. Interactions between plasticizer molecules and water molecules can alter the refractive index of the LP (locust protein) component and thus the transparency of the resulting film. Similarly, in research on insect protein mixed with chitin, as the mixing ratio of Black Soldier Fly protein powder was reduced, the degree of browning of the film lessened (Chandran et al., 2021). Two research articles using chitin extracted from crickets as food packaging films showed that these films were relatively dark. Researchers (Malm et al., 2021) found that the brightness values of cricket chitin films were lower than those of conventional commercial shrimp chitin films at the same degree of deacetylation, as shown by the L* values in Table 3. This is attributed to the absence of dark (brown/yellow) pigments in shrimp chitin/chitosan, which is different from that of crickets in Orthoptera, a result of the different mechanisms that crustaceans use during the production of their exoskeletons. In addition, some researchers have observed that the

Table 2
Extraction and preparation of packaging films from insects.

Species of insects	Material extracted	Extraction method	Preparation method	Film formation & PH setting	Reference
Grasshoppers	Protein (gelatin)	Freeze-dried, degreased by hexane, alkaline dispersion and acid precipitation	5 %, 10 %, 15 %, 20 % (w/v) gelatin powder was stirred at 50 °C for 0.5 H, + 10 % glycerol	Casting 45 ℃	(Qoirinisa, Arnamalia, Permata, & Ramdani, 2022)
	Protein		+ Glycerol 45 % (w/weight of protein powders) + Xylose (5 %, 10 %, and 15 % (w/w)	Casting 40 ℃ pH 10	(Zhang, Zhou, Fang, & Wang, 2022)
Migratory Locust	Protein		~ 6 % (w/v) GP/SPI blends (Proportion 8/2, 7/3, 6/4) were dissolved in deionized water + Glycerol 45 % (w/w) of protein powders + Xylose 5, 10, 15 % (w/w) of protein powders.	Casting 50 ℃ pH 9/10/11	(Zhang, Fang, et al., 2022)
Cricket *(Acheta domesticus , Gryllodes sigillatus* and *Gryllus bimaculatus)*	Chitin and Chitosan	At 90 °C remove endogenous enzymes, at 55 °C protein was hydrolysed, centrifuge at 4 °C to obtain chitin, add 67 % w/v NaOH to vary the degree of deacetylation	Different degrees of deacetylation: 72 %, 76 % and 80 %. Chitosan solution (1 % w/v) by dissolving cricket chitosan in 1 % acetic acid (v/v) solution +glycerol 37.5 % (w/w chitosan) as plasticizer	Casting 50 ℃	(Malm, 2021)
	Chitosan	Sodium hydroxide to remove protein, sodium hypochlorite to decolorize, oxalic acid to demineralize	8 – 12 ml of film-forming solution containing 1:2 glycerol: chitosan (w/ w) per petri dish, 8.5 cm diameter	Casting Room temperature	(Jarolimkova, 2015)
	Protein	Full-fat or low-fat conditioning of insect powder with ethanol	SPI and full/low CF were formulated in mass ratios of 100:0 (standard), 85:15, 70:30, and 55:45 on dry matter basis.	HMEC Fed rate at 0.4 kg/hr and screw speed at 150 rpm	(Kiiru et al., 2020)
Maggot (Fly Larvae and Mealworm)	Chitin	Purification by Soxhlet extraction with hexane, positive pressure filtration with PVDF membrane. Sodium chloride removes protein, sodium hypochlorite decolorizes	Films (30 g/m2) were produced using a positive pressure filtration unit with a 0.45 μm PVDF membrane.	Hot-pressed at 100 °C + 70 bar for 30 mins or cold-pressed under a load of 0.012 bar and dried at room temperature. pH 3 or 7	(Pasquier et al., 2021)
Black Soldier Fly (*Hermetia illucens*)	Protein	Freeze-dried and milled, defatted with n-hexane.	Insect powder solution 4 % (w/w) and chitosan solution 1 % (w/w) were prepared in the ratio of (0:100, 70:30, 50:50 and 30:70) to film-forming solution, + a constant amount of Glycerin (0.5 ml)	Casting 25 ℃	(Chandran et al., 2021)
Large pine weevil (*Hylobius abietis L.*)	Chitosan	Oven dried and milled, 0.5 % NaOCl bleached, 2 M HCL demineralized, 2 M NaOH demineralized, deacetylated in hot NaOH	10 mg chitosan and 50 μl glycerol were mixed in 1 % acetic acid solution (10 ml) for 2 days, the experimental group was supplemented with 0.1 mg β-carotene	Casting 35 ℃	(Kaya et al., 2019)
Tenebrio molitor	Chitosan	Freeze-dried and milled, demineralization and deproteinization, and deacetylation to obtain chitin.	Chitosan (1 %, w/w) dissolved in acetic acid solution (1 %; v/v), + 30 % glycerol (w/w; based on chitosan content)	Casting Room temperature	(Saenz-Mendoza et al., 2020)
Periplaneta americana	Chitosan	Degreased with n-hexane, deproteinized in a hot alkaline bath, and desalted, bleached and deacetylated	Chitosan (1 g) was dissolved in 50 ml of 1 % acetic acid solution at room temperature, + 1 g glycerol	Casting 65 ∘C	(Chen et al., 2021)
Snails	Chitosan	Ozone disinfection and citric acid stimulating solution, stored at 4 °C	1 g of chitosan was added to 70 ml of A (1 % v/v) or L (1 % v/v) followed by 30 ml of snail solution to give 100 ml of chitosan-S mixture in a ratio of 70:30.	Casting Room temperature	(Di Filippo , M. F. et al., 2020)

optical properties of the film are not only related to the source of the material, but also to the molecular weight and the degree of deacetylation of the chitosan (Jarolimkova, 2015).

In respect to the light transmittance of insect-derived films, the chitin film from *Hylobius abietis* has a transmittance of 70.1 % at 600 nm (Kaya et al., 2019), while chitin films from *Periplaneta americana* have a transmittance of 80.316 % at 600 nm (converted from the provided opacity and thickness values) (Chen et al., 2021). Chitosan films derived from crickets also have a light transmittance of about 70 %, even when different cricket species are used (Jarolimkova, 2015; Malm et al., 2021). Another study on *Hermetia illucens* (Chandran et al., 2021) tested a mixture of protein and chitosan films, giving opacity values from a 600 nm UV spectroscopy test. The opacity of the 100 % chitosan film as a control was 4.853 ± 0.40(λ/mm), while the mix with 70 % protein showed 10.082 ± 0.22(λ/mm). The films with half protein and half chitosan exhibited an opacity of 6.087 ± 0.48(λ/mm) and the opacity of the films with 70 % chitosan was 5.558 ± 0.44(λ/mm). Also, based on the film thickness and opacity equations during the test, the absorbance of each mix at 600 nm was calculated as 0.33971, 1.20984, 0.54783 and 0.50022. The transmittance (%) was 45.739 %, 6.168 %, 28.325 % and 31.607 % respectively. The opacity of the films increased with increasing protein composition. In addition to films prepared by ordinary casting methods, hot-pressing and cold-pressing methods to fabricate chitin nanofiber films (Fly Larvae and Mealworm) have also been used by some researchers (Pasquier et al., 2021). The transmittance of the Fly Larvae chitin fibre film when cold-pressed was 21 ± 2 %, while that of the hot-pressed film was only 1.8 ± 0.2 % (UV wavelength was 550 mm). Researchers in the study suggested that the impermeability of the films may be due to the high porosity. When the film is hot pressed, the rate of drying and moisture evaporation is much higher than that of overnight cold drying (Pasquier et al., 2021). Thus, the chitin nanofibers in hot pressing had little time to rearrange and entangle, leaving porous or defective structures in the stacked flakes. In addition, the films made of chitosan extracted from *Periplaneta americana* (Chen et al., 2021) exhibited excellent UVC (200–300 nm) light resistance, and the light transmittance was significantly lower than that of commercial shrimp chitosan films. That is considered to be because a large amount of the pigment deposited in the stratum corneum is bound to chitin (Chen et al., 2021).

3.2. Barrier properties

One of the primary functions of food packaging is to prevent or reduce moisture transfer between the food and the surrounding environment (Alamri et al., 2021), although barrier requirements depend on end use. In general, biodegradable polymers have some disadvantages relative to conventional packaging in terms of moisture resistance (Shaikh, Yaqoob, & Aggarwal, 2021; Wu, Misra, & Mohanty, 2021).

In ideal food packaging, a barrier to maintain a low level of oxygen and a controlled degree of moisture is essential in order to conserve dry, moist or textured products (Trajkovska Petkoska, Daniloski, D'Cunha, Naumovski, & Broach, 2021). These traditional packaging attributes also apply to packaging films using insect-derived materials.

Food packaging films are often tested for contact angle, which is one of the methods commonly used to measure the wettability of surfaces or materials (Huhtamäki, Tian, Korhonen, & Ras, 2018). Wetting refers to the study of the behaviour of liquids on substrates, whether it is diffusion or the ability of liquids and solids to form boundary surfaces. It was found in one study (Zhang, Zhou, Fang, & Wang, 2022) that the hydrophobicity of the film was increased by the soy protein isolate in the mixture material, and xylose as a cross-linking agent did not restrict access to the hydrophilic groups in the protein mixture. When 30 % cinnamaldehyde was added, the WCA (water contact angle) of the composite film was further increased to 38°, because CIN (cinnamaldehyde) conjugated with free amine groups to replace the hydrophilic groups with hydrophobic aromatic groups, thereby improving the hydrophobicity of the films. Another film, extracted from *Locusta migratoria* and also composed of protein, is hydrophilic (Zhang, Fang, et al., 2022). In general, WCA > 65° can be regarded as a hydrophobic surface, and < 65° is regarded as a hydrophilic surface (Feng et al., 2018). A rise in protein content increased the hydrophobicity of the surface, but when the glycerol content increased from 35 % to 45 %, the WCA decreased from 45.9° to 38.6°. Some researchers (Zhang, Fang, et al., 2022) believe that the added plasticizer glycerol tends to reduce the surface tension of the film, which is beneficial to the wettability of the film surface; the increased mobility of the polypeptide chain can promote water absorption and transport within the film. In addition, after the pH of the film-forming solution was adjusted from 9 to 11 in this study, the WCA decreased from 49.4° to 42.7°. The effect of pH on protein structure altered the WCA performance of the final films. These researchers (Zhang, Fang, et al., 2022) also mentioned that *L. migratoria* protein contains very low levels of cystine. The density of disulphide bonds in proteins is influenced by cystine. A low concentration of cystine leads to a low density of disulphide bonds in proteins, resulting in low-energy disulphide bonds within and between molecules that are more soluble, thus making the film itself more hydrophilic and soluble.

Unlike the cricket protein blend film, the shellac produced by lac bugs helped the original glycan film to have a higher WCA (Du et al., 2019), and this improvement may be attributed to the intrachain and interchain interactions between KGM (Konjac glucomannan) and SHL (shellac) molecules. The interaction between them forms a rigid structure. However, in Cricket chitosan films, the increased water contact angle may be a result of the possible presence of melanin (hydrophobicity) and possibly other residual components (Malm et al., 2021).

Table 3
Optical L*/a*/b* values and light transmittance of edible insect films.

Insect & material	Composition	Thickness (mm)	L*	a*	b*	Transparency (%)	Reference
Large pine weevil (*Hylobius abietis* L.)/Chitosan	10 mg chitosan and 50 µl glycerol in 1 % acetic acid (10 ml)	0.044 ± 0.001	/	/	/	70.1 at 600 nm	(Kaya et al., 2019)
Cricket/Chitosan	1:2 glycerol: chitosan (w/w) (8–12 ml)	0.061 ± 0.006	89.22 ± 0.67	-0.25 ± 0.04	12.07 ± 0.87	/	(Jarolimkova, 2015)
	cricket chitosan in 1 % acetic acid (v/v) + 37.5 % (w/w) glycerol	/	/	/	/	~70 at 600 nm	(Malm et al., 2021)
Black Soldier Fly (*Hermetia illucens*)/Protein	4 % insect protein & 1 % Chitosan (ratio 70:30) + 0.5 ml glycerol	0.12 ± 0.02	32.46 ± 0.11	5.04 ± 0.04	11.39 ± 0.04	6.168 at 600 nm	(Chandran et al., 2021)
Maggot (Fly Larvae and Mealworm)/Chitin	cold-pressed (0.012 bar) Fly Larvae chitin	/	/	/	/	21 ± 2 (550 nm)	(Pasquier et al., 2021)
Cockroach (*Periplaneta americana*)/Chitosan	Chitosan (0.5 g) + 25 ml of 1 % acetic acid + 0.5 g glycerol	0.080 ± 0.004	/	/	/	65.39 at 600 nm	(Chen et al., 2021)
Migratory Locust/Protein	7 % Locust protein + 40 % glycerol + pH 10	0.376 ± 0.042	11.542 ± 3.125	0.059 ± 0.087	0.535 ± 0.292	/	(Zhang, Fang, et al., 2022)

Table 4
WVP properties of insect derived food packaging films.

Top Performing Group	WVP (g/m s Pa)	Characteristics of the films	Reference
Grasshopper chitosan	1×10^{-10}	The microstructure of the CCF films appears to be rougher and more aggregated, leading to an increase in the length of the tortuous path for the diffusion of water vapour across the film. Ultimately, this will lead to a decrease in the water vapour permeability of the CCF, while the microstructure of the chitosan film is smoother and more compact, and the propagation path length of the water vapour will be shorter.	(Malm et al., 2021)
KSH5 (10 ml SHL solution mixed)	$\sim 1.134 \times 10^{-4}$	One characteristic is the presence of intermolecular hydrogen bonds between KGM and SHL, which may reduce the number of hydrophilic groups. Furthermore, the presence of ester bonds in the blended films contributes to the formation of compact structures. Also, the decreased WVP of the hybrid film with increasing SHL content is due to the presence of uniformly dispersed SHL in the composite structure, which may force water vapour to overcome the tortuous path through the polymer matrix, resulting in an effective path with increased diffusion length.	(Du et al., 2019)
T. molitor	4.77×10^{-11}	As the melanin concentration increased, the WVP value increased. The WVP value of *T. molitor* chitosan film was 13 % lower than that of *B. magna* chitosan film. These differences may be due to the Mw, as the Mw of *T. molitor* chitosan is higher than that of *B. magna* chitosan.	(Saenz-Mendoza et al., 2020)
"6–40–10"	$\sim 1.3 \times 10^{-11}$	Glycerol: Tends to aggregate with itself at high concentrations to increase chain spacing, thereby promoting the diffusivity of water vapour through the membrane and accelerating its transport. Alkaline pH changes protein structure. Growth of protein content increased WVP due to increased film thickness.	(Zhang, Fang, et al., 2022)
PaCSF	$(64.85 \pm 4.82) \times 10^{-11}$	Higher Mv (viscosity) may contribute to better water repellency. And since many water molecules escaped from the chitosan film after drying and storage, many binding sites for water could freely accept water molecules again.	(Chen et al., 2021)
70 %GP+ 30 %SPI	2.0×10^{-9}	The formation of the cross-linked network contributes to the dense structure of the film and reduces the permeability, but after adding xylose and CIN, there is no significant change in WVP compared with the 30 % SPI group. This suggests that the influence of the substrate on the WVP is more important than that of the crosslinker.	(Zhang, Zhou, Fang, & Wang, 2022)

Therefore, if melanin crosslinks are present, intramolecular interactions increase and lead to a decrease in the ability of the film surface to interact with water. The increased complexity of cricket chitosan may be an advantage of chitosan biobased food packaging. In the study mentioned above, using hot-pressing and cold-pressing techniques (Pasquier et al., 2021), the contact angles of the hot-pressed shrimp chitin nanofiber film and the cold-pressed fly nano-chitin film ranged from $29.0 \pm 0.3^\circ$ to $40.0 \pm 2.0^\circ$, respectively, which were highly hydrophilic. Compared with cold pressing, hot pressing gives a smoother film surface, which tends to lower contact angles. The films made from worms had slightly higher contact angles than the former. Due to the presence of a charge opposite to that of chitin, there are fewer water-interacting groups. Varying the pH between 3 and 7 did not affect the contact angle of the films.

The "water vapour barrier" property is important in a food packaging film, since the ability to block the passage of water vapour directly affects the shelf life of food. To delay food spoilage, the water vapor permeability value should be kept at a reasonably achievable low level (Bourlieu, Guillard, Vallès-Pamiès, Guilbert, & Gontard, 2009).

Table 4 lists the water evaporation rate performance of insect-derived films in the current research field, where molecular weight (Mw), cross-linking agent, film-forming material bulk and pH are all factors that affect water vapour permeability (WVP). Among the film-forming materials seen, the combination of glucomannan and shellac exhibited levels that were significantly different, by 10^{-7} to 10^{-6} orders of magnitude, compared to the other two materials (protein and chitin).

The last test related to water is the solubility or water absorption capacity of the packaging material in the water environment. A total of four groups of researchers investigated the water solubility of *Hylobius abietis L* chitosan films, *Tenebrio* and *Brachystola magna* insect chitosan films, Schisandra-containing cricket chitosan, and grasshopper protein films mixed with soybean protein (Kiiru et al., 2020; Saenz-Mendoza et al., 2020; Kaya et al., 2019; Zhang, Zhou, Fang, & Wang, 2022).

The results showed that the water solubility decreased after adding β-carotene to *Hylobius abietis L* chitosan films. The water solubility values of the chitosan control and chitosan-β-carotene films were recorded as 28.4 ± 1.21 % and 31.1 ± 1.34 %, respectively. For soil solubility, the weight loss values for chitosan control and chitosan-β-carotene films were 30.4 % and 23.5 %, respectively (Kaya et al., 2019). Chitosan films of *B. magna* (≈41.2 %) showed higher solubility (≈35.4 %) than those of *T. molitor*. However, these values did not show significant differences ($P < 0.05$), and insect chitosan films were more soluble than commercial chitosan films. The lower solubility of films of *T. molitor* chitosan can be explained by its higher Mw than *B. magna* chitosan. In addition to the above, the higher solubility in insect chitosan films may be due to the smaller intermolecular forces between chitosan chains. This is a result of ingredient residues (probably melanin) and the moisture content of the film. (Saenz-Mendoza et al., 2020) Some researchers believe that the water solubility and degree of swelling of cricket chitosan films are lower (WS 13.12 ± 3.42 %; SD swelling degree 1.15 ± 0.43) compared with commercial shrimp chitosan, but adding *Schisandra chinensis* extract slightly increases the degree of swelling (Jarolimkova, 2015). A possible explanation for the difference between shrimp and cricket chitosan is the lower degree of deacetylation and very low molecular weight of chitosan films, but there are no studies on the use of insect-derived chitosan or very low molecular weight/low deacetylation chitosan films. In the latest grasshopper protein film study, the authors found that WS with 10 % xylose was significantly reduced from 91 % to 46 %. But when the dosage reaches 15 %, the saturation effect occurs (Jarolimkova, 2015).

The choice of protein/chitosan concentration, pH, temperature and plasticizer determines solubility and water absorption capacity (Mihalca et al., 2021). WVP is directly affected by many factors (e.g., polymer chain mobility, thickness, film integrity). The main influence tending to increase water vapour permeability is the increased solubility of protein-based films and chitosan-based films.

3.3. Mechanical properties

Mechanical strength depends on the composition and process conditions when making biopolymer films (Gheribi, Gharbi, El Ouni, & Khwaldia, 2019). It is responsible for maintaining the integrity of the packaging during handling and storage. Mechanical properties include tensile strength, elongation, elasticity and Young's modulus (Assad, Bhat, Gani, & Shah, 2020). These can be improved and enhanced by different moulding conditions, processing parameters and the addition of plasticizers depending on the source and application. Table 5 summarizes the mechanical properties of existing films derived from insect components, including the tensile stress and elongation at break of the films.

Table 5
Tensile stress and elongation of several film materials prepared from insects.

Insect	Material	Tensile stress (MPa)	Elongation at break (%)	Reference
Fly Larvae and Mealworm	Chitin	89.6	10.6	(Pasquier et al., 2021)
Crickets	Chitosan	27.5 ± 3.3	49.6 ± 8.7	(Malm et al., 2021)
Laccifer lacca	Shellac	13.8	20.6	(Du et al., 2019)
Snail	Chitosan and Mucus	15 ± 4	13 ± 6	(Di Filippo , M. F. et al., 2020)
Tenebrio molitor and *Brachystola magna*	Chitosan	43.51 ± 0.91	66.28 ± 2.48	(Saenz-Mendoza et al., 2020)
Migratory locust	Protein	2.51	13.16	(Zhang, Fang, et al., 2022)
Grasshopper	Protein/Soy Protein Isolate/Cinnamaldehyde	3.38 ± 0.23	38.1 ± 3.1	(Zhang, Zhou, Fang, & Wang, 2022)

Some researchers (Zhang, Zhou, Fang, & Wang, 2022) found that films with xylose glycosylation were more likely to form dense structures with high molecular weights. When xylose was increased from 10 % to 15 %, TS (tensile stress) and EAB (elongation at break) decreased due to saturation effects. CIN has a negative effect on TS and EAB, especially when added at levels above 10 %. The effect of CIN on polymer mechanical properties depends on the substrate, and there is no particularly consistent trend. Some researchers (Zhang, Fang, et al., 2022) used the response surface design in their migratory locust study to obtain the TS and EB values of the films through the response surface formula. The plasticiser used has an increasing and then decreasing effect on TS, as the plasticising capacity of glycerine exceeds the threshold. For proteins, the difference in content affects the degree of aggregation between molecules. Of course, pH may lead to different degrees of accumulation by adjusting the charge properties of the protein network.

In an insect chitosan film study (Saenz-Mendoza et al., 2020), TS (≈42–44 MPa) and EM (≈737–1060 MPa) values in insect chitosan films were lower than those obtained in commercial chitosan films. In contrast, the E % (Elongation at break) in insect chitosan films (≈56–66 %) was higher than in commercial chitosan films (≈38–41 %). Insect chitosan films are more flexible than commercial chitosan films because insect films are about 15–25 % more ductile. The mechanical properties of the film may be due to residual melanin in the insect chitosan, as well as higher film moisture content.

When a group of researchers (Di Filippo , M. F. et al., 2020) studied the mechanical properties of chitosan films with added snail mucus, they found that the effect of adding snail mucus was similar to that of a plasticizer. At higher snail mucus concentrations, the increased ductility of the films can be attributed to the solution-polymer interaction. This reduces intermolecular interactions between polymer chains, promoting their sliding and fluidity, and improving overall ductility.

Additionally, the shellac-containing films were more stretchable in the tensile stress test. Possibly because of the low molecular weight of shellac, it can occupy the space between the macromolecules of the film, resulting in weaker connections between the film macromolecules and thus increasing the flexibility of the food packaging film (Du et al., 2019).

And in another study, Malm et al. (2021) found that compared with commercial shrimp chitosan films, cricket chitosan had similar or better tensile strength (TS), and the degree of deacetylation had no significant effect on the films. The elongation rate is basically not as good as that of commercial chitosan films. The author believes that because chitosan is covalently cross-linked with the residual melanin of insects, it can be compared with commercial shrimp shell chitosan in terms of TS. The molecular weight of chitosan prepared from crickets is smaller, so the elongation rate is basically inferior to that of commercial chitosan films.

Using a hot-pressing process, some researchers (Pasquier et al., 2021) found that the strength of the chitin nanofiber network is mainly affected by the assembly conditions (CP or HP) rather than by the properties of the chitin precursors. The hot press process greatly reduces the maximum tensile strain and toughness. S-ChNF decreased from 5.5 ± 0.7–1.9 ± 0.2 % and F-ChNF decreased from 5.0 ± 0.6–1.4 ± 0.1 %. The reason is that after hot pressing, the moisture in the film is reduced. Cold-pressed products have better mechanical properties. In addition, it was found that the cellulose composition in W-NF was different from that of conventional CNF. Possibly W-NF molecules are smaller or highly impregnated with pigments or are entangled.

3.4. Antibacterial properties

In a study using cinnamaldehyde as an antibacterial agent in cricket protein films (Zhang, Zhou, Fang, & Wang, 2022), due to high volatility, the composite film has antibacterial activity only when the amount of cinnamaldehyde reaches 20 %. In a study that also used crickets as research material, the experimenters compared the antibacterial properties of chitosan films and films to which *Schisandra chinensis* extract had been added (Jarolimkova, 2015). This author shows that the antibacterial activity of the pure chitosan film itself depends on a complex combination of different factors, including molecular weight, degree of deacetylation, pH, film moisture content and bacterial strain species. The experimenter designed the agar diffusion experiment because it was thought to more realistic for bacterial growth unless it was necessary to package beverages. And tests were performed on a variety of common strains (e.g., *Bacillus cereus, Escherichia coli, Listeria monocytogenes*). The combined effects of *S. chinensis* extract and cricket chitosan were found. Diffusion of the extract likely inhibited the initial growth, an effect supported by the slow diffusion of cricket chitosan after several days.

In contrast to adding antibacterial agents, some researchers (Chen et al., 2021; Kaya et al., 2019) have conducted experiments on the inherent antibacterial properties of the film made from insect components themselves. The performance of the *Periplaneta americana* chitosan film against common food-borne pathogens *Serratia marcescens* and *Escherichia coli* was significantly better than that of the commercial chitosan film. The *H. abietis* chitosan film has been studied with 28 different bacterial species (against 18 of which it had antibacterial properties) It has the highest activity against *Vibrio parahaemolyticus*, followed by *Acinetobacter baumannii* and *Streptococcus pneumoniae*, and relatively low activity against *Klebsiella pneumoniae* subsp.

4. Perspectives

Insects are already being commercialized as food in Western markets but they are not mainstream (Reverberi, 2021). They face many commercial challenges, including production costs, certifications and regulations, marketing communications, and retail distribution and consumer positioning. In the current situation, most countries or regions, because of dietary habits, cultural background and religious beliefs, do not accept insect products to a high degree. For example, this review finds that because the image of *Orthoptera* insects may be more acceptable to humans than other insects, mainly because they are mostly herbivorous and widely distributed around the world, this group of insects is the most frequently studied. However, the use of packaging derived from insects such as *Periplaneta americana* and fly maggots will be limited by people's traditional consumption concepts. This type of perception about a food product is very visceral and difficult to change and may require a large investment in marketing or a drastic change in public awareness, triggered by an external event, which in this case may be climate change.

Compared with the accumulated information that is available with respect to the safety of conventional animal and plant-derived materials, there are very few studies on insects as raw materials. Marshall, Dickson, & Nguyen, 2016 described in detail the types of infectious and intoxicating bacteria, viruses and parasites related to edible insects. Their paper also provides examples of careful insect food processing and preparation methods that ensure a safe, wholesome and nutritious product for consumers. Vandeweyer, De Smet, Van Looveren, & Van Campenhout, 2021 identify the top three bacterial pathogens associated with insects for food as *Staphylococcus aureus*, pathogenic *Clostridium spp*. and pathogenic species of the *Bacillus cereus* group. Contamination risk assessments for the insect species employed will need to be carried out in the future. Edible insect supply chains may require the implementation of detailed sampling plans and, in each chain, the prediction of potential hazardous microorganisms to gain insight into the quality of the overall supply chain. Otherwise, there may be a risk of contamination of insect-derived film-forming materials.

In addition, Alok Bang et al. (2021) have warned that, in general, industrial farming of insects for feeding purposes is based on production models that use large numbers of non-native insect species. These insect species have considerable invasive potential. If there are loopholes in the implementation of transportation and breeding, or a lack of adequate policies and production standards, there may be threats to regional or even global biodiversity (Bang & Courchamp, 2021). This issue must be taken into account when planning and instituting future developments in the farming of insects.

5. Conclusions

This review summarizes the results of the main scientific studies on the use of insects to prepare edible packaging that have been published over the past five years. The insect species currently receiving more in-depth study are crickets/grasshoppers/locusts in the order Orthoptera. This is likely because the image of Orthoptera is more acceptable to humans than that of other insects, because most of them are herbivorous and widely distributed worldwide. Rather than extracting proteins from insects as a substrate for making packaging films, researchers have preferred to extract chitosan from insects. Chitosan films generally have higher tensile stress than protein films. With respect to antibacterial properties, protein-based films can carry antibacterial agents in combination to achieve antibacterial effects, while chitosan films themselves have certain antibacterial activity.

The currently available insect-derived food packaging films still have much room for improvement with respect to various attributes. In particular, insect pigments have a positive effect on the light tolerance of packaging films and the protection of the wrapped food from light, but more research and design work are needed to make them more aesthetically acceptable. The hydrophilic, hydrophobic and solubility characteristics of the films are generally not as good as those of traditional plastic packaging. In addition, the protein concentration, pH, temperature and choice of plasticizer of the insect-derived material all determine the final solubility and hydrophobicity of the film. In terms of mechanical properties, differences in the film fabrication processes used will have a huge impact.

Ethics statement file

This research did not include any human subjects and/or animal experiments.

CRediT authorship contribution statement

S. Weng: Conceptualization, Methodology, Investigation, Writing – original draft. **I. Marcet:** Methodology, Writing – review & editing, Supervision. **M. Rendueles:** Methodology, Writing – review & editing, Supervision. **M. Díaz:** Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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