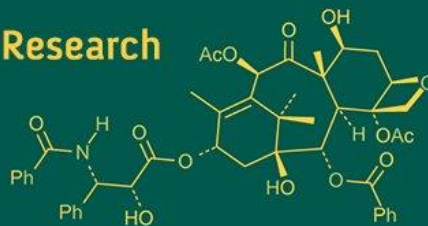
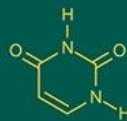
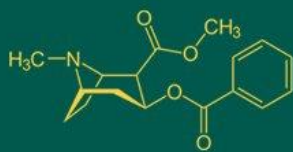


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Pravin Dalavi
Ph.D. (Scholar), Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu & Kashmir, India

Dnyaneshwar Ingole
Ph.D. (Scholar), Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Maharashtra, India

Karthikeyan P
M.Sc. (Scholar), Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu & Kashmir, India

Shahid Mulani
Assistant Professor, Shiram College of Agriculture, Paniv, Maharashtra, India

Priya Shinde
Ph.D. (Scholar), Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu & Kashmir, India

Siddhi Sawant
Assistant Professor, K. K. Wagh College of Horticulture, Nashik, Maharashtra, India

Arti Adhau
Ph.D. (Scholar), PGI-PHM, Roha, Maharashtra, India

Mangesh Kamble
M.Sc. (Scholar), Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu & Kashmir, India

Corresponding Author:
Pravin Dalavi
Ph.D. (Scholar), Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Jammu & Kashmir, India

Edible insect: Emerging non-convictional source of protein -A Review

Pravin Dalavi, Dnyaneshwar Ingole, Karthikeyan P, Shahid Mulani, Priya Shinde, Siddhi Sawant, Arti Adhau and Mangesh Kamble

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Abstract

The continuously increasing world's population along with the problems like climate change, limited land and water resource the pressure on food resources is increasing continuously. The population is now more aware about the balance diet. Due to the health benefits of protein the demand of protein rich food is increasing day by day. The consumption of meat and animal based products is increasing due to its balance amino acid profile. The cardio-vascular risk is associated with excessive meat consumption. The greenhouse gases are also emitted due to the livestock production. The vegetarian sources are deficient in the essential amino acid needed for body development. The insects are emerging as a new alternative source of protein and nutritious food and feed. The environmentally friendly and sustainable food is needed for future demand. The insect is ideal choice for the protein rich sustainable food for future demand. The edible insects are consumed in Asia, Africa and some parts of Australia. The species mainly used for consumption are crickets, grasshoppers, locusts, bees, beetles, wasps, ants, cicadas, caterpillars, termites, dragonflies, and flies. The edible insect contains all the essential amino acid needed for the healthy body along with the carbohydrate, vitamin and minerals. The different protein extraction methods are used to extract protein from edible insects. The consumption of insect is associated with some food safety concerns and allergies. There are regulations regarding edible insect use in food and feed.

Keywords: edible insects, insect protein, entomophagy, protein extraction methods, functional foods, sustainable nutrition, alternative protein sources, food safety, allergenicity, bioactive compounds

Introduction

The population of the world is increasing continuously according to the recent study the population of the world reached to 9 billion by 2025 which results in increasing demand of quality food. Along with the population rise, problems like climate change, excessive fishing practice, limited land for agricultural practices, etc. challenges the food and feed security (Gnana Moorthy Eswaran *et al.* 2022) [9]. The demand of protein is increasing now a days due to its health benefits. The awareness of population on protein rich diet and healthy lifestyle leads to increase in demand of protein rich food (Henchion *et al.*, 2017) [14]. The value of global protein ingredient market is USD 38 billion in 2019 and it is expected to rise at the rate of 9.1% from 2021 to 2027 (Ismail *et al.* 2020) [16]. The conventional sources of protein are meat, eggs, fish, dairy, pulses and cereals. Meat is one of the excellent sources of protein along with vitamins and minerals which is consuming worldwide. Meat contains all the essential amino acid needed for healthy body and have high net protein utilization and digestibility. The protein content in raw meat is 20-25% and in cooked it is 28-36%. But the over consumption of meat increases the risk of cardiovascular diseases to human. The greenhouse gases are also emitted in livestock production which adversely affect the environment (Henchion *et al.*, 2017) [14]. The chicken eggs are superior source of dietary protein. Protein is the main component of all the three parts of egg i.e. egg shell, egg white and egg yolk. Egg white is a major source of protein. The egg protein is high in nutritional quality and comprises of all the essential amino acid needed for development of human body. Egg protein have excellent digestibility. Egg white contains more than 50 proteins (Guha *et al.* 2019) [11]. The 100g of edible whole egg contains 12.58g of protein, 9.94g of fat, 0.86g of ash and 0.77g of carbohydrate (Li-Chan and Kim, 2008) [19]. The pulses and cereals are major source of protein for vegetarian and vegan population. Pulses contain approximately 10% moisture, 20-25% crude protein, 1-1.5% lipid, 60-65% carbohydrate and 2.5-4% ash. The pulses like soybean and lupin are exception it contains up to 45-50% of

Protein. The cereals are one of the important food which we consume daily. Wheat, rice and maize are the major cereals which globally consume in larger quantity and from which we get our dietary protein. Compared to other cereals oat has higher amino acid content and high quality of protein. Oats has high lysine content and low proline and glutamic acid content which make it an ideal choice for people having allergies and gluten intolerance problem. The concern of the vegan and plant base protein diet is nutrient deficiency due to unbalance protein source. Plant does not contain all the essential amino acid unlike animal base food. Pulses and cereals are deficient in essential amino acid content needed for human body. Pulses are deficient in sulphur containing amino acid, it also contains anti-inflammatory components such as hydrolase inhibitors and lectins which are the part of defensive mechanism of the seed and able to inhibit several biological functions in body (Henchion *et al.*, 2017) [14]. The milk majorly contributes the human nutrition, the bovine milk contains more than 200 types of protein. Along with the protein milk is also high in minerals like calcium, potassium, magnesium and sodium. Milk is rich in fat soluble vitamin like vitamin A, D, E and K (Mehta, 2015) [22]. The milk protein has higher digestibility and biological value. The milk protein is easily absorbed and utilized by human body (Rafiq *et al.* 2016) [31]. But many people are lactose intolerance due to which they are not able to drink milk (Swagerty *et al.* 2002) [37].

The insect is a non-conventional source of protein, it is alternative source of nutritious food. The future demand of food needed novel and environmentally friendly food, the insect is one of the ideal source for it. Insects are important nutritious food due to its high and valuable protein content (Mezes, 2018) [23]. Entomophagy has been practiced from thousands of years in the countries like Africa, Asia and some parts of Australia. Insect species which are majorly consume are crickets, grasshoppers, locusts, bees, beetles, wasps, ants, cicadas, caterpillars, termites, dragonflies, and flies. Insects are excellent source of protein because it contains all essential amino acid. Depending on the insect species, their life cycle stage the protein content of insect varies, it can range from 50% to 75% (dry basis). Along with protein insect also contains carbohydrate, lipids, minerals and vitamins (Liceaga, 2019) [18]. Edible insect has adequate amounts of vitamins like pantothenic acid, riboflavin, biotin and folic acid and minerals including iron, copper, magnesium, phosphorus, selenium, manganese and zinc (Gnana Moorthy Eswaran *et al.* 2022) [9].

Edible insects and their diversity

Edible insects are insects that are consumed by humans as food or used in animal feed due to their high nutritional value and sustainability. The practice of eating insects, known as entomophagy, has been followed for centuries in many regions of Asia, Africa, Latin America, and parts of Oceania. More than 2,000 insect species are reported to be edible worldwide, providing an important source of proteins, fats, vitamins, minerals, and bioactive compounds. Edible insects belong mainly to several insect orders, including Coleoptera (beetles), Lepidoptera (caterpillars and silkworms), Orthoptera (grasshoppers, locusts, and crickets), Hymenoptera (bees, ants, and wasps), Hemiptera (true bugs), Diptera (flies), and Isoptera (termites). Among these, beetles represent the largest proportion of edible insect species consumed globally. Crickets, mealworms, grasshoppers, silkworm pupae, and black soldier fly larvae are among the most commercially important edible insects (Rumpold, and Schlüter, 2013) [32]. Different insect species vary considerably in nutritional composition, taste, texture, and functional properties. For example, *Acheta domesticus* and *Gryllus bimaculatus* are valued for their high protein content, while *Tenebrio molitor* larvae are rich in lipids and essential fatty acids. Silkworm pupae contain bioactive peptides and minerals, whereas black soldier fly larvae are widely used in animal feed and waste bioconversion (Hunter, 2021) [15]. The diversity of edible insects is influenced by geographical location, cultural practices, climate, and biodiversity. Traditional communities often collect insects seasonally from forests and agricultural lands, while modern insect farming technologies now enable controlled large-scale production. Increasing interest in sustainable food systems, environmental conservation, and alternative protein sources has accelerated global research and commercialization of edible insects. Their diversity and adaptability make them promising resources for future food and feed security (Payne *et al.* 2016) [28].

Nutritive value of insects

Insect species used for human consumption are known as edible insects or insects as food. However, insect protein is said to have enhanced nutritional value because it contains all the Essential Amino Acids (EAAs), including Leu, Ile, Lys, Met, Thr, Trp, Phe, and Val, and the amount of EAAs is higher than the adult's daily FAO requirement for amino acids. Legume proteins have been widely used in many commercial food products. (Van Huis *et al.* 2013) [38]. The nutritional composition of insect given below in Table No 1.

Table 1: Edible insects and their nutritional composition

Common name	Order	Species	Material	Product manufacturing	Nutritional composition (Proximate composition) g/kg DM	References
Grasshopper	Orthoptera	(<i>Schistocerca gregaria</i>)	Powder	Bread making	Protein-353 ± 26 Fat-133 ± 2 Ash-39 ± 1 Dietary fiber-82 ± 8	Haber <i>et al.</i> (2019) [12]
Dung beetle	Coleoptera	(<i>Aphodius rufipes</i>)	Powder		Ash-2.74 ± 0.10 Crude protein-22.42 ± 0.10 Crude fat-30.50 ± 1.20 Crude fiber-28.12 ± 0.20	Paiko <i>et al.</i> (2012) [26]

					Carbohydrate-13.07 ± 0.00	
Sago Grubs	Coleoptera	(<i>Rhynchophorus ferrugineus</i>)	Powder		crude protein: 14.02%DW crude lipid: 58.7% DW ash: 2.5% DW carbohydrate: 24.7% DW	Chaijan <i>et al.</i> (2022) ^[6] AOAC USA, (1975) ^[2]
short-horned grasshopper	Orthoptera	(<i>Chondacris rosea</i>)	Powder		Crude protein- 68.883 ± 1.118 Crude fat- 7.883 ± 0.123 Crude fiber- 12.383 ± 0.778 Ash- 4.161 ± 0.301	Chakravorty <i>et al.</i> (2014) ^[7]
mole cricket	Orthoptera	(<i>Brachytrupes orientalis</i>)	Powder		Crude protein-65.740 ± 0.825 Crude fat-6.326 ± 0.290 Crude fiber-8.753 ± 0.228 Ash-4.326 ± 0.162	Chakravorty <i>et al.</i> (2014) ^[7]
mopane worm	Lepidoptera	(<i>Gonimbrasia belina</i>)	Dry insect Powder		Crude Protein- 56.95±0.04 Crude Fat- 10.0±0.2 Ash- 7.0±0.6 Carbohydrates- 7.8±0.5	Siulapwa <i>et al.</i> (2014) ^[35]
speckled emperor	Lepidoptera	(<i>Gynanisa maja</i>)	Powder		Crude Protein- 55.92 ± 0.04 Crude Fat- 12.1±0.2 Ash- 7.4±0.4 Carbohydrates- 10.7±0.3	Siulapwa <i>et al.</i> (2014) ^[35]
East African longhorn grasshopper	Orthoptera	(<i>Ruspolia differens</i>)	Powder		Crude Protein- 44.59 ±0.03 Crude Fat- 49.0±0.1 Ash- 2.2±0.1 Carbohydrate-8.4±0.4	Siulapwa <i>et al.</i> (2014) ^[35]
Termites	Blattodea	(<i>Macrotermes falciger</i>)	Powder		Crude Protein- 43.26±0.03 Crude Fat-43.0±0.2 Ash- 7.3±0.4 Carbohydrate- 32.8±0.6	Siulapwa <i>et al.</i> (2014) ^[35]

Extraction methods

1. Alkaline extraction: Alkaline extraction is the most commonly used method for insect protein recovery. In this process, defatted insect powder is mixed with an alkaline solution such as NaOH at pH 9-11. Under alkaline conditions, proteins become soluble and can later be precipitated at their isoelectric point (pH 4-5). This method provides high protein yield and is suitable for industrial-scale production. However, very high pH may cause partial protein denaturation (Yi *et al.* 2013)^[40].

$pH \approx 9 - 11 \rightarrow$ protein solubilization, $pH \approx 4 - 5 \rightarrow$ protein precipitation

2. Aqueous extraction: Aqueous extraction uses water as the extraction medium to dissolve soluble proteins from insects. The insect powder is mixed with water, stirred, and centrifuged to separate proteins. This method is simple, eco-friendly, and inexpensive, but the protein recovery is generally lower compared with alkaline extraction (Stone *et al.* 2019)^[36].

3. Acid extraction: In acid extraction, proteins are extracted under acidic conditions, usually at pH 2-4. Acid helps dissolve certain proteins that are soluble in low pH conditions. This method is useful for specific protein fractions, although the overall extraction efficiency is lower than alkaline extraction (Bußler *et al.*2016)^[5].

4. Supercritical CO₂ extraction: Supercritical carbon dioxide extraction is mainly used for defatting insects before protein extraction. CO₂ under high pressure behaves like both liquid and gas, effectively removing lipids without leaving toxic solvent residues. It is considered a green extraction technology (Rumpold and Schlüter 2013)^[32].

5. Microwave-Assisted Extraction (MAE): Microwave-assisted extraction uses microwave energy to rapidly heat insect tissues and improve protein diffusion into the solvent. This method is fast and energy efficient, but excessive heating may damage proteins (Pereira *et al.* 2023)^[29].

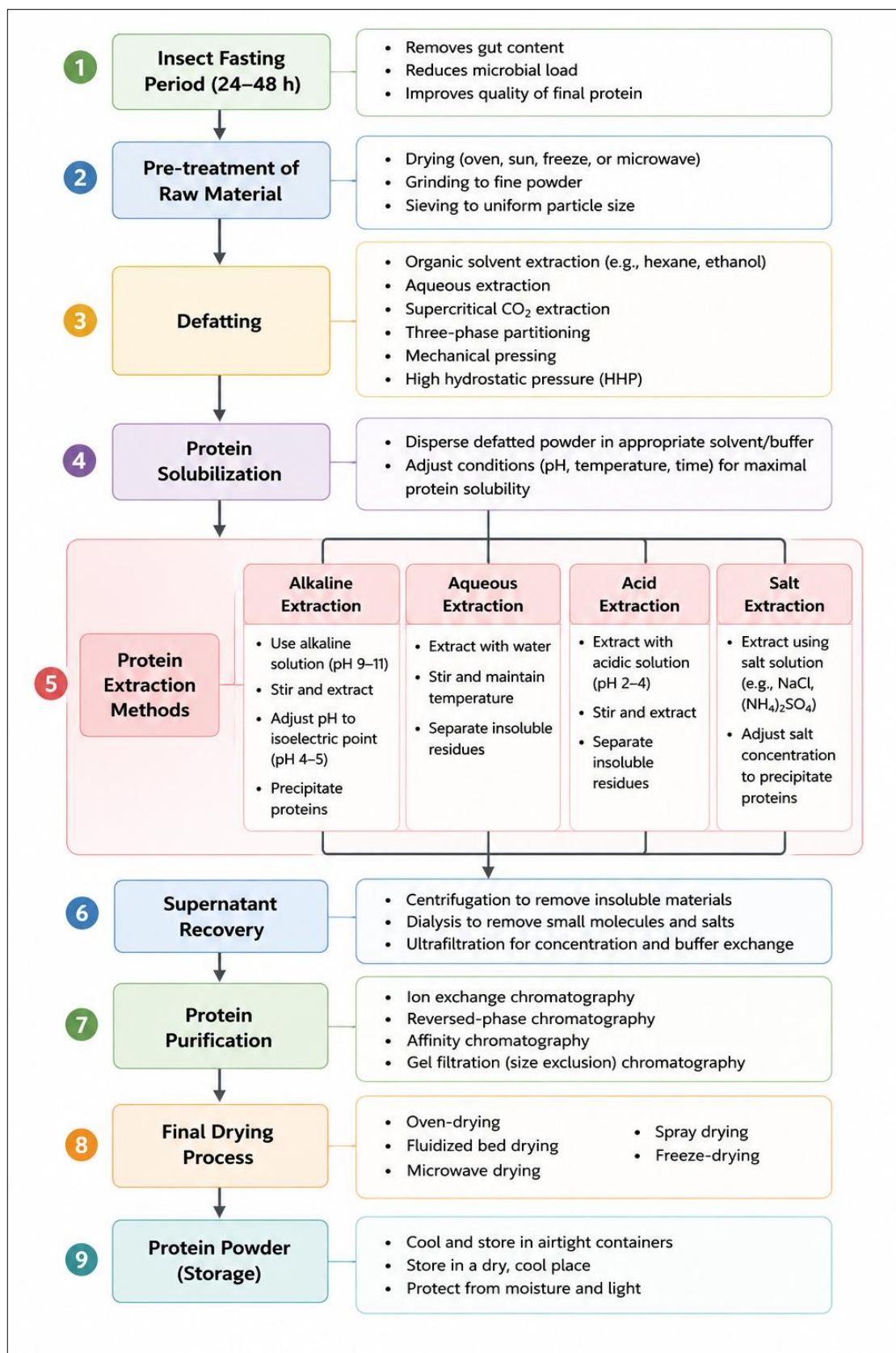


Fig 1: Extraction methodology flow chart

The flowchart illustrates the complete process of insect protein extraction and purification from edible insects such as mealworms, crickets, silkworm pupae, and black soldier fly larvae. The process begins with an insect fasting period of 24–48 hours before processing. Fasting helps to empty the digestive tract of insects, thereby reducing microbial contamination, removing unwanted gut materials, and

improving the cleanliness and quality of the final protein product. This preliminary step is important for producing safe and hygienic insect-derived protein ingredients. After fasting, the insects undergo pre-treatment of raw material. In this stage, insects are dried using methods such as oven drying, freeze drying, microwave drying, or sun drying to reduce moisture content and prevent spoilage. The

dried insects are then ground into fine powder and sieved to obtain a uniform particle size. Proper pre-treatment increases the efficiency of extraction by improving solvent penetration and protein release from insect tissues. The next step is defatting, which removes lipids present in insects because high fat content can interfere with protein extraction and reduce protein purity. Several methods are used for defatting, including organic solvent extraction using hexane or ethanol, aqueous extraction, supercritical CO₂ extraction, mechanical pressing, three-phase partitioning, and high Hydrostatic Pressure (HHP). Defatting improves protein concentration, enhances storage stability, and increases the functional properties of insect proteins. Following defatting, protein solubilization is performed. In this stage, the defatted insect powder is mixed with suitable solvents or buffers to dissolve proteins. Protein solubility depends on factors such as pH, temperature, extraction time, and ionic strength. Efficient solubilization is essential because it directly affects the amount of protein that can be recovered during extraction (Yi *et al.* 2013)^[40].

The flowchart then presents four major protein extraction methods: alkaline extraction, aqueous extraction, acid extraction, and salt extraction. Among these, alkaline extraction is the most commonly used industrial method because it provides high protein yield. In alkaline extraction, proteins are solubilized at alkaline pH values around 9-11 and later precipitated near their isoelectric point at pH 4-5. Aqueous extraction uses water as the extraction medium and is considered simple, economical, and environmentally friendly, although the protein yield is usually lower. Acid extraction is carried out under acidic conditions (pH 2-4) and is useful for extracting certain acid-soluble proteins. Salt extraction uses salt solutions such as sodium chloride or ammonium sulfate to improve protein solubility and recover salt-soluble proteins while maintaining their functional properties. After extraction, the soluble protein-containing

liquid known as the supernatant is separated from insoluble residues through supernatant recovery processes. Techniques such as centrifugation, dialysis, and ultrafiltration are commonly used. Centrifugation removes insoluble materials, dialysis removes salts and small molecules, and ultrafiltration concentrates the proteins and improves purity. These steps are important for obtaining high-quality protein fractions suitable for food and industrial applications. The recovered proteins then undergo protein purification to further enhance purity and functionality. Purification techniques shown in the flowchart include ion exchange chromatography, reversed-phase chromatography, affinity chromatography, and gel filtration chromatography. These methods help separate proteins based on charge, size, hydrophobicity, or specific binding properties. Protein purification is especially important when producing protein isolates, bioactive peptides, or nutraceutical ingredients (Bußler *et al.* 2016)^[5].

After purification, the proteins are subjected to the final drying process to convert them into stable protein powder. Common drying methods include oven drying, fluidized bed drying, microwave drying, spray drying, and freeze drying. Drying reduces moisture content, prevents microbial growth, and extends shelf life. Freeze drying is particularly useful because it preserves nutritional quality and protein functionality. Finally, the dried insect protein powder is packaged and stored under cool and dry conditions in airtight containers to prevent moisture absorption and oxidation. Proper storage maintains protein quality, nutritional value, and shelf stability for long-term use. Overall, the flowchart demonstrates a systematic approach for producing high-quality insect protein suitable for applications in food products, animal feed, nutraceuticals, and sustainable protein industries (Stone *et al.* 2019)^[36]. The different extraction methods used for protein extraction was given below in Table No 2.

Table 2: The different extraction methods used for protein extraction

Insect name	Method	Optimum condition	Yield	References
<i>Hermetia illucens</i>	Solvent alkaline solution extraction	Modified protocol (MP) (with conditions: Time 60 min, Ratio 15:1 alkaline solution to sample ratio, and Temp 40 °C) Optimized protocol [OP]) conditions time 59.43 min, alkaline solution to sample ratio 24.85:1.00, and temperature 52.23 °C.	Yield (64.44%)	Mintah <i>et al.</i> (2020) ^[24]
<i>Rhynchophorus phoenicis</i>	aqueous extraction method	pH 9.0-10.0	Yield (54%)	Mba <i>et al.</i> (2021) ^[21]
<i>Tenebrio molito</i>	Alkaline extraction method	pH alkaline	Yield (59.9%)	Azagoh <i>et al.</i> (2016) ^[3]
Cricket	Protein extract (NaOH) Protein extract (Ascorbic acid)		61.75% (NaOH) 69.69% (Ascorbic acid)	Amarender <i>et al.</i> (2020) ^[1]
Cricket (<i>Acheta domesticus</i>)	Alkaline solubilization	Ratio 1 : 50 cricket powder : 0.5 M NaOH, stir for 60 min; 2 mL of mixture are withdrawn at 15 min intervals and centrifuged (10 000g, 10 min at 20 °C). The supernatant was isolated and stored at 4 °C.	Yield (63.49%)	Machado <i>et al.</i> (2022) ^[20]
<i>Gryllus bimaculatus</i>	Ultrasound extraction method	Ratio -1 : 16 defatted insect coarse meal : distilled water containing 9.46 mM ascorbic acid, sonication was carried out for 20 min on ice at 20 kHz with a 75% AMP and pulsed every 3 sec. Then the aliquots were collected at 1, 2, 5, 10, 15, and 20 min. Samples were sieved through a stainless-steel filter (pore size of 1 mm) and filtrates were collected and freeze-dried.	Yield (37%)	Choi <i>et al.</i> (2017) ^[8]
(<i>Tenebrio molitor</i> , L.)	Alkaline solubilization method	Deionized water was added to a concentration of 600 g L ⁻¹ and the slurry was mixed for 60 s, pH 10.5 and stirred for 2 hour, then centrifuged (4000g, 10 min). The supernatant fraction was separated, frozen at -30 °C and freeze-dried at 0.2 mbar for 72 hour.	Yield (58.7%)	Purschke <i>et al.</i> (2018) ^[30]

Factors affecting protein extraction from edible insects

The efficiency of protein extraction from edible insects is influenced by several factors, including pH, temperature, extraction time, solvent concentration, particle size, and processing methods. These factors directly affect protein yield, solubility, nutritional quality, and functional properties of the extracted proteins. Among these parameters, pH plays a crucial role in protein solubilization. Most insect proteins exhibit higher solubility under alkaline conditions, typically between pH 9 and 12. Alkaline extraction disrupts protein-chitin and protein lipid interactions, thereby improving protein recovery. However, excessively high pH may cause protein denaturation and reduce functional quality. Acidic extraction methods are also used but generally provide lower yields compared to alkaline extraction. Temperature significantly influences extraction efficiency. Moderate temperatures enhance protein solubility and diffusion, leading to higher extraction yields. However, excessive heating can denature proteins, reduce amino acid quality, and impair functional properties such as emulsification and foaming. Therefore, controlled temperatures are preferred during extraction and drying processes. Extraction time and solvent-to-solid ratio are equally important. Longer extraction periods improve protein release from insect tissues, but excessive extraction may increase oxidation and degradation. Similarly, higher solvent ratios increase mass transfer and protein recovery, although excessive solvent use may reduce process efficiency and increase costs (Choi *et al.* 2017)^[8].

Particle size also affects extraction performance. Finely ground insect powder provides greater surface area, facilitating better solvent penetration and protein release. Defatting treatments using organic solvents or supercritical carbon dioxide are often performed before extraction because lipids may interfere with protein solubilization. Advanced extraction techniques such as ultrasound-assisted extraction, enzyme-assisted extraction, microwave-assisted extraction, and pulsed electric field technology have been shown to improve extraction yield and functionality. These methods enhance cell disruption, reduce processing time, and increase protein recovery while maintaining nutritional quality. Optimization of extraction conditions is therefore essential for obtaining high-quality insect protein suitable for food and industrial applications (Yi *et al.*, 2013)^[40].

Functional properties of insect proteins

Insect proteins possess several important functional properties that make them suitable ingredients for food formulations and nutraceutical applications. These properties include solubility, emulsifying capacity, foaming ability, water-holding capacity, oil-holding capacity, and gelation behavior. The functionality of insect proteins depends on insect species, extraction methods, processing conditions, and protein composition. Protein solubility is one of the most significant functional properties because it influences other characteristics such as emulsification and foaming. Studies have shown that proteins extracted from edible insects such as *Acheta domesticus* and *Tenebrio molitor* exhibit improved solubility at alkaline pH values. Alkaline extraction and enzymatic hydrolysis are commonly used to enhance protein functionality (Yi *et al.*, 2013)^[40]. Insect proteins also demonstrate good emulsifying properties due to their ability to stabilize oil water interfaces. This characteristic is useful in processed foods

such as sausages, bakery products, beverages, and protein supplements. In addition, insect protein concentrates have shown appreciable foaming capacity and foam stability, making them useful in aerated food systems. Water-holding and oil-holding capacities are essential for improving texture, juiciness, and flavor retention in food products. Mealworm and cricket proteins have shown high oil-binding capacities because of their hydrophobic amino acid composition. Furthermore, insect proteins can form gels under suitable heating and pH conditions, contributing to texture development in meat analogues and functional foods. The functional behavior of insect proteins can be modified by processing techniques such as ultrasonication, fermentation, enzymatic treatment, and defatting. These modifications improve their techno-functional performance and broaden their industrial applications. Due to their favorable nutritional profile and functional characteristics, insect proteins are increasingly considered promising alternatives to conventional animal and plant proteins in sustainable food systems (Yang *et al.*, 2025)^[39].

Food application and regulations

Human food applications are the ultimate higher-value use for mass-produced insects and insect-based substances. In addition, due to their high protein content and bioavailability, they can and have been used as fish and animal feed. In addition, the feed industry is arguably the first industry to utilize insect proteins extensively, followed by uses in human food. Insect proteins used in food must have a functional primary component (protein) that contributes to the product's safety, processing viability, flavour, texture, digestion, nutritional value, and product stability during storage. The ingestion of whole insects in fried or roasted forms is primarily found in Africa, Latin America, and East Asia in the past, suggesting that the use of whole insects is largely adapted to local taste and culture (Lamsal *et al.*, 2019)^[17]. Edible insect active compounds offer a wide range of favourable functional benefits on human health. Tumour suppression, immunomodulation, antibacterial, antioxidant, anti-inflammatory, management of blood glucose and lipids, lowering of blood pressure, regulation of gut bacterial flora, and cardiovascular protection are only a few of the benefits of insects. Researchers are particularly interested in the anti-cancer impact because it is one of the most significant effects of functional chemicals in insects. Many of the edible insects' ingredients have anti-cancer properties. Activated peptides, active proteins, trace elements, vitamins, chitosan, and other compounds are a few examples (Zhou *et al.*, 2022)^[41]. In addition to the many nutrients that edible insects provide, care must be taken to avoid the endogenous and exogenous risks associated with eating insects. Some insects are not safe to eat or are not edible, much like with food from plants and animals. Examples of endogenous risk factors include allergies and antinutrient compounds (Rumpold and Schluter, 2013)^[32]. Microorganisms that are connected to insects may affect how safe they are to eat. The hygienic parameters of the substrate and surroundings, namely the raising conditions, have an impact on the presence of harmful microorganisms. On farms or in the wild, pathogenic microorganisms such as bacteria (*Staphylococcus*, *Bacillus*, *Campylobacter*, *Pseudomonas*, *Micrococcus*, *Acinetobacter*, *Proteus*, *Escherichia*, and other

spore-forming bacteria), viruses, fungi, and protozoa can infect the insects (Mezes, 2018) ^[23].

Oxalate, tannin, phytate, and thiaminases are just a few examples of the toxins and antinutrients that must be taken into account while choosing insect species that are fit for human consumption. According to whether they are ingested by the insect from the feed or produced by the insect itself, toxins and antinutrients should be separated. The appropriate food safety regulations should be followed while creating insect rearing conditions. Therefore, it is important to maintain insects chosen for use in the production of food and food ingredients in a way that prevents or minimises the buildup of poisons, medicines, or antinutrients brought from the outside. Insect (glyco) proteins, which include the allergens found in insect venom

(such as phospholipase A and hyaluronidase), are the major allergenic structures in insects. These are primarily ubiquitous or "pan-allergenic" proteins that, in a nutshell, fall into the categories of enzymes (such as arginine kinase, triosephosphate isomerase, -amylase, trypsin, phospholipase A, and hyaluronidase) and cellular proteins (such as tubulin) as well as circulating proteins (such as hemocyanin and defensin). Although there hasn't been a comprehensive research of the many stages of insect development up to this point, around half of the entries in the arthropod database now deal with allergens in insects. Therefore, it is uncertain how much an insect's developmental stage influences its allergenicity. The different food applications of insect proteins was given below in Table No 3.

Table 3: The different food applications of insect proteins

Food Application	Description	Common Insect Sources	Benefits in Food Products	References
Bakery Products	Insect protein powder is added to bread, biscuits, cookies, muffins, and cakes to improve protein content.	Crickets, mealworms	Increases protein, minerals, and amino acids; improves nutritional quality.	Yi <i>et al.</i> 2013; Mintah <i>et al.</i> 2020 ^[24, 40]
Protein Bars & Snacks	Cricket or mealworm protein is incorporated into energy bars, chips, and snacks.	Crickets, black soldier fly larvae	High protein snacks with improved sustainability and nutritional value	Sharma <i>et al.</i> , 2024 ^[34]
Meat Analogues & Hybrid Meat Products	Insect proteins are mixed with plant or meat proteins in burgers, sausages, nuggets, and patties.	Crickets, mealworms	Improves texture, protein enrichment, and reduces environmental impact.	Yang <i>et al.</i> 2025 ^[39]
Pasta & Noodles	Insect flour is added to pasta and noodles to enrich protein and micronutrients.	Mealworms, crickets	Enhances protein quality and essential amino acid profile.	Stone <i>et al.</i> , 2019 ^[36]
Dairy Alternatives & Beverages	Insect proteins are used in protein shakes, smoothies, and dairy substitute beverages.	Cricket protein isolate	High digestibility and improved nutritional functionality.	Sharma <i>et al.</i> 2024 ^[34]
Extruded Foods	Insect proteins are used in puffed snacks and extruded cereals.	Mealworms, crickets	Improves texture, protein enrichment, and product functionality.	Gravel and Doyen, (2020) ^[10]
Functional Foods	Insect-derived peptides are incorporated into nutraceutical and health foods.	Silkworm pupae, crickets	Antioxidant, antimicrobial, antihypertensive, and bioactive properties.	Yang <i>et al.</i> 2025 ^[39]

Safety and allergenicity of edible insects

Edible insects are increasingly recognized as sustainable alternative protein sources; however, their safety and allergenicity remain important concerns for food applications. The safety of edible insects depends on species type, rearing conditions, feed substrate, processing methods, and storage conditions. Potential hazards associated with edible insects include microbiological contamination, chemical residues, parasites, heavy metals, and allergenic compounds. Microbial contamination is one of the major safety concerns because insects may harbor bacteria, fungi, yeasts, and spores during farming and processing. Pathogenic microorganisms such as *Salmonella*, *Escherichia coli*, and *Bacillus cereus* may be present if hygienic handling is inadequate. Proper thermal processing, drying, roasting, blanching, and freeze-drying are commonly used to improve microbial safety and extend shelf life (Belluco *et al.* 2013) ^[4].

Chemical safety is another important aspect. Insects can accumulate heavy metals, pesticides, veterinary drug residues, and environmental contaminants depending on their feed and habitat. Therefore, standardized rearing substrates and strict quality control measures are necessary for safe commercialization. Additionally, chitin present in the insect exoskeleton may affect digestibility in some individuals. Allergenicity is considered one of the most

critical challenges in edible insect consumption. Insect proteins show cross-reactivity with allergens from crustaceans, mites, and mollusks because they share similar allergenic proteins such as tropomyosin and arginine kinase. Individuals allergic to shrimp, crab, or dust mites may therefore experience allergic reactions after consuming edible insects. Reported allergic responses include skin irritation, respiratory symptoms, gastrointestinal discomfort, and anaphylaxis in severe cases. Processing methods such as enzymatic hydrolysis, fermentation, and heat treatment may reduce allergenic potential by altering protein structures. Nevertheless, further toxicological and clinical studies are needed to establish safety standards and allergen labeling regulations. International regulatory frameworks and good manufacturing practices are essential to ensure the safe utilization of edible insects in food systems (Pali-Schöll *et al.* 2019) ^[27].

Environmental and economic importance of edible insects

Edible insects are gaining global attention because of their environmental sustainability and economic potential as alternative protein sources. Compared with conventional livestock production, insect farming requires less land, water, and feed while producing lower greenhouse gas emissions. These advantages make edible insects promising

contributors to sustainable food systems and global food security. Insects possess high feed conversion efficiency, meaning they can convert feed into body mass more effectively than cattle, pigs, or poultry. For example, crickets require significantly less feed and water to produce the same amount of protein as traditional livestock. Additionally, many edible insects can be reared on agricultural by-products and organic waste streams, thereby reducing environmental pollution and supporting circular bioeconomy practices (Halloran *et al.* 2016)^[13].

Greenhouse gas and ammonia emissions from insect farming are substantially lower than those from conventional livestock. Insect cultivation also requires minimal land area, helping reduce deforestation and habitat destruction associated with animal agriculture. Furthermore, insects reproduce rapidly and have short life cycles, enabling efficient large-scale production with relatively low resource consumption. From an economic perspective, the edible insect industry is expanding rapidly due to increasing demand for sustainable proteins in food, feed, pharmaceutical, and nutraceutical sectors. Insect farming offers income-generation opportunities for rural communities, small-scale farmers, and entrepreneurs. The production of insect-based protein powders, snacks, animal feeds, and functional foods has created new commercial markets worldwide (Oonincx, and De Boer, 2012)^[25].

The use of insect meal in aquaculture and poultry feed is particularly important because it can partially replace expensive soybean meal and fishmeal. This substitution may reduce feed costs and dependence on limited natural resources. Moreover, advancements in processing technologies, automation, and regulatory approvals are supporting industrial-scale insect production. Despite these advantages, challenges such as consumer acceptance, legislation, standardization, and large-scale processing remain barriers to commercialization. Nevertheless, edible insects have strong potential to contribute to sustainable agriculture, environmental conservation, and economic development in the future.

Future challenges in insect protein research include improving consumer acceptance, ensuring food safety and allergen control, developing standardized and cost-effective extraction methods, enhancing functional and sensory properties, increasing shelf life and storage stability, and achieving large-scale commercial production. Additional challenges involve establishing international regulations, improving microbiological quality control, optimizing green extraction technologies, evaluating environmental sustainability, studying protein digestibility and bioavailability, and developing innovative insect-based food products with better market acceptance. Further research is also needed for efficient utilization of insect processing by-products and increasing public awareness about the nutritional and environmental benefits of insect proteins (Yi *et al.*, 2013; Yang *et al.*, 2025)^[39, 40].

Conclusion

Edible insect is one of the best non convectional source of protein which contains all the essential amino acid along with the fat, carbohydrate, vitamins and minerals. Edible insect protein is one of the source by which we can satisfy the continuously rising demand of protein of the new world. Edible insect protein has many application in food as well as feed. Along with its benefits and application in food it also

has concerns regarding to the food safety. Edible Insects also contain toxins, allergens, antinutrients and microbial load which can harm the health badly. The removal of toxins, allergens, antinutrients and microbes are essential before its application. Further study is required on the Edible insect protein for its safely consumption and application in food and feed products.

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