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# Insect Gut Microbiota and Their Role in Cellulose Degradation: A Brief Review

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

Insects are most versatile organisms in animal kingdom. They are about to live in different environment and are successful in habiting most of the niches. The adaptability of insects are due to the enzymes they produce and the symbiotic relationship they have with microorganisms. Cellulose is the fibre which provides strength to plant cell. It is flexible and strong and higher animals are not able to digest it on their own. Some bacteria, fungi and protozoa produce cellulase which breaks down the cellulose chain into shorter fragments enabling them to utilize the molecules for their growth. Many such bacteria live in symbiotic relationship with insects which are herbivores or omnivores as generally insects do not produce cellulase of their own. There are certain insects which have developed the capacity to produce cellulases but their numbers is too less than those which do not produce those enzymes. The current review is an attempt to provide information about the insects who harbour bacteria in their guts and are able to degrade cellulose. This review explores the critical role of cellulose degrading bacteria in the insect gut, focusing on their symbiotic relationships and potential applications in biofuels, waste management, and industrial processes. Highlighting diverse insect species, this study discusses enzyme production, bacterial interactions, and industrial utilization.

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*Keywords: Insects; insect guts; bacteria; cellulose; cellulase.*

## 1. INTRODUCTION

Insects, our everyday companions, have the greatest biological diversity in the planet. In the entire globe, this kind of creature can be spotted everywhere. This animal was the first to fly and quickly spread throughout the entire globe. Dipterans, which include houseflies, moths, butterflies, honeybees, and others, are insects with only one pair of wings that can fly whereas others cannot. Due to factors such as caste differentiation, evolution, and adaptation, certain insects, like silverfish, firebrats, jumping bristletails, and springtails, belong to a group known as Apterygotes. These insects are characterized by their lack of wings and inability to fly (Salces-Castellano et al. 2021). Insects can be classified as herbivorous, carnivorous, or omnivorous based on their dietary preferences (Potapov et al. 2022). Cellulase, which facilitates digestion, is either produced by or dependent on gut bacteria in some herbivorous and omnivorous insects. Both omnivore and herbivorous in general, herbivorous insects consume plant matter; the enzyme cellulase is required to break down the cellulose-based plant cell wall. Some insects can make this enzyme on their own, while others need the assistance of bacteria that break down cellulose (Martínez-Romero et al. 2021). Cellulase enzymes come in three different types: β-glucosidases, 1,4-β-Endogluconase, and 1,4-β-Exogluconase. With its help, this enzyme converts cellulose, which is found in plant cell walls, into beta-glucose, oligosaccharides, and polysaccharides. The bulk of the tough, flexible, and rigid cell wells found in plants are composed of cellulose, a lengthy chain of polysaccharides. Smaller molecules between 30 and 60 kDa can completely pass through the outermost protective layer of the cell membrane (Jayasekara and Ratnayake 2019). Insects are capable of producing the digestive enzyme that breaks down cellulose. Certain insect species, such as termites, silverfish, and cockroaches, have the capability of doing this. Certain insects, including as caterpillars, lesser grain, bombyx mori, and others, live on our planet and are supported by symbiotic bacteria found in their midgut (Barbosa et al. 2020). This enzyme is used extensively in industrial purpose, but day by day its utilization continues to increase.

**Cellulase:** A variety of enzymes are required for the complex process of cellulose breakdown in order to convert it into sugar. Cellulase is a class of enzymes that breaks down cellulose by hydrolysing the β-1,4-glycosidic linkage, a polysaccharide, into smaller monosaccharaides like beta-glucose, oligosaccharides, and polysaccharides. It is typically produced by bacteria, protozoa, and fungi (Machineni 2020). The cellulase enzyme is able to create a magnificent image in this field because of its substantial contribution to the global industrial market. On the contrary, it ranks third all enzymes used in industries. This enzyme is in high demand in the food and beverage, detergent, animal feed, pulp and paper, and textile industries. Cellulase enzymes are the way of the future in the biofuel business (Ejaz et al. 2021, Yoon et al. 2014). To further enhance its utility, researchers are focusing on boosting cellulase activity by isolating the enzyme from the gut of insects. These insects possess natural mechanisms to break down cellulose efficiently, making them an excellent source for studying and optimizing cellulase for industrial use.

**Classification of cellulase enzyme and mechanism:**

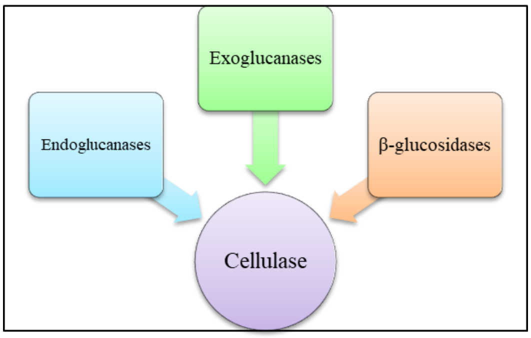


**Fig. 1. Classification of Cellulase enzyme based on their activity**

There are three primary types of cellulase based on substrate selectivity and the catalytic domains' mode of action (Fig. 1).

Endogluconase: β-1,4-glycosidic bonds, the internal linkage of cellulose chains is sporadically broken by 1,4-β-endoglucanase (EC 3.2.1.4), resulting in oligosaccharides chain and a new chain being released (Nandy et al. 2021) (Fig. 2).

Exogluconase: When 1,4-β-exoglucanase (EC 3.2.1.91) targets the reducing and non-reducing ends of microcrystalline cellulose, it releases either glucose which is known as glucanohydrolases or cellobiose referred to as cellobiohydrolase (Escuder-Rodríguez et al. 2018) (Fig. 2).

β-glucosidases: The crucial enzyme component of cellulase, β-glucosidase (EC 3.2.1.21), aids in the completion of the last stage of cellulose hydrolysis by converting cellobiose to glucose (Naraian and Gautam 2018). Fig. 2).

Each of these three enzymes works in concert with the others to hydrolyse cellulose in a sequential manner.

Two carboxyl groups in the catalytic centre mediate the hydrolysis of β-1,4 links in cellulose chains, and cellulolytic enzymes exhibit either retaining or inverting reactions upon hydrolysis of cellulose (Fig. 3), depending on their three-dimensional architectures. One carboxyl group functions as an acid and another as a base in an inverting enzyme. The carboxyl group exposes the C4 carbon at the cutting site by providing a hydrogen nucleus to the C4 terminal, which is the end of cellulose chains. A nearby water molecule's hydrogen nuclei are drawn to and accepted by the carboxyl group, and the hydroxyl ion that is created is transferred to the unchained C1 terminus—the end of cellulose chains that exposes the C4 carbon. In this instance, the new anomeric carbon's conformation differs from that of the β-1,4-bonding before to hydrolysis (Xie and Liu 2024).

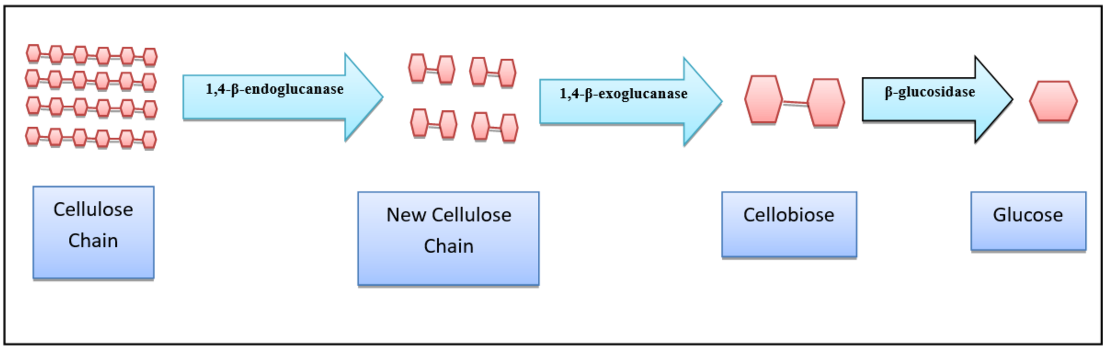


**Fig. 2. Cellulolysis Mechanism**

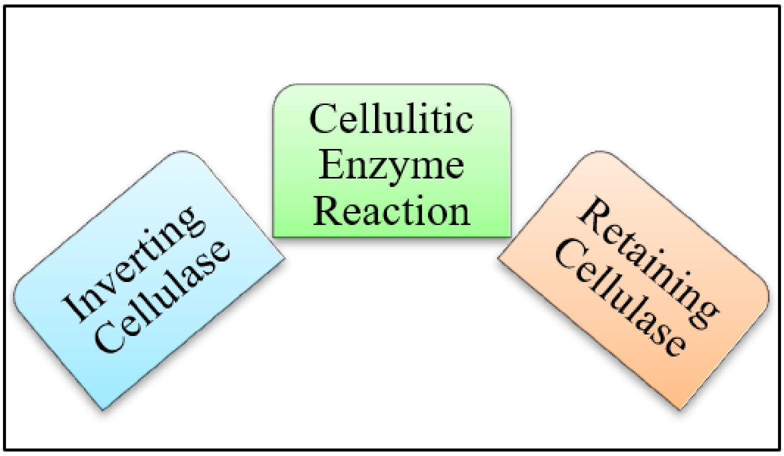


**Fig. 3. Cellulolytic enzymes reactions on hydrolysis of cellulose**

In the retention enzyme, the carboxyl group of the acid/base catalyst generates a hydroxyl ion from a nearby water molecule and transfers it to the C1 terminus, while also providing a hydrogen nucleus to the C4 terminus. Only the C1 nuclei of the cutting site are drawn to the other carboxyl group on the opposite side, which is always ionised. The original conformation is maintained by the newly produced anomeric carbon at the C4 terminal (Xie and Liu 2024).

## 2. INSECT BIODIVERSITY AND ROLES

There are thirty different kinds of orders in the entire world, and the main order of the insecta class is Lepidoptera, Coleoptera, Hymenoptera, Hemiptera, and Diptera (Lima et al. 2020). Among all, several insect orders possess the ability of breaking down cellulose and convert it into glucose. Numerous researchers have shown that the guts of some insect species exhibit cellulolytic activity. According to Carvalho et al. (2022), cockroaches, which are members of the Blattodea order, produces Bacteroides sp., Clostridium sp., and yellow strains of *Chryseobacterium* sp. in their guts. These microorganisms have a mutually beneficial relationship with cockroaches and aid in the breakdown of cellulose polysaccharide. From the research article of Pandiarajan and Revathy (2020), bombyx mori, a member of the Bombycidae family, is found to contain an extensive variety of harmoniously bacteria, including Serratia marcescens, Klebsiella pneumonia, *Enterobacter hormaechei*, *Lysinibacillus sp*., *Bacillus sp., Bacillus thuringiensis, Paenibacillus sp., Solibacillus silvestris, and Bacillus aryabhattai*. Bombyx mori provides these bacteria the survival support as well as assists in the digestion of cellulose. It is known from Nandy et al. (2021), the herbivorous insect caterpillar, which is a member of the Lepidoptera order, is capable of producing the digestive enzyme cellulase by way of intestinal microorganisms, albeit the bacteria responsible have not yet been discovered. Additionally, researcher have discovered that some insect species are capable of producing their own cellulase enzyme in their digestive tracts. They find that Silverfish, higher termite have the potential of doing this (Carrijo et al. 2023). Cockroach has both ability it can produce own cellulase enzyme in salivary gland and produce bacteria in its gut.The order, family, and species names of insects exhibiting cellulolytic activity are presented in Table 1 below.

**Table 1. List of the order of the insects who can degrade cellulose**

| Order | Family | Species Name | References |
|---|---|---|---|
| Zygentoma, | Lepismatidae | *Ctenolepisma lineata* | (Martin 1983) |
| Blattodea | Cryptocercidae | *Cryptocercus punctulatus* | (Martin 1983) |
| | Blattidae | *Periplaneta Americana* | (Martin 1983, Schapheer et al. 2024) |
| Isoptera | Mastotermitidae | *Mastotermes darwiniensis* | (Martin 1983) |
| | Kalotermitidae | *Kalotermes flavicollis* | (Martin 1983, Guariento and Demetz 2019). |
| | | *Neotermes bosei* | (Martin 1983) |
| | Hodotermitidae | *Zootermopsis angusticollis* | (Martin 1983) |
| | Rhinotermitidae | *Coptotermesformosanus* | (Martin 1983) |
| | | *Heterotermes indicola* | (Martin 1983) |
| | | *Reticulitermes flavipes* | (Martin 1983) |
| | Termitidae | *Macrotermes natalensis* | (Martin 1983) |
| | | *Nasutitermese phratae* | (Martin 1983) |
| Coleoptera | Buprestidae | *Chalcophora mariana* | (Martin 1983) |
| | | *Capnodis sp.* | (Martin 1983) |
| | Anobiidae | *Anobium punctatum* | (Martin 1983) |
| | | *A.striatum* | (Martin 1983) |
| | | *Ptilinus pectinicornis* | (Martin 1983) |
| | Scarabaeidae | *Oryctes nasicornis* | (Martin 1983) |
| | | *Sericesthis geminate* | (Martin 1983) |
| | Cerambycidae | *Acanthocinus aedilis* | (Martin 1983) |
| | | *Aegosoma scabricornae* | (Martin 1983) |
| | | *Cerambyx cerdo* | (Martin 1983) |
| | | *Ergates faber* | (Martin 1983) |
| | | *Gracilia cerdo* | (Martin 1983) |
| | | *Hylotrupes bajulus* | (Martin 1983) |
| | | *Leptura rubra* | (Martin 1983) |

| Order | Family | Species Name | References |
|---|---|---|---|
| | | *Macrotoma palmate* | (Martin 1983) |
| | | *Morimus funereus* | (Martin 1983) |
| | | *Oxymirus cursor* | (Martin 1983) |
| | | *Phymatodes testaceus* | (Martin 1983) |
| Hymenoptera | Siricidae | *Sirex cyaneus* | (Martin 1983) |
| | | *S. gigas* | (Martin 1983) |
| | | *S. phantoma* | (Martin 1983) |

**Table 2. List of the Insects' food preference**

| Species Name | Order | Family | Food preference | References |
|---|---|---|---|---|
| *Periplaneta americana* | Blattodea | Blattidae | Sweets, bakery products, fermented foods, paper, book bindings, wallpaper glue, fruit, old rice, putrid sake, dead or wounded cockroaches of their own or other species. | (Carvalho et al. 2022, Neupane 2022) |
| *Oxya chinensis* | Orthoptera | Acrididae | Rice leaves, stems that are delicate during the heading and vegetative phases of rice growth | (Ling et al. 2022) |
| *Helicoverpa armigera* orCotton Bollworm | Lepidoptera | Noctuidae | Cotton, tomato, chickpea, potato, brinjal and monocot crops such as maize, sorghum, bajra etc. | (Dar et al. 2021) |
| *Glenea cantor* | Coleoptera | Cerambycidae | Bombax malabaricum trees, kapok trees. | (Su et al. 2024) |
| sirex woodwasp or *Sirex noctilio* | Hymenoptera | Siricidae | Wood of the tree prefer Pinus species. | (Adams et al. 2011, Li et al. 2021) |
| *Pararcyptera microptera* meridionalis | Orthoptera | Acrididae | Plant materials | (Ling et al. 2022) |
| *Gastrimargus marmoratus* | Orthoptera | Acrididae | Soft plantand partially decomposed materials, | (Ling et al. 2022) |
| *Calliptamus abbreviatus* | Orthoptera | Acrididae | Plant materials | (Ling et al. 2022) |
| *Ostrinia nubilalis* | Lepidoptera | Crambidae | Leaves and stalks of maize | (Li et al. 2022) |
| *Bombyx mori* | Lepidoptera | Bombycidae | Lettuce, Osage oranges, and white mulberry leaves | (Pandiarajan and Revathy 2020, Li et al. 2023) |
| White grub beetle or *Lepidiota mansueta* | Coleoptera | Scarabidae | Roots of grasses | (Handique et al. 2017) |
| *Locusta migratoria* | Orthoptera | Acrididae | Graminaceous plants | (Li et al. 2024) |

The dietary habits of different insect species vary; some are carnivorous, omnivorous, herbivorous, or detritivores, while others rely on parasites to get their energy needs met. Insects that consume plant matter, such as herbivorous and omnivorous species, use the enzyme cellulase to break down cellulose or depend upon symbiotic microorganisms for assistance. We can infer that insects' cellulose degradation process is influenced by their dietary preferences. The dietary preferences of insects which havecellulolytic activity are shown in Table 2.

## 3. ENZYMATIC DIGESTIVE PROCESSES IN INSECTS

The digestive systems of insects produce a variety of enzymes, including lipases, cellulases, trypsin, amylases, proteases, and chymotrypsin-like enzymes, to deal with the incoming food material. Cellulase enzyme is only produced by specific omnivorous and herbivorous insect species. A basic explanation of the digestive enzymes, locations, and their functions is provided in the table below (Table 3).

## 4. CELLULASE PRODUCING INSECTS

Since their digestive system are not capable to properly break down cellulose, all herbivorous and omnivorous insects avoid consuming it. Certain insect species possess the enzyme cellulase, and microorganisms that can manufacture it are able to convert cellulose into glucose. Cellulase is an enzyme that higher termites and silverfish can make in their own gut or salivary gland. The digestive tract of these insects has been deliberately changed, making them extremely unique. The cellulase enzyme, which is abundant in the environment and difficult to obtain, is produced by their special digestive system; other animals lack the ability to obtain an excess of this particular enzyme (Banerjee et al. 2022).

**Table 3. Chart of insects' digestive enzyme and their function**

| Digestive enzyme | Location | Function | Species Name | References |
|---|---|---|---|---|
| Amylase | Midgut | • Aids in insect development and progression by breaking down α-D-(1,4)-glucan linkages | Drosophila, True flies, Cockroach etc. | (Da Lage 2018) |
| Chymotrypsin-like enzyme | Midgut | • Helps to increase resistance power and assist insects to withstand in circumstances that are extreme | Larvae of the tobaccobudworm or *Heliothis virescens*, Cockroach, Locusta migratoria, *Tribolium castaneum* etc. | (Hemmati 2020, Johnston et al. 1995) |
| Trypsin | Midgut | • It is necessary for the beginning step of the degradation process of proteins.<br>• Insects may become dead if the activity of this enzyme decreases | Anticarsia gemmatalis, *Helicoverpa zea* etc. | (Hemmati and Mehrabadi 2020, Pilon et al. 2017, Volpicella et al. 2003) |
| Lipase | Midgut | • Aids in the production of fatty acids and the breakdown of food's fatty content. | *Samia ricini, Bombyx mori, Gryllus bimaculatus etc.* | (Zielińska et al. 2020, MsangoSoko et al. 2022, Weidlich et al. 2015) |
| Protease | Midgut | • Helps digest the peptide bond which found in protein-type diet insects.<br>• This enzyme produces the amino acids needed for improvement, the continuation of life, and the process of conception | *Gryllotalpa orientalis*, *Periplaneta americana* etc. | (Singh et al. 2020, Zheng et al. 2024) |
| Cellulase | Salivary gland, midgut, foregut, hindgut | • Break down the Cellulose which is a carbohydrate. | Cockroach, Termites, Mole cricket etc. | (Ling et al. 2022, EZIMA et al. 2024) |

**Silverfish:** The silver fish belongs to the Lepismatidae family; its genus is Lepisma, its order is Zygentoma, and scientists refer to it as *Lapisma saccharinum* because of its dietary habits. The entire world calls them silverfish since they have beautiful silvery light grey colour along with fish-like activity**.** To sense their surroundings, these tiny, wingless, ancient insects have a single set of antennae. This innocuous insect always tries to keep itself far away from light because it actually prefers darkness. Their favourite foods are those that contain starch and dextrin, such as carbohydrate kinds. These consist of books, carpets, coffee, dandruff, wallpapers, pictures, and plaster. Consume their own excrement, leather, and synthetic materials when they are extremely hungry. These insects simply need water to survive for extended periods of time (Joshi et al. 2020).

Compared to other insects, silverfish have a far simpler gastrointestinal mechanism. It has a glandular midgut, a smooth-walled hindgut and rectum, a proventriculus featuring advanced teeth, a thin-walled esophagus and crop, and Malpighian tubules that separate the midgut and hindgut. Silverfish's midgut is essential for the digestion of cellulose. In their unique midgut, it produces the enzyme cellulase. Gastric caeca, which resemble vessels are found in the glandular midgut, are variations that absorb minerals through food after complete the digestion process. A single layer of columnar cells with a rough boundary membrane makes up the midgut epithelium (Joshi et al. 2020).

**Termites:** Among the most prosperous insects on the planet are termites. They can consume a variety of organic materials. Cellulose, their primary dietary source, is found in wood, leaves, grass, humus, dung, and other vegetative materials. There are two kinds of termites: lower termites and higher termites. Termitidae, the largest termite family having 2,105 recognized species, is the higher termite family. The most unique termite group belongs to the Blattodea order, of which Isoptera is the infraorder and Neoisoptera is the nanorder (Ling et al. 2022).

Compared to other termites, higher termites have a far more sophisticated digestive system. The midgut, foregut, mixed segment, and hindgut contain the enzymes needed to break down cellulose. Compared to lower termites, higher termites have a more asidicforgut. The foregut of *Nasutitermes exitiosus* contains 19% of the cellulase. Termites that eat wood have two different ways of breaking down cellulose: one in the midgut and one in the hindgut. Higher termites have more cellulases in their midgut, which are used by the termite's salivary glands and midgut epithelium to break down cellulose. In the midgut, 59% of the cellulase is produced by *Nasutiterm esexitiosus* (Ling et al. 2022).

**Cockroach:** The omnivorous, sociable cockroach, which is a member of the Blattodea group, is frequently seen in human habitats. To get the energy they need, they eat things like bread, fruits, books, paper, dead insects, and more. Cockroaches have a highly developed digestive system, with the foregut, midgut, and hindgut being the three sections of its lengthy alimentary canal. Proteases, peptidases, and trypsin were produced during the midgut digestive action. In order to break down cellulose, the foregut and midgut produce another crucial enzyme with the aid of Bacteroides sp., Clostridium sp., and yellow strains of *Chryseobacterium* sp. (Guariento and Demetz 2019). Furthermore, the cockroach's salivary glands have the ability to generate the enzyme cellulase. Both are demonstrated by cockroaches, which can both generate their own cellulase enzyme and provide the perfect environment for bacteria to do so (Wada-Katsumata and Schal 2021).

**Symbiotic relationship between insects and bacteria:** The term "symbiotic" refers to a mutually beneficial relationship in which insects provide a favourable environment for bacteria, which in turn aid in the digestion of consumption of food and other processes that are essential for existence. The interaction between insects and their gut bacteria is crucial to their survival, and insects have a diverse microbial population in their guts. As a result of this interaction, insects have been successful and diversified. In addition to aiding in digesting, bacteria in the intestines also aid in detoxification as well as offering a robust barrier against infections. Examples of bacteria that are found in insects' guts and that also benefit them include Proteobacteria, Clostridium, Bacteroidetes, Betaproteobacteria, and others (Banerjee et al. 2022).

**Cellulase Producing Bacteria in Insects' gut:** The interaction between intestinal bacteria and the insects that host them is extremely complicated. This reciprocal relationship benefits both parties equally. The bodies of all animals exhibit this kind of relationship, which is also seen in insects. These microorganisms assist them in numerous vital processes, including the digestion of cellulose, which is facilitated by certain unique bacteria. Insects that are herbivorous or omnivorous frequently receive assistance from bacteria that can create the enzyme cellulase, which breaks down plant components like cellulose and lignin. Numerous insects take advantage from their gut microbes, which can specifically have the ability to break down cellulose. Examples of these insects include mole crickets, lower termites, cockroaches, bombyx mori, grasshoppers, caterpillars, smaller grain, and more. Herbivorous lower termites benefiting from Diplobacilli, Streptobacilli, and Staphylococci sp. (Xie et al. 2021), herbivorous cotton bollworm benefitting from Klebsiella sp. (Dar et al. 2021), herbivorous lesser grain receiving assistance from Staphylococcus Sp., Bacillus Sp. (Pandiarajan and Revathy 2020), and Enterobacteriaceae, Bacteroides, Staphylococcus, Streptococcus, and Bacillus providing support for grasshoppers (Gur Ozdal and Algu 2022). The gut bacteria that have a symbiotic relationship with them and are capable of producing cellulose enzyme through cellulose degradation are discussed in the table below (Table 4).

**Table 4. List of insects whose guts produce bacteria that break down cellulose**

| Species Name | Order | Family | Bacteria | References |
|---|---|---|---|---|
| *Periplaneta americana* | Blattodea | Blattidae | *Bacteroides sp. Clostridium sp. yellow strain of Chryseobacterium sp.* | (Carvalho et al. 2022, Neupane 2022). |
| *Oxya chinensis* | Orthoptera | Acrididae | *Bacteroidetes, Firmicutes, Epsilon bacteraeota, Tenericutes, Verrucomicrobia, Actinobacteria, Acidobacteria, Planctomycetes, and Rokubacteria.* | (Ling et al. 2022) |
| *Helicoverp aarmigera* or Cotton Bollworm | Lepidoptera | Noctuidae | *Klebsiella sp.* | (Dar et al. 2021) |
| Glenea cantor | Coleoptera | Cerambycidae | *Proteobacteria, Firmicutes, Cyanobacteria, Bacteroidetes, Actinobacteria and Patescibacteria* | (Su et al. 2024) |
| sirex woodwasp or *Sirex noctilio* | Hymenoptera | Siricidae | *Streptomyces spp. γ-Proteobacteria* | (Adams et al. 2011, Li et al. 2021) |
| *Pararcyptera microptera* meridionalis | Orthoptera | Acrididae | *Bacteroidetes, Firmicutes, Epsilon bacteraeota, Tenericutes, Verrucomicrobia, Actinobacteria, Acidobacteria, Planctomycetes, and Rokubacteria* | (Ling et al. 2022) |
| *Gastrimargus marmoratus* | Orthoptera | Acrididae | *Bacteroidetes, Firmicutes, Epsilonbacteraeota, Tenericutes, Verrucomicrobia, Actinobacteria, Acidobacteria, Planctomycetes, and Rokubacteria* | (Ling et al. 2022) |
| *Calliptamus abbreviatus* | Orthoptera | Acrididae | *Bacteroidetes, Firmicutes, Epsilon bacteraeota,* | (Ling et al. 2022) |

| Species Name | Order | Family | Bacteria | References |
|---|---|---|---|---|
| | | | *Tenericutes, Verrucomicrobia, Actinobacteria, Acidobacteria, Planctomycetes, and Rokubacteria* | |
| *Ostrinia nubilalis* | Lepidoptera | Crambidae | *Pseudomonas or Firmicutes* | (Li et al. 2022) |
| Bombyx mori | Lepidoptera | Bombycidae | *Solibacillus silvestris, Bacillus aryabhattai, Lysinibacillus sp., Bacillus sp., Bacillus thuringiensis, Paenibacillus sp., Serratia marcescens, Klebsiella pneumonia and Enterobacter hormaechei* | (Pandiarajan and Revathy 2020, Li et al. 2023) |
| White grub beetle or *Lepidiota mansueta* | Coleoptera | Scarabidae | *Citrobacter sp.* | (Handique et al. 2017) |

## 5. OVERVIEW OF INSECTS EXHIBITING CELLULOLYTIC ACTIVITY THROUGH GUT BACTERIA

**Bombyx Mori:**Bombyx Mori, frequently referred to as the domestic silk moth, is a member of the Lepidoptera order and is a member of the Bombycidae family. This insect is herbivorous and prefers to consume lettuce, Osage oranges, and white mulberry leaves (Pandiarajan and Revathy 2020, Li et al. 2023). This insect has a symbiotic relationship with cellulose-degrading bacteria that are located inside its midgut, which makes the midgut extremely important. *Solibacillus silvestris, Bacillus aryabhattai, Lysinibacillus sp., Bacillus sp., Bacillus thuringiensis, Paenibacillus sp., Serratia marcescens, Klebsiella pneumonia and Enterobacter hormaechei*, bacterias that break down cellulose, assists in the breakdown of cellulose derived from their preferred diet (Pandiarajan and Revathy 2020, Li et al. 2023).

**Mole Cricket:** The mole cricket, scientifically designated as *Gryllotalpa africana*, is a destructive agricultural pest that is a member of the Gryllotalpidae family in the order orthoptera. This insect exists within soil; during the summer it stays around the surface, and during the winter it descends to a depth of 0.8 to 1.2 meters. Potatoes, wheat, maize, barley, oats, sugar beets, rice, soy, vegetable crops, and grasses are among their favourite foods.This insect consumes a lot of cellulose from these foods, and in order to digest it, it needs the enzyme cellulase, which is produced by symbiotic bacteria that live within its gut. The cellulose-degrading bacterium *Acintobacter junii* is found in the intestinal tract of mole crickets. These bacteria aid the insect in breaking down cellulose and generating glucose product, which serves as its primary source of energy (Banerjee et al. 2020).

**Application of cellulase enzyme:** Despite the fact that cellulases have been used in commercial settings for over thirty years, both industry and academic research continue to be interested in this enzyme. Based on business volume, their extensive use in the textile and detergent industry, food processing industry, biofuel industry and paper processing industries placed them second in the global industrial enzyme market (Ejaz and Ghanemi 2021).

Paper and pulp industry: The world's largest industry is the paper and pulp sector. In this field, cellulase enzymes are extremely important. This enzyme is employed in pulp refinement, fibers biomodification, deinking, and bleaching. It aids in making softwood kraft mash more bleachable. The runnability, paper sheet, and trouble-free printing process are all enhanced by cellulase, either by itself or in combination with hemicellulose. Using cellulase and xylanase together is an incredibly efficient method of recycling garbage paper from old books, newspapers, and magazines etc. This procedure is called deinking. It causes either ethanol or newsprint to develop. Enhancing strength qualities, reducing tiny particles in the pulp, and improving fiber brightness and cleanliness are all possible with enzymatic deinking. In addition to preventing alkaline yellowness, Deinking uses cellulases at an acidic pH to alter the size of the ink particles (Nandy et al. 2021).

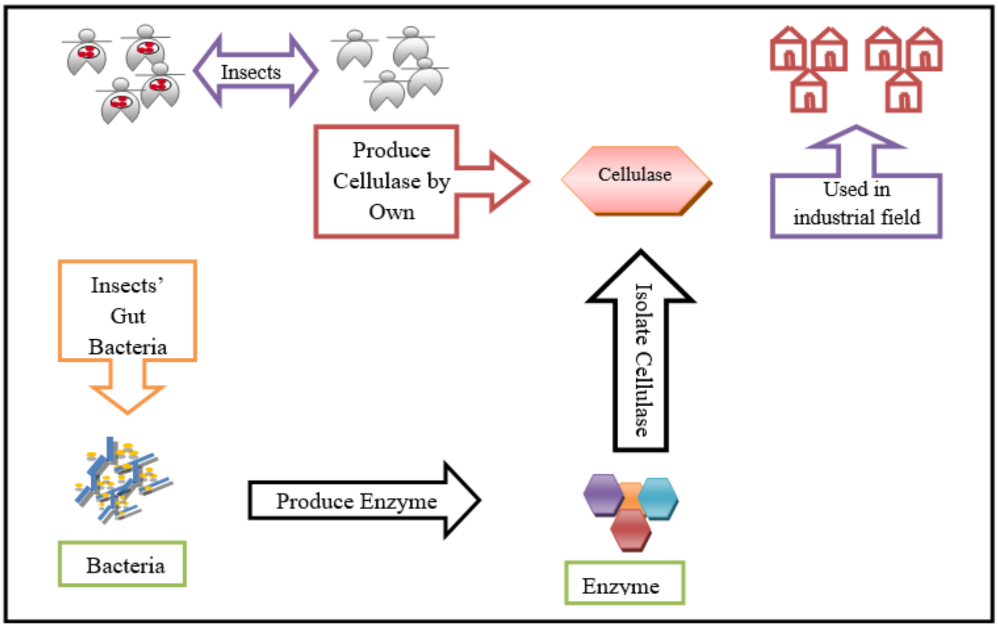


**Fig. 4. Key findings**

Food processing industry: When fruit businesses started making juice in the early 1930s, they had a lot of trouble filtering it to a suitable level of clarity. Low product yields and stability are their main issues. These challenges were addressed by the advancement of enzyme technology, specifically the development of pectinases, cellulases, and hemicellulases from food-grade microorganisms Aspergillus niger and Trichoderma sp. Fruit and vegetable juice extraction and clarity depend heavily on the macerating enzymes, which are a mixture of pectinase, cellulase, and hemicellulose. It can be applied on fruits and vegetables to enhance their flavour, texture, and stability. Olive oil is extracted from olive seeds using a mixture known as Olivex, which is made up of pectinase and low levels of hemicellulose, and cellulase (Nandy et al. 2021). An essential component of the wine industry is the cellulase enzyme. Maceration, or the removal of components from the solid parts of the grape, is aided by the exogenous enzymes hemicellulase, pectinase, and β-glucanase. The cellulase enzyme enhances the wine's quality and helps with colour extraction, clarity, and filtration. By hydrolysing glycosylated precursors into glucose and aglycones, β-glucosidases enhance the bouquet of wines (Ejaz and Ghanemi 2021).

Textile and Detergent Industry: The cellulase enzyme has the greatest success in the detergent and textile industries. It gives denim and jeans materials a softer look and enhances the biostoning process. This enzyme is used to bio-polise textiles such as cotton, linen, and viscose, which helps to keep cotton clothing looking smooth, brighter, and shiny by removing surface fibers and fuzz. Cotton clothing typically gets puffy and drab after several washings. The cellulase enzyme, which is added to household detergents, helps cotton get rid of puffy fibers and restores the original colour of clothing (Sarwan 2022).

Biofuel Industry: The plant matter is hydrolyzed by cellulase to provide glucose, a simple sugar. After that, it brewed to produce bioethanol or fuel. The biological transformation of renewable lignocellulosic material is the primary function of cellulase enzyme. Three phases make up the degradation of such biomass: pretreatment, enzyme-assisted saccharification, and fermentation (Ejaz and Ghanemi 2021). According to Menendez et al. (2015), it is anticipated that using cellulolytic bacteria to bioprocess biomass can lower process costs by 40%. Many nations have currently enacted laws pertaining to cellulosic ethanol and established goals to transition the biomass resource from cane or starchy sugars to materials based on cellulose.

The industry is currently experiencing a rapid increase in demand for the cellulase enzyme. Despite the fact that there are alternative ways to extract the cellulase enzyme, the bacterial source is the most promising because it is much easier to isolate and cultivate than fungi and protozoa. This is best accomplished by the microbes found in the gut of insects. This article focuses on the feeding preferences of the species exhibiting cellulolytic activity. The digestive enzyme and its role in those insects are also covered here. Additionally, this review paper briefly discusses gut bacteria that form symbiotic relationships with insects and aid in their digestion of cellulose. The insights gained from this study will enhance our understanding of insects that display cellulolytic activity, contributing to more efficient enzyme applications in industrial processes.

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

"The work was carried out in collaboration between all authors. Author a (paramita ghosh) designed the study. Performed the analysis. Author b (prashant shukla) wrote the first manuscript and author c (poulami maji) managed literature searches. Author d (megha maji) analysed the study and performed manuscript checks."

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