DOI : 10.58993/ijh/2025.82.2.1

Indian J. Hortic. 82(2), June 2025: 117-129

Review

Application of novel sustainable bio-plastic materials in horticultural production

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ABSTRACT

Bioplastics have emerged as a sustainable and safe alternative in the production of various horticultural crops, with applications ranging from nursery practices to packaging. Over the past two decades, increasing ecological awareness has driven significant advancements in the development and use of biodegradable polymers to address the issue of plastic waste. Biopolymers derived from renewable resources offer strong potential as eco-friendly substitutes for petroleum-based plastics. Research and practical applications have demonstrated the effective use of biodegradable plastics in horticulture, including mulching films, biodegradable pots, seed encapsulation, bioplastic granules for pest and disease management, and controlled-release systems for pesticides, fertilizers, and packaging materials. Notably, the first bioplastic was synthesized from a bacterium as early as 1926. However, despite their early discovery, synthetic polymers came to dominate due to their versatility and widespread industrial use, including in agriculture. The primary concern arises from their non-biodegradable nature, leading to persistent environmental pollution and the growing problem of microplastics due to excessive use and inadequate recycling. In response, the past two decades has seen renewed efforts to synthesize bioplastics from agricultural products and bio-waste to mitigate the negative impacts of conventional plastics. This review highlights current research and development in bioplastics, their applications in agriculture and horticulture, and their influence on crop productivity, soil and plant health, and produce quality.

Key words: Bio-degradable, agricultural waste, micro-plastic, environmental compatibility, sustainability.

INTRODUCTION

Plastics have become integral to modern agriculture, significantly enhancing productivity, sustainability, and operational efficiency. However, their widespread and often unregulated use has led to serious environmental challenges, particularly related to plastic pollution and microplastic accumulation (Fig. 1). Notably, India has emerged as the largest contributor to global mismanaged plastic waste, accounting for nearly 20% of global plastic pollution emissions. Although the country produces only about 3.5% of the world's total plastic waste, its inadequate waste management infrastructure has significantly amplified its environmental footprint. Alarmingly, global plastic production is projected to rise to 1,231 million metric tons by 2060, outpacing the growth rates of most other raw materials (Zhang and Natakani, 54). To mitigate the environmental risks posed by microplastics, ongoing efforts aim to improve recycling technologies, reduce plastic dependency, develop sustainable alternatives, and implement effective waste management systems. Addressing this issue requires a comprehensive, multi-pronged approach that includes industry participation, public awareness, and regulatory enforcement (Martin-Closas *et al.,* 25). In response to these concerns, bioplastics have emerged as innovative and sustainable materials that are both bio-based and biodegradable. These are derived from renewable resources such as sugarcane, starch, cellulose, cotton, bacteria, algae, and in some cases, polysaccharide-based nanoparticles. Agricultural and food industry by-products like banana peels, corn starch, potato starch, rice straw, sugarcane bagasse, and oil palm fruit bunches are increasingly being utilized as raw materials for bioplastic production (Martin-Closas *et al.,* 26). Natural microorganisms such as bacteria, algae, and fungi play a vital role in degrading these materials, reinforcing their ecological value. For instance, bioplastics produced from fruit waste, especially banana peels blended with glycerol, have demonstrated promising properties such as durability, flexibility, and user-friendliness. Due to their natural polymer composition, such materials perform well in degradation studies like soil burial tests, making them ideal candidates for environmentally responsible applications.

In horticulture and agriculture, biodegradable polymers offer distinct advantages, particularly in organic and sustainable farming systems. Their adaptability enables practical applications such as biodegradable mulch films, which eliminate the

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Fig. 1. Harmful effect of microplastics on environment, wild life and human health.

need for post-use retrieval and washing, allowing them to be ploughed directly into the soil (Zhang *et al.,* 51; Chung *et al.,* 9). These films are now increasingly customized to suit specific crops and environmental conditions. Additional applications of bioplastics in horticulture include protective films for fruit bunches, fastening devices, propagation and cultivation pots, fertilizer carriers, and pheromone traps, many of which require no post-use disposal. Though plastics offer significant benefits in agriculture such as versatility, durability, and cost-effectiveness there is increasing concern regarding their environmental impact, particularly due to pollution and accumulation of plastic waste. In response, efforts are underway to develop more sustainable alternatives and improve recycling practices to minimize the negative consequences associated with plastic usage in agricultural systems. Commonly used petrochemical-based plastics including polyethylene terephthalate (PET), polybutylene terephthalate (PBT), polypropylene (PP), polystyrene (PS), and polyvinyl chloride (PVC) are prevalent in everyday agricultural applications due to their affordability, lightweight nature, and excellent thermal properties (Kumar *et al.,* 22; Chisti, 8; Gadhave *et al.,* 14). However, mounting environmental concerns about plastic waste and its long-term ecological effects have accelerated the development of environmentally friendly alternatives. Among these, bioplastics have emerged as one of the most promising and innovative materials. With a lower carbon footprint, bioplastics offer a sustainable substitute to conventional plastics (Thompson *et al.,* 43). Biodegradable polymers such as polyhydroxyalkanoates (PHA), polylactic acid (PLA), and polyhydroxybutyrate (PHB) are being produced with performance characteristics comparable to traditional plastics, but with the added advantage of biodegradability, thus reducing dependence on petro-based plastics (Barnes *et al.,* 5). Despite the practical advantages of conventional plastics, their excessive and often unregulated use has triggered serious ecological concerns. These issues have intensified the search for eco-safe alternatives that minimize environmental harm. In this context, bioplastics stand out as a sustainable and scalable solution. A number of reviews have investigated their role in agricultural production systems, highlighting both their utility and environmental benefits. Comparative evaluations between bioplastics and fossil fuel-derived plastics focus on key parameters such as degradation behavior, ecological footprint, and waste management potential.

Therefore, the present review aims to consolidate existing knowledge on the diverse applications of bioplastics in horticulture, with a particular emphasis on sustainability, environmental compatibility, and their potential for large-scale implementation in future agricultural systems.

INVENTION OF BIOPLASTIC

The journey of plastics began in 1855 with Alexander Parkes, who invented Parkesine, a material derived from cellulose and considered the first man-made plastic. In 1907, Leo Baekeland introduced Bakelite, the first fully synthetic plastic, marking a significant milestone in industrial chemistry (Fig. 2). These early developments led to the rapid expansion of synthetic plastic production, transforming sectors

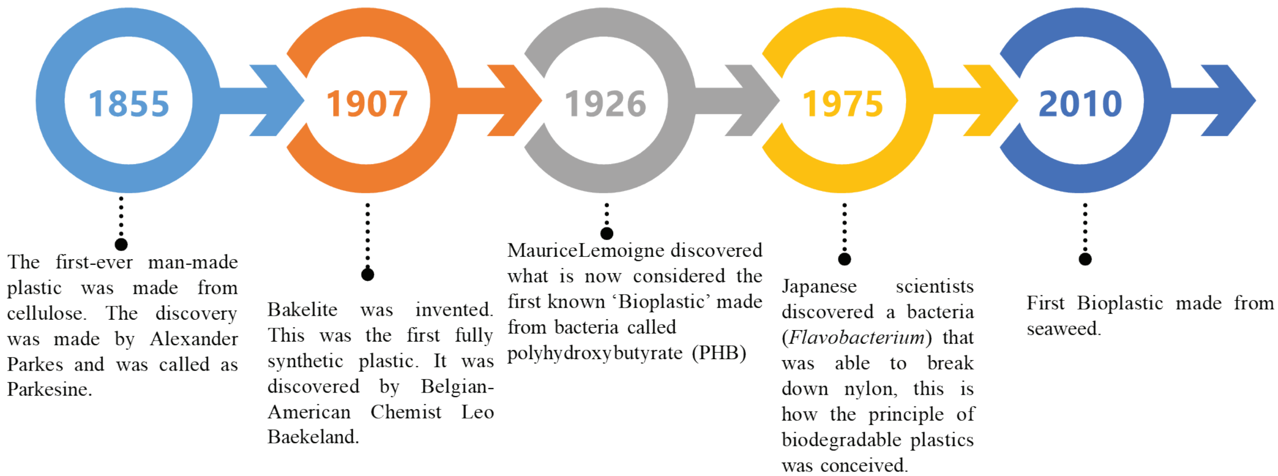

Fig. 2. Timeline of bio-/ plastic research.

such as packaging, agriculture, healthcare, and consumer goods (Zhang and Natakani 54). However, the environmental consequences of petroleum-based plastics soon became evident. In response, scientists began exploring bio-based alternatives, giving rise to bioplastics materials derived from renewable sources. The modern bioplastic era gained momentum in the late 20th century, with innovations like polylactic acid (PLA) and polyhydroxyalkanoates (PHA) offering biodegradable and sustainable solutions. Bioplastics are positioned as key materials for reducing plastic pollution and supporting circular economy goals (Garcia-Garcia *et al.,*15).

TYPES OF BIOPLASTICS

Bioplastics are classified based on their source materials and biodegradability. They can be derived from renewable biomass like starch, cellulose, and plant oils, and may be biodegradable or non-biodegradable depending on their chemical structure. Table 1 indicated that the biodegradable bioplastics that are dependent on natural materials are starch plastics, cellulose polymers, sugars, lignin and chitosan plastics, polylactic acids (PLA), and polyhydroxyalkanoates (PHAs), but also polyhydroxybutyrates (PHBs), polyhydroxyvalerates (PHV) and their copolymers in different percentages (PHBV). In detail, starch-based polymers are typically biodegradable polysaccharide polymers, an alternative to polystyrene (PS) materials, and are used in food processing, disposable tableware and cutlery, coffee machine capsules, and bottles. Starch is a cheap, renewable, and widely available biopolymer, but intermolecular tensions and hydrogen bonding prevent it from being treated as a thermoplastic material. Therefore, a plasticizer (urea, glycerol, sorbitol, or glycerin) is needed in addition to water to generate thermoplastic starch (TPS), a deformable thermoplastic polymer. Because of its cost effectiveness and abundance, TPS can be employed in the food packaging sector as a viable choice by increasing its qualities. TPS can be mixed with a variety of polymers, each with its own range of attributes and applications (Rasheed *et al.*, 33).

Table 1. Types of bio-based and fossil-fuel-based plastics.

Type	Plant	Microorganism
Biodegradable (bio-based plastic)	Cellulose and its derivatives (polysaccharide) Lignin Starch and its derivates (monosaccharide) Alginate (polysaccharide) Lipids (triglycerides) Wheat, corn, pea, potato.	PHAs (e.g., P4HB, PHB, PHBH, PHBHx, PHBV) PHF Bacterial cellulose Hyaluronan (Xanthan, Curdlan, Pullulan Silk (protein) gellan
Biodegradable (fossil-fuel based plastic)	Poly (alkylenedicarboxylate)s (*e.g.*, PBA, PBS, PBSA, PBSE, PEA, PES, PESE, PESA, PPF, PPS, PTA, PTMS, PTSE, PTT) PGA, PCL, PVOH, POE, Polyanhydrides (PPHOS)	
Non-biodegradable (bio-based/ fossil-fuel based plastic)	PE (LDPE, HDPE), PP, PVC PET, PPT, Pu, PC Poly(ether-ester)s polyamides, (PA 11, PA 410, PA 610, PA 1010, PA 1012) polyester amides, unsaturated polyesters Epoxy Phenolic resins	

APPLICATIONS OF BIO-PLASTICS MULCHING

Mulching is a generally utilized rural strategy that incorporates covering the dirt with a characteristic or manufactured material made into sheet to keep dampness in the dirt, keep weeds to save supplements, shield it from soil sicknesses, and give the most ideal developing circumstances for plants. Logical exploration has focused on biodegradable materials in light of polymers created from sustainable sources as a practical substitution for unrefined petroleum determined polymer intensifies in nursery, bundling, and other rural applications with an end goal to decrease the impeding ecological impacts of petrol-based plastics (Jandas *et al.*, 20). At the point when biodegradable polymers are discarded in bioactive settings, microorganisms, parasite, and green growth can separate them enzymatically and produce biomass, carbon dioxide, water or methane, contingent upon whether the climate is oxygen consuming or anaerobic all through the corruption cycle (Herrera *et al.*, 17). Most of industrially accessible biodegradable mulches are starch-based films made with thermoplastic handling methods. Blends with different polymers and additionally plasticizers are made to upgrade the feeble mechanical qualities of starch. Biosafe™ (Xinfu Drug Co., China), Eco-Flex® (BASF®, Germany), Ingeo® (NatureWorks, USA), and Mater-Bi® (Novamont, Italy) are a couple of the items that are presently accessible in the market that incorporate starch (Hayes *et al.*, 16). Notwithstanding starch, thermoplastic polymers like polylactic corrosive (PLA) and polyhydroxyalkanoates (PHAs) can be utilized in thermoplastic mulching films from now on. "Green" polymers, or polyhydroxyalkanoates, are promising biodegradable materials that are made by the maturation of sugars and additionally lipids, notwithstanding the way that microbes are the essential wellspring of PHAs (Fig. 3). Using non-woven textile technology, new experimental agricultural mulches made of mixtures of PLA and PHA have been created (Hayes *et al.*, 16; Riggi *et al.*, 35). Even if the thermoplastic polymers mentioned above are derived from renewable resources, their manufacturing process calls for the use of lubricants, plasticizers, and/or additives, all of which have the potential to have a negative environmental impact on both conventional and organic crop production.

In the Hawaiian Islands, asphalt paper mulch was widely used in the early 1900s to suppress weeds and conserve soil moisture in pineapple cultivation (Freeman, 13). Farmers adopted tarred paper treated with asphalt, which effectively inhibited weed growth, absorbed soil heat, and reduced soil evaporation. According to Coulter (11), this technique significantly lowered the cost of pineapple production in Hawaii by reducing the need for field labor and agricultural inputs. Without the development of paper mulch, large-scale pineapple cultivation on the islands characterized by a small population and reliance on manual farming methods would not have been feasible.

Banana

The creation of bio-mulching film from extra egg shells and banana strips is a new forward leap in the horticulture area (Table 2). A biodegradable plastic

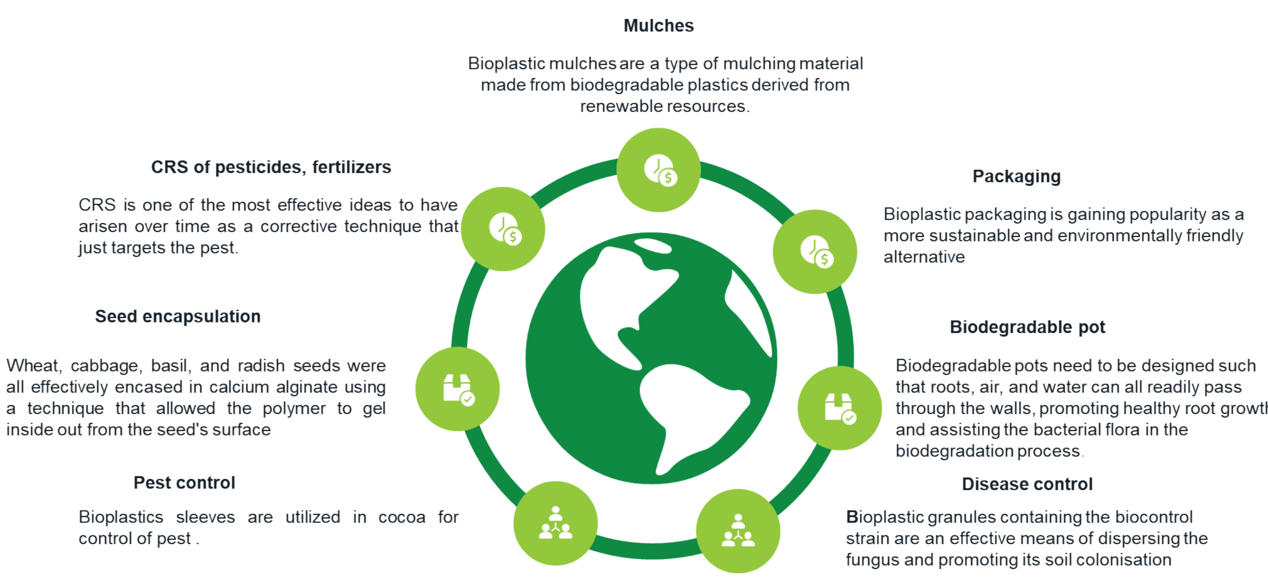

Fig. 3. Application of bio-plastics in agri- and horticulture.

Table 2. Horticulture crops biomass used for making bioplastics.

Horticultural crop(s)	Type of bioplastic	Compound(s) prepared	Common uses	Reference
Cococnut, berries, plantains, strawberry and pineapple	Polyhydroxyalkanoates (PHAs)	Starch, Fibre, acids and cellulose	Packaging, Medical devices, mulches, toys, utensils	Zhang *et al.* (51)
Mango, durian, fig, berries, watermelon, peach, pomegranate, papaya and melons	Modified thermoplastic starch	Starch	Packaging, utensils, toys, nursery pots	Yang *et al.* (50)
Kiwi, plum, apple, guava, passion fruit and grape, walnut	Polylactate (PLA)	Lactic acid, cellulose, acids, carboxymethyl cellulose	Packaging, disposable products, pots	Qian *et al.* (31)

film known as “bio-mulching film” can be utilized to further develop the local soil organization and dampness content, the two of which are vital for solid plant development (Hoque *et al*., 18). Eggshell is utilized as filler, extra banana strips as supporting fiber, and epoxy sap as the lattice to make the slender film. The slender film had a thickness of 0.10 to 0.15 mm. In a dirt entombment test, the epoxy/squander banana strip with poultry eggshell (EWE) 10% was exposed to bio-crumbling where surface harm happened, consequently worsening the actual property debasement (Nik-Yusuf *et al.*, 30).

Strawberry

Mulching and irrigation are the two crucial cultural techniques in the commercial cultivation of strawberries (Bilck *et al*., 7) produced biodegradable black and white films for use as mulch film by extruding blends of poly (butylene adipate-co-terephthalate) and cassava starch. The films' adsorption isotherms, mechanical characteristics, and water vapour permeability were measured. In order to assess the distinctions between commercial and biodegradable films, the average mass of the fresh fruit was evaluated. Five weeks after the PBAT film was placed on the ground, the structure began to exhibit minor fractures. Eight weeks later, the maximum tensile strength, elongation at break, and water sorption were all lower. The quantity and quality of the fresh produce were unaffected by these modifications to the film's structure.

Potential of paper mulches

The potential of mulches like, made of paper for use in vegetable production systems and stuff, was demonstrated (Monks *et al*., 28; Coolong, 10). The technique of rice direct sowing with paper mulches, originally proposed by Ueno *et al.* (45), was further refined by combining non-woven mesh with recycled paper sheets using a heat-melting adhesive. Rice seeds were placed in pre-punched holes at appropriate planting densities, allowing them to germinate and grow effectively. In this sense, the mulch can prevent weed growth, negating the need for pesticides and stuff, saving labour, requiring no specialised equipment, and eliminating the requirement for transplanting and stuff.

Biodegradable sprayable mulch film

In recent years, there has been a growing interest in the development and application of sprayable polymer-based frameworks for creating protective soil coatings. In agriculture, foliar application of pesticides and insecticides through spraying is a common practice (Smith *et al.,* 41). Similarly, film-forming polymers have gained attention in horticulture and crop protection as spray adjuvants and anti-transpirant films. These materials form artificial layers on plant surfaces, such as leaves, to help manage pest and disease pressures and reduce water loss. A variety of substances have been explored for this purpose, including oils, waxes, silicones, and an array of synthetic and natural polymers. Notable commercial examples include *Vapo-Gard* by Agspec, derived from natural pinolene, and *Moisturin* by WellPlant, a vinyl-acrylic formulation. These products exemplify the diverse approaches to enhancing plant surface protection through polymer films. Recent studies have highlighted the innovative strategy of continuously misting soil with biopolymer-based formulations to develop in-situ mulch films, rather than applying pre-formed films. This dynamic method offers potential advantages in adaptability, biodegradability, and environmental sustainability. Such approaches represent a significant advancement in the design of functional soil coverings, aligning with modern goals of sustainable agriculture and reduced synthetic input dependency (Tzika *et al*., 44).

Sodium alginate-based spray

Alginic corrosive, in its sodium salt structure, fills in as the critical underlying component in the intercellular walls of earthy coloured kelp or

Phaeophyceae. The algal tissue acquires expanded strength and adaptability inferable from the presence of alginic corrosive. As the tissue decays and changes into an earthy coloured mass, alginic corrosive is gotten from the grounded thallium. It expects the type of an insoluble gel, including a combination of calcium, magnesium, sodium, and potassium salts. Alginates, being direct and water-solvent polysaccharides, comprise this gel and are made out of different parts like the blended polymer (MG), polymannuronic corrosive (MM), and polygluronic corrosive (GG) (Immirzi *et al.*, 19).

Galactomannan-agar-based shower

Galactomannans are polysaccharides that are gotten from the seeds of insect bean gum (Grasshopper bean gum) and Leguminous plants (Guar-gum). These are heterogeneous sugars comprising of an essential chain of D-mannopyranose (Man) units connected by 1-4 connections, and D-galactopyranose (Lady) units connected by 1-6 connections. Reality, twofold supported gels might be created at exploratory settings much lower than those required for the gelation of single polymers because of the synergistic actual connection of galactomannans and agar, blended in water arrangement in an adequate extent and utilized for shower (Leja *et al.*, 23).

Polysaccharide polymers

Polysaccharides have acquired ubiquity in the plan of water-based items because of their various benefits like expense adequacy, non-poisonousness, biodegradability, biocompatibility, and sustainable starting points (Avella *et al.*, 3; Mormile *et al.*, 29). Notwithstanding, in spite of broad examination on the physical and synthetic properties administering their water opposition and mechanical strength, their restricted water obstruction and substandard mechanical properties keep on presenting difficulties. The water obstruction and mechanical properties of polysaccharides can be affected by different variables, including macromolecular redesigns, retrogradation and gel-arrangement processes, pH changes, and cross-connecting processes. Notwithstanding these continuous examinations, the low water opposition and poor mechanical properties persevere as constraints.

Chitosan-based spray

With regards to novel water-borne sprayable mulching plans, chitosan a straight polysaccharide comprising of (1-4)-2-acetamido-2-deoxy-ß-D-glucan (N-acetyl D-glucosamine) and (1-4)-2-amino-2-deoxy-ß-D glucan (D-glucosamine) units-is one more biopolymer that is frequently used and explored different avenues regarding. Since chitin is a homopolymer of 1-4 associated 2-acetamido-2-deoxy-ß-D-glucopyranose, it could be promptly blended from fractional basic deacetylation of chitosan, which is in this way not frequently tracked down in the climate (Fig. 4). Chitin is the essential primary part of the exoskeletons of scavangers, bugs, growth, and a few sorts of green growth It is likewise the third most pervasive polysaccharide tracked down in nature, after cellulose and starch (Marques *et al.*, 24).

BIODEGRADABLE POTS

Transplanting is the process of relocating a plant from its soil or block to earthen/plastic pots or a bigger container and is a widely accepted cultural technique in horticulture. The usage of biodegradable pots might be a good substitute for the use of thermoplastic pots made of petroleum (Sandak *et al.*, 37). Biodegradable pots need to be designed such that roots, air, and water can all readily pass through the walls, promoting healthy root growth and assisting the bacterial flora in the biodegradation process. Biodegradable pots offer multiple benefits, including efficient plant transplanting, easy field clean-up, and no need for pot disposal. They can be directly planted into the soil alongside seedlings or young plants, saving time, money, and preventing environmental contamination. To promote natural root growth and prevent tangling and binding, biodegradable pots allow roots to grow more freely in the growing medium, whether in an open field or larger containers like greenhouses (Miller *et al.*, 27). When buried in the soil, these pots undergo biodegradation, breaking down into biomass and inorganic compounds such as water and carbon dioxide (Fig. 5).

Chitosan has unique polycationic characteristics that set it apart from other abundant polysaccharides and natural polymers in general, it can be used. When applied to plants, chitosan functions as a fungicide to stop microbial infections as well as a nutrient to hasten plant germination and growth

Fig. 4. Application of sprayable biodegradable polymer membrane shortlyafter spraying and polymer treatment plots. (Courtesy: Santagata *et al.*, 38).

Fig. 5. Molds and casting biodegradable nursery plant pots. (Courtesy: Santagata *et al*., 38).

(Xanthos *et al.*, 47). Its insoluble nature makes it valuable for use in soil applications where it can withstand regular agricultural procedures like plant watering and ensure the fibres of pots remain bound together for the duration of their life cycle. Calcium chloride was used to crosslink sodium alginate, while polyglycerol filled in as a plasticizer.

SEED ENCAPSULATION

Wheat, cabbage, basil, and radish seeds were all effectively encased in calcium alginate using a technique that allowed the polymer to gel inside out from the seed's surface. When the sodium alginate solution was heated and the kind of alginate was carefully chosen, encapsulated seeds were produced in basil, cabbage, and radish plants that had soil emergence percentages that were comparable to those of untreated seeds (Sarrocco *et al.*, 39). The seeds were submerged for 30 min. at room temperature in a $CaCl_2.2H_2O$ 2M solution (Bashan *et al.*, 6). Following drying, the treated seeds were submerged for 20 min. in an agitated 1% (w/v) sodium alginate water solution that had been heat treated for 15 min. at 120°C. Thereafter, the encapsulated seeds were stirred for 20 min. with a magnetic stirrer in double-distilled water. Coated seeds (pellets) were placed on a single layer of Myracloth® and dried for 24 h at 30°C with ventilation. While bran and chitin added to the pellets at a rate of 12.5 g L^{-1} did not affect seedling emergence, adding these co-formulants at a rate of 25 g L^{-1} stopped the pellets from growing around the basil seeds. For several uses, calcium alginate has been widely used to encapsulate living structures. Calcium alginate has been used to ensnare viable cells of microorganisms to create alginate pellets or to coat real seeds for biological seed treatment. Alternatively, naked embryos have been used to create synthetic seeds. Entrapment in calcium alginate has the potential to provide a number of benefits, including the opportunity to add materials that improve the viability of immobilised live organisms and simple handling, protection against environmental conditions, and controlled release of entrapped material.

FERTILIZER ENCAPSULATION

Plants require triple super phosphate (TSP) fertiliser, which mostly consists of phosphorus. Since because phosphorus is highly soluble in water, it may be readily washed out of the soil and into rivers, leading to issues with algal blooms. Using fertiliser coated with a starch-chitosan-based substance is the answer to the issue. It was anticipated that the coated hydrogel bead fertiliser will exhibit controlled-release phosphorus behaviour and hold onto the phosphorus to enable extended soil retention. This study examined the phosphorus-releasing behaviour of a fertiliser based on starch and chitosan, as well as the materials' shape and water-uptake characteristic, or swelling (Zhang *et al.*, 52). A suspension of starch and chitosan was utilized to cover the business granular compost TSP. Showering was the methodology used to apply the coatings. The presence of chitosan on the covering framework makes the surface become permeable, while the accessibility of starch will in general diminish how much openings in the surface (Zhang *et al.,* 53). The enlarging concentrate on shows that the chitosan-starch coatings worked on the material's capacity to retain water. The extent of expanding ascends with expanding chitosan content. As per the examination of delivery conduct, the ideal covered compost has a mass proportion of 30:70 for chitosan to starch and a centralization of 1% for starch (Xu *et al.*, 48).

CONTROLLED RELEASED SYSTEM (CRS) OF PESTICIDES

The controlled delivered framework is one of the best plans to have emerged after some time as a remedial strategy that simply focuses on the vermin. Keeping up with the focus between the greatest and least levels from a solitary organization, hence keeping away from continued dosing is the point of CRS (Fig. 6). Quite possibly of the quickest developing field in science is controlled or brilliant pesticide dissemination, where researchers from different foundations scientific experts, substance engineers, formulators, and so forth are endeavouring to increment rural yield, while minimising negative natural impacts. The dealing with and security of these mixtures are further developed by these transporter frameworks including typified or entangled insect sprays (Rudzinski *et al.*, 36). Pesticides can be typified utilizing various strategies, including waxes (Yan *et al.*, 49), earth/ organoclay emulsions planned

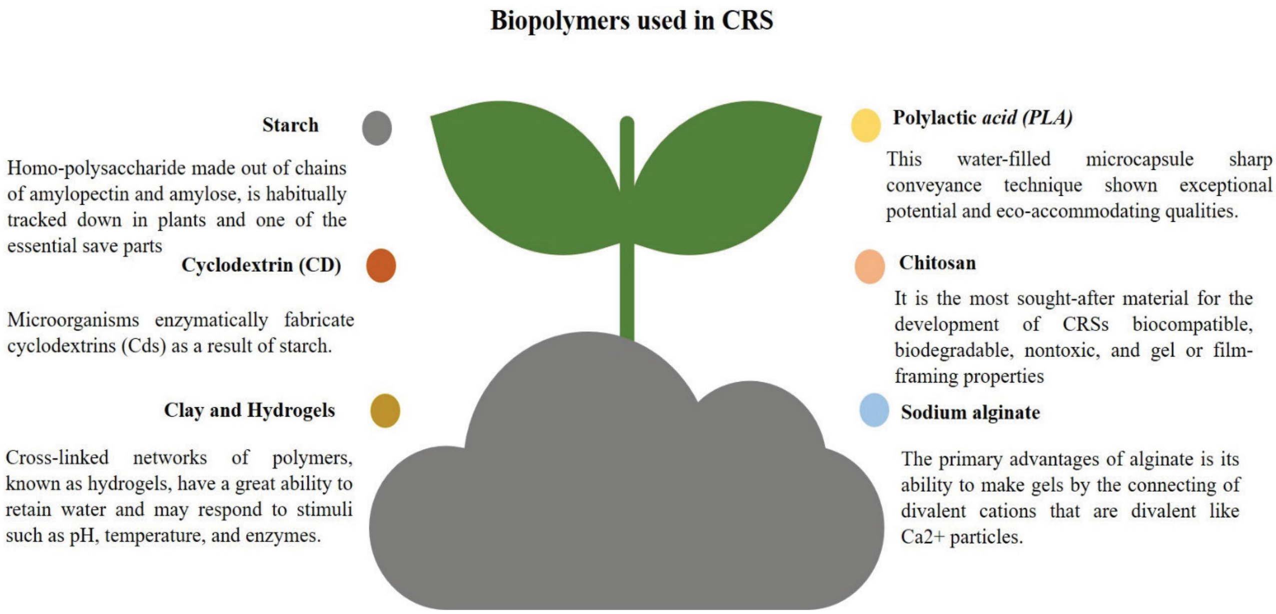

Fig. 6. Biopolymers used in CRS.

hydrogels (Rashidzadeh *et al.*, 34), engineered and regular polymers.

DISEASE CONTROL

Accinelli *et al.* (1) led examination to investigate new utilizations of bioplastic materials in controlling *Aspergillus flavus* in corn bioplastic granules containing non-harmful *A. flavus* NRRL 30797 spores. Research facility and handle tests have shown that these granules produced using the starch-based bioplastic Mater-Bi®, really convey the biocontrol strain. The granules have a reasonable timeframe of realistic usability and are not difficult to deal with, plan, and apply in rural regions. Moreover, this new bioplastic arrangement effectively lessens maize tainting with aflatoxin. The bioplastic framework is accepted to help the development of valuable microorganisms by going about as a food source and transporter for biocontrol parasitic specialists. Cereal grains have been normally used to present biocontrol (Fig. 7). The viability of the bioplastic-based plan stays stable for as long as 90 days when put away in a cool climate. The spores develop rapidly and the parasite develops quickly after hydration. The bioplastic granules are created in a modern setting utilizing maize starch, a sustainable asset. Notwithstanding natural advantages, the bioplastic granules offer pragmatic benefits, for example, simple taking care of and field use. By and large, the discoveries exhibit that bioplastic granules containing the biocontrol strain *A. flavus* NRRL 30797 are a powerful method for scattering the growth and advancing its colonization in soil.

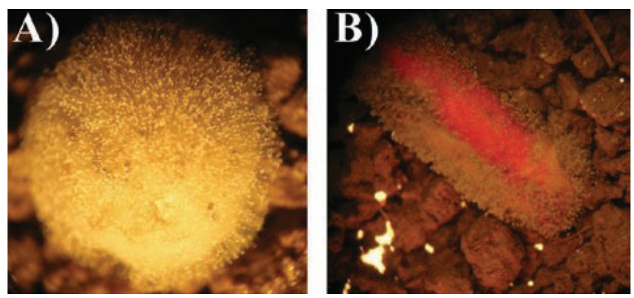

Fig. 7. After five days following field application, bioplastic granules were infected with the non-aflatoxigenic strain *Aspergillus flavus* NRRL 30797 (A). Development of *A. flavus* isolates on the bioplastic baits' surface when they are placed in soil (B). (Courtesy: Accinelli *et al.*, 1).

PEST CONTROL

Using biodegradable bioplastic sleeves on cocoa plants to manage *Helopeltis* species in Indonesian cocoa farms, *Helopeltis* sp. and *Conopomorphacra merella* are significant pests. *Helopeltis* species can destroy up to 82.2% of fruit and reduce seed output. The best way to manage the pest is to wrap and bag cocoa pods, which may cut down on pest infestations by 83%. When the pods are sleeved with traditional plastic, plastic waste is produced that is harmful to the environment. The purpose of this study was to evaluate the impact of employing biodegradable plastic on *Helopeltis* sp. infestation of pod sleeving. According to Dorner (12) biodegradable bioplastics based on starch may be broken down by microorganisms to release carbon dioxide. Additionally, starch-based bioplastic is not water-resistant. The bioplastic ages over time when it is left out in the elements. During this experiment, visible damage to the bioplastic was noted at the start of the sleeve application and every four weeks.

PACKAGING

Development in food packaging with the concept of incorporating active compounds into packaging materials or its surrounding conditions which referred as 'active packaging' evolved progressively today. This in novation has gained interests among researchers due to demand for prolong food shelf life, maintenance of food quality and food safety and enhanced food organoleptic properties (Table 3). Moreover, environmentally friendly active packaging and natural preservatives could be better options to overcome health concerns and environmental issues. The inclusion of natural compounds in biopolymer formulations had been suggested to improve the functionality of the packaging (Wang *et al.*, 46). Natural components recovered from wastes and by-products can be alternative sources for bio-based packaging production. For example, mango peels are considered as by-products from industrial processing or consumption of the fruit itself (Teixeira *et al.*, 42).

This indicates that out of all the polymers tested, PLA has the highest rigidity. Bioplastics' tensile elasticity decreased with thickness and temperature, meaning that their flexibility increased with rising temperatures (Kale *et al.*, 21). The impact on polymers' mechanical characteristics grew as the temperature dropped. The polymers PLA had the highest visible light transmission. PLA (25 µm) had water vapour transmission rate of 54.4 g/m^2 at 26°C and 51% relative humidity; in comparison, the water vapour transmission rates of LDPE (30 µm) derived from petroleum and biobased sources (Zhang *et al.*, 51). Water vapour could not easily pass through the plastic film because of its resistance to the transfer of water vapour. Bioplastics would be a suitable substitute for food packaging material (Zhang *et al.*, 52).

SUSTAINABILITY

Sustainable horticultural production with bioplastics offers an eco-friendly alternative to conventional plastics by reducing dependency on fossil fuels and minimizing environmental pollution (Fig. 8). Bioplastics, derived from renewable resources such as starch, cellulose, and polylactic acid, are biodegradable and compostable under suitable conditions (Garcia-Garcia *et al.,* 15). Their application in mulching, seedling trays, plant pots, and packaging enhances soil health, reduces plastic waste, and supports circular bioeconomy goals (Qian *et al.,* 31). Integrating bioplastics into horticultural practices aligns with sustainable agriculture principles, promoting resource efficiency and environmental stewardship (Shlush and Davidovich-Pinhas, 40).

CONCLUSION

Bioplastics degrade over varying periods, ranging from a few days to several years., depending on factors such as their chemical composition, degree of crystallinity, and surrounding environmental conditions.

Table 3. Properties and applications of common biopolymer films used in horticulture packaging.

Polymer	Film Properties	Applications	References
PBAT (Polybutylene adipate terephthalate)	Biodegradable; very tough and flexible; high elongation at break; moderate water vapor permeability	Waste bags, shopping bags, mulch films, ground nets, coated paperboards, fresh food packaging	Qiu *et al.* (32)
PCL (Polycaprolactone)	Slow biodegradation rate; flexible; opaque; chemically resistant to water; low tensile strength	Containers, bottles, retail bags, wrappings	Archer *et al.* (2)
PBSA (Polybutylene succinate adipate)	Relatively low permeability to CO_2 and O_2	Composting bags, controlled-release films, mulch films	Ayu *et al.* (4)
PLA (Polylactic acid)	Tailorable biodegradation rate; biocompatible; compostable under specific conditions; high processability; transparent; poor toughness	Mulch films and bags, compost bags, paper coatings, packaging and wrapping for fresh fruits, vegetables, salads, containers	Garcia-Garcia *et al.* (15)
PHAs (Polyhydroxyalkanoates)	Properties vary by monomer unit; fully biodegradable in various natural environments	Biocomposite films, edible films and coatings, paper coatings, drug delivery carriers, controlled-release systems, barrier films and coatings	Shlush and Davidovich-Pinhas, (40)

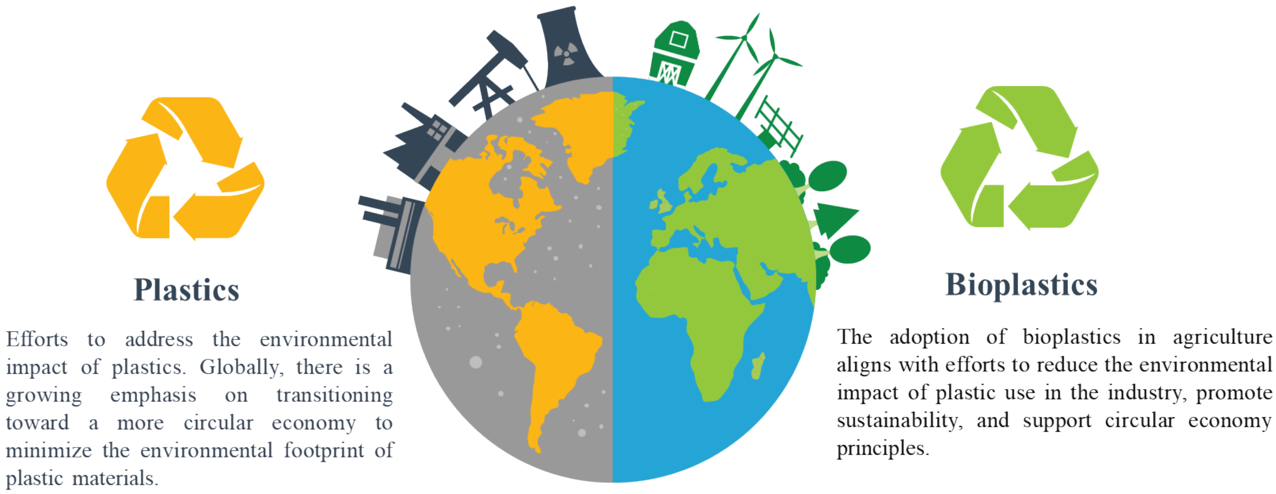

Fig. 8. Sustainable production of agriculture with bio-plastics.

Like conventional polymers, these characteristics have prompted increased focus in recent years on designing bioplastics that can effectively decompose. However, the environmental impact of bioplastics still remains to study in-depth. Biodegradable bioplastics, in particular, break down through microbial action into natural elements like carbon dioxide, water, and biomass. This degradation process is often aided by the presence of water and oxygen. This swelling breaks the material into smaller fragments, which are then readily digested by microorganisms in the soil. Despite their benefits, both traditional plastics and bioplastics have their own advantages and drawbacks. Therefore, a shift towards a 'zero-waste' approach in the horticulture sector is essential, where all by-products are efficiently reused or recycled. This strategy not only promotes environmental safety but also helps address pressing issues in sustainable food production. The global bioeconomy is currently undergoing a paradigm shift, driven by the rise of bioplastics. These materials emphasize the urgent need for an energy transition towards renewable resources. Advances in biopolymer technology are paving the way for a more sustainable plastic economy by reducing our dependence on fossil fuels, enabling carbon sequestration, and minimizing the ecological footprint of plastic use.

AUTHOR'S CONTRIBUTION

Conceptualization, writing original draft, review and editing (SKS); Writing and reviewing (MP).

DECLARATION

The authors affirm that none of the work presented in this review was influenced by any known conflicting financial interests or personal ties.

DATA AVAILABILITY

No data was used in the study. Rather the findings of the studies made in the related aspects of the review have been collected, collated and presented.

ACKNOWLEDGMENTS

The authors are thankful to the Director, ICAR-IIHR, Bengaluru and ICAR-IARI, New Delhi for the facilities and sharing the information.

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(Received : June, 2025; Revised : June, 2025; Accepted : June, 2025)