Use of Propolis in Sustainable Agriculture

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Propolis, also known as “bee glue”, is a resinous substance collected by honeybees from various plant sources. For centuries, propolis has been valued for its medicinal properties, primarily in human health applications. The effectiveness of propolis in controlling common pests and diseases that affect crops, suppressing postharvest illnesses of fruits and vegetables, stimulating plant defenses and increasing stress resistance, is reviewed herein.

propolis pesticides herbicides fungicides bactericides postharvest disease control

1. Introduction

Recent years have seen a significant global drive towards sustainable and ecological agricultural practices. This change is due to growing concerns about the harmful effects of synthetic pesticides and chemical fertilizers on ecosystems and human health [1]. Researchers and farmers are exploring alternative methods to increase crop productivity and ensure the long-term viability of agricultural systems. One such natural solution that is gaining more and more attention is propolis.

Propolis, also known as “bee glue”, is a resinous substance collected by honeybees from various plant sources. For centuries, propolis has been valued for its medicinal properties, primarily in human health applications [2]. However, its potential as a tool for sustainable agriculture has only recently begun to emerge as an area of study and research [3].

2. Propolis Chemical Composition, Origin and Biological Activity

Honeybees, *Apis mellifera* L., collect resinous materials from plants, such as exudates on buds and leaves, gums, resins, latices, etc., and mix them with wax to produce propolis. Bees use propolis as a building material to fill in holes and cracks in the hive, repair combs and strengthen the thin borders of the combs. Propolis also plays a crucial role in the so-called “social immunity” of the bee colony due to its ability to effectively suppress bacteria, fungi and viruses [4]. It serves as the “chemical weapon” of the bees.

For this reason, bee glue has been used for millennia, by ancient Greek and Roman physicians as an antiseptic and cicatrizing agent. Modern scientific research has confirmed propolis’ antimicrobial potential against fungi, bacteria and viruses, along with a variety of other beneficial pharmacological and health-promoting activities, including antioxidant, anti-inflammatory, hepatoprotective, immunomodulatory, antiallergic, antitumor and antidiabetic properties [2][5][6]. Nowadays, propolis is globally popular as a remedy and is readily available in its pure form or as an ingredient in over-the-counter preparations, cosmetics and health food supplements when combined with other natural products.

The antimicrobial properties of propolis are attributed to its chemical constituents, which are derived from plant resinous material. The most important bioactive propolis constituents, especially in terms of their antimicrobial and antioxidant properties, are considered to be phenolic compounds: flavonoid aglycones, phenolic acids and their esters and prenylated benzophenones [7]. Terpenoids also play an important role in the pharmacological properties of some propolis types [8].

The release of antimicrobial substances is a common phenomenon in the plant kingdom, with numerous plant species producing potent antimicrobial resins to protect their young leaves, vegetative tips and injured tissues [9]. Thus, the very origin of propolis from plant defense materials suggests its potential as a natural substance that can be used in agriculture to protect crop plants from different pests. Scientific research in this field started at the beginning of the 21st century, and interest in the use of propolis as an agrochemical has steadily increased in recent years [2].

An important feature of propolis is that its chemical composition varies greatly depending on the source plant(s). There are different types of propolis, each characterized by specific bioactive plant metabolites. As a result, the number of substances identified as propolis constituents now exceeds 800, but only a fraction of them can be found in a particular propolis sample. Based on their chemistry and plant origin, the most widespread and well-studied types of propolis are briefly listed, together with their most important bioactive marker constituents:

Poplar type (European) propolis:

- Found in Europe, North America and non-tropical regions of Asia;
- Plant source: *Populus* spp. bud exudates;
- Main biologically active compounds: flavonoids (pinocembrin, chrysin, galangin, pinobanksin 3-O-acetate), phenolic acids (coumaric, ferulic, caffeic) and phenolic acid esters (CAPE, prenyl caffeates) [10][11].

Green Brazilian propolis:

- Found in Brazil;
- Plant source: *Bacharis dracunculifolia* leaves;
- Main biologically active compounds: p-coumaric acid derivatives (artepillin C, baccharin, drupanin) and flavonoids [12][13].

Red Brazilian propolis:

- Found in the states of northeastern Brazil;
- Plant sources: *Dalbergia ecastaphyllum* resin and *Clusia* spp. flower resin;
- Main biologically active compounds: isoflavonoid derivatives (medicarpin, isosativan), prenylated benzophenones. [14][15].

Mediterranean propolis:

- Found in southern Greece, Mediterranean islands and North Africa;
- Plant source: *Cupressus sempervirens* resin;
- Main biologically active compounds: diterpenoids (isocupressic acid, communic acid, pimaric acid, totarol) [8].

Pacific propolis:

- Found in the Pacific islands (Okinawa, Taiwan, Hawaii);
- Plant source: *Macaranga tanarius* fruit resin;
- Main biologically active compounds: prenylated flavonoids [16].

Many propolis types contain flavonoids. Plant flavonoids are not only antimicrobial and antioxidant but also have protective properties against some biotic and abiotic stress situations. The polyphenolic structure of flavonoids allows for various modes of action, promoting plant survival in various challenging environments [17].

It is essential to note that different propolis types have varying chemical compositions and may differ in their biological activity. Therefore, researchers should be aware of this variability and work with chemically well-characterized propolis samples.

3. Propolis as Fungicide and Bactericide

Despite the chemical variability of propolis from different parts of the globe, its antimicrobial activity remains consistent. Propolis is collected by bees from materials secreted by plants, which are well known for their important role in plant self-defense. These secretions help preserve vegetative apices, young leaves, injured tissues and many plant species exude highly antibacterial resins [9] This, combined with the well-documented effectiveness of propolis against human pathogens [18], has attracted the attention of scientists searching for natural (“green”) fungicides and bactericides for application in sustainable agriculture [9].

Plant pathogenic fungi are widespread and are among the most dangerous pathogens of important agricultural crops, causing significant losses in quality and yield. It was thus natural for scientists to investigate the effects of propolis on fungal phytopathogens. Reports about these effects are the most numerous among the data on propolis as an agrochemical. Research in this area covers the microorganisms that cause the most significant damage to agricultural production. The potential of propolis to suppress phytopathogenic bacteria has also been demonstrated. Many of the studies have been performed in vivo.

In these studies, propolis was applied as a solution, using mostly ethanolic extracts with varying concentrations. In some cases, aqueous extracts [19][20] and extracts obtained with supercritical fluids [21] were used in the experiments. It is important to note that the use of different solvents, even with the same propolis, will result in different chemical compositions of the solutions.

The mechanism of action of propolis against some phytopathogens has been studied. Pazin et al. [22] investigated the effect of propolis extract on model membranes made of zwitterionic and anionic unilamellar vesicles and found that it significantly interacted with nano-organized amphiphilic structures, modifying their physicochemical and structural properties. In a later study, the same research group demonstrated that artepillin C in Brazilian green propolis increased the permeability of membranes with relatively high fluidity in their lateral structure [23]. The number of such studies is limited; further research on the mechanism of action of propolis on microbial plant pathogens is necessary.

In addition to its action against phytopathogens, propolis can activate the defense mechanisms of plants. Guginski-Piva et al. [24] demonstrated that propolis application resulted in the induction of phytoalexins in soybean (*Glycine max*) cotyledons, potentially helping to control the powdery mildew. Recently, propolis extracts were also tested for their capacity as plant defense activators of the defense response genes WRKY70 and CaBP22 in *Arabidopsis thaliana*; propolis induced the expression of these genes [25].

The antimicrobial properties of propolis have been used not only for plant protection but also in postharvest preservation of the quality of economically important fruits and vegetables [26]. Postharvest losses of fruits and vegetables range from an estimated 5% to more than 20%, and postharvest fungicides have traditionally been the main for controlling these losses. However, due to the harmful effects of synthetic fungicides on human health, as well as the development of pathogen resistance to many of the important preparations, the use of postharvest fungicides is progressively decreasing [26][27].

4. Propolis as Herbicide

Weeds are among the most significant causes of severe damage to crops, alongside plant pests and diseases. A large number of pesticides are used to control weeds, most of them being chemically synthesized. Often these herbicides pose risks to people, pollinators and other non-target creatures [28]. Due to this reliance on pesticides, several issues arise, including resistance and secondary pest outbreaks, as well as environmental and health risks.

Growing concerns have invigorated the search for new environmentally compatible herbicides of natural origin [29][30].

Given the diverse reported bioactivities of propolis, it has been a subject of research in this context. Reports dating back to the 1960s mention the phytoinhibitory and phytotoxic activities of propolis extracts [31] (and references cited therein). It is worth noting that there are publications describing the prevention or delayed germination of seeds from cultivated plants by propolis extracts [32][33]. Sorkun et al. [32] found that Turkish propolis could inhibit the division of plant cells, while King-Diaz et al. [30] demonstrated that individual flavonoids found in Mexican propolis inhibit photophosphorylation in freshly lysed chloroplasts.

5. Propolis as Insecticide

Honeybees use propolis to defend their colonies against microbial pathogens and it can also protect them against other pests. Invaders and parasites, such as insects and arthropods, must be stopped and neutralized within the hive. It has been demonstrated that propolis can have a negative impact on the reproduction of their major ectoparasite, the arthropod *Varroa destructor* [34], and that it is toxic to the larvae of another dangerous pest, the lesser wax moth, *Achroia grisella* [35]. These effects suggest that propolis could be useful in protecting crops from arthropod and insect pests.

Ethanol extracts of propolis were used in most experiments, although aqueous extracts also showed activity [36]. However, not all experiments demonstrated a high potential for propolis. For example, in the case of the larger grain borer *Prostephanus truncatus*, propolis extract had only a week effect on mortality [37]. The lack of studies on the mechanism of action of propolis and/or its constituents against arthropods and insects is evident; future studies should aim to clarify this.

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