GLYCASPIS BRIMBLECOMBEI (HEMIPTERA: APHALARIDAE) IN EUCALYPTUS FOREST PLANTATIONS: A REVIEW

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ABSTRACT
The species Glycaspis brimblecombei is a psyllid that severely affects eucalyptus plantations in Brazil. This exotic pest poses a significant threat to the forest agroindustry, a crucial sector for the Brazilian economy. G. brimblecombei is a sucking insect that feeds on eucalyptus leaves, causing damage to forest productivity. Its multivoltine characteristic allows multiple generations per year, complicating control. Although the specific economic impact of G. brimblecombei is not mentioned, similar pests can reduce yields by up to 20%. To manage this and other pests, the forestry sector adopts Integrated Pest Management (IPM), which combines various strategies such as biological control, selection of resistant plants, and constant monitoring. However, each region in Brazil receives a different impact from this pest due to variations in environmental conditions. Climatic factors, especially temperature and precipitation, significantly influence the population density of G. brimblecombei. Rainfall, in particular, can drastically reduce populations of the insect by removing the nymphs' protective shells. Periods of drought, on the other hand, favor the population growth of the pest. Thus, rainier regions may suffer less severe damage than drier regions. Therefore, the heterogeneous distribution of rainfall in Brazil results in variations in the presence of the psyllid, requiring management strategies adapted to different regions to ensure the sustainability of forest production.

Keywords: Glycaspis brimblecombei. Management of forest resources. Forest production. Economic impact.

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INTRODUCTION

The forestry agroindustry in Brazil stands out as one of the main economic activities contributing to the national Gross Domestic Product (GDP), (IBÁ, 2023; IBGE, 2023a). In addition, it boosts local economies and promotes the development of regions far from large urban centers (Souza, 2023; AGEFLOR, 2020; Basso, 2015). In addition to its economic relevance, the sector plays a significant role in mitigating environmental degradation through the implementation of sustainable forest management measures and the preservation of native forests (IBÁ, 2023; Poyer, 2021).

Forestry activity in Brazil covers a wide production chain, encompassing several segments that result in the production of pulp, paper, lumber, charcoal, wood panels, laminate flooring, furniture, and non-wood products (IBÁ, 2023; IBGE 2023a; AGEFLOR, 2020). Each product has its own specific production chain, but all depend on a solid and sustainable forest base. The success of these products is directly related to the balance between economic, social, and environmental aspects (IBÁ, 2023; Souza, 2023).

In 2022, the extension of planted forest areas in the country reached the mark of 9.94 million hectares. Eucalyptus plantations represent the significant majority, 76% of this total (7.6 million ha), while areas destined to pine cultivation comprise 19% (1.9 million ha). The other species, such as rubber trees, acacia, teak and paricá, make up the remaining portion, occupying about 5% (440 thousand ha) (IBÁ, 2023; IBGE 2023a). The plantations are distributed throughout the Brazilian territory, the states of Minas Gerais, Mato Grosso do Sul, Paraná and São Paulo concentrate the main producers of planted forests (IBÁ, 2023)

Brazil's edaphoclimatic characteristics, combined with investments in research and development, give the country a prominent position in the forestry market (IBÁ, 2022). The genus Eucalyptus has been the main species implanted due to its high productivity, rapid growth, adaptability, and wide range of applications (Dallacort, 2020; Queiroz, 2009). According to IBÁ (2022), in Brazil, eucalyptus plantations have a higher productive potential than in other regions of the world. These indices have evolved over the years, with species of this genus reaching an estimated average productivity of 32.7 m³/ha/year in a 6.7-year cycle (IBÁ, 2023).

In recent decades, forest pests have gained prominence as one of the main factors that impact wood productivity and quality (Litholdo *et al*., 2018). Among the main exotic pests of eucalyptus are the shell psyllid (*Glycaspis brimblecombei*) (Hemiptera: Aphalaridae), the bronze stink bug (*Thaumastocoris peregrinus*) (Hemiptera: Thaumastocoridae), the eucalyptus gall wasp (*Leptocybe invasa*) (Hymenoptera: Eulophidae) and the eucalyptus weevil (*Gonipterus platensis*) (Coleoptera: Curculionidae).

In addition, native insects such as leafcutter ants (*Atta* spp. and *Acromyrmex* spp.) (Hymenoptera: Formicidae: Attini), termites, and defoliating caterpillars (*Thyrinteina arnobia*) (Lepidoptera: Geometridae) also contribute to the challenges faced by the forestry sector (Lemes *et al*., 2021; Wilcken, 2017).

The economic impacts of these pests have not yet been completely determined. According to Wilcken (2017), the tan bug is capable of causing an estimated reduction of approximately 15% to 20% in the Average Annual Increment (IMA). The plaintiff estimated that the economic damages during the period from 2010 to 2015 reached the amount of R$ 1.1 billion. Valente *et al.* (2018) estimated that an infestation of *Gonipterus platenses* in Portugal resulted in losses of 648 million euros over a 20-year horizon.

To mitigate the impacts and ensure the sustainability of the forestry sector, silviculture adopts Integrated Pest Management (IPM) as a strategy. This approach aims to ensure the optimal development of the forest and, consequently, the final product (Lemes *et al*., 2021). IPM encompasses the integration of various management tactics, such as the selection of pest-resistant genetic materials, the use of biological control, the use of chemicals, and constant monitoring (Lemes and Zanuncio, 2021). In addition, the development of innovative research and technologies also plays a crucial role in the search for more effective and sustainable solutions to mitigate the adverse effects caused by pests.

GLYCASPIS BRIMBLECOMBEI

Morphological and biological aspects

The *Glycaspis brimblecombei* Moore (Hemiptera, Aphalaridae) commonly known as the shell psyllid is a phytophagous insect-pest with a sucking habit that feeds exclusively on the leaves of *Eucalyptus* spp. In the current context of the forestry sector, the species assumes a prominent role as one of the main exotic pests of eucalyptus (Barcik *et al.*, 2023; Santos et al., 2021; Litholdo, 2018; Sá and Wilcken, 2004)

The species has a hemimetabolous development, characterized by a life cycle composed sequentially of egg, nymph and adult stages (Ramirez *et al.*, 2003). According to Firmino-Winckler *et al.* (2009), the total duration of the cycle, from the embryonic stage to the death of adult individuals, varies according to the host species and the conditions of the environment.

The eggs are deposited on the leaf surface with a peduncle, and can be grouped into masses or placed individually. The clusters assume circular shapes, aligned in straight rows or arranged in semicircles, the latter being the most common in field observations (Sánchez *et al.*, 2002). They have a shiny appearance, oval shape and yellow-orange color (Ramirez *et al.*, 2003).

The nymphs pass through 5 instars, being distinguished by the structure and number of antenna segments, ranging from 3 to 9 (Ramirez *et al.*, 2003; Sánchez *et al.*, 2002). In the first 3 instars, they are yellowish in color, while in the last 2 they take on a light brown color. At this stage, *G. brimblecombei* has a dorsoventrally flattened body (Favaro, 2006).

When hatching, the nymphs explore the leaf surface and choose the appropriate place for permanence, where they insert the stylet in search of the sap-conducting vessels, preferring regions close to the veins (Phillips, 1992). After fixation, the nymph begins its feeding and produces a sugary secretion, known as "honeydew", which is used for the formation of the shell (Favaro, 2006).

The shells have a conical shape, whitish color, and shelter the nymphs until the adult stage (Cuello, 2019; Fávaro, 2006). For most of their developmental period, nymphs remain inside the shell, and as they grow, they gradually enlarge the size of this structure. They can remain inside the shell until the adult stage or move around, in which case it is necessary to build a new structure (Favaro, 2006).

G *. brimblecombei* has sexual dimorphism, in which females are slightly longer than males, measuring between 2.7 and 4.5 mm in length, and males are between 2.7 and 3.95 mm (Favaro, 2006; Sá and Wilcken, 2004). Reproduction is sexual, and females have a reproductive structure in the terminal portion of the abdomen, through which eggs are laid. On the other hand, males have a projection in the upper abdomen that helps in the immobilization of the female during copulation. Both have filiform antennae with ten segments, as well as two pairs of transparent and membranous wings (Ramirez *et al*., 2003; Fávaro, 2006).

G. brimblecombei is characterized by being a multivoltine species, that is, it manifests multiple reproductive cycles within a single year, with these generations occurring in a continuous and overlapping manner (Cuello, 2019; Favaro, 2006; Morgan, 1984). According to Collett (2001), the number of generations is modulated by the biological characteristics of the insect, by the conditions of the environment and by the availability of resources of the host. Morgan, (1984) reports the occurrence of two to four generations per year, while Cuello, (2019) observed the development of six generations in different eucalyptus species.

Multivoltine pests have an accelerated capacity for reproduction, which results in their constant presence and cumulative damage throughout the year. This characteristic affects the effectiveness of control actions, since the overlapping of generations favors the reinfestation of controlled areas, requiring successive interventions during the year.

As observed by Silva (2010), *G. brimblecombei* presents an aggregated spatial distribution in all its stages of development in the field. The authors also found that population density is not influenced by position within the field, whether in the center, on the sides or on the edges. The aggregated spatial distribution creates favorable conditions for outbreaks to occur in a concentrated manner, increasing pest pressure at certain points in the forest. This distribution pattern suggests the need for adjustments in monitoring and control strategies, focusing on the insects' aggregation points. In addition, the presence of the species in several positions within the plot implies the need for more intense sampling during monitoring, in order to obtain representative information of the forest.

Bioecology

The density of a population and its fluctuations over time are influenced by a variety of factors. According to Coulson and Witter (1990), these elements comprise climatic characteristics, host susceptibility, availability of appropriate habitat, levels of parasitism and the presence of diseases.

The adoption of mosaic plantations instead of continuous blocks comprises a strategy adopted by companies in the forestry sector to circumvent some of these factors. This management, by creating sites with distinct characteristics, contributes to the heterogeneity of the ecosystem, reduces the risk of pests and diseases and favors the development of natural enemies (Conrado *et al*., 2014).

The detection of *G. brimblecombei* is recorded in several regions of the country, however, its presence does not necessarily imply the occurrence of economic damage. Environmental factors are not able to restrict the development of the shell psyllid, however, they play an important role in regulating its population density (Favaro, 2006). The meteorological conditions that exert the greatest influence on the species are air temperature and rainfall volume (Barcik *et al.,* 2023; Ferreira Filho *et al.,* 2017; Ferreira Filho 2010)

Rainwater has the ability to displace the shells, resulting in the removal of the nymphs' protection. This displacement impairs the insects' adherence to the leaves, creating unfavorable conditions for their survival and reproduction (Favaro 2006). In addition, high humidity during the rainy season contributes to the increased incidence of entomopathogenic fungi capable of killing psyllid nymphs (Rámirez *et al.,* 2002).

Oliveira *et al.* (2012), in a research involving the application of artificial rain, found that just 2 consecutive days of exposure to rain were enough to cause a reduction of more than 50% in the population, reaching an effectiveness of 96% after 5 consecutive days. The authors associate this decrease with the moistening of the leaves, which results in the melting of the shells and, consequently, in the exposure of the nymphs to environmental conditions and predators. These results indicate that precipitation demonstrates a regulatory effect on psyllid populations.

In the study conducted by Ferreira Filho (2005), it was observed that the species showed low incidence when rainfall was evenly distributed in the study area. However, as rainfall became more irregular, this variability promoted favorable conditions for a significant increase in its occurrence. Tuller *et al.* (2017) verified the existence of a strong relationship between the effects of rainfall and the density of eggs and nymphs in *E. camaldulensis*, with an increase in density in the dry season and a reduction in the rainy season.

Rámirez *et al.* (2002) observed the existence of a relationship between the levels of infestation of the shell psyllid and precipitation rates. The authors noticed that the population density of *G. brimblecombei* remained high in the dry periods and reduced significantly in the rainy months. Similar results were observed by Barcik *et al.* (2023); Ferreira Filho *et al.* (2017); Camargo *et al.* (2014); Silva *et al.* (2013); Silva (2010); Ferreira Filho (2010); Ferreira *et al.* (2009); Ferreira Filho *et al.* (2005); Sookar *et al.* (2003).

There is a great variation in precipitation patterns between regions of the Brazilian territory. The North and South of the country are characterized by a high volume of annual precipitation, which is well distributed throughout the year, without a defined dry season. In the Northeast, most of the precipitation (55 to 70%) is concentrated in a period of three consecutive months, while the remaining months may experience drier conditions. In contrast, the Southeast and Midwest have a more uniform distribution throughout the year, with approximately 25 to 60% of the total precipitation occurring in three consecutive months (Nimer, 1989).

The heterogeneity in the distribution of rainfall throughout the country can establish areas with favorable or unfavorable environmental conditions for *G. brimblecombei*. In the North and South regions, for example, where rainfall is evenly distributed throughout the year, it is possible that the species has a low population density when considering only the distribution of precipitation.

Under conditions of water deficit, plant species can manifest physiological and biochemical changes that affect their resistance against insects and other stressors (Franco, 2018; Yihdego *et al*., 2019). Water deficit contributes to the successful establishment of the shell psyldeum in periods of drought. During this season, there is a significant increase in the density of eggs and nymphs of the species (Tuller *et al.*, 2017).

In the cerrado biome and in the Northeast region, where the water deficit is more pronounced, *G. brimblecombei* tends to present higher population density. In this sense, IPM programs should be adapted to these specific conditions. This implies carrying out frequent monitoring to detect the presence of the pest insect early, especially during periods of water scarcity. Another important aspect in this process is the selection of genetic materials for planting that demonstrate tolerance to both water deficit and pest.

Different studies conducted with the shell psyllid indicate that temperature is the main factor involved in the population dynamics of the shell psyllid (Ramirez *et al*.; 2003; Paine *et al*., 2000). In the laboratory environment, Firmino *et al.* (2004), identified that the optimal temperature for the development and reproduction of the insect pest was 26ºC, while the least adequate temperature was 30ºC. In the field, Ferreira Filho (2005) found similar results, when the maximum temperature was around 31°C, the populations remained low, and as the temperature decreased to about 27ºC the population density began to increase.

In a study developed in the southern region of Brazil, Favaro (2006) identified a negative correlation between nymphs and maximum temperature, suggesting that high temperatures may have an adverse influence on the development of the species. Regarding minimum and mean temperatures, positive correlations were observed; however, none of the results reached statistical significance.

Opposite to this, in the United States, Paine *et al*. (2000) and Dahlsten (2002) documented the population density peaks of the pest in the warmer months. Ferreira Filho (2005) attributes this difference to the specific climatic characteristics of Brazil, which are different from the countries of the northern hemisphere. In the Brazilian context, there is an increase in temperatures during the summer; However, this period is marked by higher rainfall, resulting in a decrease in population density. Meanwhile, winter is marked by drier months and milder temperatures. Different occurs in the northern hemisphere the seasonal pattern is characterized by severely low temperatures in winter and mild in summer, this provides favorable conditions for the development of *G. brimblecombei* in summer, since its life cycle is limited in winter.

Ferreira *et al.* (2009) found that lower temperatures associated with decreased rainfall provide favorable conditions for the establishment and reproduction of the psyllid. On the other hand, the increase in temperatures and the frequent occurrence of rainfall contribute to the reduction of the population.

The host species is also a determining factor for the population density of *G. brimblecombei*. The intensity of infestations and the length of the life cycle are not homogeneous among the species of *Eucalyptus* spp. and *Corymbia* spp. (Firmino-Winckler *et al.*, 2009; Pereira 2011). In the laboratory, Firmino-Winckler *et al.* (2009) carried out tests with 6 commercial forest species and concluded that 5 of them behaved as favorable hosts for the development of the shell psyllid. Among these species, *E. camaldulensis* and *E. teriticornes* proved to be the most suitable, while *C. citriodora* exerted a lethal effect on the insect, inhibiting its development from the first nymphal stage.

When monitoring 11 species of eucalyptus in the interior of São Paulo in the field, Ferreira *et al.* (2009) found that the species *E. tereticornis* and *E. camaldulensis* were the most susceptible to pest attack. On the other hand, individuals of *C. citriodora*, *E. paniculata* and *E. torelliana* were not infested. In a study on oviposition preference in the laboratory, Pereira *et al*. (2013) observed that the genotypes of *E. urophylla* and *E. grandis* were the least visited by adults, while there was a high preference for *E. camaldulensis*.

Brennan *et al.* Sánchez et al. (2001) conducted an assessment of the susceptibility of 21 eucalyptus species in San Francisco, California, USA, and found that only three species (*E. camaldulensis, E. rudis* and *E. tereticornis*) showed heavy defoliation, being classified as moderately to highly susceptible. Several studies have demonstrated the high susceptibility of *E. camaldulensis* (Camargo *et al.,* 2014; Montes and Raga, 2005; Wilcken *et al., 2003*).

Despite being highly susceptible to attack by the shell psyllid, *E. camaldulensis* stands out as a species of economic interest, due to its versatility of uses and ability to adapt to unfavorable environmental conditions, such as water deficit (Costa *et al.,* 2017). In the face of scenarios like this, genetic improvement programs have been dedicated to the production of hybrids that combine high productivity, with wood quality and greater resistance to biotic and abiotic factors, such as pests and diseases.

Trees in the genus exhibit distinct characteristics that play significant roles in their resistance against phytophagous insects. Its leaves have glands that synthesize essential oils, often enriched with terpenoids. Additionally, the leaves contain secondary metabolites such as tannins, phenols, and waxes, which have the potential to make them less palatable to insects. And the presence of leaf hardness, known as sclerophilia, adds an additional physical barrier (Ohmart and Edwards, 1991).

Different species of eucalyptus may have unique leaf characteristics that affect interaction with psyllids (Reifenrath *et al*., 2005). According to Brennan and Weinbaum (2001), the presence of epicuticular wax in young leaves of *E. globulus can negatively* *impact the survival and feeding behavior* of the species. This wax is able to reduce the adhesion of the nymphs to the leaves and make it difficult to probe the stylet.

Geographical distribution of *Glycaspis brimblecombei*

The Glycaspis brimblecombei Moore (Hemiptera, Aphalaridae) is an insect native to Australia, and current records demonstrate its distribution across all continents (EPPO, 2023). Its first observation outside the natural environment was reported in June 1998, in the Americas. The infestation occurred in *Eucalyptus* spp. plantations in El Monte, Los Angeles, USA (Brennan *et al.*, 1999)*element.*

The following year, the species was detected in different cities in Mexico (Cibrian-Tovar and Iniguez-Herrera, 2001). In 2003, it was already present in 24 states of the country (Ramirez, 2003). In South America, its first observation was recorded in Chile in 2002, with infestations reported in different regions, such as Santiago, Chacabuco, San Felipe and Los Andes (Sandoval and Rothmann, 2002).

In Brazil, *G. brimblecombei* was detected for the first time in 2003, in the municipality of Mogi Guaçu, in the interior of the state of São Paulo. In September of the same year, the pest had already been observed in 86 more municipalities in the state. Its occurrence was later recorded in several Brazilian states, including Paraná, Goiás, Minas Gerais (Wilcken *et al*., 2003), Mato Grosso do Sul (Sá and Wilcken, 2004); Santa Catarina (Lutinski *et al*., 2006), Rio Grande do Sul (Oliveira *et al*., 2006), Mato Grosso (Silva, 2010), Espírito Santo (Resende and Santana, 2008), Bahia (Masson *et al*., 2009), Pernambuco (Breda *et al*., 2010); Rio de Janeiro, Tocantins, Piauí (Wilcken *et al*., 2015); Pará (Saliba *et al*., 2019) and Maranhão (Favoreto *et al.,* 2022; Santos *et al*., 2021). This insect has also been detected in other South American countries, such as Argentina (Bouvet *et al.*, 2005), Ecuador (Onore and Gara, 2007), Venezuela (Rosales *et al.*, 2008), Colombia (Rodas *et al.,* 2014), Paraguay (Díaz *et al.*, 2013) and Peru (Burckhardt *et al.*,2008), (Figure 1).

Currently, the shell psyllid is present in 16 Brazilian states, which are distributed across the five regions of the country. The rapid expansion and dispersion of the pest in the Brazilian territory are attributed by Santana *et al.* (2003), its adaptability to the country's climate and the extensive area planted with eucalyptus. In addition, this species has a high capacity for adaptation to colonize new areas (Queiroz *et al*., 2013).

Figure 1 - Distribution of *G. brimblecombei* in Brazil.

The continuous expansion of eucalyptus forest plantations has contributed to the spread of the pest throughout the territory. The introduction of eucalyptus in previously unpopulated areas creates a favorable environment for the occurrence of *G. brimblecombei*, since the species is specific and the climatic conditions are not limiting for its incidence in Brazil. Both the temperature and the volume of rainfall do not reach extremes that limit the presence of this species in the country. In addition, the extensive areas offer an abundance of resources and shelter for insect pests (Firmino-Winckler *et al.,* 2009).

In the period between 2014 and 2022, eucalyptus forest plantations in Brazil registered a growth of 2.6%. During this interval, the Southeast (4.1%), Central-West (2.3%) and Northeast (0.5%) regions stood out as the ones with the highest growth, while the South region suffered a reduction of 6.1% (IBGE, 2015; IBGE, 2023). According to Junqueira (2016), between 2010 and 2015, *G. brimblecombei* infested an area of approximately 51 thousand ha.

Damage

The intensity of damage caused by insects, whether qualitative or quantitative, is shaped by a complex interaction of several factors (Favaro, 2006). Among these, the population density of the pest, the temporal extent of exposure of the plant to the infestation, as well as the stage of development and the plant structure of the affected host deserve to be highlighted. In addition, the susceptibility of plant species can vary throughout their life cycle.

According to Gallo *et al.* (2002), the damage caused by pests varies between countries. This disparity is influenced by elements intrinsic to each region, including climatic characteristics, cultivated varieties, agronomic or silvicultural practices adopted, and socioeconomic reality. In this way, pest management strategies need to be adapted and adjusted based on these factors to achieve effective results.

The presence of *G. brimblecombei* in eucalyptus plantations can result in different types of damage. This damage arises due to the feeding of nymphs and adults, which prey on young and mature leaves, indicating the occurrence of infestations at any age of the forest (Queiroz *et al*., 2016). Studies have shown a preference of the pest insect for the upper part of the crown, where the leaves and young shoots are found (Santana 2005; Montes and Raga, 2005; Pereira *et al*., 2013; Carnielli, 2018). However, Pereira *et al.* (2013) observed, under laboratory conditions, that the leaves of the upper and middle third of seedlings were preferred for oviposition.

The authors support the idea that the less lignified tissue facilitates the feeding of the insect pest, as it has characteristics that facilitate ingestion. In addition, the region is attractive due to the abundance of nitrogen and other nutrients. Unlike the other authors, Jere *et al*., (2020) found that the insect did not show a preference for any specific part of the canopy of *E. camaldulensis*, *E. tereticornis*, *E. grandis* in eucalyptus stands in Malawi.

Infestations of *G. brimblecombei* can cause several reactions in plants, resulting in defoliation, dryness of the tips, reduction of leaf size, deformation and curling of the leaf blade, (Sá and Wilcken, 2004; Wilcken *et al*., 2003). According to Gill (1998), the damage caused by this insect pest can cause up to 15% of plant mortality in the first year. If control measures are not implemented, mortality can reach 40% in the following year.

The presence of *G. brimblecombei* leads to secondary impacts, such as the induction of the appearance of sooty mold. Sooty mold develops from the colonization of saprophagous fungi to the *honeydew* excreted by the pest insect, resulting in a dark film that covers leaf surfaces, stems, or other plant structures. This phenomenon results in a reduction in the photosynthetically active area of the plant and attenuates the susceptibility to attack by other insects (Ferreira Filho, 2010).

During the first outbreak in 2003 in Brazil, a defoliation rate in the range of 20% to 30% was recorded. In the dominated trees, total defoliation was observed, reaching 100% of the canopy area, with no possibility of recovery. (Wilcken *et al*., 2003). The occurrence of defoliation was also identified in Portugal and Tunisia, where infestation rates ranged from 5% to 75% and 8.8% to 80.5%, respectively (Dhahri *et al*., 2014).

Control methods

To control *G. brimblecombei*, several techniques can be adopted, such as chemical methods, biological control, silvicultural practices, and the introduction of resistant genotypes (Oliveira, 2020). Santana *et al.* (2003) and Barbosa *et al.* (2021) suggest Integrated Pest Management (IPM) as the most promising alternative for controlling this insect pest within the Brazilian context. The justification for this approach lies in the extensive area occupied by monoculture, the adaptability of the species to environmental conditions and its rapid dispersion throughout the national territory.

The monitoring of this insect pest is the basis for decision-making in IPM programs, as they aim to identify places of occurrence and the need for control. Monitoring is carried out continuously and requires trained labor to ensure the effectiveness of the measures adopted. Such measures aim to ensure the early identification of infestations, establish priority areas for interventions, and evaluate the effectiveness of different control methods.

The main monitoring techniques used are yellow adhesive traps and foliage sampling. Sticky traps are preferred due to their reliable, accessible, and low-cost approach (Queiroz, *et al*. 2012). On the other hand, foliage sampling provides detailed information on the presence and population dynamics (Erbilgin *et al.*, 2004). This method involves collecting the first seven leaves from the first three branches of a plant suspected of infestation. The leaves are then placed in plastic bags for further analysis of the number of individuals present, as well as the different stages of development, over a period of four weeks. Other techniques have been researched, such as the use of Unmanned Aerial Vehicles (UAVs) (Wantroba *et al*., 2023).

Due to the wide dissemination of the species in several regions of the country, chemical control is a measure of high cost and limited efficacy (Santana *et al.,* 2003). Sá and Wilcken (2004) also point out the environmental impacts related to the application of these products, as well as their temporary effect. The short-lasting effect is intrinsically linked to the overlapping of generations of the species, implying the need for successive spraying.

In this scenario, products with a systemic mechanism of action stand out as the most used in pest control. This preference is due to their greater effectiveness when compared to contact action products. The latter face challenges in reaching nymphs, due to the protection conferred by the shell and reduced mobility during the life cycle (Wilcken *et al*., 2003).

Twelve years after the initial identification of the pest in Brazil, there were no records of chemicals for its control in the Ministry of Agriculture, Livestock and Supply (MAPA) (Wilcken *et al*., 2015). Currently, there are seven products registered with MAPA, coming from three active ingredients: bifenthrin, acetamiprid and etofenproxi. These products act through mechanisms of systemic action, contact, and ingestion, in some cases with a combination of these mechanisms and, in others, an isolated action (MAPA, 2023).

There are several species of natural enemies that are associated with the shell psyllid. However, some of them are considered inefficient in controlling the pest, as they have a low parasitism rate (Wilcken *et al.,* 2015; Dahlsten *et al*., 2002). This limitation occurs due to the lack of adaptations in generalist predators to pierce the protective shells of the pest nymphs, which have a hard consistency (Wilcken *et al.,* 2003).

Foram documentados casos de predação ou parasitismo de ninfas ou adultos do psilídeo de concha por espécies como: *Anoplolepis longipes* (Hymenoptera: Formicidae) (Sanchéz-Martinéz *et al*., 2005), *Anthocoris nemoralis* (Hemiptera: Anthocoridae) (Garonna *et al*., 2011), *Atopozelus opsimus* (Hemiptera: Reduviidae) (Dias *et al*., 2009), *Cycloneda sanguinea* (Coleoptera: Coccinellidae) (Berti Filho *et al*., 2003), *Exochomus aethiops* (Coleoptera: Coccinellidae) (Sookar *et al*., 2003), *Psyllaephagus bliteus* (Hymenoptera: Encyrtidae) (Wilcken *et al*., 2015) e *Vespula sp*. (Garonna *et al.,* 2011).

Psyllaephagus bliteus, a parasitoid native to Australia, is known to be specific to *G. brimblecombei*, and to have a relationship of dependence with its population density (Dias, 2013; Silva *et al*., 2013). This insect has the ability to parasitize nymphs, even when they are protected by shells. In Brazil, its introduction occurred naturally along with the arrival of the pest (Berti Filho *et al.,* 2003).

The females of the parasitoid lay their eggs in the thorax or abdomen of the psyllid nymphs, preferably in those of the third or fourth instar. After about two weeks, the adults of the parasitoid emerge, leaving a visible circular hole in the shell. In addition, P*. bliteus* females have the ability to lay eggs without the need for copulation, reproducing by arrenotoca parthenogenesis (Plascencia-Gonzáles *et al*., 2005; Daane *et al*., 2005; Montes and Raga, 2005).

Biotic and abiotic factors have the potential to influence the rate of insect parasitism (Margiotta *et al*., 2017; Caleça *et al*., 2018). According to Daane *et al.,* (2005) temperature plays a determining role in the life cycle of the species. The authors observed a decrease in longevity and fertility rate with increasing temperature.

In countries with a warm climate, such as Brazil and California, the establishment of the insect has been challenging (Ferreira Filho *et al.*, 2015; Daane *et al.*, 2012). In forest plantations of *E. camaldulensis* in the states of São Paulo and Minas Gerais, the rate of natural parasitism showed reduced levels, ranging from 0.2% to 11%, indicating the need for successive Masal releases (Wilcken *et al.,* 2005). In regions where there was mass release of *P. bliteus* , the results revealed an increase in parasitism levels in the field, reaching up to 94% (Ferreira-Filho *et al*., 2015; Huerta *et al.*, 2010).

Among the generalist predators, *Atopozelus opsimus* (Hemiptera: Reduviidae) has shown potential to be a viable alternative in biological control programs. This perspective is reinforced by the fact that the insect is native and has adapted its diet to the predation of exotic pests (Dias, 2013). The natural enemy has been observed preying on several pests, including *Glycaspis brimblecombei, Thaumastocoris peregrinus*, *Leptocybe invasa* and *Diaphorina citri.*

According to Dias (2009), the psyllid is the preferred food source of *A. opsimus.* The insect has a feeding pattern that includes nymphs at different stages of development, as well as adults of psyllids, standing out for its ability to raise the protective structures of the nymphs, in order to capture their prey (Dias, 2009). In this study, the author observed that the insect was able to complete its life cycle by feeding exclusively on nymphs and adults of the psyllid.

The use of entomopathogenic fungi emerges as a viable alternative for the biological control of *G. brimblecombei*, as I contudi, its efficacy is related to environmental conditions. According to Wilcken *et al*. (2003), this technique demonstrates expressive results only in environments characterized by a relative humidity above 60%.

Favaro (2006) conducted a laboratory study to evaluate the efficacy of the fungi *Lecanicillium* sp. and *Beauveria* sp. in controlling the pest. The results indicated high susceptibility of nymphs and adults to the attack of these fungi. In semi-field conditions Dal Pogetto *et al.* (2011) observed that the 3 products tested (*Beauveria bassiana*, *Metarhizium anisopliae* and *Lecanicillium longisporum*) caused a reduction in the population density of the psyllid. The treatments with *B. bassiana* and *M. anisopliae* showed the best results, reaching an efficiency of more than 80%.

In addition to the reduction in forest productivity, the presence of the insect can increase production costs. It is estimated that the cost of applying chemical insecticides to control *G. brimblecombei* varies around R$ 85.00 per ha, requiring at least three applications per year (Sá *et al.,* 2014). Biological control has been gaining prominence within companies in the forestry sector in Brazil. This control method is a more viable and cost-effective alternative compared to the use of chemical insecticides.

The growth in the use of biological control is driven by pressure from consumer markets for more sustainable products. Certifiers, such as the FSC (*Forest Stewardship Council*), play a crucial role in promoting these practices (Lemes and Zanuncio, 2021). The main advantages of biological control include its specificity to the target pest, ability to minimize problems such as the development of resistance by pests and water and soil contamination. In addition, it represents a safer alternative for human health and the environment (Campanhola, 2003).

As a result, forestry companies have been adopting this approach as part of their IPM programs. These companies have invested in the creation of their own laboratories to meet their pest management needs. Laboratories are responsible for the production and distribution of natural enemies necessary for the control of the main pests found in their crops. In addition, in Brazil, there are private companies dedicated to the commercial production of specific natural enemies for control in agricultural and forest areas. The market for biodenfensive products grew more than 70% in one year in the country (MAPA, 2019).

CONCLUSIONS

The rapid spread of *Glycaspis brimblecombei* in eucalyptus forest plantations in Brazil is a significant concern for the sector. Its easy adaptation to the country's climatic conditions, combined with the extension of areas cultivated with eucalyptus and the low efficiency of control methods, suggest the need for an integrated management program. This program must consider not only aspects of the morphology and biology of the pest, but also its complex interaction with the environment and other organisms.

The introduction of *G. brimblecombe* was able to influence several processes within the forestry sector, including IPM and breeding programs, in the forestry, research and environment sectors. However, some important gaps are identified in relation to this insect pest. Understanding the relationship between the economic damage caused by *G.*

brimblecombei and environmental conditions is fundamental for the development of more effective management strategies, adapted to the different regions of Brazil. In addition, estimating the financial impacts resulting from their infestations allows us to assess the cost of this threat to the forestry industry. Filling these gaps through research is necessary to ensure the health of forest plantations and mitigate the economic losses associated with the pest.

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