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Integrated pest management of soybean emerging pests in Brazil and United States: a review.

Manejo integrado de pragas emergentes da soja no Brasil e nos Estados Unidos: uma revisão

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ABSTRACT

Soybean cultivation is crucial for meeting global demand for vegetable oil and protein, with Brazil being the largest global producer, followed by the United States. However, intensifying soja production has led to the emergence of new pests, such as whitefly, thrips, and leaf miners, which cause damage to plants and reduce crop productivity. The integrated pest management approach is essential for sustainable pest control, minimizing pesticide use, and maintaining ecological balance. However, further research is needed on emerging pests and their management strategies.

Keywords: Pest control; Sustainability; Crop protection; Productivity; Economic thresholds.

RESUMO

O cultivo de soja é crucial para atender à demanda global por óleo vegetal e proteína, sendo o Brasil o maior produtor mundial, seguido pelos Estados Unidos. No entanto, a intensificação da produção de soja levou ao surgimento de novas pragas, como a mosca-branca, os trips e os minadores de folhas, que causam danos às plantas e reduzem a produtividade das colheitas. A abordagem de manejo integrado de pragas é essencial para o controle sustentável de pragas, minimizando o uso de pesticidas e mantendo o equilíbrio ecológico. No entanto, mais pesquisas são necessárias sobre pragas emergentes e suas estratégias de manejo.

Palavras-chave: Controle de pragas; Sustentabilidade; Proteção de culturas; Produtividade; Limiares econômicos.

INTRODUCTION

The cultivation of soybeans is widespread across large areas around the world, making this crop alone responsible for supplying half of the global demand for vegetable oil and protein (Bortolotto et al., 2015). Brazil is the largest soybean producer in the world, with 39% of the global production in 2024, followed by the United States with 29% of the production (USDA, 2024). Thus, soybean cultivation holds great importance for the global economy (USDA, 2024). With the expansion and intensification of soybean farming, new insect problems have been observed in these fields, which are now considered emerging pests.

Insects are the most diverse class of organisms, with over a million identified species and about 10 million yet to be discovered; however, fortunately, only a small portion (<1%) is considered a pest, and many are beneficial to agricultural production (O'Neal and Johnson, 2010). Various pest insects from different orders feed on soybeans throughout the season. These orders include different feeding groups such as defoliators (Lepidoptera, Coleoptera, Orthoptera), phloem feeders (Hemiptera), and seed pests (Coleoptera, Diptera) (O'Neal and Johnson, 2010). As they feed, these insects cause damage to plants. The damage results from insect feeding on seeds, seedlings, roots and nodules, stems, foliage, and fruit structures; certain phytophagous species also provide access to disease-causing organisms or directly transmit them to the plants (Turnipseed and Kogan, 1976).

Integrated pest management (IPM) is an essential strategy for ensuring efficient pest control, reducing the excessive use of pesticides, and preserving environmental balance. In recent years, advances in agricultural technologies, such as precision agriculture and artificial intelligence, have enabled significant improvements in IPM. IPM can be defined as the selection, implementation, and integration of pest control methods based on ecological, economic, and social principles (Bottrell, 1979). IPM is used for managing various crops, aiming to maintain the sustainability of the agroecosystem, keeping it as close as possible to biological balance (pests versus natural mortality) (Bortolotto et al., 2015). IPM strategies are crucial for the effective management of pests in soybean plantations (Kogan and Heinrichs, 2020). Therefore, this work aims to elucidate the integrated pest management of soybean emerging pests in Brazil and the United States.

INTEGRATED PEST MANAGEMENT OF SOYBEAN IN BRAZIL: A BRIEF HISTORY.

IPM for soybeans was first implemented in Brazil in the late 1960s and early 1970s, with soybeans becoming more prominent in the region. Regional studies and a bulletin featuring color images of pests, and their natural enemies contributed to the popularization of IPM concepts (Bueno et al., 2021). Brazilian soybean growers adopted IPM, which led to more appropriate use of insecticides and reduced pesticide usage to about two applications each season after three to four years (Bortolotto et al., 2015).

The next big accomplishments of Brazilian IPM were: (1) From 1975 to 1978, extensive studies on sampling methods, leaf loss indices, and damage caused by sucking bugs on grains were conducted, which led to the establishment of the beating cloth method for pest monitoring and action thresholds for defoliating caterpillars and phytophagous bugs (Bueno et al., 2012); (2) the discovery of a naturally occurring nuclear polyhedrosis virus (AgNPV) called *Baculovirus anticarsia* capable of controlling the velvet bean caterpillar, *Anticarsia gemmatalis* (Hübner), that was the main pest of soybeans back then, causing significant defoliation of the plants (Panizzi, 2013); (3) a new control tactic using egg parasitoids micro-hymenopterans (*Trissolcus basalis* Wollaston and *Telenomus podisi* Ashmead) to promote the biological control of stink bugs (Panizzi, 2013).

The current agricultural system of double cropping in Brazil has led to a growing pest population, and the use of conventional insecticides has become overused because secondary pests like chewing caterpillars, mites, thrips, and whiteflies have also increased in abundance (Panizzi, 2013). The intensive use of fungicides to control soybean rust has also weakened the role of natural enemies against soybean pests, leading to the abandonment of the IPM program in Brazil toward the end of 2010 (Panizzi, 2013).

INTEGRATED PEST MANAGEMENT OF SOYBEAN IN THE UNITED STATES: A BRIEF HISTORY.

IPM was first outlined in national policy in the 1970s (Bueno et al., 2021). During the expansion of soybean production in the southern USA, entomologists warned against automatic insecticide application practices due to the lack of a "key pest," economics, insecticide resistance, primary pest resurgence, secondary pest outbreaks, and environmental contamination (Lincoln et al., 1975; Boethel, 2004). They developed an IPM system, primarily developed for the southern USA, which involved systematic scouting, action-decision rules based on Economic Injury Levels (EILs), and conservation of natural enemies through minimum insecticide rates (Turnipseed and Kogan, 1994; Boethel, 2004). In the northern USA, the IPM system was modified to focus on predicting infrequent pest outbreaks and reducing reliance on monitoring (Boethel, 2004). Before the early 2000s, soybean arthropod pest pressure in the US was low, with less than 1% of soybean acreage treated with insecticides (Bueno et al., 2021). Management focused on localized outbreaks of defoliating insects (Bueno et al., 2021). In 2000, less than 0.1% of soybean acreage was treated for arthropod pests (Bueno et al., 2021). However, the introduction of the soybean aphid, improved pesticide seed treatment technology, and changes in farmers' perceptions and agronomic realities led to a shift in IPM strategies for many arthropod soybean pests (Bueno et al., 2021). Today, the federal government institutionalizes and supports IPM at the state, local, and national levels through initiatives like information sharing, research grant programs, and IPM training provided by extension offices (Bueno et al., 2021).

INTEGRATED PEST MANAGEMENT STRATEGIES

IPM is essential for sustainable agriculture, avoiding the excessive use of artificial pesticides (Bueno et al., 2021). IPM includes not only the adoption of economic thresholds for the rational use of pesticides but also the integration of various pest management approaches, such as resistant crops, augmentative biological control, and biotechnology (Kogan, 1998; Bueno et al., 2021). Although each of these approaches can provide a different degree of pest management, their combinations can result in a significant reduction in yield losses (Dara, 2019; Bueno et al., 2021).

Finding an effective control strategy requires accurate identification of the pest, knowledge of its biology and seasonal population trends, knowledge of the damaging life stages and their habitats, an understanding of the nature of the damage and its economic significance, an understanding of how vulnerable each life stage is to one or more control options, host preference and alternative hosts, predictability of pest occurrence based on the environment, cropping trends, farming practices, and other influencing factors, and all related information (Dara, 2019).

IPM is based on certain principles, among them are prevention, monitoring and identification, threshold levels, multiple control tactics, sustainability, and environmental safety (Jack and Ellis, 2021). The goal of prevention is to eliminate the environments that draw pests or encourage the growth of their populations (Pedigo, 1995; Jack and Ellis, 2021). Effective prevention and the reduction of pest pressure depend on temporal and spatial diversification (Barzman et al., 2015). Crop rotation is the most successful agronomic substitute for synthetic pesticides in organic arable crop production (Barzman et al., 2015). One of the main tools for enhancing the resilience of cropping and farming systems in annual crops is the modification of crop sequence to disrupt the life cycle of pests by rotating crop species from different families, in this approach, the pest populations cannot be selected for or accumulate because of a diverse crop sequence (Barzman et al., 2015). The IPM paradigm relies heavily on research and outreach to detect and predict pest issues, create preventive and curative measures, and efficiently distribute knowledge using both conventional and contemporary communication techniques (Dara, 2019).

Monitoring is an essential part of integrated pest management, because pest populations are dynamic, and can change significantly in a short period (Bottrell, 1979). Only through monitoring is it possible to determine whether control is necessary and whether natural control is maximized (Bottrell, 1979). IPM relies heavily on accurate pest identification because incorrect identification can result in treatment that is unnecessary, resource waste, and even damage to the agricultural system (Jack and Ellis, 2021). Insect population monitoring often involves either direct sampling to ascertain their numbers or indirect estimations of relative densities derived from an examination of damage symptoms (Apple and Smith, 1976). Another important aspect of IPM is identification of pests and natural enemies. IPM relies heavily on accurate pest identification because incorrect identification can result in treatment that is unnecessary, resource waste, and even damage to the agricultural system (Jack and Ellis, 2021).

The foundation of IPM is the idea that crop plants may withstand specific damage levels without experiencing a production drop that would be economically significant (Higley and Peterson, 1996; Bortolotto et al., 2015). According to Stern et al. (1959), the lowest pest population that can harm plants economically is known as the Economic Injury Level (EIL). However, the decision of whether to control or not a pest population should always be made before the pest reaches the EIL (Bortolotto et al., 2015). Thus, the Economic Threshold (ET) was established as the suitable moment to begin the management strategy to keep the pest population from reaching the EIL (Pedigo et al., 1986; Bortolotto et al., 2015). Based on that, pest management is only justified when pests exceed these economic or damage thresholds (Bueno et al., 2021). The value of produce, the expense and effectiveness of pest management techniques, and the propensity of these species to harm plants all have an impact on EIL (Pedigo et al., 1986; Pereira et al., 2017; Picanço Filho et al., 2024). The potential of these organisms to harm plants and the expense of pest control are directly correlated with EILs, while the value of production is negatively correlated with them (Pedigo et al., 1986; Pereira et al., 2017; Picanço Filho et al., 2024). The crop yield and the price of the agricultural product have an impact on the value of production. The price of the items used, the application technique, and the quantity of applications all affect the cost of control (Pedigo et al., 1986; Picanço Filho et al., 2024).

Sampling plans are crucial for IPM decision-making tools (Binns and Nyrop, 1992; Arcanjo et al., 2024). Monitoring pest populations in an IPM program begins with a traditional sample plan (Lopes et al., 2019; Santos et al., 2021; Arcanjo et al., 2024). A sampling unit, a method for scouting the pest, and the quantity of samples required to assess pest density or damage while keeping an eye on the data frequency distribution are all required components of this sampling strategy (Lopes et al., 2019; Arcanjo et al., 2024). Additionally, it might offer scientific data for creating and validating smartphone apps and sequential sampling programs. To improve farmers' usability, a good standardized sample strategy should combine accuracy with manageable time, expense, and performance (Santos et al., 2021; Arcanjo et al., 2024)

For soybean pests IPM, uses a range of management techniques with the dual goals of minimizing pest damage and lowering the need for chemical pesticides. In IPM for soybeans, chemical control, host plant resistance, and biological control are the most often employed techniques.

The foundation of IPM systems is biological control, which emphasizes the use of natural enemies like predators and parasitoids to suppress pest populations. According to research, maintaining natural enemies can greatly improve pest control—such as eliminating the need for chemical interventions—of pests like stink bugs in soybean crops (Bueno et al., 2013; Ávila et al., 2024). Additionally, as it lessens the chance of insect return and resistance development brought on by excessive pesticide usage, integrating biological control with other techniques can result in more environmentally friendly pest management practices (Oliveira et al., 2024).

Within the IPM framework, host plant resistance is yet another essential technique. Without the use of chemical controls, the use of soybean cultivars resistant to some specific pests, such as the soybean aphid (*Aphis glycines*) and other lepidopteran pests, can greatly reduce pest damage (Clifton et al., 2018). Studies have indicated that the integration of resistant genotypes in soybeans into pest management approaches can successfully decrease pest populations and minimize the use for insecticides, hence reducing the negative effects on the environment (Ongaratto et al., 2021). Furthermore, high efficacy in suppressing important lepidopteran pests has been demonstrated by the creation of genetically modified (GM) soybean cultivars, such as those expressing *Bacillus thuringiensis* (Bt) Cry proteins. This further supports the significance of host plant resistance in integrated pest management (IPM) (Horikoshi et al., 2021).

Chemical control is still a crucial part of managing pests in soybeans, especially when populations of pests surpass economic limits. But according to the IPM strategy, pesticides should only be used sparingly and in concert with other forms of control (Bortolotto et al., 2015). Furthermore, the adoption of economic thresholds optimizes pest management efforts and minimizes needless pesticide applications by assisting farmers in making well-informed decisions about when to apply chemical controls (Bueno et al., 2013).

EMERGING SOYBEAN PESTS IN BRAZIL AND THE UNITED STATES

With the expansion and intensification of soybean cultivation, new insect problems have been observed in these crops which are considered as emerging pests. A high number of pest species can occur along the culture cycle, but these previously occasional or secondary pests may reach new levels of population density and suddenly change the status of pests, raising them to the status of emerging pests (Jones et al., 2019).

The whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) represents significant threats to soybean crops, causing direct and indirect damage through their feeding. Whiteflies feed on plant sap, leading to physiological disorders that can affect photosynthesis and overall plant health, causing stress and reduced growth in soybean plants (Silva et al., 2024). High levels of infestation affect gas exchange parameters, decreasing photosynthetic rates and water use efficiency, particularly in susceptible cultivars (Toledo et al., 2021). Indirectly they can cause damage as they act as vectors for viruses, exacerbating crop losses. Whiteflies transmit begomoviruses and criniviruses, leading to severe viral diseases that can devastate soybean yields (Silva et al., 2024). Infestations can reduce soybean yields by up to 80%, potentially resulting in total crop failure if not managed (Erdiansyah et al., 2023).

Thrips are tiny insects that feed on plants. They are pests of most agricultural and horticultural crops (Rajesh et al., 2023). Most thrips are phytophagous, but there are also mycophagous and predatory species. These insects inhabit a wide variety of habitats; however, they are generally found in tropical, subtropical, and temperate regions (Ananthakrishnan, 1993). In the case of phytophagous thrips, their damage to plants can be direct (sap-sucking) or indirect (virus transmission) (Neves et al., 2022; Santos et al., 2021). In soybeans, thrips are important pests in some production areas and preferentially attack the aerial parts of the plants, such as leaves, flowers, branches, and fruits, causing productivity losses (Santos et al., 2021; Gent et al., 2004). The main thrips species found causing damage to soybean plants belong to the genera *Caliothrips* and *Frankliniella* (Gamundi and Perotti, 2009; Santos et al., 2021).

Leaf-mining insects are known for causing injury to the leaf tissue of their host plants, the mines caused by the larvae while feeding protected inside the leaves (Kirichenko et al., 2023; Liu et al., 2015). Three native leaf miners are known to feed on soybean in North America, *Odontota horni* (Smith), *O. dorsalis* (Thunberg), and *Sumitrosis rosea* (Weber) (Coleoptera: Chrysomelidae) (Buntin and Pedigo, 1982, McPherson and Ravlin, 1983). However, these species hardly ever have economic relevance for soybean production (Buntin, 1994). On the other hand, *Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae) is a serious pest of soybean in Africa, Asia, and Australia (Buthelezi et al., 2021; Koch et al., 2021). Recently, a new leaf-mining insect has been documented feeding on soybean in Canada and the United States, *Macrosaccus morrisella* (Fitch) (Lepidoptera: Gracillariidae), the soybean tentiform leafminer (Koch et al. 2021; Ribeiro et al., 2024). The leaf tissue where *M. morrisella* feed on eventually dies, which reduces the photosynthetic area of the leaf, and could potentially lead to a reduction in plant yield (Ribeiro et al., 2024).

INTEGRATED PEST MANAGEMENT OF WHITEFLY

Because chemical pesticides have historically played a major role in whitefly management in Brazil, resistant populations of *B. tabaci* MEAN1 have emerged (Dângelo et al., 2018). Because of the vascular transfer of whitefly nymphs within soybean plants, systemic insecticides such neonicotinoids have been found to be efficient in controlling them (Pozebon et al., 2019). According to research, several genotypes of soybeans include antixenosis and antibiosis features that can dramatically lower the number of whiteflies and their harm (Silva et al., 2012). In addition, techniques for sampling and monitoring have been developed to enhance the evaluation of whitefly populations and guide management choices. Arcanjo et al., (2024) proposed a standardized sampling plan specifically designed to assess *B. tabaci* adults across all stages of commercial soybean cultivation in tropical areas.

Because whiteflies are less common in the United States than they are in Brazil, the management strategy for soybean crops there is a little different. In the United States, scouting, economic treatment thresholds, and the application of selective insecticides that reduce damage to beneficial insects are frequently combined as management methods (Bueno et al., 2013). Predators and parasitoids are two more biological control agents that are used, though less so than in Brazil. Similar emphasis is placed on resistant soybean varieties, with current research aiming at cultivating and releasing cultivars that are resistant to infestations by whiteflies (Silva et al., 2012).

INTEGRATED PEST MANAGEMENT OF THRIPS

Thrips have emerged as important pests in Brazil's soybean fields (Neves et al., 2022; Santos et al., 2024). The integration of chemical applications, biological control, and cultural practices is emphasized in the Brazilian IPM method. Crop rotation and the elimination of substitute hosts that might support thrips populations are examples of cultural practices (Santos et al., 2024; Bortolotto et al., 2015). Given that some genotypes show decreased vulnerability to thrips infestations, the usage of resistant soybean cultivars is also being investigated (Neves et al., 2022). In Brazil, chemical control is still an important part of managing thrips, especially when populations surpass economic criteria. Depending on the extent of the infestation and the design of the fields, insecticides are administered sparingly, frequently with the use of tractors or aerial applications (Neves et al., 2022). But an excessive dependence on chemical controls has sparked worries about thrips populations developing resistance, calling for a well-rounded strategy that incorporates a variety of management techniques (Kilaso, 2022). The control of soybean thrips in the United States is distinguished by an emphasis on economic thresholds and monitoring. Because thrips populations can fluctuate greatly over the growing season, scouting for them is crucial (Funderburk et al., 2016). The United States' IPM tactics place a strong emphasis on biological management, much like

Brazil does. Studies have shown that natural enemies can effectively lower thrips populations (Funderburk et al., 2016).

INTEGRATED PEST MANAGEMENT OF SOYBEAN TENTFORM LEAFMINER

Regarding *M. morrisella*'s ecology and management, relatively little is known (Koch et al., 2021). However, two parasitoids, *Sympiesis marylandensis* Girault and *Pediobius albipes* (Provancher) (Eulophidae: Hymenoptera), are reported to prey on this species (Koch et al., 2021). As it is a new species, there are still no economic thresholds and sampling plans or control recommendations for this pest.

CONCLUSION

In conclusion, new pest species have emerged as a result of the development and intensification of soybean farming, posing a threat to crop yield in both Brazil and the US. In order to address these problems, integrated pest management, which combines chemical control, cultural practices, and biological control, has proven to be an effective technique. Sustainable techniques, including crop rotation, monitoring, and the adoption of resistant cultivars, are being used to reduce the environmental effect and prevent chemical resistance for pests like thrips and whiteflies. Although these pests have been managed more effectively, new threats such as *Macrosaccus morrisella* necessitate additional research to create sustainable management plans in order to maintain the sustainability of soybean production.

REFERÊNCIAS

ANANTHAKRISHNAN, T. N. Bionomics of thrips. **Annual Review of Entomology**, v. 38, n. 1, p. 71-92, 1993.

APPLE, J. L.; SMITH, R. F. (Ed.). **Integrated pest management**. New York: Plenum Press, 1976.

ARCANJO, L. P.; PEREIRA, P. S.; SANTOS, J. L.; REIS, K. H. B., GUEDES, A. G., FREITAS, D. R., LIMA, M. S.; LOPES, M. C.; SARMENTO, R. A.; PICANÇO, M. C. The first standardized sampling plan designed to scout *Bemisia tabaci* (Hemiptera: Aleyrodidae) adults in neotropical soybean crops. **Crop Protection**, v. 175, p. 106490, 2024. https://doi.org/10.1016/j.cropro.2023.106490

ÁVILA, C. J.; VESSONI, I. C.; SILVA, I. F.; VIEIRA, E. C. S.; MARIANI, A.; MOREIRA, S. C. S. IPM in soybeans: how to reduce crop damage and increase profit for the farmer. **Revista de Agricultura Neotropical**, v. 11, n. 2, p. e8214, 2024. https://doi.org/10.32404/rean.v11i2.8214

BARZMAN, M.; BÀRBERI, P.; BIRCH, A. N. E.; BOONEKAMP, P.; DACHBRODT-SAAYDEH, S.; GRAF, B.; HOMMEL, B.; JENSEN, J. E.; KISS, J.; KUDSK, P.; LAMICHHANE, J. R.; MESSÉAN, A.; MOONEN, A. C.; RATNADASS, A.; RICCI, P.; SARAH, J. L.; SATTIN, M. Eight principles of integrated pest management. **Agronomy for sustainable development**, v. 35, p. 1199-1215, 2015. https://doi.org/10.1007/s13593-015-0327-9

BINNS, M. R.; NYROP, J. P. Sampling insect populations for the purpose of IPM decision making. **Annual Review of Entomology**, v. 37, n. 1, p. 427-453, 1992.

BOETHEL, D. J. Integrated Management of Soybean Insects. In: SHIBLES, R. M.; HARPER, J. E.; WILSON, R. F.; SHOEMAKER, R. C. (Ed.). **Soybeans: Improvement, Production, and Uses.** 3. ed. v. 16. Madison: American Society of Agronomy, 2004. p. 853-882.

BORTOLOTTO, O. C.; POMARI-FERNANDES, A.; BUENO, R. C. O. F.; BUENO, A. F.; DA CRUZ, Y. K. S.; SANZOVO, A.; FERREIRA, R. B. The use of soybean integrated pest management in Brazil: a review. **Agronomy Science and Biotechnology**, v. 1, n. 1, p. 25-32, 2015. https://doi.org/10.33158/ASB.2015v1i1p25

BOTTRELL, D.R. **Integrated Pest Management.** Washington: Council on Environmental Quality, 1979.

BUENO, A. F.; PANIZZI, A. R.; CORRÊA-FERREIRA, B. S.; HOFFMANN-CAMPO, C. B.; SOSA-GOMEZ, D. R.; GAZZONI, D. L.; HIROSE, E.; MOS-CARDI, F.; CORSO, I. C.; OLIVEIRA, L. J.; ROGGIA, S. Histórico e evolução do manejo integrado de pragas da soja no Brasil. In: HOFFMANN-CAMPO, C. B.; CORRÊA-FERREIRA, B. S.; MOSCARDI, F. (Ed.). **Soja: manejo integrado de insetos e outros Artrópodes-praga.** Brasília, DF: Embrapa, 2012. p. 37-74.

BUENO, A. F.; PANIZZI, A. R.; HUNT, T. E.; DOURADO, P. M.; PITTA, R. M.; GONÇALVES, J. Challenges for adoption of integrated pest management (IPM): the soybean example. **Neotropical Entomology**, v. 50, p. 5-20, 2021. https://doi.org/10.1007/s13744-020-00792-9

BUENO, A. F.; PAULA-MORAES, S. V.; GAZZONI, D. L.; POMARI, A. F. Economic thresholds in soybean-integrated pest management: old concepts, current adoption, and adequacy. **Neotropical Entomology**, v. 42, p. 439-447, 2013. https://doi.org/10.1007/s13744-013-0167-8

BUNTIN, G. D.; PEDIGO, L. P. Foliage consumption and damage potential of *Odontota horni* and *Baliosus nervosus* (Coleoptera: Chrysomelidae) on soybean. **Journal of Economic Entomology**, v. 75, n. 6, p. 1034-1037, 1982. https://doi.org/10.1093/jee/75.6.1034

BUNTIN, G. D. Soybean leafminer. In: HIGLEY, L. G.; BOETHEL, D. J. (ed.). **The handbook of soybean insect pests.** Lanham: The Entomological Society of America, 1994. p. 79-80.

BUTHELEZI, M. N.; CONLONG, D. E.; ZHARARE, G. E. Review of the biosystematics and bio-ecology of the groundnut/soya bean leaf miner species (Lepidoptera: Gelechiidae). **Austral Entomology**, v. 60, n. 2, p. 276-284, 2021. https://doi.org/10.1111/aen.12528

CLIFTON, E. H.; TYLKA, G. L.; GASSMANN, A. J.; HODGSON, E. W. Interactions of effects of host plant resistance and seed treatments on soybean aphid (*Aphis glycines* Matsumura) and soybean cyst nematode (*Heterodera glycines* Ichinohe). **Pest Management Science**, v. 74, n. 4, p. 992-1000, 2018. https://doi.org/10.1002/ps.4800

DÂNGELO, R. A. C.; MICHEREFF-FILHO, M.; CAMPOS, M. R.; DA SILVA, P. S.; GUEDES, R. N. C. Insecticide resistance and control failure likelihood of the whitefly *Bemisia tabaci* (MEAM1; B biotype): a Neotropical scenario. **Annals of Applied Biology**, v. 172, n. 1, p. 88-99, 2018. https://doi.org/10.1111/aab.12404

DARA, S. K. The new integrated pest management paradigm for the modern age. **Journal of Integrated Pest Management**, v. 10, n. 1, p. 12, 2019. https://doi.org/10.1093/jipm/pmz010

ERDIANSYAH, I.; SUWARDI, S.; WULANDARI, G. *Beauveria bassiana* untuk Pengendalian *Bemisisa tabaci* pada Budidaya Kedelai Organik. **Agrotechnology Research Journal**, v. 7, n. 2, p. 79-84, 2023.

FUNDERBURK, J.; FRANTZ, G.; MELLINGER, C.; TYLER-JULIAN, K.; SRIVASTAVA, M. Biotic resistance limits the invasiveness of the western flower thrips, *Frankliniella occidentalis* (Thysanoptera: Thripidae), in Florida. **Insect science**, v. 23, n. 2, p. 175-182, 2016. https://doi.org/10.1111/1744-7917.12250

GAMUNDI, J.C.; PEROTTI, E. Evaluación de daño de *Frankliniella schultzei* (Trybom) y *Caliothrips phaseoli* (Hood) en diferentes estados fenológicos del cultivo de soja. **Para mejorar la producción**, v. 42, p. 107-111, 2009.

GENT, D. H.; SCHWARTZ, H. F.; KHOSLA, R. Distribution and incidence of Iris yellow spot virus in Colorado and its relation to onion plant population and yield. **Plant Disease**, v. 88, n. 5, p. 446-452, 2004. https://doi.org/10.1094/PDIS.2004.88.5.446

HIGLEY, L. G.; PETERSON, R. K. D. The biological basis of the EIL. In: HIGLEY, L. G.; PEDIGO, L. P. (ed.). **Economic thresholds for integrated pest management.** Nebraska: University of Nebraska Press, 1996. p. 22-40.

HORIKOSHI, R. J.; DOURADO, P. M.; BERGER, G. U.; FERNANDES, D. S.; OMOTO, C.; WILLSE, A.; MARTINELLI, S.; HEAD, G. P.; CORRÊA, A. S. Large-scale assessment of lepidopteran soybean pests and efficacy of Cry1Ac soybean in Brazil. **Scientific Reports**, v. 11, p. 15956, 2021. https://doi.org/10.1038/s41598-021-95483-9.

JACK, C. J.; ELLIS, J. D. Integrated pest management control of Varroa destructor (Acari: Varroidae), the most damaging pest of (*Apis mellifera* L. (Hymenoptera: Apidae)) colonies. **Journal of Insect Science**, v. 21, n. 5, p. 6, 2021. https://doi.org/10.1093/jisesa/ieab058

JONES, R. W., ILLESCAS-RIQUELME, C., LÓPEZ-MARTÍNEZ, V., BAUTISTA-MARTÍNEZ, N., & O'BRIEN, C. W. Emergent and possible invasive pest species of weevils in Mexico. **Florida Entomologist**, v. 102, n. 3, p. 480-485, 2019.

KILASO, M. Toxicity for control of *Frankliniella schultzei* and *Selenothrips rubrocinctus* (Thysanoptera: Thripidae) of several common synthetic insecticides. **Florida Entomologist**, v. 105, n. 2, p. 155-159, 2022.

KIRICHENKO, N. I.; KOLYADA, N. A.; GOMBOC, S. First discovery of the north American leaf-mining moth *Chrysaster ostensackenella* (Lepidoptera: Gracillariidae) in Russia: the genetic diversity of a novel pest in invaded vs. native range. **Insects**, v. 14, n. 7, p. 642, 2023. https://doi.org/10.3390/insects14070642

KOCH, R. L.; MOISAN-DE SERRES, J.; RIBEIRO, A. V. First Reports of *Macrosaccus morrisella* (Lepidoptera: Gracillariidae) Feeding on Soybean, *Glycine max* (Fabales: Fabaceae). **Journal of Integrated Pest Management**, v. 12, n. 1, p. 44, 2021. https://doi.org/10.1093/jipm/pmab038

KOGAN, M. Integrated pest management: historical perspectives and contemporary developments. **Annual review of entomology**, v. 43, n. 1, p. 243-270, 1998. https://doi.org/10.1146/annurev.ento.43.1.243

KOGAN, M.; HEINRICHS, E. A. **Integrated management of insect pests: current and future developments.** Cambridge: Burleigh Dodds Science Publishing Limited, 2020.

LINCOLN, C.; BOYER, W. P.; MINER, F. D. The Evolution of Insect Pest Management in Cotton and Soybeans: Pas Experience, Present Status, and Future Outlook in Arkansas. **Environmental Entomology**, v. 4, n. 1, p. 1-7, 1975. https://doi.org/10.1093/ee/4.1.1

LIU, W. H.; DAI, X. H.; XU, J. S. Influences of leaf-mining insects on their host plants: A review. **Collectanea botanica**, v. 34, p. 005, 2015.

LOPES, M. C.; RIBEIRO, A. V.; COSTA, T. L.; ARCANJO, L. P.; FARIAS, E. S.; SANTOS, A. A.; RAMOS, R. S.; ARAÚJO, T. A.; PICANÇO, M. C. Practical sampling plan for *Liriomyza huidobrensis* (Diptera: Agromyzidae) in tomato crops. **Journal of Economic Entomology**, v. 112, n. 4, p. 1946-1952, 2019. https://doi.org/10.1093/jee/toz091

MCPHERSON, R. M.; RAVLIN, F. W. Locust leaf miner development on soybean in Virginia. **Journal of the Georgia Entomological Society**, v. 18, n. 1, p. 58-60, 1983.

NEVES, D. V. C.; LOPES, M. C.; SARMENTO, R. A.; PEREIRA, P. S.; PIRES, W. S.; PELUZIO, J. M.; PICANÇO, M. C. Economic injury levels for control decision-making of thrips in soybean crops (*Glycine max* (L.) Merrill). **Research, Society and Development**, v. 11, n. 9, p. e52411932114, 2022. https://doi.org/10.33448/rsd-v11i9.32114

OLIVEIRA, R. C. D.; IKUNO, P. H. P.; PRATISSOLI, D.; CARVALHO, J. R. D.; HOBACK, W. W.; SALAMINA, B. A. Z. Biological characteristics and thermal requirements of *Telenomus podisi* and *Trissolcus basalis* (Hymenoptera: Scelionidae) in fresh and cryopreserved eggs of *Euschistus heros* and *Nezara viridula* (Hemiptera:

Pentatomidae). **Agronomy**, v. 14, n. 1, p. 170, 2024. https://doi.org/10.3390/agronomy14010170

ONGARATTO, S.; SILVEIRA, C. M.; SANTOS, M. C.; GORRI, J. E. R.; SARTORI, M. M. P.; HUNT, T. E.; LOURENÇÃO, A. L.; BALDIN, E. L. L. Resistance of soybean genotypes to *Anticarsia gemmatalis* (Lepidoptera: Erebidae): Antixenosis and antibiosis characterization. **Journal of Economic Entomology**, v. 114, n. 6, p. 2571-2580, 2021. https://doi.org/10.1093/jee/toab197

O'NEAL, M. E.; JOHNSON, K. D. Insect pests of soybean and their management. In: SINGH, G. (Ed.). **The soybean: botany, production and uses**. Cambridge: CAB International, 2010. p. 300-324. https://doi.org/10.1079/9781845936440.0300

PANIZZI, A. R. History and contemporary perspectives of the integrated pest management of soybean in Brazil. **Neotropical entomology**, v. 42, n. 2, p. 119-127, 2013. https://doi.org/10.1007/s13744-013-0111-y

PEDIGO, L. P. Closing the gap between IPM theory and practice. **Journal of Agricultural Entomology**, v. 12, n. 4, p. 171-181, 1995.

PEDIGO, L. P.; HUTCHINS, S. H.; HIGLEY, L. G. Economic injury levels in theory and practice. **Annual Review of Entomology**, v. 31, p. 341-368, 1986.

PEREIRA, P.S.; SARMENTO, R.A.; GALDINO, T.V.S.; LIMA, C.H.O.; DOS SANTOS, F.A.; SILVA, J.; DOS SANTOS, G.R.; PICANÇO, M.C. Economic injury levels and sequential sampling plans for *Frankliniella schultzei* in watermelon crops. **Pest Management Science**, v. 73, n. 7, p. 1438-1445, 2017.

PICANÇO FILHO, M. C.; LIMA, E.; CARMO, D. G.; PALLINI, A.; WALERIUS, A. H.; DA SILVA, R. S.; SANT'ANA, L. C. S.; LOPES, P. H. Q.; PICANÇO, M. C. Economic Injury Levels and Economic Thresholds for *Leucoptera coffeella* as a Function of Insecticide Application Technology in Organic and Conventional Coffee (Coffea arabica), Farms. **Plants**, v. 13, n. 5, p. 585, 2024. https://doi.org/10.3390/plants13050585

POZEBON, H.; CARGNELUTTI FILHO, A.; GUEDES, J. V. C.; FERREIRA, D. R.; MARQUES, R. P.; BEVILAQUA, J. G.; PATIAS, L. S.; COLPO, T. L.; ARNEMANN, J. A. Distribution of *Bemisia tabaci* within soybean plants and on individual leaflets. **Entomologia Experimentalis et Applicata**, v. 167, n. 5, p. 396-405, 2019. https://doi.org/10.1111/eea.12798

RAJESH, V.; RAKESH, V.; JANGRA, S.; GHOSH, A. RNA Interference in Thrips Vectors: A Step Forward Toward Sustainable Management. **Indian Journal of Entomology**, p. 1–10, 2023. https://doi.org/10.55446/IJE.2023.1113

RIBEIRO, A. V.; MENGER, J. P.; FÜHR, F. M.; KOCH, R. L. Immature development and adult longevity of the soybean tentiform leafminer (Lepidoptera: Gracillariidae). **Environmental Entomology**, v. 53, n. 4, p. 723-729, 2024. https://doi.org/10.1093/ee/nvae059.

SANTOS, J. L.; PEREIRA, P. S.; REIS, K. H. B.; FREITAS, D. R.; PICANÇO FILHO, M. C.; PELUZIO, J. M.; SARMENTO, R. A.; GUEDES, R. N. C.; PICANÇO, M. C. Decision-making for thrips control in soybean fields using precision agriculture principles. **Journal of Applied Entomology**, v. 148, n. 2, p. 140-149, 2024. https://doi.org/10.1111/jen.13215

SANTOS, R. C.; LOPES, M. C.; SARMENTO, R. A.; PEREIRA, P. S.; PICANÇO, M. M.; PIRES, W. S.; NOLETO, L. R.; ARAÚJO, T. A.; PICANÇO, M. C. Conventional sampling plan for thrips in tropical soybean fields. **Crop Protection**, v. 148, n. 1, p. 105740, 2021. https://doi.org/10.1016/j.cropro.2021.105740

SILVA, L. B.; ALMEIDA, L. C.; SILVA, M. C. F.; BRITO, R. R.; MIRANDA, R. S.; RODRIGUES, R. H. F.; SANTOS, C. M. P.; RIBEIRO, G. S.; MORAIS, J. V. S.; SILVA, A. F. T.; MAYARD, H.; OLIVEIRA, T. R.; LIMA, V. M. G. C.; FONTES, L. S.; ROCHA, N. S.; LACERDA, J. J.; PAVAN, B. E. Change in the Physiological Aspects of Soybean Caused by Infestation by *Bemisia tabaci* MEAM1. **Agronomy**, v. 14, n. 3, p. 481, 2024. https://doi.org/10.3390/agronomy14030481

SILVA, J. P. G. F.; BALDIN, E. L. L.; SOUZA, E. S.; LOURENÇÃO, A. L. Assessing *Bemisia tabaci* (Genn.) biotype B resistance in soybean genotypes: antixenosis and antibiosis. **Chilean Journal of Agricultural Research**, v. 72, n. 4, p. 516, 2012.

STERN, V. M.; SMITH, R. F.; VAN DEN BOSCH, R.; HAGEN, K. S. The integration of chemical and biological control of the spotted alfalfa aphid: The integrated control concept. **Hilgardia**, v. 29, n.2, p. 81-101, 1959. https://doi.org/10.3733/hilg.v29n02p081

TOLEDO, C. A. L.; PONCE, F. S.; OLIVEIRA, M. D.; AIRES, E. S.; SEABRA JÚNIOR, S.; LIMA, G. P. P.; OLIVEIRA, R. C. Change in the physiological and biochemical aspects of tomato caused by infestation by cryptic species of *Bemisia tabaci* MED and MEAM1. **Insects**, v. 12, n. 12, p. 1105, 2021. https://doi.org/10.3390/insects12121105

TURNIPSEED, S. G.; KOGAN, M. Principles and history of soybean pest management. In: HIGLEY, L. G.; BOETHEL, D. J. (Ed.). **Handbook of soybean insect pests**. Lanham: Entomological Society of America, 1994. p. 109-110.

TURNIPSEED, S. G.; KOGAN, M. Soybean entomology. **Annual Review of Entomology**, v. 21, n. 1, p. 247-282, 1976.

USDA - UNITED STATES DEPARTMENT OF AGRICULTURE FOREIGN AGRICULTURAL SERVICE. **Production - Soybeans.** 2024. Available at: https://fas.usda.gov/data/production/commodity/2222000. Accessed on 07 Aug. 2024.