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Herbivorous Insects in Barley Cultivation: Impact and Control Methods

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Abstract Barley, as an important global grain crop, faces threats to its yield and quality from various herbivorous insects such as aphids, cereal leaf beetles, and wireworms. These insects not only cause direct damage to the crop through feeding and tunneling but also indirectly affect barley yield by transmitting diseases and triggering secondary infections. This study systematically analyzes the biological characteristics of these insects, their impact on barley yield, and existing control methods, including chemical control, biological control, cultural control, and Integrated Pest Management (IPM). By summarizing existing research findings and case studies, this study aims to provide guidance for future pest monitoring, resistance breeding, and the application of emerging technologies in barley cultivation, and to identify areas for further research.
Keywords Herbivorous insects; Barley cultivation; Integrated Pest Management (IPM); Disease transmission

1 Introduction

Barley (*Hordeum vulgare* L.) is a significant cereal crop cultivated globally for its use in food, feed, and brewing industries. It is particularly valued for its adaptability to diverse climatic conditions and soil types, making it a staple in many agricultural systems. The cultivation of barley involves various agronomic practices aimed at optimizing yield and quality, including soil preparation, seeding, fertilization, and pest management.

Herbivorous insects pose a substantial threat to barley cultivation by directly consuming plant tissues and indirectly affecting plant health through the transmission of diseases. These pests can lead to significant yield losses and reduced grain quality, impacting the economic viability of barley farming. For instance, the wheat stem sawfly (*Cephus cinctus* Norton) is known to cause considerable damage to barley crops by feeding on the stems, leading to plant lodging and reduced grain fill (Achhami et al., 2020). Additionally, the cereal leaf beetle (*Oulema melanopus* L.) has been documented to invade barley fields, causing defoliation and further compromising crop productivity (Dosdall et al., 2011).

This study synthesizes the existing knowledge on the effects of herbivorous insects on barley cultivation and evaluates various control methods. This includes studying the evolutionary adaptation of pests to different agricultural practices, the role of plant immunity and chemical defense in mitigating insect damage, and the potential of biological control agents such as entomopathogenic fungi. By integrating the results of several studies, it aims to gain a comprehensive understanding of the challenges faced by herbivorous insects in barley cultivation and highlight innovative approaches to sustainable pest management.

2 Major Herbivorous Insects Affecting Barley

2.1 Aphids

Aphids are a significant group of phloem-feeding insects that impact barley cultivation. Several species of aphids are known to infest barley, including the bird cherry-oat aphid (*Rhopalosiphum padi*), the rose-grain aphid (*Metopolophium dirhodum*), the corn leaf aphid (*Rhopalosiphum maidis*), and the Russian wheat aphid (*Diuraphis noxia*) (Anton and Cortesero, 2022). These species vary in their impact on barley, with some being major pests and others causing occasional or minimal damage. For instance, *R. padi* and *M. dirhodum* are considered significant pests of cereal crops, while *R. maidis* is an occasional pest (Skoracka et al., 2022). Aphids affect barley in several ways, primarily through direct feeding and the transmission of plant viruses such as Barley Yellow

Dwarf Virus (BYDV). The feeding activity of aphids can lead to a reduction in plant biomass, as observed with a biomass conversion ratio indicating a 3.4 mg reduction in plant growth for each milligram gained in aphid biomass. This feeding can also alter the physiological responses of barley, such as changes in gas-exchange parameters and chlorophyll fluorescence, which can affect the plant's photosynthetic capacity (Anton and Cortesero, 2022).

Moreover, aphid infestations can be influenced by environmental factors and interactions with other organisms. For example, the presence of soil protozoa has been shown to increase the nitrogen content in barley plants, thereby enhancing aphid performance. Additionally, interactions with weeds can affect aphid acceptance of barley plants, with certain weed species reducing aphid colonization on barley. Control methods for aphid infestations in barley include the use of insecticide seed treatments and foliar insecticides, which have been shown to significantly reduce aphid populations and the incidence of BYDV, thereby increasing crop yield (Myers and Sarfraz, 2017). Furthermore, understanding the molecular interactions between barley and aphids can aid in developing resistant barley varieties. For instance, the up-regulation of thionin genes in barley has been associated with increased resistance to aphid infestation (Rashidi et al., 2020).

2.2 Barley yellow dwarf virus (BYDV) vectors

Aphids are the primary vectors of the Barley Yellow Dwarf Virus (BYDV), which is a significant pathogen affecting barley and other cereal crops. The most prevalent aphid species involved in the transmission of BYDV include *Rhopalosiphum padi*, *Schizaphis graminum*, and *Sitobion avenae*. These aphids acquire the virus by feeding on infected plants and subsequently transmit it to healthy plants during their feeding process. The efficiency of virus transmission varies among aphid species, with *R. padi* being particularly effective in spreading BYDV-PAV, the most common serotype of the virus (Abdel-Samed, 2017). The transmission dynamics are influenced by factors such as aphid population density, feeding behavior, and environmental conditions (Aradottir and Crespo-Herrera, 2021). Infected barley plants exhibit a range of symptoms including yellowing of leaves, stunted growth, and reduced tillering. These symptoms can lead to significant yield losses, with reductions in grain yield ranging from 5% to 80% depending on the severity of the infection and the specific BYDV serotype involved (Thackray et al., 2009). The damage caused by BYDV is not only due to the direct effects of the virus on plant physiology but also due to the secondary effects of aphid feeding, which can further stress the plants and exacerbate the symptoms(Aradottir and Crespo-Herrera, 2021).

2.3 Cereal leaf beetles

Cereal leaf beetles (*Oulema melanopus*) are another important pest in barley cultivation. The lifecycle of the cereal leaf beetle includes four stages: egg, larva, pupa, and adult. The larvae are the most damaging stage, feeding on the leaves of barley plants and creating long, narrow strips of damage (Elimem et al., 2022). This feeding behavior reduces the photosynthetic capacity of the plants, leading to decreased growth and yield. The adults also feed on the leaves but cause less damage compared to the larvae. The economic impact of cereal leaf beetles on barley cultivation can be substantial. Infestations can lead to significant yield losses, particularly if they occur during the early stages of plant development. The cost of managing these pests includes expenses related to monitoring, insecticide applications, and potential yield losses (Velchev et al., 2023). Effective management strategies are essential to minimize the economic impact and ensure sustainable barley production.

2.4 Wireworms

Wireworms, the larvae of click beetles (Elateridae), are another group of pests that affect barley roots. Several species of wireworms are known to infest barley fields, with variations in their biology and behavior. These larvae are typically found in the soil, where they feed on the roots and underground stems of barley plants. Wireworms have a long lifecycle, often taking several years to develop from egg to adult, which makes them a persistent problem in infested fields (Poggi et al., 2021). Wireworms cause significant damage to barley roots by feeding on them, which can lead to poor plant establishment, stunted growth, and reduced yield. The damage is often more severe in fields with a history of wireworm infestations (Frank et al., 2014), as the larvae can survive in the soil for extended periods. Effective management of wireworms involves a combination of cultural practices, such as crop rotation and soil management, and the use of insecticides to reduce larval populations.

2.5 Other notable herbivorous insects

In addition to the major pests discussed above, several minor herbivorous insects can also affect barley cultivation. These include various species of thrips, leafhoppers, and caterpillars, which can cause damage to leaves, stems, and grains. While these pests are generally less impactful than aphids, cereal leaf beetles, and wireworms, they can still contribute to overall yield losses, particularly when present in high numbers or in combination with other stress factors. Integrated pest management strategies that include monitoring, biological control, and targeted insecticide applications are essential to manage these minor pests effectively.

3 Impact of Herbivorous Insects on Barley Yields

3.1 Direct damage: feeding and tunneling

Herbivorous insects cause significant direct damage to barley crops through feeding and tunneling activities. For instance, the Oulema spp. beetles, which include *Oulema melanopus* and *Oulema cyanella*, are known to induce volatile organic compounds (VOCs) in barley as a defensive response to their herbivory. This indicates substantial feeding damage that triggers the plant's defense mechanisms (Piesik et al., 2011). Additionally, aphid species such as *Rhopalosiphum padi* and *Rhopalosiphum maidis* have been documented to cause a 25.5% reduction in barley yield due to their feeding activities. The direct consumption of plant tissues by these insects not only reduces the photosynthetic capacity of the plants but also weakens their overall structure, leading to decreased growth and productivity (Meijden, 2015).

3.2 Indirect effects: disease transmission and secondary infections

Beyond direct feeding damage, herbivorous insects also play a crucial role in the transmission of plant diseases, which can further exacerbate yield losses. For example, the barley yellow dwarf virus (BYDV), transmitted by aphids such as *Rhopalosiphum padi* and *Sitobion miscanthi*, has been shown to cause a 39% reduction in barley yield, which is more severe than the damage caused by direct feeding (Kauppi et al., 2021). Furthermore, the presence of herbivorous insects can create entry points for secondary infections by pathogens. The mechanical injury caused by insects can facilitate the invasion of fungal pathogens like *Fusarium* spp., leading to additional stress and damage to the barley plants. This combination of direct and indirect effects significantly impacts the overall health and yield of barley crops.

3.3 Economic implications for barley production

The economic implications of herbivorous insect damage on barley production are substantial. Yield reductions due to insect herbivory translate directly into financial losses for farmers (Figure 1). For instance, the economic loss attributed to aphid feeding on barley is estimated at $19 per hectare, while the loss due to BYDV transmission is approximately $21 per hectare (Sánchez-Bayo, 2021). In boreal growing conditions, the yield reduction caused by insect pests in spring barley can range between 418 and 745 kg per hectare, highlighting the significant economic burden on barley producers (Bui et al., 2018). These losses underscore the importance of effective pest management strategies to mitigate the impact of herbivorous insects on barley yields and ensure the economic viability of barley cultivation.

4 Control Methods for Herbivorous Insects in Barley

4.1 Chemical control

Chemical control of herbivorous insects in barley primarily involves the use of insecticides. Organophosphates, such as chlorpyrifos and methidathion, are commonly applied to control pests like false wireworms and earth mites. These insecticides are often used prophylactically or reactively at higher concentrations to ensure effective pest control (Hill et al., 2017). However, the efficacy of these insecticides can vary, and their application needs to be carefully managed to avoid non-target effects and resistance development. The use of broad-spectrum insecticides poses significant risks, including the disruption of natural enemy communities and the potential for secondary pest outbreaks. For instance, the application of organophosphates has been shown to reduce the number of predatory beetles, which in turn can lead to an increase in slug populations, causing significant yield loss in subsequent crops like canola (Thompson et al., 2022). Additionally, the overuse of chemical insecticides can lead to the development of resistance in pest populations, necessitating the exploration of alternative control methods.

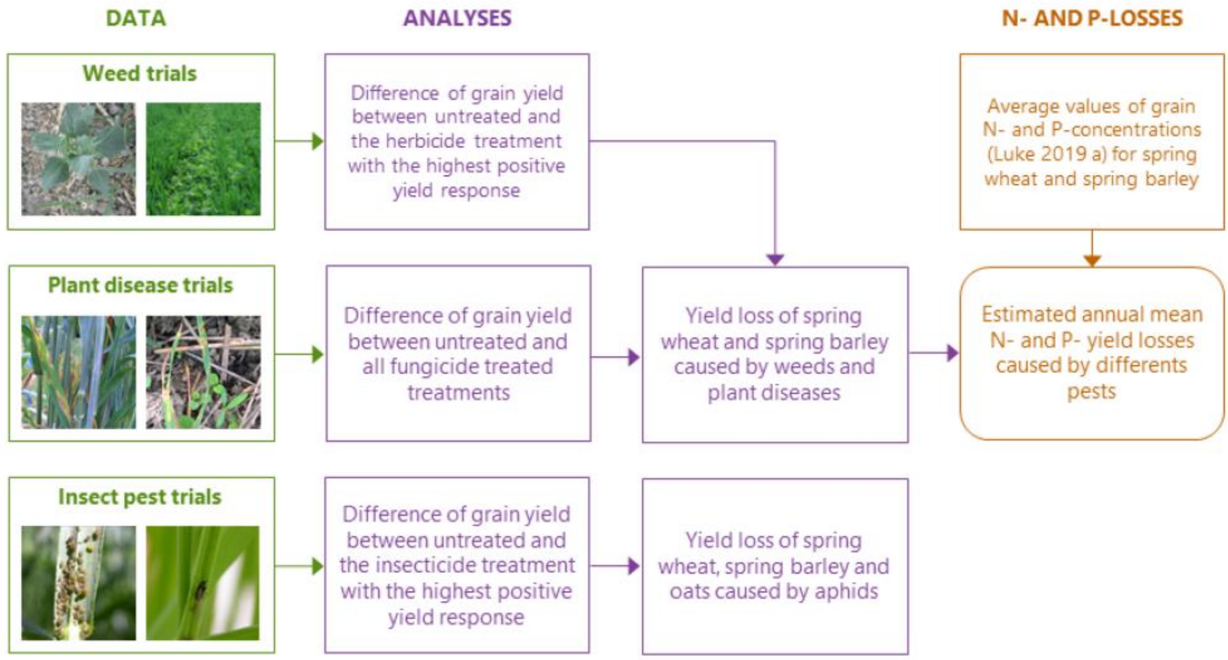

Figure 1 Plant diseases and insect pests on the grain yield of spring barley and spring wheat (Adopted from Kauppi et al., 2021)

4.2 Biological control

Biological control leverages natural enemies such as predators and parasitoids to manage herbivorous insect populations. For example, the use of synthetic herbivore-induced plant volatiles (HIPVs) can attract natural enemies like parasitoids and predatory insects to the crop, enhancing biological control (Simpson et al., 2011; Stetkiewicz et al., 2022). Transgenic crops expressing *Bacillus thuringiensis* (Bt) toxins also play a role by reducing the need for chemical insecticides, thereby benefiting natural enemy populations (Bažok et al., 2022). Conservation and augmentation strategies aim to maintain and enhance the populations of natural enemies. The 'attract and reward' approach, which combines HIPVs to attract beneficial insects and nectar plants to sustain them, has shown promise in increasing the abundance and residency of natural enemies in crops like sweetcorn and broccoli (Simpson et al., 2011). Such strategies can be integrated into pest management programs to reduce reliance on chemical controls and promote sustainable agriculture.

4.3 Cultural control

Cultural control methods, including crop rotation and field management, are essential for managing herbivorous insects in barley. Rotating barley with non-host crops can disrupt the life cycles of pests, reducing their populations. Effective field management practices, such as maintaining soil health and removing crop residues, can also minimize pest habitats and reduce infestations (Hill et al., 2017). Adjusting the timing of planting and harvesting can help avoid peak pest populations. For instance, planting barley early in the season may allow the crop to establish before pest populations reach damaging levels. Similarly, timely harvesting can prevent pests from completing their life cycles within the crop, thereby reducing their impact.

4.4 Integrated pest management (IPM)

Integrated Pest Management (IPM) in barley involves a combination of chemical, biological, and cultural control methods to manage pest populations sustainably. The principles of IPM include monitoring pest populations, using economic thresholds to guide control decisions, and integrating multiple control strategies to minimize the reliance on any single method (Romeis et al., 2006). Successful IPM implementation in barley has been demonstrated through the use of Bt-transgenic crops, which reduce the need for chemical insecticides and support biological control by natural enemies (Simpson et al., 2011). Additionally, the 'attract and reward' approach has shown potential in enhancing biological control in various crops, suggesting its applicability in barley cultivation as well. These case studies highlight the importance of integrating diverse control methods to achieve effective and sustainable pest management.

5 Case Study

5.1 Background and location

This case study focuses on barley cultivation in the western Canadian prairies, specifically in the provinces of Alberta, Saskatchewan, and Manitoba. These regions are significant for their extensive agricultural activities, particularly in the cultivation of cereals such as barley (*Hordeum vulgare* L.), which is a staple crop in these areas. The agroecosystems here have faced numerous challenges due to the invasion of various herbivorous insect species, which have had substantial impacts on crop yield and quality (Dosdall et al., 2011).

5.2 Overview of herbivorous insect challenges

Barley crops in the western Canadian prairies have been subjected to invasions by several alien herbivorous insects. These insects, including the cereal leaf beetle (*Oulema melanopus* L.) and the pea leaf weevil (*Sitona lineatus* L.), have caused significant damage by feeding on the crops and reducing their productivity. The cereal leaf beetle, in particular, has been a major pest (Figure 2), leading to considerable economic losses due to its feeding habits, which damage the leaves and reduce photosynthetic capacity (Agrawal and Maron, 2022). Additionally, the presence of these insects has been linked to the transmission of plant viruses, further exacerbating the challenges faced by barley farmers (Wielkopolan et al., 2021).

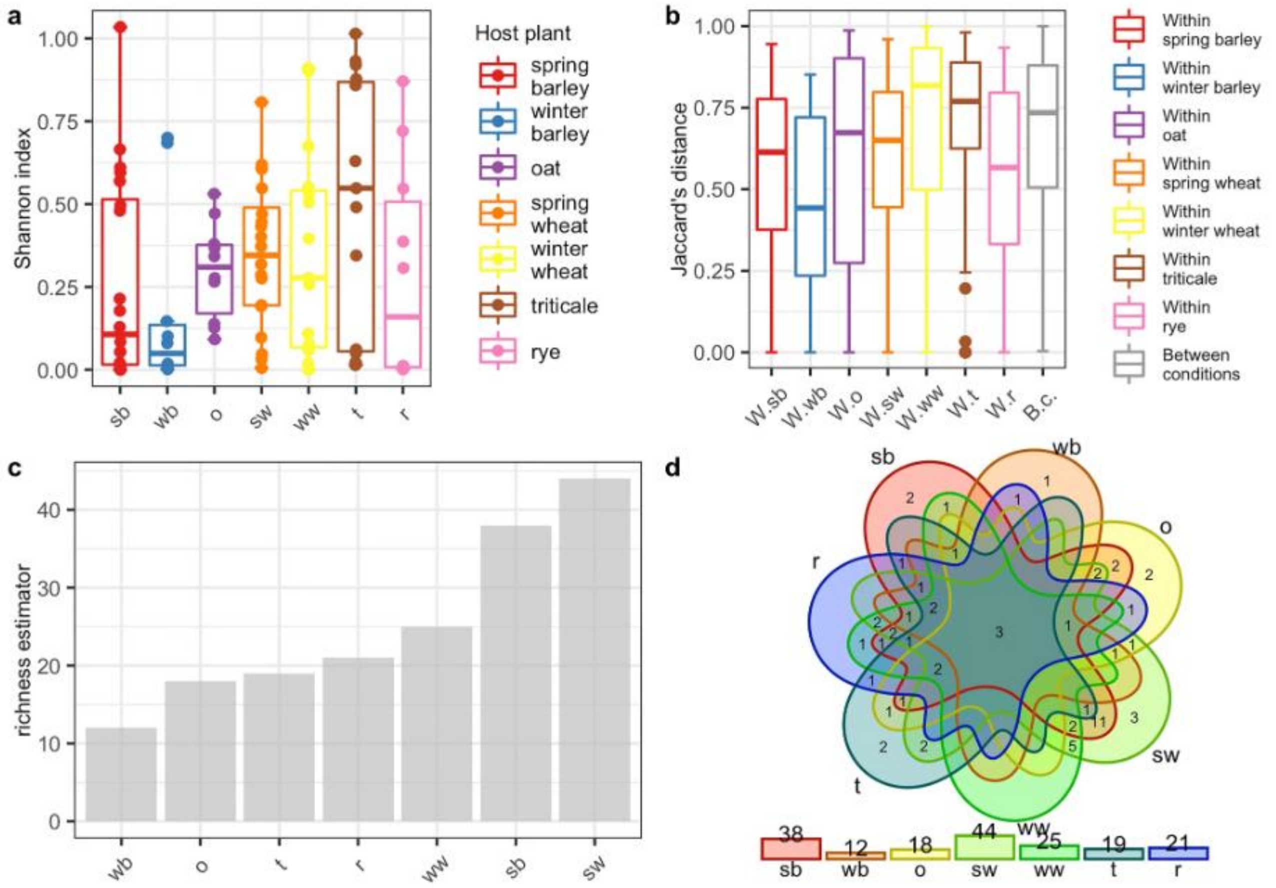

Figure 2 The structure of the cereal leaf beetle (*Oulema melanopus*) microbiome depends on the insect's developmental stage, host plant, and origin (Adopted from Wielkopolan et al., 2021)

Image caption: (a) alpha diversity of each group according to the Shannon index, (b) beta diversity of each sample according to the Jaccard distance (the vertical lines indicate the range excluding the outliers, the middle lines represent the median value, the boxes represent the upper and lower quartile values, (c) the jacknife coefficient determine the level of richness of bacterial community, (d) Venn diagram showing the number of shared bacteria species between insects collected from various cereal plant hosts observed in at least one sample (Adopted from Wielkopolan et al., 2021)

The figure of Wielkopolan et al. (2021) illustrates the diversity of microbiome structure in the cereal leaf beetle (*Oulema melanopus*), depending on the developmental stage of the insect, the host plant, and its origin. Through the analysis of Shannon index and Jaccard distance, it can be seen that there are significant differences in microbial diversity among different cereal hosts. In particular, the microbial communities of spring barley and winter wheat showed high diversity and richness. This study shows that host plants have a significant impact on the diversity and composition of the cereal leaf carapace microbiome, providing important clues for understanding the challenges faced by herbivores.

5.3 Applied control methods and their outcomes

To combat these herbivorous insect challenges, various control methods have been implemented. One effective strategy has been the use of biological control agents, such as the parasitoid *Tetrastichus julis* (Walker), which targets the cereal leaf beetle. This biological control method has shown promising results in reducing the population of the cereal leaf beetle and mitigating its impact on barley crops (Fernández-Conradi et al., 2018). Additionally, the application of entomopathogenic fungi has been explored as a biological control measure. These fungi infect and kill insect pests, providing a natural and environmentally friendly alternative to chemical pesticides. The integration of these biological control methods into pest management strategies has led to a reduction in insect populations and an improvement in barley crop yields.

5.4 Lessons learned and recommendations

The case study of barley cultivation in the western Canadian prairies highlights several important lessons. Firstly, the use of biological control agents, such as parasitoids and entomopathogenic fungi, can be highly effective in managing herbivorous insect populations and reducing their impact on crops. These methods offer sustainable and environmentally friendly alternatives to chemical pesticides, which can have detrimental effects on non-target organisms and the environment. Secondly, the importance of monitoring and early detection of invasive insect species cannot be overstated. Timely identification and intervention are crucial in preventing the establishment and spread of these pests. Finally, ongoing research and collaboration between farmers, researchers, and policymakers are essential to develop and implement effective integrated pest management strategies. By combining biological control methods with other cultural and mechanical practices, it is possible to achieve long-term and sustainable control of herbivorous insect pests in barley cultivation (Myers and Sarfraz, 3017).

6 Future Directions and Research Gaps

6.1 Advances in pest monitoring and early detection

Recent advancements in pest monitoring and early detection have shown significant promise in improving the management of herbivorous insects in barley cultivation. Technologies such as hyperspectral proximal sensors and machine learning algorithms have been successfully employed to predict insect herbivory damage and differentiate between types of insect attacks based on spectral responses. For instance, a study demonstrated the effectiveness of a machine learning-based approach using leaf reflectance measurements to monitor herbivory damage in maize, which could be adapted for barley (Furuya et al., 2021). Additionally, the use of drones equipped with advanced imaging technologies has been highlighted as a non-invasive method for early detection of pest outbreaks, allowing for timely and precise interventions (Filho et al., 2019). These technologies can detect physiological changes in plants due to biotic stress, providing a valuable tool for integrated pest management.

6.2 Potential of genetic resistance in barley varieties

The development of genetically resistant barley varieties presents a promising avenue for reducing the impact of herbivorous insects. Understanding the genetic basis of resistance and incorporating these traits into new barley cultivars could significantly enhance crop resilience. Research into the plasticity of chemical host plant recognition in herbivorous insects suggests that manipulating plant chemical cues could be a viable strategy for pest control (Anton and Cortesero, 2022). By breeding barley varieties that either repel pests or are less attractive to them, it may be possible to reduce the reliance on chemical pesticides and promote more sustainable agricultural practices.

6.3 Emerging technologies in pest control

Emerging technologies in pest control are revolutionizing the way we manage herbivorous insects in barley cultivation. The use of drones for precision pest management is particularly noteworthy. These drones can be used for both monitoring and actuation, such as releasing natural enemies or applying pesticides precisely where needed (Meng et al., 2018). Additionally, the exploitation of herbivore-induced plant volatiles (HIPVs) for pest monitoring is an innovative approach that could lead to more effective and environmentally friendly pest management strategies. HIPVs can serve as reliable indicators of plant health and pest presence, enabling early intervention and reducing crop losses (Skoracka et al., 2022).

6.4 Identified research needs and areas for exploration

Despite these advancements, several research gaps and needs remain. There is a need for further studies to fully understand the potential of HIPVs in pest monitoring and to develop reliable, cost-effective sampling techniques (Agrawal and Maron, 2022). Additionally, more research is needed to explore the genetic mechanisms underlying pest resistance in barley and to develop new resistant varieties. The integration of advanced technologies such as machine learning and drones into existing pest management frameworks also requires further investigation to optimize their use and ensure their accessibility to farmers. Collaborative, multidisciplinary research efforts will be essential to address these challenges and to develop sustainable, effective pest control methods for barley cultivation.

7 Concluding Remarks

Herbivorous insects pose significant challenges to barley cultivation, impacting both yield and quality. Studies have shown that alien insect species, such as the cereal leaf beetle and pea leaf weevil, have invaded agroecosystems in regions like the western Canadian prairies, causing substantial economic and ecological damage. The defense mechanisms of barley against these pests involve complex biochemical pathways, including the production of toxins and defensive proteins, as well as the emission of volatiles to attract natural predators. Additionally, the role of entomopathogenic fungi and other biological control agents has been explored as part of integrated pest management strategies to mitigate these impacts. Research also indicates that soil decomposer invertebrates can indirectly affect herbivorous insect populations by altering plant nutrient content, thereby influencing aphid performance on barley.

The findings underscore the critical need for effective pest management strategies in barley cultivation to ensure food security. The invasion of alien herbivorous insects and their subsequent impact on crop yields highlight the vulnerability of barley to pest outbreaks, which can have far-reaching consequences for global food supply. The dynamic nature of plant immunity to insect herbivores suggests that enhancing these natural defense mechanisms could be a viable approach to improving crop resilience. Moreover, the integration of biological control agents, such as entomopathogenic fungi, into pest management programs offers a sustainable alternative to chemical pesticides, potentially reducing environmental impact and promoting ecosystem health.

The battle against herbivorous insects in barley cultivation is ongoing and multifaceted. Continued research into plant defense mechanisms, pest invasion patterns, and biological control methods is essential for developing robust strategies to protect barley crops. Policymakers, researchers, and farmers must collaborate to implement integrated pest management practices that leverage both traditional and innovative approaches. By doing so, we can enhance the resilience of barley cultivation systems, safeguard global food security, and promote sustainable agricultural practices. Immediate action is required to address these challenges, ensuring that future generations can rely on a stable and secure food supply.

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Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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