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Comprehensive management strategies for *Alternaria brassicicola*-induced leaf spot in broccoli: botanical, chemical, and biological approaches

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Abstract

The *Alternaria* genus, comprising diverse fungal species, poses a substantial threat to global agricultural crops. Among these, *Alternaria brassicicola* significantly impacts broccoli cultivation, necessitating effective management. This deuteromycete fungus, lacking a known sexual stage, relies on asexual conidia production, contributing to its distinctive appearance. ALS consequences extend beyond direct crop damage, affecting seeds, seedlings, leaves, and heads. Understanding ALS population dynamics is crucial for targeted management, especially in organic farming. A comprehensive survey was conducted to gather information on the management of *Alternaria brassicicola*, the pathogen causing leaf spot in broccoli. The survey comprised seven sections, addressing demographic information, understanding of *Alternaria brassicicola*, botanical management, chemical management, biological management, integrated management approaches, and future strategies. The target participants included individuals involved in agriculture and horticulture, such as farmers/growers, researchers/scientists, agronomists, students, and others with varying years of experience in broccoli cultivation. Participants expressed moderate familiarity with *Alternaria brassicicola*, and the survey delved into their experiences, challenges, and perspectives related to management strategies. Results highlighted the utilization and effectiveness of botanical, chemical, and biological methods, with a notable acceptance of an integrated approach.

The findings underscore the prevalent use of chemical and biological methods, with a growing recognition of the potential of integrated approaches. Future research priorities should focus on understanding the pathogen's genetics, advancing biological controls, and developing disease-resistant cultivars, emphasizing a collaborative and holistic approach to effectively address *Alternaria brassicicola* in broccoli cultivation.

Keywords: *Alternaria brassicicola*, broccoli cultivation, disease management, integrated approach, survey

Introduction

The *Alternaria* genus plays a ubiquitous role in both air and soil ecosystems, encompassing various fungal species. While many of these species' act as saprophytes or opportunistic plant pathogens, some exhibit highly destructive characteristics, posing a substantial threat to a diverse range of agricultural crops globally (Rotem, 1994) [11]. Among these pathogenic species, *Alternaria brassicicola* emerges as a significant concern for the cultivation of broccoli and other Brassica spp., impacting crop yield and seed production and necessitating the implementation of effective management strategies (Humpherson-Jones & Maude, 1982) [7].

As deuteromycetes, *Alternaria* fungi lack a known sexual stage, relying solely on the production of asexual spores called conidia. These pigmented, elongated, club-shaped spores, featuring transverse and longitudinal septations, define the genus and contribute to its distinctive appearance (Humpherson-Jones & Maude, 1982; Andersen *et al.*, 2006) [7, 11]. Conidia can be produced individually or in chains, either on simple or branched conidiophores or directly on hyphae. Several *Alternaria* species have been identified as causing diseases in cultivated brassicas, with particular relevance to broccoli. Notable examples include *A. japonica*, affecting radish (*Raphanus sativus*), *A. brassicae*, known for its impact on oil and mustard seed crops (*B. rapa* and *B. napus*) and occasionally on vegetable crops (*B. oleracea*), and *A. brassicicola*, the predominant species affecting vegetable crops but also capable of infecting seed crops. Distinguishing between *A. brassicae* and *A. brassicicola* based on field symptoms or morphological characteristics in laboratory cultures can be challenging,

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emphasizing the need for effective management strategies (Andersen *et al.*, 2006) ^[1]. The consequences of *Alternaria* leaf spot (ALS) extend beyond direct crop damage, affecting seeds, seedlings, leaves, and heads. The disease's persistence during the storage of vegetable crops, such as cabbage, exacerbates its impact (Babadoost *et al.*, 1993) ^[3].

Understanding the population dynamics of ALS is pivotal for designing targeted and effective management approaches, considering the unique characteristics and dynamics of local ALS populations. Simultaneously, exploring disease management strategies compatible with organic farming is essential, given the increasing trend in organic cabbage production. These strategies encompass a range of practices, including cultural methods, biocontrol agents, resistant cultivars, and other organic-approved interventions (Hong *et al.*, 1996) ^[5]. As we delve deeper into the exploration of botanical, chemical, and biological approaches, it is crucial to understand the intricate interplay between *Alternaria brassicicola* and its host plants. The genetic and physiological factors influencing the pathogen's virulence and the host's resistance mechanisms will be explored to provide a holistic view of the disease dynamics (Chen *et al.*, 2003) ^[4].

The genetic diversity and population structure of *Alternaria brassicicola* are essential aspects that demand meticulous investigation. By employing advanced molecular techniques, such as DNA fingerprinting and sequencing, researchers aim to unravel the complex genetic landscape of the pathogen population. Understanding the genetic variations among different isolates will contribute to delineating the factors influencing the adaptability and aggressiveness of *Alternaria brassicicola* strains in the region (Chen *et al.*, 2003) ^[4]. Simultaneously, elucidating the genetic basis of host resistance mechanisms is integral to developing durable and sustainable management strategies. The identification of resistance genes within Brassica spp. and the exploration of their interaction with specific pathogen avirulence factors will guide the development of resistant cultivars. This genetic approach aligns with the overarching goal of breeding broccoli varieties that are inherently less susceptible to *Alternaria brassicicola* (Köhl *et al.*, 2011) ^[8] reducing the reliance on external disease management interventions.

In addition to genetic factors, the physiological and biochemical aspects of the interaction between *Alternaria brassicicola* and Brassica spp. will be thoroughly examined. This involves an in-depth analysis of the plant's defense mechanisms, including the production of secondary metabolites, phytoalexins, and the activation of defense-related genes (Lawrence *et al.*, 2008) ^[9]. Understanding the intricate biochemical pathways involved in the host's response to pathogen invasion is crucial for designing targeted strategies to enhance the plant's natural resistance.

A key component of effective disease management is a thorough understanding of the epidemiology of ALS. Epidemiological studies will investigate the spatial and temporal dynamics of *Alternaria brassicicola*, identifying hotspots and critical periods for disease development. The influence of climatic factors, such as temperature, humidity, and precipitation, on disease prevalence will be scrutinized to develop predictive models. This information is paramount for implementing timely and targeted disease management interventions. The role of cultural practices in ALS management will be explored, with a focus on optimizing planting dates, crop rotation, and intercropping strategies. These practices aim to disrupt the pathogen's life cycle, reduce inoculum levels, and create an unfavourable

environment for disease development. Furthermore, the integration of biocontrol agents, such as antagonistic microorganisms and beneficial insects, will be investigated for their potential in suppressing *Alternaria brassicicola* populations. This biological approach aligns with the principles of organic farming and offers sustainable solutions for ALS management (Lawrence *et al.*, 2008) ^[9]. Research will also delve into the potential of botanical extracts and essential oils as alternative management tools against ALS. The antimicrobial properties of certain plant extracts have shown promise in inhibiting the growth of *Alternaria brassicicola*. Investigating the efficacy of these botanical compounds in greenhouse and field trials will provide valuable insights into their practical applicability as eco-friendly alternatives to conventional fungicides (Chen *et al.*, 2003; Köhl *et al.*, 2011) ^[4, 8]. The chemical management of ALS will be addressed through a systematic exploration of fungicidal agents. This involves evaluating the effectiveness of existing chemical fungicides against *Alternaria brassicicola* and assessing their compatibility with organic farming practices. Additionally, the potential development of novel biofungicides and plant-based formulations will be explored, emphasizing a sustainable and environmentally friendly approach to chemical disease management (Ma & Michailides, 2004) ^[10]. As organic farming gains momentum, the challenges and opportunities it presents for ALS management cannot be understated. The 406% increase in organic cabbage production in NYS between 2008 and 2011 underscores the need for tailored disease management strategies compatible with organic practices. Investigating the efficacy of cultural, biological, and botanical approaches within the organic framework will provide insights into sustainable disease management practices for organic broccoli cultivation (Köhl *et al.*, 2011; Ma & Michailides, 2004) ^[8, 10]. Thus, this comprehensive paper of the botanical, chemical, and biological management of *Alternaria brassicicola*, the pathogen causing leaf spot in broccoli, aims to address the multifaceted challenges posed by ALS.

Materials and Methods

A comprehensive survey was conducted to gather information on the management of *Alternaria brassicicola*, the pathogen causing leaf spot in broccoli. The survey comprised seven sections, addressing demographic information, understanding of *Alternaria brassicicola*, botanical management, chemical management, biological management, integrated management approaches, and future strategies. The target participants included individuals involved in agriculture and horticulture, such as farmers/growers, researchers/scientists, agronomists, students, and others with varying years of experience in broccoli cultivation. The survey adhered to ethical guidelines, ensuring participant anonymity, informed consent, and confidentiality. The study protocol was reviewed and approved by an ethical review board. The survey was distributed electronically, and participants were encouraged to respond voluntarily. The questionnaire consisted of multiple-choice and open-ended questions, allowing for a detailed exploration of participants' experiences, challenges, and perspectives related to *Alternaria brassicicola* management in broccoli cultivation. Responses were collected over a designated period, ensuring a diverse and representative sample of individuals engaged in broccoli cultivation.

Survey analysis

In this study, we conducted a survey targeting individuals deeply involved in the intricate realm of broccoli cultivation.

Participants encompassed a diverse spectrum of roles within the agricultural and horticultural sectors, ranging from farmers and growers to seasoned researchers and agronomists. The survey took into account the wealth of experience these individuals brought to the table, with varying durations of involvement in broccoli cultivation. Additionally, participants were queried about their familiarity with *Alternaria brassicicola*, a pathogen of paramount concern in broccoli farming. Our study delved into the participants' experiences with *Alternaria brassicicola*, aiming to unravel the intricacies of their encounters with this pathogen. We probed the diagnostic methods employed by these individuals, seeking insights into the diverse approaches utilized for identifying *Alternaria brassicicola* in broccoli crops. Furthermore, participants were prompted to explain the predominant symptoms they observed, shedding light on the nuanced manifestations of this pathogen in the context of broccoli cultivation.

Within the realm of botanical management, our survey explored the utilization and effectiveness of various botanical methods employed by participants in their battle against *Alternaria brassicicola*. The challenges faced in implementing these botanical strategies were meticulously documented, providing a comprehensive understanding of the practical hurdles encountered. Additionally, participants were encouraged to provide valuable suggestions for improving the efficacy of botanical approaches, thereby contributing to the refinement of future disease management practices. The survey extended its focus to chemical management strategies employed by participants to combat *Alternaria brassicicola*. Participants shared insights into the specific chemical methods they utilized, the frequency of application, and the challenges faced in implementing chemical treatments. This section aimed to unravel the complexities associated with chemical interventions, exploring the nuances of their efficacy in real-world broccoli cultivation scenarios. Participants also offered suggestions for enhancing chemical treatments, pointing towards potential avenues for improvement and innovation. The use of biological control agents in managing *Alternaria brassicicola* was a crucial aspect explored in our survey. Participants provided insights into the effectiveness of biological methods, shedding light on their experiences with beneficial microbes, fungal antagonists, and predatory insects. Challenges faced in implementing biological management strategies were highlighted, offering a realistic perspective on the complexities associated with harnessing biological controls. Participants also contributed valuable suggestions for enhancing the efficiency of biological approaches in the context of broccoli cultivation.

Participants were invited to express their views on the integration of botanical, chemical, and biological methods for a holistic approach to *Alternaria brassicicola* management. Their perspectives on the perceived challenges and experiences with an integrated management approach were sought, offering a nuanced understanding of the feasibility and effectiveness of combining multiple strategies. This section aimed to unravel the synergies and potential hurdles associated with adopting an integrated approach in the intricate landscape of broccoli cultivation. The survey culminated in an exploration of participants' opinions regarding future advancements, research priorities, collaboration opportunities, and the role of public awareness in managing *Alternaria brassicicola* effectively. This segment aimed to capture the forward-looking perspectives of individuals deeply entrenched in the field, providing a roadmap for future research, innovation, and collaborative efforts to tackle the challenges posed by *Alternaria brassicicola* in the realm of broccoli cultivation.

Results

The demographic survey on individuals involved in broccoli cultivation reveals a diverse group with 21 participants, primarily composed of students (11), followed by researchers/scientists (7) and farmers/growers (3). The participant's exhibit varied levels of experience, with 14 having less than 1 year, 6 with 1-5 years, and 1 with 6-10 years in broccoli cultivation or related fields. Regarding *Alternaria brassicicola*, a majority of respondents (15) consider themselves moderately familiar, while 3 are very familiar and 3 are not familiar with the pathogen's impact on broccoli. Out of those who have encountered *Alternaria brassicicola* (9 respondents), most report a mild infestation affecting a small area, with 3 implementing management strategies and 3 experiencing economic losses.

Identification methods for *Alternaria brassicicola* varied, with visual symptoms being the most common, selected by 9 respondents. Multiple methods, including laboratory analysis and consulting with agricultural experts, were employed by some participants, highlighting a comprehensive approach to diagnosis. Predominant symptoms observed in cases of *Alternaria brassicicola* include circular leaf spots, dark lesions on stems, yellowing or wilting of leaves, blackening of leaf veins, and other manifestations. As illustrated in Figure 1, visual symptoms were the most prevalent diagnostic method. Respondents often reported observing multiple symptoms, emphasizing the complex nature of the pathogen. However, the data reveals a multi-faceted approach to diagnosis, with some participants going beyond visual inspection.

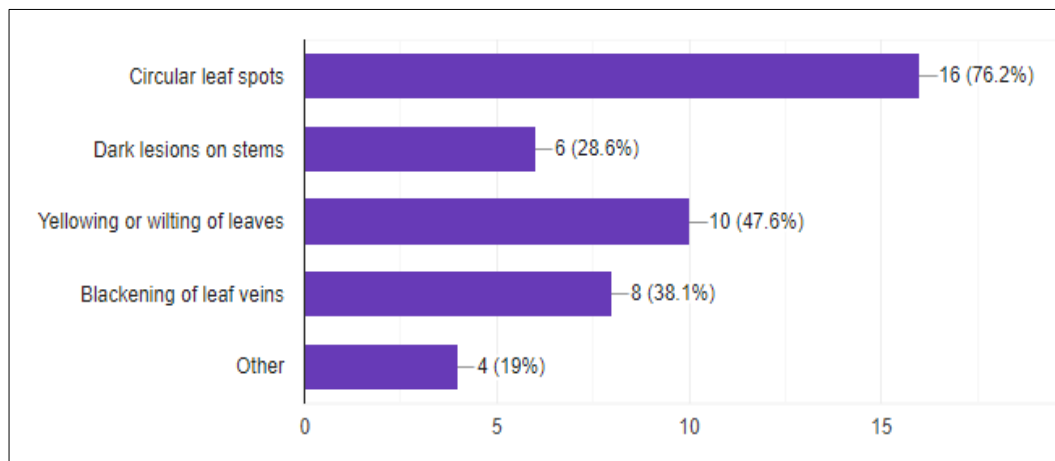


Fig 1: The survey on characteristic symptoms of *Alternaria brassicicola* infection.

In terms of management strategies, 12 respondents attempted various approaches, including botanical methods, chemical treatments, biological control agents, and integrated approaches. The satisfaction levels varied, with 14 respondents being moderately satisfied and 7 very satisfied with the effectiveness of the strategies employed against *Alternaria brassicicola*. The Figure 2 depicts the common challenges faced by broccoli growers when managing *Alternaria brassicicola*. As the figure shows, a significant

portion of respondents (47.6%) identified the rapid spread of the pathogen as a major challenge. Common challenges faced by broccoli growers dealing with *Alternaria brassicicola* include the rapid spread of the pathogen, limited effective control methods, economic losses, and environmental concerns with management techniques. Some respondents reported facing multiple challenges simultaneously, highlighting the intricate nature of managing *Alternaria brassicicola* in broccoli cultivation.

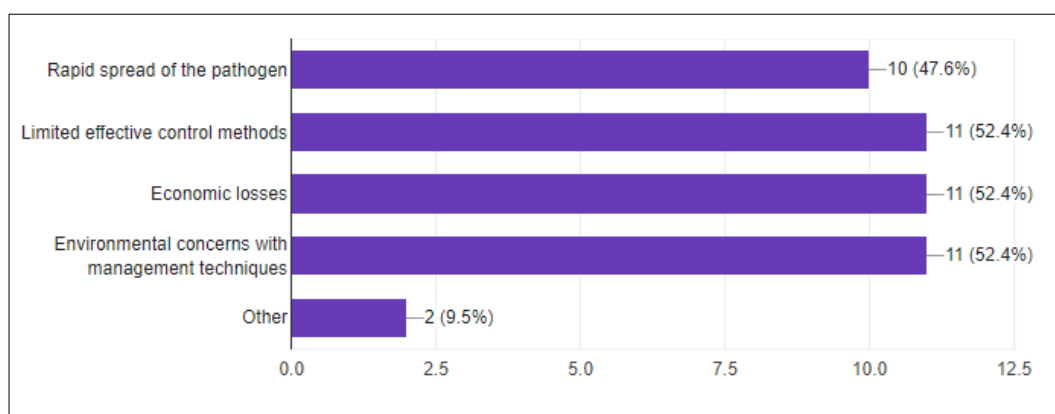


Fig 2: Challenges Faced by Broccoli Growers in Managing *Alternaria brassicicola*

Botanical Management for *Alternaria brassicicola* in Broccoli Cultivation

The survey delves into botanical methods employed for managing *Alternaria brassicicola* in broccoli cultivation, providing valuable insights from participants with diverse experiences. Among the respondents, the utilization of neem oil application, planting resistant broccoli cultivars, and utilizing companion plants emerged as common botanical

approaches. The survey examined the use of botanical methods to manage *Alternaria brassicicola* in broccoli crops. Among the participants, several approaches emerged as popular choices. The most common methods included applying neem oil (used by 38.1% or 8 respondents), planting broccoli cultivars resistant to the disease (66.7% or 14 respondents), and utilizing companion plants (33.3% or 7 respondents) (Figure 3).

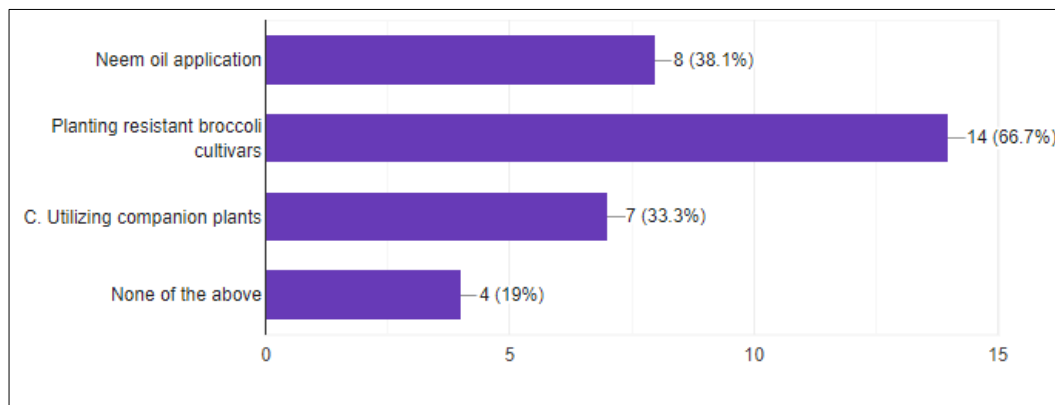


Fig 3: Botanical Management Methods Used by Survey Participants

The perceived promise of botanical methods varied, with neem oil application and planting resistant broccoli cultivars being frequently identified as promising or effective. The feasibility of applying botanical methods on a larger scale was considered moderately feasible by 16 respondents and highly feasible by 4, while only 1 respondent deemed it not feasible. Challenges in implementing botanical management strategies included concerns about the availability of effective botanical products, resistance development in pathogens, cost implications, and technical difficulties in application which are reflected in the pie chart (Figure 4).

Respondents provided valuable suggestions for further research, emphasizing the need to identify specific botanical compounds effective against *Alternaria brassicicola*.

Additionally, exploring optimal application methods and concentrations, understanding the active compounds in botanical extracts, and studying efficacy under diverse environmental conditions were highlighted. The diverse range of suggestions for enhancing botanical methods included cultivating specific plants under favourable conditions, understanding environmental factors influencing crop health, using liquid copper fungicides, applying spent mushroom compost as a soil amendment, and exploring the control of *Alternaria brassicicola* through botanical extracts. The data suggests a positive inclination towards the efficacy of botanical methods, with a majority finding them moderately to very effective.

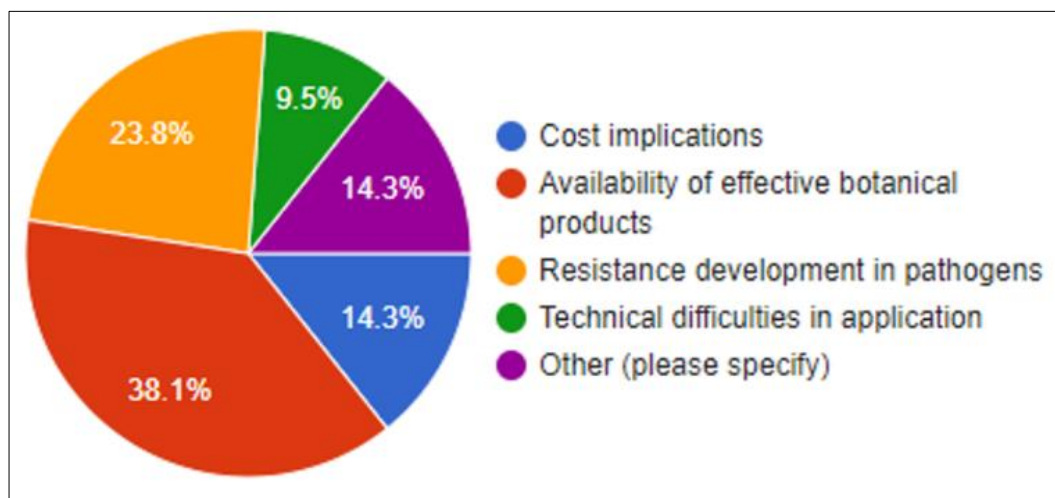


Fig 4: Challenges in Implementing Botanical Management

Chemical Management

The survey provides a comprehensive overview of chemical methods employed for managing *Alternaria brassicicola* in broccoli cultivation, offering valuable insights from diverse experiences. Among the respondents, 14 participants utilized both fungicides and bactericides, 6 opted for fungicides alone, while 1 did not employ any chemical treatments. Frequency of chemical treatment application varied, with 9 respondents applying bi-weekly, 8 applying weekly, and 4 applying monthly. A range of approaches were evident, with some growers utilizing both fungicides and bactericides (66.7%), while others opted for fungicides alone (28.6%) or avoided chemical treatments entirely (4.8%) (Figure 5). The frequency of application also varied, with bi-weekly applications being the most common (42.9%), followed by weekly (38.1%) and

monthly (14.3%) applications (Figure 6). The choice of specific fungicides or bactericides showed diversity, with some noting variation in effectiveness among different chemical treatments.

Challenges and limitations encountered during chemical treatments included concerns about the development of resistance in the pathogen, environmental impacts, safety for farmworkers or consumers, and the cost-effectiveness of chemical treatments. The determination of appropriate timing for chemical treatments predominantly relied on observing initial symptoms or following a regular schedule, while weather conditions and expert consultation played minor roles. Adverse effects of chemical treatments were reported by some respondents, including negative impacts on beneficial organisms, residue accumulation on produce, and reduced efficacy over time. Suggestions for improvements or

alternatives focused on developing more targeted and specific fungicides, exploring the use of biopesticides, and integrating cultural practices like crop rotation and proper plant nutrition. The data suggests a balanced approach among respondents regarding the use of chemical treatments for *Alternaria*

brassicicola management. While challenges and adverse effects are acknowledged, the respondents demonstrate a willingness to explore alternatives and improvements for more sustainable and efficient disease management practices.

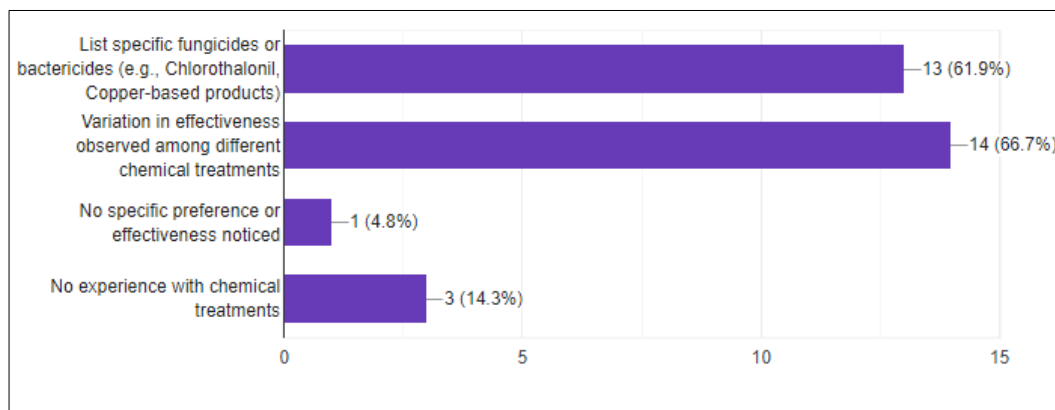


Fig 5: Chemical controls for managing *Alternaria brassicicola* in broccoli cultivation.

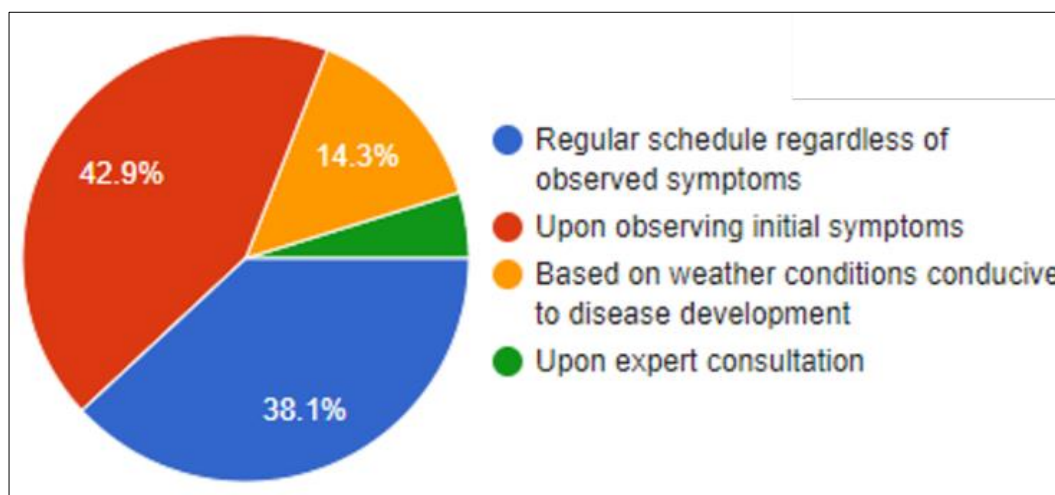


Fig 6: The frequency of application of chemicals for managing *Alternaria brassicicola*

Biological Management

The survey reflects a substantial engagement with biological control agents among broccoli cultivators in their efforts to manage *Alternaria brassicicola*. Of the respondents, 17 have utilized biological control agents, while 4 have not explored this avenue. Various biological control methods have been considered, with 6 respondents combining beneficial microbes and fungal antagonists, and 5 opting for beneficial microbes alone. Challenges and limitations faced in implementing biological control methods include difficulties in establishing control agent populations, resistance development in pathogens, and technical application issues.

Regarding effectiveness, beneficial microbes and fungal antagonists were acknowledged for reducing disease severity and minimizing pathogen impact, respectively. However, challenges and limitations were reported, emphasizing the need for further research to optimize these methods. Among the respondents, 7 considered the combination of beneficial microbes and fungal antagonists as the most promising or effective in controlling *Alternaria brassicicola*. However, uncertainty or no opinion was expressed by 2 respondents. The perceived feasibility of applying biological control methods on a larger scale in broccoli cultivation for managing *Alternaria brassicicola* was considered moderately feasible by 14 respondents, highly feasible by 5, and not feasible by 2.

Challenges in implementing biological management strategies included the availability of effective biological control agents, difficulties in establishing and maintaining control agent populations, resistance development in pathogens, and technical application difficulties. To enhance the efficacy of biological control methods, respondents expressed the need for further research in selecting and optimizing beneficial microorganisms. Understanding their modes of action, interactions with the pathogen, and the best application methods and timing are highlighted areas for investigation.

Integrated Management Approach

The survey indicates a notable acceptance and recognition among broccoli cultivators for an integrated management approach in combating *Alternaria brassicicola*. A majority of respondents, with 11 strongly agreeing and 9 somewhat agreeing, expressed their belief in integrating botanical, chemical, and biological methods for disease management. Challenges foreseen in implementing an integrated approach were diverse, with 6 respondents highlighting compatibility issues between different control strategies as a major concern. Other challenges included cost implications, resistance development in pathogens, environmental impact, lack of knowledge or resources, and difficulties in coordination among different methods.

Respondents identified several potential advantages of an integrated approach, emphasizing reduced reliance on chemicals and fungicide resistance, sustainability by minimizing environmental impact, and preserving the natural balance of ecosystems. In terms of prioritizing integrated methods, 14 respondents leaned towards prioritizing based on the effectiveness of each method, indicating a pragmatic

approach to disease management. However, 4 respondents advocated for an equal emphasis on all methods. Despite the positive perception, only a few respondents (4) reported having previously attempted an integrated approach for managing *Alternaria brassicicola*. The experiences shared were limited, with one emphasizing the reduced reliance on chemicals and another stating the effectiveness of fungicides.

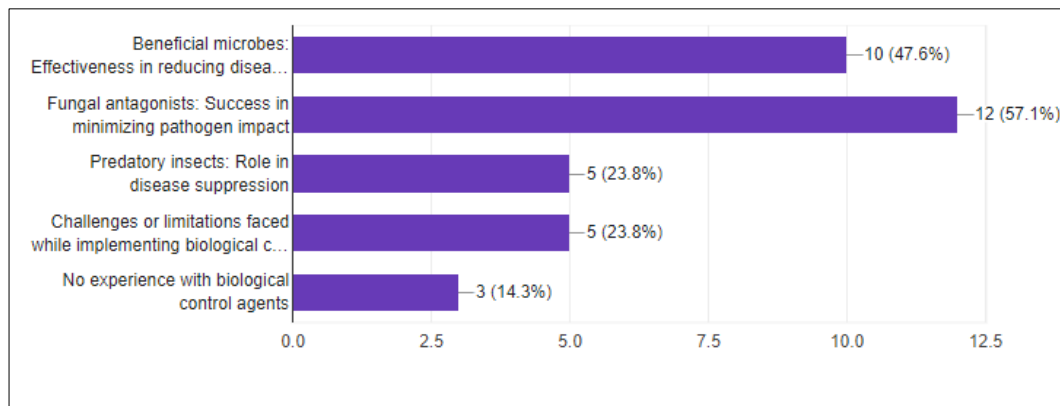


Fig 7: Broccoli Cultivator Awareness of Biological Control Methods

As illustrated in Figure 7, a significant portion of respondents (47.6%) were aware of the potential benefits of beneficial microbes for disease control. Similarly, a majority (57.1%) acknowledged the success of fungal antagonists in minimizing pathogen impact. However, the survey also identified knowledge gaps regarding predatory insects (23.8%) and challenges associated with implementing biological control methods (23.8%). A concerning 14.3% of respondents reported no prior experience with biological control agents, highlighting the need for increased education and outreach efforts in this area. Regarding the necessary support or guidance for successful implementation, respondents stressed the importance of comprehensive training, education on different control strategies, and access to up-to-date information. Consulting with experts or agricultural extension services was considered crucial for addressing specific challenges and providing tailored recommendations. Suggestions include developing more targeted and environmentally friendly chemical treatments, leveraging technology such as precision agriculture and remote sensing, and focusing on advancements in machinery for applying biological methods.

Future Strategies

The survey reflects a cautiously optimistic outlook among respondents regarding future advancements in managing *Alternaria brassicicola* in broccoli. A majority of respondents, with 13 expressing moderate optimism and 8 indicating very optimistic views, foresee positive developments in disease management strategies. In terms of research priorities, a diverse range of areas emerged as crucial for improving management strategies. The top priorities, selected by all respondents, include understanding the pathogen's biology and genetics for targeted control, advancing biological control methods, and enhancing disease-resistant broccoli cultivars. The emphasis on these areas indicates a holistic approach, combining genetic understanding, eco-friendly botanical approaches, and the development of disease-resistant varieties.

Respondents also highlighted the importance of collaboration among researchers, growers, and policymakers. The

consensus is that researchers play a key role in developing innovative solutions, growers provide practical insights and implementation feedback, and policymakers support these efforts through sustainable policies and funding. The call for a collaborative approach underscores the need for a concerted effort across different stakeholders to effectively combat *Alternaria brassicicola*. Public awareness and education were deemed crucial by all respondents. The acknowledgment of the significance of public awareness suggests a recognition of the collective responsibility in disease management. Education programs were highlighted as essential for disseminating knowledge about *Alternaria brassicicola*, its symptoms, and prevention methods. This indicates a proactive approach to involve the broader community in safeguarding broccoli crops. Interestingly, only a minority of respondents (4) reported actively engaging in research or initiatives focused on improving *Alternaria brassicicola* management. While this may indicate a gap between belief and direct involvement, it also emphasizes the potential for increased participation and collaboration in future initiatives.

Thus, the survey points towards a positive sentiment regarding the future of *Alternaria brassicicola* management in broccoli cultivation. The identified research priorities, emphasis on collaboration, and recognition of the role of public awareness collectively form a foundation for future advancements in disease management strategies. However, the limited reported engagement in active research suggests potential untapped opportunities for broader involvement and contribution in addressing this agricultural challenge.

Discussion

The survey conducted to explore the management of *Alternaria brassicicola*, the pathogen causing leaf spot in broccoli, provides valuable insights into the current strategies employed by individuals involved in agriculture and horticulture. This comprehensive study encompassed various aspects, including demographic information, understanding of *Alternaria brassicicola*, botanical, chemical, and biological management approaches, integrated strategies, and future perspectives. The results shed light on the challenges faced by broccoli cultivators and their experiences in tackling this

prevalent issue. In terms of demographics, the participants, consisting primarily of students, researchers/scientists, and farmers/growers, presented a diverse spectrum of roles within the agricultural sector. The varying levels of experience, ranging from less than 1 year to 6-10 years in broccoli cultivation, further enriched the data, offering a nuanced understanding of the subject matter. The familiarity of participants with *Alternaria brassicicola* indicated that a majority considered themselves moderately familiar with the pathogen. This self-assessment is essential as it influences the approaches and strategies individuals employ in disease management. Furthermore, the survey delved into the impact of *Alternaria brassicicola* on broccoli cultivation, revealing that out of those who encountered the pathogen, a significant number reported mild infestations affecting small areas. However, it is noteworthy that despite the observed impact, only a fraction of respondents implemented management strategies, potentially indicating a gap in awareness or available effective solutions. The identification methods for *Alternaria brassicicola* showcased a reliance on visual symptoms, with laboratory analysis and consultation with agricultural experts playing supplementary roles. This highlights the practical challenges associated with rapid and accurate diagnosis in the field. The predominant symptoms reported, including circular leaf spots, dark lesions on stems, yellowing or wilting of leaves, and blackening of leaf veins, align with typical manifestations of *Alternaria brassicicola*. This detailed symptomatology aids in understanding the varied presentations of the pathogen, contributing to more accurate and timely diagnosis.

The management strategies employed by respondents encompassed a range of approaches, including botanical, chemical, and biological methods, as well as integrated strategies. The satisfaction levels varied, with a notable number expressing moderate satisfaction with the effectiveness of the strategies. The challenges faced by broccoli growers in dealing with *Alternaria brassicicola* highlighted the multifaceted nature of the issue. Rapid pathogen spread, limited effective control methods, economic losses, and environmental concerns underscore the complexity of disease management in broccoli cultivation.

The survey investigated into botanical management, exploring the utilization and effectiveness of various botanical methods. Neem oil application, planting resistant broccoli cultivars, and utilizing companion plants emerged as common botanical approaches. While the majority found these methods moderately effective, the challenges faced during implementation, including difficulties and limitations, emphasized the need for further research to optimize these botanical approaches. Respondents provided valuable suggestions, underscoring the importance of identifying specific botanical compounds effective against *Alternaria brassicicola* and exploring optimal application methods and concentrations.

Chemical management strategies were widely employed, with participants utilizing both fungicides and bactericides. The frequency of chemical treatment application varied, reflecting diverse practices among respondents. Challenges and limitations, such as the development of resistance, environmental impacts, and safety concerns, were acknowledged. The respondents demonstrated a balanced approach, acknowledging the challenges while expressing a willingness to explore alternatives and improvements for more sustainable and efficient disease management practices.

Biological management emerged as a crucial aspect, with a significant number of participants utilizing biological control agents. The challenges faced in implementing these methods, including difficulties in establishing control agent populations, resistance development, and technical application issues, highlight the complexities associated with harnessing biological controls. The effectiveness of biological methods, particularly beneficial microbes and fungal antagonists, was recognized, but challenges and limitations underscored the need for further research to optimize these approaches.

The survey showcased a notable acceptance of an integrated management approach among broccoli cultivators. The majority expressed belief in integrating botanical, chemical, and biological methods for disease management. Challenges in compatibility between different control strategies, cost implications, and environmental impact were acknowledged. Despite the positive perception, only a few respondents reported having attempted an integrated approach, indicating potential areas for increased adoption and exploration.

The future strategies segment of the survey revealed a cautiously optimistic outlook among respondents regarding advancements in managing *Alternaria brassicicola*. Research priorities, including understanding the pathogen's biology and genetics, advancing biological control methods, and enhancing disease-resistant broccoli cultivars, were identified. Collaboration among researchers, growers, and policymakers was emphasized, highlighting the need for a concerted effort across different stakeholders to combat *Alternaria brassicicola* effectively. Public awareness and education were deemed crucial, reflecting a proactive approach to involve the broader community in safeguarding broccoli crops.

Other studies

The study by Verma *et al.* 2018^[12], successfully isolated and characterized *Alternaria alternata* as the pathogen responsible for *Alternaria* leaf spot in broccoli in Bangladesh. Morphological observations, such as concentric rings and black spots surrounded by yellow halos on infected leaves, supported the identification of *Alternaria* sp. Microscopic analysis revealed septate and branched mycelium, with conidia typically produced singly at the apex of conidiophores. The morphological characteristics, coupled with molecular analysis using ITS gene sequencing, confirmed the isolates as *A. alternata*.

Understanding the biology of *A. alternata* is crucial for developing effective management strategies. The study demonstrated optimal fungal growth at temperatures ranging from 20°C to 30°C, with the maximum growth recorded at 35°C, consistent with previous findings for *Alternaria* spp. (Hubballi, *et al.*, 2010)^[6]. In terms of disease management, fungicides were evaluated, and results indicated the efficacy of Ridomil MZ 68 WP, Rovral 50 WP, Autostin 50 WGD, Dithane M-45, and Tilt 250 EC. Tilt 250 EC, containing propiconazole, and exhibited excellent inhibition of *Alternaria* sp. growth at recommended doses. This aligns with previous studies highlighting propiconazole's effectiveness against *A. brassicae*. The study provides valuable insights into fungicidal options for managing *Alternaria* leaf spot in broccoli, contributing to enhanced disease control practices in agriculture (Hubballi, *et al.*, 2010; Azad *et al.*, 2016)^[6, 2]. The survey on *Alternaria brassicicola* management in broccoli cultivation has several noteworthy limitations. Firstly, the sample size of 21 participants may restrict the generalizability of the findings, necessitating a larger and more diverse sample

to offer a comprehensive understanding of the challenges faced by a broader community of broccoli cultivators. The reliance on self-reported data introduces potential bias, as participants might unintentionally skew their experiences, practices, or challenges related to *Alternaria brassicicola* management. The narrow geographic focus on a specific region, without explicit mention, raises concerns about the applicability of the findings to diverse geographical contexts with varying climate conditions and agricultural practices.

Additionally, the varying levels of experience among participants, ranging from less than 1 year to 6-10 years, pose a challenge in accurately capturing disease management strategies. The exclusive focus on *Alternaria brassicicola* neglects potential interactions with other pathogens or environmental factors, limiting the holistic understanding of disease dynamics. While the survey extensively explores botanical, chemical, and biological management, the lack of depth in assessing the impact of cultural practices, such as crop rotation and soil health, hinders a comprehensive understanding. Finally, the absence of quantitative data limits the ability to perform statistical analyses, infer causation, or measure the strength of associations between variables, compromising the research's overall robustness.

Conclusion

In conclusion, this survey provides a comprehensive analysis of the management strategies employed by individuals involved in broccoli cultivation to combat *Alternaria brassicicola*. The diverse demographic representation, including students, researchers, and farmers, offers a multifaceted perspective on the challenges faced in the field. The findings underscore the prevalent use of chemical and biological methods, with a growing recognition of the potential of integrated approaches. Challenges such as pathogen spread, limited control methods, and economic losses highlight the urgent need for effective disease management strategies. The survey also identifies promising avenues, including botanical methods and the integration of diverse control strategies. However, the limited engagement in active research suggests untapped opportunities for collaboration and innovation. Future research priorities should focus on understanding the pathogen's genetics, advancing biological controls, and developing disease-resistant cultivars, emphasizing a collaborative and holistic approach to effectively address *Alternaria brassicicola* in broccoli cultivation.

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