Yellow Mosaic Virus (YMV) in Green Gram: Impacts, Management, and Future Perspectives

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ABSTRACT

Yellow mosaic virus (YMV) is a destructive viral pathogen that affects green gram (*Vigna radiata*) crops, leading to significant yield losses and economic repercussions. This review paper provides a comprehensive analysis of the impacts of YMV on green gram cultivation, explores the current management strategies employed to combat the disease, and discusses future perspectives for effective YMV control and prevention. YMV is primarily transmitted through whiteflies and infects green gram plants at various stages of growth, causing severe symptoms such as leaf yellowing, stunted growth, and mosaic patterns. These symptoms ultimately lead to reduced crop yield and quality. The virus poses a major threat to green gram production globally, demanding urgent attention and effective management practices. Various management approaches have been employed to mitigate the impact of YMV. Cultural practices, including proper field sanitation, weed control, and crop rotation, play a vital role in disease management. Insecticide application, use of yellow sticky traps, and whitefly population monitoring are important components of integrated pest management strategies aimed at reducing virus transmission. Additionally, the development and deployment of resistant cultivars through conventional breeding and biotechnological approaches have shown promise in minimizing YMV infection and its associated losses. Despite these efforts, YMV continues to pose significant challenges to green gram production, necessitating further research and innovative approaches. Future perspectives for YMV management involve the integration of advanced technologies such as molecular diagnostics, genome editing, and RNA interference to enhance disease resistance in green gram varieties. Additionally, promoting awareness among farmers about YMV symptoms, preventive measures, and adoption of integrated disease management strategies will contribute to sustainable green gram production. In conclusion, YMV represents a major threat to green gram cultivation, affecting crop productivity and economic sustainability. This review emphasizes the need for concerted efforts to develop comprehensive YMV management strategies. By combining conventional and modern techniques, effective disease control measures can be implemented to mitigate the impact of YMV and secure the future of green gram production.

Keywords: *YMV, RNA interference, genome editing, economic sustainability, conventional breeding and biotechnological approaches*

1. INTRODUCTION

Green gram (*Vigna radiata* L.), also known as mung bean, is an important leguminous crop widely cultivated for its high protein content, nutritional value, and versatility in culinary applications [1,2]. It is an important crop in the pulse category, is an annual legume belonging to Fabaceae family that is widely grown, with diploid chromosome 2n=2x=22. It can be be grown in various cropping systems [44]. It is a staple food in many countries, particularly in Asia, where it is consumed in various forms such as sprouts, dal (split and dehusked beans), and paste [3]. It can be grown in various cropping systems. It is commonly known as mungbean, is classified into three subgroups: one domesticated (*Vigna radiata* subsp. *radiata*) and two wild (subsp. *sublobata* and subsp. *glabra*) [66].Green gram cultivation is not only significant for its economic value but also for its contribution to food security and sustainable agriculture [3-4].

Yellow Mosaic Virus (YMV) poses a major threat to green gram cultivation worldwide. It belongs to the genus Begomovirus and is a member of the Geminiviridae family [5]. YMV causes yellow mosaic disease, characterized by distinctive yellow mosaic patterns on the leaves, stunted growth, reduced yield, and even plant death in severe cases. The virus is transmitted by insect vectors, primarily whiteflies (*Bemisia tabaci*) or aphids (*Aphis craccivora*) [6,7]. The impact of YMV on green gram production is substantial, leading to significant economic losses for farmers. YMV infection can result in yield reduction by as much as 30% to 70%, depending on the severity of the disease and the stage of infection [8]. In addition,YMV also affects the seed quality, leading to a decrease in market value and lessen the profitability for farmers [9].

The importance of understanding and managing YMV stems from its ability to rapidly spread and infect large areas, causing epidemics in green gram-growing regions [10]. The virus has a broad host range, infecting various legumes, including important crops such as soybean and black gram [11]. YMV can also persist in weed reservoirs, facilitating its survival and spread during off seasons. Efficient management strategies for YMV are crucial for sustainable green gram production [12,13]. These strategies encompass a combination of cultural practices, such as removing host and infected plants, crop rotation, and control of insect vectors [14]. Additionally, the development of YMV-resistant varieties through breeding programs and the use of chemical or biological control are effective in reducing the impact of YMV in green gram [15].

2. YELLOW MOSAIC VIRUS: BIOLOGY AND EPIDEMIOLOGY

2.1 STRUCTURE AND GENOME ORGANIZATION OF YMV

Yellow mosaic virus (YMV) belongs to the genus Begomovirus within the family Geminiviridae. It has a unique twinned icosahedral virion structure. The genome of YMV consists of circular, single-stranded DNA of approximately 2.7-2.8 kilobases (kb) in size. The genome is divided into two components: DNA-A and DNA-B [16].

DNA-A: This component carries essential genes for viral replication, movement, and encapsidation. It encodes proteins such as replication-associated protein (Rep), transcriptional activator protein (TrAP), coat protein (CP), and others involved in viral functions.

DNA-B: This component is not required for viral replication but contributes to symptom severity and enhances the efficiency of virus transmission. It carries a gene encoding a nuclear shuttle protein (NSP) involved in intra- and intercellular movement of the virus. Both DNA-A and DNA-B components are necessary for a complete infection and systemic spread of YMV within the host plant [17,18]. Disease Cycle YMV:

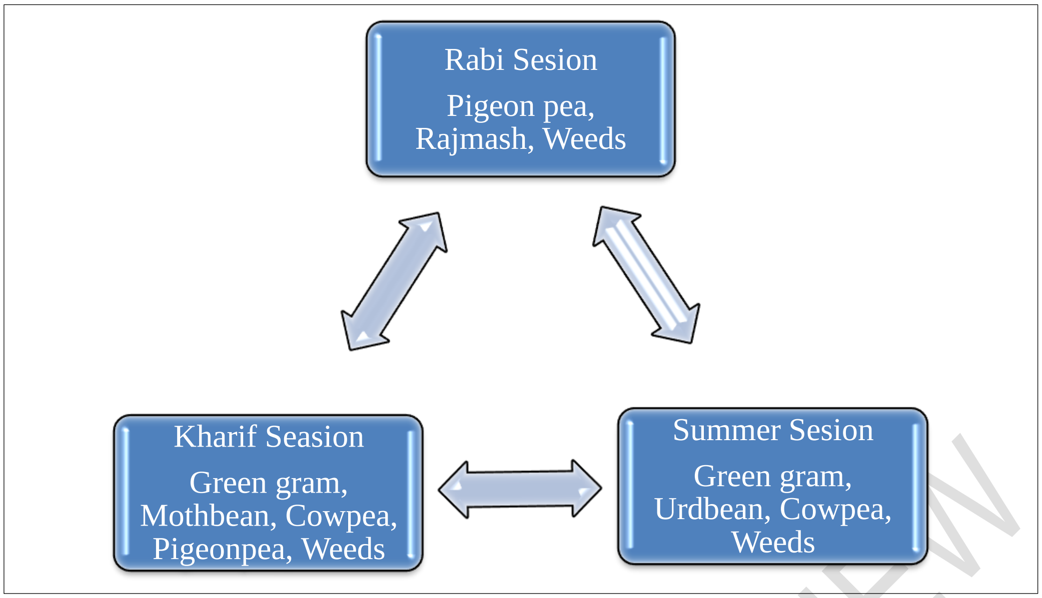
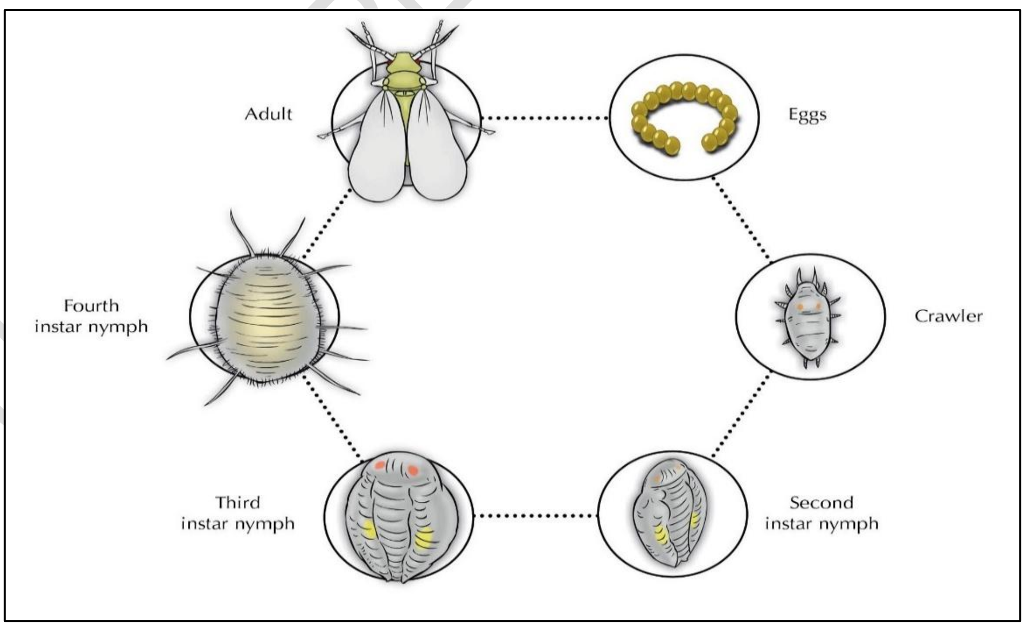


Fig. 1 Presence of vector- yellow mosaic virus at collateral and alternate hosts over the year [19].

2.2 MODES OF TRANSMISSION AND VECTORS

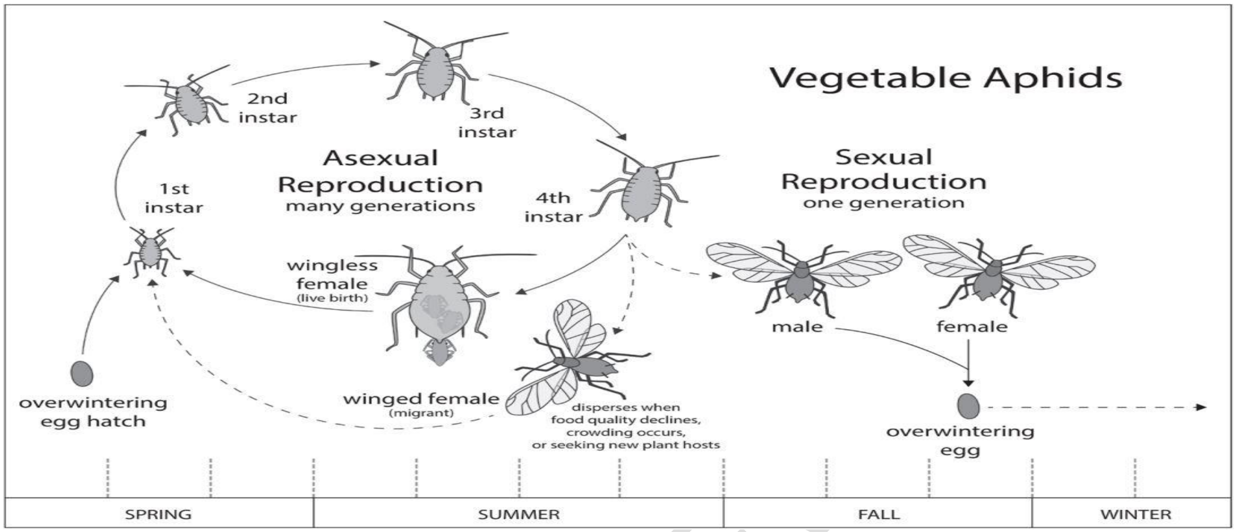
1. **Insect Vectors:** The primary mode of YMV transmission is through insect vectors, mainly whiteflies (*B. tabaci*) and occasionally aphids (*A. craccivora*). These vectors *acquire* the virus by feeding on infected plants and then transmits it to healthy plants during subsequent feeding. Whiteflies are considered the most efficient vectors for YMV transmission [20].

Fig 2. White Fly life cycle



Source: - https://www.syngentaornamentals.co.uk/whitefly-life-cycle.

Fig 3. Aphid life cycle



Source: - https://extension.usu.edu/pests/ipm/notes_ag/veg-russian-wheat-aphid.

2. **Seed Transmission:** YMV can also be transmitted through infected seeds. Infected seeds act as a source of primary infection in a new crop season. However, the contribution of seed transmission to overall YMV spread is relatively low compared to insect-mediated transmission [22,23].

3. FACTORS INFLUENCING YMV SPREAD AND INFECTION

1. **Vector Abundance and Behavior:** The population density of whiteflies or aphids affects the rate of YMV transmission. Higher vector abundance increases the chances of successful transmission between plants [24,25].
2. **Host Range and Alternate Hosts:** YMV has a wide host range and can infect various legume species, including green gram (*V. radiata*) and other related crops. Alternate hosts and weed reservoirs also play a significant role in the persistence and spread of YMV during off seasons [26].
3. **Environmental Conditions:** Environmental factors such as temperature, humidity, and light intensity influence the vector populations and their ability to transmit YMV. Favorable environmental conditions can enhance vector activity and increase virus spread [27].
4. **Plant Resistance:** The presence of resistant varieties or cultivars can limit YMV infection and reduce its spread. Host resistance plays a crucial role in managing YMV and minimizing its impact on crop yield [28].
5. **Cultural Practices and Crop Management:** Proper cultural practices, including weed control, removal of infected plants, and crop rotation, can help reduce YMV incidence and spread. Early detection and prompt control measures can prevent further virus dissemination [29].

4. SYMPTOMATOLOGY AND DISEASE IMPACT

4.1 VISUAL SYMPTOMS AND DIAGNOSTIC TECHNIQUES

Yellow Mosaic Virus (YMV) infection in green gram plants is characterized by a range of visual symptoms. The symptoms typically appear 10 to 14 days after infection and vary in severity depending on factors such as the virus strain, host genotype, and environmental conditions [30]. Common symptoms of YMV infection include:

1. **Yellow Mosaic:** Infected leaves develop distinct yellow or chlorotic patches, usually in a mosaic pattern. The intensity of the yellowing may vary, ranging from mild mosaic to severe leaf discoloration [31].
2. **Stunted Growth:** YMV-infected plants often exhibit stunted growth with reduced plant height and overall size compared to healthy plants [32].
3. **Leaf Deformation:** Infected leaves may show abnormal leaf shape, curling, or cupping [33].
4. **Reduced Leaf Area:** YMV infection leads to a decrease in leaf size and a reduction in the total leaf area of infected plants [33].
5. **Delayed Flowering and Pod Formation:** YMV-infected plants may experience delays in flowering and pod formation, resulting in decreased yield [34].

Diagnostic techniques for YMV include visual inspection of symptomatic plants, serological assays [enzyme-linked immunosorbent assay (ELISA)], and molecular techniques like polymerase chain reaction (PCR) or loop-mediated isothermal amplification (LAMP). These techniques allow for the rapid and accurate detection of YMV in plant samples [30, 35].

4.2 YIELD LOSSES AND ECONOMIC IMPACT ON GREEN GRAM PRODUCTION

Yellow Mosaic Virus (YMV) is a major viral pathogen that causes significant yield losses in green gram production. The impact of YMV on yield can vary depending on several factors, including virus strain, infection severity, crop stage at the time of infection, and management practices. Yield losses due to YMV infection can range from 30% to 70% [36].
The economic impact of YMV on green gram production is substantial. The reduced yield resulting from YMV infection directly affects the income of farmers and can lead to financial instability. Moreover, the decreased seed quality due to YMV infection affects their market value and demand, further affecting the economic returns from green gram cultivation [37].

4.3 EFFECTS ON PLANT GROWTH, PHOTOSYNTHESIS AND NUTRIENT UPTAKE

YMV infection adversely affects various physiological processes in green gram plants, leading to impaired growth and reduced productivity. The virus interferes with photosynthesis, nutrient uptake, and overall plant metabolism. Some specific effects of YMV infection include:

1. **Photosynthetic Efficiency:** YMV-infected plants show reduced photosynthetic efficiency due to the disruption of chloroplast structure and function. This results in decreased carbohydrate production and energy availability for plant growth and yield formation [38].
2. **Nutrient Imbalance:** YMV infection can lead to imbalances in nutrient uptake and utilization. The virus interferes with the absorption and transport of essential nutrients, resulting in deficiencies that further impair plant growth and development [39].
3. **Hormonal Disturbance:** YMV infection alters the hormonal balance in infected plants, affecting processes such as cell elongation, flowering, and fruit set. These hormonal disruptions contribute to stunted growth and reduced yield [40].
4. **Secondary Infections:** YMV-infected plants are often more susceptible to secondary infections by other pathogens or pests. The weakened defense mechanisms render the plants more vulnerable to further damage, exacerbating the negative impact on crop productivity [41].

4.3 HOST RANGE AND VIRUS STRAINS

Susceptible leguminous and non-leguminous hosts

Yellow Mosaic Virus (YMV) has a broad host range, infecting various leguminous and non-leguminous plants. While leguminous plants are the primary hosts, YMV can also infect non-leguminous plants under certain conditions. Some of the susceptible leguminous hosts include:

1. Green Gram (*Vigna radiata*)
2. Black Gram (*Vigna mungo*)
3. Soybean (*Glycine max*)
4. Cowpea (*Vigna unguiculata*)
5. Lablab Bean (*Lablab purpureus*)
6. Lentil (*Lens culinaris*)
7. Chickpea (*Cicer arietinum*) [42, 43]

In addition to leguminous plants, YMV can infect non-leguminous hosts, albeit with varying efficiency and severity. Some examples of non-leguminous hosts susceptible to YMV infection are:

1. Bottle Gourd (*Lagenaria siceraria*)
2. Bitter Gourd (*Momordica charantia*)
3. Cucumber (*Cucumis sativus*)
4. Sponge Gourd (*Luffa cylindrica*)
5. Pointed Gourd (*Trichosanthes dioica*) [42]

It is important to note that the susceptibility of different host plants to YMV may vary, and some species or cultivars within a host species may exhibit varying levels of resistance.

Variability and strains of YMV

Yellow Mosaic Virus (YMV) exhibits genetic variability, resulting in the presence of different strains or isolates. These strains may vary in their virulence, symptom expression, host range, and geographical distribution. The variability of YMV is attributed to several factors, including genetic mutations, recombination events, and adaptation to different host plants and environments [45].

Different YMV strains have been identified in different regions, suggesting geographical differentiation. The genetic diversity of YMV has been studied using molecular techniques, such as DNA sequencing and phylogenetic analysis. Through these studies, multiple YMV strains have been classified and characterized based on nucleotide sequence variations in specific genomic regions [46].

The presence of different YMV strains has practical implications for disease management and resistance breeding programs. Some strains may exhibit higher virulence or overcome previously resistant cultivars, necessitating continuous monitoring and evaluation of resistance levels in green gram and other susceptible host plants [47].

Understanding the variability and strains of YMV is essential for developing effective management strategies, selecting appropriate resistant cultivars, and conducting accurate diagnostics for strain identification. Continued research on YMV strains and their interactions with host plants is crucial for combating this viral pathogen and mitigating its impact on agricultural production.

5. TRANSMISSION AND VECTORS

Vector identification and biology

The primary vectors responsible for the transmission of Yellow Mosaic Virus (YMV) are whiteflies, specifically the species *Bemisia tabaci*, also known as the silverleaf whitefly or sweet potato whitefly. These small, sap-sucking insects belong to the family Aleyrodidae and are widely distributed worldwide. They have a broad host range, feeding on various plant species, including leguminous crops like green gram [48].

Whiteflies have a distinct appearance, with whitish wings and a characteristic "honeydew" secretion. The adult whiteflies are approximately 1-2 mm in length. They undergo a complete metamorphosis, progressing through egg, nymph, and adult stages [49].

Modes of transmission: persistent and non-persistent

Persistent Transmission:

Persistent transmission is the primary mode of YMV transmission by whiteflies. It involves the acquisition, retention, and transmission of the virus by the vector over an extended period. Persistent transmission of YMV occurs as follows:

Acquisition: Whiteflies acquire YMV while feeding on infected plants. The virus enters the whitefly's body and becomes systemic within its tissues, including the salivary glands.

Retention: The virus can persist in the whitefly for several days to weeks, depending on various factors such as temperature, whitefly species, and virus strain.

Transmission: When the infected whitefly feeds on a healthy plant, it injects the YMV particles along with its saliva. The virus is then introduced into the plant's vascular system, resulting in systemic infection [50].

Non-persistent Transmission:

Non-persistent transmission is another mode of YMV transmission, although it is less common compared to persistent transmission. Non-persistent transmission involves brief contact between the vector and the virus, with the virus not persisting within the vector for an extended period. It occurs as follows:

Acquisition: Whiteflies acquire YMV during short feeding periods on infected plants.

Retention: Unlike persistent transmission, the virus is not retained within the whitefly for an extended duration. Instead, it remains on the surface or stylets of the vector.

Transmission: The virus is transmitted to a healthy plant when the whitefly feeds on it, but the transmission efficiency is lower compared to persistent transmission [50, 51].

It is important to note that the mode of transmission can influence the epidemiology and management strategies of YMV. Persistent transmission by whiteflies is considered the primary and most efficient mode of YMV spread.

Understanding the transmission dynamics and biology of the whitefly vector is crucial for implementing effective control measures, such as vector management strategies and the development of resistant cultivars, to reduce YMV transmission and its impact on green gram cultivation.

6. MANAGEMENT STRATEGIES

Cultural practices:

1. Crop rotation
2. Intercropping
3. Trap cropping

Crop Rotation: Implementing crop rotation practices can help break the disease cycle and reduce the buildup of YMV in the soil. Avoid planting leguminous crops, including green gram, in consecutive seasons in the same field.

Intercropping: Intercropping green gram with non-host crops or less susceptible varieties can help reduce the spread of YMV. The presence of non-host plants can act as a barrier to whitefly movement and reduce the chances of virus transmission.

Trap Cropping: Planting trap crops that are highly attractive to whiteflies can divert their attention from the main crop. The trap crops can be monitored and managed more intensively to control whitefly populations and reduce YMV transmission [52].

Chemical control: insecticides and viricides.

Insecticides: The use of insecticides can help control whitefly populations and reduce YMV transmission. Consult local agricultural authorities or experts to identify suitable insecticides and follow recommended application practices to ensure effective control while minimizing environmental impact [53].

Viricides: Viricides are chemicals specifically designed to inactivate or suppress viral particles. However, the use of viricides for YMV management is limited, and their efficacy may vary. Consult with experts or researchers for information on available viricides and their suitability for YMV control [54].

Genetic resistance: breeding approaches and host plant resistance.

Breeding Approaches: Breeding programs aimed at developing YMV-resistant green gram varieties are crucial for long-term management. Breeders employ techniques such as conventional breeding, marker-assisted selection, and genetic engineering to introgression resistance genes into commercial cultivars. These resistant varieties can significantly reduce YMV incidence and severity [55].

Host Plant Resistance: Identifying and utilizing naturally resistant cultivars or landraces can provide immediate relief from YMV. Screening programs are conducted to identify resistant sources and incorporate their resistance traits into commercial varieties through breeding efforts [56].

Integrated Pest Management (IPM) strategies

IPM combines multiple approaches to manage YMV effectively and sustainably:

Monitoring: Regularly monitor fields for whitefly populations and YMV symptoms to assess the disease pressure and make informed management decisions.

Cultural and Biological Control: Implement cultural practices mentioned earlier, such as crop rotation, intercropping, and trap cropping, to minimize YMV incidence. Encourage beneficial organisms like predators and parasitoids that can help control whitefly populations [57].

Resistant Cultivars: Utilize YMV-resistant cultivars as part of an integrated management approach to reduce the impact of the virus.

Chemical Control: If necessary, judiciously use insecticides in combination with other management practices to control whitefly populations and reduce YMV transmission.

Farmer Education: Educate farmers about YMV symptoms, transmission, and management strategies to ensure proper implementation of control measures and timely intervention [57, 58, 59].

Implementing an integrated approach that combines cultural practices, chemical control when needed, genetic resistance. IPM strategies can provide effective and sustainable management of YMV in green gram cultivation. Continuous monitoring and adaptation of management strategies are essential to combat evolving YMV strains and checking pest dynamics.

Disease Surveillance and Diagnosis

Early detection and monitoring techniques

Early detection and monitoring of Yellow Mosaic Virus (YMV) are crucial for implementing timely control measures and minimizing the spread of the disease. Several techniques and methods can aid in the surveillance and monitoring of YMV:

Visual Inspection: Regular field visits and visual inspection of plants for characteristic symptoms of YMV, such as yellow mosaic patterns, stunted growth, and leaf deformities, can provide initial indications of virus presence. Systematic scouting of the crop is essential for early detection.

Field Surveys: Conducting field surveys to assess the incidence and severity of YMV across different locations and crops can help identify hotspots and prioritize management efforts. This can be done by recording disease symptoms and collecting samples for further analysis.

Remote Sensing and Imaging: Remote sensing technologies, such as satellite imagery and drone-based imaging, can aid in the detection and monitoring of YMV at a larger scale. These techniques can help identify areas with high disease pressure and guide targeted interventions.

Disease Thresholds: Establishing disease thresholds, which indicate the level of disease severity at which control measures should be implemented. Consequently will assist in monitoring YMV and determining the appropriate timing for intervention [60, 61]

Molecular diagnostic methods: PCR, ELISA, and next-generation sequencing

Molecular diagnostic methods are highly sensitive and specific techniques used for the accurate and rapid detection of YMV. These methods rely on detecting the presence of YMV nucleic acids or viral proteins in plant samples. Some commonly used molecular diagnostic methods for YMV include:

Polymerase Chain Reaction (PCR): PCR is a widely employed technique that amplifies specific DNA sequences of YMV. It can detect and differentiate various strains or isolates of YMV. PCR-based assays are highly sensitive and can provide rapid results [62, 63].

Enzyme-Linked Immunosorbent Assay (ELISA): ELISA is an immunological technique that detects the presence of viral proteins, such as coat proteins, in plant samples. It is a widely used diagnostic method for YMV and offers relatively quick results [63, 64].

Next-Generation Sequencing (NGS): NGS technologies enable high-throughput sequencing of the entire viral genome or specific regions. NGS allows for comprehensive analysis of YMV genetic diversity and can aid in strain identification and characterization [63, 65].

These molecular diagnostic methods require specialized equipment and expertise. They are particularly useful for confirming YMV infection, identifying virus strains, and studying viral populations in detail.

The integration of visual inspection, field surveys, remote sensing, and molecular diagnostic methods provides a comprehensive approach to YMV surveillance and diagnosis. Early detection and accurate identification of YMV facilitate effective disease management strategies and help minimize the economic impact on green gram production.

Future Directions and Challenges

Emerging Strains and Resistance Breakdown:

One of the key challenges in managing Yellow Mosaic Virus (YMV) is the emergence of new strains or variants that may overcome previously resistant cultivars. Ongoing monitoring and surveillance of YMV strains are necessary to identify any shifts in the virus population and assess their potential impact on green gram cultivation. Continuous research and breeding efforts are essential to develop and deploy resistant cultivars that can withstand the evolving YMV strains.

Sustainable Management Approaches: Moving towards sustainable management practices is crucial for long-term control of YMV. This includes reducing reliance on chemical insecticides and adopting integrated pest management (IPM) strategies that integrate multiple control measures. Enhancing cultural practices, such as crop rotation, intercropping, and trap cropping, can help minimize YMV incidence. Additionally, exploring alternative control methods, such as biocontrol agents and eco-friendly approaches, can contribute to sustainable YMV management [67,21].

Research gaps and future prospects:

There are several areas of research that require attention to enhance our understanding and management of YMV:

Mechanisms of YMV Resistance: Further exploration of the mechanisms underlying resistance to YMV in green gram and other leguminous crops can provide insights into developing more durable resistance cultivars [68].

Vector Biology and Management: Investigating the biology, behavior, and ecology of whitefly vectors, particularly *Bemisia tabaci,* can contribute to the development of targeted management strategies. Understanding factors influencing whitefly population dynamics and vector competence for YMV transmission is crucial [69].

Molecular Characterization: Continued studies on the genetic diversity and evolution of YMV strains using advanced molecular techniques can enhance our understanding of strain dynamics, emergence, and distribution patterns [53].

Virus-Host Interactions: Elucidating the molecular and physiological mechanisms underlying YMV infection and its impact on plant growth, photosynthesis, and nutrient uptake can aid in developing strategies to mitigate disease effects [54].

Integrated Approaches: Integrated management strategies that combine cultural practices, genetic resistance, biological control, and targeted insecticide use need further refinement and evaluation for their efficacy and sustainability [53].

Farmer Education and Adoption: Promoting awareness and providing training to farmers on YMV identification, management strategies, and good agricultural practices can help in the adoption of sustainable control measures [70].

7. CONCLUSION

Yellow Mosaic Virus (YMV) is a major viral pathogen that poses a significant threat to green gram cultivation. Its impact on yield and economic losses necessitates effective management strategies. Early detection techniques, such as visual inspection and molecular diagnostics, enable timely intervention and control measures. Cultural practices, chemical control, genetic resistance, and integrated pest management (IPM) approaches are essential components of YMV management. Developing YMV-resistant green gram varieties through breeding programs and promoting sustainable farming practices are key for long-term control. Continued research is needed to address emerging strains, understand virus-vector interactions, and explore sustainable management approaches. By implementing these strategies and fostering farmer education, the impact of YMV on green gram production can be minimized, ensuring a more secure and productive future for green gram cultivation.

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