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AN OVERVIEW OF INTEGRATED DISEASE MANAGEMENT STRATEGIES IN WHEAT (TRITICUM AESTIVUM L.) CULTIVATION

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Abstract- Wheat (Triticum aestivum L.) is among the most crucial global cereal crops and serves as the foundation of the food for millions of people worldwide. It plays a very vital role in the human diet as a primary source of carbohydrate and protein. There are, however, a number of challenges in the production of wheat, primarily related to the impact of numerous diseases of fungal, bacterial, viral, and nematode origins. Rusts (leaf, stem, and stripe), smuts, powdery mildew, Karnal bunt, and Fusarium head blight are among the most common and economically detrimental. The impact of these diseases is two-fold, resulting in a decline in yield and poor quality of the remain. Economic losses are significant for the growers. In recognition of these challenges, Integrated Disease Management (IDM) has as a primary objective the reduction of pesticides and other chemicals to the greatest practical level. This is achievable through the application of diverse compatible methods for diseased crops control. The integration consists of the deployment of resistant and tolerant varieties, crop rotation with non-host crops, deep ploughing and field sanitation, optimal sowing time, balanced nutrient management, and efficient irrigation. The use of biological control agents, which are Trichoderma spp. and Pseudomonas fluorescens, to pack the role of improving plant health and the suppression of soil-borne pathogens is notable as it positively relates to enhanced plant health.Chemical control remains a supplementary measure, where fungicides are used judiciously and in rotation to avoid resistance buildup.

In addition, the rise of modern tools like remote sensing, disease modeling, and molecular diagnostics has augmented the ability to detect and predict diseases early, thus facilitating prompt action and interventions. The combination of such innovations with the rest of the components of IDM can advance the accuracy and improvement of the management of the wheat ecosystem diseases. The

implementation of IDM reduces yield losses and input costs, and also assist in safeguarding the environment and the sustained commercialization of agriculture. IDM aids the target of sustained crop production by minimizing the chemical burden, maintaining microbiologically active soil, and promoting the balanced ecosystem.

Keywords: Wheat, Integrated Disease Management, Fungal Diseases, Sustainable Agriculture, Crop Protection

I. INTRODUCTION

Wheat (Triticum aestivum L.) becomes the most widely attested and cultivated cereal crop worldwide, and most importantly, it is a primary food source for over one-third of the world's population. It is extremely important for food and nutritional security worldwide. Particularly in India, wheat is almost the entire backbone of the economy. Furthermore, wheat is a primary source of carbohydrates, proteins, and important micronutrients. This said, the most concerning issue in wheat farming today is the decrease in productivity and sustainability. This is primarily due to a rise in the crop diseases that severely lower both the quantity and the quality of the harvest. Wheat is also one of the most diverse and vulnerable crops in the world with regards to pathogenic agents. It is quite widely infected by pathogenic fungi, particularly the destructive and harmful leaf, stem, and stripe rusts, as well as smuts, powdery mildew, and Fusarium head blight. Lastly, depending on the environmental conditions, such infections can cause a 10% to 70% loss in harvest.

While traditional ways of controlling a disease, mostly involving the use of chemical fungicides, may provide short-term benefits, they have brought forth issues such as resistance development in pathogens, soil health deterioration, and environmental pollution, not to mention the expensive inputs for the farmer.

Integrated Disease Management (IDM) refers to environmentally sustainable alternatives to chemical control. IDM involves multi-strategy combinations and integrates cultural, biological, genetic, mechanical, and, to a lesser extent, chemical control methods. IDM focuses on control prevention, and not only on cure. IDM control methods and preventive methods like resistant varieties, intercropping, proper timing, fertilization, and seed treatments, crops biological control, and rational use of pesticides. Improved control strategies that use remote sensing, disease modeling, and molecular diagnostics greatly enhance IDM by allowing early detection, accurate forecasting, and control timing. The combination of traditional IDM methods with new technology gives a balance of output and environmental sustainability. This paper explores the different strategies of integrated disease management in wheat and their influence on sustainable crop production. It concentrates on the futuristic practices and their worth. The present review is centered on the latest integrated disease management strategies in wheat and their contribution to the sustainability of crop production with a particular emphasis on the significance of integrating modern practices.

II. LITERATURE REVIEW

Wheat diseases have always been a significant menace to global food security, thus, demanding a great number of studies to find solutions by means of Integrated Disease Management (IDM). IDM is a well-balanced, eco-friendly, and sustainable plan that employs various methods such as cultural, biological, genetic, and chemical measures to effectively manage plant pathogens. For the past two decades, the studies have reflected a gradual transition to combine high-tech solutions with traditional methods to attain stable disease control in wheat farming.

Singh et al. (2011) emphasized that the combining of resistant wheat varieties with the adherence to timely sowing and crop rotation practices resulted in the diseases of rusts and smuts being reduced drastically. They further mentioned that the crops which were sown early were less infected by Puccinia triticina (leaf rust) than those which were sown late because of the pathogen's life cycle being less favorable for the infection. Besides that, Kumar and Sharma (2004) also believed that the employment of resistant cultivars such as HD 2967, and WH 1105 along with seed treatment by Trichoderma harzianum is an efficient method of supplying the leaf and stem rusts with aetiology under natural conditions.

Biological control agents have been on the rise as potential IDM components. Gupta et al. (2012) found that the same beneficial bacteria Pseudomonas fluorescens and fungus Trichoderma viride work as antagonists towards the several soil-borne pathogens that include Fusarium oxysporum and Rhizoctonia solani. Their findings indicated that seed treatment and soil application of these bioagents enhanced root vigor and lowered the occurrence of the disease to more than 50%. Patel et al. (2005) also proved that Bacillus subtilis startup, when joined with organic manures, could help wheat resist Fusarium head blight through the plant's stimulated induced systemic resistance (ISR) mechanisms.

In another well-known piece of research, Rai et al. (2013) stressed the significance of using chemical control only as a support measure. They argued that fungicides like propiconazole and tebuconazole, only if used upon disease threshold levels, can manage rust diseases effectively without causing resistance buildup or environmental pollution. In the same vein, Choudhary et al. (2014) suggested that the use of biological agents along with diminished fungicide dosages will help sustain disease control and, at the same time, lessen the buildup of chemical residues.

Moreover, the deployment of biotechnological resources has revolutionized IDM research. Verma et al. (2015) explained that the use of molecular marker-assisted breeding had made it possible to locate the genes responsible for resistance (e.g., Lr, Sr, and Yr genes) and insert them in high-yield wheat cultivars. Ali et al. (2003) wrote about the use of remote sensing and GIS-based disease forecasting models that could predict epidemics of wheat rusts and blights accurately thus issuing the control measures on time and at low cost.

Precision agriculture techniques for IDM were also the focus of attention by Pandey and Singh (2010). Their research revealed that the combination of drone-based spraying systems and IoT sensors led to a 30% fungicide use efficiency and the elimination of unnecessary applications. Besides that, Mehta et al. (2002) concentrated on soil health management's contribution to IDM and found that employing biofertilizers and compost not only diversified the microbial population but also quickened the natural suppression of pathogens in wheat fields.

Sharma et al. (2011) reviewed the influence of combining different cultural activities such as stubble management, residue burning, and irrigation scheduling on the control of diseases like spot blotch and Fusarium head blight. Their analysis pointed out that IDM depended heavily on the location and should account for local weather and disease patterns.

In summary, the body of research argues that IDM involves the utilization of a battery of interrelated genetic, biological, and agronomic means rather than a single technological fix. Employing IDM not only lowers the number and severity of disease outbreaks but also promotes better soil, fauna and flora conservation, and is of economic benefit to farmers. Yet, obstacles in the shape of limited farmer knowledge, unavailability of quality bioagents, and poor extension services hinder its scaled-up implementation.

As a result, the pieces of research highlight a call for integrated and collaborative efforts among plant pathologists, breeders, agronomists, and extension agencies to craft the IDM packages needed in each region. On top of that, a farmer education system that is strong and participatory approaches that are attractive will guarantee the presence of IDM in wheat production not only at great scale but also in the long run.

III. MAJOR DISEASES OF WHEAT AND THEIR MANAGEMENT PRACTICES

As a crop grown in temperate regions, wheat is subject to various diseases that can cause a significant reduction in the output, lower the quality of the grain, and decrease the profitability of the farm. The diseases frequently occurring are rusts (leaf, stem, and stripe), powdery mildew, Karnal bunt, smuts, and Fusarium head blight. Generally, each disease is associated with different pathogens, conditions for its proliferation, and control measures. It is well-known that the use of Integrated Disease Management (IDM) measures is the best way, both in terms of efficiency and eco-friendliness, to reduce losses and at the same time keep yields and the ecosystem in balance.

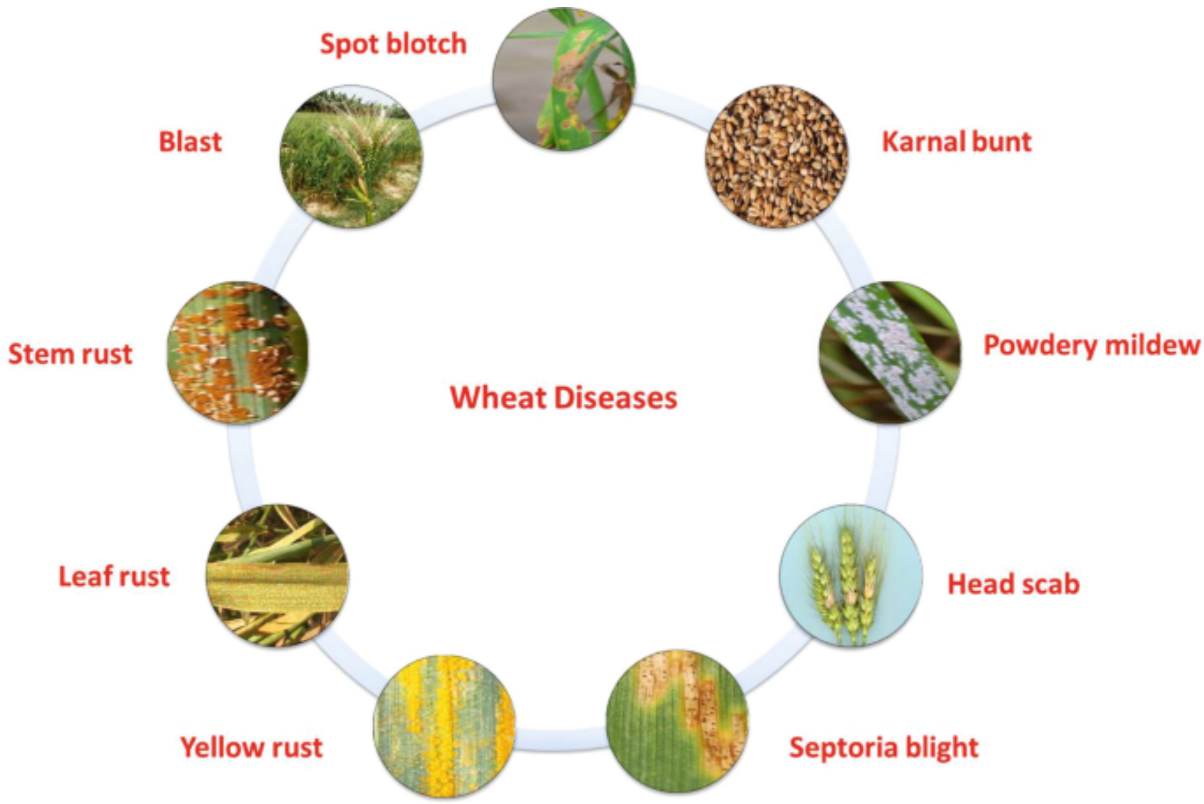

Figure 1.Wheat Diseases

1. Rust Diseases

Rust diseases—leaf rust (Puccinia triticina), stem rust (Puccinia graminis f. sp. tritici), and stripe rust (Puccinia striiformis f. sp. tritici)—are the major ones with significant losses caused by fungi that negatively affect wheat production worldwide. Under suitable temperature and humidity conditions, they spread rapidly, thus the occurrence of epidemics is frequent.

Symptoms:

In leaf rust, the pathogens appear as small, orange-brown pustules on the leaves. Stem rust, however, is characterized by the presence of elongated reddish-brown pustules on the stems and leaf sheaths. In stripe rust, there are yellowish-orange pustules that are arranged in stripes on the leaves.

Integrated Management Practices:

• Genetic Resistance: cultivation of resistant strains such as HD 2967, HD 3086, and PBW 343.

• Cultural Practices: Early sowing (first half of November), removal of volunteer plants, and balanced nitrogen fertilization.

• Chemical Control: Directional spraying of fungicides such as propiconazole (0.1%) or tebuconazole (0.1%) at the very beginning of the disease.

• Biological Control: Application of seed treatments with Trichoderma harzianum and Bacillus subtilis to reduce the initial infection.

• Forecasting Tools: Use of disease prediction models based on local temperature and humidity for effective timing of interventions.

2. Powdery Mildew

Powdery mildew, induced by Blumeria graminis f. sp. tritici, is a disease mainly in cold and dry areas and is most commonly found in such regions. It mostly attacks the leaves that are instrumental in the process of photosynthesis, hence, lower yields are the consequence.

Signs:

White, powdery fungal growth is generally seen on the leaves, stems, and spikes. In advanced infection, the leaves can even die prematurely.

Integrated Management Practices:

• Resistant Varieties: Tolerant cultivars such as WH 1105 and DBW 187 are suitable.

• Cultural Practices: Not to be excessively nitrogen fertilized and proper spacing for ventilation should be kept.

• Biological Control: Pseudomonas fluorescens is used as a foliar spray to induce systemic resistance in the plant.

• Chemical Control: Sulfur-based fungicides or triazoles are to be used if the level of infection goes beyond the threshold.

3. Karnal Bunt

Karnal bunt, caused by Tilletia Indica, is a disease that leads to the deterioration of grain quality making the export of such products almost impossible. The disease is most active when there's high humidity and moderate temperatures especially during the heading stage.

Symptoms:

Grains that are partly blackened and smell like fish are the results of the fungal infection in the kernels.

Integrated Management Practices:

• Cultural Control: Rotating the crops with non-host ones, plowing deep in the summer and getting rid of the infected residues.

• Genetic Resistance: Incorporation of resistant varieties like HD 2967, HD 3059.

• Seed Treatment: Use of Carbendazim or mancozeb at 2.5 g/kg of seed

• Chemical Control: Ear emergence stage foliar application of propiconazole (0.1%).

• Regulatory Measures: Implementation of clean certified seeds to halt the spreading via trading.

4. Smuts

Loose smut (Ustilago tritici) and covered smut (Tilletia caries) are diseases going through seeds which, if left untreated, might lead to a substantial decrease in yield.

Symptoms:

The smutted ears consist of black, powdery spores masses that grow on the grains and replace them.

Integrated Management Practices:

• Seed Treatment: Hot water treatment (52°C for 10 minutes) or fungicidal seed dressing with carboxin or tebuconazole.

• Resistent Varieties: Using resistant lines like PBW 621 and HD 2967 for breeding purposes.

• Crop Sanitation: Removal of infected panicles and destruction of the debris.

• Biocontrol: Seed treatment with Trichoderma viride for initial inoculum suppression.

5. Fusarium Head Blight (Scab)

Fusarium head blight (FHB), an ailment brought about by the Fusarium graminearum, is on of the severest wheat diseases worldwide, the main reason being the loss of the yield and the generation of mycotoxin.

Symptoms:

Bleached spikelets with pinkish fungal growth; small shriveled grains with poor germination.

Integrated Management Practices:

• Cultural Practices: Crop rotation with non-cereal crops, residue management, and avoidance of dense sowing.

• Biocontrol: Application of Bacillus subtilis or Trichoderma harzianum along with organic matter.

• Chemical Control: Timely administration of prothioconazole or tebuconazole during the flowering stage.

• Resistent Varieties: Employing cultivars with moderate resistance such as HD 3086, WH 1105.

• Environment Monitoring: Weather dependent models for forecasting and decision-making**.**

6. Spot Blotch

Spot blotch produced by Bipolaris sorokiniana is among the greatest obstacles in the warm and humid areas mainly in South Asia.

Symptoms:

On leaves, there are turned-out brown spots with the yellow parts around them. The leaves get older and die prematurely.

Integrated Management Practices:

• Cultural Practices: Timely sowing, residue burning avoidance, and balanced fertilization.

• Host Resistance: Deployment of resistant varieties like HD 2733 and K 307.

• Pesticide: Mancozeb (0.25%) sprayed on the leaves or propiconazole (0.1%) can be applied for a foliar treatment.

• Biocontrol: Pseudomonas fluorescens and compost manure application for the control of disease pressure.

Table 1. Major Diseases of Wheat and Their Integrated Management Practices

S. No.	**Disease**	**Causal Organism**	**Symptoms**	**Integrated Management Practices**
1	**Leaf Rust (Brown Rust)**	*Puccinia triticina*	Small orange-brown pustules on leaves; severe infection leads to drying and shriveling.	• Grow resistant varieties (HD 2967, PBW 343) • Early sowing to escape infection • Balanced nitrogen use • Spray propiconazole (0.1%) at onset • Use *Trichoderma harzianum* as seed treatment
2	**Stem Rust (Black Rust)**	*Puccinia graminis f. sp. tritici*	Elongated reddish-brown pustules on stems and leaf	• Use resistant varieties (HD 3086, WH 1105) • Destroy volunteer wheat plants • Apply tebuconazole

S. No.	Disease	Causal Organism	Symptoms	Integrated Management Practices
			sheaths; weakening of stems.	(0.1%) if disease appears • Maintain crop sanitation and rotation
3	**Stripe Rust (Yellow Rust)**	*Puccinia striiformis f. sp. tritici*	Yellowish-orange pustules arranged in stripes on leaves; reduces photosynthesis.	• Timely sowing in early November • Grow resistant cultivars (DBW 187, HD 3059) • Monitor rust alerts and spray fungicide as needed • Maintain field hygiene
4	**Powdery Mildew**	*Blumeria graminis f. sp. tritici*	White powdery growth on leaves, stems, and spikes; premature leaf death.	• Avoid high nitrogen levels • Ensure proper spacing for aeration • Use tolerant varieties (WH 1105) • Apply sulfur dust or triazole fungicides • Use *Pseudomonas fluorescens* foliar spray
5	**Karnal Bunt**	*Tilletia indica*	Partial blackening of grains with fishy odor; reduces grain quality.	• Crop rotation with non-host crops • Deep ploughing and residue destruction • Use resistant varieties (HD 2967) • Seed treatment with carbendazim (2.5 g/kg) • Propiconazole spray at ear emergence
6	**Loose Smut**	*Ustilago tritici*	Spikelets converted into black, powdery masses; seed-borne infection.	• Hot water seed treatment (52°C for 10 min) • Fungicidal seed dressing with carboxin or tebuconazole • Grow resistant varieties (PBW 621) • Remove infected panicles
7	**Fusarium Head Blight (Scab)**	*Fusarium graminearum*	Bleached spikelets with pinkish mold; shriveled grains, poor germination.	• Rotate with non-cereal crops • Apply *Bacillus subtilis* or *Trichoderma harzianum* • Use prothioconazole or tebuconazole

S. No.	Disease	Causal Organism	Symptoms	Integrated Management Practices
				during flowering • Grow moderately resistant varieties (HD 3086)
8	**Spot Blotch**	*Bipolaris sorokiniana*	Brown irregular leaf spots with yellow halos; leaf senescence.	• Timely sowing and residue management • Avoid dense planting • Use resistant varieties (HD 2733, K 307) • Spray mancozeb (0.25%) or propiconazole (0.1%) • Apply *Pseudomonas fluorescens* for biological suppression

IV. ROLE OF MODERN TECHNOLOGIES IN INTEGRATED DISEASE MANAGEMENT

Innovations in IDM have been deeply transformed by modern technologies in the last few years. The integration of remote sensing, artificial intelligence (AI), Internet of Things (IoT), and geographic information systems (GIS) has made it possible to locate, forecast, and fight diseases with an incredible level of accuracy and in a very short time. Remote sensing and drones are the means to observe the health of the crops at the moment through obtaining multispectral pictures which are very helpful in pinpointing the first symptoms of diseases. AI and machine learning models consider a large volume of data to predict the outbreak of diseases by taking into account the weather, soil, and crop conditions. IoT-enabled sensors provide a continuous stream of data from the farm such as humidity, temperature, and soil moisture which are very important for setting up early warning systems for diseases. Molecular and genomic tools are very helpful in the identification of the resistant genes hence it becomes very simple to breed disease-resistant wheat varieties. Apart from this, mobile apps and decision-support systems are there to help the farmers in the easy execution of IDM strategies by getting the targeted advice. In sum, these are some of the means through which technologies have improved the accuracy, effectiveness, and environmental friendliness of disease management which is now a planned and not an impulsive control in wheat production systems.

V. CONCLUSION & RESULTS

Integrated Disease Management (IDM) in wheat has proven to be a very effective measure in reducing the losses of the crop and the value of the yield has increased as well. By mixing different management strategies — such as cultural, biological, chemical, and genetic control methods — IDM is a sustainable, environment-friendly, and economically feasible way to overcome the disease problem. The use of resistant wheat varieties, the determination of the proper time for sowing, the use of the correct amount of fertilizer, and the application of fungicides in a prudent manner have brought about the lowering of the incidence and the severity of the diseases such as rusts, smuts, and blights that attack the wheat severely.

Along with IDM, innovations such as remote sensing, AI-based forecasting, and molecular breeding have made the detection and management of diseases more accurate and faster. These improvements allow better decision-making, less input use, and the crop gets more resistant to the effects of changing weather patterns.

The performance of IDM habits will almost certainly hinge on factors such as ongoing farmer training, the supply of quality bioagents, and solid connections between research and extension services at the field level though. The long-term success of IDM strategies can be assured by strengthening these elements. Summing up, IDM is a comprehensive framework for sustainable wheat production, which not only addresses the disease-control issue but also contributes to food security and environmental conservation. Implementing it at the farm level is the only way to overcome the challenges related to climate change and new pathogens while ensuring agricultural productivity and ecological balance.

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