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8. Diseases of Millets and Its Management

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Abstract:

Millets, encompassing both major and minor varieties, constitute a significant source of the human diet. They boast richness in proteins, carbohydrates, fats, fiber, and essential micronutrients, including vitamins and minerals. The annual increase in millet production can be attributed to their remarkable resilience against various biotic and abiotic stresses. However, in recent times, millets have become susceptible to a range of bacterial, viral, and fungal infections. Common diseases affecting millets include blast, downy mildew, ergot, grain mold, smut, rust, bacterial leaf strike, bacterial leaf spot, Maize stripe virus (MStV-S), Maize streak virus, and Maize mosaic virus (MMV-S). To mitigate the impact of these diseases, integrated crop management and pest control strategies are essential. This involves implementing agronomic cultural practices, utilizing resistant and tolerant cultivars, and incorporating chemical and biological control measures. By adopting these measures, the spread of diseases can be effectively curtailed, leading to increased crop yield.

Keywords:

Millets, Blast, Ergot, Grain Mold, Downy Mildew, Resistant Cultivars.

8.1 Introduction:

Millets, a crucial group of small-seeded grasses cultivated for their role in global food security, face the challenge of susceptibility to various diseases despite their nutritional benefits and resilience (Chandrashekar *et al*., 2016; Kumar *et al*., 2016). Understanding the causes, symptoms, and effective management strategies for the numerous maladies affecting millets is imperative for sustaining and enhancing their production. These diseases, caused by fungi, bacteria, and viruses targeting different plant parts, result in symptoms such as leaf spots, wilting, discoloration, stunting, and reduced grain quality. Given the diverse range of millet species and cultivation practices, a comprehensive approach to disease management is essential. Efficient management involves a multi-faceted strategy integrating cultural, biological, and chemical control measures (Nagaraja *et al*., 2016). Cultural practices, including crop rotation, intercropping, and proper spacing, aim to minimize disease incidence. Biological control methods utilize beneficial organisms like antagonistic microorganisms and predators to mitigate pathogen populations. The judicious use of resistant varieties and incorporating disease-resistant traits through breeding programs significantly contributes to disease resilience. Moreover, advancements in molecular biology and genomics have facilitated the identification and development of millet varieties with enhanced resistance to prevalent diseases (Recent Advances in Millet Research, 2021). This integration of cutting-edge technology into traditional breeding approaches holds promise for further improving disease resistance in millets.

Chemical control measures, such as applying fungicides and bactericides, are employed cautiously to minimize environmental impact and prevent the development of resistant pathogen strains. Integrated disease Management (IDM) strategies, combining various control measures in a sustainable manner, are gaining prominence in millet disease management. Millets, encompassing diverse small-seeded grasses, are globally significant crops, particularly in challenging climatic conditions. Predominantly grown in regions prone to drought, notable millets include sorghum, pearl millet, finger millets (ragi), proso millet, and foxtail millet (Gahukar and Jotwani, 1980). Renowned for being gluten-free and rich in nutrients, millets present a viable alternative to traditional staples like wheat and rice. While exhibiting tolerance to pests and diseases relative to major cereal crops, millets still face challenges, leading to significant losses in India.

The International Year of Millets, declared by the United Nations General Assembly and FAO in 2023, emphasizes the promotion of sustainable production and high-quality millet attainment. Throughout history, millets have been a vital part of the human diet, contributing to health benefits and environmental sustainability due to lower water consumption. Despite their increasing global production, millets struggle with various stresses, both biotic and abiotic, including fungal, bacterial, and viral diseases (IK Das, 2017).

Phytopathogenic fungi, bacterial pathogens, and viruses pose significant constraints on millet production. Despite these challenges, millets continue to play a crucial role in human health, aiding in increasing hemoglobin levels, alleviating constipation, reducing sugar levels, and acting as antioxidants inhibiting tumor growth. Fungal diseases in millets encompass grain mold, smut, anthracnose, ergot, and rust, as highlighted by Das *et al*. (2017).

On the other hand, bacterial pathogens, including Pseudomonas sp, Xanthomonas sp, and Erwinia sp, are responsible for inducing bacterial leaf spot, bacterial leaf stripe, bacterial leaf streak, and bacterial stalk rot (Sundin *et al*., 2016; Das *et al*., 2017). Viral diseases in millets are transmitted through vectors such as aphids and plant hoppers. The causal viruses encompass Maize stripe virus (MStV-S), Maize streak virus, Maize Mosaic Virus (MMV-S), Maize dwarf mosaic virus, Sugarcane Mosaic Virus (SCMV), and Ragi mottle streak virus (Das *et al*., 2017).

8.2 Major Diseases On Millets:

Various plant pathogens cause serious diseases in both major (Table 8.1) and minor millets (Table 8.2). The diseases on millets are broadly classified into three categories.

A. Fungal Disease
B. Bacterial Disease
C. Viral Disease

Table 8.1: Diseases On Major Millets

Types of millets	Diseases	Pathogens
Finger Millet	Rust	*Uromyces eragrostidis*
	Blast	*Pyricularia grisea Magnaportha grisea Magnaportha oryzae*
	Leaf blast	*Pyricularia setariae*
	Bacterial leaf spot	*Xanthomonas eleusinae*
Pearl Millet	Downy mildew	*Sclerospora grmainicola*
	Blast	*Pyricularia oryzae Magnaportha grisea*
	Smut	*Moesziomyces penicillariae*
	Rust	*Puccinia subtriata*
	Leaf blast	*Pyricularia grisea*
	Top rot	*Fusarium moniliforme*
Sorghum	Downy mildew	*Peronosclerospora sorghi*
	Ergot	*Claviceps sorghi Claviceps sorghicola*
	Charcoal rot	*Macrophomina phaseolina*
	Leaf blight	*Exserohilum turcicum Bipolaris turcica*
	Head smut	*Sporisorium reilianum*
	Bacterial leaf stripe	*Pseudomonas andropogonis*
	Viral diseases	*Maize Stripe Virus* (MStV) *Maize Mosaic Virus* (MMV)

Table 8.2: Diseases On Minor Millets

Types of millets	Diseases	Pathogens
Foxtail Millet	Udbatta	*Ephelis sp.*
	Blast	*Pyricularia oryzae, Pyricularia setariae, Pyricularia grisea*
	Grain smut	*Ustilago crameri Koem*
	Smut	*Ustilago crameri*
Kodo millet	Sheath rot	*Sarcoladium oryzae*
	Leaf blight	*Alternaria alternate, Drechsler asp.*
	Rust	*Puccinia subtriata*
	Udbatta	*Ephelis oryzae* Syd.
Barnyard Millet	Leaf spot	*Colletotrichum frumentacei*
	Sheath blight	*Rhizoctonia solani*

Types of millets	Diseases	Pathogens
	Leaf blight	*Helminthosporium crusgalli*
	Head smut	*Ustilago crusgalli*
Proso Millet	Sheath blight	*Rhizoctonia solani*
	Head smut	*Phacelotheca destruens*
	Blast	*Pyricularia grisea*
Little Millet	Leaf blight	*Alternaria alternata*
	Rust	*Uromyces linearis*
	Grain smut	*Tolyposporium sp.*

8.2.1 Grain Mold:

- **Causal organisms:** *Fusarium spp., Curvularia lunata, Alternaria alternata, Phoma sorghina, Bipolaris spp., Aspergillus spp*.
- **Millet host:** Sorghum, Pearl millet, Finger millet
- **Survival and spread:** Crop residues, soil; air-borne
- **Symptoms:**

The first visible symptoms on sorghum appear on spikelet tissues as pigmentation of lemma, palea or glume or fungal growth on anthers and filaments. Blasted florets, poor seed set and production of small, shriveled grains. The color varies from whitish, pinkish, grayish, to shiny black. On mature grain symptoms appear as pink, orange, gray, white, or black fungal growth on the grain surface. Discoloration of grain is less prominent on color than white-grain sorghum. Grain mold on pearl millet appears as pinkish or whitish fungal growth on mature grains, whereas on finger millet it is seen as brown to black discoloration of grains.

Figure 8.1: Grain Mold

8.2.2 Sugary / Ergot Disease:

- **Causal organisms**: *Claviceps sorghi*, *C. Africana Pearl millet ergot*, *C. fusiformis*
- **Millet host:** Sorghum, Pearl millet
- **Survival and spread:** Infected panicle, sclerotia in seed and soil, collateral host; seed-, soil-, air-borne
- **Symptoms:**

Ergot infection is exudation of honeydew like viscous droplet from infected floret.

Droplets can be seen on a single, few or all florets in a panicle. Gradually a wart like fungal structure (sclerotium) evolves in place of grain. Honeydews fall on the leaf underneath and often attract growth of saprophytic fungi, giving leaf surface a black coloration. Sclerotia are purple black to black, elongated in shape, hard in texture, and bigger than sorghum seed. They may be larger than seed, and with a pointed apex which protrude from the florets.

Figure 8.2: Ergot Diseases

8.2.3 Smut:

- **Causal organisms:-**
- **Head smut:** *Sporisorium reilianum*
- **Covered smut:** *Sporisorium sorghi*
- **Loose smut:** *Sporisorium cruenta*
- **Long smut:** *Tolyposporium ehrenbergii*
- **Survival and spread:** Externally seed-borne, **Long smut:** airborne
- **Symptoms:**

Infected plants become stunted, thin-stalked and flower earlier than healthy. All spikelet's in a panicle get malformed. Fungal like structure ruptures soon after head emergence and smut spores are blown away leaving the empty spikelet. In head smut, a sorus fully covered with a grayish-white membrane emerges from the boot leaf in place of normal panicle. In covered smut, a fungal sorus is formed in the place of grain.

The membrane like structure persists unless it is broken by mechanical force. In long smut, the sorus is covered by a whitish to dull yellow, fairly thick membrane. Sori are much longer than those of the covered and loose smuts.

Figure 8.3: Smut

8.2.4 Pearl Millet Smut:

- **Causal organisms:** *Tolyposporium penicillariae (syn., Moesziomyces penicillariae*)
- **Survival and spread:** Survives as teleutospore in infected seed or in soil; air-borne
- **Symptoms:**

Sporidia causes infection in an infected floret ovary is converted into a sorus. Initially the sorus is bright or shiny green in color which later turns brown. The sorus is larger than grain and appears as enlarged body in place of grain (Plate 4). Mature sorus rupture and releases spore balls containing teleutospores. The pathogen has a long latent period therefore secondary infection in the same aged crop is rare unless late sown or late flowering plants are available. The fungus survives as teleutospore in infected seed or in soil. Teleutospore erminates to produce sporidia, which become air-borne, fall on stigma and cause infection.

8.2.5 Small Millet Smut:

- **Causal organisms:**
- **Grain smut Finger millet:** *Melanopsichium eleusinis*
- **Foxtail millet:** *Ustilago crameri*
- **Barnyard millet:** *Ustilago panici-frumentacei*
- **Head smut Barnyard, Kodo and Proso millets:** *Sorosporium paspalithunbergii*
- **Survival and spread:** Grain smut: externally seed-borne, air-borne; Head smut: seed-borne
- **Symptoms:**

Grain smut sori are developed randomly in the grain, main rachis or in peduncle on finger, barnyard, little and foxtail millets. Ovaries are transformed into velvety gall like sori which are bigger than normal grain. Initial greenish sorus gradually turns pinkish green and finally to dirty black on drying. On foxtail millet the fungus affects grains in an ear. Head smuts are common in kodo millet, barnyard millet and proso millet. In kodo millet it causes considerable yield loss.

The entire panicle is transformed into a long sorus. Infected panicles may be enclosed in the flag leaf and may not emerge fully. The enclosing membrane bursts and exposes the black mass of spores.

Figure 8.4: Small Millet Smut

8.2.6 Downy Mildew/Crazy Top:

- **Millet host:** Sorghum, Pearl millet, Small millets Sorghum downy mildew
- **Causal organisms:** Peronosclerospora sorghi (Syn., Sclerospora sorghi)
- **Survival and spread:** Survive as oospores in host tissues and soil; Primary infection in soil, secondary infection through conidia
- **Symptoms:**

Systemically infected seedlings are pale yellow or have light-color streaking on the leaf, chlorotic and stunted and may die prematurely. The first symptoms are visible on the lower part of the leaf blade, which later progresses upward. In cool, humid weather, the lower surfaces of chlorotic leaves become covered by a white, downy growth consisting of conidia and conidiophores of the pathogen. The leaves emerging from the whorl subsequently exhibit parallel stripes of vivid green and white tissue. The infected striped areas die, turn brown, and disintegrate, resulting in a shredded appearance of the leaf. Conidia produced in the infected plants become air-borne and cause rectangular shaped local lesion on the leaf.

Figure 8.5: Downy Mildew/Crazy Top

8.2.7 Pearl Millet Downy Mildew:

- **Causal organisms:** *Sclerospora graminicola*
- **Survival and spread:** Survive as oospores in host tissues and soil; Primary infection in soil, secondary infection through sporangia
- **Symptoms:**

Developed both on the leaves and the ear head. Initial symptoms of the systemic infection are expressed as chlorosis or yellowing of the lower leaves that progressively spread to the upper leaves and the whole plant. Often the lower half of a leaf shows symptoms while its upper half remains symptomless. Numerous sporangia are produced on the lower surface of an infected leaf (arrow). A severely infected plant becomes stunted and often fails to produce an ear head. Often the infected plant produces symptoms only on the ear head in the form of the leafy structures known as 'green ear' disease. Spikelet tissues are transformed into thread-like leafy structure (Plate 8b). Such panicles generally do not produce grain. Later on the leafy growth dries up giving the panicle a dark brown to black appearance. Local lesion symptoms, as seen in sorghum, are rare in pearl millet.

Figure 8.6: Pearl Millet Downy Mildew

8.2.8 Small Millet Downy Mildew:

- **Causal organisms:**
- **Finger millet:** *Sclerophthora macrospora*
- **Foxtail millet:** *Sclerospora graminicola*
- **Survival and spread:** Survive as oospores in host tissues and soil, alternate host; Primary infection in soil, secondary infection through conidia or sporangia.
- **Symptoms:**

Downy mildew in finger millet is known as crazy top downy mildew because of appearance of bushy and leafy growth in place of fingers or grains. The white cottony growth, characteristic of many other downy mildews, is generally not seen. The disease converts the heads partially or entirely into green narrow leafy structures causing complete sterility.

The proliferation starts at the basal spikelet and gradually the whole ear gives a bush-like appearance called 'green ear' symptom. The pathogen has a wide host-range (Eleusine indica, maize, wheat, oat, Digitaria marginata). Foxtail millet downy mildew is exhibited by downy growth of the fungal structures as observed in many other downy mildews. Shredding of the infected leaves is common during later stages. Malformation of the floral organs and conversion of few or many spikelets into leafy structure is commonly observed.

Figure 8.7: Small Millet Downy Mildew

8.2.9 Anthracnose Millet:

- **Causal organisms:** Colletotrichum graminicola
- **Survival and spread:** survives on crop residues and wild sorghum; spread by air-borne conidia
- **Symptoms:**

Initial symptoms of anthracnose on the leaf appear as small, elliptic to circular spots, with straw-color center and wide margin. The lesion margin may be red, orange, blackish purple, or tan, depending on the pigment present in the cultivar (purple or tan). Adjoining spots may coalesce to give a blighted appearance on the leaf. A black dot like acervulus is often seen at the center of the necrotic spot, which is the characteristic diagnostic symptom for leaf anthracnose. Apart from leaf the symptom may appear on the mid-rib, leaf sheath on the stalk and on spikelet tissues. In case of severe infection, plants get defoliated and die before reaching maturity.

Infected mature stalks may develop reddish internal lesions, which may be continuous or discontinuous giving the stem a ladder-like appearance. Nodal tissues are rarely discolored. If the infection is early and severe, pre-emergence damping-off may occur and the seedlings wilt and die.

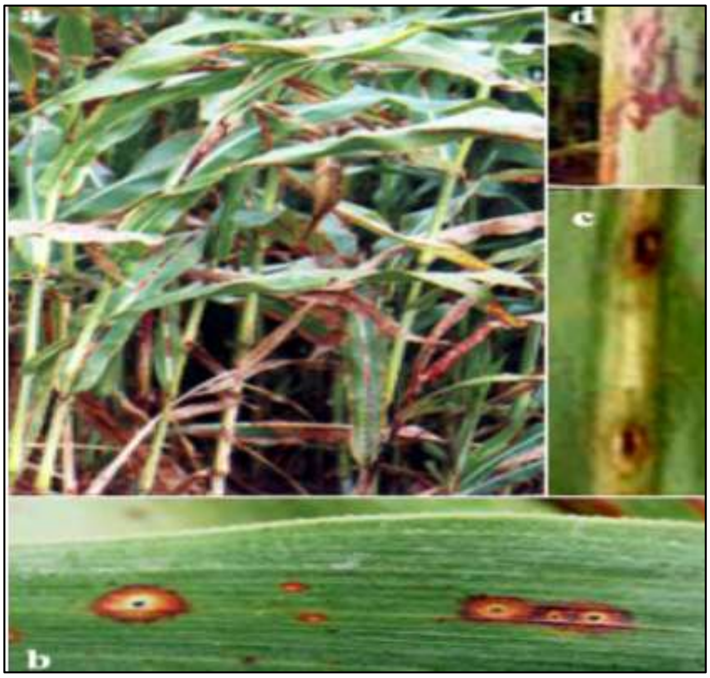

Figure 8.8: Anthracnose Millet

8.2.10 Leaf Blight Millet:

- **Host:** Sorghum, Small millets
- **Causal organisms:** Sorghum: Exserohilum turcicum (Syn., Hel. turcicum; Bipolaris turcica; Dreschslera turcica, Perfect state: Trichometasphaeria turcica)
- **Kodo millet:** Alternaria spp.
- **Survival and spread:** persists as mycelia and conidia in the infected crop residues or in the soil; spread by air-borne conidia.
- **Symptoms:**

Leaf blight symptoms on sorghum are characterized by the appearance of long, elliptical and necrotic lesions on the leaf. Centre of the lesion is straw-color, and the margin is usually dark brown. Margin is not conspicuous in tan type ltivar.

The size and shape of the lesions vary depending on the level of host resistance. The lesions, in a susceptible genotype, enlarge and coalesce to form purplish gray or tan color necrotic areas on the leaf.

The symptoms first appear on the lower or older leaves and then progress to the upper or younger leaves.

The surface of the necrotic lesions appears dark-gray or black in color due to production of spores by the pathogen, especially under damp weather. A severe disease gives the crop a distinctly burnt appearance. Similar symptoms can be seen on kodo and little millets.

Figure 8.9: Leaf Blight Millet

8.2.11 Rust Millet:

- **Host:** Sorghum, Pearl millet, Small millets Sorghum rust
- **Causal organisms:** *Puccinia purpurea*
- **Survival and spread:** survives on ratoon or successively grown sorghum, perennial and collateral hosts; spread by air-borne conidia
- **Symptoms:**

Sorghum rust appears as reddish-brown pustules first on both the surfaces of the lower leaves. Generally, the upper half of the leaf gets more severe infection than the lower half. As the disease advances the infection spreads to the younger leaves. Several adjoining pustules may coalesce to form large patches on the leaves and the infected leaves die prematurely giving the plants an unhealthy appearance which becomes visible from a distance. The pustules may appear in any parts of the plant including midrib (arrow), peduncle and stem. The pathogen produces two types of spores in the pustules on sorghum viz., urediniospore and teleutospore.

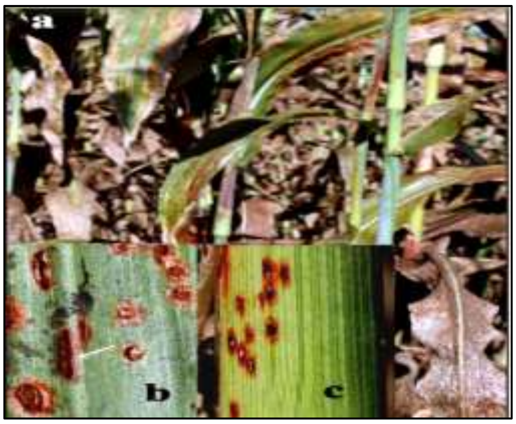

Figure 8.10: Rust Millet

8.3 Disease Management:

8.3.1 Cultural Practices:

Many agricultural practices such as deep ploughing during summer season, cleaning of field bunds after crop season, removal of crop residues from the field, uprooting the diseased plant from the field and burning, regulating irrigation water from entering into other field, if followed regularly, reduce chances of disease occurrence.

- Collateral and alternate hosts, weeds, volunteer and wild crop species harbor pathogens and serve as source of inoculums. Their timely removal helps to control diseases like ergot, downy mildew, rust, blast, leaf spots and bacterial and viral diseases.
- Deep summer ploughing, destruction of crop residues and crop rotation with non-host plant help reduce inoculums of soil-borne diseases (downy mildew, smut, charcoal rot and a few fungal and bacterial leaf diseases).
- Maintaining optimum plant spacing and regulating the amount of nitrogenous fertilizer reduces incidence of blast, downy mildew, and charcoal rot.
- Mechanical removal of sclerotia from seeds, by washing in 30% salt water reduces seed contaminated infection of ergot. In seed production plots, ensuring synchrony of flowering between A and R lines avoids the occurrence of ergot.
- Management of smut diseases requires awareness among the farmers. Practice of clean cultivation like collecting smutted heads in cloth bags and dipping in boiling water to kill the pathogen will reduce the inoculum for the next year and minimize incidence.
- Insect acts as vector for many viruses and injects viruses inside the plant. Injury caused by insects in plants sometime help many bacteria to enter and cause disease. Insect control, therefore, helps in managing such diseases.

8.3.2 Resistant Cultivar:

Host-plant resistance provides the most economic and environmentally friendly method of managing millet diseases. For poor farmers it is the only viable practice, as they hardly use any other methods of disease control in millets.

- For grain mold management use of a cultivar that escapes the disease is the best option. Use of mold tolerant cultivar (CSH16, CSH27, CSH30, CSV20 and PVK801) and harvesting the crop at maturity is the second-best option to avoid grain deterioration and weathering.
- Though high level of genetic resistance is not available against charcoal rot the present-day cultivars viz., CSV19R, CSV216R and DSV6 possess good tolerance. Drought tolerant, lodging resistant and non-senescing sorghum genotypes have good tolerance to charcoal rot.
- All recently released cultivars of pearl millet (e.g., HHB 67, ICMH 356) possess tolerance to downy mildew as they are released only after multi-location testing.
- Resistance sources against finger millet blast are rare in India and Nepal, and they need to be explored in land races from Africa. GPU 28 and GPU 48 are widely used cultivars highly resistant to neck and finger blast.

- Barnyard millet genotypes PRB 402, TNAU 92 and VL 216 have resistance against the grain and head smut as well as brown spot diseases, while foxtail millet lines GPUS 27, SiA 3039, SiA 3059, SiA 3066, SiA 3088, TNAU 213 and TNAU 235 remain free from brown spot.

8.3.3 Biological Control:

Soil-borne diseases of millets (e.g., charcoal rot in sorghum, foot rot and sheath rot in small millets), for which adequate host resistance is lacking, use of biocontrol agents are useful. Seed treatment with talc formulation of Pseudomonas chlororaphis SRB127 reduces charcoal rot incidence and increases seed weight. Bio-control agents, especially strains of Trichoderma and Pseudomonas are useful for foot rot and sheath rot in small millets.

8.3.4 Chemical Control:

Chemicals are not generally used for disease management in millet, because of involvement of high cost of chemical and labor. However, sometimes its use in combination with resistant cultivar becomes necessary. Fungicides are mostly used either as seed treatment or foliar spray. However, the combination of them gives better management.

- Downy mildew: Seed treatment with Ridomyl-MZ @ 6g/Kg seed followed by one spray of Ridomyl-MZ @ 3g/L reduces incidence.
- Loose and covered smuts: Seed dressing with sulphur (@ 4g/Kg seed).
- Banded sheath blight: Seed treatment with propiconazole (@ 1 ml/Kg seed).
- Blast: Spraying Carbendazim (@ 0.1% a.i.) or Tricyclazole (@ 0.05% a.i.) or Combination of Mancozeb 63% + Carbenadzim 12% is recommended.
- Ergot: Use of tolerant cultivar and spraying panicles with fungicides (0.1% Bavistin or 0.2% Tilt or 0.2% Mancozeb) at flowering minimizes ergot incidence and its subsequent spread.
- Rust: Foliar spray of Mancozeb @ 0.2% effectively controls the rust.
- Insect vector: Spraying of Imidachlorprid @ 1.5 ml/ L effectively reduce population of leaf hopper and decrease incidence of viral disease.

8.4 Conclusion:

Millets stand as promising crops in addressing food scarcity, particularly in famine-hit countries. Their adaptability to diverse climatic conditions, minimal water requirements, and ability to thrive in challenging environments make them easily cultivable. Millets also contribute to a cleaner environment.

To effectively manage diseases impacting millets, researchers and experts need to meticulously study disease-causing pathogens, their life cycles, virulence, host plant interactions, and modes of transmission. Adopting an integrated approach is crucial for developing appropriate disease management strategies and ensuring sustainable development. Various methods, including the use of resistant cultivars, chemical treatments, and biological control measures, are employed to combat diseases in millets.

These methods, combined with agronomic cultural practices, contribute to enhanced productivity and increased millet yields. Ultimately, these efforts play a significant role in the global initiative to achieve zero hunger.

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