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Powdery mildew: A threatening disease of cucurbits in West Bengal

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Abstract

Cucurbit vegetables specially cucumber, bottle gourd, bitter gourd, pointed gourd, ridge gourd, pumpkin, ash gourd, and various melons, hold a central place in the vegetable-based cropping systems of West Bengal. These support farm income, dietary diversity, and rural nutrition across nearly every district. Powdery mildew is among the most damaging biotic stresses for these crops. It is caused chiefly by two obligate biotrophic ascomycetes, *Podosphaera xanthii* (syn. *Sphaerotheca fuliginea*) and *Golovinomyces cichoracearum* (syn. *Erysiphe cichoracearum*). It ranks among the most widespread foliar diseases of cucurbits worldwide. Warm, humid, semi-humid subtropical climate and year-round cultivation of cucurbitaceous crops in West Bengal is favorable for disease development and spreading of the pathogen. Most available information comes indirectly from pesticide use surveys and small management trials, rather than from detailed studies measuring disease incidence, severity, pathogen identity, and yield loss. Current understanding of the causal organisms, symptoms, disease cycle, epidemiology, host range, molecular diagnostics, and host resistance, alongside the cultural, chemical, biological, botanical, and nanotechnology-based management options tested against cucurbit powdery mildew. It also considers how a changing climate might shift disease pressure in the region, and closes with a set of research priorities: statewide surveillance, pathogen race characterization, and the breeding or introgression of resistance into locally preferred cultivars needed to put powdery mildew management in West Bengal on firmer scientific ground.

Keywords: Powdery mildew, Cucurbits, *Podosphaera xanthii*, *Erysiphe cichoracearum*, West Bengal, Host resistance, Disease management

1. Introduction

Cucurbitaceae is a large and economically important family of warm-season vegetable crops grown across the tropics and subtropics. Its major cultivated members include cucumber (*Cucumis sativus* L.), muskmelon and other melons (*Cucumis melo* L.), bitter melon (*Momordica charantia* L.), bottle gourd (*Lagenaria siceraria* (Molina) Standl.), ridge gourd (*Luffa acutangula* (L.) Roxb.), pointed gourd (*Trichosanthes dioica* Roxb.), pumpkin and squash (*Cucurbita* spp.), and watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) (Mondal *et al.*, 2020) [17, 20]. Powdery mildew stands out among cucurbit diseases for how widely it occurs and how much damage it can do. Unlike downy mildew and many other biotrophic pathogens, it does not need free water on the leaf surface to infect, which lets it establish under a broader range of conditions than most foliar fungal diseases (PérezGarcía *et al.*, 2009) [23]. Two distinct fungi are responsible for nearly all i.e. *Podosphaera xanthii* (Castagne) U. Braun & Shishkoff and *Golovinomyces cichoracearum* (DC.) V.P. Heluta, with occasional reports of *Leveillula taurica* rounding out the picture (Pawelkowicz *et al.*, 2025; PérezGarcía *et al.*, 2009) [22, 23]. Of the two, *P. xanthii* is usually reported as the dominant, more widely distributed species in warm production regions of India (Agnihotri *et al.*, 2014; Khan & Khan, 1992) [2, 12].

Once established, the fungus produces white to greyish powdery colonies on leaves, petioles and stems that cause chlorosis, early leaf senescence, reduced photosynthetic area and poor fruit set. In severe cases, defoliation and deformation of fruits are common (Dhall *et al.*, 2026) [5]. Because both pathogens are obligate biotrophs that sporulate heavily and spread on the wind, so the pathogen spread rapidly. Many Indian studies report appreciable yield and quality losses from the disease, along with the recurring cost of the fungicide sprays growers use to hold it back (Agnihotri *et al.*, 2014; Jana, 2014; Khan & Khan, 1992; Pawar & Chavan, 2010) [2, 9, 12, 21].

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West Bengal sits in the humid subtropical belt of eastern India, spanning a Gangetic delta and a sub-Himalayan terai fringe, and its extended warm, semi humid spells in spring–summer and again in autumn ought to suit the pathogen. However, the state has nothing resembling the district and region-level surveys published for Uttar Pradesh, which have documented incidence and pathogen identity in some detail (Agnihotri *et al.*, 2014; Khan & Khan, 1992) ^[2, 12].

In West Bengal, the available studies are limited and scattered (Jana, 2014; Kumar *et al.*, 2018; Kundu, 2022) ^[9, 14, 15].

This review leans on the broader Indian and international literature on cucurbit powdery mildew, its biology, epidemiology, diagnostics, and management, and reads it against the own conditions of West Bengal, with the aim of pulling together what is known and pointing to where the state-specific evidence is very low.

2. Cucurbit Cultivation and Its Importance in West Bengal

India ranks among the world's largest vegetable producers, with national output above 209 million tonnes in recent years (Press Information Bureau, 2024) ^[24], and cucurbits account for a sizeable share of that total. Their short duration, wide adaptability, high multiplication ratio, and suitability for both open-field and trellised cultivation make them an easy fit for smallholder farming (Karmakar *et al.*, 2015) ^[11]. Alluvial and riverbed areas along the Ganga and the Damodar, and their tributaries, support year-round cucurbit cultivation, especially pointed gourd, ridge gourd, and local bitter gourd varieties in West Bengal. Nutritionally, these vegetables supply dietary fiber, vitamin C, provitamin A carotenoids, minerals, and, in the case of bitter gourd, bioactive compounds valued for their nutraceutical properties (Tzortzakakis *et al.*, 2018) ^[29].

However, the same features that make cucurbits attractive to smallholders also favour the disease. Mixed and intercropped plantings of several cucurbit species within a single field or homestead, combined with overlapping, successive sowings throughout the year, keep inoculum in circulation between crop cycles and across hosts with shared susceptibility. Add limited access to disease-free planting material, patchy adoption of resistant cultivars, and a habit of spraying fungicides on a calendar rather than in response to actual disease pressure, and the cucurbit production of the state looks structurally vulnerable to recurring powdery mildew outbreaks.

3. The pathogens: taxonomy, morphology, and biology

3.1 *Podosphaera xanthii*

Podosphaera xanthii (Castagne) U. Braun & Shishkoff, also known as *Podosphaera fusca* and formerly called *Sphaerotheca fuliginea*, belongs to the family Erysiphaceae, order Erysiphales, and class Leotiomycetes (Lebeda *et al.*, 2024; PérezGarcía *et al.*, 2009; Braun *et al.*, 2001) ^[17, 23, 4]. The fungus forms ellipsoid to barrel-shaped conidia, borne singly or in short chains on conidiophores that arise from a superficial mycelial network anchored by haustoria that penetrate epidermal cells. When sexual chasmothecia (cleistothecia) do form, their appendages are simple and largely unbranched, and each chasmothecium usually encloses a single ascus, which separates *Podosphaera* from *Golovinomyces* under the microscope (PérezGarcía *et al.*, 2009) ^[23].

P. xanthii cannot be grown on ordinary microbiological media; as an obligate biotroph, it needs living host tissue to survive (Soria *et al.*, 2026) ^[28]. Its haustoria hijack host cell metabolism and dampen the plant's basal immune response, and recent effector mining work has turned up more than fifty candidate secreted

proteins thought to suppress chitin-triggered immunity, blunt reactive oxygen species bursts, and keep host cells alive long enough to sustain the biotrophic relationship (Pawelkiewicz *et al.*, 2025) ^[22].

3.2 *Golovinomyces cichoracearum* (syn. *Erysiphe cichoracearum*)

Golovinomyces cichoracearum (DC.) V.P. Heluta is still widely referred to by its older name, *Erysiphe cichoracearum* DC., the second fungus behind cucurbit powdery mildew, and across much of the Indian subcontinent (Lebeda *et al.*, 2024) ^[17]. It has been found alongside *P. xanthii*, sometimes on the very same host in the same season (Agnihotri *et al.*, 2014; Khan & Khan, 1992) ^[2, 12]. It differs from *Podosphaera* mainly in its dichotomously branched chasmothecial appendages and in carrying several asci per chasmothecium rather than one. Surveys from Uttar Pradesh suggest its host range is narrower than that of *S. fuliginea*/*P. xanthii*; in some areas, it turns up mostly on wild hosts such as ivy gourd (*Coccinia* spp.), and its sexual stage appears largely confined to the cooler winter months (Agnihotri *et al.*, 2014) ^[12].

3.3 Host specialization and pathogenic variability

Both fungi show considerable variation in virulence, generally described in terms of physiological races. Standardized differential host sets have been used to type *P. xanthii* races internationally, and several races are often found coexisting within a single production region, which complicates any attempt to breed for race-specific resistance (Lebeda *et al.*, 2024) ^[17]. Race typing of cucurbit powdery mildew has been reported in India, particularly for *Sphaerotheca fuliginea* (= *Podosphaera xanthii*), with three races identified using differential cucurbit hosts. The study examined a large number of *S. fuliginea* isolates collected from different cucurbit hosts and agro-ecological regions of India. Three races—Race 1, Race 2 and Race 3—were identified. Race 3 was the most widespread and infected most cultivated cucurbits. Race 1 was mainly associated with sponge gourd, while Race 2 was more restricted to green melon (*Citrullus vulgaris* var. *fistulosus*) (Sharma & Khan, 1993) ^[27]. However, systematic race/pathotype characterization of cucurbit powdery mildew isolates specifically from West Bengal appears to be poorly documented, indicating a potential regional research gap.

4. Symptomatology and diagnostic features

In the field, cucurbit powdery mildew shows white to greyish white, powdery colonies of mycelium and conidia appear on both leaf surfaces, on petioles, and occasionally on young stems and fruit calyces, starting as small, discrete patches that later merge into one continuous mat (Symptoms usually begin on older, lower leaves as small circular spots resembling a dusting of talcum powder, and under favourable conditions these can cover an entire leaf within days (Sarkar *et al.*, 2022) ^[25]. Heavily infected leaves turn chlorotic, then necrotic, curl at the margins, and senesce well before their time, thinning the canopy, exposing fruit to sunscald, and, in cucumber and melon, cutting into fruit size and sugar content. Left unchecked, a severe epidemic can defoliate and kill a susceptible crop within two to three weeks of the first symptoms, particularly under the warm, semi-humid conditions typical of spring–summer and post-monsoon cucurbit seasons of West Bengal (Jiang & Xiao, 2024) ^[10].

P. xanthii infections often start on both leaf surfaces and progress fast in warm weather, while *G. cichoracearum*'s chasmothecia, tiny black dots scattered through the mycelial mat, tend to show up mainly in the cooler winter months (Agnihotri *et al.*, 2014; PérezGarcía *et al.*, 2009) ^[2, 23]. Confirming which species is

present, then, comes down to examining conidial and chasmothecial morphology under the microscope, or to molecular methods.

5. Epidemiology and Disease Cycle

5.1 Inoculum sources and survival

Both fungi are obligate biotrophs, so they need living cucurbit tissue to survive and cannot persist for long as saprophytes in soil or crop debris (Sarkar *et al.*, 2022) ^[25]. Where cucurbits are grown almost year-round, as they are across much of West Bengal, through successive plantings of different species and relay cropping in homestead gardens, the pathogens can simply cycle asexually from one host crop to the next, and to volunteer or wild cucurbitaceous plants in between, without needing an overwintering sexual stage at all (Sengupta *et al.*, 2024) ^[26]. Where chasmothecia do form, usually as the year cools, they add a second, hardier survival structure and a possible source of both primary inoculum and genetic recombination once conditions turn favourable again (Agnihotri *et al.*, 2014; PérezGarcía *et al.*, 2009) ^[2, 23]. Wind carries conidia over both short and long distances, and because they tolerate comparatively low humidity, the disease can continue spreading even during dry spells, a trait that sets its epidemiology apart from downy mildew and most other obligate biotrophic cucurbit pathogens, which require free moisture to infect (Mieslerova *et al.*, 2022) ^[19].

5.2 Influence of weather parameters

Temperature, relative humidity, light intensity, and canopy density all shape how fast the disease develops. Moderate temperatures paired with high humidity, though not necessarily free water on the leaf, along with reduced light or a dense, shaded

canopy, are generally reported as the conditions under which conidia germinate and sporulate best; high temperatures and strong sunlight tend to slow things down (PérezGarcía *et al.*, 2009) ^[23]. One Indian field trial on cucumber found a significant negative correlation between maximum temperature and disease intensity ($r = -0.729$), with weaker positive links to humidity and rainfall (Gayake *et al.*, 2024) ^[6]. Surveys across the upper Gangetic plains recorded the heaviest disease pressure in March–May and again in September–November, moderate levels through winter, and almost none during the peak monsoon months of June–August, perhaps because heavy, sustained rain physically rinses conidia off the leaf even as humidity stays high (Khan & Khan, 1992) ^[12]. Seasons in West Bengal follow a broadly similar arc with a warm but only moderately humid pre-monsoon stretch, a heavily wet monsoon, and a mild, drier post-monsoon and winter. If the pattern observed in neighboring Gangetic plain states holds here as well, disease pressure on the state's cucurbit crops should peak during the pre- and post-monsoon transitions (Ghosh, 2018) ^[8]. That is a reasonable inference by analogy, but it remains just that an inference until someone actually monitors the disease in West Bengal itself.

6. Geographical distribution and disease status: National and West Bengal perspective

Cucurbit powdery mildew occurs in virtually every major vegetable-growing region of India, though detailed quantitative surveys have mostly come from the north and west. Table 1 lays out what the principal published surveys and field trials found, including the handful of studies that bear directly on West Bengal.

Table 1: Comparative overview of surveys and host susceptibility

Region / State	Survey scope	Causal species identified	Incidence/severity data reported	Peak severity period	Source
Uttar Pradesh (upper Gangetic plains)	17 cucurbit taxa surveyed across plains and hill tracts	<i>Erysiphe cichoracearum</i> ; chasmothecia formed Dec.–Feb.	14 species infected; 3 taxa (watermelon, bitter melon, snake gourd) field-resistant	Mar.–May and Sep.–Nov.; absent Jun.–Aug. (monsoon)	Khan and Khan (1992) ^[12]
Rohilkhand region, Uttar Pradesh	10 cucurbit species surveyed across 8 districts (Feb.–Mar.)	<i>Sphaerotheca fuliginea</i> (dominant, cultivated hosts); <i>E. cichoracearum</i> (wild <i>Coccinia</i> only)	Bottle gourd and melons most heavily infected; other hosts "relatively less affected"	Late winter–early spring (survey period)	Agnihotri <i>et al.</i> (2014) ^[2]
Maharashtra	Kharif and Rabi season field survey, multiple cucurbit hosts	<i>Sphaerotheca fuliginea</i> (dominant in both seasons)	Pumpkin, bottle gourd and squash most affected; basal/mature leaves preferentially colonized	Post flowering / fruiting stage	Pawar and Chavan (2010) ^[21]

Neighboring Gangetic plain and western Indian states have produced dedicated, quantitative surveys and field trials measuring incidence, severity, species identity, and control; West Bengal's own evidence base, by contrast, rests mostly on an indirect proxy of grower pesticide use patterns and on breeding work aimed at a related but different disease, downy mildew.

7. Host range and yield losses

Powdery mildew affects nearly every cultivated cucurbit genus *Cucumis*, *Cucurbita*, *Citrullus*, *Lagenaria*, *Luffa*, *Momordica*, *Trichosanthes* though how susceptible a given species or cultivar varies considerably. In Uttar Pradesh, only three of seventeen cucurbit taxa surveyed showed useful field resistance: watermelon, bitter melon and snake gourd. Bottle gourd, ridge gourd, pumpkin and various melons all showed appreciable infection (Khan & Khan, 1992) ^[12]. Precise estimates of yield losses caused solely by powdery mildew in Indian cucurbit crops are limited. However, management studies consistently show that effective disease

control can significantly reduce disease severity and increase marketable yield compared with untreated crops (Gayake *et al.*, 2024; Kumar *et al.*, 2018) ^[6, 14]. In addition, the disease can cause smaller, sunscalded and poorly graded fruits, while growers also incur costs for fungicide application (Jana, 2014) ^[9]. Therefore, further studies are needed to estimate the actual yield loss caused by powdery mildew in West Bengal and to distinguish these losses from those already prevented through fungicide use.

8. Molecular detection and diagnosis

Distinguishing the two causal species is not straightforward from morphology alone, especially at the conidial stage that dominates most of the growing season, and because obligate biotrophs cannot be grown in pure culture, conventional physiological typing is off the table as well. That has pushed molecular tools to the front of pathogen identification. Species-specific PCR and quantitative PCR assays, including a duplex qPCR paired with high-resolution melt analysis that can tell *Podosphaera xanthii* apart from the cucurbit downy mildew pathogen

Pseudoperonospora cubensis in a single reaction, have been validated down to a detection limit of 0.1 pg μL^{-1} of target DNA, sensitive enough to pick up inoculum on a leaf surface or in the air before symptoms even appear (Bandamaravuri *et al.*, 2020) ^[3]. Internal transcribed spacer (ITS) sequencing remains the standard way to confirm species identity and place isolates phylogenetically, and it is particularly useful where *P. xanthii* and *G. cichoracearum* turn up on the same host a situation already documented in Uttar Pradesh and plausible enough in West Bengal's dense, mixed cucurbit plantings (Agnihotri *et al.*, 2014) ^[2].

9. Hostplant resistance and molecular breeding

For managing cucurbit powdery mildew, host resistance is usually judged the most economical, durable, and environmentally sound option over the long run, and that matters especially for West Bengal, where most cucurbit growers are resource-limited

smallholders unlikely to sustain an intensive spray program. Resistance genetics has been worked out mainly in cucumber and melon, and the effort has turned up numerous quantitative trait loci (QTLs) and, increasingly, candidate genes tied to resistance or susceptibility (Lebeda *et al.*, 2024; Pawełkowicz *et al.*, 2025; Wang *et al.*, 2024) ^[17, 22, 30]. One theme keeps recurring: susceptibility genes for Mildew Locus O (MLO). Loss-of-function mutations in specific MLO homologs CsMLO1, CsMLO8, and CsMLO11 in cucumber, for instance, confer broad-spectrum resistance that tends to hold up better over time, by derepressing localized reactive oxygen species buildup and cell-wall defenses right at the point of attempted fungal entry. That gives breeders an alternative to classical race-specific major gene resistance, which is more prone to being overcome (Pawełkowicz *et al.*, 2025) ^[22]. Table 2 lays out the resistance type, molecular approach and reported effect for a selection of these loci in cucumber and melon.

Table 2: Molecular Approaches for Powdery Mildew Resistance in Cucurbits

Host crop	Locus / gene(s)	Resistance type	Molecular approach	Reported effect	Source
Cucumber (<i>Cucumis sativus</i>)	Multiple pmQTLs (polygenic cluster, minor to major effect)	Quantitative; largely race nonspecific	QTL mapping in biparental mapping populations	Additive, quantitative resistance; individual QTLs typically explain moderate phenotypic variance	Lebeda <i>et al.</i> (2024) ^[17]
Cucumber	CsMLO1, CsMLO8, CsMLO11 (susceptibility genes)	Recessive; broad spectrum (mlotype) resistance	Comparative and functional genomics of the MLO gene family	Loss of function mutants show enhanced ROS mediated defence and durable, broad spectrum resistance	Pawełkowicz <i>et al.</i> (2025) ^[22]
Cucumber	Candidate genes in fine mapped intervals (gene level identity not yet resolved)	Race specific; qualitative / major gene	Bulked segregant analysis combined with SLAFseq	Genomic regions co-segregating with the resistant phenotype fine mapped in biparental populations	Wang <i>et al.</i> (2024) ^[30]
Melon (<i>Cucumis melo</i>)	Multiple independent Pmloci	Race dependent; major gene	KASP marker development; BSA combined with RNAseq	Loci validated for marker assisted backcrossing of resistance into elite, susceptible backgrounds	Lebeda <i>et al.</i> (2024) ^[17]

Despite this progress, the Status, Gaps and Perspectives review of powdery mildew resistance breeding in cucurbits is candid about how hard it remains to translate a mapped locus into a durable, broad-spectrum resistant cultivar suited to a specific region's pathogen population and cropping system (Lebeda *et al.*, 2024) ^[17]. West Bengal's own landraces and traditional cultivars of pointed gourd, ridge gourd, and bitter gourd, in particular, lack any formal characterization of resistance. Screening this regional germplasm against locally circulating pathogen isolates and introgressing validated resistance sources, such as MLO-based resistance where feasible (Pawełkowicz *et al.*, 2025) ^[22], would be a high-value piece of work that no one has yet taken on. The state already has some of the institutional groundwork in place: its breeding program for downy mildew tolerance in bitter gourd shows that the capacity exists (Kundu, 2022) ^[15].

10. Disease management strategies

10.1 Cultural and agronomic practices

Cultural measures remain the first line of defense, and they matter more than usual given how smallholder and low-input most West Bengal cucurbit cultivation is. Worth doing: starting with disease-free seed and healthy transplants; not growing several susceptible cucurbit species back to back or side by side in the same locality, since that just keeps inoculum circulating; spacing plants adequately and trellising them to open up the canopy and cut down the humid, shaded microclimate the fungus likes; fertilizing in balance rather than overapplying nitrogen, which pushes out lush, susceptible growth; removing and destroying badly infected leaves and crop debris promptly; and cleaning up fields between crop cycles so inoculum does not simply carry over on volunteer

plants and wild cucurbit relatives.

10.2 Host resistance and resistant cultivars

Resistant or tolerant cultivars, where they exist, offer the most sustainable control available, and Indian surveys have flagged watermelon, bitter gourd and snake gourd as comparatively resistant in the field (Khan & Khan, 1992) ^[12]. But race-specific resistance genes do not necessarily hold up forever, pathogen populations can shift and erode them, which is part of why MLO-based and other broad-spectrum resistance sources matter, and why cultivar performance against local pathogen populations needs periodic rechecking rather than one-time trust.

10.3 Chemical, biological, botanical and nanotechnology-based management

Fungicides remain the management tool growers reach for most, West Bengal included: survey evidence shows bitter gourd growers there routinely spraying, often heavily, against foliar diseases, including powdery mildew (Jana, 2014) ^[9]. Demethylation inhibitor fungicides such as propiconazole, quinone outside inhibitor fungicides such as azoxystrobin, and a range of other systemic and protectant chemistries have all shown strong *in vitro* and field efficacy against the disease (Gayake *et al.*, 2024) ^[6]. One bitter gourd trial combining seed treatment with a rotated spray schedule achieved complete field control of powdery mildew, sharply reduced the severity of co-occurring diseases, and yielded a favorable cost–benefit ratio (Kumar *et al.*, 2018) ^[14]. Beyond synthetic chemistry, native bacterial antagonists (AboElyousr *et al.*, 2022) ^[1], low-cost plant-derived and organic materials (Pawar & Chavan, 2010) ^[21], and metal-

based nanoparticle formulations (Geremew *et al.*, 2025; Lamsal *et al.*, 2011) ^[7, 16] have each shown measurable efficacy in independent trials. Table 3 pulls together the quantitative

outcomes from the main chemical, biological, botanical, and nanotechnology-based interventions covered here.

Table 3: Strategies for Management of Cucurbit Diseases

Management category	Treatment / agent	Test system	Quantitative outcome	Source
Chemical (field)	Azoxystrobin 23% SC @ 0.1%	Cucumber, field trial	Disease intensity 19.01%; yield 80.00 q ha ⁻¹ (most effective treatment tested)	Gayake <i>et al.</i> (2024) ^[6]
Chemical (field)	Propiconazole 25% EC @ 0.1%	Cucumber, field trial	Disease intensity 22.22% (second most effective treatment)	Gayake <i>et al.</i> (2024) ^[6]
Chemical (<i>in vitro</i>)	Azoxystrobin, carbendazim, propiconazole, azoxystrobin + chlorothalonil, fluxapyroxad + pyraclostrobin	Cucumber, <i>in vitro</i> Conidial germination assay	100% inhibition of conidial germination at the higher tested concentration for all five fungicides; metrafenone lowest at 66.73%	Gayake <i>et al.</i> (2024) ^[6]
Integrated (seed treatment + rotated sprays)	Sequential fungicide / biorational spray schedule	Bitter gourd, multilocation field trial	Co-occurring foliar disease severity reduced to 20.75% vs. 58.73% (untreated control); yield 108.96 q ha ⁻¹ ; cost-benefit ratio 1:2.85; plants free from powdery mildew or reduced disease severity under treated plots	Kumar <i>et al.</i> (2018) ^[14]
Biological	<i>Bacillus aerius</i> (isolate PST ₁₃) culture filtrate	Cucumber, greenhouse	77.3% reduction in disease severity <i>in vivo</i> ; 85% conidial germination inhibition <i>in vitro</i>	AboElyousr <i>et al.</i> (2022) ^[1]
Biological	<i>Bacillus licheniformis</i> (isolate KAUBL1) cell suspension	Cucumber, greenhouse	45.3% reduction in disease severity <i>in vivo</i> ; 60% conidial germination inhibition <i>in vitro</i>	AboElyousr <i>et al.</i> (2022) ^[1]
Botanical / organic	Neem leaf extract (15%), buttermilk (20–25%), cow urine (15%), wood ash spray (20%), dashparni ark (10%)	Cucurbits (pumpkin, bottle gourd, squash), field	Effective suppression reported at the concentrations shown; quantitative percent control values not reported in the source	Pawar and Chavan (2010) ^[21]
Nanotechnology	Silver nanoparticles, 100 ppm, preventive spray	Cucumber and pumpkin, field / greenhouse	Disease incidence reduced to ≈18–20% (cucumber) and ≈20% (pumpkin) vs. 82–85% in untreated controls	Lamsal <i>et al.</i> (2011) ^[16]

The trouble with fungicides, though, is that the causal fungi are notorious for developing resistance quickly to single-site mode of action chemistries DMIs, QoIs, and benzimidazoles, especially once they are used repeatedly without rotation. That is a well-documented problem internationally, and it carries particular weight for West Bengal given how heavily its growers already appear to rely on chemical sprays (Jana, 2014; McGrath, 2001) ^[9, 18]. Rotating fungicides across unrelated chemical groups, sticking to recommended doses and intervals, and folding in the biological, botanical, and nanotechnology-based options from Table 3 alongside cultural practices and resistant cultivars, matters both for keeping the chemistry working long-term and for containing costs and pesticide-residue concerns on the ground. No single tactic will hold up on its own under West Bengal's diverse, near-continuous cropping conditions; an integrated disease management approach guided by disease forecasting or threshold-based scouting rather than a fixed spray calendar offers the more sustainable path forward.

11. Climate change and future disease dynamics in West Bengal

Climate change is expected to reshape how often, how severely, and where many plant disease epidemics occur, powdery mildews among them, through shifts in temperature, humidity, rainfall, and the timing of seasons (Kumar & Mukhopadhyay, 2025) ^[13]. Cucurbit powdery mildew is a plausible candidate for such shifts: it thrives in an intermediate temperature and humidity window and does not need free leaf moisture to infect, so anything that lengthens the pre and post-monsoon transitions, shifts monsoon timing, or brings more warm, humid, rain-free spells could widen the window in which the disease can establish in West Bengal. A recent analysis of climate-driven risks to plant pathogens, coauthored notably by researchers based at agricultural institutions within the state, argues for region-specific risk

assessment and climate-informed management rather than leaning on historical disease calendars (Kumar & Mukhopadhyay, 2025) ^[13].

12. Research gaps and future perspectives

Pulling the available literature together points to several research priorities specific to West Bengal. The most basic need is for systematic, multi-season surveys across several districts, to establish a baseline for incidence and severity across the state's major agroclimatic zones, the kind of documentation Uttar Pradesh already has (Agnihotri *et al.*, 2014; Khan & Khan, 1992) ^[2, 12], but West Bengal does not. Such surveys should break the data down by host species, given how many different cucurbits the state grows, and should measure yield loss directly rather than inferring it from management trial comparisons, as the existing indirect evidence forces us to do now.

Molecular characterization of the local pathogen population is a close second. Knowing whether *P. xanthii* or *G. cichoracearum* predominates, and how much genetic and racial diversity exists within it, would sharpen resistance-breeding priorities considerably, and the PCR/qPCR and sequencing tools to do this already exist (Bandamaravuri *et al.*, 2020) ^[3].

A third priority follows naturally from the first two: screening locally preferred landraces and cultivars pointed gourd, ridge gourd, and bitter gourd, especially against whatever pathogen isolates turn out to be circulating regionally, and introgressing validated broad-spectrum resistance sources, MLO-based resistance among them (Pawelkowicz *et al.*, 2025) ^[22], into these backgrounds. The state's existing breeding infrastructure for downy mildew tolerance in bitter gourd (Kundu, 2022) ^[15] is a reasonable starting point for this work rather than something that would need building from scratch.

Field testing is needed too. Most of the biological, botanical, and nanotechnology-based options summarized in Table 3 have only

been validated elsewhere or under controlled greenhouse conditions, not under the realities of West Bengal's agroclimatic and cropping systems.

There is also a case for auditing current fungicide use patterns and checking for emerging resistance in field populations, given how heavily the state's growers already seem to depend on chemical sprays (Jana, 2014) ^[9]; protecting what still works matters as much as finding new options.

And finally, pairing climate projections with disease-favourability modeling would help anticipate how shifting temperature and humidity regimes might change powdery mildew pressure over the coming decades, turning management planning proactive rather than reactive.

13. Conclusion

Powdery mildew driven mainly by *Podosphaera xanthii* and *Golovinomyces cichoracearum* is a serious, widespread threat to cucurbit production wherever these crops are grown, and West Bengal's warm, humid to semi-humid subtropical conditions suit the pathogen for much of the cropping year. The wider Indian and international literature has a fairly detailed handle on the pathogen's biology, epidemiology, diagnostics, host resistance and management options. What West Bengal itself lacks is a dedicated, quantitative documentation of its disease burden: what exists relies on indirect indicators such as grower pesticide-use surveys rather than formal epidemiological or pathogen characterization work. Closing that gap through systematic regional surveillance, pathogen characterization, resistance screening, and field testing of integrated management packages tailored to the state's smallholder-dominated, continuously cropped cucurbit systems would put the management of this threatening disease in West Bengal on a considerably firmer scientific footing.

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