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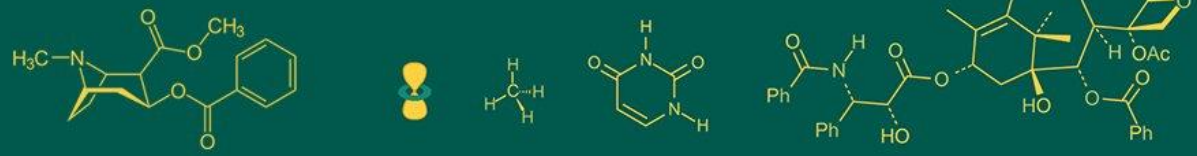

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Suresh BC
School of Agriculture, Dev Bhoomi Uttarakhand University, Chakrata Road, Manduwala, Naugaon, Uttarakhand, India

Preeti Handa Kakkar
School of Agriculture, Dev Bhoomi Uttarakhand University, Chakrata Road, Manduwala, Naugaon, Uttarakhand, India

Paratikshya Khadka
School of Agriculture, Dev Bhoomi Uttarakhand University, Chakrata Road, Manduwala, Naugaon, Uttarakhand, India

Manisha Phaugat
School of Agriculture, Dev Bhoomi Uttarakhand University, Chakrata Road, Manduwala, Naugaon, Uttarakhand, India

Anupama Raj
School of Agriculture, Dev Bhoomi Uttarakhand University, Chakrata Road, Manduwala, Naugaon, Uttarakhand, India

Corresponding Author:
Paratikshya Khadka
School of Agriculture, Dev Bhoomi Uttarakhand University, Chakrata Road, Manduwala, Naugaon, Uttarakhand, India

Powdery mildew in pea (*Pisum sativum* L.): A comprehensive review

Suresh BC, Preeti Handa Kakkar, Paratikshya Khadka, Manisha Phaugat and Anupama Raj

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Abstract
Pea (*Pisum sativum* L.) is a globally significant vegetable and pulse crop valued for its nutritional richness, soil-enriching capabilities, and adaptability across diverse agro-climatic zones. However, its productivity is severely constrained by powdery mildew, a pervasive fungal disease primarily caused by *Erysiphe pisi*. This disease thrives in warm, dry days followed by cool, dewy nights and is particularly devastating in late-sown or maturing crops, causing yield losses ranging from 10% to over 70%, depending on disease intensity and crop stage. The fungus colonizes the aerial parts of the plant, forming characteristic white powdery patches and reducing both yield and quality, including pod size, seed weight, and market value. Morphologically, the pathogen is ectophytic, forming haustoria, conidia, and cleistothecia that facilitate its reproduction and spread. Various management strategies have been explored, including the application of fungicides such as propiconazole, hexaconazole, tebuconazole, and sulphur, as well as the use of botanicals like neem and ginger extracts. Biocontrol agents such as *Trichoderma harzianum* and *T. hamatum* have also shown promising results. This review summarizes the disease's epidemiology, economic impact, and integrated management strategies, highlighting the need for durable resistant cultivars, improved farmer awareness, and region-specific disease control packages for sustainable pea production.

Keywords: *Pisum sativum*, powdery mildew, *Erysiphe pisi*, yield loss, fungicides, botanicals, biological control, disease management

1. Introduction
One important vegetable and pulse crop that is farmed worldwide is the pea (*Pisum sativum* L.). Pea holds its place as the third most important legume crop globally after soyabean and common bean (Azmat *et al.*, 2010) [5]. It's believed to have originated in the Mediterranean region, specifically Southern Europe and Western Asia, which includes areas like Italy, Southwest Asia, and India. This pod bearing plant belongs to the Leguminosae (Fabaceae) family and its Papilionaceae subfamily (Blixt, 1970) [8]. There are two subspecies of *Pisum sativum*: *Pisum sativum* Linn. subspecies "*hortense*" (Garden Pea), which is a variation of the common pea, and *Pisum sativum* subspecies "*arvense*" (Field Pea), which is thought to be indigenous to Ethiopia. Depending on the season, peas can be grown successfully anywhere from the terai (less than 100 meters) to high mountain regions (3000 meters) (Kumari *et al.*, 2024) [24]. Summer sowing of peas results in the production of green pods during the off-season, which are highly profitable for farmers in the plains. The peas cultivated in hilly regions are especially valued for their unique flavor, sweetness, tenderness, and freshness, leading to greater market demand and better prices . Peas contribute to increased soil fertility by leaving the soil with nitrogen-rich nodules that can fix molecular nitrogen from the atmosphere after forming a symbiotic relationship with bacteria of the genus Rhizobium (Popescu & Roman, 2008; Matsumiya *et al.*, 2013) [29, 13].
Peas are susceptible to various abiotic and biotic stresses, with powdery mildew caused by fungi belonging to the order *Erysiphales* posing a significant global challenge to garden pea cultivation. Powdery mildew, a fungal disease, was first observed in India in 1918 by Butler in Dehradun, Uttarakhand (Kumari *et al.*, 2024) [24]. When field peas are hit with powdery mildew (specifically *Erysiphe pisi*), they struggle. The infected plants transpire less, their water potential initially goes up, and their tissues lose moisture. This nasty pathogen thrives

in conditions where days are warm and dry, but nights are cool enough to reach or drop below the dew point (Tiwari *et al.*, 2023) [35].

An almost annual occurrence, powdery mildew is a severe and common fungal disease that frequently manifests as severe epidemics. Rainfall does not, however, promote the disease because it effectively removes the conidiophores the disease-transmitting structures from the plants (Sivapalan, 1993) [32]. The disease is most likely to affect crops that are sown or mature later. The first sign of powdery mildew often appears as small, scattered, light-colored spots on the older, lower leaves of a plant. As the disease progresses, these spots become covered with a white, powdery fungal growth. If you were to look closely, you'd see that the fungus has tiny threads (mycelial hyphae) growing on the plant's surface. These threads produce short stalks called conidiophores, which then carry the spores (conidia) that spread the disease. The secondary infection brought on by the spread of conidia is significantly influenced by wind. Furthermore, the seeds' quality suffers since they might acquire unfavorable processing characteristics or a bitter flavor. When pea plants get powdery mildew, it's caused by a fungus that basically takes over the plant's above-ground parts. This fungus has a hidden sexual stage called a cleistothecium. But what you mostly see is a white, powdery coating on the top of the leaves. That's because the fungus produces tons of tiny spores called conidia all over the leaf surface, making it look like someone dusted the plant with flour.

2. Diseases of Field Pea

The pea, scientifically known as *Pisum sativum* L. and commonly called "Matar" locally, holds significant importance as a leguminous crop in India. Its value lies in its versatility, serving both as a vegetable and a pulse crop. Among pulses, field pea stands out as the most widely cultivated crop in the country. However, the cultivation of pea is not without challenges, as it faces various fungal pathogens that can negatively impact its growth and yield.

Pea plants are susceptible to a number of fungal diseases that mainly affect the roots and foliage. Common fungal infections include root rot brought on *by Pythium ultimum*, *Rhizoctonia solani*, and *Aphanomyces euteiches*. Significant risks also come from Fusarium wilt and pea foot rot, which are brought on by *Fusarium oxysporum f. sp. pisi* and *Phoma medicaginis var. pinodella*, respectively (Soylu *et al.*, 2011). White mould (*Sclerotinia sclerotiorum*), foot rot (*Fusarium oxysporum*, *Fusarium solani*, and *Fusarium culmorum*), and black root rot (*Thielaviopsis basicola*) are additional fungi linked to pea root rots. Pea plants are vulnerable to foliar fungal diseases in addition to root diseases. These include rust (*Uromyces fabae*), powdery mildew (*Erysiphe pisi*), downy mildew (*Peronospora viciae*), Alternaria leaf and stem spot (*Alternaria alternata*), and the Ascochyta blight complex (caused by *Ascochyta pisi*, *Mycosphaerella pinodes*, and *Phoma medicaginis var. pinodella*) (Kerr, 1963; Blad *et al.*, 1978; Persson *et al.*, 1997; Kraft and Pfleger, 2001; Marcinkowska, 2002; Koike *et al.*, 2007) [16, 7, 28, 21, 25, 20]. Different countries and regions have different effects of these diseases on pea yield. According to Munjal *et al.* (1963) [27] and Fallon and Viljanen-Rollinson (2001) [15], powdery mildew, which is caused by *Erysiphe pisi* DC, is one of these fungal diseases that is especially notable for its negative effects on crop yield.

3. Morphology of fungus

The fungus (*Erysiphe pisi* DC) responsible for powdery mildew is characterized as septate, ectophytic, and an obligate parasite. It produces whitish mycelium and hyaline conidia. The colonies of the fungus are typically found on the undersides of leaves (hypophyllous), as well as on petioles and stems. The mycelium can persist on the host surface, starting off white and gradually changing to a brownish and then grayish color as it matures. You can think of conidiophores as little stalks that sprout straight up from the fungal threads (hyphae) on a host's surface. These stalks are responsible for producing conidia, which are essentially the fungus's spores. The conidia themselves are quite distinctive: they appear alone, have internal pockets (vacuoles), are granular, and can be either elongated or egg-shaped. They typically measure between 31 and 38 micrometers long and 17 to 21 micrometers wide, though sometimes they're observed as 25-35 x 13-16 micrometers. Interestingly, all the key fungal structures the hyphal cells, the conidiophore cells, the conidia, and the feeding structures called haustoria each contain a single nucleus. In addition, the fungus forms cleistothecia, which are scattered and range in shape from globose to depressed-globose, with a diameter of approximately 90 µm. The cells of the cleistothecial wall measure 9-18 µm in width. The appendages of the cleistothecia are mycelioid, geniculate, and brown in color. They can be septate or aseptate and range from 8 to 12 in number, with a flexuous shape and a length of up to 500 µm. The asci, which contain the ascospores, are ovate to broadly ovate in shape and usually number between 3 and 8. They possess a short stalk at the base and measure approximately 48-60 µm in length and 39-51 µm in width. The ascospores, typically numbering 3 to 6 per ascus, are ovoid in shape and measure 18-21 µm in length and 15-18 µm in width.

4. The Infection

Erysiphe pisi, a type of powdery mildew fungus, is an obligate parasite, meaning it can only survive by feeding on living plant cells. It accomplishes this by developing haustoria, specialized structures that penetrate the epidermal cells of its host plant (Agrios, 1988) [2]. This fungus has a survival strategy for the winter months, either by living on other host plants or by overwintering on the leftover debris from infected pea plants (Falloon, 1989). Conidia, which are tiny, airborne spores, are the primary way *Erysiphe pisi* spreads through the air. When a conidium lands on a suitable host, it germinates and forms a germ tube, which then develops into a lobed primary appressorium. If this structure's penetration peg successfully pierces the host's protective cuticle and cell wall, a primary haustorium forms inside the epidermal cell. This haustorium acts as a lifeline, drawing essential nutrients from the plant cell, which fuels the growth of secondary hyphae. As these secondary hyphae spread across the host's epidermis, they produce more hyphal appressoria, leading to the formation of secondary haustoria. Eventually, aerial conidiophores emerge from these surface hyphae, producing new conidia and thus initiating a new infection cycle.

5. Yield losses

Uppal *et al.* (1953) [36] found that a severe powdery mildew infection that prevented even one picking significantly reduced pod formation in peas when compared to 6-7 pickings in healthy crops. Powdery mildew (*Erysiphe polygoni*) caused a 23% reduction in pea yield in field settings. The effect of powdery mildew on pea crops was examined in a 1963 study by Munjal *et al.* (1963) [27]. The amount of yield loss, which ranged from 50% to 100%, was found to be directly correlated with the disease's severity. A yield loss of 21-31% in terms of pod number and 26-47% in terms of pod weight was observed, even in situations where the crop was completely infected (100% intensity). However, it should be mentioned that this correlation between disease severity and yield loss was only seen when the first flush of pods started to show mature symptoms. Depending on the stage at which various disease intensities occurred within the crop, the disease's losses varied considerably. According to Srivastava *et al.* (1973) [33], powdery mildew caused a 39% reduction in pea yield. According to earlier research (Dixon, 1978) [10], pea powdery mildew causes yield losses of about 10%. Nonetheless, concerning reports of yield losses surpassing 70% have been made (Gritton and Ebert, 1975). According to Singh *et al.* (1978) [31], pea infection with *Erysiphe polygoni* results in a marked decrease in yield since infected plants produce fewer pods and seeds per plant. When the incidence of powdery mildew was 100%, Raut and Wangikar (1979) found that the number of pods decreased by 34.50%, the weight of the pods decreased by 42.31%, the size of the grain decreased by 31.81%, and the weight of 100 pea grains decreased by 50.84%. According to Mahmood *et al.* (1983), *Erysiphe polygoni* infection caused yield losses in eight garden pea varieties ranging from 10.1% to 18%. Alderman and American cultivars were comparatively more tolerant than Alaska and PN 25. In comparison to fast mildews, Krishna (1989) [22] found that slow mildewing pea cultivars consistently experienced lower losses in pod length, number of grains per pod, 1000 grain weight, and total grain yield.

6. Management of powdery mildew disease of pea

Several studies have explored different approaches to manage pea powdery mildew, caused by *Erysiphe pisi* or *Erysiphe polygoni* DC, focusing on botanicals, fungicides, and biocontrol agents.

A study investigating the efficacy of six botanicals—garlic (*Allium sativum* L.), tulsi (*Ocimum sanctum* L.), neem (*Azadirachta indica* A. Juss.), cashewnut (*Anacardium occidentale*), ghaneri (*Lantana camera*), and ginger (*Zingiber officinale* Rosc.)—against *Erysiphe pisi* found that three sprays of NSKE (Neem Seed Kernel Extract) and ginger were particularly effective in reducing disease severity and improving yield (Source information not provided for this specific botanical study, but it is implied by the prompt that the information comes from a primary source). Deshmukh *et al.* (2018) [9] conducted field studies on the effectiveness of both fungicides and biocontrol agents against pea powdery mildew caused by *Erysiphe polygoni* DC in pea cultivar Arkel. Their fungicide trials revealed that all spray treatments effectively reduced disease intensity and increased seed yield compared to unsprayed controls. Specifically, three applications of Hexaconazole (17.78%) and Propiconazole (21.42%) demonstrated the lowest disease severity and comparable yields. In their separate study on biocontrol agents, Deshmukh *et al.* (2018) [9] found that all spray treatments of biocontrol agents were effective in mitigating powdery mildew severity and significantly boosting seed yield. Among the six tested agents, three applications of *Trichoderma harzianum* and *Trichoderma hamatum* proved most effective in reducing disease severity and increasing yield, with comparable performance. Ahiladevi and Prakasan (2019) [3] carried out a field trial at the Horticulture Research Station in Ooty, Tamil Nadu, from March to June over the course of two years (2012 to 2013). Along with 50% WP carbendazim, the treatment included sulphur at 1500, 1875, 2500, and 3000 g ha-1. The findings showed that sulphur, at a dose of 1875 to 2500 g ha-1, successfully managed the pea powdery mildew disease. This dose produced a higher yield than the other treatments and was comparable to higher doses. Up to 5000 g ha-1 of sulphur, or twice the effective dose, no phytotoxicity was seen. Meena and Godika (2019) used natural field conditions to test six fungicides for the treatment of pea powdery mildew by spraying them twice at 15-day intervals. All of the fungicides significantly reduced the intensity of powdery mildew disease compared to the control (64.63 percent), according to two years' worth of pooled data on disease intensity. When Karathane was applied, the disease intensity decreased by 80.43 percent, resulting in a minimum of 12.65 percent. Hexaconazole, on the other hand, came in second place with a disease intensity reduction of 71.43 percent to 18.47 percent. Propiconazole and wettable sulphur were found to be moderately effective, with disease intensity recorded at 30.47 percent and 22.68 percent, respectively. When treating wettable sulphur, the highest disease intensity of any fungicide—34.11 percent—was observed. An experiment was conducted by Agrawal *et al.* (2020) [1] to evaluate the relative effectiveness of several novel fungicides in treating garden pea powdery mildew disease. According to a recent study, Tebuconazole 50% + Trifloxystrobin 25% WG applied at 300 grams per hectare, and Tebuconazole 250 EC (with 25.9% w/w Tebuconazole) at 700 ml per hectare, were the most effective fungicides for controlling powdery mildew. These treatments consistently outperformed other fungicides after the first, second, and third applications.

7. Conclusion

This review consolidates current knowledge on the pathogen's biology, infection process, and symptoms while highlighting the importance of early detection and integrated disease management strategies. Various chemical fungicides, including propiconazole, hexaconazole, tebuconazole, and sulphur-based compounds, have proven effective in reducing disease severity and enhancing yields when applied in timely and adequate doses. Additionally, botanical extracts such as neem seed kernel extract and ginger, along with biocontrol agents like Trichoderma harzianum and T. hamatum, offer promising eco-friendly alternatives. However, for long-term and sustainable management, an integrated approach combining resistant cultivars, cultural practices, biological agents, and rational use of fungicides is essential.

Future research should focus on the development of durable resistant varieties, deeper insights into host-pathogen interactions, and the standardization of integrated disease management packages suited to diverse agro-climatic zones.

Strengthening disease surveillance and farmer training will also be crucial for minimizing losses due to powdery mildew and ensuring stable pea production.

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