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Effect of botanical and bioagents against powdery mildew of garden pea: A review

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Abstract
Powdery mildew is a worldwide airborne disease that is especially harmful for late-planted crops and late-maturing pea cultivars. Although *Erysiphe pisi* is the primary cause, infections in peas have also been connected to other species, including *E. baeumleri* and *Erysiphe trifolii*. Pod count, biomass, node number, seeds per pod, and plant height are all affected by this disease, which can result in yield losses of 25% to 50%. Furthermore, it deteriorates the quality of green peas.
Fungicide application, early sowing, and the development of resistant cultivars are examples of current control strategies. Although systemic and protective fungicides are both beneficial alternatives, public concerns about pesticide use, environmental effects, and the increasing prevalence of fungicide-resistant disease strains are making them less popular. Interest in alternate approaches to disease management has risen as the consequence.
Non-chemical substitutes including soluble silicon, various oils, plant-derived extracts, and salts are being studied but are not yet suitable for broad commercial application. Mycophagous arthropods, yeasts, fungi, and mycolytic bacteria have all demonstrated promise in biological control; however, further research is need to confirm their efficacy in practical settings.
The most effective, economical, and environmentally friendly management strategy is still genetic resistance. *er1* is the most often utilized resistance gene in breeding efforts, and only three resistance genes—*er1, er2, and Er3*—have been found in Pisum species to date. But depending heavily on one gene increases the chance of resistance breaking down, particularly if new strains of the virus appear. The long-term durability of resistance may be improved by adding polygenic resistance or combining many important resistance genes.

Keywords: *Erysiphe baeumleri*, *Erysiphe trifolii*, *Erysiphe pisi*, *Pisum sativum*, disease resistance, chemical control, and biological control

Introduction

Pisum sativum L., a nutritious pea that is grown worldwide and can withstand freezing temperatures, is a member of the Leguminosae family (Kour *et al.*, 2020; Tulbek *et al.*, 2017) [13, 25]. India produces more green peas than any other country in the world, second only to China, and ranks tenth in terms of production among vegetable crops. Globally, over 22 million tons of dried pea seeds and 14.5 million tons of green pea seeds are produced annually (FAOSTAT, 2019; Mondor, 2020; Senapati *et al.*, 2019) [6, 17, 20]. In addition to having low levels of saturated fat, cholesterol, and sodium, pea seeds are a good source of soluble and insoluble fibers, proteins (tryptophan and lysine), complex carbohydrates, vitamin B, folate, and minerals (calcium, potassium, and iron) (Table 1).There are 17-22 g of carbs, 20-50 g of starch, 14-26 g of dietary fiber, 6.2-6.5 g of protein, 0.4-g of fat, and 1.0-g of ash in 100 g of fresh green pea seeds. Furthermore, by enhancing the nutritional value and techno-functional characteristics of peas and their protein, cutting-edge methods like pulse electric fields and ultrasonication have shown a notable impact on efficiency (Ma *et al.*, 2018; Melchior *et al.*, 2020) [15, 16].

Peas are susceptible to a wide range of bacterial, fungal, viral, and nematode diseases. In the best of conditions, these diseases significantly lower yield and quality. Important types of organisms that cause soilborne infections in peas include nematodes, bacteria, and fungi. Seedling diseases are caused by Pythium spp. and Rhizoctonia solani Kühn; root rots are caused by *Aphanomyces euteiches* Drechs., *Fusarium solani f. sp. pisi* (Jones) Snyd. &

Hans., and *Thielaviopsis basicola* (Berk. and Broome) Ferraris; wilts are caused by *Fusarium oxysporum f. sp. pisi* (van Hall) Snyd. & Hans. races 1, 2, 5, and 6. Nematode infections are primarily caused by root knots (*Meloidogyne spp.*), pea cysts (*Heterodera goettingiana* (Liebscher)), and root-lesion nematodes (*Pratylenchus penetrans* (Cobb) Filip. & Schuur.-Stek.). Fungi and bacteria are the main causes of pea foliar diseases. Foliar diseases like pea rust (*Uromyces fabae* (Grev.) Fuckel), powdery mildew (*Erysiphe pisi* DC.), downy mildew (*Peronospora viciae* (Berk.) Casp.), white mold (*Sclerotinia sclerotiorum* (Lib.) de Bary), and Ascochyta blight (a complex of three fungi) are caused by *Ascochyta pisi* Lib., *Mycosphaerella pinodes* (Berk. & Bloxam) Vestergr., and/or *Phoma medicaginis var. pinodella* (Jones) Boerema. Brown spot, which is caused by *Pseudomonas syringae pv. syringae*, and bacterial blight, which is caused by *Pseudomonas syringae pv. pisi* (Sackett) Young, Dye, and Wilkie, are significant bacterial infections. Alfalfa mosaic virus, bean leafroll virus, pea enation mosaic virus, pea streak virus, red clover vein mosaic virus, and pea seedborne mosaic virus are among the major viruses that cause these illnesses (Chen *et al.*, 2004) [10].

Table 1: Nutrition value per 100 g of fresh, raw green peas (*Pisum sativum* L.) (Source: USDA National Nutrient database)

Principle	Nutrient Value	Percentage of RDA
Energy	81 Kcal	4%
Carbohydrates	14.45 g	11%
Protein	5.42 g	10%
Total Fat	0.40 g	2%
Cholesterol	0 mg	0%
Dietary Fiber	5.1 g	13%
Vitamins		
Folates	65 µg	16%
Niacin	2.090 mg	13%
Pantothenic acid	0.104 mg	2%
Pyridoxine	0.169 mg	13%
Riboflavin	0.132 mg	10%
Thiamin	0.266 mg	22%
Vitamin A	765 IU	25.5%
Vitamin C	40 mg	67%
Vitamin E	0.13 mg	1%
Vitamin K	24.8 µg	21%
Electrolytes		
Sodium	5 mg	<1%
Potassium	244 mg	5%
Minerals		
Calcium	25 mg	2.5%
Copper	0.176 mg	20%
Iron	1.47 mg	18%
Magnesium	33 mg	8%
Manganese	0.410 mg	18%
Selenium	1.8 µg	3%
Zinc	1.24 mg	11%
Phyto-Nutrients		
Carotene-B	449 µg	-
Crypto-xanthin-B	O µg	-
Lutein-zeaxanthin	2477 µg	-

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Pea Powdery Mildew: Pathogen and Impact

Powdery mildew, a widespread airborne illness that is particularly problematic in regions with warm, dry days and cool nights, is caused by the obligate biotrophic fungus Erysiphe pisi DC (Smith *et al.*, 1996) [23]. The disease can reduce yields by 25-50% (Munjal *et al.*, 1963; Warkentin *et al.*, 1996) [18, 28] and affect total biomass, pod and seed quantities, plant height, and node count (Gritton and Ebert, 1975). It may also accelerate maturity, which can cause tenderometer readings to spike and the quality of the green pea crop to decline (Falloon and Viljanen-Rollinson, 2001) [4]. Severe infections cause unpleasant off-flavors, discolor seeds, and deteriorate the quality of the seeds and processing. Machine operators may also be at risk for respiratory problems from airborne spores and fungal residues. Late-maturing or late-sowing cultivars are especially susceptible, and the more damage, the earlier the disease development.

Disease Symptoms and Spread

Powdery mildew infects all green tissues of pea plants. Initial symptoms appear as small, diffuse spots on lower leaves and stipules, eventually forming white or pale grey powdery patches that can merge to cover entire surfaces (Falloon and Viljanen-Rollinson, 2001) [4]. Control strategies currently include early sowing, fungicide application, and the use of resistant varieties.

Pathogen Diversity

Erysiphe pisi, previously misidentified as *E. communis* or *E. polygoni*, has multiple variants: *E. pisi* var. *pisi* affects *Pisum*, *Medicago*, *Vicia*, *Lupinus*, and *Lens*, while *E. pisi* var. *cruchetiana* targets *Lathyrus* and *Ononis* (Braun, 1987) [3]. Other species, like *E. baeumleri* and *E. trifolii*, have also been linked to pea powdery mildew in the Czech Republic and the Pacific Northwest USA (Ondřej *et al.*, 2005; Attanayake *et al.*, 2010) [19, 1] (Table 2). These species differ genetically (rDNA ITS sequences) and morphologically, particularly in the structure of chasmothecial appendages. The presence of multiple species may complicate resistance breeding efforts and could explain observed breakdowns in resistance.

Table 2: Powdery mildew pathogen *Erysiphie spp.*, diversity with their affected crops.

Powdery mildew pathogen diversity	Affected crops	References
E. pisi var. *pisi*	*Pisum sativum, Medicago, Vicia, Lupinus, and Lens culinaris*	(Braun, 1987) [3]
E. pisi var. *cruchetiana*	*Lathyrus and Ononis*	(Braun, 1987) [3]
E. baeumleri and *E. trifolii*	*Pisum sativum*	(Ondrej *et al.*, 2005; Attanayake *et al.*, 2010) [19, 1]

Cultural Management

Early planting or the use of early-maturing cultivars helps prevent outbreaks of severe mildew since late crops are more susceptible to infection. Phosphorus lowers disease incidence, while high nitrogen increases susceptibility through increased vegetative growth (Jarvis *et al.*, 2002) [12]. Though it is not feasible for producers to artificially stress plants to lessen susceptibility, dense, lush canopies are more vulnerable to infection. Crop rotation is not very beneficial since seed transfer is infrequent (Tiwari *et al.*, 1999a) [24] and the disease spreads quickly over wide areas (Viljanen-Rollinson *et al.*, 1998a) [27].

Chemical Control

Protective fungicides like sulphur and dinocap have been used successfully (Sharma and Mathur, 1984; Singh and Singh, 1978) [21, 22], but their repeated use is often impractical due to cost and application logistics. Reactive spraying—only when symptoms appear—is more economical. Fungicides are most effective when applied early in infection (<5% plant coverage). Wettable sulphur, though less favoured due to late-stage application challenges, remains viable, especially for organic systems or areas where aerial spraying is restricted.

Newer fungicide options include triazoles (e.g., triadimefon, tebuconazole), morpholines (e.g., fenpropimorph, fenpropidin), and broader-spectrum products like strobilurins and anilinopyrimidines. Spiroxamine and quinoxyfen, both mildew-specific, are also in use. Mixtures like pyraclostrobin + boscalid have recently been tested and approved.

Natural Product-Based Control

Growing resistance and environmental concerns have sparked interest in substitute items such plant extracts, oils, silicon, and salts (Bélanger and Labbé, 2002) [2]. *in vitro* and field studies have demonstrated the effectiveness of extracts from neem (*Azadirachta indica*), garlic, ginger, *Flueggea microcarpa*, and other plants in reducing *E. pisi*. Methionine-riboflavin formulations have been found to be just as effective as traditional fungicides (Tzeng *et al.*, 1996) [26]. Other substances that have shown potential include phosphorous acid, bicarbonate, and potassium silicate.

Biological Control

Biological control remains a promising yet underdeveloped area. Various antagonists, including bacteria (*Bacillus subtilis*, *B. pumilus*), fungi (*Ampelomyces quisqualis*, *Trichoderma harzianum*), and yeasts (*Pseudozyma flocculosa*), have shown potential. Commercial products such as AQ10®, Sporodex®, Serenade®, and Sonata® have been released in some markets. Additional fungal and bacterial agents, including *Pseudomonas fluorescens* and *Paecilomyces fumosoroseus*, are under investigation. Some natural antagonists like *Acrodontium crateriforme* and *Ramichloridium apiculatum* remain unexplored for practical use.

Induced Resistance

Plants can develop systemic resistance through exposure to certain pathogens or stimuli. This resistance is often broad-spectrum and race non-specific (Kuc, 1995) [14]. Chemicals such as salicylic acid, chitosan, and β-aminobutyric acid have shown effectiveness in inducing resistance in peas (Frey and Carver, 1998; Bélanger and Labbé, 2002) [8, 2]. Neem products and vermicompost extracts have similarly been linked to resistance induction. Soil amendment with vermicompost boosts phenolic acid production, which correlates with enhanced resistance.

Genetic Resistance

To date, three genes conferring powdery mildew resistance in pea have been identified: two recessive (*er1*, *er2*) and one dominant (*Er3*) (Harland, 1948) [11]. *er1*, the most widely used, functions via loss-of-function in the *PsMLO1* gene (Humphry *et al.*, 2011). *er2* confers temperature-dependent resistance, most effective at 25 °C or in mature leaves (Fondevilla *et al.*, 2006) [7]. *Er3*, from *Pisum fulvum*, has been successfully introgressed into cultivated lines and shows broad-spectrum resistance.Molecular markers linked to these genes facilitate marker-assisted selection. For instance, SSR and SCAR markers are available for *er1* (LG VI), *er2* (LG III), and *Er3*. Besides major resistance genes, several accessions with moderate, uncharacterized resistance have also been identified in *P. sativum* and wild relatives.

Resistance Mechanisms

In susceptible peas, *E. pisi* penetrates epidermal cells, forming haustoria that support further fungal development and conidia production (Falloon *et al.*, 1989) [5]. In *er1* lines, most conidia germinate but fail to develop secondary hyphae. *er2*-mediated resistance varies with leaf age and temperature and is linked to hypersensitive responses (Fondevilla *et al.*, 2006) [7]. Proteomic analyses indicate that resistant lines like JI2480 have higher baseline levels of defence-related proteins, possibly contributing to their resistance.

Conclusion

Powdery mildew, primarily caused by *Erysiphe pisi*, poses a significant threat to pea cultivation worldwide, particularly under conducive climatic conditions. Traditional management through fungicides and cultural practices, while effective, faces challenges due to environmental concerns and fungicide resistance. As a result, there is growing interest in alternative control measures such as botanical extracts, biological agents, and induced resistance. Although several natural products and microbial antagonists show promise, their commercial viability and field-level consistency require further research. Genetic resistance, especially through the er1 gene, remains the most reliable and sustainable approach, though reliance on single-gene resistance could be risky. An integrated disease management strategy combining cultural, chemical, biological, and genetic tools offers the best path forward for durable and eco-friendly control of powdery mildew in peas.

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