IMPACT OF FUNGAL AEROSPORA ON CROP PRODUCTION: A COMPREHENSIVE REVIEW

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Abstract:
Aerobiology is a part of science that reviews natural particles, like microorganisms, contagious spores, tiny creepy crawlies, dust grains and infectious particles, which are latently moved by the air. The aerobiological perceptions are valuable to decipher measures continuing in science, meteorology and nature yet in addition these disciplines are of extraordinary assistance in comprehension of aerobiological measures. Aerospora are wide spread all around the world and high ecological weights have been influenced by different variables, like breeze, dampness, and temperature and air contamination on aerospora this prompts different changes as for aerospora species and amounts starting with one season then onto the next. The convergence of airborne air conceived spores has been connected to wind, mugginess, temperature precipitation, elevation, vegetation and different pollutions. A great number and diversity of fungal particles found in air. Air is the way airborne particles can be transported their spores even hundred or even thousands of kilometres. Fungal spores occupied most of the portion of air, their quality and quantity totally depends upon seasons, weather and climatic conditions. The spores of *Cladosporium*, *Curvularia*, *Alternaria*, Smut, Rust, *Helminthosporium*, *Cercospora* and *Nigrospora* were reported most commonly in agricultural fields. In addition, previous studies have found a direct relation of seasonal variation with variability of type and density of aerospores. The number of fungal types varied throughout the year with more or less similar trend in the fungal concentrations. Maximum number of fungal spore was registered in August and minimum in January. The fungal spores present in the atmosphere are responsible to cause various diseases over many important crops, which affect overall crop production of farmers.

Keywords: Fungi, Aerospora, Crop production, diseases, *Alternaria*

INTRODUCTION

Fungal spores are microscopic biological particles that allow fungi to be reproduced, serving a similar purpose to that of seeds in the plant world. Fungi decompose organic waste and are essential for recycling of carbon and minerals in our ecosystem. It has been estimated that fungi recycle millions of tons of organic waste annually. There are thousands of different fungi in the world which are essential for the survival of other organisms. Unfortunately, fungi produce lots of spores that can also be detrimental to both plants and animals including humans. Many fungal spores contain allergens which can trigger a range of respiratory symptoms in those susceptible. These symptoms include sneezing, runny nose, mucous production, cough, congestion, sinusitis, earache, headache, wheezing, asthma and a range of bronchial symptoms and diseases. It is estimated that around 3-4% of the general population get allergy symptoms from fungal spores, including the majority of asthma sufferers. Many fungal spore types have similar allergens which are released at different times of the year. This means that sufferers of fungal spore allergies are likely to be sensitive to many types for large parts of the year. In plants, they infect the leafy shoots and flowers which affects the plants growth, development and reproductive success.

TYPES OF FUNGAL SPORE

Fungi come in a wide range of types and sizes, most are microscopic but some, such as mushrooms and bracket fungi, are quite large. Fungal spores themselves are all microscopic, some as small as two micrometres in size. Most fungi require warmth and humidity to grow, reproduce and release their spores into the environment. Many fungi produce only small amounts of spores which rarely get airborne in quantity. However, some species are very prolific and widespread, producing high concentrations of spores which are readily dispersed into the atmosphere. The main types that trigger most symptoms in allergy sufferers are: *Alternaria*, *Cladosporium*, *Epicoccum*, *Aspergillus*, *Penicillium*, *Didymella*, *Pleospora* and a group of species collectively referred to as Basidiospores. Also important to asthma sufferers are Sporobolomyces and Tilletiopsis, which are very small spores produced primarily during warm, humid nights.

1. ALTERNARIA

Habitat / Substrates:

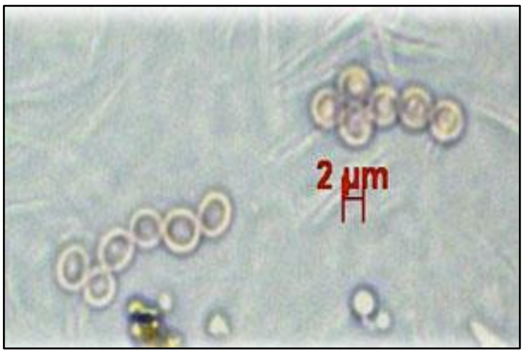
Alternaria fungi produce highly allergenic spores across quite a few species, the most potent of which is *Alternaria alternata*. This species causes leaf spot fungus on a wide range of plants, including cereals and grasses. As a result, the spores are abundant during the main season. *Alternaria* can also occur indoors on foodstuffs, carpets, textiles and window frames. Fungal colonies are usually black or grey.

Season:

The risk from *Alternaria* is high from mid-July to mid-September. *Alternaria* fungi require a temperature threshold of about 20^{o}C to start spore production. The first peak of *Alternaria* spores usually occurs after a warm, dry spell followed by rain, then another warm, dry period for spore release. Thereafter, further peaks occur following the same weather patterns. During the harvesting of cereal crops we often see the greatest release of *Alternaria* spores. In 2019, conditions during the summer and again during harvesting were perfect for the production and release of *Alternaria* spores so the concentrations were excessively high.

2. ASPERGILLUS/PENICILLIUM

Habitat / Substrates:



There are many of *Aspergillus* and *Penicillium*, which live on a wide range of substrates. The spores can be very prevalent during the peak periods, triggering a range of respiratory problems. The spores are particularly prevalent in wooded areas, compost heaps, rotting wood chips and bark mulch. Some species rot down pine needles, so conifer plantations should be avoided during Autumn. *Penicillium chrysogenum* is found widely in nature, occurs on indoor substrates and is the type used to produce the antibiotic penicillin. N.B. Houseplants can be sources of spores, particularly *Aspergillus*/*Penicillium* types. If you're keen to have houseplants, only have cacti, which require dry conditions, and ensure the soil surface is covered in grit.

Season:

Aspergillus and *Penicillium* spores are present in the air throughout the year but the main peak periods are late August to October and January to February.

***Allergenicity*:**

High for some types, particularly *A. fumigatus* and *P. chrysogenum*. *A. fumigatus* is a major cause of aspergillosis (farmer's lung).

3. CLADOSPORIUM

Habitat / Substrates:

Cladosporium can be found on a wide range of plant substrates and in soil. Indoor substrates include paint and textiles. The mould colonies are generally black or olive-brown to brown.

Season:

The main season runs from May to October, with a peak starting in June and running until mid-September. The spores are released during dry weather and the highest risk occurs on warm, sunny days.

ALLERGENIC FUNGAL SPORE CALENDARS

These show the monthly average totals of spores per cubic metre of air, for the five year period, 2006-2010. The concentrations of spores produced by fungi vary greatly. For example, the *Alternaria* peak monthly average spore concentration is 3400, while for *Cladosporium* it is 210,000 and for *Didymella* 35,000. As a result, the thresholds for symptoms will also vary. However, thresholds have only been ascertained for *Alternaria* and *Cladosporium* so far.

The calendars have been produced by averaging 5 years of data collected in Worcester. Worcester is located in the centre West of the country and receives high amounts of pollen and spores due to very suitable weather and sources. Although the trends shown will be similar for much of the country, the average amounts will tend to be lower in western coastal regions and mountainous areas. The spore seasons in Northern Ireland, Scotland and the far North England will also start a few days to two weeks later than in the more southerly regions.

Spore levels show trends throughout the year:

Spring:
In the spring, most spore types are at low levels, apart from *Pleospora*. *Cladosporium* and *Tilletiopsis* can start increasing in May if the weather is warm and dry.

Summer to early Autumn:
The spore risk starts to rise in mid-June with the increase in temperatures. The risk peaks in late June/early July and continues until late September. Typically, during the day, there will be the 'dry-weather' spore types of *Alternaria* & *Cladosporium* and some types of *Penicillium* and *Aspergillus*. 'Wet-weather' spores respond to the dew during the night, such as *Didymella*, *Sporobolomyces* and *Tilletiopsis*. Therefore, there are a wide range of types that can affect people during each 24 hour period. In addition, rainfall will help the production of spores which are then released after heavy rain or during light showers or drizzly rain. There is a lower spore risk in very windy, unusually cold and dry weather. When late August and September are warm and humid, *Penicillium* and *Aspergillus* types can become very problematic for those affected by them, triggering a range of symptoms including hay fever, mucous production, cough, wheezing and asthma.

Mid-Autumn:
Penicillium and *Aspergillus* types can continue to be quite high into October - and even November and early December if temperatures remain mild. There are usually some of these spores present in the air throughout the autumn and even lower levels can trigger some symptoms. Many other spore types are starting to decline, but the risk can be moderate to high on warmer, humid days. By the end of November, the risk decreases to low unless it is very mild and damp. The lowest risk is on dry, cold frosty days. Spores from mushrooms and bracket fungi reach their peak at this time of year, particularly in rural areas, although the risk is low to moderate for most spore sufferers as these are milder allergens.

Winter:
Aspergillus and *Penicillium* types quite often have a second peak in January and early February. Other spore types are low in winter, although *Pleospora* can start increasing from February.

ROLE OF FUNGI IN AGRICULTURE

Fungi are a group of eukaryotic organisms and source of food, organic acids, alcohol, antibiotics, growth-promoting substances, enzymes, and amino acids. They include microorganisms like molds, yeasts, and mushrooms. They live on dead or living plants or animals' tissue. Fungi are very different from other living organisms; they are the primary decomposers of substances in the ecological system. Fungi are tremendous decomposer of organic waste material and most readily attack cellulose, lignins, gums, and other organic complex substances. Fungi can act also under a wide range of soil reaction from acidic to alkaline soil reactions. Fungi conjointly play a basic role in different physiological processes as well as mineral and water uptake, chemical change, stomatal movement, and biosynthesis of compounds termed biostimulants, auxins, lignan, and ethylene to enhance the flexibility of plants to ascertain and cope environmental stresses like drought, salinity, heat, cold, and significant metals.

The microorganism was used from the very beginning of the civilization in the agriculture and industrial processes even before their existence was well known. Production of fermented beverages, bread and vinegar are traditional processers practiced from the time of early civilization. Recent advancement in our understanding about the genetics, physiology, and biochemistry of fungi, has led the exploitation of fungi for preparation of different agriculture and industrial products of economic importance. All the environmental factors influence the distribution of the fungal flora of soil.

The primary functions of filamentous fungi in the soil are to degrade organic matter and help in soil aggregation. Besides this property, bound species of *Alternaria, Aspergillus, Cladosporium, Dematium, Gliocladium, Humicola* and *Metarhizium* manufacture substance like organic compounds in soil and therefore could also be necessary for the maintenance of soil organic matter. Plant growth regulators and chemical fertilizers have been used to increase crop production. Application of chemical fertilizers to crop plants negatively affects human health and environments. Recent studies have focused on identification of alternative methods to enhance plant productivity and protect the soil. Soil borne microbes can enter roots and establish their population in plants as endophytes, and many plant-associated fungi are well known for their capacity to promote plant growth; however, the relationship between these microbes and plants is still uncertain. Microorganisms have the ability to produce phytohormones, solubilize insoluble phosphate and convert complex organic substances to simple forms. Endophytic fungi have also been shown to impart plants with tolerance to salt, drought, heat and diseases.

The four endophytic fungi (GM-1, GM-2, GM-3, and GM-4) were tested for their ability to improve soybean plant growth under salinity stress conditions. The seed germination and plant growth were higher in seeds pretreated with endophytic fungal cultures than their controls. The positive influence of fungi on plant growth was supported by gibberellins analysis of culture filtrate (CF), which showed wide diversity and various concentrations of Gibberellic acids.

Application of rhizospheric fungi is an effective and environmentally friendly method of improving plant growth and controlling many plant diseases. Three predominant fungi (PNF1, PNF2, and PNF3) isolated from the rhizospheric soil of peanut plants were screened for their growth-promoting efficiency on sesame seedlings. Among these isolates, PNF2 significantly increased the shoot length and fresh weight of seedlings compared with controls. Analysis of the fungal culture filtrate showed a higher concentration of indole acetic acid in PNF2 than in the other isolates.

The fungal associations with plants influence the primary and secondary metabolism of plants at all developmental stages. Photosynthesis is an important primary mechanism, and the main source of energy for plants. Its efficiency is related to photosynthetic pigments such as chlorophylls and carotenoids. Leaf chlorophyll a was increased in fungi-treated plants more so than in the controls.

FUNGAL DISEASES IN VEGETABLE CROPS

Fungi constitute the largest number of plant pathogens and are responsible for a range of serious plant diseases. Most vegetable diseases are caused by fungi. They damage plants by killing cells and/or causing plant stress. Sources of fungal infections are infected seed, soil, crop debris, nearby crops and weeds. Fungi are spread by wind and water splash, and through the movement of contaminated soil, animals, workers, machinery, tools, seedlings and other plant material. They enter plants through natural openings such as stomata and through wounds caused by pruning, harvesting, hail, insects, other diseases, and mechanical damage.

Some of the fungi are responsible for foliar diseases – Downy mildews; Powdery mildews; and White blister are some of the highly prevalent foliar diseases. Other fungi – Clubroot; *Pythium* species; *Fusarium* species; *Rhizoctonia* species; *Sclerotinia* and *Sclerotium* species – are soil borne diseases.

Some fungal diseases occur on a wide range of vegetables. These diseases include Anthracnose; Botrytis rots; Downy mildews; Fusarium rots; Powdery mildews; Rusts; Rhizoctonia rots; Sclerotinia rots; Sclerotium rots. Others are specific to a particular crop group, e.g. Clubroot (*Plasmodiophora brassicae*) in brassicas, Leaf blight (*Alternaria dauci*) in carrots, and Red root complex in beans.

Some examples of common fungal diseases of vegetable crops are provided in the table below with some typical symptoms.

Fungal disease	**Factors conducive to spread**	**Crops affected**	**Symptoms**
White blister/White rust (*Albugo candida*)	Optimum conditions for disease development are 3-4 hours in mild temperatures (6-24^{0}C).	Brassicas (including Asian leafy brassicas).	White blisters and swellings on leaves and heads of affected plants; blisters consist of masses of white dust-like spores; up to 100% losses have been reported.
Downy mildews (individual species damage particular crop families)	High humidity, leaf wetness and cool to mild temperatures (10-16 °C).	Wide host range including onions; peas; lettuce; celery; spinach; kale; herbs; cucurbits; brassicas; Asian leafy brassicas.	Symptoms usually begin with yellowish leaf spots which then turn brown; downy growth appears on underside of leaves.
Powdery mildews (some species are restricted to particular crops or crop families)	Moderate temperatures (20-25 ^{0}C); relatively dry conditions (unlike downy mildews).	Wide host range and very common, especially in greenhouse crops: cucumber; melons; pumpkin; zucchini; parsnip; beetroot; potato; herbs; peas; bitter melon; tomato; capsicum; Brussels sprouts; cabbage; swedes.	Small, white, powdery patches on most above-ground surfaces; usually observed first on undersides of leaves but eventually cover both surfaces; affected leaves become yellow, then brown and papery and die.

Clubroot (*Plasmodiophora brassicae*)	Warm weather; acidic soil (pH less than 7); high soil moisture.	Brassicas (including Asian leafy brassicas).	Plants are yellow and stunted and may wilt in hotter parts of the day; large malformed 'clubbed' roots which prevent the uptake of water and nutrients, reducing the potential yield of the crop.
Pythium species	Cold, wet soil conditions; known as water moulds, they enter untreated water supplies; water supplies for irrigation and hydroponics should be tested regularly.	Many vegetable crops in including cucurbits; brassicas; lettuce.	May kill seedlings, which die before they emerge or soon after emergence; plant collapse.
Sclerotinia rots (*S. sclerotiorum* and *S. minor*) – a range of common names are used	Windy, cool, humid weather; wet soil; survival structures known as sclerotia remain viable in soil for long periods (10-15 years).	Most vegetable crops.	Water-soaked rotting of stems, leaves, and sometimes fruit; followed by a fluffy, white and cottony fungal growth which contain hard black pebble-like sclerotia.

Sclerotium rots (Sclerotium rolfsii and S. cepivorum)	*S. rolfsii* – Warm, moist conditions. *S. cepivorum* – Development is favoured by cool soil conditions (14-19^{0}C) and low moisture.	*S. rolfsii* – Wide host range including: beans; beets; carrot; potato; tomato; capsicum; cucurbits. *S. cepivorum* – only affects onions, garlic and related Alliums (shallots; spring onions; leeks).	*S. rolfsii* – Lower stem and root rots; coarse threads of white fungal growth surround the diseased areas; small brown fungal resting bodies. *S. cepivorum* – Yellowing and wilting; fluffy fungal growth containing black sclerotia forms at the bases of bulbs.
Fusarium wilts and rots (Various Fusarium species including *F. solani and F. oxysporum*)	Warm to hot weather.	Wide host range including: brassicas; carrots; cucurbits; onions; spring onions; potato; tomato; herbs; peas; beans.	Causes severe root and crown rots or wilt diseases by attacking roots and basal stems; cucurbit fruit and potato tubers can be affected in storage.
Botrytis rots – for example Grey mould (*Botrytis cinerea*)	Cool, wet weather.	Celery; lettuce; beans; brassicas; cucumber; capsicum; tomato.	Softening of plant tissues in the presence of grey fungal growth.
Anthracnose (*Colletotrichum* spp. except for in lettuce – *Microdochium panattonianum*)	Cool, wet conditions.	Wide range of crops including: lettuce; celery; beans; cucurbits; tomato, capsicum; potato; globe artichoke.	Typical symptoms begin with sunken and water-soaked spots appearing on leaves, stems and/or fruit.
Rhizoctonia rots (*Rhizoctonia solani*) – range of common names, e.g. Bottom rot (lettuce) and Wire stem (Brassicas)	Warm, humid weather; can survive for long periods in the soil in the absence of a host plant.	Wide host range including: lettuce; potato; brassicas; beans; peas; beets; carrots; capsicum; tomato; cucurbits.	Range of symptoms depending on the crop being grown but can affect roots, leaves, stems, tubers and fruit; plants wilt and may collapse and die.

Damping-off (*Pythium*, *Rhizoctonia*, *Phytophthora*, *Fusarium* or *Aphanomyces*)	Occurs under cold, wet soil conditions; shore flies and fungus gnats can spread *Pythium* and *Fusarium*.	Many vegetable crops including: leafy vegetables; brassicas; carrots; beetroot; cucurbits, eggplant; tomato; coriander; spring onions; beans	Young seedlings have necrotic stems or roots; seedlings die or show a reduction in growth.
Cavity spot (*Pythium sulcatum*)	Growing carrots after carrots; acidic soil; not harvesting carrots as soon as they reach marketable size.	Carrots.	Cavity spots are small elliptical lesions often surrounded by a yellow halo.
Tuber diseases (Various species)		Potato and sweet potato.	Potato tubers may be infected with superficial skin diseases, such as common scabs, powdery scab, and *Rhizoctonia*. Sweet potatoes may be infected by scurf.
Rusts (several species, e.g. *Puccinia sorghi* – sweet corn; *Uromyces appendiculatus* – beans; *Puccinia allii* – spring onions).	Wind can spread spores great distances; favored by low rainfall, 100% relative humidity and cool to mild temperatures.	Sweet corn; beans; onions; spring onions; beets; celery; silver beet; endive.	Small, red or reddish-brown pustules that form on the underside of the leaves and sometimes on the pods as well; dusty reddish-brown spores released from pustules (may be black in cold weather).
Black root rot (Different species on different vegetable crops)	Cool soil temperatures; high soil moisture.	Lettuce; beans; cucurbits.	Blackening of roots; stunted plants; plants may die.

***Management*:**
Integrated Crop Protection (ICP) or the Integrated Pest Management (IPM) approach has achieved success in the management of the fungal diseases. ICP considers the production system as a whole, including all pests and the importance of soil health. It requires a good understanding of the fungi; the periods during which the crops are susceptible; and the influence of environmental conditions.

Tips for managing fungal diseases include:

- Understand the lifecycles, survival mechanisms, and conducive environmental conditions for fungi
- Be committed to farm sanitation – clean up your farm and remove all weeds, crop debris, and volunteer hosts
- Use resistant or tolerant varieties
- Use clean transplants and seed (and seed treatments)
- Monitor weather conditions (particularly temperature, humidity, and leaf wetness)
- Have knowledge of relevant disease prediction models
- Understand the implications for irrigation timing and minimise free moisture and high humidity periods (e.g. irrigating at around 4 am rather than at dusk, not irrigating during peak periods of spore release)
- Appropriate crop rotations (long rotations with non-host crops may be necessary)
- Avoid heavily infested blocks by testing soil for soilborne diseases prior to planting
- Monitor crops regularly and be able to detect early symptoms on your crop
- Amend and manage soil to disadvantage the fungi (some fungal diseases can survive in the soil for 30 years or more)
- Minimise ways in which the disease can spread on-farm – remove and destroy sick plants when symptoms first show
- Understand the influence of planting time, plant spacing and overlapping crops
- Apply preventative fungicides based on weather conditions
- Understand fungicide resistance and rotation of chemical groups.

Conclusions

The increased absorption of available nutrients from soil as the fungus changes root morphology, which result in the larger root surface available for nutrient absorption. Fungal filaments also act as the absorption surface and increasing the nutrient availability by solubilizing insoluble nutrients like phosphorus, which thus become available to plant and increasing the nutrient mobility due to faster intracellular nutrient mobility and mobilizing nutrients from the soil mass not visited by the roots system but traversed by the mycorrhizal hyphae. The arbuscular mycorrhizal fungi protected plants by up-regulating the activity of antioxidant enzymes and osmolytes and by regulating the synthesis of phytohormones, which might possibly interconnect the various tolerance mechanisms for cumulative stress response. The prominent effect of arbuscular mycorrhizal fungi against salinity was proven to be due to a restriction in sodium uptake by roots and to the homeostasis of nutrient uptake.

Many questions concerning fungal infection of plants remain unanswered. However, research in this field obtains its significance from the fact that these microorganisms are major pathogens of many crop species. An understanding of fungal pathogenicity will not only afford insights into the evolution of fungi but also into the highly dynamic process of their coevolution with plants. In addition, the various factors fungi developed to manipulate the physiology of their hosts to optimize the parasitic lifestyle represent valuable tools to study the affected plant processes. This is clearly demonstrated by the impact of fusicoccin and other phytotoxins on unraveling the roles of the plasma membrane H+-ATPase in plant cells.

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