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Seed Pathology: Its Place in Modern Seed Production

Fig. 1. Seed of oilseed rape showing pycnidia of *Leptosphaeria maculans* after incubation on damp blotters.

Fig. 2. Oilseed rape stem residue showing perithecia of *Leptosphaeria maculans*.

Fig. 3. *Chaetomium* spp. on soybean seed, after incubation on blotters.

When the American farmer plants seed, he usually expects almost all of it to emerge at about the same time and produce a uniform stand of healthy seedlings. For the most part, his expectations are realized. A complex technology is required to maintain this standard of quality in an industry that must provide sufficient seed to plant more than 350 million acres of crops annually in the United States. The product is the end result of a procedure involving growing, harvesting, conditioning, storing, and planting the seed. Throughout this process, the seed must be handled carefully to avoid mechanical damage and must be protected from adverse environmental conditions and from insect pests and diseases.

No one of these factors is necessarily more important than the others. There are few seed crops, however, in which some measure of disease control is not necessary during production. Some well-known examples of such control are treating corn seed with fungicides, testing bean seed for bacterial blights, and producing seed of cruciferous crops in the Pacific Northwest. These practices, developed because diseases severely limited seed production, have been used successfully for many years. As agricultural technology changes, however, with the introduction of new varieties, modifications in cultural practices, development of new crops, and increased movement of germ plasm across geographical boundaries, the seed disease situation may alter significantly, either because known pathogens change in importance or because new ones appear.

It is generally recognized that with many of the major crops in the world, plant breeding is unlikely to continue with the dramatic yield increases achieved in the past. Greater emphasis will be placed on improving other aspects of crop production to optimize yield potential. An increasing demand for high-quality seed is therefore likely. Seed pathology, because of its important role in seed quality, will have to develop as a subdiscipline of plant pathology to meet these future needs of the seed industry.

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The Seed Pathologist's Role

Even though plant pathologists have had some notable successes in solving seed pathology problems in the United States, the prevailing image of seed pathology is that it is primarily involved with laboratory testing for seedborne organisms. This is an important part of seed pathology, but the role of the seed pathologist goes beyond this activity. This role can best be defined by relating it to the plant disease cycle.

The life cycle of a plant pathogen can be viewed as consisting of four basic phases: survival, transmission, infection, and disease development. Seeds can be involved in each phase. They may act as a means of survival of a pathogen from one growing season to the next. They can provide a means of transmission if a pathogen associated with the planted seed can move to the new crop. Systemic infections of the new crop can occur in the seed, as with embryo infection in loose smut of cereals. The infection and disease development phases of the life cycle also are important for diseases in which seeds produced in the field are infected by pathogens that can reduce yield or seed quality.

Each phase of the life cycle can be affected by environmental factors. Survival of a pathogen on seed may depend on how long the seed is stored before planting. Seedborne inoculum of *Kabatiella caulivora* in red clover, for example, cannot survive if the seed is stored for 2 years before planting. If certain climatic conditions are necessary for infection of seed to occur in the field, disease severity will depend on weather during crop growth. Moist, warm conditions are required for scab of wheat, caused by *Fusarium* spp., to become a serious problem. The seed pathologist should be prepared to study the seed aspects of the disease cycle and their interactions with the environmental factors that influence the cycle. With this kind of information, the significance of seedborne organisms can be realistically assessed and effective control practices possibly developed.

Scope of Seed Disease Problems

The annotated list of seedborne diseases published in 1979 (10) records almost 1,500 seedborne microorganisms on about 600 genera of agricultural, horticultural, and tree crops. From the plant quarantine standpoint, these statistics do not exaggerate the magnitude of the problems involved in controlling the movement of seedborne microorganisms into areas where they have not previously been recorded. The figures are misleading, however, in estimating the extent of seedborne microorganisms as problems when seed is produced for established crop production areas where the microorganisms are known to be present.

To obtain a perspective of this aspect of seedborne diseases, seedborne microorganisms can be considered under four classes. The first consists of pathogens for which the seed is the main source of inoculum; when seed infection is controlled, the disease is controlled. An example would be lettuce mosaic virus. For many of these pathogens, the importance of seedborne inoculum has long been recognized, and control practices have been developed.

The second class consists of important pathogens in which the seedborne phase of the disease is of minor significance as a source of inoculum. An example is *Leptosphaeria maculans*, the cause of blackleg of oilseed rape. In Victoria, Australia, where this pathogen is a limiting factor in oilseed rape production, I (6) showed that some inoculum was seedborne (Fig. 1). In fields in which rape was grown the previous year, however, large amounts of rape residue covered with perithecia of *L. maculans* (Fig. 2) were found at the beginning of the following season. When seedlots with different amounts of seed infection were planted in a field in which rape had not been grown but which was located near fields where rape had been grown the previous year, blackleg severity was the same across plots from all seedlots throughout the growing season. This suggests that crop residues in neighboring fields were the major source of inoculum and that seedborne inoculum was of minor importance.

The third and largest group of seedborne organisms consists of those that have never been shown to cause disease as a result of their presence on seeds. An example would be *Chaetomium* spp. on soybeans (Fig. 3). Recent studies (7) of nine fungal genera commonly found on soybean seeds showed that only *Phomopsis* and *Fusarium* spp. were associated with reduced viability of seeds. Rather than having detrimental effects on seeds, some microorganisms in this class may in fact be beneficial. Interactions between fungi on soybean seeds (7) could possibly be manipulated to control pathogenic fungi.

The presence of nonpathogenic fungi in seedlots can cause considerable confusion in routine laboratory germination tests. The environmental conditions during these tests usually involve high humidity and high temperature, allowing rapid growth of such fungi as *Rhizopus* and *Aspergillus* on the seed that tends to exaggerate the amount of contamination of the seedlot. Perfectly healthy seedlots sometimes are considered by inexperienced seed analysts to be "diseased" because of the growth of such fungi, in spite of high germination counts (Fig. 4).

The fourth class is a group of microorganisms that can infect seed either in the field or in storage and reduce yield and seed quality. Examples of field fungi are *Diplodia*, *Gibberella*, and *Fusarium* spp. on corn and *Fusarium*, *Cladosporium*, and *Alternaria* spp. on cereals. The storage fungi, *Aspergillus* and *Penicillium* spp., can invade most types of seeds under high-moisture storage conditions.

At present, only a small proportion of the 1,500 microorganisms listed as being seedborne can be realistically assigned to any of the four classes. They have been shown to be associated with seeds, but there usually is little information to indicate the significance of the seedborne nature of many of these microorganisms.

Options in Seed Disease Control

Seed pathology is essentially an applied discipline. Research thrusts, therefore, tend to be directly related to practical control measures. Although many of the strategies used in controlling diseases in grain crops also can be applied for seed crops, special considerations regarding the quality of the product make disease control in seed crops a more complicated matter. In addition, some of the options for controlling seed diseases cannot be used for grain crops.

Cultural practices may be appropriate when inoculum persists in the soil or on crop residues. Burning grass seed production fields in Oregon destroys the inoculum of *Gloeotinia temulenta* (blind seed disease) and *Claviceps purpurea* (ergot) that can survive on unharvested seed. Soybean seed infection by *Phomopsis* spp. can be reduced by

Fig. 4. Germination test of corn seeds on paper towels showing growth of nonpathogenic fungi.

Fig. 5. *Aspergillus* and *Penicillium* spp. storage fungi growing from grass seeds on tomato juice agar.

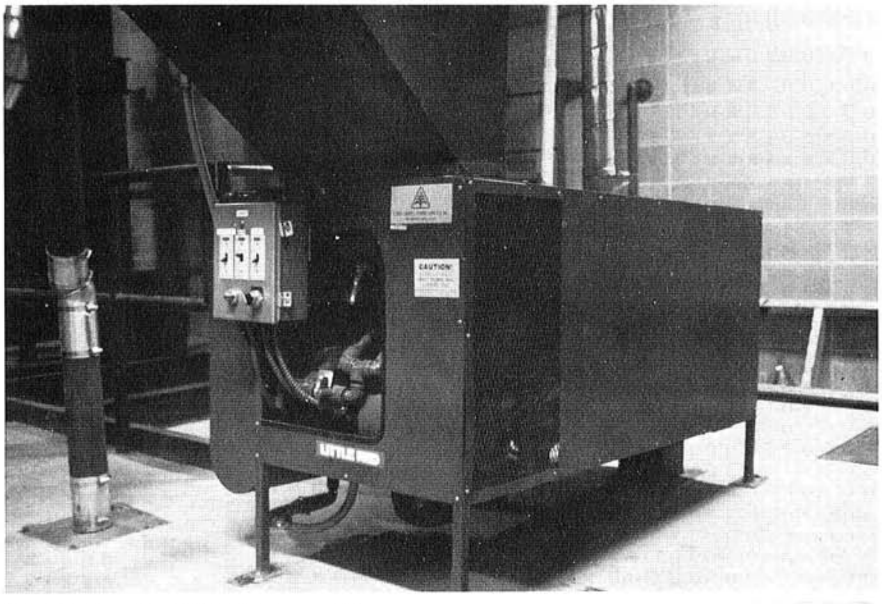

Fig. 6. Commercial fungicide seed treater.

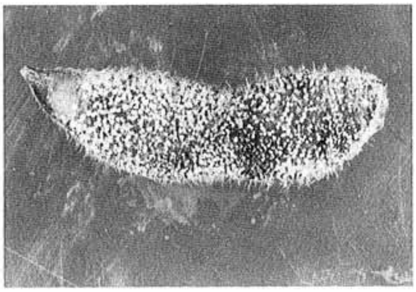

Fig. 7. Detached soybean pods tested for the presence of *Phomopsis* by treating with a herbicide to induce pycnidial development.

rotating soybean seed fields with corn. Other cultural practices, such as varying planting time, are sometimes effective. Winter wheat sown early in autumn may escape infection from bunt (*Tilletia foetida, T. caries*) because plants are past the susceptible growth stage before spores germinate, whereas crops sown later may become infected.

Breeding for resistance to seed diseases specifically to improve seed quality is usually not economically feasible in temperate regions of the world unless the disease also is an important problem in grain production fields. This approach may be more important in underdeveloped countries where the major source of seed is what the farmer saves from his grain crop.

Disease control has been a major consideration in locating seed production in particular geographical areas. Much seed production is concentrated in California, Oregon, and Washington, where warm, dry conditions are unfavorable for disease development. On a smaller scale, isolating seed fields from other fields of the same crop within the same growing region is of value. The primary purpose of this practice is to maintain varietal purity, but it also serves to isolate the fields from inoculum of airborne pathogens.

Storage conditions are a major consideration in maintaining seed quality (2). Most seedsmen appreciate the importance of correct storage conditions, but probably few realize that preventing invasion by storage fungi (*Aspergillus* and *Penicillium* spp.) (Fig. 5) is one of the main reasons for maintaining seed moisture content below certain levels. In many tropical countries, where controlled environment storage facilities may not be available, maintaining seed viability under conditions of high relative humidity and temperature is one of the most important limiting factors of seed production.

The importance of seed conditioning in controlling seed diseases is often overlooked. The process of cleaning and sizing seedlots automatically eliminates diseased seeds with altered physical characteristics and pathogen structures, such as galls and sclerotia. Seed conditioning equipment has considerable potential for reducing the amount of a pathogen in a seedlot to tolerable levels. There are few examples in the literature, however, of research in this direction.

Perhaps the most widely used seed disease control practice is treatment of seed with fungicides (Fig. 6). For some crops (eg, corn and peanuts), fungicides with broad spectra of activity against soilborne and seedborne pathogens have been tried and tested over many years and the benefits are well established. Treatment of cereal seeds with fungicides specifically active against smuts also has proved beneficial in some circumstances. With other crops, such as soybeans, however, the value of fungicide seed treatment has not been clearly demonstrated. This is due in part to a lack of knowledge of the factors influencing the efficacy of seed treatment. Application practices usually are determined by relating treatment rates to subsequent emergence and yield in a series of field tests in different locations and under a variety of environmental conditions. If repeated often enough, this type of experiment may provide reasonably reliable information on application rates, but very little information is obtained about disease epidemiology. As a result, failures in control practices cannot be explained, and more fungicides tend to be used than are necessary.

Fungicide seed treatments will have to be used with more discretion in the future. Federal and state regulations may restrict the use of existing materials. Mercury-based fungicides were banned some years ago, and captan is presently under a Rebuttable Presumption Against Registration (RPAR) by the U.S. Environmental Protection Agency. Measures implemented to protect operators and the environment from agricultural chemicals in the field and in conditioning plants have tended to make the procedure more complicated and therefore more expensive. Newer fungicides that may have potential as seed treatments also may experience the problem of tolerance in the target organisms. Minimizing the exposure of pathogen populations to a fungicide may prolong the useful lifetime of the chemical.

To improve the use patterns of fungicide seed treatments, more in-depth research will be required than has been done in the past. A project was begun in our laboratory in 1980 to study the influence of cultural, environmental, and pathological factors on soybean seed treatment. Preliminary data show that seed treatment may improve the emergence of *Phomopsis*-infected seeds but does not improve the performance of mechanically damaged seeds. The objective of our study is to delineate the sets of circumstances in which seed treatment will be beneficial.

Physical seed treatments using hot water or aerated steam also are used to control seed diseases. The benefits of these treatments often have to be balanced against the damage done to seed viability, however. The use of hot water to control blackleg (*Phoma lingam*) and black rot (*Xanthomonas campestris*) in high-value hybrid cabbage seed exemplifies this problem.

There has been considerable interest in recent years in treating seed with fungi and bacteria that are antagonistic to seedborne or soilborne pathogens. So far the results have been inconsistent. As Kommedahl and Windels (5) suggest, one of the major problems with this approach is a lack of understanding of the ecology of the microorganisms involved. Biological seed treatment certainly has potential but will not be widely accepted by the seed industry until these problems are resolved.

Fungicides also are used as foliar sprays to control disease on the seed. This method is not used as widely as seed treatment, primarily because of costs. In the United States, foliar application of benomyl on soybeans has been used to control *Phomopsis* spp. seed infection. The value of this treatment has been questioned, however, in production areas such as Iowa where disease severity in some years does not justify use of the fungicide. The criticisms about the methods of developing application practices for seed treatments also apply here. The recommendations for the use of benomyl were based on little knowledge of the disease epidemiology. Using earlier information from Ohio (4) and new data on the epidemiology of seed infection obtained in Iowa during the last 2 years, we have made considerable progress on developing a predictive scheme for the use of foliar fungicides on soybean seed crops based on measurements of *Phomopsis* pod infection (Fig. 7) and rainfall. The scheme could lead to much more efficient use of this control practice.

Seed diseases also can be controlled by seed health inspection programs. These are carried out either by field inspection of seed crops or by laboratory tests on harvested seeds. These methods are used for seedlots that have to be certified for plant quarantine purposes and for pathogens with established seedborne inoculum tolerances.

Seed Health Testing

Seed health testing is one aspect of seed pathology that has been well investigated. Diseased seeds can sometimes be detected by visual examination of dry seed (Fig. 8), but this method of assessing seedborne inoculum rarely is sensitive enough to be of practical value. Most tests involve plating seeds on culture media (Fig. 5), incubating them on blotters (Figs. 1 and 3), or growing them in sand or soil mixes (Fig. 9). Certain special tests are possible for particular pathogens, such as the embryo test for loose smut of cereals or

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the water droplet test for *G. temulenta* in ryegrass (9). Serological tests for detection of seedborne bacteria and viruses also have been developed (1,3).

Seed pathologists in Europe have made significant contributions in developing quantitative laboratory testing procedures for many seedborne organisms (9). These tests have been of great value in plant quarantine situations, where the most sensitive tests possible are needed to detect seedborne pathogens. Unfortunately, for many pathogens the values obtained in laboratory tests cannot be related to the risk of disease development once the seed is planted. The test that provides the highest count for a pathogen may not be the most useful in predicting field disease.

Fig. 8. Purple seed stain caused by *Cercospora kikuchii* on soybean.

In tests for seedborne *Fusarium avenaceum* on subterranean clover in Australia, seed infection averaged 67% on culture plates and 5% on blotters (8). A selective medium was used in the plate test to prevent other seedborne organisms restricting the growth of *F. avenaceum* from the seed onto the medium. In the blotter test, however, the pathogen was detected only after it had grown on the seed and caused rotting of the emerged radicle. It is possible that the latter test gave a better measure of the seedborne inoculum with potential to cause root rot in the field. Unless epidemiological studies are made to relate laboratory seed health tests to the risk of subsequent field disease, these tests are of little practical value.

Fig. 9. (Left) Healthy subterranean clover seedlings grown from uninfected seed and (right) seedlings with symptoms of root rot grown from seed infected with *Fusarium avenaceum*.

New Importance and an Identity

There is considerable evidence from the last 5 years that seed pathology is assuming new importance in the seed industry in the United States. Facilities have been built and personnel hired at public and private institutions specifically to study seed pathology problems. The American Phytopathological Society and the Association of Official Seed Analysts both have formed seed pathology committees.

Even though many important seed pathology problems have been solved over the years, seed pathology has experienced an identity crisis in the United States. I have attempted to establish this identity by describing, in general terms, how seed pathology can contribute to the improvement of modern seed production.

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