Disease Management Programs for Berry Crops in the 21st Century

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Introduction

In view of the technological breakthroughs in the past 20 years alone, the advances that could conceivably occur over the next 15 to 20 years, are almost unimaginable. This is especially true in the areas of molecular genetics, bioengineering, and biotechnology. We have made great strides in better understanding and managing many of the major diseases and disease complexes for most berry crops in the 20th century. However, due to the ability of pathogens to adapt, new cultivar introductions and constantly changing production practices, diseases will continue to be a constraint to berry crop production in the 21st century, despite our past successes. Although fungicides, as well as other disease control chemicals and products, will probably remain an important part of future disease management programs, their use will most certainly be highly regulated and scrutinized by regulatory agencies as well as the general public. In order to effectively control diseases with minimal or no use of pesticides, the continued development and implementation of truly integrated disease management programs must be emphasized.

The objective of integrated disease management is to provide a commercially acceptable level of disease control on a consistent (year to year) basis with minimal fungicide use. Developing a program the *integrates* all available control methods can meet this objective. An effective disease management program must emphasize the integrated use of: knowledge of the pathogen and disease biology; disease resistant cultivars; specific cultural practices; effective biological controls; and the timely application of fungicides and other crop protection materials when needed. In order to reduce the use of fungicides to an absolute minimum, the use of disease resistance cultivars, appropriate cultural practices, and biological control will need to be strongly emphasized.

This discussion will focus on the various components of an integrated disease management program. Major pathogens attacking berry crops world-wide are numerous and varied including primarily viruses, mycoplasmas, fungi, bacteria, and nematodes. All of these pathogens can be extremely important; however, this discussion will focus primarily on fungal pathogens of strawberry and raspberry. Due to the futuristic nature of this discussion, the author assumes a certain degree of license and will attempt to briefly discuss some of the more recent or significant advances in the 20th century, as well as speculate on potential advances in the 21st century.

Knowledge of Pathogen Biology and Disease Epidemiology

This knowledge is critical to the development of effective disease management strategies, especially if minimal fungicide use is desired. In fact, it is difficult to imagine how we can effectively "manage" any plant disease without a basic knowledge of pathogen ecology, etiology and disease epidemiology. Whereas we know a great deal about most of the fungal pathogens and the diseases they cause on strawberry, when one critically reviews this body of knowledge from a disease management perspective, the gaps in our knowledge quickly become apparent. In order to improve our disease management programs in the 21st century, a great deal of research will be required in order to fill these gaps. Huge advances were made in the 20th century in developing basic knowledge of the major pathogens on most berry crops. We need to continue to develop this type of information in order to better understand how pathogens are disseminated and survive. Information on the effects of environmental conditions (primarily temperature, wetness duration and wind) on infection and dissemination of plant pathogens will be essential for continued development of disease predictive models and disease forecasting systems. Information on sources of primary inoculum and exactly when and how the pathogens infect the crop is also essential, especially in relation to clean plant production and application timing for biological control agents or other plant protection materials. The following are just a few examples of where relatively recent plant pathology research has lead to new knowledge that has greatly improved our current disease management programs. Research conducted by Braun and Sutton in the late 1980's on the ecology and epidemiology of Botrytis fruit rot clearly demonstrates the impact new knowledge can have of on disease management programs. Botrytis fruit rot or gray mold, caused by the fungus *Botrytis cinerea,* is a major pathogen of strawberry worldwide. The majority of fungicides applied world-wide to strawberry are probably directed at control of this disease. Prior to Braun and Suttons work, it was assumed that Botrytis was ubiquitous in the environment and blew into berry plantings from several sources. Growers in perennial matted-row systems generally applied fungicides from early spring through harvest for Botrytis control. Symptoms of Botrytis fruit rot do not generally appear until near harvest as fruit is maturing; thus, it was customary to apply fungicide for Botrytis control through harvest. Obviously, this resulted in an intensive use of fungicide and increased fungicide residues on fruit. Braun and Sutton demonstrated that most of the primary inoculum for fruit infection in perennial matted-row systems comes from leaf residue within the row, and not from outside the planting. They further demonstrated that most fruit infection actually occurs during bloom. Bristow in 1986 also demonstrated the importance of flower infection in strawberry. The fungus enters (infects) the fruit during bloom often through old floral parts and remains as a latent infection in green fruit. As the fruit matures, the fungus becomes active and fruit rot develops. As mentioned previously, fungicides were routinely applied shortly prior to or during harvest when the fruit rot symptoms appeared. Due largely to the research of Braun and Sutton, our current fungicide programs emphasize spraying fungicides only during bloom and generally do not recommend sprays for Botrytis during prebloom or during harvest. Thus, through better understanding the epidemiology of this disease, spray timing has been greatly improved. In addition, overall fungicide use and fungicide residues on the fruit have been greatly reduced or eliminated. Additional reductions in fungicide use could potentially result from the implementation and use of disease forecasting systems for Botrytis fruit rot.

Root rot of raspberry is a serious disease, primarily of red raspberry, world wide. It is generally a problem on poorly drained soils and usually results in death of infected plants. Prior to research reported by Wilcox in 1989, the exact cause of raspberry root rot was not known, and most people, this author included, considered the cause to be excessive soil moisture (wet feet). Importance of raspberry root rot rapidly increased in the late 1980's and early 1990's as it reached epidemic levels world-wide. Wilcox's research demonstrated that raspberry root rot was a disease caused by several species of Phytophthora. He further demonstrated differences in varietal susceptibility to the disease, and developed an integrated disease management program for root rot control based on the use of disease resistant cultivars, cultural practices and fungicide use.

Anthracnose fruit rot of strawberry, caused by the fungus *Colletotrichum acutatum*, it is an extremely destructive disease of strawberry world-wide. The disease was first identified in Ohio in 1991, and was not observed on strawberry prior to that date. Since its first occurrence in Ohio, it has become a major threat to strawberry production. The disease appears to develop sporadically and randomly in plantings at locations where it had not been seen before. The big question was, "how is the pathogen being introduced into new plantings". Research conducted by Leandro at Iowa State University in 2001, demonstrated that *C. acutatum* can sporulate and germinate on symptomless strawberry leaves. The pathogen survives and reproduces (sporulates) on apparently healthy plants; thus, its movement on apparently healthy nursery stock is very probable and at least partially explains how the disease has become so widely distributed. Knowledge about how the fungus survives and multiplies within the planting should allow us to better control the disease through development of more effective detection methods and production and distribution of disease free planting material.

For bacterial plant pathogens, primarily angular leaf blight of strawberry, caused by *Xanthomonas fragariae*, little progress in effectively controlling the disease has been made. Fortunately, there are relatively few bacterial plant pathogens that affect berry crops. In order to effectively manage bacterial plant pathogens in the 21st century, a great deal of research in the areas of pathogen detection, epidemiology and development of disease resistant cultivars will be essential.

These are just a few examples of how research has added to our knowledge base and directly benefitted or improved our disease management programs in the 20th century. Our success in controlling the major diseases and disease complexes on berry crops in the 21st century will depend largely upon the level and quality of our research programs that support all phases of production.

Use of Disease Resistance

The use of disease resistant culitvars should be and generally is the backbone of any modern plant disease management program. The importance of developing high quality cultivars with durable resistance to major diseases can not be over emphasized. Unfortunately, disease resistance to many of the most economically important diseases is not currently available in many of the currently used varieties of several berry crops. A few common examples include mummy berry of blueberry, orange rust of blackberry and black raspberry, anthracnose and Botrytis fruit rot of strawberry, angular leaf spot or bacterial blight of strawberry, and many important virus diseases on several berry crops. The lack of resistance to many economically important diseases has forced producers in the 20th century to rely heavily upon fungicides for effective disease control. It should also be noted that for many of our most limiting diseases, primarily viruses, chemical controls are not currently available.

Although resistance to many diseases is lacking in various berry crops, good resistance to several diseases is available within specific crops. Where reliable resistance is available, it should be used whenever possible. In the last century, strawberry breeding programs world-wide have done an excellent job in developing cultivars with high levels of resistance to several foliar and root rotting pathogens. Within the Midwest and Eastern United States, use of varieties with resistance to foliar diseases (leaf spot, leaf scorch, powdery mildew) and root rots (red stele and Verticillium wilt) is a major component of the disease management program. However, even with the strict use of available disease resistance, dependence upon fungicide use is still quite strong in most strawberry production areas. This is largely due to the high number of diseases that make up the disease complex, especially in humid growing areas. In addition, resistance to some of the more damaging fruit rots (Botrytis fruit rot and anthracnose fruit rot) is generally lacking at present.

Current advances in molecular genetics, genomics, bioengineering and biotechnology in general should result in rapid and highly significant advances in the discovery of resistance genes or gene products and their incorporation into high quality, high yielding varieties. In fact, it is difficult to imagine the advances that could conceivably occur within the next 20 years or less. Conventional breeding programs that have been highly successful during the 20th century need to be maintained and well supported as we enter the 21st century. However, the use of new technologies for the identification and rapid incorporation of resistance genes or gene products should be exploited as much as possible.

Through the use of biotechnology, the identification and incorporation of resistance genes or gene products into currently available varieties has great potential. In 1993, Williamson purified a polygalacturanase-inhibiting protein (PGIP) from immature raspberry fruits. The wall-bound protein acts specifically as an inhibitor of endopolygalacturanases (PGs) produced by *Botrytis cinerea*. These fungal PGs are thought to be important in pathogenesis and the onset of aggressive fruit rot as fruit matures. The presence of PGIP is probably responsible for the fact that green or immature raspberry and strawberry fruit are generally resistant to rot by Botrytis. The PGIP gene from raspberry has been cloned with the ultimate objective of using recombinant DNA technology to enhance the expression of the gene in fully ripe fruits. Through this approach, it may be possible to rapidly incorporate durable Botrytis fruit rot resistance into existing and future raspberry cultivars.

This type of research and technology, and possibly the same genes, could be applied to other fruit crops where Botrytis is an important pathogen. On strawberry, research on genetic modification to achieve Botrytis resistance has been an ongoing program at HRI, East Malling, West Malling, Kent ME196BJ since 1985. They have used gene technology methods to induce Botrytis resistance in strawberries by over expression of a polygalacturanase inhibitor (PGIP) originally isolated from pear. They are evaluating transformed clones for gene expression in petals, stamens, carpels and leaves. Thus far, two lines have shown high resistant scores on bioassays on detached flowers. Results thus far have been very promising and are an excellent example of how the use of modern genetic modification techniques may shorten the long term nature of conventional breeding programs by adding only a few desired characters at a time.

Although this new technology is exciting and has great potential, it also faces some potentially serious problems. Despite the fact that genetic modification could be used to rapidly develop Botrytis resistant raspberries and strawberries; thus, greatly reducing the current use of fungicides for fruit rot control, public reaction to the development and use of genetically modified organisms (GMOs) could prevent the use of this technology. Especially in Europe, there is strong resistance to the introduction and use of GMOs. In fact, the previously mentioned work using PGIP to develop Botrytis resistant strawberries at East Malling has been terminated. Although the development and testing of the genetically modified clones will be continued in the United States, the public and/or political acceptance of genetically modified strawberries and other fruit crops remains an unknown.

Biological Control

The use of biological control against fungal pathogens of berry crops has great potential in the 21st century. At present, several biocontrol products are registered in the U.S. for control of specific diseases on various berry crops. However, current use of biological control in disease management is limited and has had relatively little impact on disease management in the 20th century. Although excellent research has clearly demonstrated the potential for biological control for specific diseases in controlled experiments, the wide-scale use of biocontrol has not been adopted in commercial production systems. A great deal of research has been published on the use of various microorganisms for control of Botrytis gray mold on strawberry. Most studies have focused on the use of these microorganisms to protect flowers and fruits from infections.A wettable powder formulation of *Trichoderma harzianum* has been marketed in Israel under the trade name Tricodex, and *Trichoderma* isolates have been distributed to strawberry growers in Bulgaria. It is difficult to find published information as to the success or failure of these materials in relation to control of *Botrytis cinerea* (gray mold) on strawberry under commercial field conditions. Additional research by Sutton, on the use of *Gliocladium roseum* for gray mold control is quite promising, and may lead to the development of highly effective materials in the future. However, at least in the short term, the commercialization and use of effective biological control agents or products for control of several serious pathogens on berry crops faces many challenges, especially when their performance is compared with the use of effective fungicides.

The use of biological control for control of soilborne pathogens also has great potential in the future. The demand for effective replacements for the soil fumigant, methyl-bromide, will provide increasing pressure to fund research to explore the potential for biological alternatives. The incorporation of organic amendments such as various composts has shown great potential for suppression of soilborne pathogens in other cropping systems and should be beneficial for disease control in berry crops as well. As with all other areas of plant pathological research, biotechnology will undoubtedly have great impacts on the future of biocontrol of plant diseases. The ability to genetically manipulate or bioengineer biocontrol agents could result in more efficient and consistently reliable products. This combined with increased understanding of the microbial ecology in fruit production systems and how cultural practices impact pathogen and biocontrol agent populations should provide breakthroughs for the successful implementation of biocontrol. Molecular tools are currently being developed to identify and quantify pathogen populations as well as organisms with biocontrol capabilities. Through a great deal of innovative and multidisciplinary research, biological control will undoubtedly be an integral component of integrated disease management programs in the 21st century.

Use of Cultural Practices

The use of cultural practices as effective tools for the management of berry crop diseases is becoming widely recognized. The importance of cultural practices will most certainly increase in the future, especially if reducing our dependence of fungicides remains a top priority. Any practice that affects the macro- or micro-environment within the planting can have a direct effects on disease development. In order to fully utilize these practices, a great deal of multidisciplinary research is required to better understand their affects on pathogen biology and disease epidemiology. There are numerous cultural practices that have great potential for use in disease management. The following are only a few examples of how cultural practices can impact upon our disease management programs.

The importance of pathogen free nursery stock cannot be over emphasized. During the 20th century, the nursery industry for most berry crops has made good progress towards producing high quality plants for producers. Virus indexing programs have been very effective for cleaning up the more damaging viral pathogens; however, indexing programs to insure that plants are free of fungal and bacterial pathogens generally do not exist. Genetic molecular technology that is currently available and will continue to develop and improve should be used to develop extremely sensitive indexing programs for detecting fungal, bacterial and other plant pathogens on nursery stock. Future efforts should focus on developing nursery indexing programs for detection of all important pathogens in order to provide producers with truly “disease free” planting material.

The identification and utilization of good horticultural production practices will always be critical to successful berry production. Soil drainage has long been recognized as a critical component of the disease management program. Any practice that promotes better drainage to avoid saturated soils is critical for control of root rots, caused by *Phytophthora* spp. on most berry crops. Conventional practices, such as tiling and the use of raised beds, have aided greatly to disease control in the 20th century. Innovative research in the area of soil and water management and irrigation practices will contribute greatly to the disease management program for soilborne diseases in the 21st century.

Effects of plant nutrition, primarily on development of foliar and fruit attacking pathogens have long been recognized. Excessive use of nitrogen in the spring has been associated with increased levels of *Botrytis* fruit rot and powdery mildew on several berry crops. Although the affects of plant nutrition on plant disease is widely acknowledged, little practical data or information actually exist that can be directly used as an integral portion of the disease management program. This is an area that demands a great deal of multidisciplinary research in order to determine the effects of plant nutrition on disease susceptibility. The effect of nutrition on plant canopy development and plant architecture also could have profound effects on development and dissemination of many important diseases by creating micro environments in the canopy that are more conducive to disease development.

Ground covers can have a direct effect on the development of fungal fruit rots in strawberry. A good layer of straw mulch between the rows has been shown to be highly effective for control of leather rot, caused by *Phytophthora cactorum*. The straw acts as barrier that protects the fruit from contact with the soil. In addition, straw mulch aids greatly in reducing splash dispersal of fungal pathogens that cause leather rot and anthracnose. Conversely, plastic mulch, which is commonly used in annual production systems, has been shown to enhance splash dispersal of *Collectotrichum* spp. and increase the incidence of anthracnose fruit rot. Whereas the benefits of plastic ground cover in relation to overall production may greatly outweigh the disadvantages in relations to disease development, it is important to realize the effects that ground covers and other practices may have on disease development. Future research in the development of berry crop production systems may well need to address the importance of ground covers and other factors that affect splash dispersal of pathogens, especially if these systems emphasize decreased fungicide use.

Any practice that reduces air circulation and light penetration into the plant canopy can effect the development of several plant diseases. Most fungal pathogens require water on the fruit surface in order to infect. Practices that promote faster drying of the fruit after wetting events should aid greatly in disease management. Legard demonstrated the effects of within-row plant spacing on the incidence of Botrytis fruit rot of strawberry. Wider within-row plant spacing (a more open canopy) reduced the incidence of Botrytis fruit rot.

The practice of sanitation has long been considered an important cultural practice for many diseases of berry crops. Removing infected material from the planting should aid in reducing the amount of primary and secondary inoculum and; therefore, should be beneficial in reducing disease. Although this is a good “common sense” practice, there is little information in the literature that documents the effects of sanitation on disease management. In fact, Mertely demonstrated that leaf sanitation (removal of senescent and necrotic leaves) and fruit sanitation (removal of unmarketable fruit from alleys between beds) did reduce the incidence of Botrytis fruit rot on strawberry, but did not increase marketable yield. In addition, they demonstrated that supplementing fungicides with leaf and fruit sanitation did not improve disease control and frequently reduced yield in annual strawberries.

Fungicide Use

Due to the number and potential severity of fungal pathogens on berry crops, combined with public demand for blemish free, high quality fruit, it is the authors opinion that fungicides will remain an important component of disease management programs for berry crops in the 21st century. However, there minimal use within integrated disease management programs will be strongly emphasized. Public concern and political mandate will most certainly affect the use of fungicides and other crop protection chemicals in the future. It is not inconceivable that fungicide use could be banned at some time, at least in specific areas or even countries. If such drastic action were to occur, we would have to rely solely on the remaining components of the disease management program. The best way to insure future use of fungicides is to use them safely and wisely. It is our responsibility to educate the public as to the importance of fungicides in food production, and to assure the public that they are used safely and only when needed. We need to emphasize that they are simply one component or “tool” used within the integrated disease management program.

In relation to the use of fungicides in the 21st century, it is important to remember that we have little concept of what future research in fungicide chemistry and development may achieve. It is highly probable that the fungicides and other crop protection products of the future will be highly efficacious at very low rates, environmentally benign, and nontoxic to mammals. In addition, they may have strong curative or after-infection activity for use in disease forecasting systems.

As we enter the 21st century, new diseases or other problems related to plant health will undoubtedly arise. Hopefully, plant pathologists and other plant health professionals in cooperation with the berry crop industry will be able to deal with them in a timely manner. There are, however, certain factors over which we as scientists and producers appear to have little control. Public opinion, especially in relation to topics such as GMOs and pesticide use, as well as political mandates could have strong influences on disease management programs in the 21st century.