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Gibberella and Fusarium Ear Rots of Maize in Hawai‘i

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Two distinct ear rot diseases of maize (corn, *Zea mays* L.) in Hawai‘i are caused by similar plant pathogens. The fungus *Gibberella zeae* or its asexual stage, *Fusarium graminearum*, causes Gibberella ear rot of maize. Fusarium ear rot of maize, however, is caused by *Fusarium verticillioides*. This fungal pathogen is also known as *F. moniliforme*, *F. proliferatum*, and *F. subglutinans* as well as their sexual stages, which are different mating types of *Gibberella fujikuroi*. These diseases have a worldwide distribution and are present in all climates where corn is grown. They are of sporadic importance in Hawai‘i. However, these ear rots are the most important problem facing the production and development of new sweet and waxy corns in the tropics (J. Brewbaker, *personal communication*).

Gibberella ear rot

The prevalence of corn ear rots in tropical and sub-tropical regions such as Hawai‘i is particularly troublesome because multiple yearly cropping cycles allow the pathogens to develop large populations. In addition, these fungi create mycotoxins that are harmful to humans and livestock when consumed. This creates a need for public awareness in Hawai‘i for both economic and health reasons.

By 2006 the value of the corn industry in Hawai‘i had increased by over 13,000% compared with 40 years previous, and it has almost doubled again since then (*Hawaii Annual Stat. Bull*., Proctor et al. 2010). In 2012 the total value of corn production in Hawai‘i was nearly 250 million dollars (*Hawaii Annual Stat. Bull*.). Under certain weather conditions, however, large losses from ear rots can occur. In this paper we discuss the pathogens, symptoms they produce, and integrated management practices for these diseases.

Pathogens

Gibberella zeae is the sexual stage (teleomorph) of the pathogen causing Gibberella ear rot of corn. It is an ascomycete fungus, which means it produces ascospores in special sacs called asci. Ascospores are typically ovoid with two or three cells per spore (Hanlin 1990). Asci are contained in bluish-black perithecia formed by the fungus on and among the kernels of corn. Perithecia are visible to the naked eye as small dots but can be observed more readily through a hand lens.

The anamorph (asexual stage) of *G. zeae* is *Fusarium graminearum*. It mainly produces large spores known as macroconidia. These are multi-celled spores varying in shape from banana-like to nearly straight, with each spore having a curved terminus. Chlamydospores may also be present, although they tend to develop slowly, if at all. These are large, round spores that serve as long-term survival structures for the fungus (Leslie et al. 2006).

Gibberella fujikuroi and its anamorph *F. verticillioides* produce both microconidia and macroconidia, but no chlamydospores. Their macroconidia are longer and narrower than those of *F. graminearum* but have the same general shape. The microconidia are small, oblong, ovoid, single-celled spores, but they may be difficult to identify by their shape and size. They grow in long chains above the mycelium.

Fusarium subglutinans also produces microconidia and macroconidia but not chlamydospores. These microconidia are oval, shorter than those of either *F. graminearum* or *F. verticillioides,* and instead of chains they form in aerial bunches called false heads. This species is more prevalent in cooler regions so is of less importance in Hawai‘i.

Fusarium proliferatum produces both microcondidia and macroconidia, but no chlamydospores. The micrononidia are club-shaped with a flattened base. The macroconidia are similar in appearance to those of *F. graminearum*.

Pathogen Dissemination and Disease Cycles

Gibberella and *Fusarium* spores are dispersed primarily by wind and rain (Corn Insect and Disease Guide: Gibberella Ear Rot 2014, Das 2014). Certain insects, such as the European corn borer, can vector the pathogens when they infest corn ears or contact corn silks (*Mycotoxins in Grain* 1997). This insect has not been reported in Hawai‘i, however. Some species of thrips present in Hawai‘i are causal agents of “silk-cut” symptoms, which coincide with a higher incidence of *Fusarium* infections and rots of corn ears. In addition to thrips, corn earworms are significantly correlated with increased ear rot occurrence (Parsons 2008).

Gibberella zeae and *F. graminearum* infect through the silks of the corn ear. The infections progress basipetally, from the tip towards the base of the ear, and may reach the peduncle of an ear during a severe epidemic. When *G. zeae* matures, it forms perithecia and spores that disseminate to initiate succeeding cycles of disease within or continuing cycles among fields. The inoculum that will cause infection in the next crop is mostly found in crop debris but can also come from infected corn seed (Munkvold et al. 1997).

Fusarium species associated with *G. fujikuroi* tend to enter the corn ears through wounds, especially those

Gibberella infection progresses from the tip to the base of the ear.

created by insects; the resultant symptoms usually do not to affect the entire ear. These infections tend to occur on the silks and in feeding injuries caused by thrips and corn earworms (Parsons 2008). The spores of *Fusarium* can attach to insects and be carried to new plants, or the fungus can persist in crop debris after harvest. It lives in the debris as a saprophyte and moves with wind or splashing rain after a new, susceptible corn crop is planted.

Moist environments favor development of Gibberella ear rot in the first 21 days after silking (Woloshuk et al. 2010). Temperatures from 26 to 28°C (79 to 82.5°F) favor the disease (Parsons 2008), but the disease may also occur in cooler weather (Willyerd et al. 2010, Woloshuk et al. 2010). In Hawai‘i, cooler, disease-conducive temperatures for ear rot can occur in wet, low-elevation areas during the winter and spring, although such weather can also be found year round in other regions of the Islands (Brewbaker 2014). Alternatively, *Fusarium* ear rot caused by *F. verticillioides* has been associated with drought conditions and insufficient irrigation (Parsons 2008). In such cases, *Fusarium* ear rot tends to coincide with the physiological maturity of corn, when kernel moisture begins to decrease (Brewbaker 2014). Because of these broad climatic conditions in Hawai‘i, at least one type of ear rot is likely to appear in any growing season and in any corn-growing area.

Pathogen Host Ranges

The host ranges of the pathogens causing *Gibberella* ear rot and *Fusarium* ear rot of corn are broad, so identification of potential sources of inoculum near your growing area is important. Known host ranges of the pathogens causing these two diseases are listed in Table 1.

It is unknown if *F. subglutinans* has host-specific races or if it can infect multiple host species (Viljoen et al. 1997). *Fusarium graminearum* is not species-specific, however, and it can infect multiple hosts, making management more difficult (Burlakoti et al. 2008).

Among different varieties of corn, those with 12 or 16 rows of kernels usually have straight rows of kernels on a cob and flattened ear tips. These varieties of corn tend to be more susceptible to epidemics of Gibberella ear rot and to corn earworm feeding injuries, which lead to high instances of Fusarium ear rot. These varieties of corn are more typical of corn grown on the US mainland. The varieties grown for consumption in Hawai‘i typically

Table 1

Sexual Stage	Asexual Stage	Hosts
Gibberella zeae	*Fusarium graminearum*	Maize, corn (*Zea mays*), wheat (*Triticum* sp.)[1], barley (*Hordeum vulgare*)[2], oats (*Avena sativa*), rye (*Secale cereal*), and species of Lycopersicon, Pisum, Trifolium, and Solanum[3], such as potato[4], as well as sugar
Gibberella fujikuroi	*F. verticillioides* (*F. moniliforme*)	Hundreds of plants important to agriculture[5] including maize[2], rice (*Oryza sativa*)[6], Sorghum, sugarcane (*Saccharum officinale*), wheat, cotton (*Gossypium hirsutum*), banana (*Musa* spp.), pineapple (*Ananas comosus*), and tomato (*Solanum lycopersicum*)[3]
	F. subglutinans	Maize[2], mango (*Mangifera indica*), pine (*Pinus* sp.), sugarcane, pineapple, various grasses/reeds (family: Poaceae)[7]
	F. proliferatum	Maize, sorghum, mango, asparagus (*Asparagus officinalis*)[2], fig (Ficus), onion (*Allium cepa*), palm (family: Arecaceae), pine, rice[8], cucumber (*Cucumis sativus*), garlic (*Allium sativum*), salt cedar (*Tamarix* sp.)[9]

[1]Wise et al. n.d.; [2]Leslie et al. 2006; [3]Das 2014; [4]Burlakoti et al. 2008; [5]Bacon et al. 1996; [6]Hanlin 1990; [7]Viljoen et al. 1997; [8]Proctor et al. 2010; [9]Moncrief et al. 2013

have 14 rows of kernels that spiral to a pointed, narrow ear tip. These varieties tend to have a lower incidence of corn earworm and of Gibberella and Fusarium ear rots (Brewbaker 2014).

Symptoms, Signs, and Disease Diagnosis

Gibberella ear rot can be diagnosed by the color of the fungal mycelium growing on a diseased ear of corn. The diagnostic pinkish-red mold originates at the tip of an ear and grows toward the base. It usually does not infect an entire ear. The husk of a diseased ear may stick to the kernels and be difficult to remove (Wise et al. n.d.). Sometimes the mycelium is pale pink, which can lead to this ear rot's being confused with similar diseases, such as those caused by *Diplodia* and its grayish-colored mycelium ("Corn Insect and Disease Guide: Gibberella Ear Rot" 2014, VanDyk 2002). *Gibberella* species causing ear rots on corn will also produce small, dark perithecia on the kernels, stalk, or husk.

Fusarium ear rot produces white, pale pink, or pale lavender mycelia. Unlike *Gibberella*, *Fusarium* does not produce perithecia. Fusarium ear rot is often associated with insect infestations such as thrips or corn earworms. It tends not to engulf an entire ear but to remain localized around insect feeding injuries.

A visual diagnosis of these diseases using their symptoms and signs is easy to perform and without cost; therefore, serological or molecular detection methods for diagnosis, such Enzyme-Linked Immunosorbent Assay (ELISA) or Polymerase Chain Reaction (PCR), are seldom necessary. These tests require lab work, equipment, and materials, making them more costly and time consuming than a visual diagnosis.

Effects of Mycotoxins and Their Detection

Because both Gibberella ear rot and Fusarium ear rot produce mycotoxins dangerous to humans and livestock, it may be unnecessary to distinguish between the two diseases, especially when they both can occur in the same field simultaneously.

Gibberella zeae produces the mycotoxins deoxynivalenol, zearalenone and zearalenol. Deoxynivalenol, also known as "DON" and "vomitoxin," is a protein synthesis inhibitor and a powerful immunosuppressant. Symptoms of acute toxicity in animals include refusal to eat, vomiting, and weight loss (Das 2014, Willyerd et al. 2010). Symptoms of chronic exposure to the mycotoxins among humans include diarrhea, lethargy, intestinal hemorrhage, and increased susceptibility to other diseases (Das 2014). Zearalenone and its metabolite zearalenol have estrogenic properties. They can negatively affect breeding, fecundity, and hormonal balances in animals (Frizzell et al. 2011, Woloshuk et al. 2010). The United States Food and Drug Administration (FDA) has set limits for acceptable amounts of deoxynivalenol in finished animal feed at 1 part per million (ppm) for pigs and 5 ppm (food containing deoxynivalenol is not to exceed 40% of the animals' diets) for cattle, poultry, and other animals (Woloshuk et al. 2010). The established amount for humans is 1 ppm in finished flour (Willyerd et al. 2010).

Fusarium verticillioides can produce mycotoxins called fumonisins. One of the diseases caused by fumonisins is equine leukoencephalomalacia or "blind staggers" in horses. These toxins can also cause pulmonary edema in pigs. In humans, fumonisins have been associated with cancer (Das 2014). *Fusarium proliferatum* can produce fumonisins and moniliformin. *Fusarium subglutinans* only produces moniliformin (*Mycotoxins in Grain* 1997). Moniliformin causes lesions of smooth muscle tissues, like the heart, and can cause the death of animals (Harvey et al. 2002, Kamyar et al. 2006). Because of the possible presence of mycotoxins, infected ears of corn should be treated with caution. Destroying infected corn is the safest way to protect humans and livestock.

There are several different tests and test kits for mycotoxins, including lateral flow strips, ELISA, and chromatography. The cost and time taken for analysis generally increases with accuracy, and each toxin requires its own, separate test (Willyerd et al. 2010).

Lateral flow strips are fast, relatively inexpensive, and available for home use. These tests offer a simple "yes" or "no" answer as to the presence of mycotoxins. They are not useful if ppm needs to be measured. The advantages of this test are that it can be used in the field, results are available in about 15 minutes, and for single samples this test is affordable (Willyerd et al. 2010).

ELISA generally requires an equipped laboratory, sufficient materials, and trained personnel. The costs of ELISA therefore exceed those for lateral flow strips. However, when many samples are being analyzed simultaneously, ELISA may be a more cost-effective method. ELISA is semi-quantitative, producing "weak

Table 2

Type	Active Ingredient(s)	Trade Name(s)	Comments
Fungicide	prothioconazole	Proline®	Provides disease and mycotoxin suppression only. Timing is critical—apply from silking (stigmata is visible) to silk browning (stigmata becomes brown) (Staff 2011).
Insecticide	lambda cyhalothrin	Warrior II with Zeon Technology®, Lamcap™	Contact insecticide
Insecticide	dimethoate	Dimethoate	Systemic insecticide
Insecticide	permethrin	Bondie Eight®	Residential use only
Insecticide	carbaryl	Sevin®	
Insecticide	cyfluthrin	Baythroid®, Renounce®, Tombstone™	
Insecticide	Deltamethrin	Batallion™	For control of corn earworm
Insecticide	Clothianidin, *Bacillus firmus* strain I-1582	Poncho®/Votivo®	For control of thrips
Insecticide	Permethrin	Pounce®	For control of corn earworm
Insecticide	Zeta-Cypermethrin	Mustang®	For control of corn earworm
Insecticide	Bifenthrin	Brigade®	For control of corn earworm
Insecticide	Chlorpyrifos, Zeta-Cypermethrin	Stallion™	For control of corn earworm
Insecticide	methomyl	M1™	For control of corn earworm
Insecticide	Esfenvalerate	Asana®	For control of corn earworm
Insecticide	Malathion	Prentox®	For control of corn earworm and thrips
Insecticide	Piperonyl butoxide, Pyrethrins	Evergreen®	For control of corn earworm and thrips
Insecticide	Azadirachtin	Ornazin®, Amazin®	For control of corn earworm and thrips
Insecticide	Mineral oil	All Seasons®	For control of corn earworm and thrips
Insecticide	Imidacloprid	Dyna-Shield®	For control of thrips
Insecticide	Kaolin clay	Surround®	For control of thrips
Insecticide	Spinosad	Entrust®, Success™	For control of corn earworm
Insecticide	Spinetoram	Radiant®	For control of corn earworm
Insecticide	Novaluron	Rimon®	For control of corn earworm
Insecticide	Potassium salts of fatty acids	Garden Safe®	For control of thrips

Note: The pesticides listed here are for reference only. It is the sole responsibility of the user to make sure that the use of these pesticides is legal. Legality of use may change with setting (home garden, farm, forestry, etc.), certification of applicator, crops these pesticides are applied to, etc. It is not the authors’ or the University of Hawai‘i’s responsibility to ensure the legal use of any pesticides listed in this article. The pesticides listed here are listed as approved for use as of June 2014.Their registration and legal status may change over time in the state of Hawai‘i. The authors and University of Hawai‘i are in no way endorsing the use of the pesticides listed here over other brands or active ingredients of other pesticides. These pesticides are listed here as examples, for reference only.

or strong" results based on affinities to the antibodies for each mycotoxin. ELISA does not produce results in ppm (Willyerd et al. 2010).

Chromatography is an expensive, time-consuming test that offers accurate, quantitative data. It is used for large-scale applications that need specific and accurate measurement mycotoxins in ppm (Willyerd et al. 2010).

Some test kits for mycotoxins can be purchased for commercial and non-commercial use from Romer Labs (www.romerlabs.com) or Neogen (www.neogen.com) (Woloshuk et al. 2010). Others are listed at http://gipsa.usda.gov/Publications/fgis/handbooks/don_insphb.html in the DON (Vomitoxin) Handbook, along with approved procedures for use (DON (Vomitoxin) Handbook 2013). It is also important to note that black light or UV testing does not detect mycotoxins (Willyerd et al. 2010).

Integrated Management of Corn Ear Rots

Management of these diseases is most effective during the earliest stages of disease development. Therefore, prompt diagnosis of the diseases is important.

- **Quarantine.** Keeping the pathogen and its vectors from entering an area is the most effective management option. Hawai‘i has a state quarantine program to prevent entry of the European corn borer. This insect damages corn ears and creates conditions for Fusarium ear rot to occur. Continued diligence on the part of the state government and all importers of corn, as well as farmers, is essential.

- **Disease-free seed.** Planting disease-free seed is a good way to prevent the disease or reduce initial inoculum or (Das 2014). It is a form of quarantine when it excludes the pathogen from an area free of the disease.

- **Host resistance.** Selecting varieties of corn that are less susceptible to Gibberella and Fusarium ear rot is another effective way to reduce disease occurrence (Das 2014). Varieties with spiraling rows, pointed tips, and looser husks, and those that dry down quickly tend to be more resistant to both diseases (Brewbaker 2014, "Corn Insect and Disease Guide: Gibberella Ear Rot" 2014). Ears with straight rows, squared tips, and tight husks tend to be more susceptible (Brewbaker 2014). Seed catalogs provide varieties with different levels of resistance.

- **Control alternate hosts.** Weed control and elimination of alternate hosts can exclude or help minimize pathogen inocula from fields and reduce the number of susceptible hosts in a particular growing area.

Gibberella ear rot exhibits a diagnostic pinkish-red mold.

Weeds may also be alternate hosts for damaging insects, which can also carry the pathogens (Table 1).

- **Reduce initial inoculum.** Crop rotation to non-host plants can effectively reduce initial inoculum. Field sanitation, or removal of litter and crop residue from earlier crops, also reduces initial inoculum levels in the field. This is especially important in Hawai‘i because there is no winter freeze to kill the pathogens and disease pressure builds quickly in fields.

- **Pesticides.** Pesticides available for use in Hawai‘i are listed in Table 2. It is important to rotate the use of pesticides, if possible, to reduce the risk of the pathogen becoming resistant to the fungicide. Pesticides with different modes of action should be used in a rotation. A lack of these fungicides on the market increases the importance of other integrated management practices. Controlling thrips and corn earworm with insecticides can dramatically reduce the incidence of Fusarium ear rot in Hawai‘i (Parsons 2008).

- **Early harvest.** Harvesting early can reduce disease incidence and severity, as disease tends to set in at physiological maturity and not before. To avoid postharvest losses, configure processing machinery to reduce kernel damage and remove the lightest (infected) kernels (Corn Insect and Disease Guide: Gibberella Ear Rot 2014). For storage of grain, perform a quick drydown by heating the kernels until the final moisture content is at or below 15%.

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