UF IFAS Extension UNIVERSITY of FLORIDA

PP333
doi.org/10.32473/EDIS-pp333-2017

The Laccate *Ganoderma* of the Southeastern United States: A Cosmopolitan and Important Genus of Wood Decay Fungi[1]

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Summary

Ganoderma Karst. is a large and diverse genus of wood decay fungi that can rot the roots and/or lower trunk of many tree species. There are several laccate (varnished or polished) *Ganoderma* species that are found in the southeastern United States. These species can be recognized by their shiny, reddish-brown, and shelf-like fruiting bodies. These fruiting bodies have a pale pore surface on the bottom that darkens with age or handling and can be stipitate (stem present) or sessile (stem absent). Laccate *Ganoderma* species fruit year-round in most parts of the southeastern United States, but fruiting may be restricted to warm months in northern areas. When *Ganoderma* fruiting bodies are observed, it is an indication that wood decay is active, whether on fallen logs, buried roots, or the trunks of living or dead trees.

Introduction

Ganoderma species are white rot fungi, which means they can break down both cellulose and lignin, the structural components of wood (Sinclair and Lyon 2005). *Ganoderma* species are generally associated with the decay of roots and/or the lower trunk and root flare, which can lead to hazardous tree conditions and tree failures, resulting in serious damage to property and life.

Fruiting bodies of *Ganoderma* are often found in association with declining trees, especially in urban landscapes. However, they can also be found at the base of affected living trees where there are localized pockets of decay within the tree, on dead trees, or associated with buried infected wood or roots of previously removed trees. The presence of *Ganoderma* fruiting bodies on living trees does not always indicate imminent tree failure or death, and some *Ganoderma* species are more aggressive pathogens than others. For example, *G. zonatum* Murrill has been documented as a serious pathogen of palm trees and can contribute to tree mortality and failure by windthrow (Elliott and Broschat 2001) (Figure 1A). Other species, such as *G. sessile* Murrill and *G. curtisii* (Berk.) Murrill, seem to be opportunistic pathogens and typically only cause serious decay in old or stressed trees (Sinclair and Lyon 2005). Some tree species, such as *Quercus virginiana* (southern live oak), can resist decay because they produce dense wood with antimicrobial chemicals and they compartmentalize infections. In contrast, species such as *Quercus hemisphaerica* ("laurel" or Darlington oak) are less efficient at combating fungal infections and are therefore more susceptible to decay. Knowledge of which *Ganoderma* species is present and what tree species is infected can assist with tree structure evaluations and risk assessments of hazardous trees.

Taxonomy

The taxonomy (classification) of North American *Ganoderma* species is quite confusing and has been in a state of flux for the past 20 years. However, with the advancement of molecular genetic investigations, the species complex is being elucidated (Cao et al. 2012; Moncalvo et al. 1995; Zhou et al. 2015). In the past century, many authors that have reported findings of *Ganoderma* in the United States have used the name *'G. lucidum'* for any laccate *Ganoderma* species growing on hardwood trees (Adaskaveg and Gilbertson 1988, 1989; Gilbertson and Ryvarden 1986; Hapuarachchi et al. 2015). It is now recognized that *G. lucidum* sensu stricto (Curtis) Karst only occurs endemically in Europe and possibly northeastern China (Cao et al. 2012; Hennicke et al. 2016; Moncalvo et al. 1995). Similarly, many of the wild-collected and commercially available cultivated species have been given the general label of 'G. *lucidum'* in Asia, where laccate *Ganoderma* species have been used for medicinal purposes for centuries (Hennicke et al. 2016; Wang et al. 2012). This group of fungi are commonly referred to as "reishi" or "Ling-zhi" (Hennicke et al. 2016). It is now recognized that cultivated "reishi or "Ling-zhi" in Asia actually represents several species, such as *G. lingzhi* Sheng H. Wu, Y. Cao & Y.C. Dai, *G. sichuanense* J.D. Zhao & X.Q. Zhang, and *G. multipileum* Ding Hou (Cao et al. 2012).

Laccate *Ganoderma* Species of the Southeastern United States

There are approximately ten laccate *Ganoderma* species that have been reported in the southeastern United States (Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, and Tennessee). These are *G. curtisii, G. martinicense* Welti & Court., *G. meredithiae* Adask. & Gilb., *G. ravenelii* Stayaert, *G. sessile, G. tsugae* Murrill, *G. tuberculosum* Murrill, *G. weberianum* (Bres. & Henn.) Steyaert, *G. zonatum,* and *Tomophagus colossus* (Fr.) Murrill (formerly known as *G. colossum* (Fr.) Baker). The most commonly observed species in the southeastern United States are *G. curtisii* and *G. sessile*, but in Florida *G. zonatum* is also commonly found, specifically on palm trees (Figure 1).



Figure 1. Common laccate *Ganoderma* species of the southeastern United States. A) Canopy collapse symptom of *Butia odorata* (Jelly palm) infected with *Ganoderma zonatum*; B) *Ganoderma zonatum* fruiting on a trunk of *B. odorata*; C) *Ganoderma curtisii* fruiting bodies on a root flare of a *Quercus* sp. (oak); D) *Ganoderma sessile* fruiting bodies on a trunk of a *Salix* sp. (willow); E) *Ganoderma tsugae* fruiting on *Tsuga canadensis* (hemlock) trunk.
Credit: A) Andrew Loyd, UF/IFAS; B) Andrew Loyd, UF/IFAS; C) Andrew Loyd, UF/IFAS; D) Matt Losey, Bartlett Tree Experts; E) Robert Blanchette, University of Minnesota, Department of Plant Pathology

The morphology of basidiocarps (conks) of the laccate *Ganoderma* species can be highly variable, which presents challenges for species level identification. For example, species such as *G. curtisii* and *G. meredithiae* are practically identical in the field. However, the former is typically found in association with hardwood trees (especially oaks), while the latter is associated with pines. Some species are generalists and can be found in association with a diverse range of host trees, and other species are specialists. For example, *G. sessile* is a generalist that can be commonly found on many species, such as oaks, maples, redbuds, and other deciduous trees, whereas *Ganoderma zonatum* is a specialist that can only be found on palms.

Generally, all laccate *Ganoderma* species have woody to spongy fruiting bodies that grow on the lower portions of trees (i.e. lower trunk, root flare, roots, etc.). The characteristics that are most helpful for species identification are the color of the fruiting body, whether it has stipitate or sessile anatomy (presence or absence of a stalk), context tissue characters (tissues between cap crust and tubes and throughout the stem, Figure 3A), and host tree species. Fruiting bodies range in color from yellow to brown to reddish-brown and are mostly "shiny" on non-spore producing surfaces. Stipes (stalks) can be present or absent (sessile) and when present can range from short, stocky stalks that are referred to as pseudostipes to lengths that are equal to or greater than the diameter of the cap (Figure 2). The context tissue ranges from white or cream to dark brown in color and corky to felty in texture. Black, often shiny, resinous deposits throughout the length of the stipe and/or concentric zones in the context tissue are features that are important characteristics for some species (Figure 3).

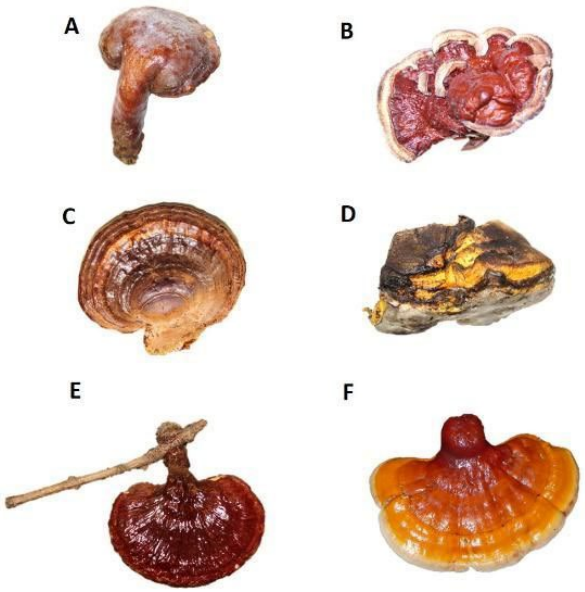


Figure 2. Range of different macromorphological characters of laccate *Ganoderma* spp. A) Reddish-brown with subtle purple hues of a stipitate form of a typical *G. curtisii*; B) Highly varnished, red sessile fruiting body typical of *G. sessile*; C) Reddish-brown, sessile form of *G. zonatum* with conspicuous concentric zones typical of this species; D) Yellow, spongy fruiting body typical of *Tomophagus colossus* (syn. *G. colossus*); E) pseudostipitate (short stocky stipe (stalk)) form of *G. sessile;* F) Latterally pseudostipitate, reddish-orange fruiting body with a white margin typical of an actively growing *G. tsugae* fruiting body.
Credit: A) through E) Andrew Loyd, UF/IFAS; F) Robert Blanchette, University of Florida, Department of Plant Pathology

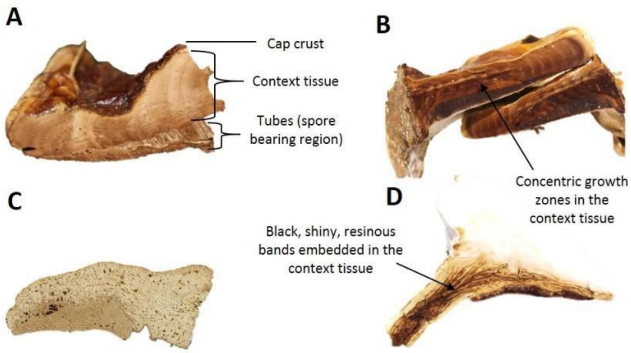


Figure 3. Range of context tissue characters of the laccate *Ganoderma* spp. A) Cream-colored context tissue with concentric growth zones typical of *G. sessile*, illustrating the location of specific basidiocarp tissues; B) Dark brown colored context tissue with concentric growth zones (arrow) of *G. tuberculosum*; C) All white, homogenous context tissue of *G. tsugae*; D) Cream-colored context tissue with black, shiny resinous bands (arrow) typical of *G. curtisii*.
Credit: Andrew Loyd, UF/IFAS

Microscopically, spore size and shape can distinguish some species, but in most species the spores are quite similar. All *Ganoderma* species have bitunicate (double-walled) basidiospores that are pigmented, appearing golden-brown (Figure 4A). The inner wall is pigmented and extends through the hyaline (not pigmented) outer wall as small pillars, making the spores appear subtly echinulate (spiny) under the light microscope (Figure 4A). Some species have spores that appear "rough," while others have spores that appear "smooth." The distinction between "rough" and "smooth" spores can be subjective and is only a relative distinction among the species, resulting from differences in the thickness and abundance of pillars from the inner spore wall (Steyaert 1980) (Figure 4). Lastly, there are species of *Ganoderma* that produce chlamydospores in the fruiting body or in culture. Chlamydospores are thick-walled asexual spores that function as survival structures, which can persist in extreme temperatures and drying conditions. These structures are variable within the genus *Ganoderma* and can be hyaline to pigmented, round to obovate, and smooth or ornamented, depending on the species (Figure 4). A rudimentary key to the southeastern US laccate *Ganoderma* species is provided below.

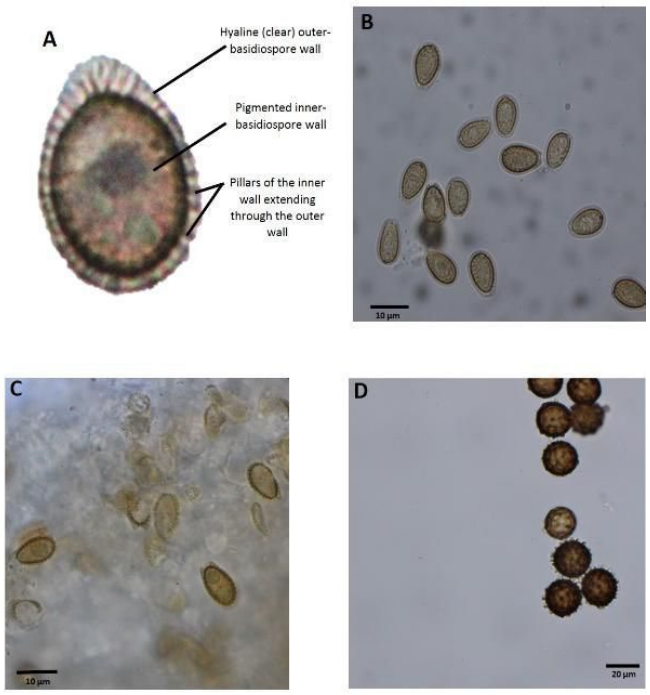


Figure 4. Basidiospore and chlamydospore morphology. A) Typical morphology of basidiospores of *Ganoderma* species, depicting the hyaline (non-pigmented) outer wall and pigmented inner wall that protrudes through the outer wall as small pillars; B) "Smooth" basidiospores of *G. sessile,* which appear smooth due to thin pillars of the inner spore wall; C) "Rough" basidiospores of *G. curtisii,* which appear rough due to thicker pillars of the inner spore wall; D) Pigmented, highly-ornamented, chlamydospores of *T. colossus*, which can be found consistently throughout the context tissue of the fruiting body.
Credit: Andrew Loyd, UF/IFAS

Basic Key to the Laccate *Ganoderma* spp. of the Southeastern United States

Disclaimer: This key is rudimentary and is mostly based on macromorphology, geography, and host. This is not to be final and is based on species designations present in the literature at the date of this publication. The designations are subject to change as more investigations are made (Figure 5).

1. Typically stipitate fruiting body with a true stipe (commonly laterally produced)..... 2

1. Sessile fruiting body, or if a stipe is present, less than half the length of the cap diameter..... 4

2. Cream or buff context tissue with no black, shiny, resinous deposits..... *G. ravenelii*

2. Cream or buff context with black, shiny resinous deposits present..... 3

3. Found predominately on hardwoods, especially oaks, growing from roots..... *G. curtisii*

3. Found predominately on pines with a distribution in the Gulf South..... *G. meredithiae*

4. Fruiting body yellow, spongy (not woody), large basidiospores (13–18 x 9–12µ)..... *Tomophagus colossus*

4. Not as above..... 5

5. Context tissue dark brown..... 6

5. Context tissue white to cream to light brown..... 8

6. Found predominately on palms, slender basidiospores (length/width?2)..... *G. zonatum*

6. Not as above..... 7

7. Mostly sessile, limited to South Florida, squatty basidiospores (length/width?1.3–1.5)..... *G. tuberculosum*

7. Typically centrally pseudostipitate with resinous bands present in the context tissue)..... *G. martinicense*

8. Context tissue nearly pure white, in temperate locales, mainly on *Tsuga* spp..... *G. tsugae*

8. Not as above..... 9

9. Pigmented chlamydospores in context tissue, limited to south Florida..... *G. weberianum*

9. No pigmented chlamydospores in context tissue, found in all states east of the Rockies..... *G. sessile*

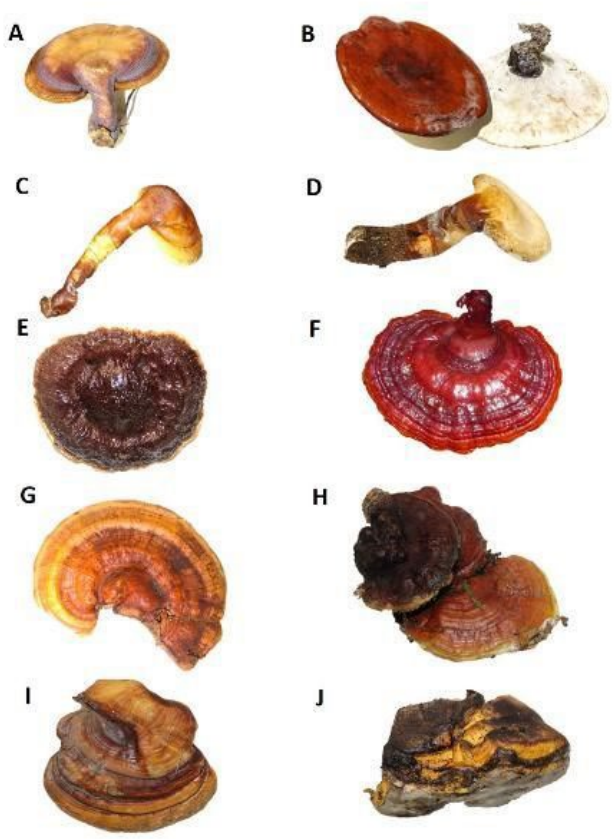


Figure 5. Representative fruiting bodies of *Ganoderma* species from the southeastern United States. Disclaimer: morphology of fruiting bodies can be highly variable within a species due to age, environment, and location. (A-J) These represent fruiting bodies of typical form from collections within the southeastern United States: A) *G. curtisii,* B) *G. martinicense* (top and bottom view), C) *G. meredithiae,* D) *G. ravenelii,* E) *G. sessile,* F) *G. tsugae,* G) *G. tuberculosum,* H) *G. weberianum,* I) *G. zonatum,* and J) *Tomophagus colossus*.
Credit: A) through E) Andrew Loyd, U F/IFAS; F) Robert Blanchette, University of Minnesota, Department of Plant Pathology; G) through J) Andrew Loyd, UF/IFAS

Management

With the exception of *G. zonatum,* a pathogenic species affecting virtually all palm species in the United States, *Ganoderma* species in the southeastern United States are mostly opportunistic pathogens that take advantage of stressed plants. Information on management for *G. zonatum* can be found in *Ganoderma Butt Rot of Palms*, https://ask.ifas.ufl.edu/publication/PP100 (Elliott and Broschat 2000). Drought-stressed plants and plants growing under suboptimal conditions in urban settings appear to be more susceptible to decay by *Ganoderma.*

Choosing the appropriate tree species that meets the expectations of maintenance inputs for a given landscape can be an effective management strategy to prevent and/or slow decay. For example, in low maintenance landscapes, such as median plantings along roadsides, utilizing relatively drought-tolerant plants can reduce the chances of pest problems such as decay fungi. Planting tree species that are chemically and physiologically tolerant to decay is another effective management tactic to avoid potential infections. Specific trees have different relative tolerance to fungal decay because of their chemical, morphological, and physiological characteristics (Scheffer and Cowling 1966; Scheffer and Morrell 1998). For example, black walnut and black locust are generally more tolerant to decay than cottonwoods and birches (Scheffer and Morrell 1998). Maintaining healthy trees by preventing wounding and providing proper fertilization, irrigation, mulching, and other plant health care tactics will improve the resiliency and resistance of trees to decay fungi.

When *Ganoderma* fruiting bodies are found in the landscape, a tree risk assessment, as outlined by the ISA Best Management Practice, should be performed to evaluate the level of hazard presented (Dunster et al. 2014). Fruiting bodies of *Ganoderma* can be found in trees with localized pockets of decay as well as trees that have extensive decay. Structure evaluations as basic as "sounding" the tree with a mallet or using a probe can estimate the extent of decay in a particular part of a tree. More advanced methods, such as using sonic and electrical resistance tomography, can also be used to quantify the area of decay within trees, relative to healthy wood. These types of approaches may help with management decisions, such as when to remove a tree because decay is extensive and the tree hazardous (Elliott et al. 2016).

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[1] This document is PP333, one of a series of the UF/IFAS Department of Plant Pathology. Original publication date January 2017. Visit the Ask IFAS website at https://ask.ifas.ufl.edu/ for the currently supported version of this publication.

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