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Rusts of *Acacia koa*: *Atelocauda digitata* (Gall Rust)

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Koa, *Acacia koa* Gray, the woody monarch of Hawaiian forests, hosts at least five distinct rust diseases. The name "rust" derives from the uniquely powdery texture and brownish to yellowish or orange coloration of fungal spore masses that appear on plants; in the case of koa, these are mainly brownish spore masses on diseased phyllodes, flowers, and fruits.

A general diagnosis of "koa rust" is readily determined by the presence of these distinctive and typical spore masses. To narrow the diagnosis to one of the specific rust diseases of *A. koa* requires an understanding of symptom expression and the fungal morphology of the pathogen.

One of the most widespread and important rust diseases of *A. koa* in Hawai'i and one of the most important of all diseases of *Acacia mangium* in Java, Sumatra, and Indonesia is caused by the rust fungus, *Atelocauda digitata*. This is one of the rare macrocyclic rust fungi in Hawai'i, meaning that it produces all five of the spore stages typical of macrocyclic rust fungi. *Atelocauda digitata* occurs on all major Hawaiian islands except Lāna'i.

The disease caused by *A. digitata* is known as gall rust or phyllode rust, and it can cause witches' broom on some *Acacia* species. The brooms are the result of the systemic infection of *A. koa* by the pathogen. This

A young witches' broom on a branch terminal of *Acacia koa* on Saddle Road on the island of Hawai'i in 2005, caused by the plant pathogenic rust fungus *Atelocauda digitata*. The brown coloration is due to the masses of erumpent rust spores emerging through the epidermis. The hypertrophic phyllodes are swollen, distorted, and twisted. The branch's growth pattern and elongation are abnormal. The fungus eventually will consume all of the plant's cells, killing the seasonal or new growth of the branch terminal, and will remain dormant inside the koa branch until the next flush of new growth or flowering occurs. (Photos are by S. Nelson, unless otherwise noted.)

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endophytic relationship causes hormonal changes in *A. koa* organs (phyllodes, flowers, fruits), which result in unusually swollen or galled tissues and abnormal branching and floral development.

Much of what we know about the koa rusts in Hawai'i stems from the careful research of Don Gardner and his colleagues. In the 1970's, '80s, and '90s, Gardner, working in Hawai'i, and his colleagues studied and classified the rusts. They found that the "koa rust" in Hawai'i was not caused by just one or two species but by several species, each unique, causing unique disease symptoms, and producing unique fungal life cycles.

This publication discusses one of the several important koa rusts in Hawai'i, a gall rust caused by *A. digitata*. It also describes how rusted koa organs attract fungal-feeding rust parasites, generating extraordinarily interesting micro-ecosystems on plant surfaces.

The pathogen, hosts, and infection

Atelocauda digitata, causing *Atelocauda* rust, gall rust, phyllode rust, *Acacia* rust, or koa rust, infects a wide range of *Acacia* species, including *A. koa, mangium, auriculiformis, aulococarpa, crasicarpa, leptocarpa, mearnsii,* and *polystacha*. *Atelocauda digitata* was first recorded from Australia by Berkeley and Broom (1881–1887). Reports indicate that *A. digitata* is a genetically variable fungal species.

The pathogen's scientific name is *Atelocauda digitata* (G. Winter) Cummins & Hiratsuka. However, based on a revision of the genus by Walker (2001), it has been renamed *Racospermyces digitatus* (G. Wint.) J. Walker comb. nov. By choice, that new name is not used in this publication. *A. digitata* is in the order Uredinales. It has also been known as *Uromyces digitatus* Winter and *U. phyllidiorum* (B. and Br.) McAlp. Pathogen dispersal to infect shoots, phyllodes, flowers, seedpods, and juvenile leaves is generally by wind. Although it infects seedpods and seeds, *A. digitata* is not regarded as seedborne, although the large number of spores produced on lesions and the capacity of the pathogen to infect flowers and fruits make contamination of seed lots a possibility.

On *A. mangium*, phyllode rust caused by *A. digitata* has potentially devastating effects in plantations in Java, Sumatra, and other parts of Indonesia. The pathogen can cause severe damage to foliage and young stems in nurseries and young plantations. Seeds pods may be heavily damaged and deformed. Severe infections result in foliar deformation, defoliation, reduced growth and stunting. On *A. mangium,* infected phyllodes, shoot tips, petioles, and even fruits may suffer gross malformation or have galls or blister-like swellings. *A. mangium* trees in young stands cam become severely infected. Young shoots may be malformed and branches may develop multiple stems. Severely infected plants are prone to premature defoliation. Where the disease occurs in *A. mangium* nurseries, the entire stock of plants may be infected and subject to being destroyed by the grower. The surface of older lesions may be colonized by fungal parasites (e.g., fungi, insects).

Atelocauda digitata in Hawai'i is a macrocyclic rust, with five distinct spores stages, all occurring on *A.koa*. Spermagonia and aecia of the koa rust pathogen, *A. digitata*, coincide with the seasonal initiation of flowering and shoot growth of *A. koa* in Hawai'i. This depends upon site elevation and may vary among years. The aeciospores appear on the witches' brooms in the several months after flowering and shoot growth begin.

Disease cycle

New cycles of disease probably occur every year on a given koa tree, and for the life of that tree. Yearly disease cycles always occur on fresh host growth. Infection and symptoms occur on the growth at the branch terminals (growth tips, phyllodes, flowers, seed pods). New cycles of disease derive from the systemic infection of branches; when new growth blooms the systemic infections become active and move into the young tissues, distorting them and sporulating upon them. Initial infections of new trees and/or branch terminals or phyllodes or juvenile leaves are most likely by windborne aeciospores or urediniospores.

Effects of this disease on *A. koa* plants

This rust disease is not fatal to koa trees. Severe symptoms (witches' brooms) are mainly confined to several or more branch terminals. Seedpods can be severely affected. The rust can destroy all seedpods on a given tree, and do so yearly. The disease symptoms can vary significantly among koa genotypes and locations.

Disease symptoms and signs

Witches' brooms and hypertrophy at branch terminals

The twisted, gnarled, swollen, deformed, spore-covered witches' brooms at the branch terminals is a diagnostic

Table 1. Spores types and generally associated symptoms for koa rust caused by *Atelocauda digitata* in Hawai'i.

Spore type	Where found on *A. koa*	Symptoms
Urediniospore	Scattered on normal phyllodes or juvenile leaves	Spots/pustules on phyllodes (uredinial-telial sori)
Teliospore	Scattered on normal phyllodes or juvenile leaves, often produced in same sorus as urediniospores	Spots/pustules on phyllodes (uredinial-telial sori)
Sporidia (basidiospores)	Scattered on normal phyllodes or juvenile leaves	Spots/pustules on phyllodes (uredinial-telial sori)
Aeciospore	Associated with hypertrophied tissues	Vary with host and location. Witches' brooms, galls, hypertrophy of shoots, flowers, seed pods and phyllodes
Spermatia	Associated with aecia on hypertrophied tissues	Vary with host and locations. Witches' brooms, galls, hypertrophy of shoots, flowers, seed pods and phyllodes


Left: Incipient witches' broom; stem and phyllodes are distorted; erumpent rust sporulation emerges through the epidermis. Right: Phyllodes are swollen and twisted, covered with rust pustules; stems are twisted, swollen and have unusual branching patterns.


Left: Phyllodes are swollen and twisted, covered with rust pustules; stems are twisted, swollen, and have unusual branching patterns. Right: Etiolated stems and reduced phyllodes occur in a witches' broom at a koa branch terminal.

Left: Compare and contrast normal koa flowers with a swollen, diseased inflorescence that has undergone hypertrophy of floral organs. Right: Incipient abnormal symptom in a flower of *A. koa,* caused by *Atelocauda digitata*.

symptom of gall rust of *A. koa* caused by the fungal plant pathogen *A. digitata*. Appearance of the brooms is annual-seasonal and coincides with flowering and fruit production.

The witches' brooms for this disease can grow approximately 15 cm tall. Witches' brooms do not appear on all types of *A. koa* that are infected by this pathogen. Brooms are covered with powdery brown spore masses that are easily rubbed off. From one to many brooms may occur on a tree.

The *A. digitata*-induced witches' brooms produce aeciospores and spermatia of the pathogen.

Floral hypertrophy

Koa flower organs may undergo hypertrophy. As the erumpent pathogen bursts through the epidermis with pustules full of powdery brown spores, the infected flowers resemble miniature witches' brooms.

The distortion and hypertorphy and abnormal expression of plant hormones in reproductive organs of the host exemplify the growth-altering effects that typify systemic rust diseases of plants.

Seed pods and fruits: galling and distortion

The rust can destroy the developing seeds by attacking the pods while still green. Pods are distorted, twisted, deformed, swollen or galled, with erumpent rust spores masses bursting though the galled tissues.

Powdery brown spore masses of the erumpent pathogen, *Atelocauda digitata*, burst through the epidermis of an *Acacia koa* inflorescence. The infected flower has undergone hypertrophy and resembles miniature witches' broom.

Disease management

Trimming off witches' brooms does not cure the plant of infections; the disease is systemic in branch terminals. However, trimming of witches' brooms can help to reduce the number of rust spores in the environment. In nurseries, preventive sprays of approved fungicides for rust control may protect young plants from infection, however this disease is probably not a problem for most

Atelocauda digitata can cause severe disease of *Acacia koa* seed pods in Hawai'i. Aeciospores are commonly found on these tissues.

A. koa nurseries in Hawai'i, unless the nursery is in or near a koa forest. However, the disease is reported to be very severe in *A. mangium* nurseries in some locations outside of Hawai'i. This could be due to local conditions or enhanced virulence in the rust populations. Do not outplant rusted acacias.

Protect young forest plantings of *Acacia* species by sanitation: removal of witches' brooms and diseased seed pods from nearby trees might help to delay disease development on newly planted, uninfected plants.

Avoid moving rusted plants to any other locations, especially areas where the disease is not reported to occur.

Acacia koa tree with most seed pods heavily rusted by *Atelocauda digitata*, from Saddle Road on the island of Hawai'i in 2005. There were few to no viable seeds produced by this tree.

The fungus *Tuberculina maxima* Rostrup, a hyperparasitic biological control agent for *Atelocauda digitata*

Advanced-stage rust brooms may have naturally occurring rust hyperparasites or fungal-feeding insects that consume the rust spores. In August, 2005 we noted insects and fungi as parasites and consumers of the koa rust spores (*A. digitata*).

Raised, sporulating pustules; the uredinial-telial sori that typically appear on rusted koa phyllodes infected by *Atelocauda digitata*

One of the habitats of *Atelocauda digitata* rust of *Acacia koa*, this is a small, high-elevation kipuka near Saddle Road on the island of Hawai'i near Pu'uhuluhulu and the Mauna Kea Observatory Road.

There can occur on the witches' brooms an unusual hyperparasite, the fungus *Tuberculina maxima,* a hyperparasite of *A. digitata*, the gall rust pathogen.

Tuberculina maxima is a brightly colored fungus, in shades of deep violet. Expanding colonies of *T. maxima* become established on lawns of rust spores on the brooms. As the colonies expand, they are fringed with their own whitish mycelium, lending the colonies a white-halo effect.

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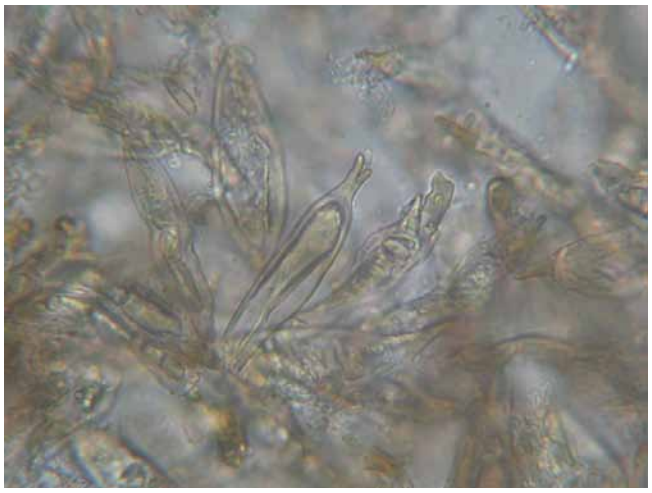
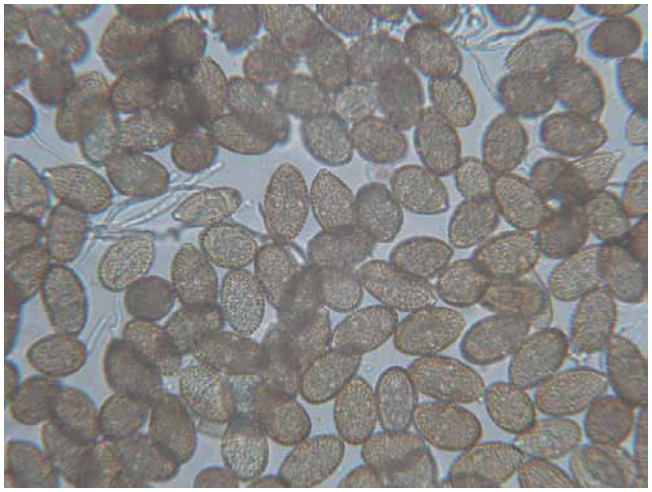
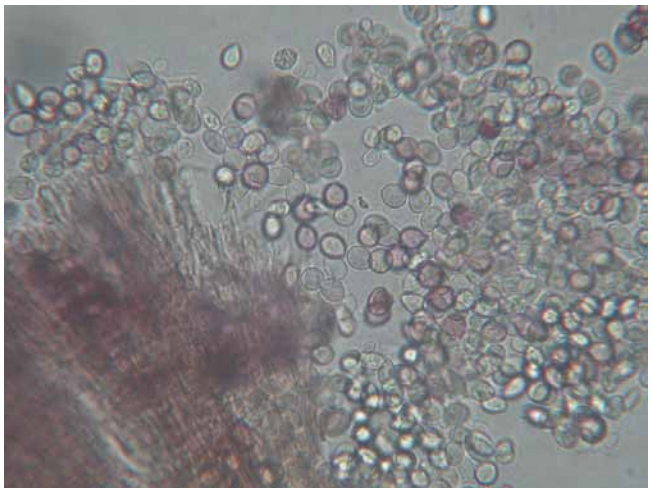


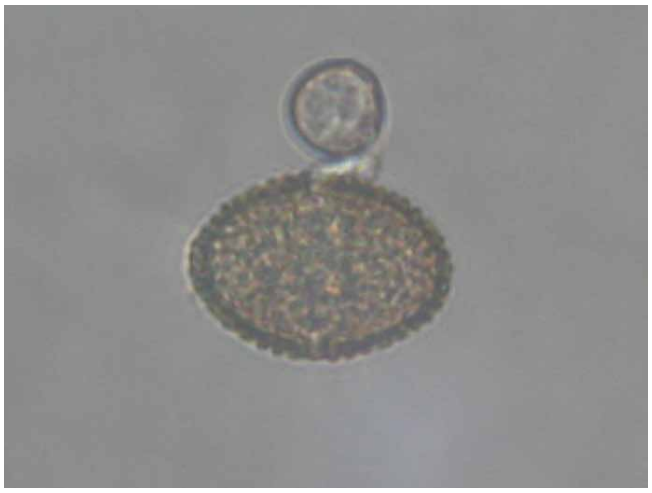
Teliospores of *Atelocauda digitata* (highly magnified) showing typical apical finger-like projections



Here, highly magnified, are mainly aeciospores of the gall rust pathogen, *Atelocauda digitata*, recovered from an aecial-spermagonial broom from a branch terminal of an infected *Acacia koa* tree.

Tuberculina maxima (purple areas and whitish rings) as a parasite of *Atelocauda digitata* on phyllodes of *Acacia koa*. The witches' brooms for this disease can grow approximately 15 cm tall.





Purplish *Tuberculina maxima* spores and brownish colored *Atelocauda digitata* aeciospores, scraped from the lawn of spores on a rusted koa phyllode. Right: A spore of *Tuberculina maxima* sends an attacking attachment tube-like appresorium to begin its parasitism of an aeciospore of *Atelocauda digitata*.

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Don Gardner sent correspondence regarding the rust disease and *Tuberculina maxima*; Pat Conant (HDOA) identified an insect that feeds on the aeciospores of *A. digitata* on the spermagonial-aecial witches' brooms; Brian Bushe (UH-CTAHR) assisted with microphotography; J. B. Friday (UH-CTAHR) provided a photograph; Fred Brooks (UH-CTAHR) provided review.

An old and majestic forest specimen of *Acacia koa* in Hawai'i
(Photo: J.B. Friday)