Abstract: The Botanical Research Institute of Texas campus grounds was the site where *Lysurus mokusin*, a colorful stinkhorn, was discovered on a mixture of bark and wood chip mulch. Heavy rains during August, 2018 resulted in the appearance of basidiomycete fungi in a single spot on mulch around a *Quercus fusiformis* tree. The developmental morphology of this stinkhorn was described and photographed from the immature egg stage, emerging stipe and cap stage, and mature fruit body stage with slimy foul-smelling spore mass, and insects attracted to the malodorous spores on the cap surface. Among the insects attracted to the stinkhorns were species of the families Calliphoridae and Sarcophagidae, true flies widely known for scavenging rotting animal carcasses as well as stinkhorns; putrivoric flies are considered a primary vector of stinkhorn spores.

Observations of the stinkhorn *Lysurus mokusin* (Phallales: Phallaceae), and other fungi found on the BRIT campus in Texas.

Bob O'Kennon[1], Harold W. Keller[1*], and Britt A. Bunyard[2]

[1]Botanical Research Institute of Texas, 1700 University Drive, Fort Worth, Texas 76107-3400; [2]PO Box 98, Batavia, Illinois 60510; [*]Corresponding author: haroldkeller@hotmail.com

Introduction

The Botanical Research Institute of Texas (BRIT) is located in the cultural district of Fort Worth on 7.5 acres. This landscape is dominated by many *Ulmus crassifolia* (cedar elm) trees, attractive white flowering shrubs such as *Spiraea cantoniensis*, and a multitude of showy flowering species, especially *Lupinus texensis* (Texas bluebonnet or lupine), the Texas state flower. Bluebonnets are annuals that appear from seed in early spring (March and April) displaying spectacular bright blue blooms at the

Figure 1. Squirrels appeared to avoid the stinkhorns but were observed eating other mushrooms (*Gymnopus* sp.) only a few inches from the stinkhorns.

Figure 2. Immature fruit bodies ("eggs") of *Lysurus mokusin*. These eggs measured 1.5 inches in length and 0.4 inch in diameter.

Figure 3. Longitudinal sections of *Lysurus mokusin* eggs from Fig. 2.

BRIT front entrance. Two prominent species of ivy cover the building walls, *Ficus pumila* (climbing fig) and *Parthenocissus quinquefolia* (Virginia creeper). A master list of 175 plant taxa includes *Asclepias tuberosa* (butterfly weed) as part of a pathway pollinator garden that attracts butterflies.

There are fungi and slime molds too. As one example, a rarely seen white crust fungus, *Dendrothele jacobi*, is home here. Recent tree plantings on the BRIT grounds have bark-wood chip mulch surrounding the tree base that serves as an ideal habitat for myxomycetes (*Fuligo septica*; Keller et al., 2017) and numerous fleshy fungi, including developmental stages of *Lysurus mokusin* (the ribbed lizard's claw or lantern stinkhorn) discussed herein. Mulch at this location was "chipper trash" from downed trees on the BRIT campus and Fort Worth Botanic Garden along with tree trimmings. Mulch was not purchased from an outside source and transported to BRIT. The mulch is very helpful in retaining moisture in this dry habitat. Water is further conserved through a series of bio-retention swales in the parking lot, a limestone prairie barrens is replicated on portions of a living rooftop, and a 3-acre mixed grass prairie is on the campus grounds.

Stinkhorns featured in FUNGI

Stinkhorns occupy a special place in fungal lexicon because of their spectacular beauty in shape and form that often attracts the attention of mushroom enthusiasts. The article by Ryan and Nelles in FUNGI (2018) captured the pictorial essence of striking bright colors displayed by this group of fungi in Queensland Australia. Graphic illustration of a "claw-like future cap" is represented by the genus *Lysurus*. Indeed, three species of *Lysurus* occur in Australia, *Lysurus cruciatus*, *L. gardneri*, and *L. mokusin.* The latter species was represented by a closeup photograph of the claw with an insect and photographs of a sectioned egg and mature fruit body with angled stipe.

Habit and geographical distribution

Lysurus mokusin was found growing on bark-wood chip mulch at the base of *Quercus fusiformis* (live oak tree), August 10, 2018, near the walkway leading to the side entrance of the BRIT building. The fruiting bodies were buried in the substrate and not directly on the wood fragments. The distinctive ribbed and angled shape of the stipe, color and shape of the cap, and overall appearance of this fungus made possible picture key identification accurately and reliable.

Lysurus mokusin occurs in parks, gardens, and lawns but often is associated with wood chip mulch. It was first described from China but also reported from South Korea, Japan, Canary Islands, and Italy. It is thought to have been introduced into North America on nursery stock from Asia. What properties of this species facilitate its growth in urban areas? This question appears answered in part by mulch or nursery stock entering from Asia through California then spreading throughout the USA. The pathogenic fungus *Cryphonectria parasitica* (cause of chestnut blight disease) had a similar pathway that destroyed America's giant chestnut trees in Great Smoky Mountains National Park (Keller and Barfield, 2017).

Most of the collections of this

mushroom in the U.S.A. come from California (Desjardin et al., 2015), indeed outside of California it is rarely seen and hardly known. A search of MycoPortal (188 observations) and iNaturalist (345 observations) resulted in the following urban centers and county locations. Multiple collections of this species were obtained in urban environments in the U.S.A. California: Alhambra (Los Angeles County); Bakersfield (Kern County); Burbank (Los Angeles County); Glendale (Los Angeles County); Hanford (Kings County); Chico (Butte County), Claremont (Los Angeles County); Kern (Kern County); Redlands (San Bernardino County); Santa Barbara (Santa Barbara County); Whittier (Los Angeles County); Iowa: Sioux City (Woodbury County); Kansas: Wichita (Sedgwick County), Topeka (Shawnee County); Maryland: Oxon Hill (Prince Georges County); Nebraska: Omaha (Douglas County); New York (Manhattan County); Oklahoma: Oklahoma City (Oklahoma County); Tennessee: Nashville (Davidson County); Texas: Dallas (Dallas County); Denton (Denton County); Houston (Harris

Figure 4. *Lysurus mokusin* fruit bodies beginning to emerge through mulch. Note the ruptured outer peridium and exposed gelatinous mass inside.

Figure 5. Fully mature fruit bodies have the angled stipe and furrowed cap usually with four reddish claws/arms fused and separated but still attached to the white stipe.

County); Fort Worth (Tarrant County); Washington D.C. (District of Columbia).

Immature stinkhorn "egg" stage

Immature fruit bodies ("eggs") represent the underground premature stinkhorn stage encased in a two-layered peridium with a firm white outer wall covering attached by conspicuous rhizomorphs to the mulch mixture (Fig. 2). Elongate eggs were clearly visible to the naked eye measuring about 1.5 inches in length and 0.4 inches in diameter. Longitudinal sections revealed the preformed stinkhorn with the lighter hollow stipe at the base nearest the rhizomorphs and the upper half represented by the fused claws (arms), bearing the future fertile gleba (Fig. 3). Growth and expansion of the internal contents ruptured the outer peridium exposing a gelatinous mass at the apex as the egg broke through the mulch (Fig. 4). Photographs were taken in the early morning hours. Supposedly the stinkhorn egg stage is edible but these "eggs" do not look very appetizing. Furthermore, other immature poisonous fungi buried in soil or mulch may also appear similar in external morphology perhaps creating confusion.

Mature stinkhorn stages

During the course of a morning and afternoon (6–10 hours) the stinkhorn reaches maturity. Fully mature fruit bodies have the angled stipe and furrowed cap usually with four reddish claws/arms fused and separated but still attached to the white stipe (Fig. 5). Portions of the white peridium from the egg still remain attached to the top of the fruit body and also as a peridium or sac at the base (Fig. 6). Development is asynchronous with some egg stages and mature fruit bodies in the same cluster. The angled and furrowed stipe varies from white to pinkish and continues upward into an angled, fluted cap with a sharp conical point (Fig. 7). Stipe dimensions vary from 1.5–2.5 inches in height and the overall height is 3.5–4.5 inches. This gives the cap a spire-like shape (Fig. 6). The spore mass forms in the furrows between the angles and varies from olive-brown when more immature to a more brownish black spore mass when fully mature (Fig. 7). The spore mass when mature has an offensive fetid smell comparable to "dog feces" and attracts flies (Fig. 8).

Stinkhorn spore dispersal

The Phallales are a widely dispersed group of macrofungi. Members of this order are usually recognized by their large fruit bodies referred to as stinkhorns, but some are sequestrate (truffle-like) and do not develop into a stalked mushroom. All or nearly all are considered to be saprotrophic, rotting debris in woodlands and urban areas (some are common on lawns and in woodchip mulch). Some species have even been moved around the world in wood chips and probably nursery stock as well.

The Phallales comprises six families, with the Phallaceae and Clathraceae the most well known in North America; Lysuraceae is less well known in North America but sightings of the nonnative *Lysurus mokusin* are on the increase. The other families within this order are the Protophallaceae, Claustulaceae, and Trappeaceae. For a review, see Trierveiler-Pereira, 2014.

Somewhere along their evolutionary history, members of the Phallales

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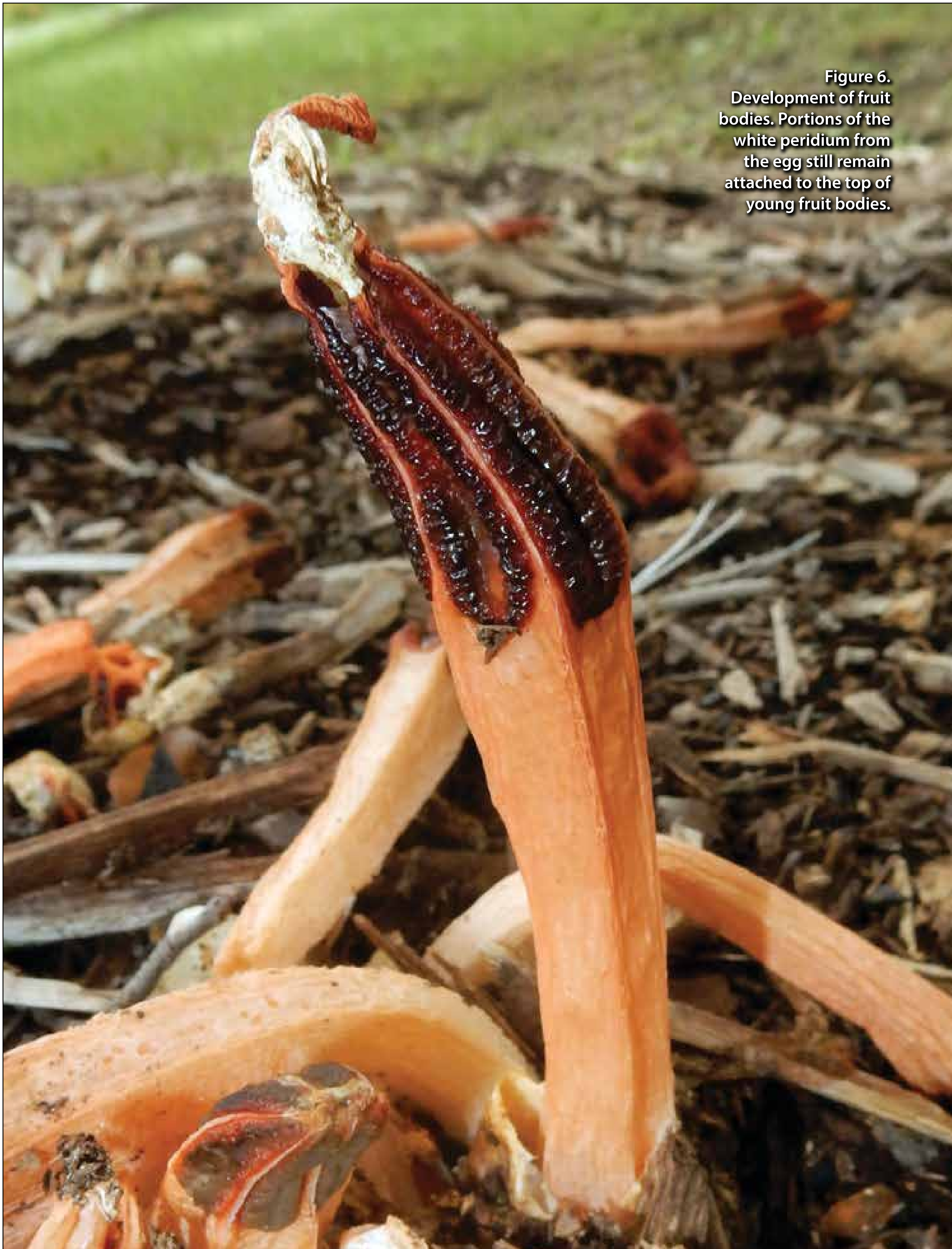

Figure 6. Development of fruit bodies. Portions of the white peridium from the egg still remain attached to the top of young fruit bodies.

Figure 7. Development of fruit bodies. Mature specimens among eggs; note the angled and furrowed stipe which is pinkish at maturity but soon fades to nearly white. Fluted cap terminates with a sharp conical point.

Continued from page 44.

lost their ability to forcibly discharge their spores, termed ballistospory, the common method of spore dispersal among basidiomycete fungi. A solution to this problem has been through the attraction of insects, especially scavenging and carrion-feeding flies (Webster and Weber, 2007). As the fruit body matures, a fertile gleba mass is produced and begins to give off strong sulfurous smells. Mature basidiospores are embedded in the liquid gleba mass. The smell attracts flies to the gleba which reportedly has a sweet taste; the flies feed voraciously on the gooey gleba and spore matrix. Typically the entire gleba mass is removed within a few hours. The ingested basidiospores are defecated by the flies elsewhere.

A number of studies have demonstrated that stinkhorn spores can pass unharmed through the gut of flies. For example, Tuno (1998) found that small flies like *Drosophila* spp. can have up to 240,000 spores from stinkhorns within their gut. Frequent visitors to stinkhorns, large carrion-feeding flies can hold up to 1.7 million spores. Tuno (1998) also showed that germination of stinkhorn spores was unaffected by passage through the gut of flies. Similar findings have been seen with mycophagous flies and other groups of basidiomycete fungi (Bruns, 1984; Bunyard and Foote, 1990; Tuno, 1999; Bunyard, 2003; Bunyard, 2007), as well as with other insects (Bunyard, 2015). Possibly the best known of the scavenging flies are the green bottle or blow flies, members of the family Calliphoridae. The common green bottle fly, *Lucilia (Phaenicia) sericata* was an abundant visitor of the stinkhorns (Figs. 8a, 8b). This species is well known to scavenge rotting debris, carrion, and feces. A very large (and large-bodied) group carrion-feeding flies is the family Sarcophagidae. Among its members is *Sarcophaga haemorrhoidalis*, a species well known to feed on carrion and stinkhorns and seen in our observations herein (Fig. 8c).

Other macrofungi co-observed with stinkhorns at BRIT

Species of birds nest fungi (*Crucibulum laeve* and *Cyathus striatus*) and a fleshy gilled mushroom, *Gymnopus* sp., also grew in the same mulch spot as the stinkhorn. Rainfall and cloudy weather in the Fort Worth area provided ideal conditions for the growth and development of fungi (2.99 inches for August and 55.97 inches for year). Saturated mulch with water and cloudy weather for several days combined with temperatures in the high seventies was unusual for August as well as record rainfall for the year 2018. Fox squirrels (*Sciurus niger*) live on the BRIT campus sometimes foraging on fungi especially mushrooms (Fig. 1). Squirrels appeared

Figure 8. Scavenging flies observed feeding on *Lysurus mokusin*. A) above & B) page 48 (top). Common green bottle fly, *Lucilia* (*Phaenicia*) *sericata* was an abundant visitor of the stinkhorns. C) page 48 (bottom), *Sarcophaga haemorrhoidalis*, a common carrion-feeding fly, was seen feeding on *Lysurus mokusin*.

Figure 8B.

Figure 8C.

to avoid the stinkhorns in all stages from the hypogeal eggs to the mature fruit bodies but were observed eating *Gymnopus dryophilus* only a few inches from the stinkhorns (Fig. 1).

Conclusions

This species of stinkhorn appears to have an urban distribution in familiar habitats such as yards in residential areas, gardens, and mulching around trees. This does not explain, however, the fungal morphology and genetic adaptations exhibited by these species that enable them to survive and thrive in urban habitats. More research is needed on urban fungi that addresses the question of why these fungi are found mostly in these habitats.

Acknowledgments

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