

Short Communication

Anatomical and physiological effects of *Gynaikothrips uzeli* Zimmerman (Thysanoptera: Phlaeothripidae) feeding on *Ficus benjamina* L. leaves

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Feeding by *Gynaikothrips uzeli* on *Ficus benjamina* causes extensive morphological changes (leaf curling and galling) to its leaves and reduced plant vigour. This in turn decreases the aesthetic horticultural appeal and economic value of the plant. In an effort to determine the extent of these changes, histological sections were made from mature healthy and galled leaves of *F. benjamina*. In addition, physiological parameters viz., leaf osmotic potential, stomatal conductance, chlorophyll content, leaf specific area and leaf dry matter content were assessed. Histological comparisons indicated that the lower epidermis, upper hypodermis, palisade and spongy mesophyll layers were significantly thinner in galled leaves than in healthy leaves. Additionally, stomatal density in galled leaves was approximately half that in healthy leaves. Leaf area and specific leaf area were significantly lower in infested leaves than in healthy leaves while osmotic potential was significantly more negative in infested than in healthy leaves. However, while levels of chlorophylls a and b decreased significantly in galled leaves compared to healthy leaves, the chlorophyll a/b ratio was not significantly different. The current study has identified several significant anatomical and physiological changes to leaves of *F. benjamina* infested with *G. uzeli*.

Keywords: *Gynaikothrips uzeli*, *Ficus benjamina*, anatomy, physiology

Thrips are minute, slender insects usually a few millimetres long with feather-like wings delicately fringed with long hairs. They have a worldwide distribution, with a preponderance of tropical followed by temperate species. Most thrips species are phytophagous, feeding on flowers, leaves and/or fruits and cause extensive yield loss in a range of commercially important crops (Lewis 1997; Cook et al. 2011).

Mound and Kibby (1998) state that members of the genus *Gynaikothrips* are mainly oriental and all induce leaf folding and galling. One species, the weeping fig thrips, *Gynaikothrips uzeli* Zimmerman (Thysanoptera: Phlaeothripidae), has recently been recorded in North, South and Central America and some Caribbean islands (Held et al. 2008; Cambero-Campos et al. 2010; Cavalleri et al. 2011) and continues to spread throughout the region. This species feeds almost exclusively on *Ficus benjamina* (Moraceae) and the latter is the only recorded species on which it can complete its life cycle (Cambero-

Campos et al. 2010). Feeding on *F. benjamina* leaves by *G. uzeli* causes galling and adaxial folding along the midrib. The folded leaves are then used as a secure habitat by *G. uzeli* which is thus protected from external environmental conditions, most predators, as well as insecticides used for its control. Severe infestations by *G. uzeli* can cause premature defoliation and stunted growth, however, it rarely causes mortality in *Ficus* spp. Damage to plant leaves by thrips can cause a reduction of chlorophyll content based on the method of feeding (Naik et al. 2000; Deligeorgidis et al. 2006; Gill et al. 2015) and this could further reduce photosynthetic efficiency (Boateng et al. 2014). Additionally, leaf damage by *Gynaikothrips* spp. reduces the aesthetic appeal of plants with the concomitant economic losses to the horticultural industry (Shogren and Paine 2016). The current study seeks to determine the effect of *G. uzeli* infestation on the leaf anatomy and physiology of *F. benjamina*.

Materials and methods

Plant material

Mature healthy and *G. uzeli* infected leaves showing galls were collected from a *F. benjamina* tree at The University of the West Indies, St. Augustine Campus, Trinidad.

Anatomical investigation

Leaf cross sections from 25 infected leaves, each of similar age, maturity and health were prepared according to Johansen (1940), the thicknesses of upper and lower epidermis, hypodermis, palisade and spongy mesophyll were measured and compared.

Physiological investigation

Stomatal density of the abaxial leaf surfaces of 10 leaves for each treatment was determined using epidermal impressions viewed with light microscopy (Olympus® 13x50 Research microscope with Pixera Penguin 600CL® imaging system). The leaf osmotic potential (Ψ_L) of the leaves was calculated using the standard protocol by Rosner and Kutta (2002) for measuring weight changes of tissues in varying osmotic solutions. Stomatal conductance of 10 healthy and 10 infected leaves was measured between 11:00 and 14:00 using a leaf porometer (SC-1, Decagon Devices Pulman WA, USA). The chlorophylls a and b contents were measured for 10 healthy and 10 infected leaves using the procedure developed by Arnon (1949). Line drawings of the 10 healthy and 10 infected leaves were photographed and uploaded to ImageJ software (<https://imagej.nih.gov/ij/>, National Institutes of Health, USA), to determine leaf area. Dry matter content was done according to Garnier et al. 2001. The specific leaf area was determined as the ratio of leaf area to dry weight, while leaf dry matter content was calculated as the ratio of dry leaf weight to fully saturated leaf weight.

Statistical analysis

Mean and standard errors of the mean were calculated for data on healthy and galled *F. benjamina* leaves. Means were compared by two-tailed t-tests to determine if there was significance ($P \leq 0.05$) between values using Minitab 18® statistical package.

Results

Analysis of the upper and lower epidermal layers of both healthy and *G. uzeli* infested leaves with galls indicated that the mean thickness of the lower epidermis of damaged leaves ($9.15 \pm 0.65\mu\text{m}$) was significantly less than that of healthy leaves ($13.06 \pm 0.91\mu\text{m}$) (Table 1). The difference between the mean thicknesses of upper epidermal layers of galled ($10.95 \pm 0.95\mu\text{m}$) and healthy leaves ($13.06 \pm 0.91\mu\text{m}$) was marginally significant ($P = 0.07$). However, in the case of the hypodermis, the mean thickness of the upper layer in galled leaves ($20.50 \pm 2.47\mu\text{m}$) was significantly less than that in healthy leaves ($44.72 \pm 1.84\mu\text{m}$) while there was no significant difference ($P = 0.77$) in thickness of lower galled ($26.20 \pm 2.06\mu\text{m}$) and healthy ($26.94 \pm 1.43\mu\text{m}$) hypodermal layers. The mean thicknesses of both palisade ($41.00 \pm 2.99\mu\text{m}$) and spongy ($66.13 \pm 6.51\mu\text{m}$) mesophyll layers of *G. uzeli* infested leaves with galls were significantly less than that of corresponding layers in healthy leaves (Table 1). The mesophyll of the galled leaves showed reduced air spaces due to hypertrophy (increase in cell size) and hyperplasia (increase in cell number) when compared to the healthy leaf (Figure 1). Mean stomatal density in thrips damaged leaves ($27.80 \pm 1.76/\text{mm}^2$) was approximately one half that of healthy leaves ($50.67 \pm 3.16/\text{mm}^2$) and was significantly different from each other. Mean stomatal length in thrips infested ($230.00 \pm 15.28\mu\text{m}$) and healthy ($275.00 \pm 15.37\mu\text{m}$) leaves were very nearly significantly different from each other (Table 1). Many stomata on the abaxial surface showed

structural changes viz., disruption of the subsidiary cells and abnormal distribution (Figure 2)

Leaf area, specific leaf area and leaf osmotic potential in *G. uzeli* galled leaves ($8.27 \pm 0.19\text{cm}^2$, $25.36 \pm 1.74\text{cm}^2/\text{g}$ and $-1.91 \pm 0.05\text{MPa}$ respectively) all decreased significantly from that of healthy leaves (Table 2). While mean levels of chlorophylls a and b decreased significantly in galled (5.77 ± 0.20 and $3.98 \pm 0.10\text{mg/g}$ tissue respectively) compared

to healthy (16.41 ± 0.14 and $11.03 \pm 0.15\text{mg/g}$ tissue respectively) leaves, the chlorophyll a/b ratio was not significantly different in damaged and healthy leaves (Table 2). Numerous stomata in *G. uzeli* infested leaves appeared to be damaged and without guard cells compared with undamaged leaves (Figure 1). Mean stomatal conductance in damaged leaves ($25.73 \pm 1.60 \text{mmol/m}^2/\text{s}$) was almost twice that of and significantly different from that of healthy leaves ($13.66 \pm 0.97 \text{mmol/m}^2/\text{s}$) (Table 2).

Table 1: Comparison of anatomical parameters in *Gynaikothrips uzeli* damaged and healthy *Ficus benjamina* leaves

Tissue	Healthy	Mean \pm SE Galled	t value	P
Epidermal thickness (μm)				
- Upper	13.17 ± 0.96	10.95 ± 0.95	$t_{16} = 1.96$	0.07
- Lower	13.06 ± 0.91	9.15 ± 0.65	$t_{17} = 3.56$	0.002
Hypodermal thickness (μm)				
- Upper	44.72 ± 1.84	20.50 ± 2.47	$t_{17} = 7.73$	<0.0001
- Lower	26.94 ± 1.43	26.20 ± 2.06	$t_{17} = 0.29$	0.77
Mesophyll thickness (μm)				
- Palisade	49.72 ± 2.44	41.00 ± 2.99	$t_{17} = 2.23$	0.04
- Spongy	106.94 ± 4.22	66.13 ± 6.51	$t_{17} = 5.13$	<0.0001
Stomatal density/ mm^2	50.67 ± 3.16	27.80 ± 1.76	$t_{17} = 6.50$	0.0001
Stomatal length (μm)	275.00 ± 15.37	230.00 ± 15.28	$t_{18} = 2.08$	0.05

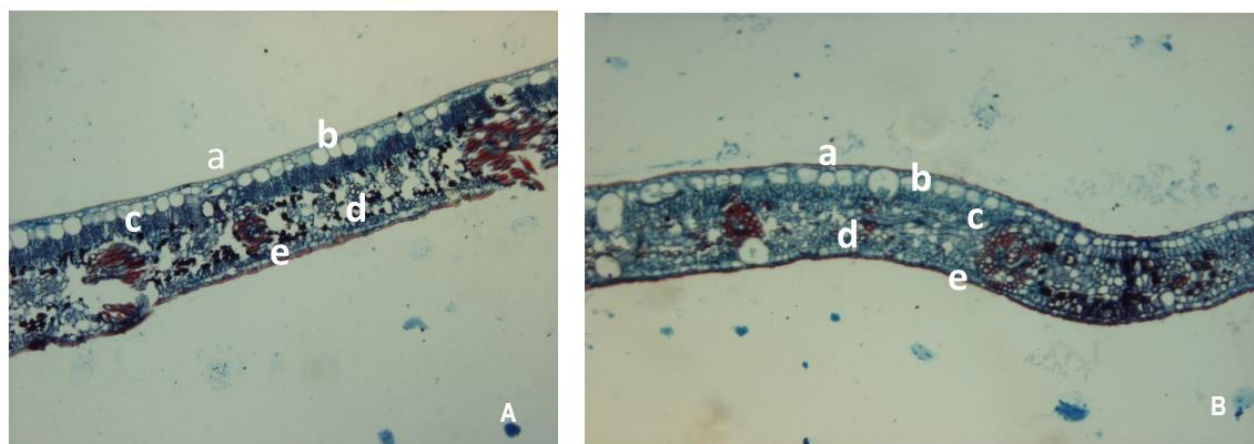


Figure 1: Cross sections of *F. benjamina* leaf (A) undamaged not affected by *G.uzeli* - large air spaces in mesophyll tissue (B) damaged by *G.uzeli* feeding – reduced air spaces due to hypertrophy and hyperplasia. Lower epidermis, upper hypodermis, palisade and spongy mesophyll layers of galled leaves were significantly thinner than healthy leaves. (a) upper epidermis (b) upper hypodermis (c) palisade mesophyll (d) spongy mesophyll (e) lower epidermis

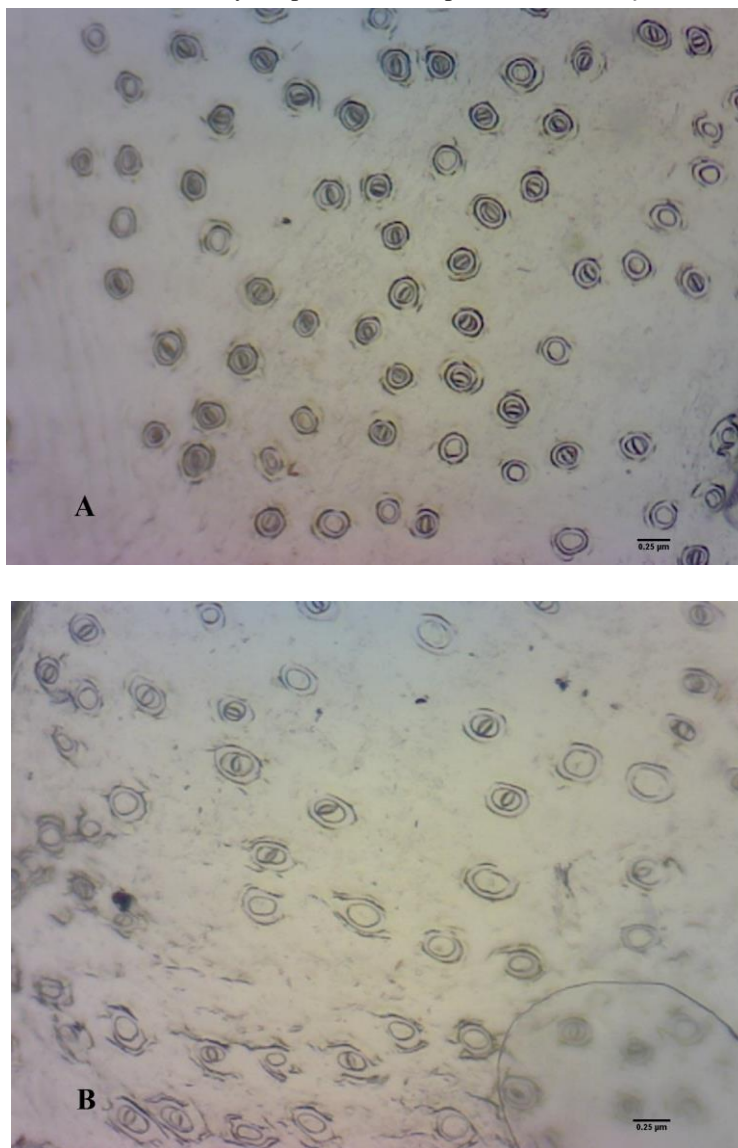


Figure 2: Stomata from *Gynaikothrips uzeli* healthy (A) and galled (B) *Ficus benjamina* leaves

Table 2: Comparison of physiological parameters in *Gynaikothrips uzeli* damaged and healthy *Ficus benjamina* leaves

Parameter	Mean \pm SE		t value	P
	Healthy	Galled		
Leaf area (cm ²)	10.38 \pm 0.20	8.27 \pm 0.19	t ₁₈ = 7.55	<0.0001
Leaf dry weight (g)	0.22 \pm 0.01	0.34 \pm 0.02	t ₁₈ = 4.74	0.0002
Leaf dry matter content (g/g)	0.31 \pm 0.01	0.53 \pm 0.02	t ₁₈ = 12.01	<0.0001
Specific leaf area (cm ² /g)	47.03 \pm 1.51	25.36 \pm 1.74	t ₁₈ = 9.39	<0.0001
Chlorophyll content (mg/g tissue)				
a	16.41 \pm 0.14	5.77 \pm 0.20	t ₁₈ = 43.49	<0.0001
b	11.03 \pm 0.15	3.98 \pm 0.10	t ₁₈ = 39.75	<0.0001
a/b ratio	1.49 \pm 0.01	1.46 \pm 0.07	t ₁₈ = 0.34	0.74
Stomatal conductance (mmol m ⁻² s ⁻¹)	13.66 \pm 0.97	25.73 \pm 1.60	t ₁₂ = 6.45	<0.0001
Leaf osmotic potential (MPa)	-0.98 \pm 0.01	-1.91 \pm 0.05	t ₈ = 17.10	<0.0001

Discussion

Studies have indicated that insect damage can have adverse effects on leaf and stem anatomy and morphology (Duncan 1973; Kitroongruang et al. 1991). Dai et al. (2009) noted that feeding damage to leaves of *Hypericum sampsonii* Hance (Hypericaceae) by *Thrips tabaci* (Lindeman) (Thysanoptera: Thripidae) resulted in changes in the proportion of spongy tissue thickness to the whole leaf thickness in addition to photosynthetic changes. Destruction and plasmolysis of mesophyll cells as well as collapse of epidermal cells as a result of feeding by *Limothrips cerealium* (Hal.) (Thysanoptera: Thripidae) have also been reported (Chisholm and Lewis 1984). Stafford et al. (2012) refer to thrips as cell rupture feeders, whereby they use their single, greatly reduced left mandible to breach the cell walls of plant tissue and subsequently imbibe the contents which ooze out. The empty cells die and this leads to the development of scar and corky tissues on *F. benjamina* leaves in the case of *G. uzeli* feeding. In the current study, the thicknesses of both spongy and palisade mesophyll layers in *G. uzeli* damaged *F. benjamina* leaves decreased significantly compared to that of healthy leaves and may be as a result of the feeding mechanism of thrips in general and *G. uzeli* in particular. Additionally, the hypoplasia and hypotrophy observed were also reported by de Souza et al. (2000) who observed disorganized mesophyll in the region of lateral veins due to cell hypertrophy and tissue hypoplasia in leaves of *Ficus microcarpa* L.f. infected with *G. ficorum*. Leaf dry weight and dry matter content both increased significantly in galled compared to healthy leaves. This was different from that observed by Mamun et al. (2016) who noted an increase in both parameters in red spider mite (*Tetranychus urticae* Koch) infested tea (*Camellia sinensis* L. Kuntze) leaves and may be as a result of increased amounts of necrotic tissue due to feeding by *G.*

uzeli. Cong et al. (2013) also note that chlorophyll content in *Phaseolus vulgaris* leaves decreased with increased feeding time and population density of *Frankliniella occidentalis*; additionally, there were significantly lower levels of chlorophylls a and b in infested compared to non-infested tea leaves, which was comparable to that of the current study. Naik et al. (2000) working in India on mulberry (*Morus alba*) leaves, compared the leaf constituents of healthy and thrips-damaged leaves of cultivars M5, MR2 and Mysore Local. It was found that the total chlorophyll content in all cultivars tested was significantly lower in thrips-damaged compared to the healthy leaves. However, thrips damage does not always result in lower chlorophyll content. Ellsworth et al. (1994) note that pear thrips, *Taeniothrips inconsequens* (Uzel) (Thysanoptera:Thripidae) damage to sugar maple (*Acer saccharum* Marsh) leaves did not cause a reduction in chlorophyll content.

Pearcy and Sims (1994) concluded that some types of stress can increase the chlorophyll a/b ratio while it may be reduced in other types of stress situations.

Damage to leaves by insects can cause a reduction in leaf area since their feeding habit can impact directly on the leaves or indirectly on reduction on fruit yield and the sugar content. McNally et al. (1985) reported a 20% reduction in leaf surface area of *G. uzeli* galled *F. benjamina* leaves compared to healthy leaves of similar age. *Frankliniella occidentalis* (Thysanoptera:Thripidae) damage to chrysanthemum (*Dendranthema x grandiflora*) also resulted in large reductions in leaf area to all the genotypes tested (Van Dijken et al. 1994).

The stomatal density of healthy leaves obtained in this study was similar to that of Klimko and Truchan (2006) on various *Ficus* spp. In their study, stomatal density of *F. benjamina* cultivars ranged between 45.20 – 101.70 mm². The stomatal density of healthy leaves in the current study was 50.67/mm² but

decreased significantly in galled leaves to 27.80 mm². Damaged and non-functioning abaxial stomatal guard cells may result in an increase in the rate of water loss, CO₂ uptake, stomatal conductance and a decrease in osmotic potential in these leaves. Altered stomata on the abaxial surface of *F. microcarpa* leaves of *G. ficorum* plants was also observed by de Souza et al. (2000). Relationships between stomatal conductance, stomatal density and leaf osmotic potential have been established for healthy (Ripullone et al. 2007; Buckley 2013; Kröber and Bruelheide 2014) and environmentally stressed plants (Garnier and Berger 1987; Gomes et al. 2004). In the current study, there was an almost 2-fold increase in stomatal conductance of damaged *F. benjamina* leaves compared with that in healthy leaves from 13.66 mmol m⁻² s⁻¹ to 25.73 mmol m⁻² s⁻¹. Stomata of *G. uzeli* infested leaves appeared damaged and without guard cells indicating that the stomata were constantly in the open position resulting in the much higher stomatal conductance. Prats et al. (2006) also found that barley leaves infected with the pathogen, *Blumeria graminis* f. sp. *hordei* caused guard cell death resulting in stomatal conductance increasing significantly compared with uninfected leaves.

Leaf osmotic potential can play a role in insect survival as Castane and Save (1993) found that the survival of eggs of *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae) was significantly decreased when they were exposed to high concentrations of mannitol solutions. They concluded that the leaf osmotic potential affected the survival of *T. vaporariorum*. Survival of *G. uzeli* eggs may thus be adversely affected by the lower leaf osmotic potential recorded on damaged leaves but, unlike *T. vaporariorum*, survival of *G. uzeli* eggs may be compensated for by folding of *F. benjamina* leaves along the midrib providing for an increase in relative humidity.

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