

# Effect of Leaf Removal on Shoot Decay of Various Cultivars of *Plumeria rubra* (Apocynaceae), Part II

DONALD R. HODEL, ELIZABETH MENDOZA, DIANA DONNELLAN,

MAX F. ROTHSCHILD, JOSUE CHINCHILLA-VARGAS, IRENE TRUONG,

FRANK NGUYEN, IGNACIO OLIVEROS, AND JAMES E. HENRICH

Because of their handsome, fragrant, and showy flowers, plumerias or frangipani are among the most highly esteemed shrubs and small trees in tropical and subtropical regions of the world. They have an ardent, world-wide following of collectors and growers who breed, select, propagate, and cultivate these handsome plants for landscape and personal adornment.

A horticultural practice among some plumeria growers and collectors is to defoliate the plants in late fall or winter, manually removing and disposing of the leaves. This practice is done for a variety of reasons, including to help control some diseases, like foliar rust, and overwintering pests, such as leafhopper (Hodel et al. 2017), to reduce wind loads and subsequent blow over of plants during windy times of the year, and/or to prepare plants for indoor storage in cold-winter areas. While horticultural sanitary practices include leaf removal and disposal for general disease and pest management, specific information supporting this practice on plumerias is lacking. The act of removing leaves from the shoots (stems) before they are naturally ready to senesce and drop can create wounds, especially on semi-succulent plumeria shoots, which could facilitate pathogen entry and cause shoot decay.

Indeed, many plumerias in the “Grove” at the Los Angeles County Arboretum and Botanic Garden in Arcadia, California, about 20 km northeast of Los Angeles, which is one of the largest public collections of plumerias in the United States, typically suffer from various shoot decays in late winter and spring. In fact, removal of decaying shoots in the spring to prevent even more damage later in the summer is one of the most critical, annual practices in the Grove. Because winter leaf removal on plumerias is often practiced among growers and collectors, we devised a two-part study to determine what impact, if any, this practice has on the development of shoot decay.

In Part 1 of this study (Hodel et al. 2023), we identified three cultivars of *Plumeria rubra*, ‘Hollywood Pink’, ‘Nebel’s Rainbow’ No. 1, and ‘Pink Cloud’ at the Grove that had a tendency for shoot decay when leaves were removed prior to normal senescence. Here, in Part 2, we report on a more in-depth and detailed study of the effects of leaf removal on shoot decay of two of these cultivars, ‘Hollywood Pink’ and ‘Nebel’s Rainbow’ No. 1. We excluded ‘Pink Cloud’, from



1. The plant of *Plumeria rubra* 'Hollywood Pink' used in this study retained some leaves through the winter and into the spring.



2. The plant of *Plumeria rubra* 'Nebel's Rainbow' No. 1 used in this study retained many leaves through the winter and into the spring.

the Part 2 of the study because the plant was so tall that shoot treatments and data collection would have necessitated a ladder and been exceedingly difficult if not dangerous, but we suspect that it might respond similarly as ‘Hollywood Pink’ and ‘Nebel’s Rainbow’ to leaf removal.

## Materials and Methods

In Part 1 of this study, Hodel et al. (2023) reported on the location, climate, soil, and other environmental parameters and cultivation of plumerias in the Grove on Tallac Knoll at The Los Angeles County Arboretum and Botanic Garden in Arcadia, which includes the two cultivars in part two of this study, ‘Hollywood Pink’ (20100337\*1) and ‘Nebel’s Rainbow’ No. 1. (20110307\*1) (As a point of clarification, the “No. 1” is not part of the official name of this cultivar; we added it simply to distinguish it from a second ‘Nebel’s Rainbow’ in part one of this study.). These two cultivars were part of a group of 15 cultivars that we mostly randomly selected for Part 1 of this study; however, these two were included in Part 1 intentionally because they had a history of shoot decay and tendency naturally to retain their leaves through the winter into spring.

We were unable to use multiple plants of these two cultivars in this study because the collection had only one plant of ‘Hollywood Pink’ and two plants of ‘Nebel’s Rainbow’, one of the latter of which, No. 2, was considerably smaller than No. 1 and had an insufficient quantity of shoots for the study. The two plants used in part two of this study are similar in habit and condition to plants of these two cultivars in other collections in Southern California.

The plant of ‘Hollywood Pink’ had a trunk of 21.0 cm diameter at 15 cm above the ground, was 3.7 m tall, and had a north-south × east-west canopy spread of 5.5 × 4.8 m (**Fig. 1**). The plant of ‘Nebel’s Rainbow’ No. 1 had a trunk of 13 cm diameter at 15 cm above the ground, was 3.7 m tall, and had a north-south × east-west canopy spread of 4.0 × 3.5 m (**Fig. 2**).

In December, 2022, on each plant of ‘Hollywood Pink’ and ‘Nebel’s Rainbow’ No. 1, we randomly selected, tagged, and marked 30 shoots (60 shoots total across the two cultivars), and measured overall shoot length (comprising several years of growth), shoot length and diameter for 2022 (shoot length and diameter produced in 2022 only), and quantity of leaves per shoot. On each cultivar, we randomly stripped the leaves from 10 shoots, cut off the leaves from 10 shoots with hand clippers, and left the leaves on of the remaining 10 shoots as Hodel et al. (2023) described and illustrated. In the latter treatment, the control where the leaves were not removed, many if not most leaves did senesce, abscise, and fall off naturally over the course of the study although some leaves did not fall off and were present at the end of the study in late May, 2023. At the end of the study, we recorded occurrence and extent of decay on the selected shoots and occurrence of black leaf scar, the latter of which might be a precursor of shoot decay.





**3.** Shoot tip decay initially occurs at the shoot tip and typically works proximally down the shoot over time. 'Hollywood Pink', leaves stripped.



**4.** Very early stage of black tip. 'Nebel's Rainbow' No. 1, leaves cut off. Note the new growth just proximal of the decayed tip.



5. Black tip on 'Nebel's Rainbow' No. 1 in 2022. Note the new growth just proximal of the decayed tip.



6. A shoot with black tip from Nebel's Rainbow No. 1 in 2022 sliced longitudinally to show the extent of decay.





7. Lateral decay typically initiates on the side of a shoot between the tip and base. 'Hollywood Pink', leaves stripped. Note the black leaf scars that might have been a precursor to decay.



8. Closer view of lateral decay of 'Nebel's Rainbow' No. 1 in Figure 7.

We also classified the decayed shoots into three categories as Hodel et al. (2023) described and illustrated: 1) shoot tip; 2) black tip; and 3) lateral:

1. As the name suggests, shoot tip decay initially occurs at the shoot tip and typically works proximally down the shoot over time, often decaying the entire shoot, which can be to 50 cm long or more; in such cases, it typically stops when it reaches the origin of the shoot (**Fig. 3**).

2. In contrast, black tip decay, also on the shoot tip, appears to move very little proximally down the stem, only a few cm, and new growth typically appears proximally of it rather early in the growing season (**Figs. 4–5**). Black tip decay typically occurs later in the spring, just as new leaves are beginning to push out (**Fig. 6**), than do shoot tip decay and lateral decay. Some cultivars, like ‘Nebel’s Rainbow’, seem especially susceptible to it. In its early stages at least, black tip decay initially has rather distinctive symptoms: the shoot tip, while black as in other decays, mostly retains its natural shape and does not shrivel or become deformed significantly and remains “full,” smooth, solid, and glossy. Later, affected shoots do tend to shrivel and become deformed as the decays progresses and or ages.

3. Lateral decay initiates well proximally of the shoot tip, leaving the tip initially healthy, and typically works distally up and proximally down the shoot, in some cases, destroying the entire shoot to its origin (**Figs. 7–8**).

In our data analyses, though, we did not distinguish the type of decay; we classified it all as simply “shoot decay.” Representative samples of decayed shoots were analyzed to determine which pathogens, if any, were present.

We determined means, medians, and standard deviations of overall shoot length, 2022 shoot length and diameter, and quantity of leaves, occurrence of black leaf scar (**Figs. 9–10**), and occurrence and extent of shoot decay, if any. We performed statistical analyses using the R base package (R Core Team, 2021) and the CAR package (Fox and Weisberg 2019). We used regression analysis to determine which variables such as shoot length and diameter and quantity of leaves that might predict shoot decay and/or black leaf scar. We compared the two cultivars and three leaf removal treatments using ANOVA and estimating mean differences that were significant ( $P < 0.05$ ) or close to significant ( $P < 0.10$ ) ( $P$  value is the probability of the measured effect occurring by chance). Waypoint Analytical, Anaheim, CA, identified potential pathogens.

## Results and Discussion

In **Table 1**, we report means, medians, and standard deviations for overall shoot length, 2022 shoot length and diameter, and quantity of leaves per shoot in December, 2022, and quantity of occurrences of decay per shoot, extent of decay per shoot (cm), and occurrence of black leaf scar per shoot in May, 2023, of ‘Hollywood Pink’ and ‘Nebel’s Rainbow’ No. 1.



**9.** Black leaf scar, which might be a precursor to decay. 'Nebel's Rainbow' No. 1, leaves stripped.



**10.** Healthy leaf scars. 'Hollywood Pink', no leaf removal. Leaves were allowed to fall off naturally.



**Table 1. Means, medians, and standard deviations of overall shoot length (cm), shoot length produced in 2022 (cm), shoot diameter in 2022 (cm), and quantity of leaves per shoot (December 2022), and quantity of occurrences of decay per shoot, extent of decay per shoot (cm), and occurrence of black leaf scar per shoot on 30 shoots each of *Plumeria rubra* ‘Hollywood Pink’ and *P. rubra* ‘Nebel’s Rainbow’ No. 1 (May, 2023), at the Los Angeles County Arboretum and Botanic Garden, Arcadia, California.**

Cultivar	Overall shoot length.	Shoot length 2022.	Shoot diam.	Quantity of leaves per shoot.	Occurrence of shoot decay.	Extent of shoot decay.	Occurrence of black leaf scar.
<b>‘Hollywood Pink’</b>							
mean	37.3	15.1	2.3	18.6	0.3	10.4	0.1
median	37.0	14.0	2.4	19.0	0.0	0.0	0.0
std. dev.	10.2	6.7	0.3	4.8	0.5	17.5	0.4
<b>‘Nebel’s Rainbow’ #1</b>							
mean	28.9	10.7	2.2	9.8	0.1	0.7	0.3
median	27.0	10.0	2.2	8.7	0.0	0.0	0.0
std. dev.	11.0	5.9	0.3	3.8	0.3	2.7	0.5

‘Hollywood Pink’ appeared to be a more vigorous grower than ‘Nebel’s Rainbow’, tending to have longer mean overall shoot length (37.3 vs. 28.9 cm), longer mean 2022 shoot length (15.1 vs. 10.7 cm), larger mean shoot diameter (2.3 vs. 2.2 cm), and greater mean quantity of leaves per shoot (18.6 vs. 9.8).

‘Hollywood Pink’ tended to have more mean occurrences (0.3 vs. 0.1) and mean extent of shoot decay (10.4 vs. 0.7 cm) than ‘Nebel’s Rainbow’ but had fewer mean occurrences of black leaf scar than ‘Nebel’s Rainbow’ (0.1 vs. 0.3) (**Table 1**).

### Occurrence and Extent of Decay by Cultivar and Treatment

Both ‘Hollywood Pink’ and ‘Nebel’s Rainbow’ No. 1 had the most occurrences and most extensive shoot decay when subjected to one or the other of the two leaf removal treatments. Hollywood Pink’ had nine shoots with decay, five on shoots where leaves were stripped off, three on shoots where leaves had been cut off, but only one on a shoot where leaves had not been removed (**Table 2**). Thus, in ‘Hollywood Pink’, 50% of shoots with stripped leaves had decay, 30% of shoots with cut-off leaves had decay, and 10% of shoots with no removal had decay. Of the nine shoots with decay, six were shoot tip decay and three were lateral decay, the latter of which only occurred on shoots where leaves had been removed. Black tip was not observed. Total extent of decay (and mean extent per occurrence) was 176 cm (35.2 cm) for shoots with stripped leaves, 81 cm (27.0 cm) for shoots with cut-off leaves, and 56 cm (56 cm) for shoots with no leaf removal.

‘Nebel’s Rainbow’ No. 1 had three shoots with decay, one on a shoot where leaves had been stripped off and two on shoots where leaves had been cut off (**Table 2**). Thus, in ‘Nebel’s Rainbow’ No. 1, 10% of shoots with stripped leaves had decay, 20% of shoots with cut-off leaves had decay, and 0% of shoots with no removal had decay. Of the three shoots with decay, two were shoot tip decay and one was black tip, the latter of which occurred on a shoot where leaves had been cut off. Total extent of decay (and mean extent per occurrence) was 7 cm (7 cm) for shoots with stripped leaves, 15 cm (7.5 cm) for shoots with cut-off leaves, and 0 cm (0 cm) for shoots with no leaf removal.

**Table 2. Occurrence of decay (and percent of treatment) and total extent of decay (and mean extent per occurrence) (cm) of three leaf removal treatments of *Plumeria rubra* ‘Hollywood Pink’ and *P. rubra* ‘Nebel’s Rainbow’ No. 1 (10 shoots per treatment per cultivar) at the Los Angeles County Arboretum and Botanic Garden, Arcadia, California, May 2023.**

Leaf treatment.	‘Hollywood Pink’		‘Nebel’s Rainbow’ No. 1	
	Shoots with decay (and percent of treatment).	Total extent of decay (and mean extent per occurrence).	Shoots with decay (and percent of treatment).	Total extent of decay (and mean extent per occurrence).
<b>Stripped.</b>	5 (50%)	176 (35.2)	1 (10%)	7 (7.0)
<b>Cut off.</b>	3 (30%)	81 (27.0)	2 (20%)	15 (7.5)
<b>No removal.</b>	1 (10%)	56 (56.0)	0 (0%)	0 (0.0)

In summary, in these two cultivars, 20 shoots stripped of leaves had four with shoot tip decay and two with lateral decay; 20 shoots with the leaves cut off had three with shoot tip decay, one with lateral decay, and one with black tip; and 20 shoots with the leaves not removed had only one with shoot tip decay.

### Occurrence of Black Leaf Scar

Like shoot decay, black leaf scar was more common on shoots subjected to leaf removal than on shoots where leaves were not removed. In ‘Hollywood Rainbow’, black leaf scar occurred four times, one on shoots with stripped leaves and three on shoots with cut off leaves, while in ‘Nebel’s Rainbow’, it occurred nine times, seven on shoots with stripped leaves and two on shoots with cut off leaves. In both cultivars black leaf scar did not occur on shoots where the leaves were retained.

### Occurrence of Black Tip

That black tip was observed on only one shoot of ‘Nebel’s Rainbow’ No. 1 is remarkable because this cultivar is generally acknowledged as unusually susceptible to this category of shoot decay and in May, 2022 numerous shoots exhibited black tip (Hodel et al. 2023). Why nearly no black



tip occurred this year is intriguing and might be related to weather conditions, specifically temperature. In the Grove, a few nights of freezing temperatures occurred in the winter of 2021–2022 and, while the winter of 2022–2023 was unusually cool (and wet), freezing temperatures did not occur but near-freezing temperatures did occur. Thus, black tip might be caused by freezing or near freezing temperatures. Miller et al. (2007) noted six-spotted spider mites caused damage that appears similar to or the same as black tip on plumeria but we detected no mites or observed the minute but distinctive craters noted to occur with mite-caused black tip (see the web version of Miller et al. 2007) on our shoots with black tip in 2022. More than one factor might be responsible for black tip and further research is needed on this subject.

### Plant Characteristics That Can Predict Shoot Decay and Black Leaf Scar

Of the four variables, overall shoot length, 2022 shoot length, shoot diameter, and quantity of leaves per shoot, only shoot length tended to be a predictor of shoot decay and black leaf scar (**Table 3**). In ‘Hollywood Pink’, longer overall shoot length and longer 2022 shoot length tended to lead to more decay ( $P < 0.10$ ). In ‘Nebel’s Rainbow’ only longer 2022 shoot length tended to lead to more extensive decay and black leaf scar ( $P < 0.10$ ). However, that longer shoots tended to have more extensive decay might simple be an artifact of the nature of decay progression in plumeria shoots, where decay typically moves proximally and only tends to stop at the origin of that shoot. Thus, longer shoots would typically display more extensive decay.

**Table 3. Variable and predicted effect on *Plumeria rubra* ‘Hollywood Pink’ and *P. rubra* ‘Nebel’s Rainbow’ No. 1, at the Los Angeles County Arboretum and Botanic Garden, Arcadia, California, May, 2023.**

Cultivar.	Variable.	Effect.	P Value.
‘Hollywood Pink’	Overall shoot length.	Shoot decay.	0.06
	2022 shoot length.	Shoot decay.	0.10
‘Nebel’s Rainbow’ No. 1	2022 shoot length.	Shoot decay.	0.07
	2022 shoot length.	Black leaf scar.	0.07

### Comparison of ‘Hollywood Pink’ and ‘Nebel’s Rainbow’ for Shoot Decay and Black Leaf Scar

Across both cultivars, mean extent of shoot decay in ‘Hollywood Pink’ was significantly greater than that in ‘Nebel’s Rainbow’ (10.4 vs. 0.7 cm,  $P < 0.05$ ) (**Table 4**). For occurrence of black leaf scar, ‘Nebel’s Rainbow’ had significantly more occurrences than ‘Hollywood Pink’ (0.3 vs. 0.1,  $P < 0.05$ ).

**Table 4. Comparison of *Plumeria rubra* ‘Hollywood Pink’ and *P. rubra* ‘Nebel’s Rainbow’ No. 1 for mean extent of shoot decay (cm) and mean occurrences of black leaf scar at the Los Angeles County Arboretum and Botanic Garden, Arcadia, California, May, 2023.**

	‘Hollywood Pink’	Nebel’s Rainbow’	P value.
Shoot decay.	10.4	0.7	0.003
Black leaf scar.	0.1	0.3	0.003

### Significance of Leaf Removal Treatments

Overall, across both cultivars, treatment differences were nearly significant for shoot decay, with stripping of leaves having the largest mean extent of shoot decay followed by cutting off leaves and not removing leaves (9.2 vs. 4.7 vs. 2.8 cm, respectively,  $P < 0.1$ ). (Table 5). Treatments had no significant effect on occurrence of black leaf scar.

**Table 5. Treatment effect of stripping leaves, cutting off leaves, and no leaf removal on mean extent of shoot decay (cm) on *Plumeria rubra* ‘Hollywood Pink’ and *P. rubra* ‘Nebel’s Rainbow’ No. 1 at the Los Angeles County Arboretum and Botanic Garden, Arcadia, California, May, 2023.**

Stripping leaves.	Cutting off leaves.	No leaf removal.	P value.
9.2	4.7	2.8	0.08

### Significance of Leaf Removal Treatments on ‘Hollywood Pink’

Because ‘Hollywood Pink’ had significantly more extent of shoot decay than ‘Nebel’s Rainbow’ and treatments were nearly significant, we looked more closely at treatment effects on ‘Hollywood Pink’. Although overall treatments were still not significant, stripping leaves had greater mean extent of decay than cutting off leaves or not removing leaves (17.6 vs. 8.1 vs. 5.6 cm, respectively, Table 5). However, mean extent of shoot decay on stripped leaves was significantly greater than not removing leaves ( $P < 0.05$ ). Treatment had no effect on occurrence of black leaf scar on ‘Hollywood Pink’.

**Table 6. Effect of stripping leaves, cutting off leaves, and no leaf removal on mean extent of shoot decay (cm) on *Plumeria rubra* ‘Hollywood Pink’ at the Los Angeles County Arboretum and Botanic Garden, Arcadia, California, May, 2023.**

Stripping leaves.	Cutting off leaves.	No leaf removal.	P value.
17.6	8.1	5.6	0.3

That our data strongly suggest stripping leaves prior to natural senescence can lead to increased decay on plumeria shoots is not surprising. In the natural abscission process, a protective layer composed of cork cells typically forms prior to or just after leaf senescence (Addicott 1982).





**11.** Potential fungal pathogens *Glomerella* sp. and *Pestalotiopsis* sp., 'Hollywood Pink', leaves stripped.



**12.** Potential fungal pathogens *Glomerella* sp. and *Pestalotiopsis* sp. and bacterial pathogen *Pectobacterium carotovorum*, 'Hollywood Pink', leaves stripped.



**13.** Potential fungal pathogens *Glomerella* sp. and *Phomopsis* sp. and bacterial pathogen *Pectobacterium carotovorum*, ‘Hollywood Pink’, leaves stripped.



**14.** Potential fungal pathogen *Dothiorella* sp., ‘Hollywood Pink’, leaves cut off.



Adjacent parenchyma cells on either side of the cork layer produce and inject suberin and lignin into the cork tissue, creating a durable, waterproof, and even more protective layer (Kozlowski 1973). This protective layer covers over the abscission wound, helping to exclude decay-causing pathogens and pests. If the leaf is stripped off the shoot, wounds can compromise the formation of the protective layer, leaving the wound and unprotected abscission zone open to pathogens and pests.

### Potential Pathogens

**Table 7** summarizes the potential pathogens that lab analyses isolated from samples of shoot decay. These included the fungi *Dothiorella* sp., *Glomerella* sp., and *Pestalotiopsis* sp. on ‘Hollywood Pink’ (**Figs. 11–14**) and *Alternaria* sp., *Botrytis cinerea*, and *Dothiorella* sp. on ‘Nebel’s Rainbow’ No. 1 (**Figs. 15–16**). Also, a soft, mushy, and foul-smelling decay, often associated with bacterial pathogens, was detected on two samples, one each of ‘Hollywood Pink’ (**Figs. 12–13**) and ‘Nebel’s Rainbow’ (**Fig. 16**), and the bacterium *Pectobacterium carotovorum* (formerly *Erwinia carotovora*) was isolated from these; maggots were present on the sample of ‘Nebel’s Rainbow’ No. 1. We did not perform Koch’s Postulates to confirm that these potential pathogens were causing the decay.

**Table 7. Lab analyses for potential pathogens of *Plumeria rubra* ‘Hollywood Pink’ and *P. rubra* ‘Nebel’s Rainbow’ No. 1 at the Los Angeles County Arboretum and Botanic Garden, Arcadia, California, May 2023.**

Cultivar.	Leaf removal treatment.	Rep. No.	Type of Decay.	Potential pathogen.
‘Hollywood Pink’	Stripped.	1	Tip.	Fungi: <i>Glomerella</i> sp., <i>Pestalotiopsis</i> sp. Bacterium: <i>Pectobacterium carotovorum</i> .
	Cut.	3	Lateral.	Fungi: <i>Glomerella</i> sp., <i>Phomopsis</i> sp.
	Cut.	6	Tip.	Fungus: <i>Dothiorella</i> sp.
‘Nebel’s Rainbow’ #1	Stripped.	4	Tip.	<i>Alternaria</i> sp.
	Cut.	5	Tip.	Fungus: <i>Botrytis cinerea</i> . Bacterium: <i>Pectobacterium carotovorum</i> ; maggots present.
	Cut.	6	Black tip.	Fungus: <i>Dothiorella</i> sp.



**15.** Potential fungal pathogen *Alternaria* sp., ‘Nebel’s Rainbow’ No. 1., leaves stripped.



**16.** Potential fungal pathogen *Botrytis cinerea* and bacterial pathogen *Pectobacterium carotovorum*, ‘Nebel’s Rainbow’ No. 1., leaves cut off.

## Conclusions

Although leaf removal treatment effects were variable, ranging from insignificant to weakly to strongly significant, a trendline suggests that the practice of leaf removal, especially stripping off leaves, might be responsible for more shoot decay than simply allowing the leaves to remain on the shoot until they fall away naturally. Removal of leaves prematurely, either by cutting or especially stripping them off, can cause wounds on the shoots, which can facilitate entry of decay-causing primary and secondary pathogens.

If leaf removal is implemented, leaves should be cut off, not stripped, and removal should be done in early fall to allow petiole scars to cover over prior to the onset of cool, wet weather, the latter of which can enhance pathogen entry and decay initiation and development. For cultivars that tend to retain leaves naturally through the winter, consider leaf removal in spring before new growth emerges and when warmer, drier conditions prevail, which can reduce pathogen entry and decay initiation and development. Also, avoid wounding of any kind when performing horticultural tasks on plumerias because their semi-succulent shoots are especially fragile and susceptible to bruising, sun burn, and other wounding, which can enhance pathogen entry and subsequent decay.

More research is needed on this subject to help bolster the emerging trendline that tends to dissuade the practice of leaf removal. Nonetheless, plumeria collectors and growers should consider a prudent approach, carefully weighing the perceived benefits of leaf removal to the potential shoot decay damage that can arise from it.

Also, when leaves are retained on the shoot, they might offer protection against early and mid-winter shoot cold damage; thus, shoots devoid of leaves might be more susceptible to cold damage. Cold damage itself can lead to entry of primary or secondary pathogens and subsequent decay.

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**Donald R. Hodel** is the Emeritus Landscape Horticulture Advisor for the University of California Cooperative Extension in Los Angeles and specializes in the taxonomy, selection, and management of palms and trees. [drhodel@ucanr.edu](mailto:drhodel@ucanr.edu)

**Elizabeth Mendoza** is Arboretum Horticultural Supervisor at the Los Angeles County Arboretum and Botanic Garden, Arcadia, California [EMendoza@parks.lacounty.gov](mailto:EMendoza@parks.lacounty.gov)

**Diana Donnellan** specializes in plumerias and is a volunteer, heading up the Grove Volunteer Team and leading special plumeria events, like the Annual Plumeria Day and various workshops, at the Los Angeles County Arboretum and Botanic Garden, Arcadia, California [dianadonnellan@gmail.com](mailto:dianadonnellan@gmail.com)

**Max F. Rothschild** is CF Curtiss Distinguished Professor Emeritus, Iowa State University, Ames, Iowa [mfrothsc@iastate.edu](mailto:mfrothsc@iastate.edu)

**Josue Chinchilla-Vargas** is a Research Associate at Iowa State University, Department of Animal Science, Ames, Iowa [josuechinchilla14@gmail.com](mailto:josuechinchilla14@gmail.com)

**Irene Truong** is Arboretum Horticulturist at the Los Angeles County Arboretum and Botanic Garden, Arcadia, California [Irene.laarboretum@gmail.com](mailto:Irene.laarboretum@gmail.com)

**Frank Nguyen** is Arboretum Ground Maintenance/Tallac Knoll Gardener at the Los Angeles County Arboretum and Botanic Garden, Arcadia, California

**Ignacio Oliveros** is Arboretum Gardener at the Los Angeles County Arboretum and Botanic Garden, Arcadia, California

**James E. Henrich** is the Curator of Living Collections at the Los Angeles County Arboretum and Botanic Garden, Arcadia, California. [Jim.Henrich@arboretum.org](mailto:Jim.Henrich@arboretum.org)

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