

# *Kadua haupuensis* (Rubiaceae: Spermaceae), a new endemic species from Kaua'i, Hawaiian Islands

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**Abstract.** The new species *Kadua haupuensis* is described and illustrated from the isolated Mt. Ha'upu region of Kaua'i, Hawaiian Islands. This new species belongs to *Kadua* subg. *Kadua* sect. *Wiegmannia*. It is characterized by a subdioecious (leaky dioecious) breeding system and appears most closely related to another apparently dioecious species endemic to Kaua'i, *Kadua flynnii*, with which it is compared. Although the only original wild population is critically endangered and may possibly be extinct, this new species has been successfully propagated and is currently secure in cultivation.

**Key Words:** Endemic, *Kadua*, Kaua'i, Hawaiian Islands, Rubiaceae, subdioecious.

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Generic delimitations in the genus *Hedyotis* L. (Rubiaceae, Spermaceae, Hedyotidiinae) in the broad sense have not been fully resolved (Terrell, 1996). Most modern taxonomic and floristic treatments of the 22 native Hawaiian species have placed them in *Hedyotis* s. l. (Fosberg, 1943; Wagner et al., 1990). However, a recent study of the Hawaiian species focusing on seed morphology demonstrated that seeds of the Hawaiian and certain South Pacific species are distinct from other Asian and Pacific species and from North American species of *Hedyotis* L. (Terrell et al., 2005). Based on seed morphology and a suite of other characters, species belonging to the former group have been transferred to the genus *Kadua* Cham. & Schltld., the earliest available generic name for these species (Terrell et al. 2005). This position is substantiated by preliminary molecular evidence from ITS sequences (Kårehed et al. 2008; Groeninckx et al., 2009).

Recent collections made from the isolated Ha'upu Mountain range in southern Kaua'i include a new, undescribed species of *Kadua*. This new subdioecious species is most closely related to another apparently dioe-

cious species endemic to northern Kaua'i, *K. flynnii* (W. L. Wagner & Lorence) W. L. Wagner & Lorence, which differs by characters noted in the diagnosis below. The Ha'upu Mountain range occurs in southern Kaua'i and shares many floristic elements with O'ahu. Also, it is separated from the main mountainous region of Kaua'i by a non-mountainous gap, which most likely provides some degree of reproductive isolation for many of the species growing on the Ha'upu Mountains (Wood, 2005) and would help explain evolution of local endemism here.

A study of breeding systems of this new species utilizing living material revealed that using dried herbarium collections to characterize floral sexuality based on morphological descriptors such as corolla tube and lobe length and stigma and style length was inadequate because of overlapping ranges for staminate (male), pistillate (female), and hermaphroditic flowers (Laidlaw, unpubl. data). Indeed, statistical analysis of data accumulated from measurements taken of thousands of flowers from hundreds of plants in the ex situ population of this new species suggest that precise measurements do not

reveal a clear pattern of parameters that correlate with floral sexuality. That is, some staminate individuals produce some morphologically similar but functionally hermaphroditic flowers. Like the staminate flowers, these are characterized by fertile, pollen-bearing stamens and short styles with included stigmas but which are apparently functional, as they form capsules, albeit with reduced seed germination rates. For this species the most accurate and useful gender descriptor, achieved by combining both morphological and biological characteristics, is the degree to which the stigma is exerted above the mouth of the corolla tube or included within the tube, expressed as the ratio of the stigma plus style length to the corolla tube length. Further details are given below under Breeding Systems. These data will be discussed in greater detail in a forthcoming paper (Laidlaw, unpubl. data).

All specimens have been examined by the authors unless otherwise noted ("n.v."). Measurements given herein are taken from dried herbarium specimens, although certain features such as shapes were supplemented with information from living material, alcohol-preserved flowers and fruits, field notes, and digital photos. Measurements are presented in the descriptions as follows: length  $\times$  width, followed by units of measurement (mm or cm).

**Kadua haupuensis** Lorence & W. L. Wagner, **sp. nov.** Type: U.S.A. Hawaiian Islands. Kaua'i. Koloa District: National Tropical Botanical Garden in Lawa'i Valley, from cultivated plant in the nursery NTBG #980794 (fl), *D. H. Lorence 9451* (holotype: PTBG; isotypes: BISH, MO, US). (Fig. 1)

Haec species a *Kadua flynnii* (W. L. Wagner & Lorence) W. L. Wagner & Lorence laminis foliorum 3–11.5  $\times$  0.7–3.2 mm, vaginis stipularum 1.5–3 mm longis, inflorescentia 2–4  $\times$  2–4.5 cm, 10–67-floris, capsulis 3.5–4.5  $\times$  4–5 mm, seminibus 0.5–0.6  $\times$  0.25–0.4 mm differt.

Subdioecious *shrubs* 1–1.5 m tall with erect, brittle stems, branchlets terete, glabrous except minutely puberulent at nodes, older branches with brown, longitudinally fissured bark. *Leaves* with blade oblong-lanceolate to

oblong-ovate, 3–11.5  $\times$  0.7–3.2 cm, chartaceous, adaxially glabrous and lustrous, abaxially glabrous or sparsely hirtellous, more densely so on costa; secondary veins 3–6 pairs, festooned brochidodromous, tertiary veins conspicuously reticulate, weakly prominent on both surfaces, translucent when fresh and visible to 4 $^\circ$ ; *petioles* 2–16 mm long, narrowly winged, glabrous or puberulent abaxially; *stipules* externally glabrous, with sheath 1.5–3 mm long, the awn 2–5 mm long. *Inflorescences* (6–)10–67-flowered, cymose-paniculiform, dichasial, 2–4  $\times$  2–4.5 cm, subtended by a pair of leaf-like bracts, the axes glabrous or glabrate, the primary branches 2–3 pairs, the monochasial ultimate branches each bearing 3–12 flowers, each subtended by a glabrous or sparsely puberulent, subulate to linear-oblong bract 2–8 mm long. *Flowers* with calyx 4-lobed, lobes linear-oblong to linear-oblongate, 2.5–6  $\times$  0.3–0.8 mm, glabrous or margins ciliolate, erect-spreading, green with purple tint when fresh. *Staminate flowers* with hypanthium obconic, 1–1.5 mm long, glabrous; corolla tube 10–16 mm long, lobes 2.5–3.5 mm long, oblong-ovate to elliptic, style plus stigma 4–7.5 (–12) mm long, about 2/3 the length of the tube, villous toward base, stigma slightly bilobed apically, 1–1.5 mm long, anthers 2–2.5 mm long, polleniferous, inserted 4 mm below top of tube. *Pistillate flowers* with hypanthium obconic, 1.5–2 mm long, glabrous; corolla tube 9–10 mm long, lobes 2–2.5 mm long, triangular-ovate, style plus stigma typically 6–11 mm long, villous toward base, stigma slightly bilobed apically, 3.5–4 mm long, swollen, papillose, stigma tips exerted from mouth of tube; anthers 1.2–1.3 mm long, abortive and non-polleniferous, inserted 3 mm below mouth of tube. *Hermaphroditic flowers* (occur sporadically on staminate plants) resemble staminate flowers in having larger, polleniferous anthers and short styles with stigmas included but apparently functional. *Capsules* broadly obovoid, 3.5–4.5  $\times$  4–5 mm, glabrous, weakly bisulcate, weakly compressed laterally, weakly costate, calyx lobes persistent, spreading, apical portion of capsule 0.5–1 mm long, minutely puberulent, dehiscence initially loculicidal then tardily separating septically. *Seeds* numerous, dark brown or blackish, 0.5–0.6  $\times$  0.25–0.4 mm,

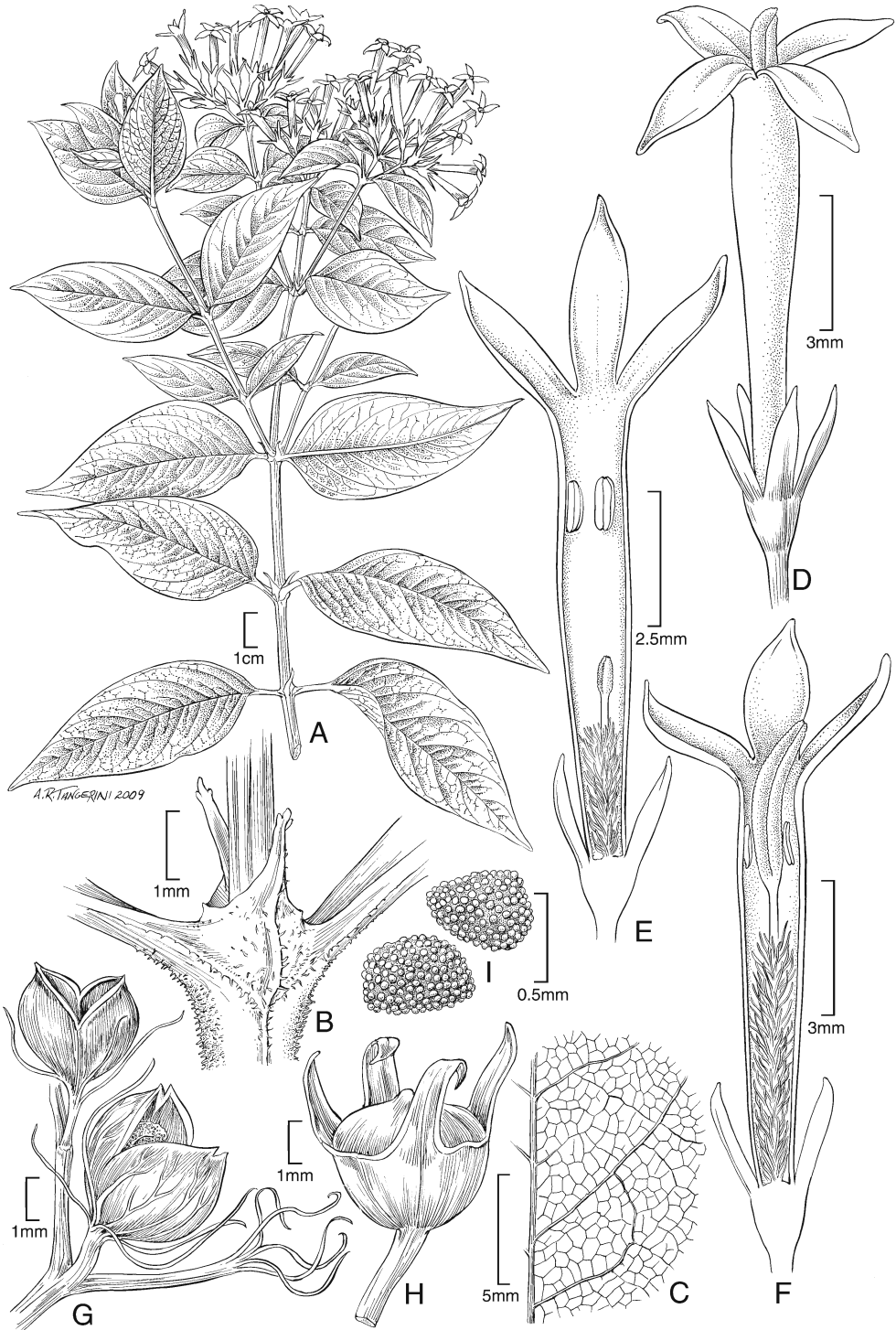


FIG. 1. *Kadua haupuensis*. A. Habit. B. Detail of node with stipules. C. Detail of venation. D, F. Pistillate flowers. E. Staminate flower. G. Old dehiscent capsules. H. Mature capsule. I. Seeds. (A, B, C, E from Lorence 9451, PTBG; D, F from Lorence 9450, PTBG; G, H, I from Wood 7492, PTBG.)

irregularly obovate to ellipsoid, somewhat angulate, compressed laterally, surface papillose with prominent, bubble-like protuberances (Figs. 3A, B).

**Distribution and ecology.**—This new species was known only from the original collection locality on the north face of Mt. Ha'upu, Kaua'i where it grew in mesic forest with *Pisonia sandwicensis* Hillebr., *P. umbellifera* (G. Forst.) Seem., *Diospyros sandwicensis* (A. DC.) Fosb., *Acacia koa* A. Gray, *Kadua acuminata* Cham. & Schltdl., *Pipturus albidus* (Hook. & Arn.) A. Gray, *P. kauaeensis* A. Heller, *Psychotria greenwelliae* Fosb., *P. kaduana* (Cham. & Schltdl.) Fosb., *P. martiniana* (Cham. & Schltdl.) Fosb., *Cyanea hardyi* Rock, *Artemisia australis* Less., *Bidens sandwicensis* Less., and *B. valida* Sherff (Wood, 2005 and pers. comm.). A single population of seven plants was originally observed covering a small area of about 10 sq. m (Fig. 2). Mature fruits with seeds were collected in September, from which eleven plants were grown at the National Tropical Botanical Garden (NTBG). Subsequently this species has been successfully propagated vegetatively from tip cuttings and also by seed. On Mt. Ha'upu this new species is threatened by invasive alien plant species including *Caesalpinia decapetala* (Roth) Alston, *Rhodomyrtus tomentosa* (Aiton) Hassk., *Passiflora laurifolia*

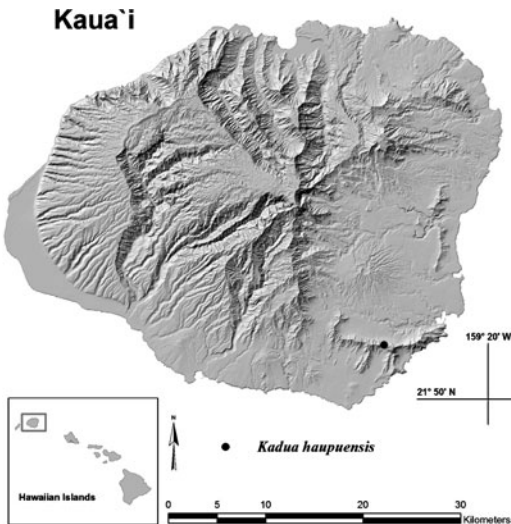


FIG. 2. Distribution of *Kadua haupuensis* on Kaua'i, Hawaiian Islands.

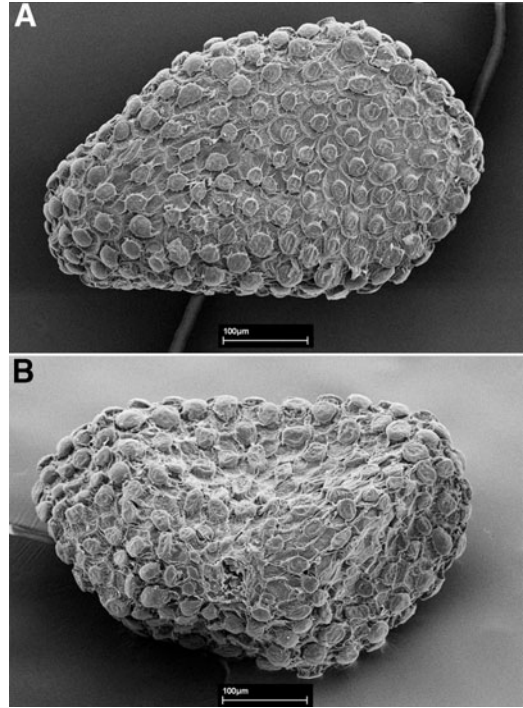


FIG. 3. Seeds of *Kadua haupuensis*. A. Lateral view. B. Basal view showing point of attachment (Wood 7492, PTBG).

*L.* and alien grasses among others. Feral pigs rooting up soil and rats eating fruits and seeds are additional threats, as are landslides. Despite efforts to relocate this species, it has not been sighted since the original collection was made and may be extinct at this locality (K. Wood, 2005 and pers. comm.).

**Additional specimens examined. U.S.A. Hawaiian Islands:** Kaua'i. Koloa District, Ha'upu Range, north facing mesic forest, just below and along cliffs on west side of summit, 366 m, 23 Sep 1998 (fr), Wood 7492 (BISH, MO, NY, PTBG, US); National Tropical Botanical Garden in Lawai Valley, McBryde Garden, NTBG nursery, 21°53'39"N, 159°39'39"W, 17 Apr 2003 (fl), from cultivated plant NTBG #980794, Dunn 164 (BISH, MO, PTBG, SASK, US), 28 Apr 2005 (fl), from cultivated plant NTBG #020415, Lorence 9449 (PTBG), from cultivated plant NTBG #020345 (fl), Lorence 9450 (PTBG, US); from cultivated plant NTBG # 98074, 7 Dec 1999 (fl), Wood & Nishek 8088 (MO, PTBG, US), from cultivated plant NTBG #980794, 7 Dec 1999 (fl), Wood & Nishek 8089 (PTBG), (fl) 8990 (PTBG).

**Conservation status.**—The original eleven plants cultivated at NTBG were grown from

seed originally collected by Kenneth R. Wood on 23 Sep 1998, from the Ha'upu Mountain range of SE Kaua'i, from the base of cliffs with north-facing mesic forest above Kipu Ranch at ca. 1200 ft (366 m) elevation. Recent field surveys (K. Wood, pers. comm.) have not relocated the original small population consisting of seven plants, suggesting it has likely been extirpated. When evaluated using the IUCN criteria for endangerment (IUCN, 2001; see also: [www.iucnredlist.org/info/categories\\_criteria2001](http://www.iucnredlist.org/info/categories_criteria2001)), *Kadua hauapuensis* falls into the IUCN Red List Category of Critically Endangered (CR), which designates species facing the highest risk of extinction in the wild. It clearly meets the criteria for CR (B1a, b iii; B2b; D): B1, known extent of occurrence estimated to be less than 100 km<sup>2</sup>; B1a, known to exist at only a single location (a single collection known), B1biii, quality of habitat declining due to feral animals and invasive plants; B2, area of occupancy of less than 10 km<sup>2</sup>, and B2b continuing decline in the quality of habitat; D, Population size estimated to number fewer than 50 individuals.

*Phenology.*— This small shrub produces a profusion of delicate white or greenish white flowers from December to April, up to several thousand per plant (Laidlaw, pers. comm.). The flowers begin producing an intensely sweet odor at 5:30–6:00 pm which lasts into the evening, suggesting pollination by nocturnal moths. Analysis of this floral odor revealed a predominance of benzyl acetate (64%), a constituent often occurring in floral scents given off by night-active species (R. Kaiser, pers. comm.).

*Ex situ propagation and conservation efforts.*— This new species is easily grown from seed or from stem tip cuttings treated with rooting hormones and placed in a mist chamber (R. Nishek, pers. comm.). Thus it has been possible to cultivate hundreds of individuals of this species at the NTBG nursery. Between 2004 and 2008 a number of different trials and planting protocols were undertaken at various NTBG trial sites and in several vegetation restoration projects at NTBG and the nearby Makawahi Cave (D. Burney, pers. comm.). Over 200 individuals were planted out at eight different locations to

test various combinations of soil media and amendments, drainage, shade, and watering regimes. Results show this new species does not tolerate heavy clay or other dense, poorly drained soils and thrives best in well drained soils under light to moderate shade. When stressed the plants are more highly susceptible to insect pests including white flies, scale insects, and root mealybugs and plant diseases such as fungal and/or bacterial pathogens that affect the root system.

*Breeding system and sex expression.*— Many oceanic islands including the Hawaiian Islands are known for their high frequency of dioecious species (Sakai et al., 1995a, 1995b), yet breeding systems have been studied in relatively few members of the Hawaiian flora. No studies of breeding systems utilizing living *Kadua* plants or populations had been carried out prior to this study. However, Wagner et al. (1990) noted that based on studies of herbarium collections, the 20 then known Hawaiian species of *Hedyotis* (now placed in *Kadua*) had flowers that varied from “...perfect to functionally pistillate, perhaps sometimes functionally staminate (and then plants gynodioecious or dioecious) ...” Certain members of the Hedyotideae, for example some species of *Houstonia* L., are heterostylous (Terrell, 1996). That is, they have two floral morphs, one with exserted stigmas and included anthers (“pin” flowers), and the other with included stigmas and exserted anthers (“thrum” flowers). Dioecy has evolved via heterostyly in other genera of Rubiaceae such as *Chassalia* Comm. ex Poir. (Pailler et al., 1998), and this is likely also the case for *Kadua*.

Observations utilizing populations of nursery grown plants have revealed that *Kadua hauapuensis* is subdioecious or “leaky dioecious,” sensu Humeau et al. (1999). That is, these taxa are not truly dioecious as they may produce occasional hermaphroditic flowers or individuals. The original population of eleven plants of this species grown at the NTBG nursery likely descended from a single fruiting pistillate plant from the original wild population (Wood, 2005). Unpublished studies by Laidlaw indicate that these 11 plants (eight staminate, three pistillate) and their

numerous F1 and F2 progeny consist of three types of plants: pistillates producing no pollen but a large number of seed bearing capsules with good (about 50%) germination; staminate plants that produce pollen but no capsules; and a significant population of staminate plants that have some hermaphroditic flowers that produce fertile pollen and a limited number of capsules with a reduced (less than 20%) seed germination rate.

Measurements of several thousand flowers of subsequent generations indicate that stigma length and anther position are strongly bimodal, with longer styles and exerted stigmas and shorter, included anthers in the pistillate plants, and shorter styles with included stigmas and longer anthers with exerted tips in the staminate plants. Fresh anthers in staminate and hermaphrodite plants are >1.5 mm long and ≤1 mm long in pistillates. Individual plants generally produce either all staminate or predominantly pistillate flowers except for a smaller but significant number of individuals with hermaphroditic flowers producing a limited number of capsules and seeds with reduced (less than 20%) germina-

tion (Laidlaw, unpubl. data). Gender of the pistillates' offspring is about equally staminate and pistillate, whereas gender of the hermaphrodites' offspring is skewed strongly with a predominance of staminate plants (3:2 staminate to pistillate). These data will be presented in a forthcoming publication.

*Phylogenetic and intrageneric relationships.*—Recent molecular data used to construct phylogenetic trees for members of tribe Spermaceae including many Hawaiian and Pacific Island species of *Hedyotis*, *Oldenlandia*, and *Kadua* place *K. haupuensis* in a clade with *K. cookiana* Cham. & Schltldl., *K. elatior* (H. Mann) A. Heller, and *K. flynnii* (Kårehed et al., 2008; Groeninckx et al., 2009; Motley, unpubl.). This confirms morphological evidence suggesting this new species is most closely related to *K. flynnii*. Based on seed morphology, this new species belongs to *Kadua* subg. *Polynesiotis* sect. *Wiegmannia* (Terrell et al., 2005), which also includes *K. cookiana*, *K. elatior*, and *K. flynnii* among others. Seeds of *K. haupuensis* have large and prominent, bubble-like papillae as do other members of section *Wiegman-*

TABLE I  
COMPARISON OF *KADUA FLYNNII* AND *K. HAUPUENSIS*.

Character	<i>K. flynnii</i>	<i>K. haupuensis</i>
Height (m)	0.2–1	1–1.5
Internode length (mm)	(4–)5–20(–30)	(4–)10–47(–59)
Stipule awn length (mm)	1.5–5	2–5
Stipule sheath length (mm)	0.5–1	1.5–3
Leaf shape	ovate to lanceolate	oblong-lanceolate to oblong to ovate
Leaf blade length (cm)	2–6	3–11.5
Leaf blade width (cm)	0.5–1.5(–2.2)	0.7–3.2
Secondary vein pairs	2–4	3–6
Flowers per inflorescence	7–15	(6–)10–67
Calyx lobe shape	oblong-ovate to subulate	linear-oblong to oblanceolate
Calyx lobe length (mm)	2–6	2.5–6
Calyx lobe width (mm)	0.5–2	0.3–0.8
Corolla tube length (mm)		
staminate	11–14	10–16
pistillate	7–8	9–10
Corolla lobe length (mm)		
staminate	7.5–8	2.5–3.5
pistillate	2.5–4	2–2.5
Style + stigma length (mm)		
staminate	5–8	4–7.5(–12)
pistillate	6–8	6–11
Capsule length (mm)	5–6	3.5–4.5
Capsule width (mm)	5–6.5	4–5
Seed length (mm)	0.6–0.9	0.5–0.6
Seed width (mm)	0.35–0.5	0.25–0.4

nia including *K. cordata*. Seeds of *K. haupuensis* (Figs. 3A, B) most closely resemble those of *K. flynnii*, although they are more irregular in shape and have somewhat longer papillae (see Terrell et al., 2005: 827, Fig. 5A, B).

Morphologically *Kadua haupuensis* differs from *K. flynnii* by its taller growth habit (1–1.5 m), longer stipule sheaths (1.5–3 mm), longer internodes ([4–]10–47[–59] mm), comparatively longer, oblong-ovate to oblong-lanceolate, stiffly chartaceous to subcoriaceous leaf blades (3–11.5×0.7–3.2 mm), larger inflorescences (2–4×2–4.5 cm) with more numerous flowers (6–67), shorter staminate corolla lobes (2.5–3.5 mm), smaller capsules (3.5–4.5×4–5 mm), and smaller seeds (0.5–0.6×0.25–0.4 mm) (Table I).

Both *Kadua haupuensis* and *K. flynnii* morphologically resemble *K. cordata* Cham. & Schlttdl. var. *waimeae* (Wawra) W. L. Wagner & Lorence (syn. *Hedyotis schlechtendaliana* Steud. var. *waimeae* [Wawra] Fosb.). However, the latter taxon differs by its more elongate inflorescences subtended by 2–3 pairs of reduced, sessile, cordate leaves, foliaceous inflorescence bracts, and hermaphroditic or possibly gynodioecious breeding system (Wagner et al., 1990; Wagner & Lorence, 1998). The new species also resembles *K. degeneri* from O’ahu, which differs by its smaller leaf blades (1–3[–4]×0.3–2 cm), shorter petioles (0–2 mm), shorter stipules (2.5–2.8 mm), inflorescences with fewer flowers (1–10), longer foliaceous calyx lobes (4–8 mm), and shorter corolla tubes (6–7 mm).

Our principal goal in this paper has been to provide a name for this critically endangered, geographically isolated, and morphologically distinct taxon from Mt. Ha’upu, Kaua’i. Further studies utilizing living plants and molecular phylogenetic work are required to resolve relationships within this species complex.

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