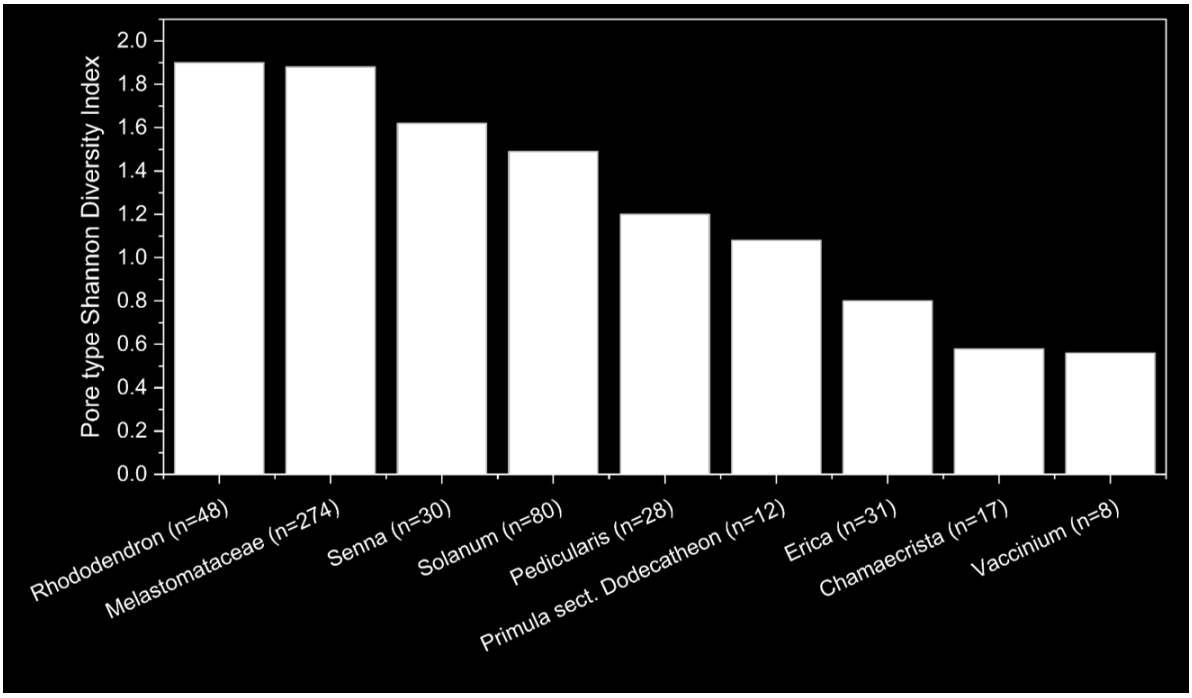
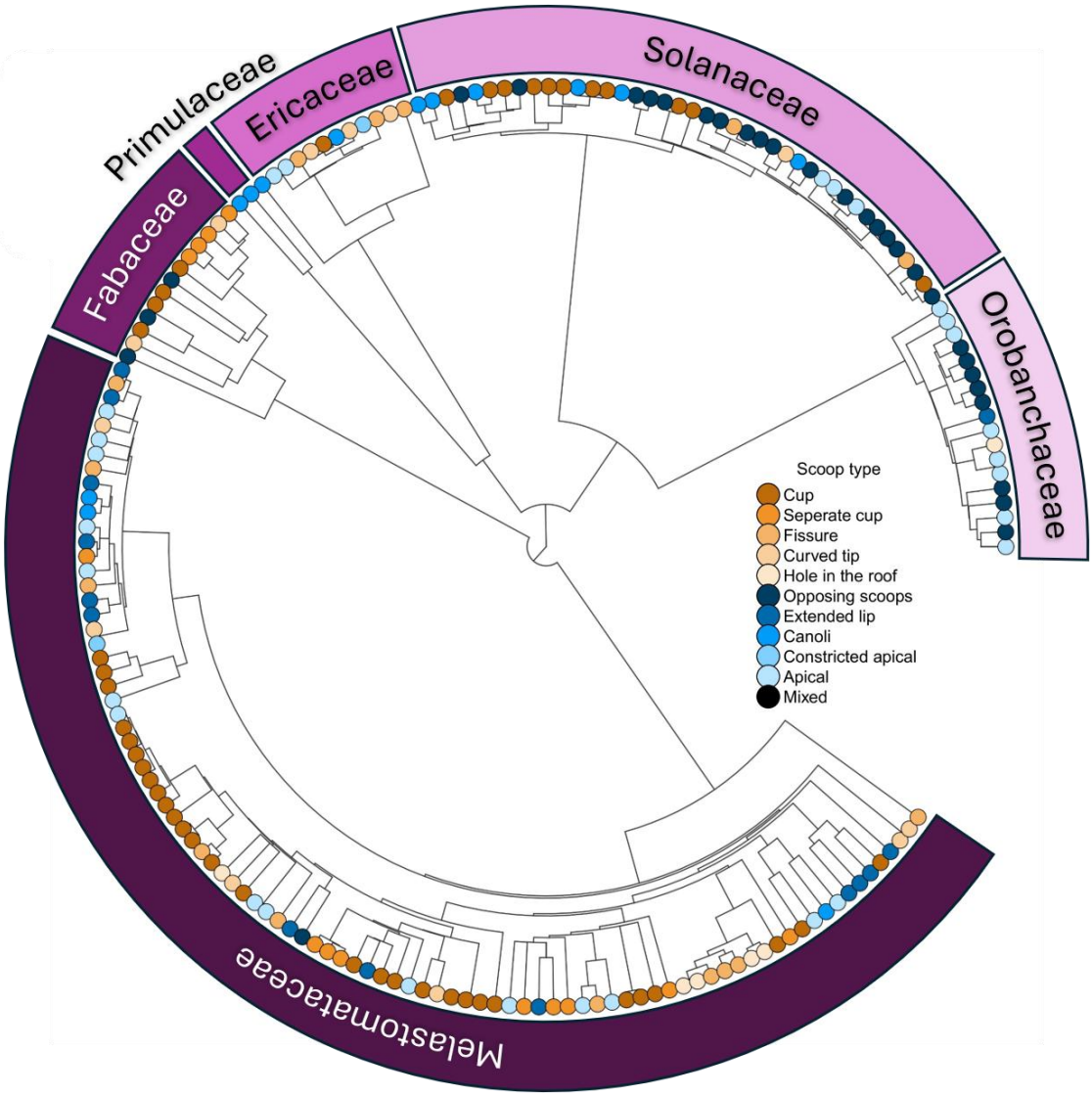
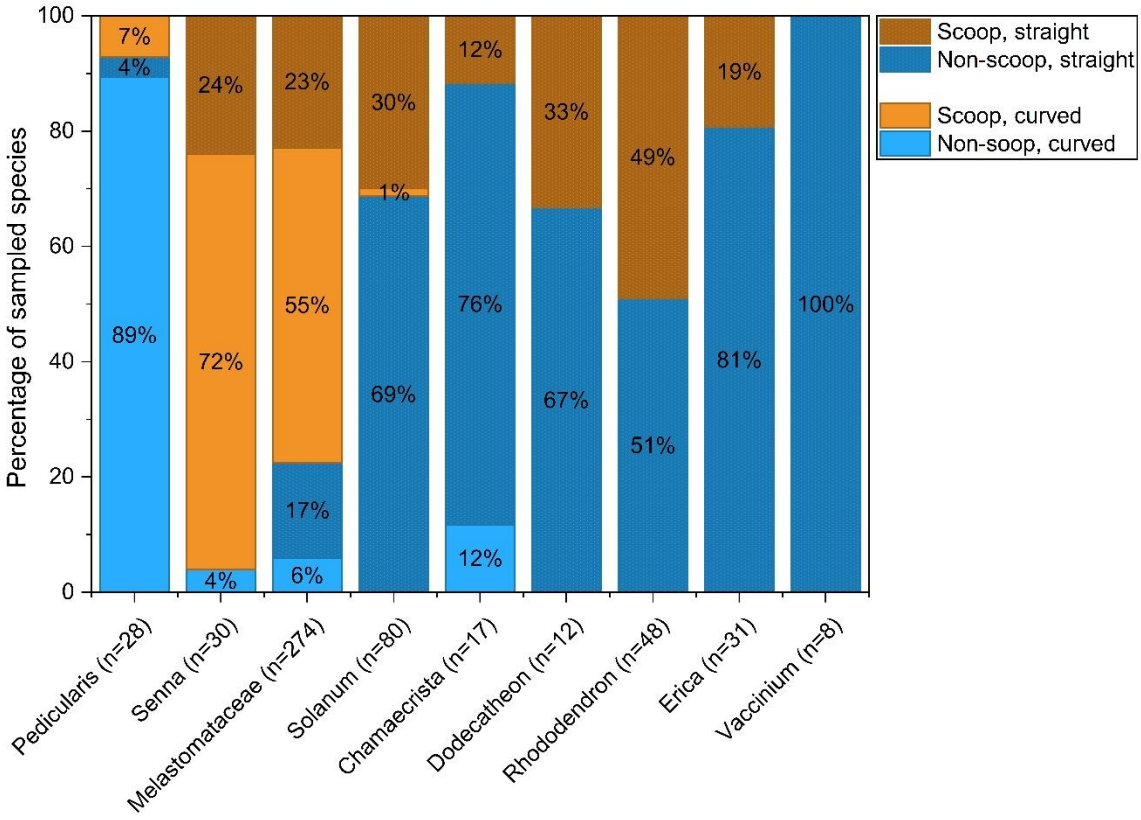


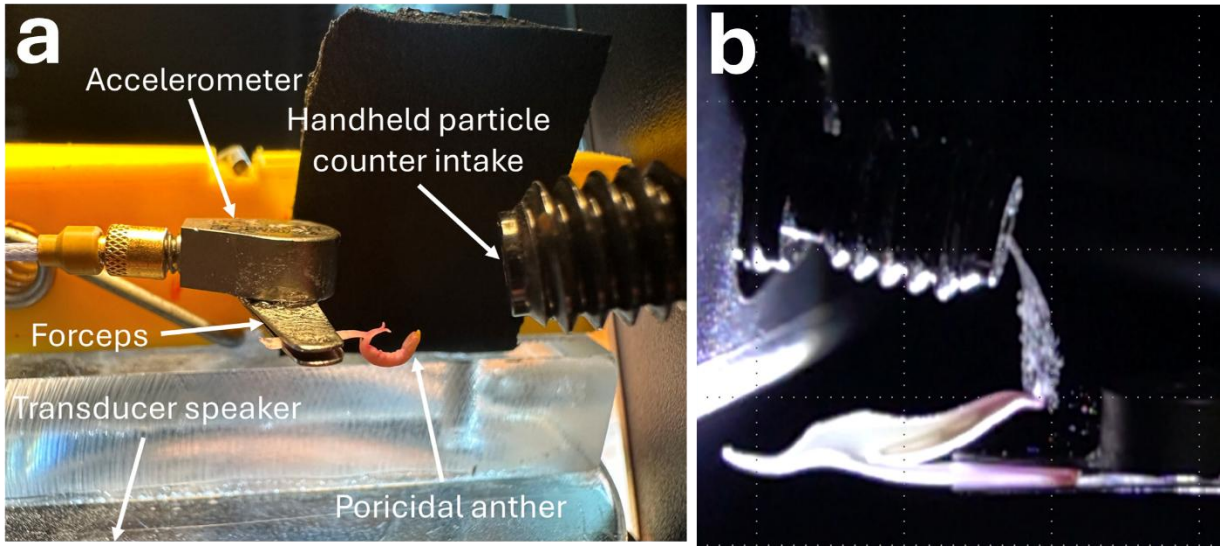
SI Figure 1 While scoop and non-scoop shaped pores appear across the clades sampled in this study, certain groups exhibited a higher morphological Shannon diversity index than others. n values listed on the plot indicate the number of independent species included from that taxonomic group.



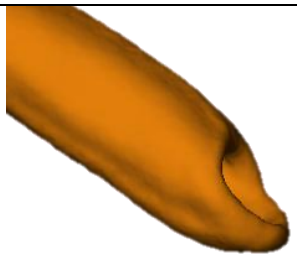
Supplemental Figure 2 Scoop type mapped onto a phylogeny for the species present in the GBOTB.extended.WP megatree from the V.PhyloMaker2 package suggest that scoop shape is a labile trait that often varies within families and amongst closely related species

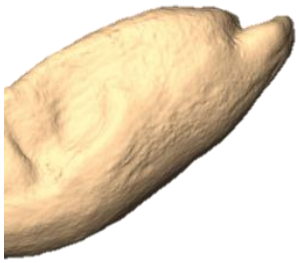
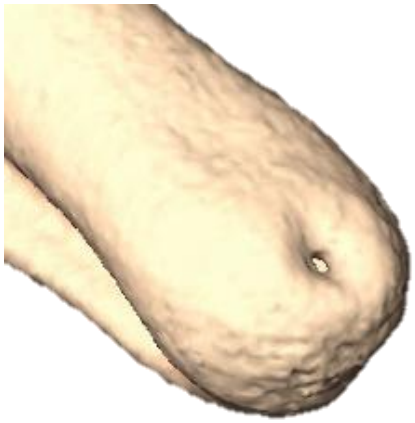
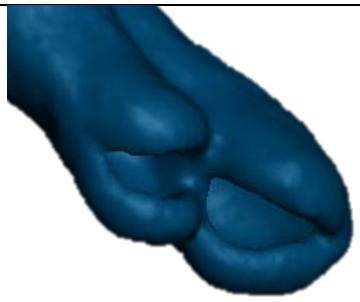


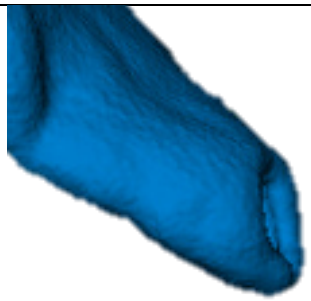
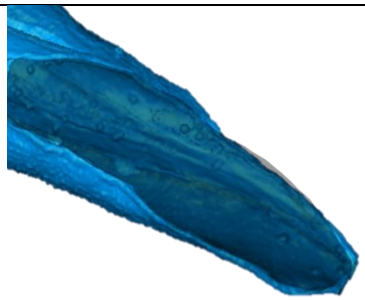
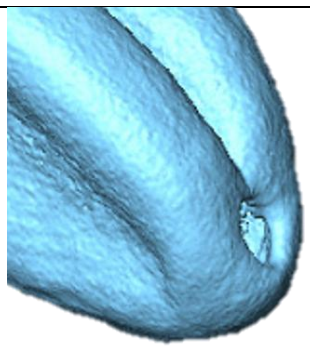
Supplemental Figure 3 When anthers are curved (note Pedicularis form pollen cavities with their corollas not their anthers), they often exhibit scoop shaped pores, while the anthers of non-scoop bearing species are nearly always straight. n values listed on the plot indicate the number of independent species included from that taxonomic group.

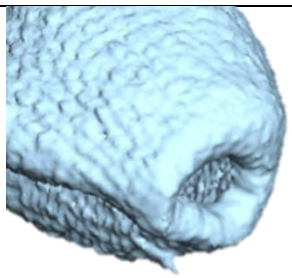


Supplemental Figure 4 A) Artificial vibration setup with vacuum particle counter (previously published in [1]) which B) pulls aerosolized pollen grains out of the airstream (previously published in [2]).

Morphology	Description	Example species	Image
Scoop morphologies			
Cup	The “cup” morphology features a lower lip that curls slightly upward, forming a shallow pocket at the pore opening.	*Pleroma Urvilleanum*, *Blakea watsonii, Meriania speciosa, Solanum americanum, Senna marilandica, Rhododendron tomentosa, Erica hintiflora*	
Separate cup	The “separate cup” morphology is similar, but the pocket at the pore opening is preceded by a narrowing of the pollen chamber before opening into a cup-shaped pore.	*Microlicia cataphracta*, *Rhynchanthera cordata*, *Senna occidentalis, Senna multiglandulosa*	
Fissure	The “fissure” morphology resembles the cup form but with a more pronounced curvature of the lower lip, such that the pore opening often appears elongated and irregular, forming shapes ranging from teardrop- to crescent-like. In some cases, this opening appears as a tear in the wall of the pollen cavity.	*Pternandra caerulescens, Mouriri grandiflora, Solanum, infundibuliforme, Senna fruticosa, Rhododendron calendulaceum, Erica bruniaefolia, Erica lincanta*	

Curved tip	The “curved tip” morphology is defined by a pronounced curvature of the anther tissue leading to the pore, which may occur in any orientation relative to the anther axis; the pore itself varies in shape and is typically positioned at or near the anther apex.	*Arthrostemma ciliatum, Miconia guianensis, Axinea macrophylla, Solanum lumholtzianum, Senna sophora, Chamaecrista mimosoides, Rhododendron carolinianum*	
Hole in the roof	The “hole in the roof” morphology consists of a small, typically circular pore positioned on the upper surface of the pollen cavity, while the surrounding cavity walls remain largely intact.	*Rhexia mariana, Oxyspora paniculata, Sonerila rudis, Primula* sect. *Dodecatheon alba, Primula* sect. *Dodecatheon hansenii, Pedicularis attolens*	
Non-scoop morphologies			
Split tip	The “split tip” morphology is distinguished by curvature of both the upper and lower margins of the pore opening. In this form, the pore often appears as an irregular horizontal split or sideways teardrop-shaped opening between	*Miconia cremdena*, *Solanum lanceolatum, Solanum kurtzianum, Chamaecrista chamaecristoides, Senna tapajozensis, Pedicularis multiflora, Pedicularis incarnata*	

	the opposing cavity walls.		
Extended lip	The “extended lip” morphology resembles the cup form but lacks an upward curl of the lower lip, resulting in a more open pore margin. This morphology occurs in a range of orientations, including upward-, lateral-, and downward-facing pores.	*Miconia aeruginosa, Monocheatum floribundum, Sonerila maculata, Osbeckia buxifolia, Senna pleurocarpa, Vaccinium arboreum, Rhododendron serrulate, Pedicularis tenuirostris*	
Canoli	The “canoli” morphology is characterized by a recessed upper margin of the pore, with the opening forming a gently curved profile rather than a straight lateral edge.	*Miconia argenta, Solanum nigrescens, Senna reticulata, Chamaecrista nigricans, Primula* sect. *Dodecatheon frigidium, Primula* sect. *Dodecatheon pulchellum, Vaccinium britonii, Vaccinium deliciosum*	
Constricted apical	In the “constricted apical” morphology, the walls of the pollen cavity gradually narrow toward a small apical opening; this arrangement was rare across the taxa surveyed in this study.	*Miconia luciana, Schwackaea cupheoides*	
Apical	The “apical” morphology represents the simplest form	*Miconia octana, Blakea involvens, Pilocosta nana, Solanum amorimii,*	

	observed, consisting of a relatively unmodified, circular apical aperture aligned with the longitudinal axis of the anther.	*Solanum cajanumense, Rhododendron colombianum, Pedicularis integrifolia*	

Supplemental Table 1 Descriptions of the different pore type categories with example species and closeup images from CT scan renderings.

Species	***Location***
Arthrostemma ciliatum	Sendero Hyca Quye trail, Santa Maria, Boyacá, Colombia
Blakea watsonii	Sendero Hyca Quye trail, Santa Maria, Boyacá, Colombia
Meriania speciosa	Sendero Hyca Quye trail, Santa Maria, Boyacá, Colombia
Miconia octona	Sendero Hyca Quye trail, Santa Maria, Boyacá, Colombia
Ceratostema lanigerum	New York Botanical Garden
Ceratostema zamorana	New York Botanical Garden
Ceratostema inflata	New York Botanical Garden
Pleroma caissara	New York Botanical Garden
Psammisia ferruginea	New York Botanical Garden
Senna hebecarpa	New York Botanical Garden
Solanum dulcamara	New York Botanical Garden
Solanum carolinense	New York Botanical Garden
Solanum nigrum	New York Botanical Garden
Rhexia virginica	New York Botanical Garden
Rhododendron 'Autumn Royalty'	New York Botanical Garden
Blakea granatensis	Jardín Botánico de Bogotá José Celestino Mutis
Tibouchina mollis	Jardín Botánico de Bogotá José Celestino Mutis
Blakea involvens	Atlanta Botanical Garden

Supplemental Table 2 Sampling location for each species used in the experimental portion of this study.

Tukey test	*Pollen per unit energy (J^{-1})*	*Pollen per second (s^{-1})*	*Pollen per cycle*
200 vs 300 hz:	p=0.03	p=0.09	p<0.001
200 vs 400 hz:	p=0.007	p=0.01	p<0.001
300 vs 400 hz:	p=0.81	p=0.60	p=0.08

Supplemental Table 3 Results from the one-way ANOVA and Tukey test on pollen release rates from Meriania speciosa *when it was buzzed at different frequencies.*

Supplementary note 1: Developmental constraints may impact the evolution of pore morphology

Besides scoop- and non-scoop pore types, we observed substantial variation in the regularity of pore shapes, which can be traced back to how pores dehisce – a character that is generally conserved within major angiosperm lineages [3]. In Melastomataceae, pores open passively through localized dehydration of non-cutinized epidermal cells in the area of the pore. The lack of a cuticle causes these cells to lose rigidity and degenerate after anthesis, which creates a controlled and highly defined opening and makes for highly regular pore shapes [3]. Melastomataceae's dehiscence contrasts sharply with other buzz-pollinated groups, where pore formation involves active processes like mechanical rupture or tissue breakdown, resulting in irregular pore shapes (such as "canoli", "fissure" or "opposing scoops" [3]). In *Solanum* (Solanaceae), for example, dehiscence is mechanically driven: a fibrous endothecium and thick-walled connective cells generate internal bending stress as they dehydrated, which ultimately ruptures the stomium to form the pore [4]. In Ericaceae, which, like Melastomataceae, lack a typical endothecium, dehiscence instead results from the collapse or enzymatic resorption of a specialized tissue inside the anther [5]. In *Senna*, pore formation occurs through both strategies — the anther tip is reinforced by thick-walled hypodermal layers, but the actual pore forms through tissue decay, producing a shared apical chamber between the thecae [6]. These lineage-specific differences in development lead to noticeable differences in pore shape even when different lineages have the same pore morphology. For example, the "cup" scoop-shaped pore morphology is found commonly in both *Solanum* and Melastomataceae, however in the former, scoops often have an irregular shape and are formed by an extension of the lower lobe of a split tip (likely due to the aforementioned rupture dehiscence mechanism) whereas in Melastomataceae "cup" pores are generally regular in shape and single-sided with a clearly defined scoop region (Figure 2A "cup" and "separate cup" examples). While not the focus of our study, our observation that the regularity in pore formation differs among lineages calls for more in-depth studies on pore development and morphometrics to quantify pore regularity and understand whether developmental restrictions limit precise pore formation and how they ultimately play out in pollen placement precision.

Finally, at least in Melastomataceae, the notion that directional pore shape is a function of pollen placement is supported by the fact that most non-scoop pore morphologies are found in largely autogamous clades such as *Miconia* [7], *Sonerila* [8], *Osbeckia* [9,10] or clades that are suspected to be autogamous due to ploidy and life history trends such as *Siphanthera* and *Pilocosta*. In self-pollinating or apomictic species, pore restrictions formed by spathulate tissue may be unnecessary for or even hinder self-pollen deposition. Explicitly exploring the relationship between pore morphology and mating system in Melastomataceae and beyond represents another fruitful avenue for clarifying the function of stamen pore morphology.

Supplementary note 2: Rationale for investigating the effect of scoop shape on pollen release in non-buzz-pollinated flowers

Poricidal anthers release pollen through small apical pores and are most commonly associated with buzz pollination, in which high-frequency vibrations visibly eject pollen into the air. However, even in species that are not classically buzz-pollinated, pollen must still be displaced from within the thecae toward the pore and subsequently expelled in a manner that allows it to contact a pollinator. In many poricidal taxa, pollen is not externally exposed at anthesis but instead retained within elongate, tubular anthers. As a result, successful pollen placement likely requires some degree of mechanical mobilization and transient aerosolization—or at minimum, directional ejection into the airspace immediately surrounding the pore—prior to attachment to a visiting pollinator.

This mechanical requirement distinguishes poricidal taxa with elongate, tubular thecae from those in which pollen is effectively pre-positioned at the aperture and available for direct contact transfer. For example, members of Araceae possess poricidal anthers with comparatively large pores, and pollen is often readily shed or dumped directly onto visiting pollinators. Similarly, in certain species of *Rhododendron*, pollen is positioned close to the pore and frequently aggregated by viscin threads, forming sticky strands that adhere directly to pollinators upon contact. In these cases, pollen placement may rely less on internal mobilization and airborne dispersal and more on passive shedding or adhesive transfer.

By contrast, in many poricidal taxa with elongate thecae or narrow apical pores, pollen is situated at a considerable distance from the aperture and lacks obvious adhesive aggregation. Under these conditions, pollen must first be transported internally toward the pore and then expelled with sufficient force or directionality to enter the surrounding airspace. Even if this expulsion is less dramatic than in canonical buzz-pollinated systems, some degree of aerosolization or mechanical shaking into the air is likely necessary for effective transfer.

Several informal hypotheses have been proposed to explain how this displacement and expulsion might occur in non-buzz systems. One suggestion is that structural deformation—such as compression of the corolla or disruption of stamen fusion—may generate a coordinated release of pollen. Anecdotal observations in some taxa indicate that mechanically fracturing the corolla or breaking connections among stamens can produce a visible burst of aerosolized pollen. A second hypothesis proposes that compressive forces generated between the pollinator and the corolla wall, potentially combined with incidental vibration during contact, may mobilize pollen internally and expel it through the pore without the high-amplitude vibrations typical of buzz pollination. Yet

another suggests that vibrations from flying visitors may be transferred to the stamens to shake pollen out.

To evaluate these possibilities, we directly examined pollen release dynamics across multiple poricidal morphotypes. Contrary to expectations that pollen might simply accumulate at the pore or be easily dislodged by handling, pollen release generally required specific and sometimes substantial mechanical input.

In the “bellows-type” species *Ceratostema lanigerum*, pollen was released only when compressive force was applied at the base of the anther; buzzing, flicking, or squeezing the apical region did not result in measurable pollen discharge. In the “spring-type” species *Ceratostema zamorana*, buzzing released no detectable pollen, and compression produced only a minor pulse of pollen. Substantial pollen release occurred primarily in response to bending and releasing the elongated rostrum leading to the pore, producing a distinct directional discharge (“scoop” effect). Notably, in this morphotype the stamens extended beyond the corolla tube.

Two additional taxa (*Ceratostema inflata* and *Psammisisa ferruginea)* exhibited morphologies similar to those of *Vaccinium*, with shorter anthers positioned within the corolla tube. In these cases, inverting the flower, handling it gently, or applying light mechanical disturbance released negligible pollen. In contrast, application of vibrational energy (buzzing) resulted in substantial pollen discharge.

Across morphotypes, pollen was not passively shed, nor was it readily transferred through simple contact at the pore. Instead, effective pollen release required mechanical disturbance capable of mobilizing pollen internally and directing it toward—and into—the surrounding airspace at the aperture. Where pollen is truly aerosolized or simply gently expelled when a pollinator engages with these flowers is unknown, however in each case the directionality of pollen release based on pore shape could be an important adaptive advantage. In each case, the thecae of the tested were elongate and deep, with substantial pollen located far from the pore, reinforcing the inference that internal transport and mechanical expulsion are integral components of pollen presentation in these systems.

Even in non-buzz taxa where pollen may not be projected far from the flower, directional morphology appears functionally relevant. Across most scoop-bearing species with tubular corollas, the scoop structure consistently faced inward toward the center. This orientation likely biases expelled pollen toward the interior of the flower—where a visiting pollinator would be positioned—rather than toward the corolla wall or indiscriminately outward. Such directionality supports the interpretation that controlled mechanical

expulsion into the air, even if subtle, remains an important and potentially widespread feature of pollen presentation across poricidal lineages.

Collectively, these observations justify a broader investigation into pollen expulsion mechanics across poricidal flowers, including those not traditionally categorized as buzz-pollinated. The presence of pore morphologies which direct pollen release suggests that at least localized aerosolization may be a general functional advantage, rather than a specialization limited to classical buzz-pollination systems.

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