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Pollen morphology and pollen elemental composition of select Philippine endemic gingers of tribe Alpinieae (Zingiberaceae)

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ABSTRACT

Pollen morphology and elemental composition offer critical insights into the structural, reproductive, and species-level diversity of endemic Philippine gingers in the tribe Alpinieae. This study characterized the pollen morphology and determined the elemental composition of four endemic ginger species collected from Mindanao, Philippines: *Alpinia haenkei* C. Presl, *Alpinia rufa* C. Presl; *Etlingera dostseiana* Naive, Demayo and Alejandro; and *Wurfbainia elegans* (Ridl.) Škorničk. and A.D.Poulsen. Pollen samples were obtained from various populations across multiple locations on the island. Pollen morphology was examined using light microscopy (LM) and scanning electron microscopy (SEM), while major and trace elements were determined using energy-dispersive X-ray spectroscopy (EDX). Pollen in all species is characterized as spheroidal and inaperturate. Pollen size ranged from 54–60 µm in *A. haenkei*, 30–45 µm in *A. rufa*, 30–55 µm in *E. dostseiana*, and 44–50 µm in *W. elegans*. Pollen color and ornamentation varied among the species: *A. haenkei*, *A. rufa*, and *W. elegans* produced brown, echinate pollen, whereas *E. dostseiana* had light-yellow, psilate pollen. Energy-dispersive X-ray spectroscopy analysis revealed that carbon (C) and oxygen (O) were the dominant elements across all species, while potassium (K) and copper (Cu) were present in trace amounts. These findings establish a comprehensive baseline for pollen morphology and elemental composition, with direct relevance to reproductive biology, species delimitation, and evolutionary research. Integrating these complementary datasets enhances our understanding of taxonomic relationships and affirms that pollen attributes are key diagnostic tools within the tribe Alpinieae.

Keywords: alpinieae; elemental composition; endemic; Philippine gingers; pollen morphology

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INTRODUCTION

The Zingiberaceae family comprises approximately 50 genera and 1,600 flowering plant species distributed worldwide. Southeast Asia is well-recognized as the center of diversity for Zingiberaceae (Saensouk and Saensouk, 2021). In the Philippines, the family comprises approximately 20 genera and over 140 extant species (Pelser *et al*., 2011; Leong-Škorničková and Gallick, 2010; Xu *and Chang,* 2017). Several species are aromatic plants widely utilized for their biological and pharmaceutical activities (Ke *et al*., 2000; Panchareon *et al*., 2000; Leong-Škorničková and Newman, 2015). Additionally, they are used as spices, food flavoring, traditional medicine, and ornamental plants (Boonmee *et al*., 2011; Lamb *et al*., 2013). The tribe Alpinieae (Zingiberaceae) comprises 23 genera, among which *Alpinia* Roxb., *Etlingera* Giseke, *Hornstedtia* Retz., *Meisteria* Giseke, and *Wurfbainia* Giseke are well-known. Most species within this tribe are distributed across the Indo-Malayan and Pacific regions (Ke *et al*., 2000; Kress *et al*., 2005). Members of the tribe Alpinieae are morphologically diverse and are characterized by a combination of vegetative and floral traits rather than a single diagnostic feature. Common features include leaves that are generally oriented perpendicular to the rhizome, alongside variations in floral architecture, such as the presence or absence of lateral staminodes fused to the labellum (Simpson, 2010). However, supplementary diagnostic characters, including inflorescence arrangement, labellum morphology, and stamen anatomy—are equally crucial for delimiting genera within the tribe. For instance, *Alpinia* species, such as *A. galanga* and *A. zerumbet*, characteristically exhibit distinct labellum forms with partially fused or reduced lateral staminodes. Common features include leaves that are typically oriented perpendicular to the rhizome and variation in floral structures such as the presence or absence of lateral staminodes fused to the labellum (Simpson, 2010). However, additional diagnostic characters such as inflorescence arrangement, labellum morphology, and stamen structure are also important in delimiting genera within the tribe. For instance, *Alpinia* species such as *A. galanga* and *A. zerumbet* typically exhibit distinct labellum morphologies with partially fused or reduced lateral staminodes. In contrast, *Etlingera elatior* is characterized by a conspicuous labellum and well-developed floral bracts. *Hornstedtia scottiana* exhibits reduced staminodal structures and compact inflorescences, whereas *Amomum* species display considerable variation in bract morphology and floral tube length. For instance, *A. masticatorium* possesses a longer corolla tube and distinct floral structures, while *A. testaceum* is characterized by papery oblong bracts and elongated tubular flowers. Collectively, these characters contribute to generic delimitation within Alpinieae. Overall, these morphological traits indicate that taxonomy within Alpinieae relies on a combination of multiple characters rather than a limited set of diagnostic features (Kress *et al*., 2005; Thomas *et al*., 2011; Leong-Škorničková and Newman, 2015).

Phylogenetic and evolutionary relationships within this family are often confounded by ecological conditions or evolutionary convergence, complicating efforts to resolve relationships based strictly on vegetative and floral traits (Kress *et al*., 2005). In Zingiberaceae, vegetative and floral characteristics are often insufficient for resolving evolutionary relationships. For instance, cytotaxonomic evidence proved essential for supporting species delimitation within *Kaempferia* subg. *Prothanthium* (Nopporncharoenkul et al., 2024.). Similarly, a phylogenetic reassessment of Asian Zingiberaceae by de Boer *et al*. (2018) and taxonomic studies on *Etlingera* by Mood *et al*. (2014) demonstrated that overlapping floral traits and morphological

convergence can complicate generic delimitation within the family, thereby highlighting the need for integrative systematic approaches. However, palynology provides conserved, diagnostic characteristics at both generic and specific levels. As a foundational tool in plant systematics, it offers an essential, independent dataset capable of identifying species-level variations and strengthening taxonomic classifications within the family (Wood *et al*., 1996). For example, pollen morphology of the genus *Gagnepainia* K. Schum. can provide important diagnostic features to support phylogenetic relationships, taxonomic classification, and species delimitation (Moonkaew *et al*., 2020; Ragho, 2020).

The pollen of Zingiberaceae species is typically spheroidal, inaperturate, and large (>50 µm), especially among members of the tribe Alpinieae. However, variations exist across genera and species, with surface ornamentation ranging from psilate (smooth) to more complex types such as echinate, verrucate, and striate. These scupteral differences become more evident under scanning electron microscopy (SEM) (Yuan-Hui, 1988; Theilade *et al*., 1993; Chen *et al*., 2013). In Zingiberaceae, palynological traits serve as key diagnostic markers, where exine patterns observed via SEM effectively delimit Alpinieae genera such as *Alpinia*, *Etlingera*, and *Hornstedtia*. However, Philippine endemic Alpinieae remain underrepresented in these datasets, limiting their taxonomic resolution (Saensouk *et al*., 2009; Chen *et al*., 2013; Lu *et al*., 2022; Mohamad *et al*., 2025). Alongside classical morphological characters, analyzing pollen elemental composition offers a non-traditional approach to plant systematics. This method provides complementary chemotaxonomic evidence derived from variations in elemental profile concentrations. Unlike morphological analysis, elemental profiling reflects underlying biochemical and physiological variations in pollen wall composition and reproductive function, thereby providing an additional layer of systematic evidence for taxonomic interpretation. Determining the chemical profile of pollen is closely linked to its physiological function, viability, and nutritional quality, which are essential for successful germination and fertilization. Assessing the micro – and macro-elements of pollen reflects nutrient uptake and genetically determined allocation during germination. Furthermore, it reveals species-specific chemical compositions that can aid in taxonomic classification (Lukšić *et al*., 2024; Wang *et al*., 2024; Sharma, 2025).

Energy Dispersive X-ray spectroscopy (EDX) coupled with scanning electron microscopy (SEM) allows for the precise, non-destructive assessment of elements within individual pollen grains. This integration provides a consistent, quantifiable chemical profile that complements traditional morphological analysis, thereby enriching datasets for taxonomic and evolutionary studies (Linskens, 1964; Theilade *et al*., 1993). Despite recent advances in Zingiberaceae palynology, data on the pollen morphology and elemental composition of most Philippine endemic ginger species within the tribe Alpinieae remain limited. Combining morphological and elemental composition analyses provides a comprehensive approach to resolving taxonomic challenges and uncovering species-level variations. Therefore, examining the pollen morphology and elemental profile of selected Philippine endemic gingers is essential to expand existing data, clarify classifications, and strengthen the taxonomic framework of the tribe Alpinieae.

MATERIALS AND METHODS

Plant samples

Fresh flowers of the four selected ginger species were collected from three distinct sites: (1) CEDAR, Impasug-ong, Bukidnon (*Alpinia haenkei* C. Presl. and *Alpinia rufa* C. Presl.); (2) Mt. Malambo, Barangay Datu Salumay, Davao City (*Etlingera dostseiana* Naive, Demayo and Alejandro); and (3) the CMU view deck, Musuan, Bukidnon (*Wurfbainia elegans* Elmer). For each species, 10 individual plants were selected, and at least five flowers were harvested per plant. The collected samples were placed in separate zip-lock bags to prevent desiccation and transported to the laboratory (approximately 1–2 hours away). Upon arrival, the samples were processed immediately to minimize deterioration and preserve pollen integrity and quality for subsequent examination.

Pollen Morphological Analysis

Pollens from each selected species were collected from the mature stamens of ten plants within the same population during anthesis to ensure that only fully developed and viable grains were sampled. The pollen grains were carefully removed from the anther sacs using a brush and forceps to avoid damage and were then stored in separate tubes for further analysis. The samples were mounted on glass slides with distilled water, covered with coverslips, and examined under a light microscope. Pollen samples were characterized by size, shape, color, aperture, and ornamentation. To capture their natural appearance, pollen color was visually assessed using hydrated samples. Acetolysis was omitted because Zingiberaceae pollen, characterized by a thin exine and thick intine, is highly susceptible to structural collapse and the subsequent loss of diagnostic features under this treatment.

SEM and Pollen Elemental Composition Analysis

For SEM and EDX analysis, the pollen samples were examined at Ateneo de Davao University, Davao City, Philippines. The pollen samples were mounted on a glass slide attached with carbon tape. The samples were coated with gold-palladium using the JEOL JFC-1600 Autofine Coater (Tokyo, Japan) to make the pollen surface well-suited for SEM characterization. The SEM images of the pollen samples were taken using the JEOL JSM-6510LA (Tokyo, Japan). Analytical SEM combined with an EDX analysis was used for the determination of pollen morphology and pollen elemental composition. Three SEM images were taken for each species at a magnification of 100x, 200x, and 500x.

RESULTS AND DISCUSSION

Pollen morphology

Pollen of the four selected Alpinieae species is characterized by a spheroidal, inaperturate structure, with variations in size, color, and ornamentation (Table 1). A total of 100 pollen grains were examined in this study, with 25 grains analyzed per species. The findings demonstrate that pollen size varies from medium to large, which is consistent with Erdtman's (1971) classification. The pollen grains of *A. haenkei* measure approximately 54–60 µm, followed by *W. elegans* at 44–50 µm, *E. dostseiana* at 30–55 µm, and *A. rufa* at 30–45 µm. In terms of coloration, *A. haenkei*, *A. rufa*, and *W. elegans* possess brown pollen, whereas *E. dostseiana* exhibits light-yellow pollen (Figure 1). The pollen exine ornamentation among the selected species was classified into two main types: echinate and psilate. *A. haenkei*, *A. rufa*, and *W. elegans* exhibit echinate ornamentation with a psilate interspinal region, whereas

E. dostseiana shows a predominantly psilate surface with distinct micro-pitting (Figure 2). The pollen morphology observed among the four selected Alpinieae species aligns with the general palynological characteristics of Zingiberaceae, typically described as spheroidal, inaperturate, and medium to large.

Table 1. Pollen morphological features of the four selected species from tribe Alpineae under the light microscope and scanning electron microscope.

Species	Size (µm)	Shape	Color	Aperture	Ornamentation
A. haenkei	55–60	Spheroidal	Brown	Inaperturate	Echinate
A. rufa	45–50	Spheroidal	Brown	Inaperturate	Echinate
E. dostseiana	30–55	Spheroidal	Light yellow	Inaperturate	Psilate
W. elegans	45–50	Spheroidal	Brown	Inaperturate	Echinate

According to Erdtman's (1971) classification, pollen grains measuring 25–50 µm and 50–100 µm are classified as medium and large, respectively, which is consistent with the size ranges recorded in this study. Pollen color variation is often driven by the distribution and concentration of pigments, sporopollenin, and phenolic compounds, which can vary both within populations and between species (Pacini and Hesse, 2005; Linskens, 1964). In addition, anthesis can affect pollen color due to pigment degradation and changes in water content following another dehiscence, reflecting the internal biochemical composition of pollen pigments (Pacini and Hesse, 2005; Shivanna and Tandon, 2014). Different pollen colors frequently indicate one or two major plant taxa or represent distinct species. Nevertheless, color-based identification is complicated by various confounding factors, including the constraints of human visual perception. Visual assessment is highly subjective, as it is easily influenced by illumination and moisture content, coupled with the limitation of the human eye in distinguishing subtle color variations among pollen grains (Shivanna and Johri, 1985). Multiple species within the Zingiberaceae family may produce pollen of similar colors, or conversely, a single species can generate pollen of varying shades. For instance, *A. galanga* and *E. elatior* commonly produce yellow-to-orange pollen grains, whereas *H. scottiana* has been reported to exhibit pale yellow pollen. Furthermore, pollen color in certain species can vary depending on developmental stages and pigment composition (Pacini and Hesse, 2005; Theilade *et al*., 1993; Shivanna and Johri, 1985). Despite these limitations, pollen color remains a useful and simple parameter for assessing pollen diversity. This is evidenced by the yellow-to-orange pollen found in *Zingiber officinale* and *Curcuma longa* (Theilade *et al*., 1993; Chen *et al*., 2013), as well as the cream-to-pale-yellow pollen in *E. elatior* and *Boesenbergia rotunda* (Chen *et al*., 2013; Saensouk *et al*., 2009). In addition, variations in exine ornamentation, specifically between echinate and psilate types, are widely recognized as key features for taxonomic studies in Zingiberaceae. Echinate ornamentation has been documented in genera such as *Zingiber*, *Curcuma*, and *Etlingera*, whereas psilate to finely

reticulate surfaces occur in *Alpinia*, *Hornstedtia*, and *Amomum*. These distinct patterns effectively support generic delimitation within the family (Theilade *et al*., 1993; Chen *et al*., 2013; Leong-Škorničková and Newman, 2015). Exine ornamentation, as observed in *A. haenkei*, *A. rufa*, and *W. elegans*, serves as a significant diagnostic character in Zingiberaceae, with the psilate type being less common than the echinate one. Psilate pollen is frequently observed in monocots and represents a consistent ornamentation pattern found in *Etlingera* species (Luo *et al*., 2015; Mendez *et al*., 2017). However, this type of pollen ornamentation has also been reported in several *Hornstedtia* species, suggesting that the psilate condition may represent an adaptive or phylogenetically conserved feature shared by both *Etlingera* and *Hornstedtia* (Theilade *et al*., 1993; Luo *et al*., 2015; Mendez *et al*., 2017). Additionally, the presence of micro-pitting in *E. dostseiana* further supports its distinct pollen morphology, given that micro-sculpturing enhances taxonomic classification within closely related taxa (Theilade *et al*., 1993; Saensouk *et al*., 2009; Chen *et al*., 2013; Punt *et al*., 2007). Overall, the pollen morphological patterns observed in the present study are consistent with previous palynological research (Theilade *et al*., 1993; Chen *et al*., 2013; Leong-Škorničková and Newman, 2015). These studies reported variations in exine ornamentation and pollen structure among species of *Zingiber*, *Curcuma*, *Etlingera*, and *Alpinia*, further supporting the importance of pollen morphology as a taxonomic tool within the tribe Alpinieae (Kress *et al*., 2005).

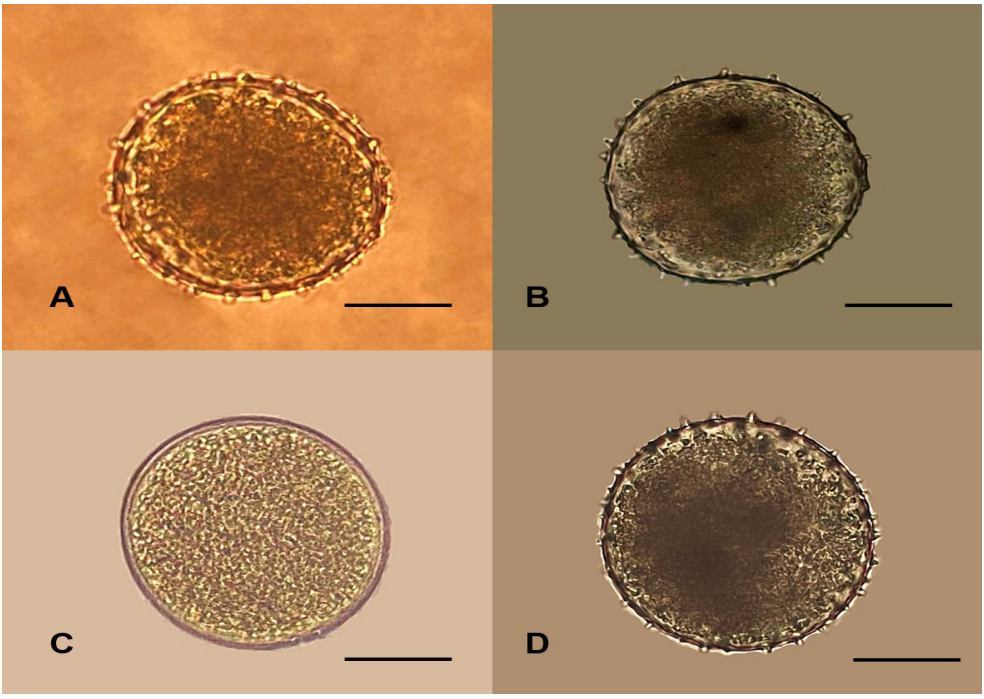

Figure 1. Light microscope images of the pollens of the four select species from tribe Alpinieae. A, *Alpinia haenkei*; B, *Alpinia Rufa*; C, *Etlingera dostseiana*; D, *Wurfbainia elegans* observed under light microscope (400x). scale bars: A–D = 50 µm.

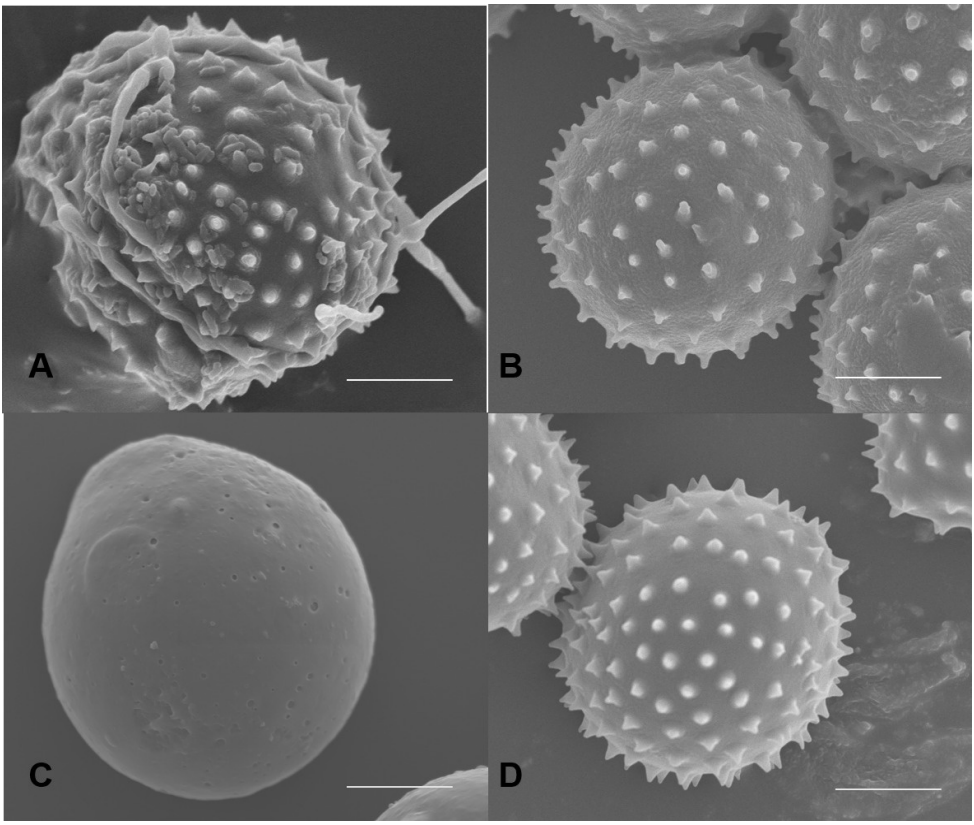

Figure 2. SEM images of pollens of the four selected Philippine endemic ginger species. A, *Alpinia haenkei*; B, *Alpinia Rufa*; C, *Etlingera dostseiana*; D, *Wurfbainia elegans* under SEM (500x). Scale bars: 50 µm.

Pollen elemental composition

EDX analysis revealed that the pollen structures of *A. haenkei*, *A. rufa*, *E. dostseiana*, and *W. elegans* (Figure 3) were predominantly composed of carbon (49–64%) and oxygen (34–40%). In addition, a notable nitrogen content (15.9%) was detected in *W. elegans* (Table 2). Trace elements were also observed across the species, including copper (0.87–1.4%), potassium (0.40–0.77%), and a minor amount of palladium (0.45%) exclusively in *E. dostseiana*.

The predominance of carbon and oxygen in the pollen of *A. haenkei*, *A. rufa*, *E. dostseiana*, and *W. elegans* reflects the conserved biochemical structure of pollen walls. In these structures, sporopollenin constitutes the exine, providing mechanical strength, UV protection, and resistance to enzymatic and microbial degradation. The elevated oxygen content is associated with polysaccharides, cellulose, and pectin, which serve as structural components and carbohydrate reserves that support pollen germination and tube growth (Luo *et al*., 2015; Mendez *et al*., 2017). These elements are crucial for maintaining pollen integrity during dispersal and initiating metabolic activation upon contact with a receptive stigma (Dominguez *et al*., 1999; Shivanna and Johri, 1985; Knox and Heslop-Harrison, 1970; Edlund *et al*., 2004). Even at low concentrations, elements such as potassium and copper play

crucial roles in pollen function. Potassium regulates osmotic potential and turgor pressure, thereby driving water uptake and pollen tube elongation during germination. Copper acts as a cofactor for enzymes involved in strengthening and remodeling the pollen tube wall. The presence of these trace elements indicates metabolic competence, aligning with previous studies that emphasize the importance of ionic balance for pollen viability and successful fertilization (Tadege and Kuhlemeier, 1999; Burkhead *et al*., 2009; Ravet and Pilon, 2023. 2023; Rathor *et al*., 2020; Wang *et al*., 2021).

The high nitrogen content (15.92%) in *W. elegans* pollen reflects an enhanced metabolic potential, given that nitrogen is a key component of proteins, amino acids, nucleic acids, and hydrolytic enzymes, all of which are essential for pollen tube emergence and growth. Nitrogen-rich pollen is associated with rapid pollen tube elongation and higher nutritive value for pollinators, which can potentially enhance pollinator visitation and reproductive success. The structural, metabolic, and physiological traits observed in *W. elegans* suggest that its pollen is both structurally resilient and metabolically enriched (Taylor and Hepler, 1997; Firon *et al*., 2012; Roulston and Cane, 2000; Keller *et al*., 2015). Nevertheless, the elemental composition detected in this study may have been partially influenced by handling and transport; the pollen samples were stored in individual zip-lock bags and transported for approximately 1–2 hours from the collection sites to the laboratory prior to analysis. Prolonged handling or transit can lead to dehydration and the adherence of atmospheric particles—such as dust and fine matter—onto the pollen surface. This may explain the presence of elements not typically observed in pollen (Shivanna and Johri, 1985).

Table 2. Pollen elemental composition (%) of the select species based on energy dispersive x-ray (EDX) analysis. Abbreviations: C, carbon; O, oxygen; N, nitrogen; K, potassium; Cu, copper; Pd, palladium.

Species	C (%)	O (%)	N (%)	K (%)	Cu (%)	Pd (%)
A. haenkei	59.71	38.22	-	0.67	1.40	-
A. rufa	59.93	40.07	-	-	-	-
E. dostseiana	64.21	34.07	-	0.40	0.87	0.45
W. elegans	49.08	34.22	15.92	0.77	-	-

Note: Pd values represent sputter coating artifacts.

Moreover, prolonged or inadequate storage conditions—such as fluctuating temperatures, high humidity, or dehydration—can compromise cytoplasmic activity and trigger biochemical alterations, thereby reducing pollen viability and altering its internal elemental composition (Halbritter *et al*., 2018; Sénéchal *et al*., 2015; Salomón-Torres et al., 2025, Buters *et al*., 2012; Cariñanos *et al*., 2014).

Additionally, vehicle emissions and industrial pollutants have been reported to cause the accumulation of heavy metals and sulfates on pollen in urban and industrial environments. This alters the chemical composition of the pollen, thereby reducing its viability and compromising its morphological integrity. The presence of palladium (Pd) in this study is likely a sputter coating artifact rather than a genuine pollen constituent; therefore, it should be treated as a contamination signal rather than a natural component (Bendale *et al*., 2015; Jin *et al*., 2016; Zhang *et al*., 2018). Overall, these findings demonstrate that while elemental profiling is a powerful tool for understanding pollen structure and function, careful methodological control is essential to distinguish intrinsic biochemical traits from artifacts and external contaminants.

Combining pollen morphology with elemental composition analysis provides valuable insights into species differentiation, pollen function, and reproductive potential among the four selected species of the tribe Alpinieae. Although the pollen characteristics in this study support taxonomic classification at the generic level, their resolution at the species level remains limited. In *Alpinia*, for instance, only pollen size varied slightly among species, while other morphological traits largely overlapped. This indicates that palynological data alone is insufficient for definitive species delimitation and should be complemented with additional morphological or molecular evidence. These findings highlight the value of palynological approaches in addressing taxonomic ambiguities and emphasize the need for continued documentation of understudied tropical lineages.

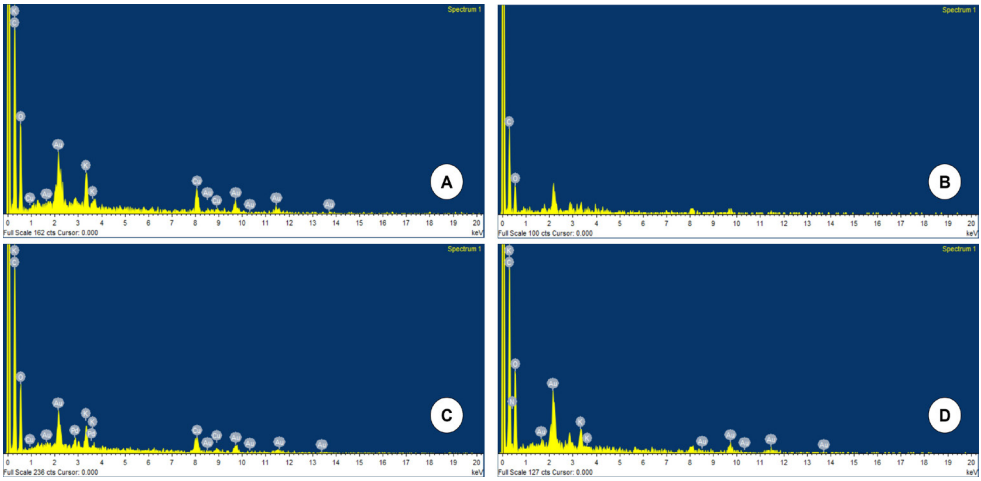

Figure 3. Energy-dispersive X-ray (EDX) spectra of pollen grains from the four Philippine endemic gingers: A, *Alpinia haenkei*; B, *Alpinia rufa*; C, *Etlingera dostseiana*; D, *Wurfbainia elegans*. Peaks associated with carbon (C), oxygen (O), potassium (K), and copper (Cu) are observed, while signals such as gold (Au) and palladium (Pd) correspond to sputter-coating materials used during SEM sample preparation.

CONCLUSION

In this study, pollen morphology and elemental composition provided complementary datasets to distinguish four endemic species of Philippine gingers within the tribe Alpinieae. Variations in exine ornamentation and elemental profiles—particularly the elevated nitrogen levels in *W. elegans*—underscore species-specific adaptations related to pollen function and reproductive potential. These findings reinforce the value of combining palynological and chemical analyses in systematic studies to enhance taxonomic classification and reproductive biology research, thereby supporting conservation efforts for understudied species. Future studies incorporating broader taxonomic sampling and molecular data could further refine the evolutionary and ecological interpretations within the tribe Alpinieae.

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