



MORPHOLOGICAL TRAITS INFLUENCING AERODYNAMIC FACTORS AND THE LONG-RANGE TRANSPORT OF *ALNUS ACUMINATA* KUNTH. POLLEN THROUGH THE ATMOSPHERE

RASGOS MORFOLÓGICOS QUE INFLUYEN EN LOS FACTORES AERODINÁMICOS Y EL TRANSPORTE DE LARGA DISTANCIA DEL POLEN DE *ALNUS ACUMINATA* KUNTH. A TRAVÉS DE LA ATMÓSFERA

Claudio Fabián Pérez^{1,2} , María M. Reader³ , Gonzalo R. Torres^{2,3} , Samuel M. Vazquez^{2,3} & Liliana C. Lupo^{2,3}

SUMMARY

1. Departamento de Ciencias de la Atmósfera y los Océanos, Facultad de Cs. Exactas y Naturales, Edificio Cero+Infinito, CABA, Argentina
2. Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET)
3. Instituto de Ecorregiones Andinas (INECOA), Universidad Nacional de Jujuy-CONICET, San Salvador de Jujuy, Argentina

*perez@at.fcen.uba.ar

Citar este artículo

PÉREZ, C. F., M. M. READER, G. R. TORRES, S. M. VAZQUEZ & L. C. LUPO. 2025. Morphological traits influencing aerodynamic factors and the long-range transport of *Alnus acuminata* Kunth. pollen through the atmosphere. *Bol. Soc. Argent. Bot.* 60: 319-330.

DOI: <https://doi.org/10.31055/1851.2372.v60.n4.49834>

org/10.31055/1851.2372.v60.n4.49834

Background and aims: This study aims to characterize the size distribution of *Alnus acuminata* pollen grains as emitted into the air near their source of origin in the southernmost South American Yungas, and to provide estimates of their settling velocity.

M&M: The samples were collected on August 22, 2023, using a Hirst-type spore trap located 1.6 m above the ground, operated at a constant suction volume of 0.06 m³ h⁻¹. The number of apertures, as well as the polar and equatorial diameters, of 2348 *Alnus* pollen grains were counted and measured on even hours for each slide using an optical microscope at 1000x final magnification.

Results: *Alnus* pollen grains have 3 to 6 pores, with the most common numbers being 4 pores (37 %) and 5 pores (61 %). The polar diameters range from 12.5 to 20 µm, depending on the time of occurrence. The equatorial diameter varied from 17.5 to 28.5 µm, with no size differences between 4- and 5-pored grains. The estimated settling velocity ranged from 0.59 to 1.48 cm s⁻¹ thus; *A. acuminata* is dispersed by turbulence similarly to particles with no inertia.

KEYWORDS

Airborne pollen, Argentina, Montane Forest, size distribution, Yungas.

RESUMEN

Antecedentes y objetivos: Este estudio busca caracterizar la distribución del tamaño de los granos de polen de *Alnus acuminata* al ser liberados a la atmósfera, en cercanías de su fuente de origen en las yungas más australes de Sudamérica, y proporcionar estimaciones de su velocidad de sedimentación.

M&M: Las muestras se recolectaron el 22 de agosto de 2023 con una trampa tipo Hirst ubicada a 1,6 m del suelo, operada a un volumen de succión constante de 0,06 m³ h⁻¹. Se contaron y midieron el número de aperturas y los diámetros polar o ecuatorial de 2348 granos de polen de *Alnus* en horas pares de la muestra diaria, con un microscopio óptico y un aumento final de 1000x.

Resultados: Los granos de polen de *Alnus* presentan de 3 a 6 poros, siendo los más comunes aquellos con 4 (37 %) y 5 poros (61 %). Los diámetros polares oscilan entre 12,5 y 20 µm, en función de la hora de ocurrencia durante el día. El diámetro ecuatorial varió entre 17,5 y 28,5 µm, sin diferencias de tamaño entre los granos de 4 y 5 poros. La velocidad estimada de sedimentación osciló entre 0,59 y 1,48 cm s⁻¹, por lo que se puede inferir que *A. acuminata* se dispersa por turbulencia de manera similar a las partículas sin inercia.

PALABRAS CLAVE

Argentina, Bosque Montano, distribución de tamaño, polen anemófilo, Yungas.

Recibido: 13 Ago 2025

Aceptado: 13 Oct 2025

Publicado en línea: 27 Nov 2025

Publicado impreso: 31 Dic 2025

Editora: Georgina Erra

ISSN versión impresa 0373-580X

ISSN versión on-line 1851-2372

INTRODUCTION

Alnus Mill. is one of the six genera of the Betulaceae family, which currently has 29 to 35 recognized species (Chen & Li, 2004). It is considered one of the oldest dicots since its pollen appears from the Late Cretaceous (Rouse, 1970; Wolfe, 1973). Most species are distributed in the boreal regions of the Northern Hemisphere, except for *Alnus acuminata* Kunth., which extends into the Southern Hemisphere through the Andes slopes (1600-2700 m above mean sea level) to approximately 29° S in Catamarca Province of Argentina (Grau, 1985).

Alnus is a monoecious, wind-pollinated plant. Cylindrical male catkins sprout in late winter, turning yellow after they ripen, releasing thousands of grains per cubic meter of air at peak times (Shayanmehr *et al.*, 2015). Among the morphological features of their pollen grains, they have three or more protruding pores arranged equatorially (stephanoporate), each one surrounded by exine thickening (annulus). Thickened, curved bands (arci) often connect the annuli of each grain. The overall shape of the pollen grains is oblate. Depending on their moisture content, they are sub-circular or polygonal in polar view. With light microscopy, no exine ornamentation is visible on the pollen grain surface (psilate) (Fægri & Iversen, 1989; May, 2011); however, it appears scabrate under a scanning electron microscope (Blackmore *et al.*, 2003). These characteristics help keep *Alnus* pollen airborne after its release, facilitate its uplift, and enable its transport over long distances. Recent studies indicate that *A. acuminata* can be transported thousands of kilometers towards southeastern South America by monsoon circulation systems such as the South American Low-Level Jet (Pérez *et al.*, 2024). However, predicting the extent of dispersal of this pollen type requires the use of atmospheric transport models, for which it is essential to input aerosol specifications, such as the aerodynamic characteristics of the particles and their emission rate. Specific variables such as settling velocity influence the persistence of wind-borne pollen in the air, which in turn determines its transport distance. Nevertheless, this variable has been quantified for relatively few plant species.

This study aims to characterize the size

distribution of *A. acuminata* pollen grains as they are emitted into the air near their source of origin in the southernmost Yungas, and to provide estimates of their settling velocity. These features will assist future studies on the reproductive fitness of anemophilous species, as well as conservation efforts and the prevention of genetically modified gene flow.

Biophysical setting of the study site

The study site is situated on an east-facing slope, near Laguna Comedero (24° 11' 06" S, 65° 48' 52" W, 2124 m above mean sea level), within the Potrero de Yala Provincial Park, Jujuy, Argentina (Fig. 1). Monitoring started on March 15, 2023, when an automatic weather station and pollen sampling device were installed. The climate

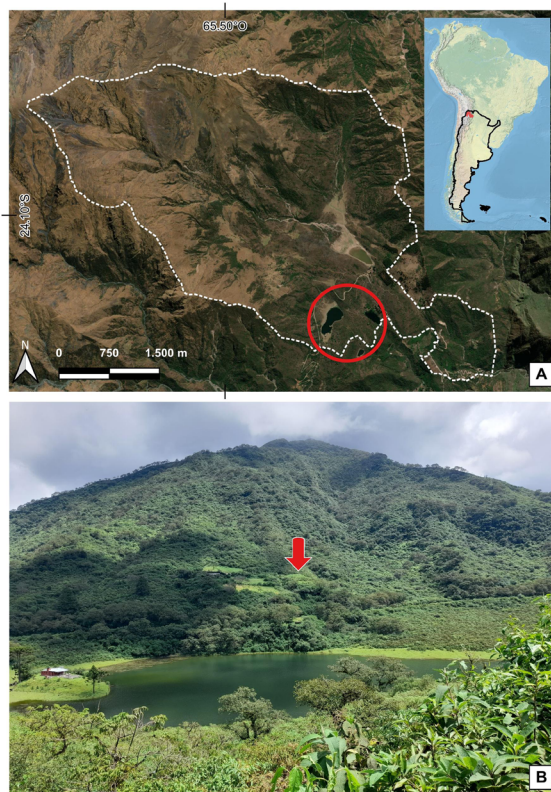


Fig. 1. A: Location of Laguna Comedero (red circle) and boundaries of the Potrero de Yala Provincial Park (white dotted line). **B:** Laguna Comedero and east-facing slope with alder forest. The red arrow shows the location of the study site.

is characterized as humid subtropical, with dry and cold winters and occasional frosts. Data recorded at a nearby meteorological station (Rodeo station, 1972-1990, 1995 m a.s.l.) showed that 86 % of the annual precipitation (1470 mm) falls during summer (October to March), and the mean annual temperature is 15.9 °C (Lupo *et al.*, 2006).

From a phytogeographical standpoint, the site is located within the Yungas province, in the Montane Forest district. The forest is characterized by open stands of 'aliso del cerro' (*Alnus acuminata* Kunth.) with an understory composed of several shrubs (Madeo *et al.*, 2014). Secondary tree species 'saúco' or 'molulo' (*Sambucus nigra* Kunth. var. *peruviana*) and 'molle' (*Schinus gracilipes* I. M. Johnst.) stand out. The sampling device is located in a clearing surrounded by abundant 'salvia' shrubs (*Lepechinia vesiculosa* (Benth.) Epling), accompanied by different *Baccharis* L. species.

MATERIALS AND METHODS

Atmospheric pollen monitoring was performed using the volumetric-isokinetic technique (Hirst, 1952), with a Sporewatch trap. For this study, we selected August 22, 2023, because large quantities of *Alnus* pollen (2348 pollen grains) were detected. The trap is operated at a constant suction volume of 0.06 m³ h⁻¹, with its inlet located 1.6 m above the ground. The technique is widely used in Europe, Asia, Africa (European Aerobiology Society, 2023-2024 EAS members), and America. Methodology is described in detail in the webpages of the *Red Latinoamericana de Aerobiología*

(REDLA) and the Spanish Aerobiology Network (REA). REA also published a management and quality manual (Galán Soldevilla *et al.*, 2007).

The preparation of anhydrous sticky surface and mounting media for slides was carried out using standard techniques (Käpylä & Penttinen, 1981). Pollen counts were conducted at even-hour intervals (local time) using an optical microscope at 400X magnification, and pollen grain identification was performed following specialized literature (Heusser, 1971; Markgraf & D'Antoni, 1978).

Number of apertures and size characterization of the pollen grains

Polar and equatorial diameter measurements [μm] were obtained using a micrometer scale at 1000X (Fig. 2). The number of apertures in each pollen grain was also counted. The results are expressed as pollen counts and relative frequencies.

Settling velocity and volume estimation for A. acuminata pollen grains

Understanding settling velocity is crucial for predicting how particles behave in a fluid. This concept describes the speed at which a particle sinks through a stationary fluid due to the force of gravity (Hanna *et al.*, 1982). Settling velocity is attained when the particle stops accelerating and moves at a constant speed. This occurs with no lateral displacement due to wind when the forces of gravity and fluid resistance are in balance. For spherical particles within the range of sizes of most pollen grains (diameters from 20 to 60 μm),

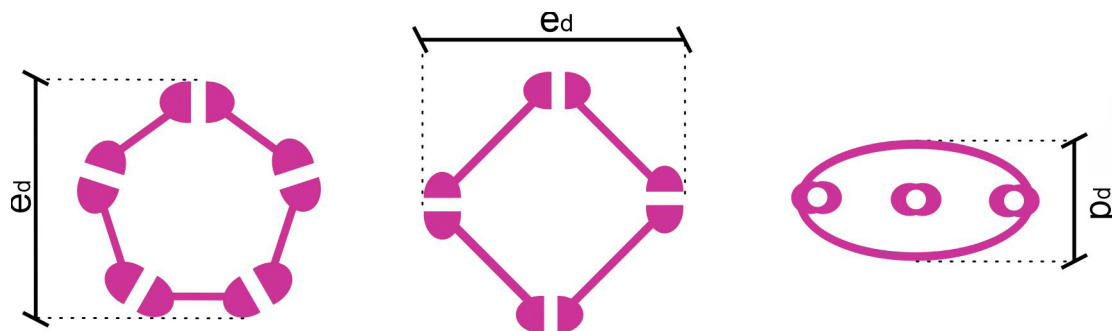


Fig. 2. Equatorial (*ed*) and polar (*pd*) diameters obtained from 4 and 5-pored *Alnus* pollen grains in polar and equatorial view.

the settling velocity can be estimated from the Navier-Stokes equation as

$$v_s = \frac{2}{9} \frac{r^2 (\rho_p - \rho_{air}) g}{\mu}$$

r is the particle radius, ρ_p and ρ_{air} are the densities of the particle and air, g is the gravitational acceleration, and μ represents the dynamic viscosity of the air. For any given release height and lateral displacement of the pollen grain per unit time, the dispersal range will increase as the settling velocity decreases (Niklas, 1985). Non-spherical particles have different drag forces; therefore, this equation can be corrected with a shape factor. Another strategy is to replace r by a spherical equivalent approximation by volume, which involves treating the particle as a sphere with equal volume. Being an oblate spheroid, the volume of *Alnus* pollen grains was calculated as:

$$v_{spheroid} = \frac{4}{3} \pi \left(\frac{ed}{2} \right)^2 \frac{pd}{2}$$

$v_{spheroid}$ is the volume (m^3), ed and pd are the equatorial and polar diameters (μm , 1×10^{-6} m), respectively. Replacing r with the oblate spheroid volume, the v_s formula can be written as:

$$v_s = \frac{2}{9} \frac{(\rho_p - \rho_{air}) g}{\mu} \left(\frac{3v_{spheroid}}{4\pi} \right)^{\frac{2}{3}}$$

Since the equatorial and polar diameter measurements were obtained from independent samples, the volume calculations were conducted using 10000 simulations based on the Monte Carlo technique. This process generated ordered pairs of both diameters, resulting in a synthetic statistical distribution of the volume of *Alnus* pollen grains. With no specific *Alnus* data available, we considered $\rho_{Betula} = 800 \text{ kg m}^{-3}$ as reported by Sofiev *et al.* (2006) to be a good approximation for v_s calculations.

The settling velocity is expressed in cm s^{-1} , making the numbers easier to handle. Data were analyzed using statistical tests (Student's *t*-test, ANOVA, Bonferroni multiple comparison test, and Dagostino's goodness of fit test).

RESULTS

Alnus pollen grains collected in the air from Potrero de Yala Provincial Park showed 3 to 6 elongated pores. However, the most common types were those with 4 and 5 pores, representing 37-61 % of the 2348 pollen grains counted (Fig. 3). These morphological traits are distributed unevenly throughout the day. Four-pored grains

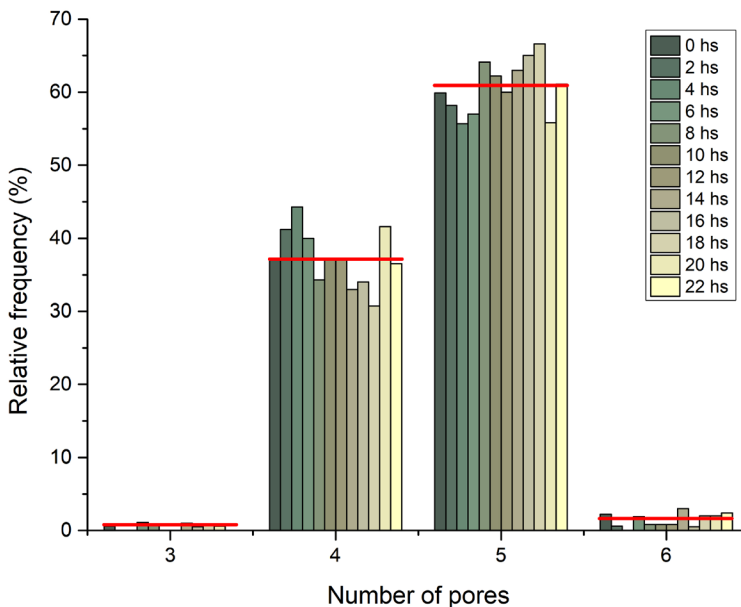


Fig. 3. Distribution of pollen grains categorized by the number of pores (indicated by the red line) and by different hours (bars).

dominate during the early morning from 2:00 to 8:00 and again at 20:00, while five-pored grains are more prevalent from 8:00 to 18:00 (Fig. 3).

Equatorial diameters range 17.5-27.5 and 18.5-28.5 μm for 4 and 5-pored grains, respectively, although mean values showed no differences (t -statistic= 0.9328, $DF= 2290$, $p= 0.351$, $\alpha= 0.05$). The calculated mean diameter for *A. acuminata* (4+5-pored grains) is $23.3 \pm 1.6 \mu\text{m}$ ($n= 2292$) with a range of 17.5-28.5 μm .

There were no variations in diameter for the 4-pored grains throughout the day (Table 1, Fig. 4); instead, variations were observed in the diameters of the 5-pored grains (Table 2, Fig. 5). The diameter at 6:00, on average, was 0.8 μm greater than at 20:00 and 22:00 (Bonferroni test $p= 0.015$ and $p= 0.012$, respectively. $\alpha= 0.05$).

Polar diameter ranged between 12.5 and 20 μm with a mean value of 16.3 μm and standard deviation $s= 1.9 \mu\text{m}$ ($n= 225$) (Fig. 6).

Table 1. One-way ANOVA summary table for equatorial diameter of 4-pored grains. Abbreviation= F: Factor (hours of the day).

	DF	Sum of squares	Mean square	F	p-value
Factor	11	552.833	48.439	16.996	0.0687
Error	869	24.766.117	28.499		
Total	880	25.298.950			

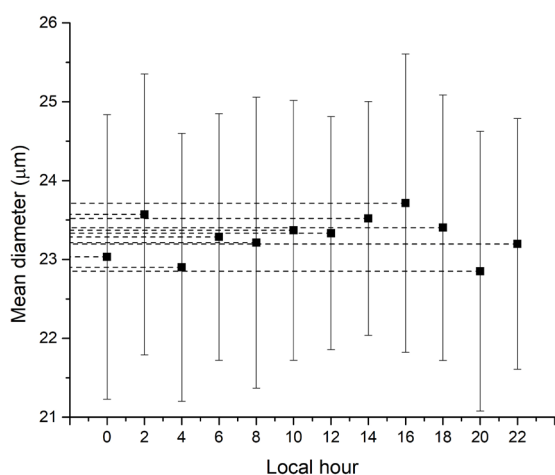


Fig. 4. Hourly mean equatorial diameter and standard deviations for 4-pored *Alnus* grains.

The polar diameters of airborne pollen grains change throughout the day (Table 3, Fig. 7). Mean diameters at 10:00, 14:00, and 16:00 were 2.3, 2.1, and 2.2 μm shorter than the 17.9 μm registered at 2:00 (Bonferroni test $p= 0.017$, $p= 0.040$, and $p= 0.013$, respectively).

Goodness-of-fit tests for the statistical distributions usually associated with aerosols (Normal, Lognormal, and Gamma distributions) for the size, volume, and mass of *Alnus* pollen grains were rejected with probabilities virtually zero. However, the size distribution can be considered normal according to the results of the D'Agostino test with a 95 % confidence (Fig. 8, Table 4).

According to the cumulative counts of figures 6 and 8, most of the collected grains are oblate. The probability of spheroidal grains is 18 %,.

Table 2. One-way ANOVA summary table for equatorial diameter of 5-pored grains. Abbreviation= F: Factor (hours of the day).

	DF	Sum of squares	Mean square	F	p-value
Factor	11	770.768	70.069	26.090	0.0027
Error	1413	37.948.530	26.856		
Total	1424	38.719.298			

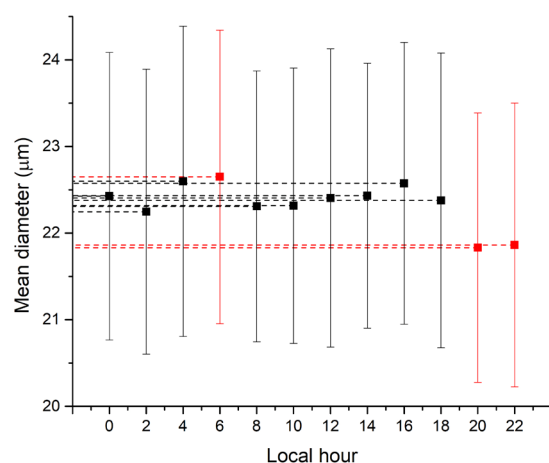


Fig. 5. Hourly mean equatorial diameter and standard deviations for 5-pored *Alnus* grains. Red-marked hours show a significant difference in diameters for the Bonferroni test ($\alpha= 0.05$).

which can be approximated as:

$$P_{(spheroidal\ grain)} \approx \sum_{i=1}^r \min(f_{polar}^i, f_{equatorial}^i) * \Delta d$$

Where r is the number of bins shared by both distributions, Δd is the width of the bin, f_{polar}^i and $f_{equatorial}^i$ the frequencies of bin i , relativized to the sum of frequencies for the shared bins.

The results of 10000 simulations yielded the synthetic distribution of *A. acuminata* pollen grain volumes (not shown), from which the corresponding settling velocities were derived. Expected v_s ranged from 0.59 cm s⁻¹ to a maximum of 1.48 cm s⁻¹ (Fig. 9). The mean value reached 1.03 cm s⁻¹, and the

standard deviation was 0.13 cm s⁻¹. Despite the remarkably symmetrical distribution, no significant fit to a normal distribution was found.

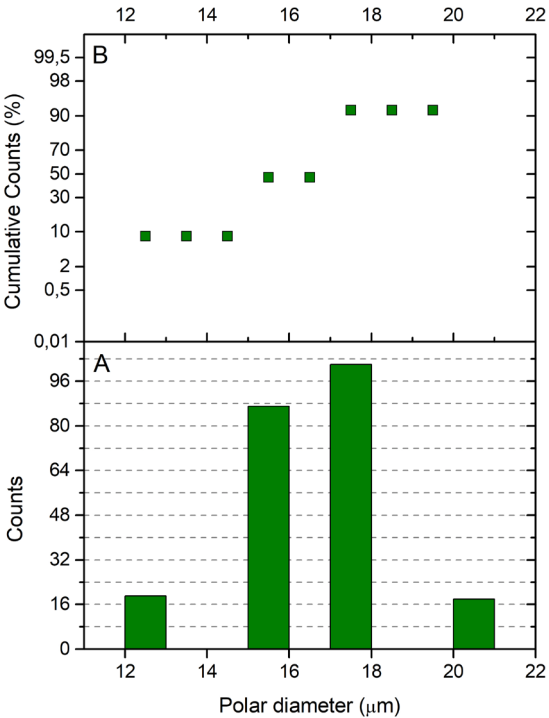


Fig. 6. Observed distributions of counts (A) and cumulative counts (B) of the polar diameter of *Alnus* pollen grains.

Table 3. One-way ANOVA summary table for polar diameter. Abbreviation= F: Factor (hours of the day).					
	DF	Sum of squares	Mean square	F	p-value
Factor	11	747.058	67.914	19.642	0.0333
Error	214	7.399.235	34.576		
Total	225	8.146.294			

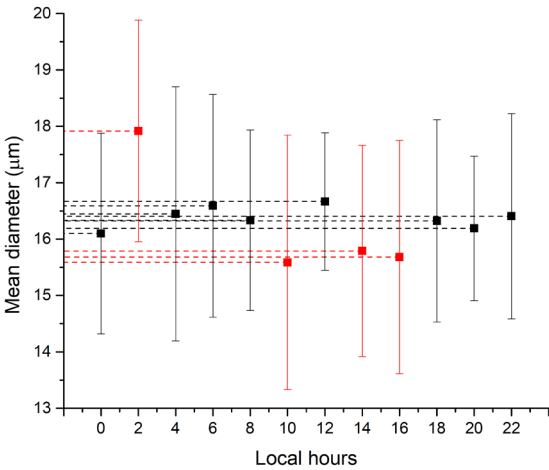


Fig. 7. Hourly mean polar diameter and standard deviations for *Alnus* pollen grains. Red-marked hours show a significant difference in diameters for the Bonferroni test ($\alpha=0.05$).

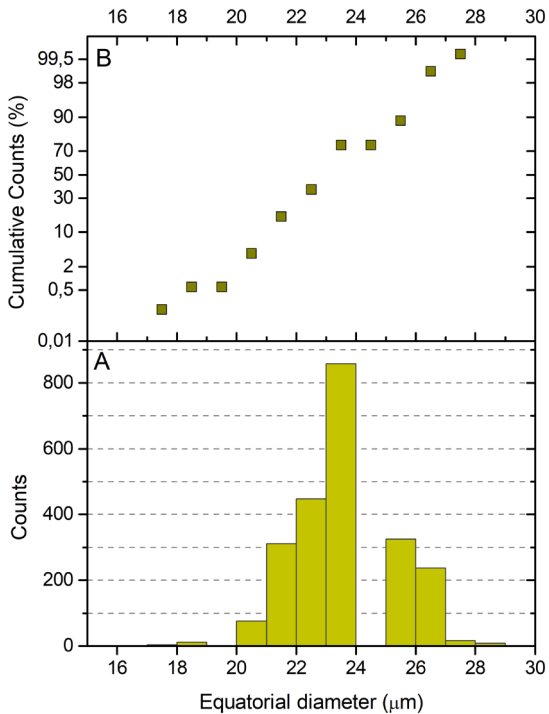
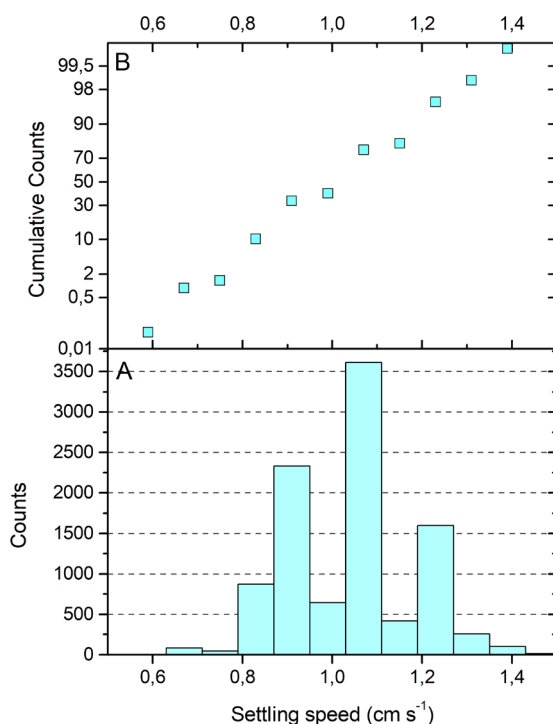


Fig. 8. Observed distributions of counts (A) and cumulative counts (B) of the equatorial diameter of *Alnus* pollen grains (4 and 5-pored grains).

Table IV. Summary table of the D'Agostino-K-squared normality test for the size distribution of *Alnus* pollen grains.

Proof	Statistic	p - value
D'Agostino omnibus	18.693	0.3927
D'Agostino skewness	-11.580	0.2468
D'Agostino kurtosis	0.7268	0.4673

**Fig. 9.** Synthetic distribution of settling velocity for *Alnus* pollen grains (4 and 5-pored grains) for counts (A) and cumulative counts (B). See text for detailed explanation.

DISCUSSION

Morphological features of A. acuminata pollen grains

Pollen grains tend to be morphologically consistent within plant species and many genera because any change could affect species fitness. However, to survive environmental changes, some degree of plasticity is also expected. In the case of wind-pollinated species, the dispersal medium exerts a strong selection on morphological traits. For instance, there is consensus that the number of

apertures is subject to significant selective pressure, which shows a wide range of variation throughout angiosperms (Heslop-Harrison, 1979; Albert *et al.*, 2022). Pores and furrows facilitate pollen tube emergence while also relieving mechanical stress during the phases of air desiccation and rehydration upon arrival at the stigma (Heslop-Harrison, 1979; Božič & Šiber, 2020). Such contrivance (harmomegathus) helps to avoid plasmolysis of the cytoplasm. As a result, there is a general evolutionary trend toward an increasing number of apertures (Furness & Rudall, 2004), which, to some extent, also produces mechanical weakening of the wall under osmotic stress (Prieu *et al.*, 2016). Some authors suggest that triaperturate pollen might be the best trade-off between these opposed trends, ensuring survival during volume changes, which presumably explains the prevalence of this morphological trait within eudicots (Harley, 2004; Albert *et al.*, 2018).

The *Alnus* pollen grains analyzed in this study exhibited a significant predominance of 4 and 5-pored grains, occurring 18 to 30 times more frequently than other aperture traits. This is consistent with data reported by other authors for different species of the genus, where 4- and 5-apertured grains also predominate (Vishnu-Mittre & Sharma, 1963; Heusser, 1971; Markgraf & D'Antoni, 1978; Leopold *et al.*, 2012; May & Lacourse, 2012; Temizer & Turkmen, 2016). According to Heslop-Harrison (1979), the number and position of the openings tend to maximize contact with the stigma and rehydration, which perhaps explains the predominance of 4 and 5-apertured grains in this genus. Four-pore grains are more common in the early morning, while 5-pore grains prevail during the day. However, this difference is not related to the equatorial diameter and consequently the size of the grains captured at those times. Therefore, we believe this could be a peculiarity of the specific capture day, rather than a recurring feature in the record.

The equatorial diameter we measured aligns with those recorded by Temizer & Turkmen (2016) but is smaller than those by Nair (1961), Heusser (1971), and Markgraf & D'Antoni (1978). This discrepancy is due to the treatment methods used. The former authors employed the Wodehouse (1935) technique, which preserves grain content, whereas the latter used acetolyzed grains, which often increase in size.

There is little information about the polar diameter. The only reports we found were a median value of $21.9 \pm 1.34 \mu\text{m}$ for *Alnus glutinosa* (Temizer & Turkmen, 2016) and an average size of $18.75 \pm 0.62 \mu\text{m}$ (Sahli *et al.*, 2023), slightly larger than our observation (mean = $16.3 \pm 1.9 \mu\text{m}$). The mean value at 2:00 was somewhat larger than at 10:00, 14:00, and 16:00 (Fig. 7), although it is not clear why these hourly differences arise. Tri-furrowed eudicots often change from an oblate-spheroidal or spheroidal shape to a prolate form when dehydrated (Halbritter & Hesse, 2004; Božič & Šiber, 2020). In contrast, pore-shaped species exhibit minimal equatorial changes, becoming cup-like upon dehydration (Halbritter & Hesse, 2004; Božič & Šiber, 2020). The polar radius is affected more than the equatorial radius, which remains stable due to support from exine reinforcements like annuli and arci. Nevertheless, the variation in shape we observed was surprisingly minimal, with most of the grains being oblate. The maximum expected probability of spheroidal grains was 18 %. This low percentage of spheroidal grains can be attributed to the prevailing meteorological conditions on August 22, 2023, with a mean temperature of $23.57 \pm 0.19 ^\circ\text{C}$ and a mean relative humidity of $4.14 \pm 0.39 \%$, which mirrored the Foehn effect, locally known as the ‘viento norte’. Such extreme dryness promotes severe dehydration of suspended pollen, leading to the reduced shape variation we recorded.

The polar and equatorial diameters do not follow common aerosol statistical distributions such as normal, lognormal, or gamma (Friedlander, 2000). Figures 6 and 8 suggest this may result from limited case reporting for specific measurement intervals, likely due to the measurement instrument’s poor accuracy. However, the D’Agostino test indicates that the distribution of equatorial diameters can be considered normal. This lesser-known test, based on shape parameters, performs well compared to traditional methods, especially with large sample sizes (D’Agostino *et al.*, 1990; Yap & Sim, 2011).

Settling velocity considerations

The turbulent intensity of the atmosphere and the terminal settling velocity of the particle are two of several factors influencing the distance a pollen grain can be dispersed from a source point. The first one depends on the wind shear and surface

roughness, while the second is determined by shape and pollen grain density. Spherical particles can be easily measured, whereas non-spherical particles require several approximation techniques (Lv & Zhao, 2022). Pollen grain density, instead, is much more difficult to estimate, mostly because of the heterogeneous constituents of the pollen grain. It depends on the exine thickness and the proportion of storage substances, primarily starch, in anemophilous plants (Roulston & Buchmann, 2000). While the exine of the cell wall is hydrophobic, the other constituents are highly hygroscopic, so the density calculation depends largely on ambient humidity. For instance, Sosnoskie *et al.* (2009) found that the density of the solid portion of *Amaranthus palmeri* pollen grains is 1435 kg m^{-3} . However, when the grains are fully hydrated, their density decreases to 1218 kg m^{-3} . This seemingly contradictory change can be explained by the fact that the volume of some pollen grains increases significantly more than their mass when water enters the protoplast. However, this is not the case for pollen grains that undergo minimal shape changes during dehydration. Although advanced experimental techniques are now available to measure pollen grain density (Van Hout & Katz, 2004; Loubet *et al.*, 2007; Sabban & Van Hout, 2011), the results remain highly dependent on the humidity conditions during testing. Thus, the density used in this study (800 kg m^{-3}) is significantly lower than the values reported by Durham (1943), but closely aligns with the findings of Hirose & Osada (2016) for different species. Establishing reliable comparisons with settling velocity observations from other authors is challenging for the same reasons outlined previously. However, our values align well with the deposition velocity measurements reported by Hirose & Osada (2016), who also studied highly dehydrated pollen. Conversely, the deposition velocity measurements from Di-Giovanni *et al.* (1995) are notably higher than ours. These tests were conducted under controlled relative humidities of around 50 to 52 %. While these levels are typically observed in natural conditions during pollen release (less than 60 %), they are significantly higher than the 4.14 % recorded during our observations. After considering all these factors, an estimated deposition velocity of 1.03 cm s^{-1} is reasonably aligned with the ranges reported by other authors

for various species. Our calculations were based on the equivalent volume of a spherical particle. The drag force for non-spherical particles can lead to differences in deposition velocities, which can be accounted for by typically dividing by a shape factor α (Hanna *et al.*, 1982). Chamberlain (1975) provides different values for this factor, which, based on the axis ratio of *A. acuminata* (1.4), would range between 1.06 and 1.14. Since these values are so close to 1, we decided not to apply a correction to the calculated value of v_s . Given the low deposition velocity, it can be inferred that *A. acuminata* is dispersed by turbulence similarly to particles with no inertia.

Our data is based on observations made during a single day with exceptionally high atmospheric pollen concentrations, likely reflecting a ‘viento norte’ condition. This raises the question of whether the measurements obtained are representative of days with less extreme temperature and humidity conditions. The day chosen for this study is likely an atypical case because days with exceptionally high concentrations are rare. Despite this, in terms of the percentage of total grains, it is possible that the vast majority of these grains were released under conditions of low relative humidity, even without northerly winds. It would therefore be necessary to analyze these proportions to determine the representativeness of the results. Additional and more comprehensive measurements are needed. If *Alnus* responds to changes in humidity by significantly deforming the pollen grain, which decreases its density, we would expect a reduction in settling velocity. This would enhance its buoyancy, allowing for transport over greater distances. The settling velocity is a key parameter in Quantitative Palynology, as outlined by Sutton’s abbreviated model (see Prentice, 1985), which tracks pollen transport until it reaches the ground. Settling velocity increases with wind speed (u), and pollen grains experience varying speeds throughout the day and seasons. Notably, the ratio $V_s u^{-1}$ remains stable over a wide range of wind conditions. Consequently, when V_s is known, this ratio is effectively treated as a single composite parameter for each taxon in Quantitative Quaternary Palynology.

The fragmentation of natural habitats caused by human activities decreases the effective population size and gene flow necessary for preserving the

genetic diversity of species (Borrel, 2012). These changes have already accelerated and are projected to worsen in the future, threatening population stability by diminishing the number of alleles and increasing the likelihood of genetic drift. The consequence of this situation is a decrease in the ability of populations to adapt to future changes. For this reason, studying tree species like *A. acuminata* is important for conservation, not only because of their value as a forest resource but also due to their ability to stabilize mountain slopes. The study of the connectivity between isolated populations of wind-pollinated trees can be effectively explored through mechanistic modeling, which relies on the type of information provided in this research. In practical applications, this approach may also be beneficial for analyzing the transfer of pests, diseases, or genetically modified genes to natural populations (Watrud *et al.*, 2004). Additionally, based on the findings related to transport distances, it may be beneficial to design buffer zones to promote isolation between populations for management purposes.

AUTHORS CONTRIBUTION

Claudio F. Pérez designed the research and wrote the manuscript, with Gonzalo R. Torres and Liliana C. Lupo. María M. Reader, Gonzalo R. Torres, and Samuel M. Vásquez performed the pollen sampling. María M. Reader and Claudio F. Pérez performed the counts and microscopic measurements. Claudio F. Pérez, María M. Reader, and Samuel M. Vásquez collaborated on the calculations, preparation of figures, tables, and bibliography.

ACKNOWLEDGMENTS

We thank the authorities of the *Ministerio de Ambiente y Cambio Climático* of Jujuy Province for granting permission for this research in the protected area (Resol. N° 040/2024-SBDS) and Mr. Juan Aima for allowing the installation of the equipment. This research was supported by ANPCyT (Agencia Nacional de Cooperación Técnica), grant PICT 2020-Series A-00366 “Biological Tracers of the Low-Level Jet in Southeastern South America. Application to the

Study of Past Climate Reconstruction,” awarded to C.F.P.

PRIMARY DATA AVAILABILITY

<http://hdl.handle.net/11336/266883>

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