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Plants that allocate more resources to flower production yield more fruit at local and global scales

Valentina Barrero-Flores[1]*; https://orcid.org/0000-0002-2719-0719
Jorge Andrés Bello-Rodríguez[1]; https://orcid.org/0009-0002-6724-6913
Eduardo José Pinel-Ramos[1]; https://orcid.org/0009-0004-4442-9164
Manuel Lequerica Tamara[2]; https://orcid.org/0000-0002-1044-3820
Pablo R. Stevenson[1]; https://orcid.org/0000-0003-2394-447X

1. Laboratorio de Ecología de Bosques Tropicales y Primatología (LEBTYP), Departamento de Ciencias Biológicas, Universidad de Los Andes, Cr. 1 no. 18ª-10 Bogotá, D.C, Colombia; valentina.barrero.vb@gmail.com (*Correspondence), ja.bello10@uniandes.edu.co, eduardo.jose.pinel@gmail.com, pstevens@uniandes.edu.co
2. School of Life and Environmental Sciences, Faculty of Science, The University of Sydney, Camperdown NSW 2050, Sydney, Australia; manuel.lequerica@sydney.edu.au

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ABSTRACT

Introduction: The internal mechanisms of plants and their interactions with the environment determine flower and fruit production. Several hypotheses have been proposed to explain these processes, emphasizing resource limitations, interactions with pollinators, selective abortion, the characteristics and positions of hermaphroditic flowers, and the influence of environmental variables on plant function.

Objectives: This research aims to evaluate whether a high allocation to flowers positively affects the fruit production of hermaphroditic plants, as predicted by the pollinator attraction hypothesis, or whether it negatively correlates, as suggested by the selective abortion hypothesis.

Methods: Both a local (Medina, Colombia) and a global database, based on the biomass of flowers and fruits collected using fruit traps were used to determine the possible relationship between the variables. The Medina database included data from 5-10 individuals for each of the seven plant species studied, with entire flowering and fruiting periods monitored. The global dataset encompassed 92 locations across 10 counties in Latin America, 2 in Europe, 2 in Africa, 2 in Asia and 1 in Oceania. This database compiled information on the total biomass of flowers and fruits of different plant species produced over at least one annual cycle.

Results: The plant species studied and the global analysis revealed a positive relationship between flower and fruit production, supporting the pollinator attraction hypothesis. Although we did not quantify the biomass of aborted fruits, we found no evidence to suggest that high flower production results in an excess of ovules that cannot develop, as predicted by the selective abortion hypothesis.

Conclusions: These findings suggest that plants have evolved allocation mechanisms for flower production that align with the potential for fruit development.

Key words: flowers; fruits; Colombia; selective abortion; pollinator attraction.

RESUMEN

Las plantas que asignan más recursos a la producción de flores producen más frutos a escala local y global

Introducción: Los mecanismos internos de las plantas y sus interacciones con el ambiente determinan la producción de flores y frutos. Para explicar estos procesos se han propuesto varias hipótesis, enfocadas en la limitación

de recursos, la interacción con polinizadores, el aborto selectivo, las características y posición de las flores hermafroditas y el efecto de las variables ambientales en los procesos internos de las plantas.
Objetivos: Evaluar si una alta asignación a flores afecta positivamente la producción de frutos de plantas hermafroditas, como predice la hipótesis de la atracción de polinizadores, o si se correlaciona negativamente, como lo sugiere la hipótesis de aborto selectivo.
Métodos: Para determinar la posible relación entre las variables se utilizó una base de datos local con muestras de Medina, Colombia y otra global, basada en la biomasa de flores y frutos recolectados mediante trampas de frutos. La base de datos de Medina incluyó datos de 5-10 individuos para cada una de las siete especies evaluadas, tomando en cuenta períodos completos de floración y fructificación. El conjunto de datos global abarcó 92 localidades, con 10 países en Latinoamérica, 2 en Europa, 1 en Oceanía, 2 en África y 2 en Asia. Esta base de datos recopiló información sobre la biomasa total de diversas especies de flores y frutos producidos durante al menos un ciclo anual.
Resultados: Las plantas estudiadas y el análisis global revelaron una relación positiva entre la producción de flores y frutos, apoyando la hipótesis de la atracción de polinizadores. Aunque no cuantificamos la biomasa de frutos abortados, no encontramos evidencias que sugieran que una alta producción de flores resulte en un exceso de óvulos que no puedan desarrollarse, como predice la hipótesis del aborto selectivo.
Conclusiones: Estos hallazgos sugieren que las plantas han evolucionado mecanismos de asignación para la producción de flores que se alinean con el potencial de desarrollo de frutos.

Palabras clave: flores; frutos; Colombia; aborto selectivo; atracción de polinizadores.

INTRODUCTION

The relationship between the production of flowers and fruits in plants allows the identification of reproductive processes, internal limitations, and environmental characteristics that can increase the reproductive success of plants (Bawa & Webb, 1984; Gao et al., 2021). In hermaphroditic plants, available resources must be split between producing fruits and flowers, which commonly results in low flower-to-fruit-ratios (Ayre & Whelan, 1989). Several hypotheses have been generated to understand this relationship and tradeoff (Gao et al., 2021). These hypotheses focus on pollinator attraction, pollen limitation, resource limitation, pollen donation, flower position within the plant, and selective fruit abortion (Ayre & Whelan, 1989; Ezoe, 2018; Holland et al., 2004; Sutherland, 1987).

The pollinator attraction hypothesis establishes that pollinators prefer to visit plants that have a greater number of flowers, since they provide a stronger signal and offer greater pollen and nectar rewards (Holland et al., 2004; Sutherland, 1987). Therefore, high flower production could ensure more pollinator visits, pollination, and fruit production (Sutherland, 1987). However, this hypothesis has not been supported by species such as *Agave mckelveyana* (Gentry) and *Pachycereus schottii* (Engelm.) D.R., since the attraction of pollinators and pollen dispersion increases with the number of flowers, while the number of fruits remains constant (Holland et al., 2004; Sutherland, 1987). Nevertheless, empirical support for this hypothesis varies across species. When referring to the pollinator attraction hypothesis, it is also important to consider that the size of the flowers could also play a significant role when attracting pollinators. Moreover, larger and long-lived flowers can attract more pollinators. It has been found that larger flowers can increase reproductive success and can be positively correlated with higher fruit gain (Teixido et al., 2011). However, there is a stabilizing effect that prevents petals from becoming too large, since larger sizes can generate indirect costs like reduced fruit production, higher herbivory, stress, and overall reduced productivity (Teixido et al., 2011; Teixido, 2014). This allocation of resources implies a trade-off between the survival of the species and the fitness obtained by those specific traits (Lundgren & Des Marais, 2020).

The pollen limitation hypothesis states that fruit production is constrained by the availability of pollen to reach stigmas and, thus, fertilize flower ovules (Sutherland, 1987; Gao et al., 2021). This hypothesis considers factors such as flower availability, flower synchrony, and flower position, as they influence pollen offer. According to this hypothesis, low fruit production indicates poor pollination success (Sutherland, 1987). Over the past decades, pollen limitation has intensified due to changes in anthropogenic land use, particularly in plant species that rely on specialized pollinators. This pollen limitation, in turn, may reduce overall plant productivity (Bennett et al., 2020). Nevertheless, in environments with abundant pollen resources, hermaphroditic plants tend to invest more in female reproductive functions. This investment includes an increase in female flower numbers, extended flowering periods, and greater nectar production. Consequently, when sufficient resources are available, more ovaries develop into fruits (Gao et al., 2021). However, some species, such as *A. mckelveyana* and *P. schottii*, produce fruits depending on the presence of generalist pollinators (Burd, 1998; Sutherland, 1987). In contrast, in other perennial plant species, great synchrony among individuals with high flower production has been observed, which increases pollination efficiency (Ehrlén & Lehtilä, 2002; Bogdziewicz et al., 2020). Thus, the relationship between flower and fruit production varies depending on the plant species evaluated, and successful pollination may also depend on additional factors, such as the flower position within the plant. For instance, flowers located in the upper part of the plant have a greater likelihood of being pollinated (Sutherland, 1987; Pyke, 1981; Holland et al., 2004).

The selective abortion hypothesis states that do not have enough energy to mature many fertilized ovules, selectively abort the excess fruits (Sutherland, 1987; Ezoe, 2018). This hypothesis is linked to the resource limitation hypothesis, since spending energy on fruits that are going to be less productive implies a loss of resources for the plant. Selective abortion does not occur in *A. mckelveyana* or *P. schottii* (Sutherland, 1987; Pyke, 1981; Holland et al., 2004), but it does occur in *Malus domestica* (Suckow) Borkh. (Hehnen et al., 2012), as well as in the *Yucca* genus (Holland et al., 2004). Thus, it may be relevant to study which plant species can selectively abort developing fruits, thus improving fitness and reducing energy loss.

Environmental variables can also influence flower and fruit production. When faced with adverse conditions, plants may adopt mechanisms to conserve energy, such as selective abortion, reduced flower or fruit production, and lower fruit weight (Rodrigo & Herrero, 2002). For instance, some species, such as *Prunus armeniaca* L., produce fewer flowers and fruits when exposed to high temperatures. Under these conditions, *P. armeniaca* flowers are lighter in weight and exhibit smaller pistil development (Rodrigo & Herrero, 2002). For tropical species such as *Solanum gardneri* Sendth., selection favors high early abortion of flowers and ovules in order to avoid investing energy in unviable fruits and seeds, particularly given its self-incompatible system (Hokche & Ramírez, 2006).

Precipitation and humidity are also key environmental factors affecting flower and fruit production (Ogaya & Peñuelas, 2007). Specifically, species such as *Quercus ilex* L. and *Arbutus unedo* L. produce fewer flowers and fruits during drought periods. In low rainfall conditions, productivity declines by 30 % in *Q. ilex* and 45 % in *A. unedo* (Ogaya & Peñuelas, 2007). This trend has also been observed in other species, such as *Pisum sativum* L. (Bueckert et al., 2015). Similarly, tropical species such as *Magnifera indica*, *Garcinia mangostana* and *Psidium guajava* also present differences in fruit quality under significantly increasing temperatures (Dinesh & Reddy, 2012). However, many species bloom during low-rainfall or drought seasons, coinciding with increased pollinator activity, including flies, wasps, beetles, bees, bumblebees, and butterflies (Stevenson et al., 2008). Therefore, understanding flower and fruit production requires considering internal

plant mechanisms, environmental variables, and their interactions.

All the previously mentioned hypotheses are not mutually exclusive, as they may complement each other to explain the flower-to-fruit ratio (Sutherland, 1986). Additionally, it is important to consider environmental influences to understand flower and fruit production. However, it is challenging to test all these factors together, but partial tests could still contribute to our knowledge.

In this study, we aim to determine whether the number of flowers influences fruit production in hermaphroditic plants at both global and local scales. The global analysis includes data from Latin America, Europe, Asia, Africa, and New Zealand, while the local analysis focuses on a sampled location in Medina, Colombia. Specifically, we aim to: (1) Test whether higher flower production increases fruit production, as predicted by the pollinator attraction hypothesis (Sutherland, 1987); (2) understand whether increased flower production leads to higher abortion rates and reduced fruit production when energy allocation is limited, reflecting a trade-off between flower and fruit production; and (3) recognize whether environmental factors that influence primary productivity, such as temperature and solar radiation, modulate the flower–fruit relationship. Along environmental gradients such as altitude, where temperature and solar irradiation vary but rainfall remains consistently high year-round, reproductive efficiency is expected to increase with energy availability due to enhanced photosynthetic carbon gain and greater resource allocation to fruit development. Higher temperatures and solar radiation promote increased assimilate production, reducing resource limitation during fruit set and development, and resulting in steeper flower–fruit relationships in warmer, more irradiated areas (Stephenson, 1981; Arroyo et al., 1985; Wittich et al., 2012).

MATERIALS AND METHODS

Databases: Two databases were used, one local and one global. The local database contains data collected in Reserva La Fortuna (Medina, Colombia) about the weight of flowers and fruits of species found in the region. The reserve is in a lowland Andean and sub-Andean Forest ecosystem. The temperatures in this area range from 26 °C to 31 °C throughout the year. Furthermore, the average temperature is 14.90 °C for the high-altitude level, 19° C for the mid-latitude level and 21.10 °C for the low-altitude level (Pinel-Ramos et al., 2026). Precipitation in this region ranges between 900 mm during the rainy months and 150 mm during the driest months (Pinel-Ramos et al., 2026). Additionally, this database includes records of the different altitudinal gradients where the species are found. The global database consists of information on flower and fruit biomass compiled from scientific studies that reported results from flower and fruit traps over a minimum period of one year (Stevenson & Obregón, 2024). A total of 92 sites were analyzed in this database (SMT1).

Medina Database: To assemble this database, three altitude levels were established, and within each level, trail circuits were set up to place 50 fruit traps (Pinel-Ramos et al., 2026). The high-altitude level, characterized as Andean Forest, ranged from 2 000-2 200 m. The mid-altitude level, representing sub-Andean Forest characteristics, was located between 1 300-1 700 m. Finally, the low-altitude level, with lowland tropical rainforest characteristics, ranged from 680-1 000 m (Pinel-Ramos et al., 2026). The 50 fruit traps, each measuring 0.78 m × 0.78 m, were systematically placed at random every 50 m along the trails within the three altitudinal gradients. All traps were suspended 1.5 m above ground to ensure they were horizontally level (Pinel-Ramos et al., 2026). Their contents, including flowers, fruits, and seeds, were collected every 15 days for one year. Each collected specimen was assigned to a morphospecies number, and a photographic record was created for later identification. After classification, the samples were dried and weighed. The first collection occurred in the first half of February 2017, and the final collection took

place in the second half of January 2018 (Pinel-Ramos et al., 2026). Species identification was based on photographic records of field observations and collections. The database was then filtered to include only hermaphroditic species through direct observations and literature reviews, including plants that exhibited a peak in flower production followed by a full season of fruit production. Seven species met these criteria: *Blakea glaberrima* (Triana) Penneys & Judd. (n = 11), *Guatteria goudotiana* Triana & Planch. (n = 6), *Guettarda crispiflora* Vahl. (n = 5), *Mendoncia* sp. (n = 6), *Palicourea* sp. (n = 18), *Quararibea caldasiana* Fern.Alonso (n = 10), and *Satyria grandiflora* Hoerold. (n = 15).

We acknowledge that the local analysis includes a limited number of species (n = 7). However, the objective of the local component was not to derive broad generalizations independently, but rather to evaluate whether patterns detected at the global scale are also expressed at a fine spatial scale under shared environmental conditions. All seven species co-occur at the study site and experience similar climatic and edaphic conditions, which reduces environmental variability and allows clearer assessment of flower-fruit relationships. While the restricted sample size limits statistical power and the scope of inference, our conclusions from the local analysis are intentionally conservative and complementary to the global dataset.

To make local and global datasets comparable despite differences in taxonomic resolution and sampling methodology, we did not directly compare absolute biomass values across scales. Local data represent species-level estimates of flower and fruit biomass, whereas global data derived from fruit traps reflect community-level reproductive output and are generally not disaggregated by species. Instead, our analyses focused on the relationship between flower and fruit production within each scale. Both datasets were log-transformed to reduce the influence of extreme values, improve normality, and allow the evaluation of scaling relationships independent of absolute units. Thus, the local analysis captures species-level patterns under shared environmental conditions, whereas the global analysis reflects community-level patterns across sites. These analyses are complementary rather than directly equivalent, allowing comparison of general trends in flower-fruit relationships across scales.

Global Database: A bibliographic review was conducted, summarizing data on flower and fruit production from more than 100 studies. The included studies had a minimum of 20. Research sites were in Argentina, Brazil, China, Colombia, France, French Guiana, Guatemala, Guyana, Indonesia, Kenya, Mexico, Nigeria, New Zealand, Panama, Peru, Puerto Rico, Spain, and Zimbabwe (SMT 1). The database recorded the specific locations of these studies, including longitude, latitude, and average altitude. Additionally, information on climatic variables such as irradiance, temperature, and precipitation were incorporated, according to the availability of this information in the compiled papers. In total, data from 92 sites were included, since these sites met the criteria of including hermaphroditic species, with flower and fruit production documentation (SMT 1).

Database comparison: We examined whether the patterns observed at the local level could be extrapolated to a broader spatial scale by grouping data from multiple species. Although the local dataset represents flower and fruit biomass for specific species along a single altitudinal gradient, and the global dataset includes multiple sites spanning diverse biomes without species-level disaggregation, comparing these datasets allows us to identify general ecological patterns rather than strict one-to-one equivalence. This approach aims to reveal whether trends observed locally, such as the relationship between flower and fruit production, are consistent at broader spatial scales, highlighting robust, potentially generalizable patterns in plant reproductive ecology. While this comparison is necessarily less precise, it avoids drawing overly reductionist conclusions from local data and helps assess the generality of observed relationships (Levin, 1992). For this

analysis, we used a linear regression model to examine the relationship between flower and fruit production across all 92 global database sites, including an additional site representing the Medina dataset.

Statistical analysis: We assessed the distribution of model residuals using the Shapiro-Wilk test and visual inspection of diagnostic plots. When necessary, logarithmic or square-root transformations were applied to meet model assumptions. A significance level of $\alpha = 0.05$ was used for all statistical tests. All analyses and graphical representations were performed in R (Kabacoff, 2015; R Core Team, 2024). The relationship between flower and fruit abundance was evaluated using linear regression models. When model assumptions could not be satisfied after transformation, generalized linear models (GLMs) with Gamma distributions were applied. To test differences in flower and fruit production across altitudinal gradients, we used a Kruskal-Wallis nonparametric test. Although hierarchical models could conceptually account for species-level variation, sample sizes within each altitudinal stratum were very small (high = 3, middle = 6, low = 4), preventing reliable estimation of random effects. Therefore, a nonparametric approach was considered more appropriate and robust for the available data.

RESULTS

At the local level (Medina database), the species *B. glaberrima, G. goudotiana, G. crispiflora, Palicourea* sp., *Q. caldasiana* and *S. grandiflora* exhibited a positive relationship between flower and fruit production. (Fig. 1, Fig 2, Table 1). Similarly, there is a positive relationship between flower and fruit production at global and local scales (Fig 2). The only scenario in which no significant difference was obtained for the relationship between flower and fruit production was for *Mendoncia* sp. (Fig. 1C), which could be due to the low sample number.

When analyzing the slopes of the seven Medina species (average slopes = 0.75) and the complete database for this site (Medina database slope 0.44), a significant difference between slopes was obtained (Table 2, Fig 2). This means that the behavior of these seven species (*B. glaberrima*, *G. goudotiana*, *G. crispiflora*, *Mendoncia* sp., *Palicourea* sp., *Q. caldasiana*, and *S. grandiflora*) cannot be extrapolated to the entire community of Medina. Some of the reasons why this difference can be obtained are that in the overall Medina database, species that are not hermaphrodites and species that have flowering periods exceeding the duration of the study are included. Therefore, it becomes evident that to evaluate a community, it is more meaningful to work at the species level because

Table 1

Statistical tests used to evaluate the relationship between the flowers and fruits produced by each of the seven plant species in Medina, Colombia.

Species	Number of samples	Statistical analysis	p- value	Adjusted R^2	Slope	Conclusion
Blakea glaberrima	11	Linear regression	0.001	0.67	0.79	Positive relationship
Guatteria goudotiana	6	Linear regression	0.031	0.66	1.44	Positive relationship
Guettarda crispiflora	5	Poisson regression	0.001	-	0.70	Positive relationship
Mendoncia sp.	6	Linear regression	0.072	0.49	0.51	No relationship
Palicourea sp.	18	Linear regression	0.022	0.24	0.49	Positive relationship
Quararibea caldasiana	10	Linear regression	0.001	0.72	0.69	Positive relationship
Satyria grandiflora	15	Linear regression	0.014	0.34	0.64	Positive relationship

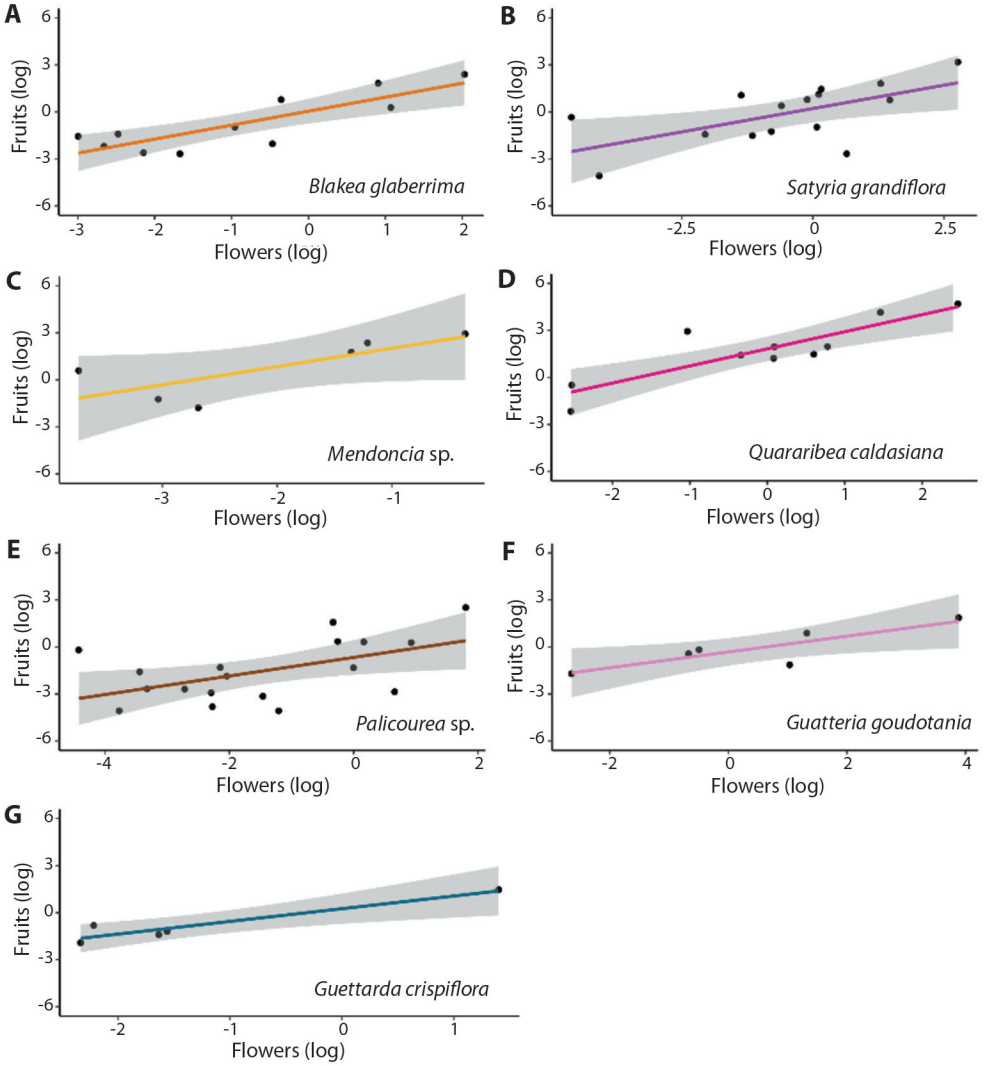

Fig. 1. Relationship between flower (X axis) and fruit (Y axis) weight for 7 species in the forest of Reserva La Fortuna (Medina, Colombia). **A.** *Blakea glaberrima*. **B.** *Satyria grandiflora*. **C.** *Mendoncia* sp. **D.** *Quararibea caldasiana*. **E.** *Palicourea* sp. **F.** *Guatteria goudotiana*. **G.** *Guettarda crispiflora*. The colored lines represent the linear model of regression, and the gray contour represents the confidence interval (95 %). Values on both axes were logarithmically transformed.

Table 2

Statistical analyses used to test the relationship between the number of flowers and fruits produced in the Medina and global databases.

Database	Number of samples	Statistical analysis	p-value	Adjusted R^2	Slope	Conclusion
Seven species from Medina	7	Linear regression	0.015	0.67	0.75	Positive relationship
All the species registered in Medina	1 775	Poisson regression	0.022	-	0.44	Positive relationship
Global	92	Linear regression	$p < 0.001$	0.23	0.56	Positive relationship
Global and local	93	Poisson regression	0.012	-	0.75	Positive relationship

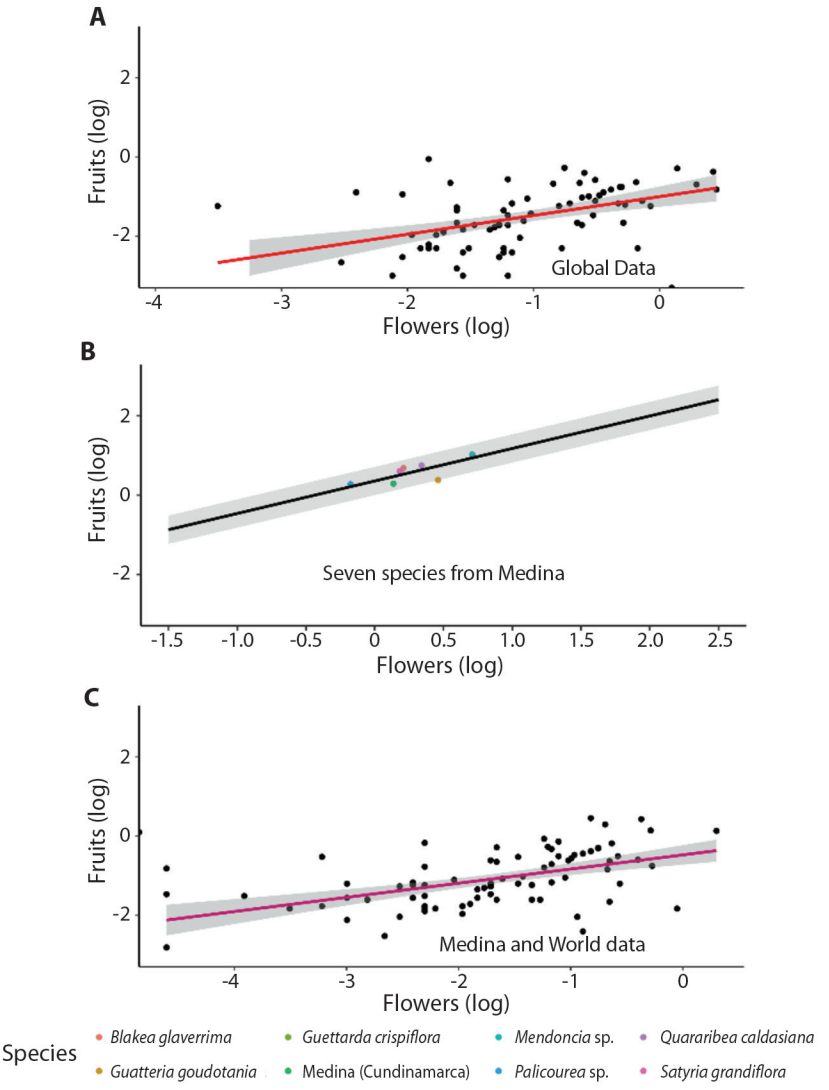

Fig. 2. Relationship between flower (X-axis) and fruit (Y-axis) weights for the world database, the Medina database and the combination of the Medina and world database. **A.** Global data. **B.** Seven species from Medina and general data. **C.** Global and local data, where the Medina data set is included as a region in the global data set. The colored lines represent the linear model of regression, and the gray contour represents the confidence interval (95 %). Values on both axes were logarithmically transformed.

in this way an extrapolation that does not apply to all species is avoided (Levin, 1992).

When analyzing the relationship of the altitudinal range with the flower and fruit production, it was determined that there is no significant difference between flower and fruit production among different altitudes for the species found in Medina (Table 3, Fig. 3). This was confirmed by a "Kruskalmc" test of multiple comparison (Siegel & Castellan, 1988), where the p-value obtained was 0.95 (Table 3).

DISCUSSION

Overall, the relationship between flower and fruit production was positive at both global

Table 3
Statistical comparison of flower and fruit production across altitudinal levels in Medina.

Altitude	Observable difference	Critic difference	Difference
High-Low	0.833	7.12	False
High- Medium	0.167	6.59	False
Medium-Low	0.667	6.02	False

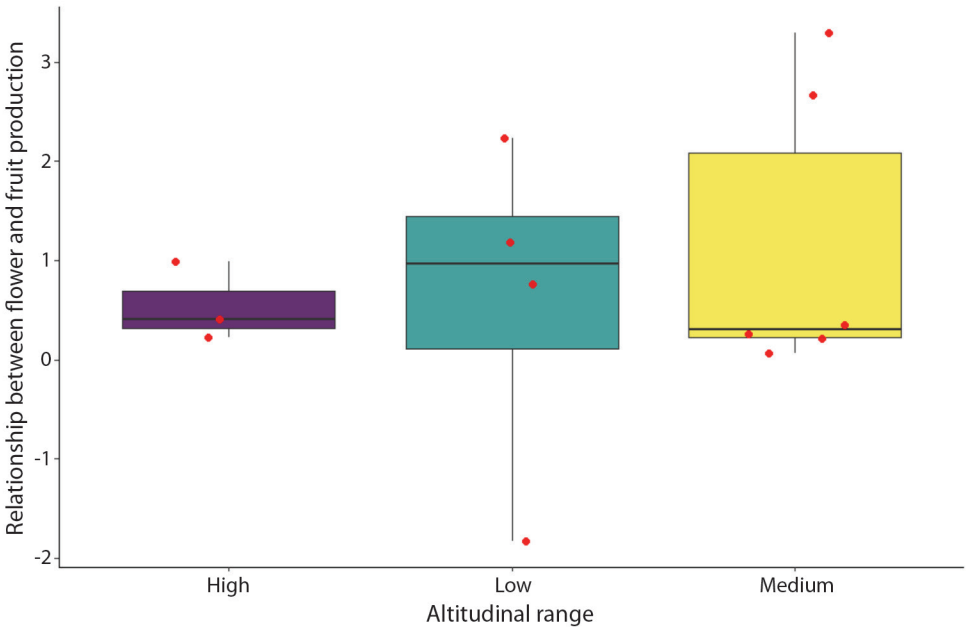

Fig. 3. Relationship between flower production and fruit set across altitudinal ranges. Boxplots show the distribution of the relationship between the number of flowers and fruit production for each altitudinal range (High, Medium, Low). The colored boxes represent the median and interquartile range, while the whiskers indicate the range of the data. Individual red points represent observed data values.

and local scales, a pattern consistent with predictions of the pollinator attraction hypothesis (Sutherland, 1987). However, this association represents an observed correlation rather than a direct causal demonstration of the hypothesis. Moreover, a positive flower-fruit relationship does not necessarily imply that environmental variables have no effect on reproductive success. Fruit production decreases with increasing altitude in Andean forests (Pinel-Ramos et al., 2026), likely due to the combined effects of lower temperature and solar radiation despite high rainfall. Thus, while flower number influences fruit production, certain environmental stressors can modulate the overall magnitude of reproductive output.

Our study provides evidence supporting the pollinator attraction hypothesis, which postulates that a greater number of flowers enhances pollinator attraction by providing stronger visual and chemical cues, as well as increased pollen and nectar rewards (Sutherland, 1987). Consequently, as supported by our findings, plants with higher flower production generally experience higher fruit production. This suggests that an abundance of flowers ensures more pollinator visits, successful pollination, and ultimately greater fruit yield (Sutherland,

1987). The pollinators of the seven species considered in this study are primarily bees, beetles, bumblebees, butterflies, and birds, which are common visitors in productive tropical plants (ter Steege et al., 2026).

Although our results support the pollinator attraction hypothesis, they do not confirm it definitively. To further investigate this hypothesis, future studies should explore the relationship between flower and fruit production under varying environmental conditions. Specifically, assessing pollinator behavior including fidelity, selectivity, density, and foraging patterns could clarify how strongly the fruit set depends on flower production. Future studies should directly examine pollinator behavior and its effects on fruit production in these specific plant species.

Furthermore, our findings suggest that flower abundance influences reproductive success at both local and global scales, consistent with previous research on hermaphroditic species such as *Phacelia linearis* (Pursh) Holz. (Eckhart, 1991). In all populations of *P. linearis* evaluated, a higher number of flowers was associated with increased pollinator visits and greater fruit production (Eckhart, 1991). However, the pollinator attraction hypothesis does not hold for species such as *A. mckelveyana*, *P. schottii*, and other plants with CAM metabolism (Sutherland, 1987), suggesting that reproductive strategies may vary depending on photosynthetic pathways. Additionally, our results do not provide evidence for the selective abortion hypothesis. While we observed high flower production and generally high fruit set, we did not quantify aborted fruits that began development but were shed before ripening. Future studies should assess fruit abortion to fully evaluate the role of selective fruit abortion in reproductive strategies.

Identifying general patterns across different ecosystems and study areas can be achieved by integrating local datasets into a global framework (Gregg & Casey, 2004; Levin, 1992). Considering plant reproduction, such an approach is valuable, as it highlights the plant reproductive mechanisms while accounting for regional-scale variations driven by specific ecosystems or species characteristics. Moreover, it helps minimize researcher bias by acknowledging that global patterns do not always hold across all contexts, thereby avoiding overly reductionist or causal explanations (Levin, 1992).

Our results did not support the hypothesis that variation along altitudinal gradients influences the flower-to-fruit ratio. However, the lack of a significant altitudinal pattern may be partly explained by the limited sample size at each elevation and by differences in species composition among altitudinal levels, which can obscure general trends. In addition, strong interspecific variation in reproductive strategies may further mask altitude-related patterns in flower and fruit allocation. Importantly, the absence of a significant effect in our study does not preclude the influence of environmental factors such as solar radiation, temperature, and precipitation on reproductive success. Indeed, Pinel-Ramos et al. (2026) reported higher fruit production in sub-Andean and lowland forests compared to Andean forests, likely reflecting reduced solar irradiation and lower temperatures at elevations above 2 000 m. Detecting such effects may require larger datasets, greater taxonomic replication, including several altitude gradients and multiyear studies that capture interannual environmental variability.

Previous studies have shown that water availability can directly affect flower and fruit production in some species. For instance, *Lesquerella gordonii* (A. Gray) S. Watson produces more flowers and fruits under high rainfall conditions (Delph, 1986). However, in our study area, all altitudinal levels experience high year-round precipitation, with rainfall increasing with elevation (Pinel-Ramos et al., 2026), suggesting that water availability is unlikely to be a limiting factor. Interestingly, some plant species increase flower production during drought periods, indicating that precipitation alone does not universally promote higher reproductive output (Stevenson et al., 2008; Pinel-Ramos et al., 2026). Instead, flower production may be strongly influenced by species-specific

responses and by pollinator interactions, which are themselves affected by environmental variables such as temperature, humidity, and solar radiation (Ogaya & Peñuelas, 2007; Stevenson et al., 2008; Bueckert et al., 2015).

Vegetation composition and pollination dynamics vary with altitude (Nogueira Ferraz et al., 2003), though they seem not to have influenced our results. The number and type of plant species evaluated at each elevation level differed. At the high level only three species were available (*G. crispiflora*, *Palicourea* sp. and *S. grandiflora*), at the medium level six species were used (*G. crispiflora*, *B. glaberrima*, *G. goudotiana*, *S. grandiflora*, *Mendoncia* sp. and *Palicourea* sp.) and at the low level, only four were available (*B. glaberrima*, *Q. caldasiana*, *G. crispiflora*, and *G. goudotiana*). Given that each species may allocate resources differently, conducting studies on widely distributed species or controlled experiments would help make evident a pattern, if it exists. Further research on *G. crispiflora* could be particularly useful, as it occurs across all altitude levels.

Future studies should also compare plant reproductive strategies across different environments (e.g., dry forests) to assess how abiotic factors influence flower and fruit production. Evaluating these dynamics at both global and local scales will enhance our understanding of plant reproductive mechanisms and their interactions with pollinators and environmental variables. Knowing the proportion of flowers that successfully develop into fruits is crucial for interpreting plant reproductive strategies (Holland et al., 2004; Sutherland, 1987).

Ethical statement: The authors declare that they all agree with this publication and made significant contributions; that there is no conflict of interest of any kind; and that we followed all pertinent ethical and legal procedures and requirements. All financial sources are fully and clearly stated in the acknowledgments section. A signed document has been filed in the journal archives.

See supplementary material
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