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Article

Effect of pollen carriers on cherimoya production in the Andean region

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Abstract

The research aimed to evaluate the effect of pollen carriers on cherimoya (*Annona cherimola* Mill.) production through the use of assisted pollination under conditions of the high Andean zone of the Lima region, Peru. The design used was a randomized complete block design with six treatments and three replications. The treatments were: T1) pollen carrier with chuño flour (potato starch); T2) pollen carrier with *Lycopodium clavatum* flour; T3) pollen carrier with white corn flour; T4) pollen carrier with wheat flour; T5) pollen carrier with industrial talc; and T6) natural pollination (control). Each experimental unit consisted of three trees arranged in a 48 m^2 area. The variables evaluated were the number of fruits set per tree, yield by fruit category (t ha^{-1}), and total yield (t ha^{-1}). The averages were compared using the Scott-Knott test at 5% level. It was found that treatment with *L. clavatum* flour significantly outperformed all other treatments, obtaining more fruits set per tree, higher total yield, and higher yield in each of the categories considered; it was followed in importance by chuño flour. The control treatment produced the lowest values for the set of characteristics evaluated and was statistically lower ($p < 0.05$) than the other treatments. It is concluded that assisted pollination with pollen carriers significantly increases cherimoya production, with treatments with *L. clavatum* flour and chuño flour standing out.

Palabras clave:

Annona cherimola Mill.,
Lycopodium clavatum
, chuño flour, corn flour, wheat flour.

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Introduction

Cherimoya (*Annona cherimola* Mill.) is native to the inter-Andean valleys of Ecuador and Peru, and due to its appetizing characteristics, the fruit has been welcomed by a growing group of consumers around the world; therefore, it is necessary to increase its production (Damme and Scheldeman, 1999; Merino, 2019).

This crop represents a strategic resource for agricultural diversification in high Andean areas, not only for its economic value, but also for its potential contribution to the food security of rural communities that depend on family farming. This last aspect is especially relevant in the face of climate change, which threatens the productive stability of traditional crops and requires alternatives resilient to the particular ecological conditions of altitude (Bernzen *et al*., 2023).

A limiting factor in cherimoya production is its reduced natural pollination, mainly due to low presence of insects that behave as pollinators and make the effect of pollination possible (Broussard *et al*., 2023), and due to floral behavior, as cherimoya presents asynchronous dichogamy (protogyny); however, the pistils mature before the stamens, leading to no synchronization between the floral organs, thus hindering self-fertilization (Kahn, 1998; Apolonio, 2015; Vásquez *et al*., 2023; Larranaga *et al*., 2024).

The cherimoya tree has flowers that are not very attractive to insects, as they are green and do not differ from the leaves, and this hinders entomophilous pollination that could favor fruiting (Gonzáles, 2013; García, 2017). Likewise, the viability of the pollen, rather than the receptivity of the stigma, is the greatest constraint to the success of cherimoya pollination in a humid tropical climate (Richardson and Anderson, 1996); for this reason, assisted pollination has become an alternative to significantly increase production (García, 2017).

Hand pollination is the most widely used technique to improve fruit set, increasing the fruiting rate by 60-90% compared with less than 5% of fruit set under natural conditions (Tineo, 2018). Results of experiments on cherimoyas have revealed that a greater amount of manually applied pollen leads to greater fruit set and development, evidencing a positive relationship between pollen load and various parameters, such as the number of seeds and fruit weight (Gonzáles *et al*., 2006).

The main motivation for practicing or recommending hand pollination is the increase in fruit set and quality (Wurz *et al*., 2021). To optimize this process, various pollen carriers have been investigated, such as plant flour or talc, which serve as pollen-transfer vehicles. Although there is more evidence in other crops (corn), its application in cherimoya is proposed as an innovative alternative: the carrier facilitates the adhesion of pollen to the brush and its subsequent release, thereby increasing the efficiency of hand pollination (Tineo, 2018).

Although the literature on the specific use of pollen carriers for cherimoyas is scarce, studies in other crops show that certain materials enable pollen to be diluted and transported in a controlled manner, maintaining its viability (Zamora-Pinedo, 2022). In cherimoya, this practice could reinforce dosage, improve coverage of flower stigmas, and ensure optimal levels of fruit set, especially in high Andean environments where pollen degradation due to climatic conditions is critical (Tineo, 2018).

The adaptation of efficient, accessible and replicable methods is key to ensuring sustainable, high-quality production, especially in family farming (Wurz *et al*., 2021). Given this context, this research aimed to determine the effect of assisted pollination with pollen carriers on cherimoya production in the high Andean region of Lima.

Materials and methods

The research was conducted in the district of Cochamarca, province of Oyón, Lima, at an altitude of 1 831 m in a cherimoya cultivation field, located at coordinates 10° 57' 08" SL and 77° 05' 51" WL, from October 2022 to August 2023. According to the Köppen classification, the region's climate is classified as BSw, characterized by dry winters with less than 500 mm of rainfall and average annual temperatures between 12 and 23 °C (Rayter, 2008). The average annual temperature in this area ranges from 12 to 23 °C.

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Regarding the characteristics of the soil (Table 1), it has a loam texture, a moderately alkaline reaction, and low organic matter content and is high in phosphorus and medium in available potassium.

Table 1. Characteristics of the soil used in the research.

Texture	EC (mS m^{-1})	pH	OM (%)	P (mg kg^{-1})	K (mg kg^{-1})
Loam	3.3	7.6	1.2	12.09	126.15

Laboratory of the National Institute of Agrarian Innovation, Lima.

It is important to note that the edaphoclimatic conditions described represent a characteristic environment of the high Andean valleys, where factors such as low relative humidity and intense solar radiation can directly affect the viability and performance of pollen during flowering, which justifies the evaluation of pollen carriers for assisted pollination that are suitable for these conditions.

The statistical design used was a randomized complete block design with six treatments arranged in three blocks. The treatments were: T1) pollen carrier based on chuño flour; T2) pollen carrier based on *Lycopodium clavatum* flour; T3) pollen carrier based on white corn flour; T4) pollen carrier based on wheat flour; T5) pollen carrier based on industrial talc; and T6) natural pollination.

The experiment was installed in October 2022 on six-year-old cherimoya trees of the ‘Cumbe’ variety, grafted on rootstock of ‘Cimarrón’ cherimoya, a genetic material adapted to adverse conditions. The distance between rows and plants was 4 m, and the number of trees per experimental unit was three, occupying an area of 48 m^2.

For assisted pollination, the procedure established by Tineo (2018) was followed. The flowers were collected at the female anthesis stage, between 5 and 11 am These flowers were taken to an environment where they were laid out to collect pollen; in this case, the pollen was extracted from 4 to 8 pm and stored in a container at a temperature of 8 °C. Pollination was carried out the next day between 5 and 11 am; to prepare the different experimental treatments, the pollen was mixed at a ratio of 1 part pollen to 0.5 parts pollen carrier. The application was performed with a squeeze bulb, and 100 flowers were pollinated per tree. It should be noted that using the squeeze bulb as an application instrument enables a controlled, homogeneous dosage of pollen onto the stigmas, which enhances the replicability of the procedure and minimizes operative variations during assisted pollination.

Regarding the conduct of the experiment, after pruning, the first fertilization was carried out by applying a dose of 5 kg of compost, 300 g of Yaramila Complex® fertilizer (12% N, 5% P_2O_5, 7% K_2O + micronutrients), 400 g of diammonium phosphate (18% N, 46% P_2O_5), and 300 g of ammonium sulfate (21% N) to each tree. The second fertilization was carried out when the fruit set occurred, after assisted pollination, and 300 g of ammonium nitrate (33% N), 400 g of Yaramila Hydran® fertilizer (19% N, 4% P_2O_5, 19% K_2O + micronutrients), and 300 g of Sulpomag® (22% K_2O, 18% MgO, 22% S) were applied for each plant.

At 200 days after hand pollination, the fruits produced in each experimental unit were harvested. After the harvest, the fruits were counted and categorized according to weight, as indicated by Heredia (2022): super extra (> 501 g), extra (between 401 and 500 g), first (between 250 and 400 g), second (between 151 and 250 g), and third (< 150 g). The results were expressed as the number of fruits per tree and t ha^{-1}. The data obtained for the variables evaluated, after assessing normality and homogeneity of variances, were subjected to analysis of variance by the F-test ($p < 0.05$), and the treatment means were compared using the Scott-Knott test. The data were analyzed using the Sisvar statistical software.

Results and discussion

Table 2 shows significant differences in the number of cherimoya fruits harvested per tree, attributable to the different pollen carriers applied. Treatments with *L. clavatum* flour (39.02 fruits plant^{-1}) and chuño flour (34.66 fruits plant^{-1}) were superior to the other treatments, forming the group with the highest productivity.

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Table 2. Effect of assisted pollination on the number of fruits per tree.

Pollination treatment	No. of fruits harvested per tree
L. clavatum flour	39.02 a
Chuño flour	34.66 a
White corn flour	19.58 b
Industrial talc	19.32 b
Wheat flour	18.53 b
Control	6.4 c
MS	570.73 **
Average	22.91
CV (%)	19.26

MS= mean squares for pollination treatments; **= highly significant differences ($p < 0.01$); CV= coefficient of variability in percentage. Means with a common letter are not significantly different ($p > 0.05$).

This marked difference could be related to the physicochemical properties of these carriers, such as their granulometry, hygroscopicity and adhesion to pollen, which favors their transport and deposition in receptive stigmas (Broussard *et al*., 2023). On the other hand, the treatments with white corn flour, industrial talc and wheat flour, although they significantly outperformed the control (6.4 fruits plant^{-1}), were less efficient than the treatments with *L. clavatum* and chuño as pollen carriers. This suggests that not all carrier materials were equally compatible with cherimoya pollen or had the same effect on pollination efficiency, which has already been highlighted in other fruit trees (Jalikop and Kumar, 2007).

With respect to the control treatment, the low yield confirmed cherimoya's dependence on human intervention for effective pollination (Table 2). The fact that the control treatment has produced only 6.4 fruits per plant underscores the need for complementary strategies, such as hand pollination with carriers, as has been highlighted in research on *Annona* species with limitations for self-pollination (Pereira *et al*., 2014).

Table 3 shows that, for all the yield categories, highly significant differences were found between pollination treatments. In general, it was observed that, across all treatments evaluated, there was a tendency to produce more fruit in the first category and less in the super extra and third categories.

Table 3. Effect of assisted pollination on cherimoya yield by fruit category.

Pollination treatment	Harvest category (t ha^{-1})					Total yield (t ha^{-1})
	Super extra	Extra	First	Second	Third	
L. clavatum flour	1.84 a	3.48 a	4.76 a	2.94 a	1.17 a	14.19 a
Chuño flour	1.34 b	2.76 b	3.71 b	2.08 b	0.87 b	10.76 b
Wheat flour	1.35 b	1.72 c	1.84 c	1.15 c	0.53 c	6.64 c
White corn flour	1.16 b	1.51 c	1.53 c	1.47 c	0.48 c	6.15 c
Industrial talc	0.86 c	1.54 c	1.65 c	1.39 c	0.63 c	6.05 c
Control	0.27 d	0.18 d	0.72 d	0.32 d	0.14 d	1.65 d
MS	1.13 **	5.21 **	9.43 **	3.1 **	0.47 **	75.36 **
Average	1.13	1.86	2.37	1.56	0.64	7.57
CV (%)	16.42	15.11	15.57	25.73	22.13	9.66

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It was followed in importance by the pollen carrier with chuño flour (potato starch) with 10.76 t ha^{-1}. The treatment with the lowest yield was the control (1.65 t ha^{-1}), being significantly lower than the other treatments.

Analyzing the results by fruit category (Table 3), it is also noted that the treatment with *L. clavatum* flour presented the highest yields in each category, followed in importance by the treatment with the pollen carrier based on chuño flour. The control treatment produced the lowest values in all categories. The superior yield obtained by *L. clavatum* not only reflects its ability to facilitate pollen adhesion to the stigma but also ensures homogeneous distribution during the hand pollination process. The uniformity observed in the proportion of high-category fruits suggests that the pollen load was sufficient and stable, allowing optimal development of the embryo and accessory tissue, which are determining factors in achieving large and symmetrical fruits (Wurz *et al*., 2021).

The results obtained in this research confirm that the use of carriers as pollen adjuvants significantly affects cherimoya fruit yield and quality under the conditions of the high Andean region (Flores, 2013). In particular, treatment with *L. clavatum* flour produced the highest total yield (14.19 t ha^{-1}) and the highest proportion of fruits in the higher commercial categories (super extra, extra, and first), indicating a higher efficiency in pollen transfer and adhesion during hand pollination. This superior yield reflects the ability of *L. clavatum* not only to facilitate pollen adhesion to the stigma but also to ensure homogeneous distribution during the hand pollination process. The uniformity observed in the proportion of high-category fruits suggests that the pollen load was sufficient and stable, allowing optimal embryo development, which are determining factors in achieving larger and more symmetrical fruits (Wurz *et al*., 2021).

These findings coincide with what was reported by Pritchard and Edwards (2005), who indicate that hand pollination significantly improves fruit set in cherimoya when natural pollinators are scarce, a frequent situation in high-altitude areas. Nonetheless, the results obtained in the research contradict those of González *et al*. (2006), who report that pollination with *Lycopodium* reduced fruit set and size, whereas applying twice the amount of pollen did not improve fruit size or fruit set. It is worth mentioning that obtaining a higher percentage of fruits in the higher categories (super extra, extra, and first), as shown in Table 3, has a direct implication on the commercial value of the production, since these sizes are in demand both in the domestic market and in potential export markets (Vásquez *et al*., 2023).

The second-best yield was obtained with chuño flour (10.76 t ha^{-1}), which is relevant because it is a local and low-cost product. Its effectiveness suggests that, in addition to its physical properties, the availability of this input makes it an accessible and practical alternative for high Andean farmers. The use of chuño (potato starch) as a pollen carrier is strategic for rural development programs, since it helps reduce production costs without sacrificing yield, favoring the adoption of appropriate technologies for small producers with limited resources. This aspect is especially relevant in contexts where access to imported inputs is restricted (Wurz *et al*., 2021).

Treatments with wheat flour, white corn and industrial talc achieved intermediate yields (between 6 and 6.6 t ha^{-1}), with lower proportions of fruits in higher categories. This indicates lower efficiency of pollen transfer (Pinillos and Cueva, 2007); however, they were higher than the control without hand pollination, which reached only 1.65 t ha^{-1}, confirming the low efficiency of natural pollination under these conditions. This deficiency has been widely documented in cherimoya morphological studies that show a high dependence on artificial reproductive management to reach acceptable commercial levels (Broussard *et al*., 2023).

Generally speaking, these results demonstrate that the choice of pollen carrier not only influences the quantity of fruit produced but also its commercial quality. The proportion of high-quality fruits achieved with *L. clavatum* flour and chuño flour suggests that these materials not only facilitate fruit set but also optimize seed formation, which is related to fruit size and symmetry (Gonzáles and Maldonado, 2014). Finally, the present study provides evidence that can serve as a basis for establishing assisted pollination protocols adapted to cherimoya production systems, thereby contributing to improving the profitability and sustainability of family farmers engaged in producing this fruit (Cabrera and De la O, 2023).

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Conclusions

The use of assisted pollination with pollen carriers improves cherimoya yield in the high Andean area of the Lima region. In particular, the use of *L. clavatum* flour proved to be the most effective treatment, not only in terms of total production amount but also because of its ability to generate larger fruits of commercial quality, key aspects for the competitiveness of the crop. The results of this research support the importance of continuing to explore and optimize assisted pollination techniques, with a view to strengthening the sustainable agricultural development of rural communities engaged in cherimoya cultivation in the Andean region.

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