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## Contributions to Sustainable Development, With the Recovery of Paramo Ecosystems Through the Study of Frailejones Germination

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### Abstract

*The recovery of paramo ecosystems is a contribution to environmental sustainability because the knowledge for the germination, development and growth of frailejón leads to revegetation and with them the recovery of paramo ecosystems is a challenge that requires research processes that allows the recovery of the Colombian moors, especially with the Espeletia killipii, a species at risk of extinction and essential for the retention and generation of water sources. The results of this research reveal procedures that lead to results with high performance in germination with specific substrates.*

**Keywords:** Sustainable Development, Recovery of Paramo Ecosystems, Germination, Frailejón.

### Introduction

The relationship between the SDGs and the protection of páramos is evident, since conserving these ecosystems contributes to several of the objectives set by the global agenda. For example, protecting páramos guarantees access to drinking water and sanitation (SDG 6), combats climate change and its effects (SDG 13), conserves the life of terrestrial species (SDG 15) and promotes the rational use of natural resources (SDG 12). Furthermore, involving local communities in the sustainable management of páramos promotes the end of poverty (SDG 1), decent work and economic growth (SDG 8), the reduction of inequalities (SDG 10) and alliances to achieve the objectives (SDG 17). Therefore, it can be stated that the protection of the paramos is a strategic action to achieve the SDGs and to ensure the sustainable development of the Andean regions where these unique and vital ecosystems are located.

The frailejón is a plant native to the moors of Colombia, Venezuela and Ecuador, which belongs to the Asteraceae family and the Espeletia genus. The life cycle of the frailejón is very long, as it can take between 100 and 300 years to reach its maximum height, which can vary between 2 and 3 meters. The frailejón has a very important ecological function, as it captures moisture from the fog with the hairs that cover its leaves and releases it to the soil through its roots, thus contributing to the formation and conservation of water sources. In addition, the frailejón serves as food and shelter for many species of birds and insects, and has medicinal properties to treat various human ailments. The frailejón is a symbol of Andean biodiversity and a valuable natural

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resource that we must protect and care for.

The frailejón is a plant native to the Andean moors, which is characterized by having thick, hairy leaves, and yellow flowers that are grouped in inflorescences. (CAR, Regional Autonomous Corporation, 2022). The frailejón has great ecological and economic importance for the moors, since it fulfills several vital functions, among which the following stand out: it regulates the hydrological cycle, capturing moisture from fog and rain, and storing it in its leaves and stems. Then, it slowly releases it into the soil, feeding the aquifers with which the water reserves of the paramos are fed, which are then used by millions of people; protects the soil from erosion, preventing the loss of nutrients and organic matter; provides shelter and food to numerous species endemic to mountain ecosystems; It contributes to the mitigation of climate change, by capturing carbon dioxide from the atmosphere and storing it in its tissues to transform it into oxygen and energy. It is estimated that the paramos store between 50 and 200 tons of carbon per hectare. For these reasons, the frailejón is a key species for the conservation of the paramos, which are unique and vulnerable ecosystems. However, anthropogenic intervention in these mountain ecosystems due to deforestation, overgrazing, forest fires, invasive species and global warming. They have led the frailejón to be a species in the process of extension because its reproduction and growth cycle is complex and requires many years, which is why the frailejón needs urgent conservation measures to avoid its extinction and protect its ecological and cultural value. and economic. Therefore, it is necessary to implement measures to protect and restore frailejón habitats, as well as promote their valuation and sustainable use by local communities. These actions can benefit both the frailejón and the people who live in or around the moors. Protecting the frailejón is protecting the water, biodiversity and climate of our planet.

The importance in terms of conservation of paramo ecosystems is linked to the different ecosystem services that they provide, however, the different pressures exerted on them are largely the product of anthropogenic actions, among which those generated by sectors related to: infrastructure development, agricultural production, mining, especially those exploitations that are carried out illicitly, on a smaller scale but with a negative effect on the commercial and tourism sector. The ecosystem changes generated have caused changes in the dynamics of the paramos, the modification of the tropical high mountain landscape, at different scales, caused by the frequency of the intervention or the magnitude that the intervention generates at the different spatiotemporal scales Cabrera & Ramírez, ( 2014). A determining factor for the conservation of the frailejón is establishing the ideal germination conditions and to do so, work must be done on the characterization of the substrate and the environmental conditions required for this process, which is why this research focuses on quantitatively evaluating these factors. finding that the most favorable germination conditions are those offered by traditional cotton, enriched with the properties offered by the water of the moor. And that the most favorable substrate for its growth is to have a high percentage of land from the original environment. Likewise, it is possible to establish the elements of collection and preparation of frailejón seeds. Finally, more extensive research is recommended to establish long-term seed performance and obtain a trend of germination, adaptation, development, growth and survival of germinated frailejón seedlings.

The frailejón, being an endemic plant of the paramo ecosystems, has adaptations to extreme conditions of cold, wind and solar radiation, characteristics that it shares and maintains with the species that form these very particular ecosystems and that, due to the indiscriminate use of agricultural activities, is being violated and threatened thus, knowing the challenges of the frailejón for its reproduction and conservation is considered a significant contribution to ecosystem conservation studies. According to the latest reports, more than 50% of the original

surface area of the frailejón ecosystems in Colombia, Ecuador and Venezuela has been lost, which puts the survival of many endemic species and the water security of millions of people at risk. It is urgent to implement conservation and restoration measures that protect these ecosystems and their vital functions.

These species are characterized by having sexual or asexual reproduction processes. Sexual reproduction involves the production of seeds, which are dispersed by wind or animals. Asexual reproduction occurs through the formation of suckers, which are lateral shoots that separate from the mother plant and generate new individuals. Both types of reproduction have advantages and disadvantages, depending on environmental and genetic conditions.

Sexual reproduction allows genetic variability, which favors adaptation to climate changes and resistance to pests and diseases. However, this type of reproduction requires pollination, which depends on the presence and activity of pollinating agents, such as bees, hummingbirds and bats.

Asexual reproduction allows rapid colonization of empty spaces, facilitating the recovery of degraded areas. Furthermore, this type of reproduction ensures the continuity of favorable genetic characteristics, which have been selected by evolution. However, this type of reproduction reduces genetic variability, which can compromise the ability to adapt and resist in the long term. Likewise, asexual reproduction can be affected by physical factors, such as trampling by livestock or landslides, which can damage or remove offspring.

The above allows us to establish that the frailejón faces several challenges to its reproduction, both sexual and asexual, which put its survival and ecological function in the moors at risk. Therefore, urgent actions are required to protect their habitat, conserve their genetic diversity and restore their populations. In order not to affect the ecosystem importance of the frailejón as a regulator of natural water sources.

To face these challenges, joint actions are required between the different social and institutional actors that have an impact on the management and conservation of the paramos. Some of these actions are: strengthening local capacities for the monitoring and restoration of the frailejón, the implementation of sustainable productive systems that reduce pressure on ecosystems, raising awareness and environmental education of the population about the importance of the frailejón and its benefits, and the generation of strategic alliances between the public, private and academic sectors to promote research and innovation around frailejón. These measures would contribute to improving the living conditions of local communities and guaranteeing the conservation of the frailejón and the Andean paramos for future generations.

## **Materials and Methods**

From the quantitative approach, this research seeks to use quantitative methods and techniques that establish the conditions and relationships between the germination variables for the frailejón *Espeletia Kipilli* that from experimental processes that contemplate a prior, objective and systematic design where by identifying and studying the variables, identify the variables and their level of incidence in the germination process of this species

Experimental research is a scientific method that consists of manipulating one or more independent variables and observing their effects on one or more dependent variables, controlling the rest of the factors that may influence the result. This type of research allows establishing causal relationships between variables and testing hypotheses through the collection and analysis of quantitative data. Experimental research is mainly applied in the natural and

social sciences, although it can also be used in other disciplines such as education, psychology or economics.

The phases in which the investigation was carried out correspond to:

#### Phase I. Collection of plant material

Seed collections from ripe fruits were carried out in four populations of frailejones located in areas surrounding the Alta Montaña Battalion No. 01 “BAMAR” located in the Sumapaz moor, the harvested material did not exceed more than 20% of the healthy seeds available ( DiSacco et al., 2020).

Each collection is supported by herbarium collections and were deposited in the Herbarium of the Botanical Garden of Bogotá. In population one, *Espeletia killipii* seeds were collected (municipality of Cabrera, Cundinamarca; N3 49,281, W74 24,244, 3,376 m, CISB herbarium voucher 990); in population two, seeds of *E. grandiflora* were collected (Cabrera, Cundinamarca; N3 49.601 W74 24.844, 3.281 m, CISB herbarium voucher 991); in population three, seeds of *E. killipi* (Cabrera; N3 50.855 W74 24.157, 3.444 m, CISB herbarium voucher 992) were collected; and in population four *E. killipii* seeds were collected (Bogotá D.C; N3 49.405 W74 23.691, 3.341 m a.s.l., CISB herbarium voucher 993). Example of tertiary heading.



Figure 1. Flower Collection Process To Obtain *Espeletia Killipii* Seeds

#### Phase II. Determination of the condition variable by proportion of full, empty and infected seeds

For each population, cutting tests were carried out on four replicates of 20 seeds. Once the cutting test was carried out, the number of full, empty and infested seeds was recorded, and the proportion of full seeds was calculated using the formula (DiSacco et al., 2020):

Proportion of filled seeds = No. of filled seeds / No. of cut seeds.

Frailejones usually have high percentages of empty seeds, which is why over-sowing was carried out, seeking to ensure that the trials had approximately the same number of seeds with embryos (DiSacco et al., 2020). The calculation of overplanting was carried out using the formula (DiSacco et al., 2020):

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Over-sowing = seeds needed by the trial / proportion of full seeds.

### Phase III. Viability tests with tetrazolium

For each population, seed viability was evaluated using the 2,3,5-triphenyltetrazolium test (tetrazolium test). In each test, three replicates were carried out, the number of seeds per replicate took into account the results of over-sowing, taking 20 seeds as necessary seeds for the trial.

To carry out this test, the seeds were hydrated with water for 24 hours; Subsequently, a 1% tetrazolium solution was added and they were placed under dark conditions in an oven at a temperature of 40 °C for 24 hours (Mancipe-Murillo, 2020; Mancipe-Murillo et al., 2018; Suárez-Ballesteros et al., 2018). Once the time was up, the number of viable, non-viable and empty seeds was recorded. The seeds were considered viable when the root zone and cotyledons were pink (DiSacco et al., 2020; Mancipe-Murillo, 2020).



Figure 2.

Image of the germinated seedlings of frailejon frailejón, *Espeletia killipii*

### Phase IV. Germination tests

The germination tests were set up on May 16 in the BAMAR laboratory. During the development of the research, the laboratory presented a maximum temperature and humidity of 29.3°C/95.6%, and a minimum temperature and humidity of 2.5°C/43.5%. and an average temperature and humidity of 12.4°C/75.8%.

For each population, germination tests were carried out in Petri dishes using cotton as a substrate. The Petri dishes were sealed with flexible paper for the population that had the highest proportion of full seeds.

Germination was evaluated in four substrates:

Substrate 1. Wasteland soil (P); six parts of paramo land, two parts of burnt rice husk and two parts of peat (PCT);

Substrate 2. Nursery soil (T); six parts of nursery soil, two parts of burnt rice husk and two parts of peat (TCT).

These trials were planted in polypropylene trays with 117 cells.

Each trial was composed of three replicates, the number of seeds per replicate depended on the results of over-sowing.

Germination monitoring was carried out once a week, to record the germination of the seeds, it was taken into account that the emergence of the radicle through the surrounding tissues was at least 2 mm (Bewley et al., 2013).

Prior to sowing, the seeds were disinfected using 1% sodium hypochlorite for five minutes, after which the seeds were washed with distilled water (Muñoz & Ackerman, 2011).

## Results and Discussion

For each population, the germination percentage (PG) and the average germination time (MTG) were calculated using the formulas (Ranal & Santana, 2006):

$$PG = (N/N_s) \times 100$$

$$TGM = \frac{\sum_{k=1}^n n_i t_i}{\sum_{k=1}^n n_i}$$

where N is the number of germinated seeds, N<sub>s</sub> is the number of total seeds, n<sub>i</sub> is the number of germinated seeds in the i<sup>th</sup> data collection, t<sub>i</sub> is the time (days) of the i<sup>th</sup> data collection and k is the time in days duration of the germination test.

Data were tested for normality using the Shapiro-Wilk test at a 95% confidence level. The significant differences between the germination percentages of the populations, the influence of the sowing conditions on the germination of the population that presented the highest proportion of full seeds and the average germination times of the different trials were evaluated.

Data that presented a normal distribution were analyzed with ANOVA, while data that did not present a normal distribution were analyzed with the Kruskal-Wallis test. Graphs and statistical analyzes were performed with STATGRAPHICS Centurion Software version 19.2.02.

Population one (*E. killipii*) presented the highest proportion of filled seeds followed by population three (*E. killipii*). Based on these results, population one (*E. killipii*) was chosen to evaluate the influence of different sowing conditions. in germination.

The viability test with tetrazolium, except for the population two arrojo (*E. grandiflora*) showed similar percentages of viable seeds, in general higher percentages of empty seeds were observed compared to viable seeds and non-viable seeds.

The *E. killipii* populations presented higher percentages of viable seeds compared to the *E. grandiflora* population (TABLE 1, Fig 1).

Population	Species	Proportion of full seeds	Retort
1	<i>Espeletia killipii</i>	0,60	33
2	<i>Espeletia grandiflora</i>	0,43	47
3	<i>Espeletia killipii</i>	0,45	44
4	<i>Espeletia killipii</i>	0,38	53

Table 1.

Results proportion of filled seeds and number of seeds sown for each replicate generated from the over-sowing formula.

Source: the autor

The evaluated species presented variations in the proportion of filled seeds and seed viability with the tetrazolium test. Regarding the proportion of full seeds, variations were found in the number of seeds with embryo, the proximity between the evaluated populations has no influence on the proportion of full seeds, this was evident in population one (*E. killipii*) which had a higher

proportion of full seeds compared to the other populations. These variations may be related to flowering behaviors within and between species which may be influenced by factors such as age, growth rates, precipitation, genotype, resource availability and soil moisture (Fagua et al 2007).

Higher percentages of empty seeds were found compared to the percentages of viable and unstained seeds. The viability of seeds in frailejones populations may vary depending on the reproductive phenology in frailejones populations, Fagua et al (2007) highlights that flowering before the dry season could reduce damage to the capitula and ensure that there are enough available. for seed maturation. Variations in seed viability have been found within the same species, as is the case of *E. killipii*, which has recorded staining percentages of 88% (Mancipe-Murillo 2020), between 31% and 25.7% in the present work and 15.9% (Mancipe-Murillo 2018). Similar cases have been found for *E. grandiflora* where staining percentages of 34.3% (Mancipe-Murillo 2018) and 13.5% in the present work were recorded.

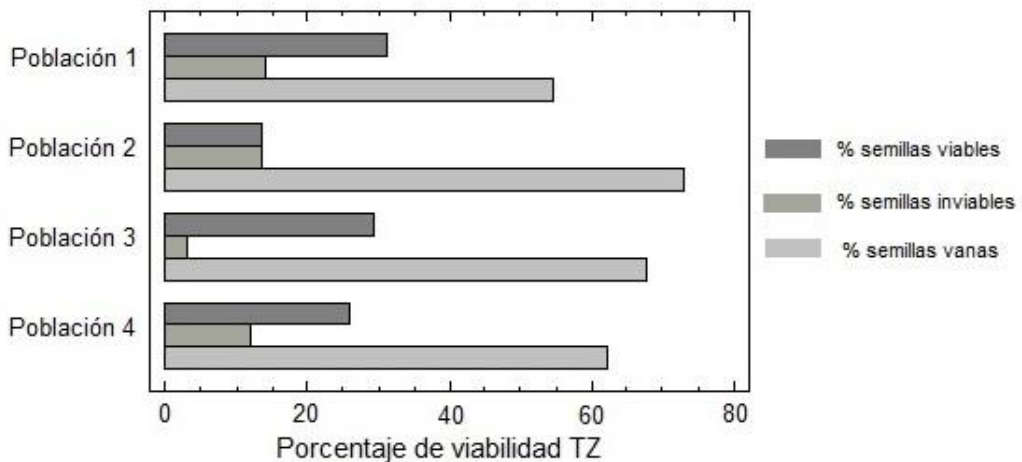


Fig 1.

Results of viability tests with the tetrazolium test for the four populations evaluated. Population 1 (*E. killipii*), population 2 (*E. grandiflora*), population 3 (*E. killipii*), population 4 (*E. killipii*).

Source: the autor

No significant differences were recorded ( $F=3.81.12$ ;  $P=0.396$ ) between the germination percentages of the four populations studied.

Population two (*E. grandiflora*) presented the highest germination percentages followed by population four (*E. killipii*) while population three presented the lowest germination percentages.

Population two presented a higher percentage of germination compared to the results of the tetrazolium viability test, otherwise, population one presented a higher percentage of viability with tetrazolium compared to the germination results (Fig 2.).

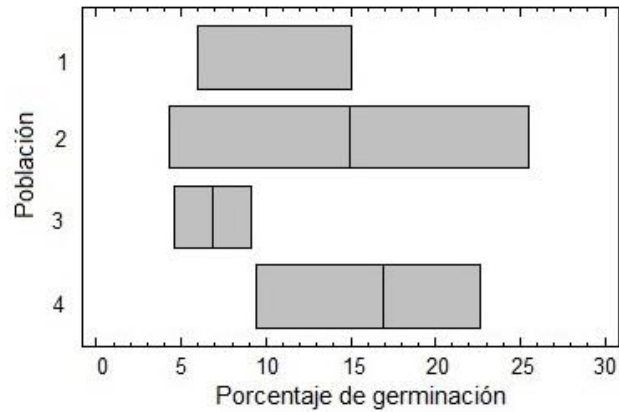


Fig 2.

Germination percentages of the trials mounted in Petri dishes using cotton as a substrate for the four populations evaluated:

Population one (*E.killipii*),

Population two (*E. grandiflora*),

Population three (*E.killipii*),

Population four (*E.killipii*).

Source: the autor

No significant differences were recorded ( $K=7.06$ ;  $p=0.13$ ) between the planting media used to evaluate the germination of population one (*E.killipii*).

The planting medium that yielded the highest germination percentages was cotton, followed by paramo soil and nursery soil; the combination of substrates yielded similar germination percentages.

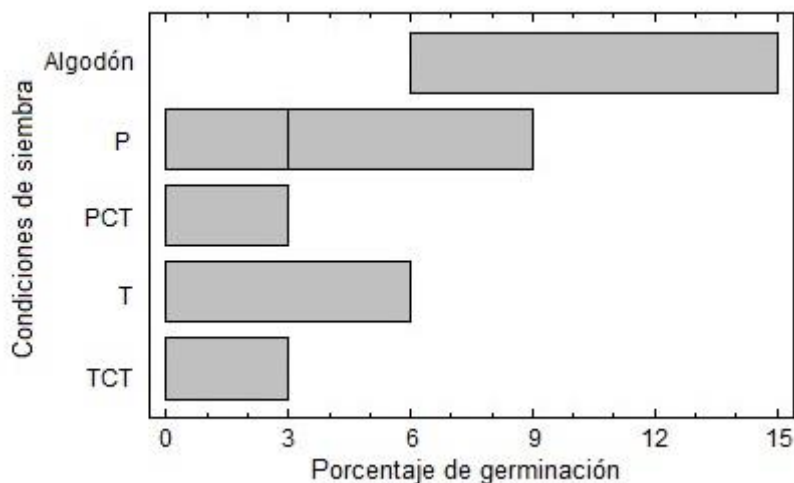


Fig 3.

Germination percentages of the planting media used to evaluate the germination of population one (*E. killipii*).

Source: the autor

No significant differences were recorded ( $K=7.06$ ;  $p=0.13$ ) between the Mean Germination Times (MTG) of the populations evaluated and the planting media used.

The planting conditions that had soil in their composition presented the lowest TMG.

TABLE 3. Average TMG (mean germination time) of the evaluated populations and the planting media used.

Population one (*E. killipii*),

Population two (*E. grandiflora*),

Population three (*E. killipii*),

Population four (*E. killipii*).

P (moor land),

PCT (six parts of paramo land, two parts of burnt rice husk and two parts of peat),

T (nursery soil),

TCT (six parts of nursery soil, two parts of burnt rice husk and two parts of peat).

Population	Planting conditions	TMG
1	P	41,22
1	T	21,00
1	PCT	44,33

1	TCT	14,00
1	Cotton	44,80
2	Cotton	48,33
3	Cotton	53,28
4	Cotton	44,93

Source: the autor

Variations between the percentages of seed viability carried out with the tetrazallium test for different species of frailejones are frequent; these may be related as previously explained by flowering behavior (Fagua et al 2007). In general, variations in staining percentages have been found for different species. Mancipe-Murillo (2020) obtained staining percentages with the tetrazolium test for the species *E. corymbosa* (71%), *E. summapacis* de (76%), *E. killipii* (88%), *E. barclayana* (52%). Mancipe-Murillo (2018) *E. barclayana* (51.2%), *E. cayetana* (12%), *E. grandiflora* (34.3), *E. killipii* (15.9), Velasco (2018) obtained staining percentages among *E. curialensis* (100% and 87%), Bohórquez-Quintero, et al. (2016) *E. paipana* (29%). It is important to highlight that the tetrazolium test varies between different works and in general no studies have been carried out that systematically evaluate the viability of seeds in different climatic periods and in altitudinal and latitudinal gradients.

These types of studies are increasingly considered of great value for environmental sustainability, due to the need to protect natural water sources, such as the moors and especially one of their main reservoirs, such as native plants such as the frailejón.

The germination, development and growth processes of the frailejón have been a challenge for many years because it is a native species whose germination process is complex and it had not been possible to have such efficient germination processes. This requires continuing with studies to analyze the reforestation processes of the paramos.



Figure 3. Treatment Process Prior to Germination of *Espeletia Killipii*

After the progress and results achieved in this research, it is necessary to continue with revegetation strategies involving the research groups, the national army that have been leading the studies, the educational institutions in the area, the environmental leaders of the region that are commit to working in an articulated manner and based on previous research results to achieve the ecosystem recovery of the Sumapaz moor. To do this, it is necessary to establish community nurseries that produce quality plants and involve local actors in the restoration process, adapt the land according to the research reports in order to provide ideal reproduction conditions for

the frailejón and the species that coexist; With the inter-institutional team, assisted or natural planting should be carried out, depending on the degree of degradation of the area and the availability of seeds or seedlings. All of the above followed by an evaluation and reengineering process that facilitates the success of adaptation, development and growth in the natural environment of the moor. As a complementary and very important element for sustainability, work must be done on the environmental education of the immediate and extensive community, as well as involving the community so that they are guarantors of the sustainability of the process and working with them to identify, develop, evaluate and provide feedback on productive alternatives more compatible with the conservation of these ecosystems.

## Conclusions

- Undoubtedly the best method for germination of frailejón seeds is cotton substrate, therefore the use of this method is recommended for future research.
- Although the husk and peat substrates are a little encouraging, the paramo soil substrate is still the best, since it has the different nutrients and conditions suitable for the germination of frailejones.
- More research time is required to infer the different birth and mortality rates, as well as the germination of frailejones seeds.
- Possible research is proposed within the framework of the current climate variability of the paramo ecosystem and its impact on the germination of frailejones in the Páramo de Sumapaz area.
- It is concluded that the species with the best germination was *Espeletia grandiflora*, followed by *Espeletia killipii*.
- An opportunity for environmental social innovation is generated, to work with the Sumpaz community in the awareness, training and leadership process to work on the recovery of training.

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