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RESEARCH ARTICLE

# Effects of different soaking intervals on germination and vegetative growth attributes of cape gooseberry (*Physalis peruviana* L.) under tropical condition

**Jahubar Ali Mohamed Jassim[1], Sethurathinam Saraswathy[1*], Jacob Rajangam[2], Thiyagarajan Anitha[3], Manivannan Umadevi[4], V Veeranan Arun Giridhari[5], Vengadachalpathy Saravanan[6], K R Rajadurai[7], Veeraiah Raja[8], Rajendran Sundarrajan[1] & Periyakaruppan Jegan[1]**

[1]Department of Fruit Science, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam 625 604, Tamil Nadu, India

[2]Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam 625 604, Tamil Nadu, India

[3]Department of Postharvest Technology, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam 625 604, Tamil Nadu, India

[4]Department of Rice, Centre for Plant Breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[5]Centre of Postharvest Technology, Agricultural Engineering College and Research Institute, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[6]Department of Plant Pathology, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

[7]Department of Floriculture and Landscape Architecture, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam 625 604, Tamil Nadu, India

[8]Division of Plant Breeding and Genetics, Regional Coffee Research Station, Thandikudi 624 216, Tamil Nadu, India

*Correspondence email - saraswathy.s@tnau.ac.in

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## Abstract

The present investigation was carried out to study the effects of different soaking intervals on germination and vegetative growth attributes of cape gooseberry (*Physalis peruviana* L.) under tropical conditions. The experiment was carried out at the Department of Fruit Science, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, Tamil Nadu, India during October 2024. The five treatments comprised five different soaking intervals of water i.e. $T_1$: one-day soak, $T_2$: two-day soak, $T_3$: three-day soak, $T_4$: four-day soak and $T_5$: control (without soak). Among the five treatments, the highest percentage of germination was recorded in $T_2$ with 93.00 % followed by $T_1$ (77.00 %), $T_3$ (68.00 %) and $T_5$ (control) with 50.00 %, while $T_4$ (40.00 %). The vegetative growth parameters of seedlings were recorded higher in $T_2$ followed by $T_1$, $T_3$, $T_5$ and $T_4$. Two day soaking of seeds registered significant improvement in both seed germination and seedling growth of cape gooseberry.

**Keywords:** cape gooseberry; germination; seed treatment; vegetative growth

## Introduction

Cape gooseberry (*Physalis peruviana* L.), a member of the Solanaceae family, is an economically important fruit crop valued for its nutritional and medicinal properties (1). Native to South America, it has gained popularity worldwide due to its rich content of vitamins A, C and B-complex, along with antioxidants and bioactive compounds (2, 3). The crop thrives in diverse agro-climatic conditions and is cultivated in various regions, including tropical and subtropical areas. However, seed germination and early vegetative growth play a crucial role in successful cultivation and commercial production (4).

Seed dormancy and variability in germination rates pose challenges in the propagation of cape gooseberry. Pre-sowing treatments, including seed soaking in water or other solutions, have been widely studied to enhance germination and seedling vigor (4). The duration of seed soaking influences water uptake, enzymatic activation and metabolic processes essential for early seedling establishment (5). Understanding the effects of different soaking intervals on germination and vegetative growth under tropical conditions is essential for optimizing agronomic practices and improving yield potential.

Despite the growing interest in cape gooseberry cultivation, low and inconsistent germination rates remain a major concern for growers. Seed dormancy, delayed emergence and poor seedling vigour contribute to uneven crop stands and reduced productivity (6). There is limited research on the impact of soaking intervals on seed germination and early vegetative growth under tropical conditions. Evaluating the optimal soaking duration can help formulate effective pre-sowing treatments to enhance seed performance, ensuring better crop establishment and productivity.

This study aims to address the existing knowledge gap and provide practical recommendations for improving the germination and early growth performance of *P. peruviana* in tropical conditions.

## Materials and Methods

### Experimental site

The present investigation was conducted to optimize the soaking interval and germination parameters of cape gooseberry. The experiment was carried out at the Department of Fruit Science, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam, Tamil Nadu, India during October 2024.

### Experimental design and treatment details

The experiment was laid out in a complete randomized design (CRD) with three replications. The treatments comprised five different intervals of seed soaking in water, i.e. $T_1$: one-day soak, $T_2$: two-day soak, $T_3$: three-day soak, $T_4$: four-day soak and $T_5$: control (without soak).

### Media preparation and protray germination

After soaking with different intervals of water, seeds were sown in protrays. The protrays contained a mixture of cocopeat, vermicompost and soil in the ratio of 4:2:1. The medium was sterilized in an autoclave to eliminate microbes and after cooling, the media was used for sowing. The protrays were disinfected with 70 % ethanol to eliminate fungal contamination (7). Each protrays contained 5 × 10 (50 cavities) cells with a depth of 85 mm. Protrays were filled with media and one seed per cell was sown at a depth of 1-1.5 cm. The protrays were then covered with paddy straw and irrigated with rose cane and kept in a shaded area. Irrigation was carried out daily and optimum moisture was maintained during the germination phase. Observations recorded after seed germination are germination percentage and vegetative growth parameters of seedlings of cape gooseberry at the nursery level.

### Germination and vegetative growth attributes

#### Days taken for germination

The number of days from sowing until the appearance of the radicle in 50 % of the seeds was recorded and counted in numbers.

#### Germination (%)

Germination percentage was calculated based on the number of seeds that successfully germinated out of the total number of seeds sown, using the formula

$$\text{Germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Total no. of seeds sown}} \text{ X } 100$$

#### Hypocotyl length

The hypocotyl length was measured in centimeters from the base of the radicle to the point of attachment of the cotyledons using a digital caliper and expressed in cm.

#### Days taken for cotyledonary leaves

The number of days from germination until the cotyledonary leaves became fully visible and expanded was recorded and expressed in numbers.

#### Days taken for true leaves

The days taken from sowing to the appearance of the first true leaf (post-cotyledonary) was recorded and indicated in numbers.

#### Days taken for plumule initiation

The initiation of the plumule was recorded as the number of days from sowing until the upward elongation of the shoot apex was first visibly distinguishable above the soil surface and recorded in numbers.

#### Leaf area (cm²)

The leaf area ($cm^2$) of seedlings was recorded by measuring the surface area of the leaves and it was expressed in $cm^2$.

#### Number of leaves

The total number of fully developed true leaves per seedling was counted and noted in numbers.

#### Mean survival (%)

The mean survival percentage was calculated based on the number of seedlings that remained alive and healthy to the total number of seedlings sown and the value was expressed as a percentage

$$\text{Mean survival (\%)} = \frac{\text{Number of living seedlings}}{\text{Number of total seedlings (spots) in protray}} \text{ X } 100$$

### Statistical analysis

All the data were subjected to statistical analysis using R, a programming language specialized for statistical computing, developed by statisticians (8). This study utilized R software (version 2.14.1) with "agricolae", "ggcorrplot", "factoextra" and "FactoMineR" package for statistical analysis, PCA and correlation analysis and OriginPro 2024 software for data visualization. Significant treatments were evaluated at the 5 % probability level.

## Results and Discussion

### Effects of different soaking intervals on days taken for germination and germination (%)

Among all the treatments, the number of days taken for seed germination on 3rd day after sowing was highest in $T_2$ (7.6), followed by $T_1$(3.5), $T_3$(1.5) and $T_5$(0.5), while $T_4$ showed no germination. On the 15th day after sowing, a higher number of seeds germinated in $T_2$ (18.6), followed by $T_1$(15.5), $T_3$(13.7) and $T_5$(10.0), whereas $T_4$ recorded only 8.0. These values are presented in Table 1.

After the 15th day of sowing, $T_2$ recorded the highest germination percent with 93.0 % followed by $T_1$(77.5 %), $T_3$(68.5 %), $T_5$(50.0 %) and the least germination percent occurred in $T_4$ (40.0 %). These values are shown in Fig. 1.

These findings align with previous studies emphasizing the role of pre-sowing treatments, such as seed soaking, in improving germination efficiency. Water uptake during soaking softens the seed coat, activates enzymes and initiates biochemical processes essential for radicle emergence (9). However, excessive soaking durations may lead to oxygen deprivation, leaching of essential nutrients or seed deterioration, which can negatively affect germination (10). These findings suggest that a two-day soaking period optimally enhances germination in cape gooseberry seeds. Soaking seeds can facilitate water absorption, activates metabolic processes essential for germination and promotes early seedling establishment (5). However, prolonged soaking beyond the optimal duration may lead to oxygen deprivation or leaching of vital nutrients, adversely affecting germination rates (10).

**Table 1.** Effects of different soaking intervals on days taken for germination

| Treatment | Day 3 | Day 6 | Day 9 | Day 12 | Day 15 | Total seed sown |
|---|---|---|---|---|---|---|
| $T_1$ | 1.5 | 6.7 | 10.5 | 12.6 | 13.7 | 20 |
| $T_2$ | 7.6 | 13.3 | 18.6 | 18.6 | 18.6 | 20 |
| $T_3$ | 3.5 | 9.6 | 13.7 | 15.0 | 15.5 | 20 |
| $T_4$ | 0 | 0 | 4.5 | 7.6 | 8.0 | 20 |
| $T_5$ | 0.5 | 3.3 | 7.4 | 8.5 | 10.0 | 20 |
| SE(d) | 0.055 | 0.147 | 0.367 | 0.393 | 0.337 | - |
| CD (0.05) | 2.57 | 2.75 | 4.11 | 3.87 | 0.751 | - |
| CV | 0.122 | 0.329 | 0.818 | 0.877 | 3.14 | - |

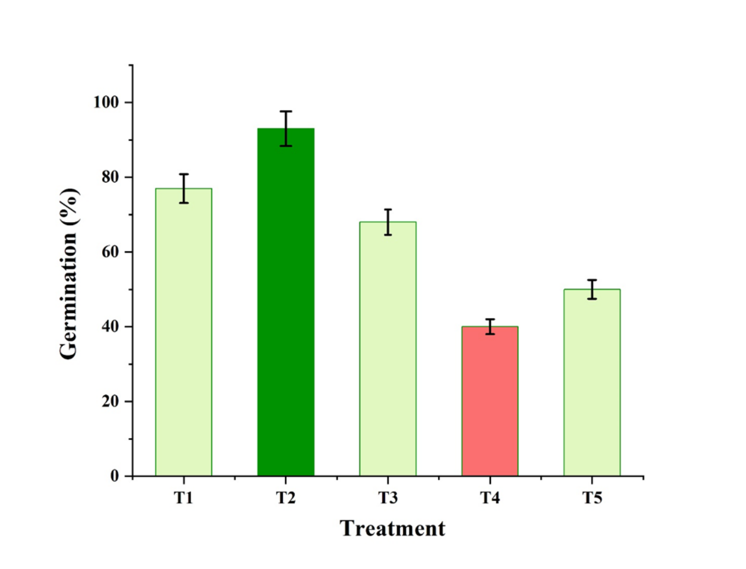


**Fig. 1.** Effects of different soaking intervals on germination (%).

A study on cape gooseberry seeds under varying water and temperature conditions found that optimal germination occurred under specific conditions and deviations from these conditions negatively impacted germination rates. This finding underscores the importance of controlling environmental factors to achieve optimal germination (10).

### Effects of different soaking intervals on hypocotyl length, days taken for the emergence of cotyledonary leaf, true leaf and plumule initiation

Among the treatments, $T_2$ exhibited the highest hypocotyl length (1.49 cm), followed closely by $T_1$ (1.38 cm), indicating a positive influence of these treatments on initial seedling growth. $T_3$ (1.10 cm) and $T_5$ (0.90 cm) showed moderate hypocotyl elongation, suggesting a lesser but still notable impact. $T_4$ recorded the shortest hypocotyl length (0.40 cm), indicating that this treatment may have inhibited elongation (Table 2).

The number of days taken for the emergence of cotyledonary leaves varied significantly among the different seed treatments. $T_1$ (8.08 days) and $T_2$ (8.30 days) recorded the shortest time for cotyledonary leaf emergence, indicating their effectiveness in promoting early seedling development. $T_3$ (9.20 days) showed a slightly delayed response, while $T_5$ (14.60 days) and $T_4$ (18.20 days) exhibited the longest durations (Table 2).

The days taken for the emergence of true leaves varied significantly. $T_2$ (10.58 days) and $T_1$ (10.75 days) showed the earliest true leaf emergence, indicating their effectiveness in promoting faster seedling development. $T_3$ (13.25 days) exhibited a moderate delay, whereas $T_5$ (19.33 days) and $T_4$ (26.31 days) recorded the longest duration (Table 2).

The days taken for plumule initiation varied significantly among the treatments. $T_2$ (2.80 days) and $T_1$ (3.44 days) recorded the earliest plumule emergence, indicating their positive influence on early seedling development. $T_3$ (5.25 days) showed a moderate delay, while $T_5$ (14.50 days) and $T_4$ (16.60 days) exhibited the longest duration, suggesting that these treatments were less effective or may have inhibited early growth (Table 2).

These findings align with research on seed priming techniques, which involve soaking seeds to enhance germination and early seedling growth. A study on tomato seeds demonstrated that soaking durations of 12 hr and 24 hr enhanced growth and dry matter accumulation, suggesting that moderate soaking periods can improve seedling vigor (11).

### Effects of different soaking intervals on the leaf area, number of leaves and seedling length at 30 days after sowing (DAS)

The number of leaves at 30 DAS showed no significant difference among treatments. The highest leaf area was recorded in $T_2$ (30.11), followed by $T_1$ (28.25) and $T_3$ (27.70). However, $T_5$ (6.05) and $T_4$ (3.10) exhibited lower leaf areas (Table 2). The superior leaf development observed in $T_2$ suggests that a two-day soaking period optimally enhances seed hydration, leading to improved germination and subsequent vegetative growth. *P. angulata* seeds soaking in a 0.2 % $KNO_3$ solution for 6 to 12 hr significantly improved germination rates and early seedling development (12). Although the species and soaking conditions differ, the principle that appropriate pre-sowing hydration can enhance early growth parameters is consistent. The minimal leaf development in $T_5$ underscores the importance of pre-sowing treatments. Seeds that were over-soaked likely experienced delayed water absorption and slower metabolic activation, resulting in reduced germination rates and stunted early growth. Untreated seeds often exhibit prolonged dormancy and suboptimal germination performance (13).

**Table 2.** Effects of different soaking intervals on seedling and vegetative growth of cape gooseberry

| Treatment | Hypocotyl length (cm) | Days taken for cotyledonary leaves | Days taken for true leaves | Days taken for initiation of plumule | Leaf area at 30 DAS | Number of leaves at 30 DAS | Seedling length at 30 DAS |
|---|---|---|---|---|---|---|---|
| $T_1$ | 1.38 | 8.08 | 10.75 | 3.44 | 28.25 | 5.50 | 19.10 |
| $T_2$ | 1.49 | 8.30 | 10.58 | 2.80 | 30.11 | 6.83 | 22.28 |
| $T_3$ | 1.10 | 9.20 | 13.25 | 5.25 | 27.70 | 4.91 | 18.50 |
| $T_4$ | 0.4 | 18.20 | 26.31 | 16.60 | 3.10 | 2.16 | 3.17 |
| $T_5$ | 0.9 | 14.60 | 19.33 | 14.50 | 6.05 | 3.65 | 4.99 |
| SE(d) | 0.016 | 0.239 | 0.220 | 0.101 | 0.579 | NS | 0.441 |
| CD (0.05) | 0.037 | 0.534 | 0.490 | 0.226 | 1.291 | NS | 0.983 |
| CV | 1.95 | 2.51 | 1.68 | 1.46 | 3.73 | NS | 3.97 |

The seedling length at 30 DAS varied significantly among the treatments. The longest seedlings were observed in $T_2$ (22.28 cm), followed by $T_1$ (19.10 cm) and $T_3$(18.50 cm). In contrast, $T_5$ (4.99 cm) and $T_4$ (3.17 cm) exhibited significantly shorter seedlings (Table 2). The superior seedling growth observed in $T_2$ suggests that a two-day soaking duration optimally facilitates water uptake, thereby enhancing metabolic activities essential for seed germination and subsequent seedling elongation. Appropriate hydration is crucial for activating the physiological processes that drive seed germination and early growth (10). Similarly, seeds that were over soaked ($T_4$) likely experienced delayed imbibition, resulting in slower germination and stunted growth.

## Effects of different soaking intervals on mean survival percentage

The mean survival percentage significantly varied among treatments. The highest survival rate was recorded in $T_2$ (98.50 %), followed by $T_1$ (94.25 %) and $T_3$ (90.10 %), indicating better adaptability and growth conditions. However, $T_5$ (78.10 %) showed a moderate decline in survival, while $T_4$ (65.25 %) had the lowest survival percentage, suggesting significant stress or unfavorable conditions affecting seedling viability (Fig. 2). The superior performance of $T_2$ suggests that this soaking duration optimized water absorption and enzymatic activation, leading to improved seed vigor and survival. The controlled hydration enhances metabolic activities, promoting higher survival rates in seeds (14).

However, $T_5$ showed a decline in survival percentage (66.60 %), demonstrating that dry-sown seeds without pre-soaking suffered from dormancy-related issues, delayed metabolic activation and poor germination, ultimately reducing survival. The seed dormancy can hinder germination and reduce overall survival rates, reinforcing the importance of pre-sowing treatments to break dormancy and enhance early seedling vigor (13).

The lowest survival percentage was recorded in $T_4$ (33.30 %), likely due to excessive water absorption leading to oxygen deprivation, seed coat weakening and possible microbial activity. Prolonged soaking can cause leaching of essential nutrients and enzymatic imbalances, negatively impacting seed viability (5).

## Principal component analysis (PCA)

PCA was performed to investigate the variance in seedling characteristics among five treatments. The first principal component (PC1) represented 96.4 % of the overall variance, whereas PC2 accounted for 2.2 %, indicating that PC1 primarily captures the substantial differences among the treatments. PC1 is positively influenced by hypocotyl length (HL), germination percentage (GP), number of leaves (NOL), mean survival percentage (MSP), seedling length (SL) and leaf area (LA). This suggests that PC1 essentially reflects seedling vigour and growth efficiency. Conversely, days taken for plumule initiation (DTIP), days taken for cotyledonary leaf (DTCL) and days taken for true leaf emergence (DTTL) adversely influenced PC1, signifying that delayed seedling emergence and development are inversely related with seedling vigour. The findings align with previous

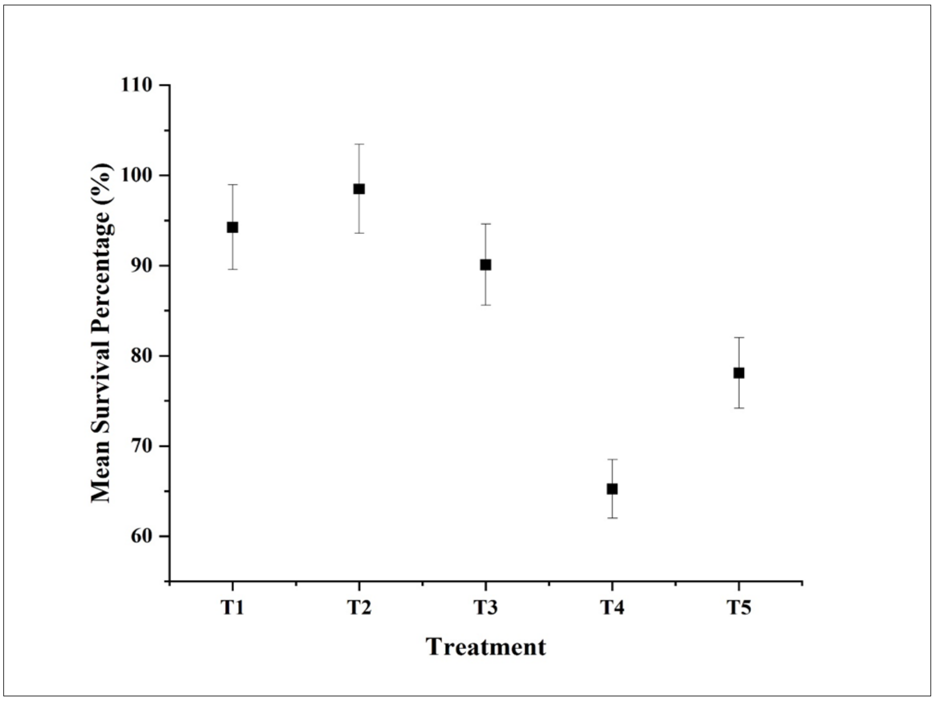


**Fig. 2.** Effects of different soaking intervals on mean survival percentage.

research, which emphasized the positive influence of large seed size on seedling characteristics (15). Their PCA analysis also supported the association of seed length with early seedling vigour traits. Similar to the present study, seedling traits were found to be more amenable to genetic improvement than seed traits. This reinforces the potential of using seed length as a reliable indirect selection criterion for enhancing early growth performance (16).

The PCA biplot illustrated distinct clustering of the treatments based on their traits. Treatments $T_1$ and $T_2$ appeared on the positive side of PC1 and were closely associated with traits reflecting better growth and survival, suggesting superior seedling performance. $T_3$ also showed alignment with favourable vigour traits, especially seedling length and leaf area. On the other hand, $T_4$ and $T_5$ were positioned on the negative side of PC1, associated with slower emergence and development traits such as DTIP, DTCL and DTTL. The opposing directions of vectors in the biplot indicate a strong negative correlation between delayed emergence and vigour-related traits. Trait contribution values ranged between 10.8 to 11.2, with LA, SL, DTIP and DTCL contributing slightly more, confirming that PC1 effectively differentiates the treatments based on early growth performance. Black gram seedlings have shown that developmental delays significantly reduced PCA scores, indicating a strong negative influence on early growth traits (17). This parallel reinforces the conclusion that prompt seedling emergence is critical for overall seedling strength and survival.

### Correlation analysis

The correlation heatmap shows that the measured seedling traits are closely correlated with each other. There is a clear negative correlation between developmental timing traits DTIP, DTCL and DTTL and seedling growth parameters such as HL, LA, NOL, SL, GP and MSP. DTIP has a perfect negative correlation with LA ($r$ = -1.00) and extremely high negative correlations with SL ($r$ = -0.99), MSP ($r$ = -0.97) and GP ($r$ = -0.95). This means that longer times for plumule initiation are substantially linked to lower growth and survival rates.

On the other hand, factors like SL, LA, HL, GP and MSP are very strongly associated with each other ($r$ > 0.90), which means that these characteristics work together to make seedlings stronger. This trend strengthens the negative correlation between seedling performance and delayed developmental phases. A study on wheat genotypes under drought stress reported strong positive correlations among SL, GP and MSP, highlighting that early emergence traits are key indicators of seedling vigour. This supports the current findings, where early growth parameters consistently aligned with superior seedling performance (18). Strong correlations between attributes give critical information on how to improve features simultaneously, as well as the direct and indirect implications of these correlations, which will eventually lead to better yield and quality (19).

## Conclusion

According to the findings, the study demonstrated that different soaking durations significantly influenced the germination and vegetative growth of cape gooseberry seeds under tropical conditions. A two-day soaking period ($T_2$) resulted in the highest germination rate (93.0 %), shortest time to germination and true leaf emergence (10.58 days) and higher hypocotyl growth (1.49 cm) and mean survival percentage of 98.50 %, suggesting it as the optimal pre-soaking duration for enhanced seedling establishment. However, excessive soaking and unsoaked seeds exhibited poor performance across all measured parameters, reinforcing the

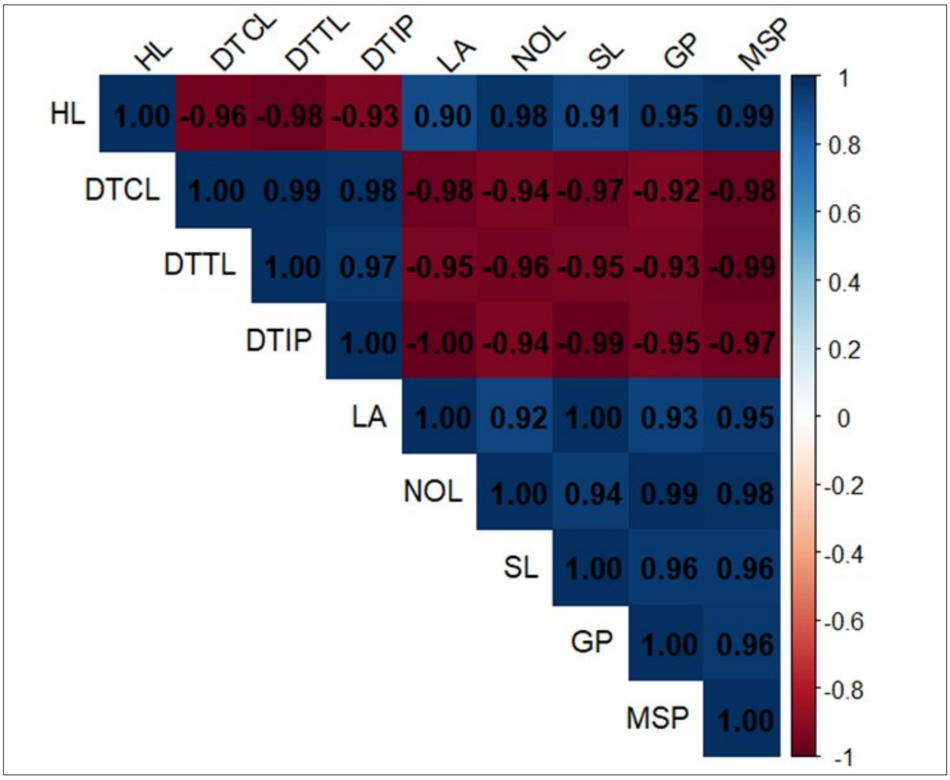


**Fig. 3.** Correlation matrix was constructed in R using ggcorrplot package to demonstrating the relationship among vegetative growth characteristics of cape gooseberry. Positive correlations are depicted in blue and negative correlations in red. *HL: hypocotyl length, DTCL: days taken for cotyledonary leaf, DTTL: days taken for true leaf emergence, DTIP: days taken for plumule initiation, LA: leaf area, NOL: number of leaves, SL: seedling length, GP: germination percentage, MSP: mean survival percentage.

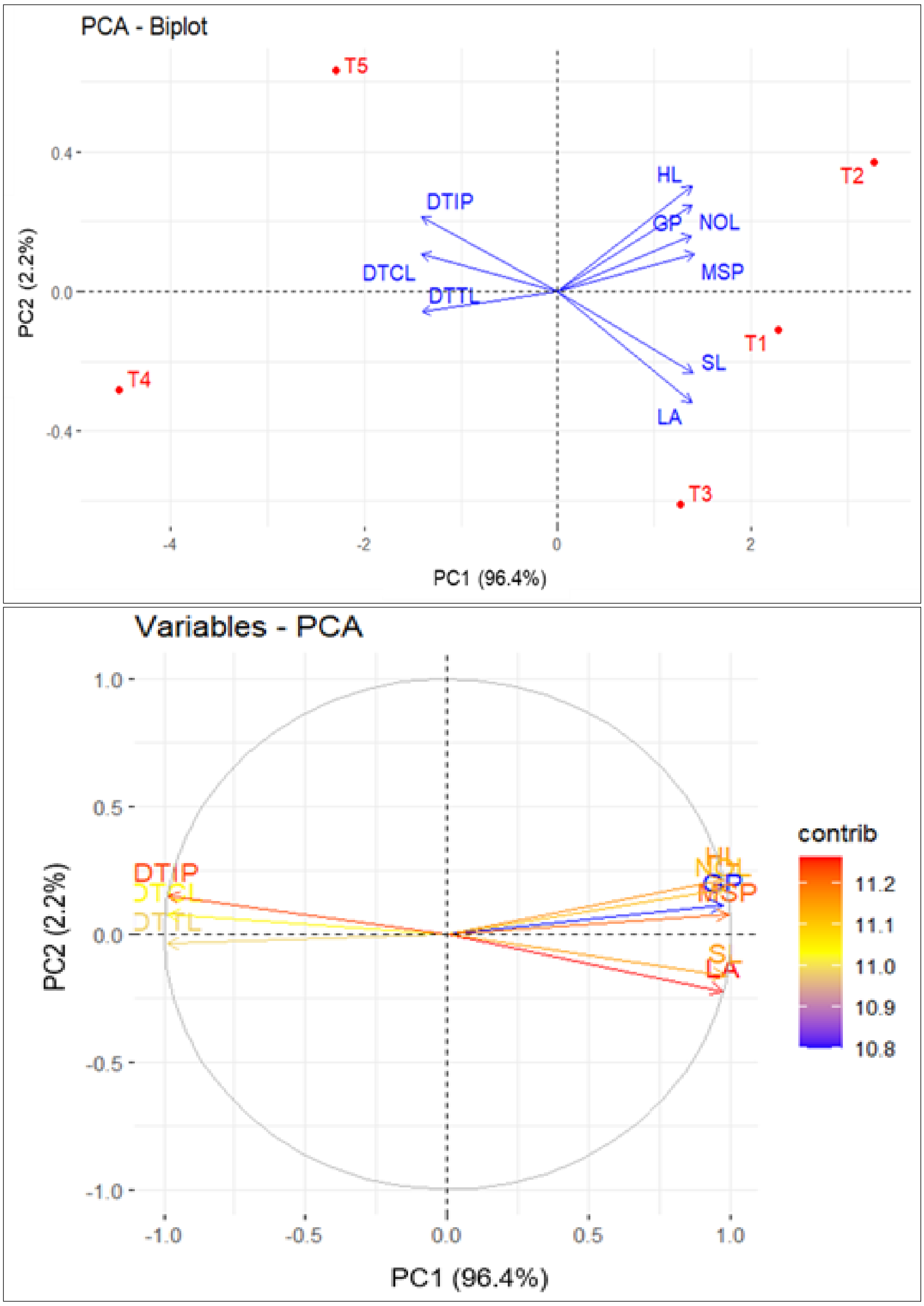


**Fig. 4.** PCA analysis was performed in R using the factoextra and FactoMineR packages to visualize PCA results. The plots depict the contribution and relationships among treatments and vegetative growth characteristics of cape gooseberry. *HL: hypocotyl length, DTCL: days taken for cotyledonary leaf, DTTL: days taken for true leaf emergence, DTIP: days taken for plumule initiation, LA: leaf area, NOL: number of leaves, SL: seedling length, GP: germination percentage, MSP: mean survival percentage.

importance of soaking for improved germination and early vegetative growth.

Overall, a controlled pre-soaking treatment of two days is recommended for cape gooseberry cultivation in tropical climates to optimize seedling vigour and establishment. Further research is planned to observe the growth and yield attributes of treated seeds and it is suggested to explore additional pre-sowing treatments, such as hydropriming or osmopriming, to enhance the germination and growth potential of *P. peruviana* in varying environmental conditions.

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## Authors' contributions

JAMJ and SS participated in the research activities, field establishment, statistical data analysis and the writing of the research article. VS and VR edited and JR, TA, MU, VVAG, KRR, RS and PJ reviewed the research article. Every author reviewed and endorsed the final manuscript.

## Compliance with ethical standards

**Conflict of interest:** The authors have no conflicts of interest to disclose.

**Ethical issues:** None

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### Additional information


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