**Impact of Interstock and Rootstock on the Vigor and Productive Development of Mango (*Mangifera indica* L.) in San Lorenzo Valley, Piura, Peru.**

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**Conflicts of interest**

The authors declare that they have no conflicts of interest.

**Author Contributions**

Conceptualization, S.C-N.; methodology, H.M-R.; formal analysis, F.L-I. and S.C-N.; investigation, E-O.N-T.; data curation, F.L-I., and S.C-N.; writing—original draft preparation, H.M-R., S.V-N., G.C-H, N.T-T, E-O.N-T, A.M-A, F.L-I. and S.C-N.; writing—review and editing, F.L-I. and L.V-A.; visualization, F.L-I. and S.C-N.; supervision, J.C. and M.R.; funding acquisition, J.C. All authors have read and agreed to the published version of the manuscript.

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**Data availability**

The original contributions presented in this study are included in the article and supplementary material. The reproducible data analysis and datasets are available in Supplementary File 1 and can be accessed through the GitHub repository at: [**https://github.com/Sebass96/prochira\_injertos**](https://github.com/Sebass96/prochira_injertos.git)

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# ABSTRACT

The mango tree *(Mangifera indica* L.) is a fruit tree known for its vigorous growth. This crop is planted at low densities because of the space it requires during vegetative development, which has a significant effect on productivity per unit area. This research was conducted in the Piura region, Peru. The objective of this study was to determine the effects of the interaction between rootstock and interstock on the agronomic characteristics and fruit biometrics of mangoes. A total of 216 ten-year-old mango trees were evaluated and planted at a distance of 6.0 m × 6.0 m over an area of 1.25 ha during the agricultural season from 2017–2019. A randomized complete block design (RCBD) with a 2 × 4 factorial arrangement and three blocks was used. The first factor corresponded to the mango rootstock from the Chulucanas and Chato varieties, whereas the second factor included the interstock from the Chulucanas, Chato, Irwin, and Julie varieties. The results indicated that the variety of cultivars used affects plant growth; however, it does not influence the biometric characteristics of the fruits.

**Keywords:** agronomic performance; biometric characteristics; fruit yield; grafting techniques; El Niño

# INTRODUCTION

The mango tree (*Mangifera indica* L.) is a fruit tree of the Anacardiaceae family that is cultivated in tropical and subtropical areas [[1]](https://www.zotero.org/google-docs/?KYtL53). It is characterized by vigorous growth and aesthetically attractive fruits, with a high content of fatty acids, and is rich in carbohydrates, minerals, and vitamins [[2]](https://www.zotero.org/google-docs/?0BmjUf). Currently, mango is cultivated at low to medium densities, ranging from 69 to 416 trees/ha, due to the need for space during vegetative growth, which is commonly associated with production [[3]](https://www.zotero.org/google-docs/?prJSqX); [[4]](https://www.zotero.org/google-docs/?J8ctbD).

The use of low densities decreases production because yields during the first few years are low [[5]](https://www.zotero.org/google-docs/?2Mz04i). However, increasing densities along with the vegetative growth of the crop reduces profits, as they complicate cultural maintenance tasks [[4]](https://www.zotero.org/google-docs/?ycpzqy). Additionally, a tall canopy results in a lower number of trees per unit area, causing competition for light and aeration [[6]](https://www.zotero.org/google-docs/?EPst85). In this context, research should focus on controlling tree vigor via cultural techniques such as pruning, the application of growth regulators, and the genetics of rootstocks or scions [[7]](https://www.zotero.org/google-docs/?9cc9XU).

The use of rootstocks is a technique commonly employed in the propagation of fruit trees, which involves the union of two parts of a plant: a root system (rootstock) and an aerial part (interstock). These parts combine through assembly to form a new plant [[8]](https://www.zotero.org/google-docs/?bP2NPR); [[9]](https://www.zotero.org/google-docs/?5NcI2h). The rootstock is correlated with tree vigor, yield, fruit quality, and tolerance to biotic or abiotic stress [[10]](https://www.zotero.org/google-docs/?CBWqXR); [[11]](https://www.zotero.org/google-docs/?YaROmg). The propagation of highly valuable varieties occurs on grafts that exhibit greater resistance to diseases, better adaptability to environmental conditions, and optimized nutrient absorption [[12]](https://www.zotero.org/google-docs/?db22is); [[13]](https://www.zotero.org/google-docs/?3vnYxl)). The viability and compatibility of the graft are influenced by the proximity between taxonomic species and the technique used to align the vascular bundles, which ensures the translocation of carbohydrates and hormones and nutrient transport [[14]](https://www.zotero.org/google-docs/?cCohvw).

While mango production is correlated with tree size [[4]](https://www.zotero.org/google-docs/?CTA9Iy), varieties such as Irwin [[15]](https://www.zotero.org/google-docs/?7JVTdD), Keitt [[16]](https://www.zotero.org/google-docs/?JuynLf), and Tommy Atkins [[17]](https://www.zotero.org/google-docs/?W4MccM) present high yields in smaller trees. These latter varieties would be suitable for planting at high densities [[4]](https://www.zotero.org/google-docs/?rKb9j7); [[18]](https://www.zotero.org/google-docs/?aUiAOn).

In this context, owing to the regulation of the vertical or horizontal growth of the tree and the modification of the sensory properties of the fruit caused by rootstock-interstock combinations in mango varieties [[19]](https://www.zotero.org/google-docs/?AGHwrZ); [[20]](https://www.zotero.org/google-docs/?zITwyr), this study aims to determine the effects of the interaction between rootstock and interstock on the agronomic characteristics and fruit biometrics of the mango cultivar.

# MATERIALS AND METHODS

## Study Area

The study was conducted during the agricultural seasons of 2017-2019 at the Hualtaco Nursery, owned by the El Chira Agricultural Experimental Station (EEA), located in the district of Tambogrande, Piura Department, at a latitude of 4° 55’ 53” South, a longitude of 80° 20’ 22” West, and an altitude of 82 m above sea level. The area has a tropical desert and subtropical climate. The mango plants are spaced at 6.0 m × 6.0 m, with a total of 216 plants.

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| Figure 1: Map of the location of the experimental research area. Hualtaco Nursery, Tambogrande District, Piura Department, Peru. |

## Plant Material

The rootstocks were obtained from seeds of ‘Chulucanas’ (Chulucanas) and ‘Chato’ (Chato) mangoes propagated in seedbeds with agricultural soil. Afterward, the plants were transplanted into polyethylene bags (16” × 8”) filled with forest agricultural soil substrate. For the interstocks, vegetative buds from the Chulucanas, Chato, ‘Irwin’ (Irwin), and ‘Julie’ (Julie) varieties were used, whereas vegetative buds from the ‘Kent’ (Kent) variety were used for top grafting. The seeds and vegetative buds were acquired from the germplasm bank located at the Hualtaco nursery of EEA-El Chira. The main characteristics of the plant material used are described below:

**Chulucanas:** This variety is known as a criollo variety from Chulucanas in the Piura region, Peru, where the climatic conditions are suitable for its development. This variety is widespread in the northern region of the country and is used as rootstock. It produces yellow and uniform fruit, with a uniquely intense flavor, a high amount of fiber around the seed, and a smaller size than the export mango fruit of CV. Kent [[21]](https://www.zotero.org/google-docs/?7GSxlc).

**Irwin:** Irwin is one of the most commercially produced and consumed varieties in Japan, Taiwan, South Korea, and Australia and is known as the “apple mango.” Irwin plants are small to medium in height, with oval-shaped fruits that have red skin coloration, measuring approximately 11.5 cm to 13 cm in length and 8 cm to 9 cm in diameter [[22]](https://www.zotero.org/google-docs/?qBA17l).

**Julie**: This variety is widespread in Nigeria. The plants exhibit an extended growth habit, with medium foliage density and lanceolate-shaped leaves; the fruit is ovoid with yellow skin coloration, measuring approximately 99.5 mm in length, 70 mm in width, and weighing 219 g [[23]](https://www.zotero.org/google-docs/?DR8sW5).

**Chato:** Known as the Chato variety from Ica, it is one of the most widely exploited cultivars in the valley of the Ica region in southern Peru. It is characterized by fruit measuring approximately 151 mm in length and 82 mm in width and weighing 291 g [[24]](https://www.zotero.org/google-docs/?NcHirf).

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| Table 1: Treatment Coding of the Study: Impact of Interstock and Rootstock on the Vigor and Productive Development of Mango (*Mangifera indica* L.) in the San Lorenzo Valley, Piura, Peru.   | **Treatment** | **Rootstock** | **Interstock** | **Scion** | | --- | --- | --- | --- | | T1 | Chulucanas | Chulucanas | Kent | | T2 | Chulucanas | Chato | Kent | | T3 | Chulucanas | Julie | Kent | | T4 | Chulucanas | Irwin | Kent | | T5 | Chato | Chulucanas | Kent | | T6 | Chato | Chato | Kent | | T7 | Chato | Julie | Kent | | T8 | Chato | Irwin | Kent | |

## Agronomic Management

Soil preparation was carried out via a tractor and a harrow, in accordance with the layout of the crop rows, hole digging, and transplanting of seedlings, following a grid planting design of 6 × 6 meters. Seed selection was performed from the mango germplasm bank, which comes from elite plants at the Hualtaco Annex of the El Chira Agricultural Experimental Station (EEA). The process of removing the pericarp, mesocarp, and endocarp facilitated better development of the embryo in the seedlings, which were obtained from polyembryonic seeds in seedbeds. The grafting of the seedlings was performed via the double tongue technique three months after their transplantation into nursery bags. Interstocks and top grafts were subsequently implemented via the same English grafting technique, or double tongue, with an interval of eight months between the two procedures. The bridge rootstock graft was performed in 2008, whereas the bud bridge graft was carried out in 2009.

The irrigation system was established via a technique, starting with one irrigation tape and two microtubes per plant in the first year. A second irrigation tape with two additional microtubes was then added to improve water efficiency. The irrigation schedule was programmed with a frequency of 15-20 days and adjusted according to the crop’s needs. Fertilization was carried out through the combined application of organic fertilizers and synthetic fertilizers, in accordance with the nutritional requirements of the mango at each stage of its development. Weeding was performed periodically via brush cutters, depending on the emergence of weeds in the field. Phytosanitary control was managed under a constant monitoring scheme and integrated pest management. Finally, activities related to flowering, fruiting, and harvesting followed the traditional agronomic practices of local producers in the San Lorenzo Valley.

## Agronomic and Biometric Characterization of the Fruit

The agronomic characterization included measuring the plant height, number of fruits, and percentage of budding and flowering. The plant height (m) was determined at the end of the agricultural season. It was measured from the base of the soil to the apex of the plant via a graduated wooden ruler. The number of fruits was determined visually by directly counting the number of fruits produced by each individual before the first harvest. The percentage of budding (%) was determined through direct observation; six branches from the middle third of the canopy on the east side and six branches from the west side were identified and monitored. The number of shoots produced by each branch and the number of buds until desiccation were evaluated [[25]](https://www.zotero.org/google-docs/?HLTDw4). The percentage of flowering (%) was visually assessed by observing the intensity of flowering in the tree canopy at the time of anthesis. The canopy was divided into two opposing sections, and the percentage of flowering was recorded on a scale of 0-100 according to the coverage of the inflorescences in each section. To calculate the overall flowering percentage of the tree, an average of both evaluated sections was taken [[26]](https://www.zotero.org/google-docs/?yF4xDY).

To determine the fruit biometrics, five fruits were randomly selected per individual at the time of harvest, and the parameters of fruit weight (g), fruit length (mm), and fruit diameter (mm) were measured. Fruits that reached physiological maturity were chosen for measurements via a Vernier caliper and balance [[27]](https://www.zotero.org/google-docs/?4pmO10).

## Experimental Design

The experiment was conducted via a randomized complete block design (RCBD) with a 2 × 4 factorial arrangement consisting of three blocks. The first factor was the mango rootstock at two levels, the Chulucanas and Chato varieties, and the second factor consisted of the interstock at four levels, the mango varieties Chulucanas, Chato, Irwin, and Julie. The experimental unit was composed of nine mango plants. The treatments consisted of the interaction between the levels of rootstock, interstock, and top grafting of the Kent variety. To determine the agronomic characteristics, all the plants were selected, and the variables measured included plant height, percentage of budding, number of fruits, and percentage of flowering. For the determination of fruit biometrics, five plants were randomly selected, and the variables measured included the weight, length, and diameter of the fruits.

## Statistical Analysis

An analysis of variance (ANOVA) was performed to determine if there were differences between the treatments. The comparison of means was carried out via Tukey’s test (α = 0.05) via the R package emmeans [[28]](https://www.zotero.org/google-docs/?2Y17VU). The variables under study were subjected to multivariate analysis via principal component analysis (PCA) via the FactoMineR package [[29]](https://www.zotero.org/google-docs/?yGRwzs). The correlation analysis of variables via PCA was conducted via the corrplot package [[30]](https://www.zotero.org/google-docs/?ULD9CT). Data analysis was performed via the statistical software R version 4.4.1 [[31]](https://www.zotero.org/google-docs/?xZRiwp) **.**

# RESULTS

## Weather conditions

To determine the weather conditions that influenced the management of mango cultivation during the agricultural seasons of 2017–2019, a graph was created with data on maximum temperature, minimum temperature, precipitation, and relative humidity obtained from the “El Partidor” weather station of SENAMHI.

The highest temperature values were recorded in 2018 from January to March, reaching a peak of 35.20 °C in March. On the other hand, the lowest temperature values were observed in 2019 from July to November, reaching 15.72 °C in August. In terms of precipitation, the highest values occurred in 2017 during February and March, peaking at 39.41 mm in March. This was an atypical event caused by the El Niño‒Southern Oscillation (ENSO) climate phenomenon. The relative humidity was also influenced by this event, with a maximum value of 89.48% occurring in March 2017. These parameters are important because they are critical factors that directly influence the growth, flowering, fruiting, and quality of mango fruit.

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| Figure 2: Climatic Conditions During the Agricultural Seasons of 2017-2019, Experiment Located in the District of Tambogrande, Piura Department, Peru. Source: SENAMHI. |

## Agronomic Characterization

To determine the agronomic characteristics of the rootstock-interstock interaction in the mango, the variables measured included plant height, number of fruits, and percentages of budding and flowering. A univariate analysis was performed via Tukey’s mean comparison test (p < 0.05) to assess whether there were significant differences between the rootstock and the interstock used ([Figure 3](#fig-id.1lhpgrqadiq1)). This study aimed to identify the rootstock-interstock relationship that exhibits the most favorable agronomic characteristics for enhancing the production and agronomic management of mango (*Mangifera indica* L.) in San Lorenzo Valley.

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| Figure 3: Agronomic Characteristics of the Rootstock and Interstock Relationship for the Mango in the Piura Region, Calculated Based on Nine Plants per Treatment. (a) Plant height at harvest. (b) Percentage of sproud. (c) Number of fruits produced during the agricultural seasons from 2017 to 2019. (d) Percentage of flowering recorded during the agricultural seasons of 2017-2019. Different letters indicate significant differences in Tukey’s mean comparison test (p-value < 0.05, n = 648). Comparison conducted among the interstock varieties within each rootstock. |

For the variable plant height, significant differences were observed between the interactions of rootstock and interstock (p-value < 0.01). The results showed that the Chuluca rootstock with the Chulucanas and Julie interstocks had lower means for the plant height variable, measuring 3.49 m and 3.46 m, respectively ([Figure 3](#fig-id.1lhpgrqadiq1)a). The Chato rootstock, on the other hand, did not significantly differ among the various interstocks used. However, the Chato rootstock, on average, achieved greater heights of 3.80 m than did the Chulucanas rootstock at 3.63 m, suggesting that the use of the latter yields better results for this variable, particularly highlighting the Chulucans-Chulucans and Chulucans-Julie relationships.

There were no significant differences in the percentage of buds among the interstocks used for each rootstock (p value > 0.05). However, for Chulucanas, higher average values were recorded for this variable, with a value of 67.47% compared with 55.99% for the Chato rootstock. The interaction of the Chulucanas-Julie rootstock-interstock combination had the highest percentage of buds, at 72.16% ([Figure 3](#fig-id.1lhpgrqadiq1)b).

For the variable number of fruits, no significant differences were observed for each rootstock or the different interstocks used (p-value = 0.46). In contrast, significant differences were observed between the agricultural seasons of 2017 and 2019 for both rootstocks (p-value < 0.001). In the case of the Chato rootstock, the number of fruits produced was lower on average in 2017, at 171.40, than in 2018 and 2019, with averages of 206.15 and 203.18, respectively. Similarly, for the Chulucanas rootstock, in 2017, an average lower number of fruits were produced 180.16, than in 2018 and 2019, with averages of 214.90 and 211.94, respectively. Furthermore, the results indicated that the Chulucanas rootstock produced higher values for this variable, with an average of 202.33 fruits, compared with 193.57 for the Chato rootstock. ([Figure 3](#fig-id.1lhpgrqadiq1)c).

Similarly, the observed percentage of flowering showed that the rootstocks did not significantly differ for the interstocks used (p-value = 0.15). However, notable significant differences were observed between the agricultural seasons of 2017 and 2019 for the Chulucanas and Chato rootstocks (p-value < 0.001). In the case of the Chato rootstock, in 2018, the average flowering percentage was 68.77%, whereas in 2017 and 2019, the percentages were 80.86% and 80.87%, respectively. Similarly, for the Chulucanas rootstock, in 2018, the average budding percentage was 71.47% lower than those in 2017 and 2019, which were 83.56% and 83.58%, respectively. Furthermore, it was observed that the Chulucanas rootstock had higher average flowering rates, with an average of 78.31% than the 76.84% reported for the Chato rootstock ([Figure 3](#fig-id.1lhpgrqadiq1) d).

To analyze the overall interaction of the variables and the use of rootstocks, a multivariate analysis of principal components (PCA) and a Pearson correlation analysis were conducted ([Figure 4](#fig-id.r1ur4b6nanx4), Supplementary Figure 1).

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| Figure 4: Principal Component Analysis (PCA) of the agronomic characteristics in mango cultivation based on the use of rootstock-interstock combinations. (a) Variables were evaluated to determine the agronomic characteristics of the rootstock-interstock combination in mango. (b) Treatments were used based on the rootstock-interstock combination for evaluating the agronomic characteristics of mango plants. The analysis was based on 648 observations (n = 648). |

To evaluate the interaction of the variables, a multivariate principal component analysis (PCA) method was used ([Figure 4](#fig-id.r1ur4b6nanx4)). The first two components represent 85.52% of the cumulative variance, accounting for 62.27% of the variance in dimension 1 and 23.26% in dimension 2 ([Figure 4](#fig-id.r1ur4b6nanx4)a, Supplementary Figure 1a). For dimension 1, the variables plant height and percentage of flowering contributed 33.26% and 29.71%, respectively, whereas the percentage of budding contributed 23.77% and the number of fruits contributed 13.26% ([Figure 4](#fig-id.r1ur4b6nanx4)a, Supplementary Figure 1b). In dimension 2, the variable number of fruits and percentage of buds had the greatest contributions, at 66.19% and 33.05%, respectively, whereas the percentage of flowers was 0.23% and plant height was 0.53%. ([Figure 4](#fig-id.r1ur4b6nanx4)a, Supplementary Figure 1c).

The vectors indicate the direction of the relationship between the variables, showing a positive relationship among the variables of budding, flowering, and number of fruits produced, in contrast to plant height, where a negative relationship is observed. Notably, there was a strong positive correlation (0.86) between the percentage of flowering and a strong negative correlation (-0.91) between the plant height variable and dimension 1. Furthermore, in dimension 2, the variable number of fruits had a strong positive correlation of 0.78 ([Figure 4](#fig-id.r1ur4b6nanx4)a, Supplementary Figure 1d).

On the other hand, it is observed that the Chulucanas-Chulucanas rootstock-interstock relationship is aligned with the vector for the number of fruits, indicating that individuals with this graft presented better characteristics for this variable. In terms of the percentage of budding, individuals with the Chulucanas-Julie and Chato-Chulucanas relationships presented the highest values for this variable. In terms of the percentage of flowers, the Chato-Chulucanas rootstock-interstock relationship presented the best characteristics. For plant height, the Chato‒Julie and Chato‒Irwin relationships presented the highest values ([Figure 4](#fig-id.r1ur4b6nanx4)b).

## Biometric characterization of the fruit

To determine the biometrics of the fruit produced by the rootstock-interstock interaction in the mango, the variables of weight, length, and diameter of the fruit were evaluated. Tukey’s mean comparison test (p < 0.05) was conducted to assess whether there were significant differences between the rootstock and the interstock used ([Table 1](#tbl-id.541d1mdcbw1l)). This study aimed to identify the rootstock-interstock relationship that produces the best quality mango fruit (*Mangifera indica* L.) in San Lorenzo Valley.

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| Table 2: Fruit biometrics in eight combinations of rootstock-interstock for mango during the 2023 agricultural season. Where rootstock (Rootstock), interstock (Interstock), mean (mean), standard deviation (sd), minimum (min), maximum (max), and significance (Sig) are presented. Calculations are based on five fruits evaluated from two plants per treatment. Different letters indicate significant differences in Tukey’s mean comparison test (p < 0.05, n = 240). Comparisons were made among the interstock varieties within each rootstock.   | **Variable** | **Rootstock** | **Interstock** | **mean** | **sd** | **min** | **max** | **Sig** | | --- | --- | --- | --- | --- | --- | --- | --- | | Fruit Weight (g) | Chato | Chato | 452.53 | 79.92 | 305 | 639 | a | |  | Chato | Chulucanas | 462.34 | 69.82 | 340 | 620 | a | |  | Chato | Irwin | 482.03 | 87.3 | 350 | 700 | a | |  | Chato | Julie | 465.97 | 92.07 | 300 | 645 | a | |  | Chulucanas | Chato | 484.97 | 101.98 | 316 | 765 | a | |  | Chulucanas | Chulucanas | 468.17 | 118.73 | 230 | 665 | a | |  | Chulucanas | Irwin | 447.23 | 70.09 | 310 | 605 | a | |  | Chulucanas | Julie | 484.7 | 93.46 | 367 | 717 | a | | Fruit length (mm) | Chato | Chato | 105.97 | 6.78 | 93 | 120 | a | |  | Chato | Chulucanas | 106.28 | 6.8 | 94 | 119 | a | |  | Chato | Irwin | 106.07 | 6.47 | 95 | 124 | a | |  | Chato | Julie | 107.67 | 7.54 | 91 | 120 | a | |  | Chulucanas | Chato | 106.53 | 7.21 | 95 | 123 | a | |  | Chulucanas | Chulucanas | 106.2 | 10.87 | 86 | 126 | a | |  | Chulucanas | Irwin | 106.43 | 7.28 | 92 | 122 | a | |  | Chulucanas | Julie | 109.73 | 8.03 | 98 | 129 | a | | Fruit diameter (mm) | Chato | Chato | 85.23 | 4.72 | 76 | 97.5 | a | |  | Chato | Chulucanas | 86.09 | 3.61 | 78.5 | 93.5 | a | |  | Chato | Irwin | 87.63 | 5.07 | 79.5 | 100 | a | |  | Chato | Julie | 86.23 | 5.56 | 75.5 | 97.5 | a | |  | Chulucanas | Chato | 87.7 | 5.4 | 78 | 100.5 | a | |  | Chulucanas | Chulucanas | 86.08 | 6.61 | 69.5 | 99 | a | |  | Chulucanas | Irwin | 84.53 | 4.03 | 77.5 | 92.5 | a | |  | Chulucanas | Julie | 86.3 | 4.68 | 79.5 | 97 | a | |

The statistical analysis performed via Tukey’s post hoc test (α = 0.05) revealed that for the fruit weight variable, no significant differences were found (p-value = 0.19). However, the highest means were recorded for the Chulucanas-Chato and Chulucanas-Julie combinations, with values of 484.97 g and 484.70 g, respectively, whereas the lowest mean was presented by Chulucanas-Irwin at 447.23 g. Similarly, the same occurred with fruit length, where no significant differences were found (p-value = 0.87). However, the highest mean was obtained with the Chulucanas-Julie combination, with a value of 109.73 mm, whereas the lowest mean was obtained with the Chulucanas-Julie combination, with a value of 105.97 mm. Additionally, for fruit diameter, no significant differences were found between the treatments used (p-value = 0.02). Nevertheless, the highest value was obtained with the Chulucanas-Chato combination at 87.70 mm, and the lowest value was obtained with the Chulucanas-Irwin combination at 84.53 mm.

To analyze the overall interaction of the variables and the use of rootstocks, a multivariate analysis of principal components (PCA) and a Pearson correlation analysis were conducted ([Figure 5](#fig-id.rtncwk932bt9), Supplementary Figure 2).

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| --- |
| Figure 5: Principal Component Analysis (PCA) of fruit biometrics in mango cultivation based on the use of rootstock-interstock combinations. (a) Variables were evaluated to determine the fruit quality of the rootstock-interstock combination in mango. (b) Treatments were used based on the rootstock-interstock combination for evaluating fruit quality in mango plants. The analysis was based on 240 observations (n = 240). |

To evaluate the interaction of the variables, a multivariate principal component analysis (PCA) method was used ([Figure 5](#fig-id.rtncwk932bt9)). The first two components represent 99.21% of the cumulative variance, with 66.97% of the variance in dimension 1 and 32.23% in dimension 2 ([Figure 5](#fig-id.rtncwk932bt9)a, Supplementary Figure 2a). For dimension 1, the variables weight and diameter of the fruit contributed the most to this dimension, with 49.14% and 40.32%, respectively, whereas the contribution of fruit length was 10.55%. ([Figure 5](#fig-id.rtncwk932bt9)a, Supplementary Figure 2b). In dimension 2, the variable fruit length had the greatest contribution, at 81.29%, compared with the contributions of weight and fruit diameter, which were 0.07% and 18.64%, respectively ([Figure 5](#fig-id.rtncwk932bt9)a, Supplementary Figure 2c).

The vectors indicate the direction of the relationship between the variables, highlighting a notable degree of positive correlation among the weight, length, and diameter of the fruits. Notably, there was a strong positive correlation for fruit weight (0.99) and fruit diameter (0.90) with respect to dimension 1. Additionally, in dimension 2, the variable fruit length has a strong positive correlation of 0.89 ([Figure 5](#fig-id.rtncwk932bt9)a, Figura Suplementaria 2d).

On the other hand, it is observed that the Chulucanas-Julie rootstock-interstock relationship is aligned with the vector for fruit length, indicating that individuals with this graft exhibit better characteristics for this variable. In terms of fruit weight, individuals with the Chulucanas-Chato and Chato-Irwin relationships presented the highest values. In terms of fruit diameter, the Chulucanas-Chato and Chato-Irwin rootstock-interstock relationships also presented the highest means.

# DISCUSSIONS

The mango is considered one of the most important export fruits in Peru. Sixty-six point seven percent (66.7%) of the mango harvest is produced in the Piura department, making it the country’s leading producer [[24]](https://www.zotero.org/google-docs/?qUQP2i). Despite the large quantity of mango produced, there is still low productivity per unit area, which significantly impacts exports. The use of rootstocks influences the growth of mango plants in terms of height, diameter, and canopy volume, potentially inducing dwarfism in individuals and thereby increasing the planting density per hectare [[32]](https://www.zotero.org/google-docs/?th5Vgb). This research evaluated the effects of rootstock and interstock on the agronomic characteristics and fruit quality of mango. The growth and productivity parameters that determine the production of mango in the San Lorenzo Valley, Piura, were assessed.

The interaction between rootstocks and interstocks plays a very important role in the process of obtaining crops with favorable agronomic characteristics [[33]](https://www.zotero.org/google-docs/?YSK8Sl); [[34]](https://www.zotero.org/google-docs/?m3J1sk); [[35]](https://www.zotero.org/google-docs/?TnA1J1). In our study, we evaluated the impact of interstocks and observed that the interaction influenced plant height ([Figure 3](#fig-id.1lhpgrqadiq1), [Figure 4](#fig-id.r1ur4b6nanx4)). The interaction of the Chulucanas rootstock with the interstocks Chulucanas, Irwin, and Julie resulted in a reduction in height. One possible factor explaining this decrease may be the size of the cultivars used, as is the case with Irwin, which produces plants with shorter heights [[22]](https://www.zotero.org/google-docs/?0bv1CM). Our results agree with those of the study by Minja et al. [[35]](https://www.zotero.org/google-docs/?7pleka), which evaluated three types of rootstocks (Ngwangwa, Sindano, and Zinzi) in six improved mango cultivars (Manzano, Ngowe, Kent, Keitt, Alphonso, and Tommy Atkins). The authors mention that growth is influenced by the type of rootstock and the cultivar of the scion or graft used. Similarly, this aligns with the findings of El Shahawy et al. [[34]](https://www.zotero.org/google-docs/?fmjzKI), who evaluated four grafts (Keitt, Naomi, Osten, and Shelly) on three rootstocks (Sukkary, Zebda, and 4/9) during two successive seasons in 2021 and 2022; their results showed that the grafts had a significant influence on growth parameters.

On the other hand, in our study, fruit budding was not influenced by the graft used. These results differ from those presented by Hamza et al. [[33]](https://www.zotero.org/google-docs/?pNcBc8), who evaluated three graft varieties (Sinddhri, Sufaid Chaunsa, Chenab Gold) at three different heights; their results revealed that the variety of the graft significantly increased the number of shoots produced. This difference may also be attributed to the variety of grafts used, as the production of shoots in different mango varieties can vary significantly due to genetic factors, resulting in differences in budding intensity [[36]](https://www.zotero.org/google-docs/?MuotqP). Therefore, it is presumed that the graft varieties used by the authors have greater genetic differences than the varieties employed in the present study. For flowering and the number of fruits, our results were also not influenced by the graft used. However, differences were observed between the years of evaluation. These differences may be due to changes in climate caused by the El Niño‒Southern Oscillation (ENSO) phenomenon. As noted by Scuderi et al. [[37]](https://www.zotero.org/google-docs/?Bgc3LW), environmental factors can influence the development of flowering and, consequently, the number of fruits produced during mango cultivation.

Rebolledo-Martínez et al. [[38]](https://www.zotero.org/google-docs/?3Zp97f) evaluated the grafting of the “Manila” mango on short (Thomas and Julie), medium (Esmeralda, Irwin Morado, Gomera 1, and Chauza), and tall (Creole) rootstocks. Their results revealed that the Julie rootstock had a positive effect on height, stem diameter, and fruit production. In our study, the interaction of rootstocks and interstocks influenced the evaluated variables, playing an important role in achieving favorable agronomic characteristics ([Figure 3](#fig-id.1lhpgrqadiq1), [Figure 4](#fig-id.r1ur4b6nanx4), [Table 1](#tbl-id.541d1mdcbw1l)).

In the evaluation of mango fruit biometrics, the interaction between the rootstock and the graft did not have a significant effect on the expression of characteristics of the variables of weight, length, and diameter during the agricultural seasons from 2017-2019 ([Table 2](#tbl-id.gu0joegsk6p1), [Figure 5](#fig-id.rtncwk932bt9)). The highest weight values were recorded with the Chulucanas-Chato and Chulucanas-Julie combinations ([Table 2](#tbl-id.gu0joegsk6p1)); therefore, it can be assumed that the Chulucanas variety used as rootstock has a direct relationship with fruit weight. However, Shivran et al., [[39]](https://www.zotero.org/google-docs/?bozTsv) reported that during the rootstock-cion interaction in mango, the fruit weight variable is determined by the scion.

Conversely, combining Chato, Irwin, and Julie grafts on the Chulucanas rootstock results in a greater fruit length than the combination on the Chato rootstock ([Table 2](#tbl-id.gu0joegsk6p1)). These results could be attributed to the fact that the Chato, Irwin, and Julie varieties produce fruits of greater length than the Chulucanas varieties. This aligns with the findings of Shivran et al., [[39]](https://www.zotero.org/google-docs/?MI54P4) regarding the influence of the scion on yield variables. In contrast, other authors emphasize that the fruit yields variables. In contrast, other authors emphasize that the fruit yield variables in mango are determined by the variety as the rootstock [[32]](https://www.zotero.org/google-docs/?F8bRFG); [[40]](https://www.zotero.org/google-docs/?XclQf8); [[18]](https://www.zotero.org/google-docs/?kAvvU1).

In our study, during the year 2017, the El Niño Southern Oscillation (ENSO) climate phenomenon occurred, which increased the precipitation and temperature in the San Lorenzo Valley ([Figure 2](#fig-id.xfyxxwypvusw)). As a result, the variables of flowering and fruit biometrics may have been affected, as reports from authors indicate that these environmental conditions cause premature fruit drop and decrease tree health, vigor, and compatibility in certain rootstocks and scions [[32]](https://www.zotero.org/google-docs/?PJvUIh); [[41]](https://www.zotero.org/google-docs/?pssLgC).

Among the limitations of this study is that the evaluations of all the variables were not conducted in consecutive years, which would have allowed for a more detailed assessment of plant height, budding, and fruit biometrics. This omission was primarily due to financial constraints, which limited the possibility of carrying out continuous data collection. Additionally, cases of regression death were recorded in the plants, resulting in incomplete evaluations of the experimental units within each treatment. Despite the limitations presented, the results of this study contribute to understanding the dynamics of interstocks in improving the agronomic and biometric characteristics of mango fruit, potentially serving as an alternative to enhance the agronomic management of the crop and benefiting producers in San Lorenzo Valley.

To address the future challenges associated with this technique, it is crucial to evaluate the quality of the fruits produced. In this context, research analyzing parameters such as fruit firmness, titratable acidity, soluble solids content, and percentage of dry matter is recommended. These attributes are essential to ensure consumer acceptance and competitiveness in both local and international markets. Investigating these aspects could not only improve mango crop management but also help farmers increase their productivity and ensure that fruit quality meets export standards and the preferences of the end consumer.

# CONCLUSIONS

The use of rootstocks in combination with interstocks influences the agronomic characteristics of mango cultivation, although it does not affect the biometrics of mango fruits. This study demonstrated that the variety of cultivars used affects plant growth; however, no significant differences in the biometric characteristics of the fruits were detected. The obtained data confirm that interstocks can induce a dwarfing effect in plants, allowing for increased planting density per hectare. This information regarding plant behavior based on the type of graft used can be valuable for optimizing the agronomic management of mango cultivation in the Piura region of Peru.

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