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# Impact of Interstock and Rootstock on the Growth and Productivity of Mango (*Mangifera indica* L.) Cultivar Kent in the San Lorenzo Valley, Peru

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**Abstract**

Mango (*Mangifera indica* L.) is a tropical fruit tree characterized by vigorous growth and high fruit production, making it one of Peru's main export crops. However, its extensive vegetative development requires substantial space, limiting productivity per unit area. This study evaluated the effects of rootstock and interstock combinations on agronomic traits and fruit biometrics, highlighting the potential of interstocks to modulate tree vigor in mango orchards of Peru's dry forest region. A total of 216 trees were established using 'Chulucanas' and 'Chato' as rootstocks and 'Chulucanas,' 'Chato,' 'Irwin,' and 'Julie' as interstocks, apically grafted with the 'Kent' cultivar, with a spacing of 6.0 m × 6.0 m. Tree performance was assessed after 10 years during the 2017–2019 growing seasons in Piura, Peru, under a randomized complete block design (2 × 4 factorial). The combination of the 'Chulucanas' rootstock with 'Chulucanas' and 'Julie' interstocks reduced tree height by 10.94% and 11.70%, respectively, facilitating orchard management and potentially increasing planting density. Yield varied significantly among growing seasons, with a 15% reduction in 2017 attributed to El Niño–Southern Oscillation (ENSO)-related increases in temperature and rainfall that affected flowering and fruit set. These results underscore the importance of cultivar selection and climate-adaptive strategies to sustain mango productivity in regions prone to climatic variability.

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

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## 1. Introduction

Mango (*Mangifera indica* L.) is a fruit tree from the Anacardiaceae family, cultivated in tropical and subtropical regions [1]. Its global production is estimated at approximately 61 million tons for the year 2023 [2]. In Peru, national production reached 378 thousand tons in 2024 [3]. The species is characterized by vigorous growth and attractive fruits, which contain high levels of carbohydrates, fatty acids, minerals, and vitamins [4]. The inflorescence is a branched terminal panicle ranging from 10 to 60 cm in length and bearing between 500 and 10,000 flowers per panicle [5]. The fruit is a large, fleshy drupe with an edible mesocarp of variable thickness [6].

Mango trees can be propagated both sexually and asexually. Although techniques such as air layering, cuttings, and micropropagation have been used, most commercial plantations are established through grafting or budding. Polyembryonic rootstocks are preferred for their genetic uniformity [7]. Currently, mango cultivation is managed at low to medium planting densities, ranging from 69 to 416 trees per hectare. This is due to the space required for vegetative growth, which is commonly associated with fruit production [8,9].

The use of low densities decreases production because yields during the first few years are low [10]. However, increasing densities, along with the vegetative growth of the crop, reduces profits because it complicates cultural maintenance tasks [9]. Additionally, a tall canopy results in fewer trees per unit area, increasing competition for light and aeration [11]. The application of growth regulators, pruning techniques, and the genetics of rootstocks and scions should be investigated to control tree vigor in this context [12].

In Peru, the Piura region accounts for approximately 67% of the country's mango production destined for export, making it the main production center in the country [13]. The predominant cultivation systems are characterized by relatively low planting densities, with traditional orchards established at around 100 trees per hectare and semi-modern systems with approximately 400 trees ha$^{-1}$, achieving average yields of up to 15 tons t ha$^{-1}$ [3]. However, these productivity levels remain modest compared to countries such as Australia and India, where high-density systems exceeding 400 trees ha$^{-1}$ have recorded yields in excess of 55 t ha$^{-1}$ [14]. This pronounced productivity gap highlights a structural limitation of conventional orchards in Piura and underscores the need for agronomic strategies that optimize the balance between vegetative growth, tree architecture, and yield, particularly through the adoption of rootstock and interstock technologies capable of modulating vigor and improving orchard efficiency.

Using rootstocks is a common method of propagating fruit trees. It involves fusing the root system (rootstock) with the aerial part (cultivar), either directly or by using an interstock. These parts combine through assembly to form a new plant [15,16]. Tree vigor, yield, fruit quality, and tolerance to biotic or abiotic stress are all related to rootstock selection [17,18]. Highly valuable varieties are propagated on grafts that exhibit greater resistance to diseases, better adaptability to environmental conditions, and optimized nutrient absorption [19,20]. The viability and compatibility of the graft depend on the proximity between taxonomic species and the technique used to align the vascular bundles, which ensures the translocation of carbohydrates, hormones, and nutrients [21].

While mango production is correlated with tree size [9], cultivars such as 'Irwin' [22], 'Keitt' [23], and 'Tommy Atkins' [24] present high yields in smaller trees. These cultivars are suitable for planting at high densities [9,25].

In this context, the combination of rootstocks and interstocks in mango cultivars can regulate vertical and horizontal growth and modify the sensory properties of the fruit [26,27]. Therefore, this study aims to determine the effects of rootstock–interstock interaction on the agronomic characteristics and fruit biometrics of the mango cultivar.

## 2. Materials and Methods

### *2.1. 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″ S, a longitude of

80°20′22″ W, and an altitude of 82 m above sea level. The area has a tropical desert and subtropical climate. The mango (*Mangifera indica* L.) plants are spaced at 6.0 m × 6.0 m, with a total of 216 plants (Figure 1).

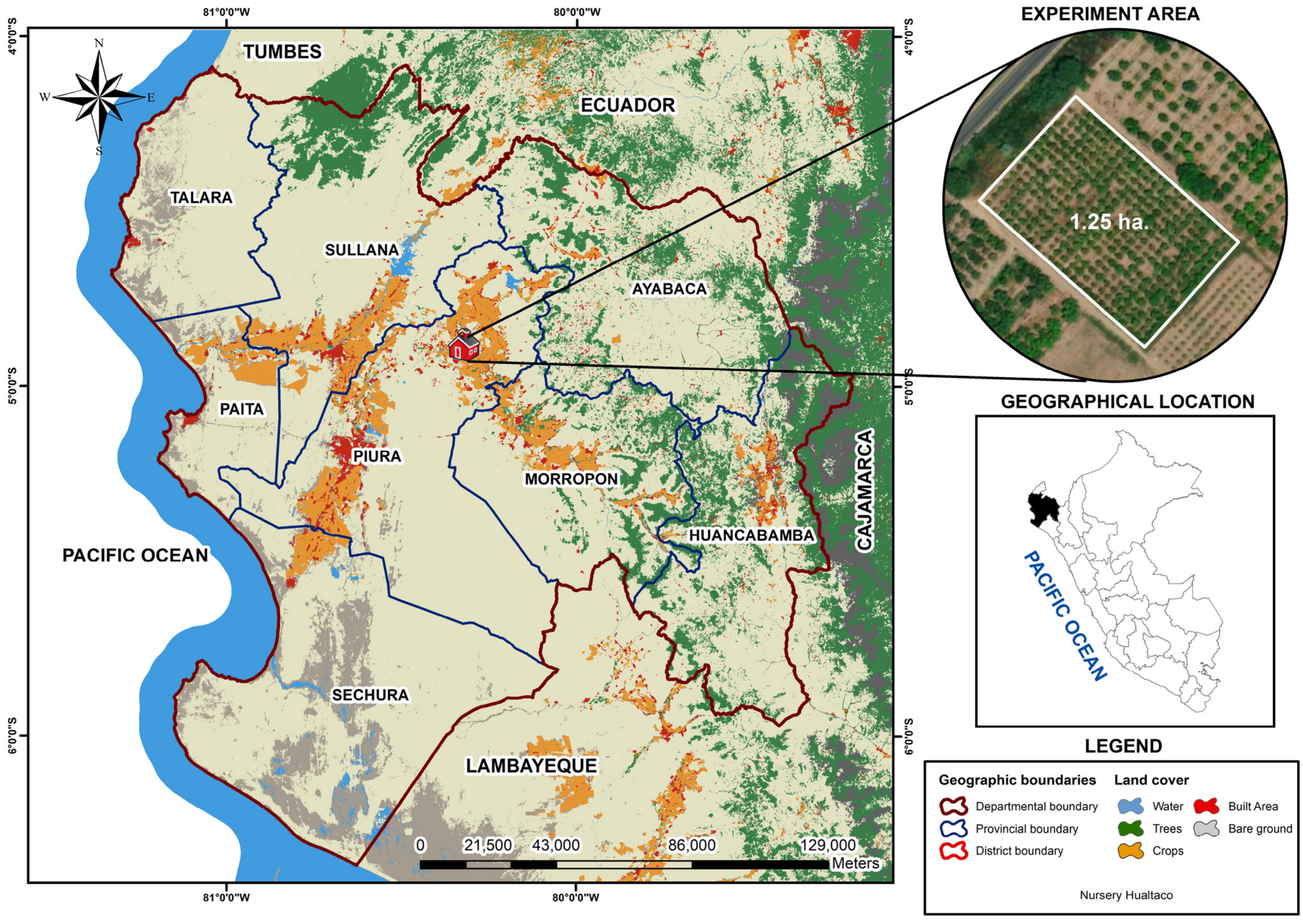


**Figure 1.** Map of the location of the experimental research area. Hualtaco Nursery, Tambogrande District, Piura Department, Peru.

### *2.2. Plant Material*

The rootstocks were obtained from seeds of 'Chulucanas' and 'Chato' mangoes propagated in seedbeds with agricultural soil. Afterward, the plants were transplanted into polyethylene bags (16″ × 8″) filled with a forest agricultural soil substrate. For the interstocks, vegetative buds from 'Chulucanas', 'Chato', 'Irwin', and 'Julie' were used, whereas vegetative buds from 'Kent' were used for top grafting (Table 1). 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 cultivar from Chulucanas in the Piura region, Peru, where the climatic conditions are suitable for its development. This cultivar 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 'Kent' [28].

**Irwin:** Irwin is one of the most commercially produced and consumed cultivars in Japan, Taiwan, South Korea, and Australia and, elsewhere [29], 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 to 13 cm in length and 8 to 9 cm in diameter [30].

**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 [31].

**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 [13].

**Table 1.** Treatment Coding of the Study: Impact of Interstock and Rootstock on the Vigor and Productive Development of Mango (*Mangifera indica* L.) cultivar Kent 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 |

### *2.3. Agronomic Management*

Soil preparation was carried out using a tractor and a harrow, following the layout of the crop rows. Hole digging and seedling transplanting were performed according to a grid planting design of 6 × 6 m. Seed selection was made from the mango germplasm bank, which originated from elite plants at the Hualtaco Annex of the El Chira Agricultural Experimental Station (EEA). The removal of the pericarp, mesocarp, and endocarp facilitated better embryo development in seedlings obtained from polyembryonic seeds in seedbeds.

Grafting was conducted using the double-tongue technique three months after the seedlings were transplanted into nursery bags. Subsequently, interstock and apical grafting were performed using the same method, known as the English or double-tongue grafting technique. This technique involves making a beveled cut on both the rootstock and the scion, followed by a longitudinal cut (approximately 1 cm deep) along one-third of the beveled surface to create interlocking tongues on both plant parts [32]. The graft components were then interwoven, secured with grafting tape, and covered with a perforated plastic bag to maintain humidity. An eight-month interval was maintained between the interstock and apical grafting to allow complete healing and the formation of a stable vascular connection, thereby minimizing physiological stress and ensuring compatibility before the second grafting stage [33,34]. Bridge rootstock grafting was performed in 2008, while bud bridge grafting was conducted in 2009.

The irrigation system was established in stages. It began with one irrigation tape and two microtubes per plant during the first year. A second irrigation tape with two additional microtubes was later 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 and synthetic fertilizers, based on the mango's nutritional requirements at each developmental stage.

Weeding was performed periodically using brush cutters, depending on weed emergence in the field. Phytosanitary control was managed under constant monitoring and integrated pest management. Finally, flowering, fruiting, and harvesting activities followed the traditional agronomic practices of local producers in the San Lorenzo Valley.

### 2.4. Agronomic and Biometric Characterization of the Tree

The agronomic characterization included the evaluation of plant height, fruit number, and budburst and flowering percentages. All the plants in the experiment were selected, and the mentioned variables were recorded.

Plant height (m) was determined at the end of the experiment. It was measured from the soil base to the plant apex using a graduated wooden ruler. The number of fruits per plant was determined at the end of each growing season through direct visual counting. The total number of fruits produced by each individual was recorded before the first harvest.

The budburst percentage (%) was determined in the final phase of the experiment through direct observation. Six branches from the middle third of the canopy on the east side and six branches on the west side of each plant were selected and monitored. The number of shoots produced by each branch and the number of buds until desiccation were evaluated [35].

The flowering percentage (%) was evaluated at the end of each growing season through visual observation. The intensity of flowering in the tree canopy was recorded during anthesis. The canopy was divided into two opposing sections, and the flowering percentage was recorded on a 0–100 scale according to the coverage of inflorescences in each section. To calculate the overall flowering percentage of the tree, the average of both evaluated sections was used [36].

For the evaluation of fruit biometrics, six individuals per treatment were randomly selected, and five fruits were collected from each at harvest, resulting in a total of 30 fruits per treatment. Fruits that reached physiological maturity were selected for measurement using a vernier caliper and a balance. Each fruit was measured for weight (g), length (mm), and diameter (mm) [37].

### 2.5. Experimental Design

The experiment was conducted via a randomized complete block design (RCBD) with a 2 $\times$ 4 factorial arrangement consisting of three blocks. The first factor corresponded to the rootstock, with two levels: 'Chulucanas' and 'Chato'. The second factor was the interstock, with four levels: 'Chulucanas', 'Chato', 'Irwin', and 'Julie'. Each experimental unit consisted of nine mango plants, totaling 216 evaluated plants. The treatments resulted from the interaction between the rootstock, interstock, and the scion graft of the 'Kent'. 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.

### 2.6. Statistical Analysis

Statistical analyses were conducted using R software version 4.4.1 [38]. A linear mixed-effects model was fitted to assess treatment effects, providing robustness against potential violations of normality and homoscedasticity assumptions [39]. Analysis of variance (ANOVA) was applied to the fitted models, and mean comparisons were performed using Tukey's honest significant difference (HSD) test at a significance level of $\alpha = 0.05$, using the emmeans 2.0.0 package [40]. Multivariate relationships among variables were explored through principal component analysis (PCA) with the FactoMineR 2.12 package [41]. Variable correlations derived from the PCA were visualized using the corrplot 0.95 package [42].

# 3. Results

## 3.1. 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 (Figure 2).

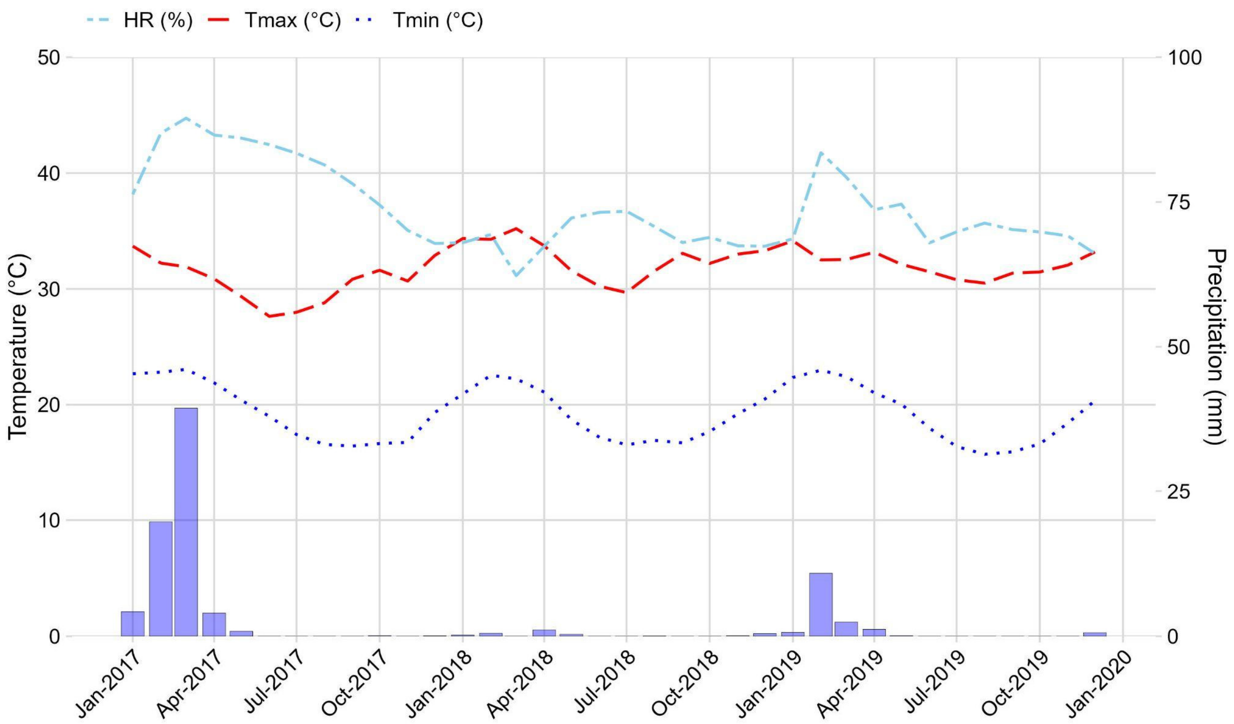


**Figure 2.** Climatic Conditions During the Agricultural Seasons of 2017–2019, Experiment Located in the District of Tambogrande, Piura Department, Peru. Precipitation is shown in blue bars. Source: SENAMHI.

## 3.2. Agronomic Characterization

To determine the agronomic characteristics of the rootstock-interstock interaction in the mango cultivar Kent, 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). 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.) cultivar Kent in San Lorenzo Valley.

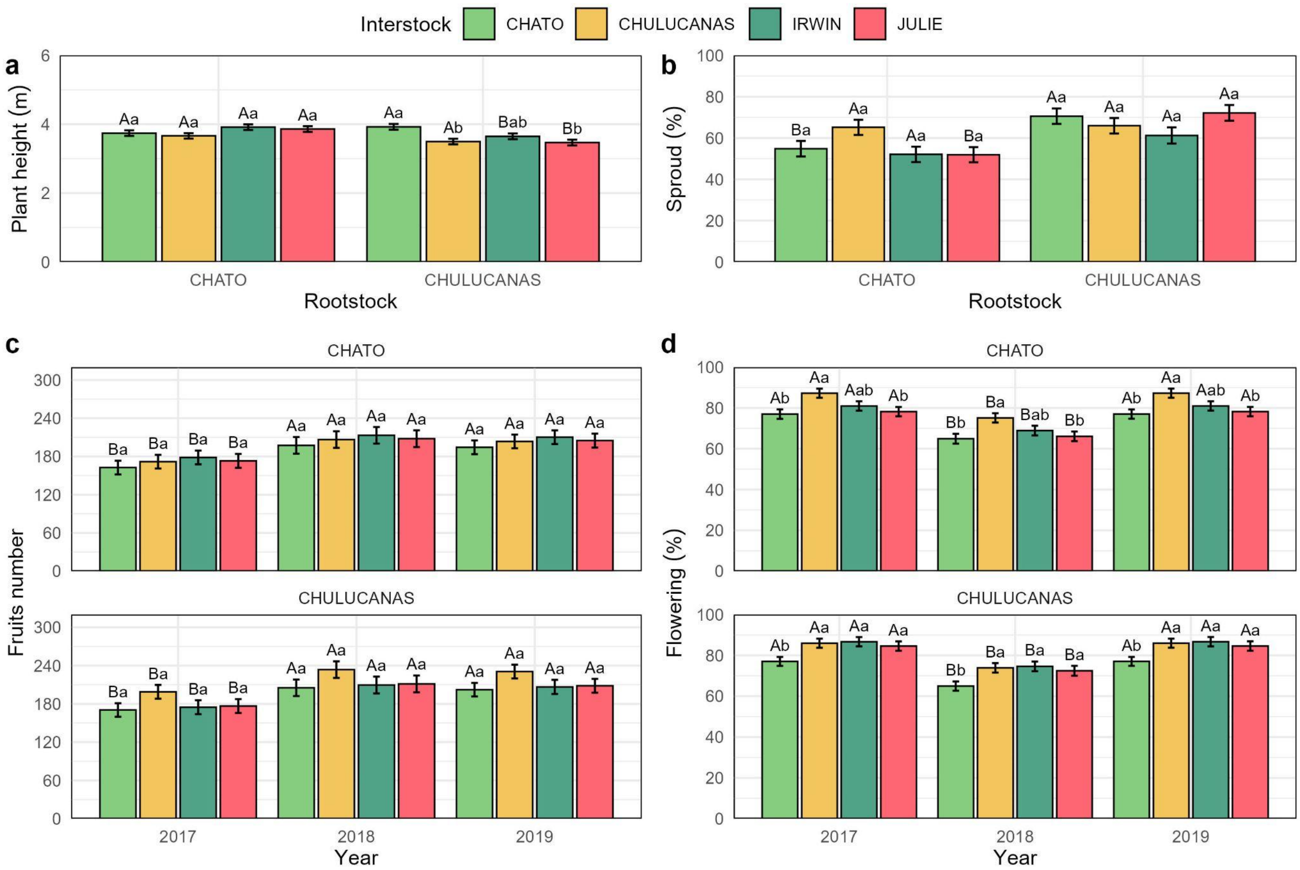


**Figure 3.** Agronomic characteristics of the rootstock and interstock relationship for mango cultivar Kent in the Piura Region, calculated based on nine plants per treatment: Plant height at harvest (**a**), percentage of sproud (**b**), number of fruits produced during the agricultural seasons from 2017 to 2019 (**c**), percentage of flowering recorded during the agricultural seasons of 2017–2019 (**d**). Data are expressed as mean ± standard error. Different uppercase letters denote statistically significant differences between rootstock, while lowercase letters indicate differences interstock treatments (**a**,**b**). Different uppercase letters denote statistically significant differences between years, while lowercase letters indicate differences interstock treatments (**c**,**d**). Mean comparison was according to Tukey's test ($p < 0.05$, n = 648).

For the plant height variable, significant differences were observed in the interaction between rootstock and interstock ($p$-value < 0.01). In particular, the use of the 'Chulucanas' rootstock in combination with 'Chulucanas' and 'Julie' interstocks showed significant differences compared to the 'Chulucanas'—'Chato' combination. Grafted plants with 'Chulucanas'—'Chulucanas' and 'Chulucanas'—'Julie' reached average heights of 3.50 m and 3.47 m, respectively, while 'Chulucanas'—'Chato' recorded a height of 3.93 m, indicating a reduction of 10.94% and 11.70%, respectively, compared to 'Chato' interstock. However, the 'Chato' rootstock did not show significant differences in plant height when associated with the different interstocks evaluated.

On the other hand, when comparing the effects of rootstocks for the same interstock, significant differences were found. Specifically, the 'Chato'—'Irwin' combination had an average height of 3.92 m, whereas 'Chulucanas'—'Irwin' reached 3.65 m, representing a 6.89% reduction. Similarly, the 'Chato'—'Julie' combination showed an average height of 3.86 m, while 'Chulucanas'—'Julie' recorded 3.47 m, which corresponds to a 10.10% reduction (Figure 3a).

No significant differences were observed in the sprouting percentage among the different interstocks within each rootstock ($p$-value > 0.05). However, when comparing the effect of rootstocks for the same interstock, significant differences were found. Specifically, the 'Chulucanas'—'Chato' combination exhibited a higher sprouting percentage (70.6%) compared to 'Chato'—'Chato' (54.8%). Similarly, the 'Chulucanas'—'Julie' association showed a higher sprouting percentage (72.2%) compared to 'Chato'—'Julie' (51.9%), highlighting the impact of rootstock on sprout induction (Figure 3b).

For the variable number of fruits, no significant differences were observed among the different interstocks within each rootstock in the same year ($p$-value = 0.46). However, significant differences were found between the evaluated agricultural seasons ($p$-value < 0.001), indicating interannual variability in fruit production (Figure 3c).

In particular, the 2017 agricultural season recorded a lower average number of fruits compared to the 2018 and 2019 seasons. Among these differences, the 'Chato'—'Julie' combination stood out, with an average of 173 fruits in 2017, while in 2018 and 2019, it reached 208 and 205 fruits, respectively, representing an approximate reduction of 16% compared to the following years. Similarly, the 'Chulucanas'—'Julie' combination had a lower average number of fruits in 2017, with 177 fruits, in contrast to the averages observed in 2018 and 2019, with 211 and 208 fruits, respectively, representing an approximate reduction of 15%. (Figure 3c).

For the variable flowering percentage, significant differences were observed among the different interstocks within each rootstock in the same year ($p < 0.05$). In the case of the 'Chato' rootstock, its association with the 'Chulucanas' interstock exhibited a higher flowering percentage across all agricultural seasons compared to its association with the 'Chato' and 'Julie' interstocks. Conversely, the 'Chulucanas' rootstock, when combined with the 'Chato' interstock, showed a lower flowering percentage in all agricultural seasons compared to its combination with the other interstocks (Figure 3d).

Furthermore, significant differences were found between the evaluated agricultural seasons ($p < 0.001$), indicating interannual variability in flowering. Specifically, the 2018 agricultural season recorded a lower average flowering percentage compared to the 2017 and 2019 seasons. Among these differences, the 'Chato'—'Irwin' combination stood out, registering an average flowering percentage of 68.9% in 2018, while in 2017 and 2019, it reached 81%. Similarly, the 'Chulucanas'—'Irwin' combination showed an average flowering percentage of 74.6% in 2018, in contrast to the 86.7% observed in 2017 and 2019. (Figure 3d).

To analyze the association between variables and individuals, a multivariate analysis of principal components (PCA) and a Pearson correlation analysis were conducted (Figure 4).

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 4a,c). 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 4a,c). 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 4a,c).

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 $r = 0.86$ between the percentage of flowering and a strong negative correlation $r = -0.91$ between the plant height variable and dimension 1. Furthermore, in dimension 2, the variable number of fruits had a strong positive correlation of $r = 0.78$ (Figure 4a,d).

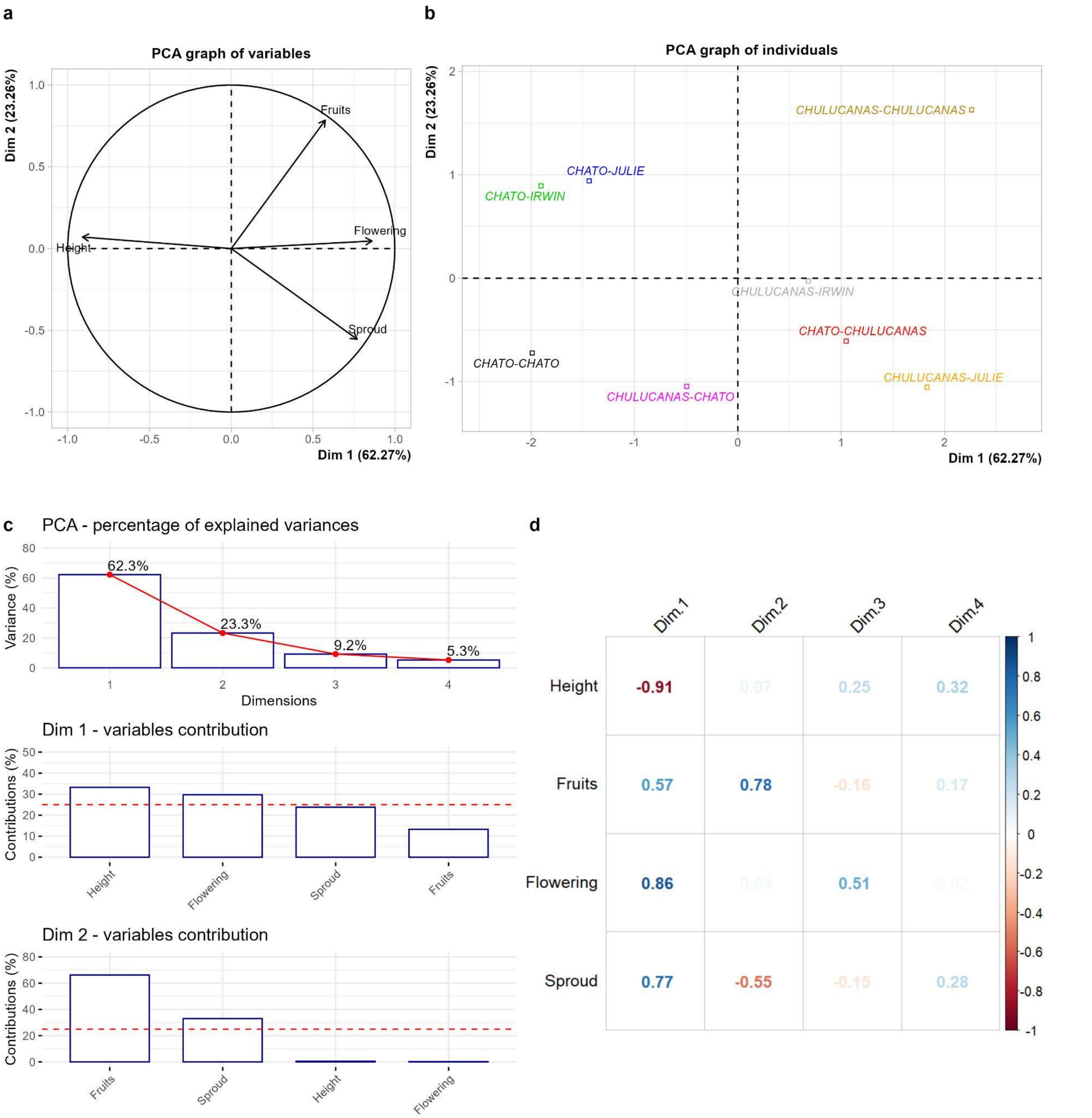


**Figure 4.** Principal component analysis (PCA) of the agronomic characteristics in mango cultivation based on the use of rootstock-interstock combinations. Variables were evaluated to determine the agronomic characteristics of the rootstock-interstock combination in mango cultivar Kent (**a**). Treatments were used based on the rootstock-interstock combination for evaluating the agronomic characteristics of mango plants (**b**). Percentage of variance explained by each dimension and contribution of the studied variables to dimensions (**c**). Correlations between the studied variables and the dimensions explaining the variance (**d**). The analysis was based on 648 observations (n = 648).

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 '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 4b).

### 3.3. 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 2). This study aimed to identify the rootstock-interstock relationship that produces the best quality mango fruit of cultivar Kent (*Mangifera indica* L.) in San Lorenzo Valley.

**Table 2.** Fruit biometrics in eight combinations of rootstock-interstock for mango during the 2023 agricultural season. Sd: standard deviation; min: minimum; max: maximum. Comparisons were made among the interstock varieties within each rootstock.

| Variable | Rootstock | Interstock | Mean | sd | Min | Max |
|---|---|---|---|---|---|---|
| Fruit Weight (g) | Chato | Chato | 452.53 | 79.92 | 305 | 639 |
| | Chato | Chulucanas | 462.34 | 69.82 | 340 | 620 |
| | Chato | Irwin | 482.03 | 87.3 | 350 | 700 |
| | Chato | Julie | 465.97 | 92.07 | 300 | 645 |
| | Chulucanas | Chato | 484.97 | 101.98 | 316 | 765 |
| | Chulucanas | Chulucanas | 468.17 | 118.73 | 230 | 665 |
| | Chulucanas | Irwin | 447.23 | 70.09 | 310 | 605 |
| | Chulucanas | Julie | 484.7 | 93.46 | 367 | 717 |
| Fruit length (mm) | Chato | Chato | 105.97 | 6.78 | 93 | 120 |
| | Chato | Chulucanas | 106.28 | 6.8 | 94 | 119 |
| | Chato | Irwin | 106.07 | 6.47 | 95 | 124 |
| | Chato | Julie | 107.67 | 7.54 | 91 | 120 |
| | Chulucanas | Chato | 106.53 | 7.21 | 95 | 123 |
| | Chulucanas | Chulucanas | 106.2 | 10.87 | 86 | 126 |
| | Chulucanas | Irwin | 106.43 | 7.28 | 92 | 122 |
| | Chulucanas | Julie | 109.73 | 8.03 | 98 | 129 |
| Fruit diameter (mm) | Chato | Chato | 85.23 | 4.72 | 76 | 97.5 |
| | Chato | Chulucanas | 86.09 | 3.61 | 78.5 | 93.5 |
| | Chato | Irwin | 87.63 | 5.07 | 79.5 | 100 |
| | Chato | Julie | 86.23 | 5.56 | 75.5 | 97.5 |
| | Chulucanas | Chato | 87.7 | 5.4 | 78 | 100.5 |
| | Chulucanas | Chulucanas | 86.08 | 6.61 | 69.5 | 99 |
| | Chulucanas | Irwin | 84.53 | 4.03 | 77.5 | 92.5 |
| | Chulucanas | Julie | 86.3 | 4.68 | 79.5 | 97 |

The statistical analysis performed via Tukey's post hoc test ($\alpha = 0.05$) revealed that for the fruit weight variable, nonsignificant differences were found ($p$-value = 0.19). Similarly, the same occurred with fruit length, where nonsignificant differences were found ($p$-value = 0.87). Additionally, for fruit diameter, nonsignificant differences were found between the treatments used ($p$-value = 0.02).

To analyze the association between variables and individuals, a multivariate PCA and a Pearson correlation analysis were conducted (Figure 5).

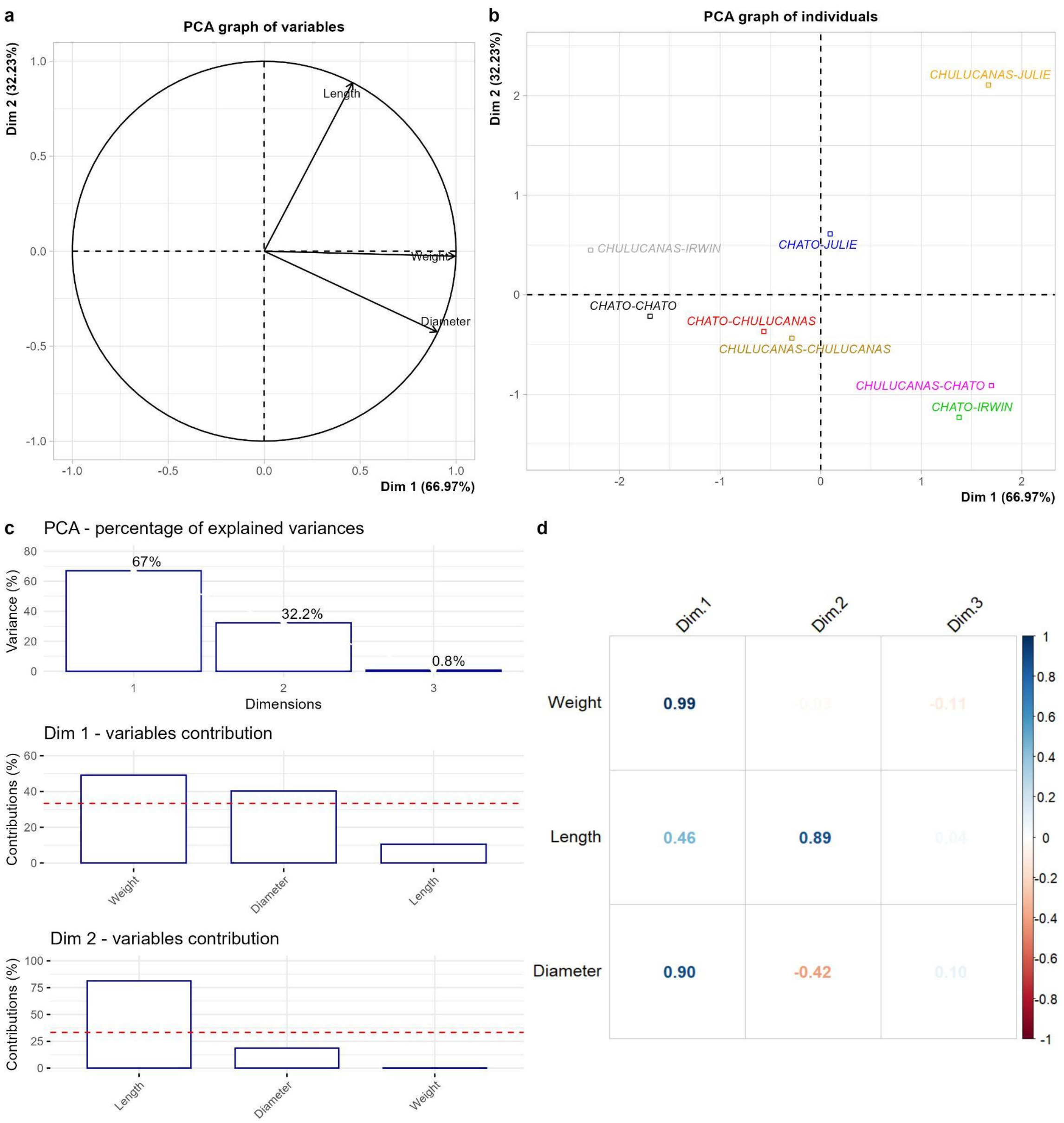


**Figure 5.** Principal component analysis (PCA) of fruit biometrics in mango cultivation based on the use of rootstock-interstock combinations. Variables were evaluated to determine the fruit quality of the rootstock-interstock combination in mango (**a**). Treatments were used based on the rootstock-interstock combination for evaluating fruit quality in mango plants of cultivar Kent (**b**). Percentage of variance explained by each dimension and contribution of the studied variables to dimensions (**c**). Correlations between the studied variables and the dimensions explaining the variance (**d**). The analysis was based on 240 observations (n = 240).

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 5a,c). 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 5a,c). 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 5a,c)

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 r = 0.99 and fruit diameter r = 0.90 with respect to dimension 1. Additionally, in dimension 2, the variable fruit length has a strong positive correlation of r = 0.89 (Figure 5a,d).

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 (Figure 5b).

## 4. 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 [13]. Despite the large quantity of mango produced, productivity per unit area remains low, significantly impacting exports. The use of rootstocks influences mango plant growth in terms of height, diameter, and canopy volume. This can potentially induce dwarfism in trees, thereby increasing the planting density per hectare [43]. This research evaluated the effects of rootstock and interstock on the agronomic characteristics and fruit quality of mango cultivar Kent. 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 key role in obtaining trees with desirable agronomic traits [44–46]. In our study, this interaction significantly influenced plant height (Figures 3 and 4), where the combination of the 'Chulucanas' rootstock with the 'Chulucanas,' 'Irwin,' and 'Julie' interstocks resulted in reduced tree height. This reduction may be partly explained by the inherent growth habit of some cultivars used as interstocks—such as 'Irwin,' which is known to produce shorter trees [30]. Our results align with those of Minja et al. [46], who reported that both rootstock type and scion genotype influence vegetative growth when evaluating three African rootstocks ('Ngwangwa,' 'Sindano,' and 'Zinzi') grafted with six improved mango cultivars. Similarly, El Shahawy et al. [44] found that graft combinations involving four scions ('Keitt', 'Naomi', 'Osteen', and 'Shelly') on three Egyptian rootstocks ('Sukkary', 'Zebda', and '4/9') significantly affected growth parameters across two successive seasons.

Importantly, the regional context reinforces the relevance of these findings: in Piura, technical documents and varietal inventories from the Peruvian National Institute of Agrarian Innovation (INIA) indicate that the local criollo materials 'Chulucanas' and 'Chato' are traditionally used as rootstocks due to their rusticity, tolerance to dry tropical conditions, and adaptability to loam–sandy soils [47]. However, the lack of formal agronomic and physiological characterization of these local materials underscores the need for experimental studies such as the present one to better understand their potential in vigor modulation and orchard management under the desert–tropical conditions of northern Peru.

In addition to the inherent vigor of the cultivars, the reduction in height observed in combinations of rootstock "Chulucanas" with the interstocks "Irwin," "Julie," and "Chulucanas" could be explained by the physiological mechanisms that regulate shoot growth. Studies on grafted perennial crops indicate that dwarfing effects are often due to alterations in hormone fluxes, particularly reduced auxin transport and decreased cytokinin synthesis [48,49]. Similarly, size-controlling interstocks can suppress gibberellin (GA) biosynthesis or signaling pathways, limiting internode elongation [50]. One hypothesis could be that the 'Chulucanas' and 'Julie' interstocks may partially inhibit GA-related growth processes, while also affecting vascular reconnection efficiency and assimilate flow, which together contribute to the observed reduction in tree height.

The reduction in tree height observed in the present study highlights the potential of interstocks to regulate vegetative vigor in mango trees. Taller canopies typically reduce planting density per unit area and increase intra-canopy competition for light and airflow [11]. Moreover, excessive vegetative growth can diminish overall profitability by complicating routine orchard management practices [9]. In this context, the use of interstocks that reduce tree height may allow growers to adopt higher planting densities, optimize light interception, and decrease costs associated with pruning, spraying, and harvesting operations. Ultimately, this approach can improve land-use efficiency and enhance economic returns in mango orchards of the Piura region.

In our study, the sprouting percentage was not influenced by the interstocks but was significantly affected by the rootstock. These findings contrast with those reported by Hamza et al. [45], who evaluated three scion varieties ('Sinddhri,' 'Sufaid Chaunsa,' and 'Chenab Gold') grafted at three different heights. Their results indicated that the scion variety significantly increased the number of sprouts produced. This difference may be attributed to genetic variability among scion cultivars, as sprouting intensity in mango can vary considerably due to genetic factors [51]. It is therefore presumed that the graft varieties used in their study exhibited greater genetic divergence than those employed in the present research.

For flowering and fruit production, our results were primarily influenced by the agricultural season. Significant differences were observed across the evaluated years, suggesting that environmental conditions or campaign-specific factors played a key role in mango productivity, regardless of the rootstock and interstock used. These differences may be related to climatic changes caused by the El Niño–Southern Oscillation (ENSO) phenomenon. As noted by Scuderi et al. [52], environmental factors can influence the development of flowering and, consequently, the number of fruits produced during mango cultivation.

Rebolledo-Martinez et al. [53] 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 showed that the 'Julie' rootstock positively affected height, stem diameter, and fruit production. In our study, the interaction between rootstocks and interstocks influenced the evaluated variables, playing an important role in achieving favorable agronomic characteristics (Figures 3 and 4, Table 2).

In evaluating mango fruit biometrics, the interaction between rootstock and graft did not significantly affect the variables of weight, length, or diameter during the 2017–2019 agricultural seasons (Table 2, Figure 5). The highest weight values were recorded for the 'Chulucanas'—'Chato' and 'Chulucanas'—'Julie' combinations (Table 2). Therefore, it can be assumed that 'Chulucanas,' when used as a rootstock, has a direct relationship with fruit weight. However, Shirvran et al. [54] reported that, during the rootstock–scion interaction in mango, fruit weight is determined primarily by the scion.

Conversely, combining 'Chato,' 'Irwin,' and 'Julie' grafts on the 'Chulucanas' rootstock resulted in greater fruit length than when grafted on the 'Chato' rootstock (Table 2). These results may be explained by the fact that 'Chato,' 'Irwin,' and 'Julie' produce fruits longer than 'Chulucanas.' This finding agrees with Shirvran et al. [54], who highlighted the influence of the scion on yield variables. In contrast, other authors emphasize that fruit yield variables in mango are determined by the rootstock cultivar [25,43,55].

The absence of significant differences in fruit biometric traits, despite the influence of rootstock and scion combinations on vegetative vigor, indicates that tree architecture and fruit quality could be regulated independently in mango cultivation. This suggests a physiological decoupling between vegetative and reproductive growth, in which intermediate grafts mainly modulate canopy size and vigor through hormonal regulation, without altering fruit development [56,57]. This independence offers a practical advantage, as it allows growers to control tree size and optimize orchard density, light distribution, and management efficiency without compromising fruit size or external quality. Similar results have been obtained in mangoes, where dwarf rootstocks or interstocks effectively reduced canopy volume while maintaining stable fruit biometric characteristics and market standards [58]. Therefore, the ability to manage tree architecture separately from fruit quality offers the opportunity to design more productive and sustainable mango orchards.

In our study, the lower mango yield observed in 2017—approximately 15% less than in 2018 and 2019—can be attributed to the ENSO event that year, which increased precipitation and temperature in the San Lorenzo Valley (Figure 2). These climatic anomalies likely affected flowering and fruit development. Previous studies have shown that such conditions can reduce tree vigor, disrupt rootstock–scion compatibility, and increase premature fruit drop [43,59]. Our results are consistent with reports highlighting the sensitivity of mango production to temperature and rainfall variability [60,61]. This emphasizes the need for climate-adaptive management strategies, particularly in regions like Piura, where seasonal fluctuations and extreme weather events frequently affect agricultural productivity [62,63].

Among the limitations of this study is that not all variables were evaluated in consecutive years, which would have allowed for a more detailed assessment of plant height, budding, and fruit biometrics. This limitation was mainly due to financial constraints that restricted continuous data collection. Additionally, some cases of regression death were recorded in the plants, resulting in incomplete evaluations of experimental units within each treatment. Despite these limitations, the results of this study contribute to understanding the role of interstocks in improving the agronomic and biometric characteristics of mango. This approach can serve as an alternative to enhance agronomic management and benefit producers in the San Lorenzo Valley.

To address future challenges associated with this technique, it is crucial to evaluate the quality of the fruits produced. Research analyzing parameters such as fruit firmness, titratable acidity, soluble solids content, and dry matter percentage is recommended. These attributes are essential to ensure consumer acceptance and competitiveness in both local and international markets. Investigating these aspects could improve mango crop management, help farmers increase productivity, and ensure that fruit quality meets export standards and consumer preferences.

## 5. 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 cultivars used affect plant growth; however, nonsignificant 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. These findings emphasize the potential of interstocks to regulate vegetative vigor and promote the establishment of high-density planting systems. By reducing canopy size and vegetative growth, interstocks can enhance orchard efficiency, lower management costs, and ultimately improve productivity and profitability per unit area. 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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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.R. and M.R.R. Funding acquisition: M.R.R. All authors have read and agreed to the published version of the manuscript.

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