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Impact of Interstock and Rootstock on the Growth and Productivity of Mango (Mangifera indica L.) in the San Lorenzo Valley, Peru
--Manuscript Draft--

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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.

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Author Comments:	Dear Editor, I hereby enclose the manuscript entitled "Impact of Interstock and Rootstock on the Growth and Productivity of Mango (Mangifera indica L.) in the San Lorenzo Valley, Peru" by Sebastian Casas-Niño et al. to be considered for publication in Journal of Plant Growth Regulation. Our research is one of the first in Peru to evaluate the impact of using rootstocks and grafts on mango production during three seasons from 2017 to 2019. We demonstrate that this technique can induce a dwarfing effect in plants, allowing for increased planting density per hectare. These findings are crucial for optimizing the agronomic management of mango cultivation that benefit producers in the north region in Peru. We think this manuscript is suitable for publication as the research reflects the aims and scope of your journal. We confirm that neither the manuscript nor any parts of its content are currently under consideration for publication with or published in another journal. All authors have approved the manuscript and agree with its submission to Journal of Plant Growth Regulation. Yours sincerely, Flavio Lozano-Isla Corresponding author
Response to Reviewers:	REVIEWER REPORTS Reviewer Comments: > Reviewer 1 Dear Reviewer, thank you very much for your comments and feedback on improving the manuscript. Each suggestion will be addressed below. All changes in the manuscript are highlighted in red. > In the introduction section, add the inflorescence name and type of fruit produced in Mango as well as its main propagation method with references . Thank you for the valuable suggestion. The requested information has been incorporated into the revised manuscript (lines 65–70), supported by the following references: Ramírez and Davenport (2016); Matheyambath et al. (2016) and Galán Saúco et al. (2021). > In the introduction section, add the data of annual global production of mango as well as annual mango production in Peru with relevant references. Thank you for the insightful suggestion. The requested information has been added to the revised manuscript (lines 62–63), along with the following references: Lebaka et al. (2021) and Ministerio de Desarrollo Agrario y Riego (2025). > The Data of table 2 is not significant all of them shoeing a in significant test. How is your findings are significant to farmers? please explain with references . Authors must apply DMRT analysis on mean values of parameters selected in table 2 and add them to show Significant difference in their mean values. We appreciate the comment and fully agree with the observation. The significance column was removed from Table 2, as the ANOVA results indicated no significant interaction effects between interstock and rootstock. Therefore, we considered it unnecessary to apply any post hoc tests such as Duncan's Multiple Range Test (DMRT). It is important to note that linear mixed-effects models were employed due to their statistical robustness. Detailed information regarding the statistical analyses can be found in the supplementary material (EM1), section 5.2, Specific Objective 2. Although no significant differences were observed in fruit biometric traits (Table 2), noticeable differences were evident in plant size. The interstock modulated tree growth by reducing plant height (Figure 3), which has practical agronomic implications. Taller canopies typically reduce planting density per unit area and increase intra-canopy competition for light and airflow (Beshir et al. 2019). Moreover, excessive vegetative growth can diminish overall profitability by complicating routine orchard management

practices (Menzel and Le Lagadec 2017). Reducing plant height may allow growers to adopt higher planting densities and reduce costs associated with cultural practices, ultimately improving economic returns. A detailed discussion has been included in the Discussion section (lines 290–301).

> Data present in figure 3 also show no signicance in 2017 and 2019 by all four selected interstate, then how your work will be helpful to enhance mango production in Peru? Please explain it with mechanism and references.

Thank you for the recommendation. The statistical analysis has been revised and expanded to include a more detailed dissection of the individual factors. The corresponding figure (Figure 3) has been updated, and the results have been clarified in the revised manuscript. For the variable number of fruits, a significant difference was observed between the 2017 season and the 2018 and 2019 seasons. Similarly, for flowering percentage, differences were identified between 2018 and the other two years (2017 and 2019).

It is important to highlight that mango production in the Piura region is frequently affected by environmental and climatic factors, particularly seasonal variability and extreme weather events such as droughts or El Niño phenomena (Aldana et al. 2021). In our study, we found significant differences in fruit production across growing seasons, with a 15% lower yield in 2017 compared to 2018 and 2019. These findings are detailed in the Results section (lines 215–235). We believe that presenting these quantitative results provides valuable insight for producers, enabling them to better anticipate the impacts of climatic variability on yield and make informed decisions to mitigate potential economic losses associated with reduced production (Gouveia et al. 2023) (lines 330–338).
> Reviewer 2

> The manuscript entitled "Impact of Interstock and Rootstock on Growth and Productivity of Mango (Mangifera indica L.) in the San Lorenzo Valley, Peru" presents a three-year investigation (2017-2019) evaluating mango cultivation systems. While the study demonstrates methodological rigor through its robust experimental design and comprehensive dataset analyzing vegetative development, productivity metrics, and tree architecture, several critical aspects require enhancement to strengthen scientific validity and practical relevance.

Thank you very much for your valuable comments and constructive feedback aimed at improving the quality of our manuscript. We have carefully addressed each of your suggestions, as detailed below. All modifications made in the revised manuscript have been highlighted in red for clarity.

> The current analysis suggests predominant rootstock influence over interstock effects. To adequately characterize interstock-scion interactions, the authors should incorporate fruit quality parameters such as total soluble solids, titratable acidity, ascorbic acid content, and pulp recovery percentage.

Thank you for your thoughtful suggestions. We acknowledge the importance of evaluating fruit quality parameters; however, this study represents a preliminary approach to the practical application of interstocks in mango cultivation and constitutes the first report of its kind conducted in the northern region of Peru. As such, the specific fruit quality traits mentioned were not assessed in this work.

The limitations of the current study, along with recommendations for future research, have been addressed in the Discussion section (lines 339–352), with the aim of encouraging further investigation into the influence of this technique on mango fruit quality.

Despite not including fruit quality parameters, we believe the practical relevance of our study lies in demonstrating the potential of interstocks to reduce tree height. This outcome has significant implications for orchard management, as it facilitates cultural practices and may lead to increased planting densities and reduced labor costs (Beshir et al. 2019; Menzel and Le Lagadec 2017). This information is included from Lime 72 to 75 in the Introduction section.

> While referencing El Niño phenomena, the study lacks quantitative correlation between climatic variables (precipitation anomalies and temperature extremes) and horticultural performance.

Thank you for your recommendation. The statistical analysis has been expanded to include a more detailed dissection of individual factors, and both the corresponding figure (Figure 3) and result descriptions have been updated accordingly. For the variable "number of fruits," a clear difference was observed between the 2017 season and the 2018 and 2019 seasons. Similarly, for "flowering percentage," differences were identified between 2018 and the other two years.

These interannual differences may be attributed to contrasting climatic conditions during each growing season, particularly the variability in precipitation, as shown in Figure 2. It is well known that mango production in the Piura region is strongly influenced by environmental and climatic factors, especially seasonal fluctuations and extreme events such as droughts and El Niño phenomena (Aldana et al. 2021). In our study, fruit yield in 2017 was approximately 15% lower than in 2018 and 2019. These findings are detailed in the Results section (lines 215–235).

Our results are consistent with existing literature that highlights the influence of climatic variability on mango productivity. For example, Normand et al. 2015 report that changes in temperature and precipitation patterns can significantly affect mango growth and fruiting, emphasizing the importance of climate-sensitive agricultural planning. Furthermore, Ogunbode et al. 2024 found that elevated temperatures and disrupted rainfall patterns are key contributors to yield reduction in mango production, reinforcing the correlations observed in our study (lines 330–338).

We believe that presenting these associations between climatic anomalies and fruit yield offers practical value for producers, helping them anticipate potential impacts and develop adaptive strategies to mitigate risks under changing climatic conditions.

1   **Impact of Interstock and Rootstock on the Growth and Productivity of Mango (*Mangifera indica* L.) in the**

2   **San Lorenzo Valley, Peru**

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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**

1 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 quality. A total of 216 trees were established using 'Chulucanas' and 'Chato' as rootstocks and 'Chulucanas,' 'Chato,' 'Irwin,' and 'Julie' as interstocks, 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. The experiment followed a randomized complete block design (RCBD) with a 2 × 4 factorial arrangement and three blocks. The first factor corresponded to rootstock varieties, while the second factor included interstock varieties.

The results indicated that the combination of the 'Chulucanas' rootstock with 'Chulucanas' and 'Julie' interstocks reduced tree height by 10.94% and 11.70%, respectively. Additionally, significant differences in fruit production were observed among growing seasons, with 2017 exhibiting a 15% lower yield compared to 2018 and 2019. However, fruit biometrics parameters remained unaffected by rootstock–interstock combinations. These findings suggest that cultivar selection plays a critical role in modulating tree growth, while environmental conditions or season-specific factors may influence yield variability.

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

2 INTRODUCTION

Mango (Mangifera indica L.) is a fruit tree from the Anacardiaceae family, cultivated in tropical and subtropical regions (Honja 2014). Its global production is estimated at approximately 51 million tons (Lebaka et al. 2021). In Peru, national production reached 378 thousand tons in 2024 (Ministerio de Desarrollo Agrario y Riego 2025). It is characterized by vigorous growth and attractive fruits, with high levels of carbohydrates, fatty acids, minerals, and vitamins (Moniruzzaman et al. 2022). The inflorescence is a branched terminal panicle, ranging from 10 to 60 cm in length, bearing between 500 and 10,000 flowers per panicle (Ramírez and Davenport 2016). The fruit is a large, fleshy drupe with an edible mesocarp of variable thickness (Matheyambath et al. 2016). 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, using polyembryonic rootstocks for their genetic uniformity (Galán Saúco et al. 2021). Currently, mango cultivation is managed at low to medium planting densities, ranging from 69 to 416 trees per hectare, due to the space required for vegetative growth, which is commonly associated with fruit production (Johnson and Robinson 2000; Menzel and Le Lagadec 2017).

The use of low densities decreases production because yields during the first few years are low (Souza et al. 2004). However, increasing densities along with the vegetative growth of the crop reduces profits, as they complicate cultural maintenance tasks (Menzel and Le Lagadec 2017). Additionally, a tall canopy results in a lower number of trees per unit area, causing competition for light and aeration (Beshir et al. 2019). The application of growth regulators, pruning

77 techniques, and the genetics of rootstocks and scions should be investigated in this context in order to control tree
78 vigor (Ibell et al. 2024).

79 Using rootstocks is a common method of propagating fruit trees that involves fusing the root system (rootstock) with
80 the aerial part (interstock). These parts combine through assembly to form a new plant (Martínez-Ballesta et al. 2010;
81 Feng et al. 2024). Tree vigor, yield, fruit quality, and tolerance to biotic or abiotic stress are all related to rootstock
82 selection (Castle et al. 2011; Khurshid et al. 2024). The propagation of highly valuable varieties occurs on grafts that
83 exhibit greater resistance to diseases, better adaptability to environmental conditions, and optimized nutrient
84 absorption (Tietel et al. 2020; Lazare et al. 2019). The viability and compatibility of the graft are influenced by the
85 proximity between taxonomic species and the technique used to align the vascular bundles, which ensures the
86 translocation of carbohydrates and hormones and nutrient transport (Baron et al. 2019).

87 While mango production is correlated with tree size (Menzel and Le Lagadec 2017), cultivars such as 'Irwin' (Lu et
88 al. 2013), 'Keitt' (Bally et al. 2000), and 'Tommy Atkins' (Silva et al. 2014) present high yields in smaller trees. These
89 latter varieties would be suitable for planting at high densities (Menzel and Le Lagadec 2017; Smith et al. 2008).

90 In this context, owing to the regulation of the vertical or horizontal growth of the tree and the modification of the
91 sensory properties of the fruit caused by rootstock-interstock combinations in mango varieties (Jukić Špika et al. 2021;
92 Dayal et al. 2016), this study aims to determine the effects of the interaction between rootstock and interstock on the
93 agronomic characteristics and fruit biometrics of the mango cultivar.

94 **3   MATERIALS AND METHODS**

95 *3.1   Study Area*

96 The study was conducted during the agricultural seasons of 2017-2019 at the Hualtaco Nursery, owned by the El Chira
97 Agricultural Experimental Station (EEA), located in the district of Tambogrande, Piura Department, at a latitude of
98 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
99 desert and subtropical climate. The mango (*Mangifera indica* L.) plants are spaced at 6.0 m × 6.0 m, with a total of
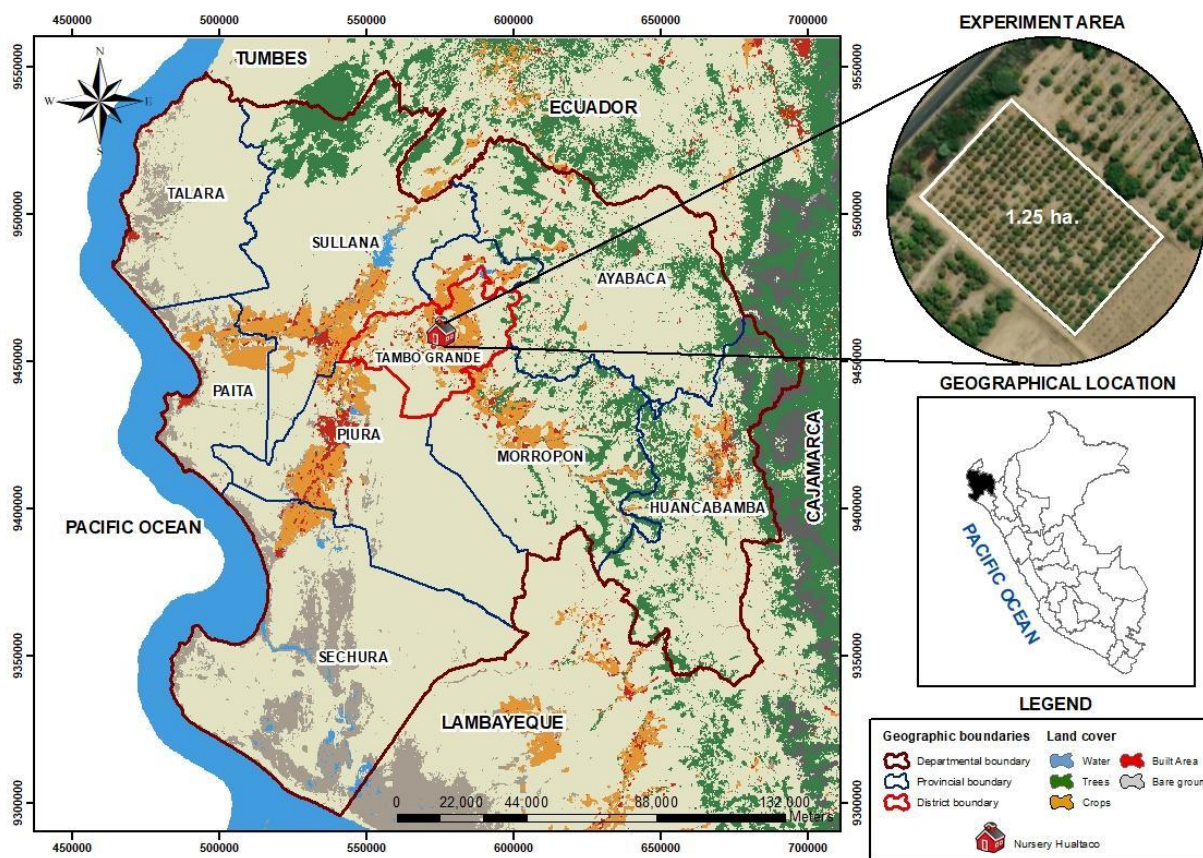100 216 plants.

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

3.2 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 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. 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' (Hernandez et al. 2021).

Irwin: Irwin is one of the most commercially produced and consumed cultivars 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

114 that have red skin coloration, measuring approximately 11.5 to 13 cm in length and 8 to 9 cm in diameter (Wijethunga
115 et al. 2023).

116 **Julie**: This variety is widespread in Nigeria. The plants exhibit an extended growth habit, with medium foliage density
117 and lanceolate-shaped leaves; the fruit is ovoid with yellow skin coloration, measuring approximately 99.5 mm in
118 length, 70 mm in width, and weighing 219 g (Esan et al. 2024).

119 **Chato:** Known as the Chato variety from Ica, it is one of the most widely exploited cultivars in the valley of the Ica
120 region in southern Peru. It is characterized by fruit measuring approximately 151 mm in length and 82 mm in width
121 and weighing 291 g (Coral and Escobar-Garcia 2021).

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

122 *3.3   Agronomic Management*

123 Soil preparation was carried out via a tractor and a harrow, in accordance with the layout of the crop rows, hole
124 digging, and transplanting of seedlings, following a grid planting design of 6×6 meters. Seed selection was performed
125 from the mango germplasm bank, which comes from elite plants at the Hualtaco Annex of the El Chira Agricultural
126 Experimental Station (EEA). The process of removing the pericarp, mesocarp, and endocarp facilitated better
127 development of the embryo in the seedlings, which were obtained from polyembryonic seeds in seedbeds. Grafting
128 was performed using the double-tongue technique three months after seedling transplanting into nursery bags.
129 Subsequently, interstock and apical grafting were conducted using the same method, known as the English or double-
130 tongue grafting technique. This technique involves making a beveled cut on both the rootstock and the scion, followed
131 by a longitudinal cut (approximately 1 cm deep) along one-third of the beveled surface, creating interlocking tongues
132 on both plant parts (Yadav et al. 2018). The graft components were then interwoven, secured with grafting tape, and
133 covered with a perforated plastic bag to maintain humidity. There was an eight-month interval between the interstock

134 and apical grafting procedures. Bridge rootstock grafting was performed in 2008, while bud bridge grafting was
135 conducted in 2009.

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

3.4 Agronomic and Biometric Characterization of the Fruit

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

147 The plant height (m) was determined at the end of the experiment. It was measured from the base of the soil to the
148 apex of the plant via a graduated wooden ruler. The number of fruits per plant was determined at the end of each
149 growing season through a direct visual count. The total number of fruits produced by each individual was recorded
150 before the first harvest. The budburst percentage (%) was determined in the final phase of the experiment through
151 direct observation. Six branches from the middle third of the canopy on the east side and six branches on the west side
152 of each plant were selected and monitored. The number of shoots produced by each branch and the number of buds
153 until desiccation were evaluated (Lopes et al. 2021). The flowering percentage (%) was evaluated at the end of each
154 growing season through visual observation, recording the intensity of flowering in the tree canopy during anthesis.
155 The canopy was divided into two opposing sections, and the percentage of flowering was recorded on a scale of 0-
156 100 according to the coverage of the inflorescences in each section. To calculate the overall flowering percentage of
157 the tree, an average of both evaluated sections was taken (Osuna-Enciso et al. 2023).

158 For the evaluation of fruit biometrics, six individuals per treatment were randomly selected, and five fruits were
159 collected from each at harvest, resulting in a total of 30 fruits per treatment. Fruits that reached physiological maturity
160 were chosen for measurements using a vernier caliper and a balance. Each fruit was measured for weight (g), length
161 (mm), and diameter (mm) (Alshallash et al. 2022).

3.5 Experimental Design

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

7

168   the plants were selected, and the variables measured included plant height, percentage of budding, number of fruits,

169   and percentage of flowering. For the determination of fruit biometrics, five plants were randomly selected, and the

170   variables measured included the weight, length, and diameter of the fruits.

171   *3.6   Statistical Analysis*

172   Statistical analyses were conducted using R software version 4.4.1 (R Core Team 2024). A linear mixed-effects model

173   was fitted to assess treatment effects, providing robustness against potential violations of normality and

174   homoscedasticity assumptions (Schielzeth et al. 2020). Analysis of variance (ANOVA) was applied to the fitted

175   models, and mean comparisons were performed using Tukey's honest significant difference (HSD) test at a

176   significance level of $\alpha = 0.05$, using the emmeans package (Lenth et al. 2024). Multivariate relationships among

177   variables were explored through principal component analysis (PCA) with the FactoMineR package (Husson et

178   al. 2024). Variable correlations derived from the PCA were visualized using the corrplot package (Wei et al. 2024).

179   **4   RESULTS**

180   *4.1   Weather conditions*

181   To determine the weather conditions that influenced the management of mango cultivation during the agricultural

182   seasons of 2017–2019, a graph was created with data on maximum temperature, minimum temperature, precipitation,

183   and relative humidity obtained from the "El Partidor" weather station of SENAMHI.

184   The highest temperature values were recorded in 2018 from January to March, reaching a peak of 35.20 °C in March.

185   On the other hand, the lowest temperature values were observed in 2019 from July to November, reaching 15.72 °C

186   in August. In terms of precipitation, the highest values occurred in 2017 during February and March, peaking at 39.41

187   mm in March. This was an atypical event caused by the El Niño–Southern Oscillation (ENSO) climate phenomenon.

188   The relative humidity was also influenced by this event, with a maximum value of 89.48% occurring in March 2017.

189   These parameters are important because they are critical factors that directly influence the growth, flowering, fruiting,
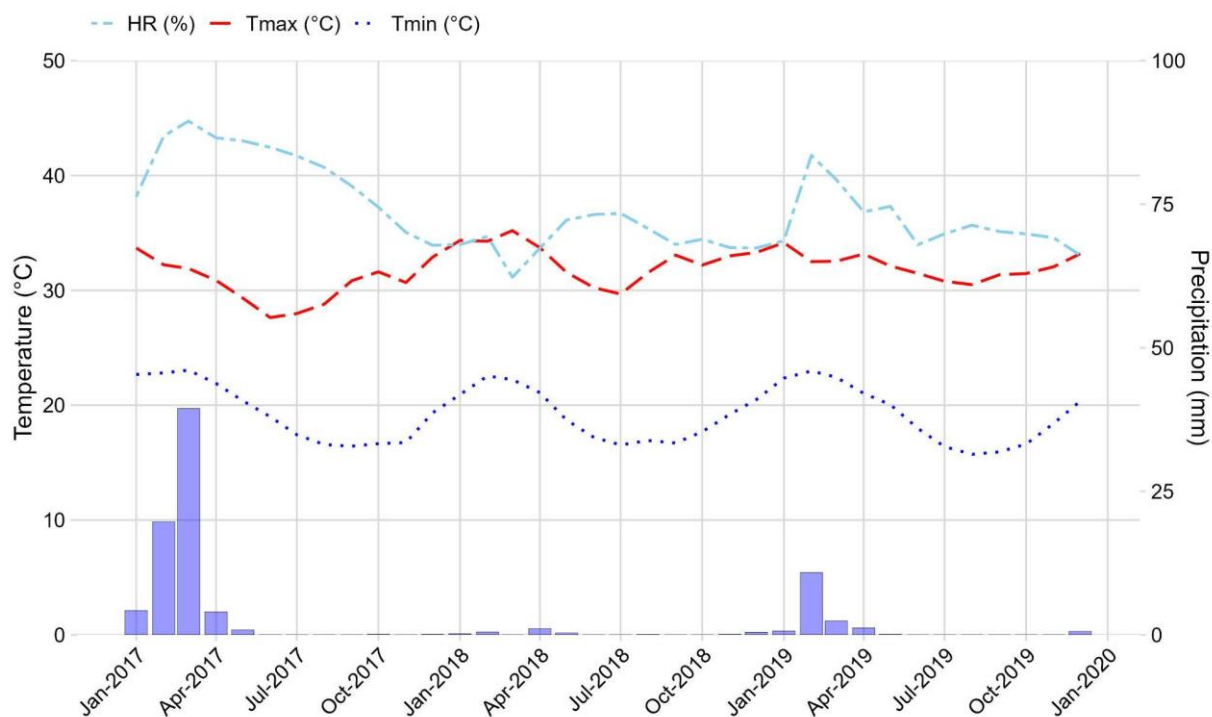
190   and quality of mango fruit.

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

4.2   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). 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.
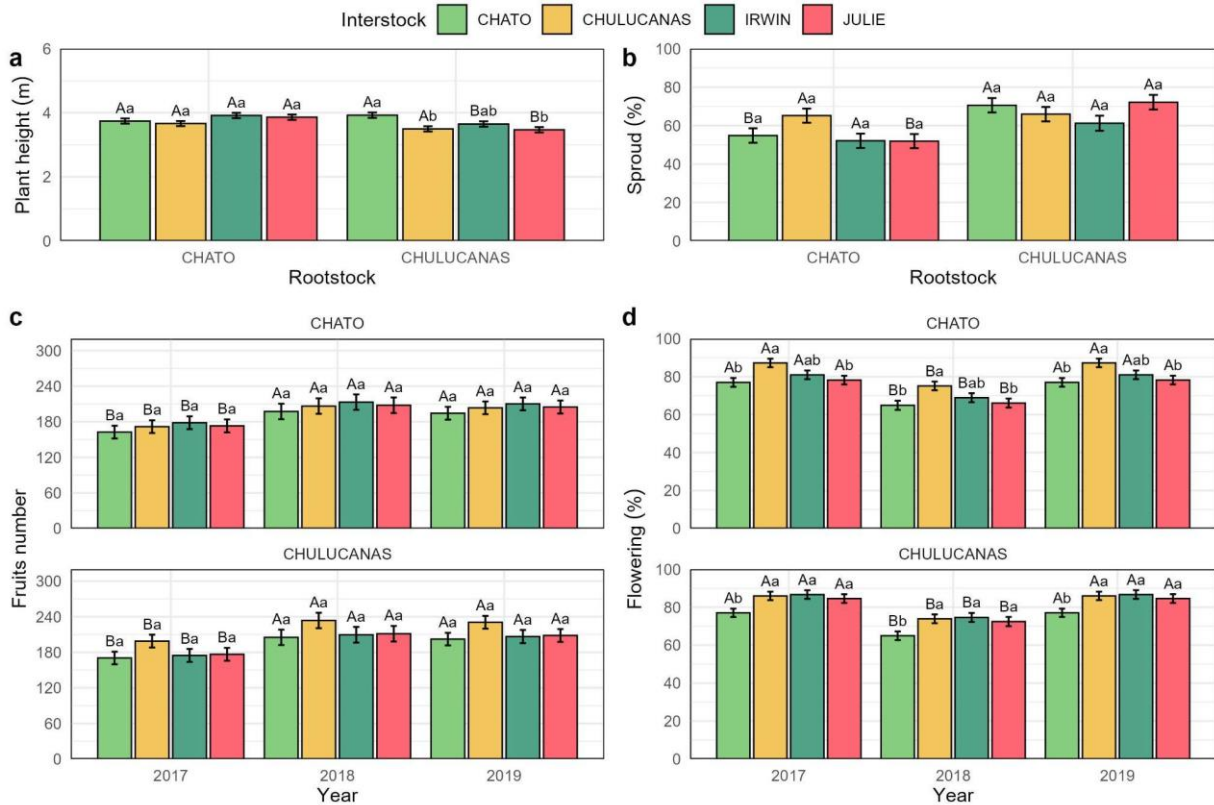
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Figure 3: Agronomic characteristics of the rootstock and interstock relationship for mango in the Piura Region, calculated based on nine plants per treatment: Plant height at harvest (a), percentage of sprout (b), number of fruits produced during the 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).

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

205 On the other hand, when comparing the effects of rootstocks for the same interstock, significant differences were
206 found. Specifically, 'Chato' – 'Irwin' combination had an average height of 3.92 m, whereas 'Chulucanas' – 'Irwin'

10

207 reached 3.65 m, representing a 6.89% reduction. Similarly, 'Chato' – 'Julie' combination showed an average height

208 of 3.86 m, while 'Chulucanas' – 'Julie' recorded 3.47 m, which corresponds to a 10.10% reduction (Figure 3a).

209 No significant differences were observed in the sprouting percentage among the different interstocks within each

210 rootstock (p-value > 0.05). However, when comparing the effect of rootstocks for the same interstock, significant

211 differences were found. Specifically, 'Chulucanas' – 'Chato' combination exhibited a higher sprouting percentage

212 (70.6%) compared to 'Chato' – 'Chato' (54.8%). Similarly, 'Chulucanas' – 'Julie' association showed a higher

213 sprouting percentage (72.2%) compared to 'Chato' – 'Julie' (51.9%), highlighting the impact of rootstock on sprout

214 induction (Figure 3b).

215 For the variable number of fruits, no significant differences were observed among the different interstocks within each

216 rootstock in the same year (p-value = 0.46). However, significant differences were found between the evaluated

217 agricultural seasons (p-value < 0.001), indicating interannual variability in fruit production (Figure 3c).

218 In particular, the 2017 agricultural season recorded a lower average number of fruits compared to the 2018 and 2019

219 seasons. Among these differences, 'Chato' – 'Julie' combination stood out, with an average of 173 fruits in 2017,

220 while in 2018 and 2019, it reached 208 and 205 fruits, respectively, representing an approximate reduction of 16%

221 compared to the following years. Similarly, in 'Chulucanas' – 'Julie' combination had a lower average number of

222 fruits in 2017, with 177 fruits, in contrast to the averages observed in 2018 and 2019, with 211 and 208 fruits,

223 respectively, representing an approximate reduction of 15%. (Figure 3c).

224 For the variable flowering percentage, significant differences were observed among the different interstocks within

225 each rootstock in the same year (p < 0.05). In the case of the 'Chato' rootstock, its association with the 'Chulucanas'

226 interstock exhibited a higher flowering percentage across all agricultural seasons compared to its association with the

227 'Chato' and 'Julie' interstocks. Conversely, the 'Chulucanas' rootstock, when combined with the 'Chato' interstock,

228 showed a lower flowering percentage in all agricultural seasons compared to its combination with the other interstocks

229 (Figure 3d).

230 Furthermore, significant differences were found between the evaluated agricultural seasons (p < 0.001), indicating

231 interannual variability in flowering. Specifically, the 2018 agricultural season recorded a lower average flowering

232 percentage compared to the 2017 and 2019 seasons. Among these differences, the 'Chato' – 'Irwin' combination stood

233 out, registering an average flowering percentage of 68.9% in 2018, while in 2017 and 2019, it reached 81%. Similarly,

234 the 'Chulucanas' – 'Irwin' combination showed an average flowering percentage of 74.6% in 2018, in contrast to the

235 86.7% observed in 2017 and 2019. (Figure 3d).

236 To analyze the association between variables and individuals, a multivariate analysis of principal components (PCA)

237 and a Pearson correlation analysis were conducted (Figure 4).
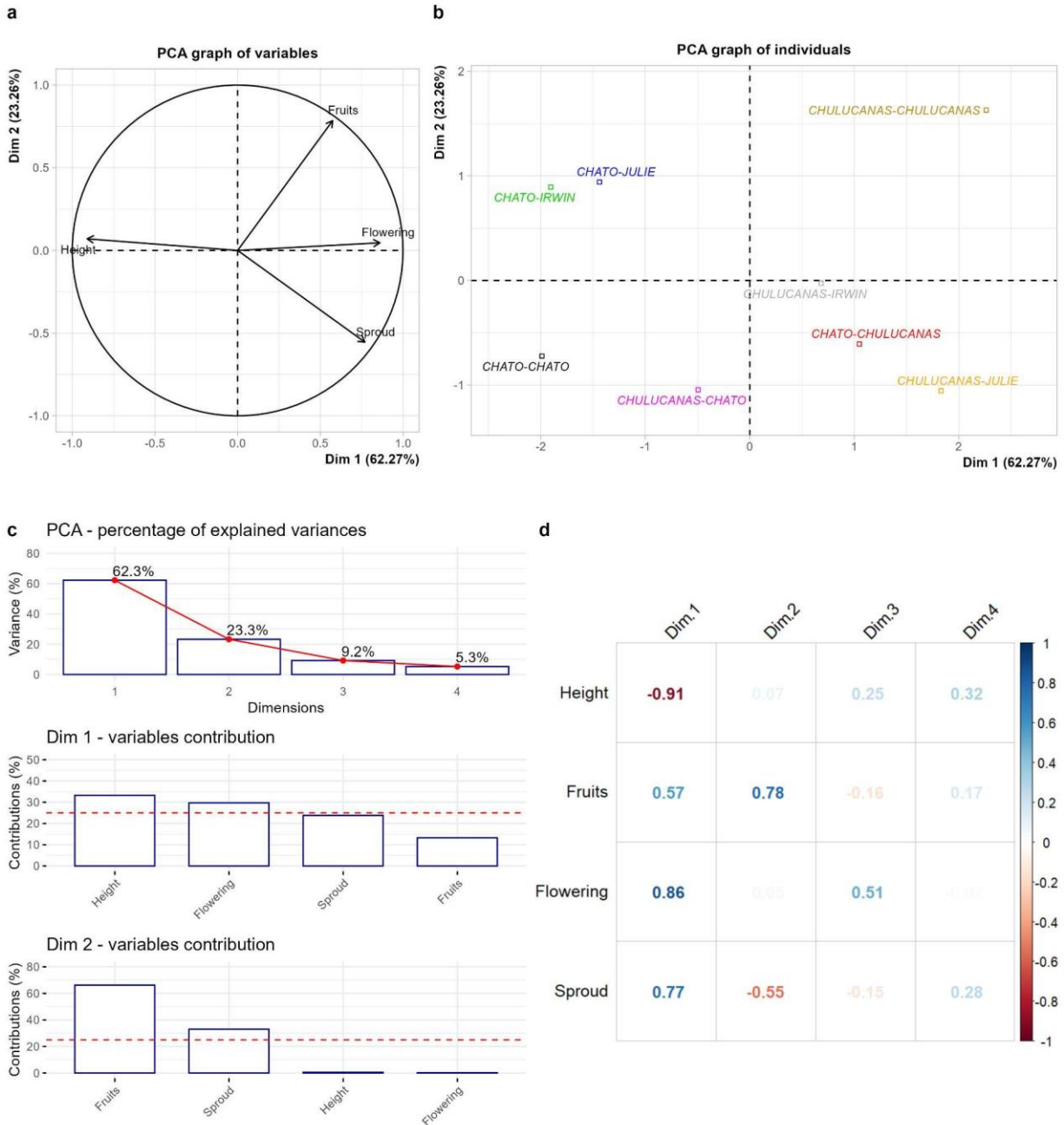
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Figure 4: Principal component analysis (PCA) of the agronomic characteristics in mango cultivation based on the use of rootstock-interstock combinations. Variables were evaluated to determine the agronomic characteristics of the rootstock-interstock combination in mango (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).

238 The first two components represent 85.52% of the cumulative variance, accounting for 62.27% of the variance in
239 dimension 1 and 23.26% in dimension 2 (Figure 4a, c). For dimension 1, the variables plant height and percentage of
240 flowering contributed 33.26% and 29.71%, respectively, whereas the percentage of budding contributed 23.77% and
241 the number of fruits contributed 13.26% Figure 4a, c). In dimension 2, the variable number of fruits and percentage
242 of buds had the greatest contributions, at 66.19% and 33.05%, respectively, whereas the percentage of flowers was
243 0.23% and plant height was 0.53%. (Figure 4a, c).

244 The vectors indicate the direction of the relationship between the variables, showing a positive relationship among the
245 variables of budding, flowering, and number of fruits produced, in contrast to plant height, where a negative
246 relationship is observed. Notably, there was a strong positive correlation r = 0.86 between the percentage of flowering
247 and a strong negative correlation r = -0.91 between the plant height variable and dimension 1. Furthermore, in
248 dimension 2, the variable number of fruits had a strong positive correlation of r = 0.78 (Figure 4a, d).

249 On the other hand, it is observed that 'Chulucanas'-'Chulucanas' rootstock-interstock relationship is aligned with the
250 vector for the number of fruits, indicating that individuals with this graft presented better characteristics for this
251 variable. In terms of the percentage of budding, individuals with 'Chulucanas'-'Julie' and 'Chato'-'Chulucanas'
252 relationships presented the highest values for this variable. In terms of the percentage of flowers, 'Chato'-'Chulucanas'
253 rootstock-interstock relationship presented the best characteristics. For plant height, 'Chato'-'Julie' and 'Chato'-
254 'Irwin' relationships presented the highest values (Figure 4b).

4.3   Biometric characterization of the fruit

256 To determine the biometrics of the fruit produced by the rootstock-interstock interaction in the mango, the variables
257 of weight, length, and diameter of the fruit were evaluated. Tukey's mean comparison test (p < 0.05) was conducted
258 to assess whether there were significant differences between the rootstock and the interstock used (Table 1). This
259 study aimed to identify the rootstock-interstock relationship that produces the best quality mango fruit (*Mangifera*
260 *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. 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
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

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

265 To analyze the association between variables and individuals, a multivariate PCA and a Pearson correlation analysis
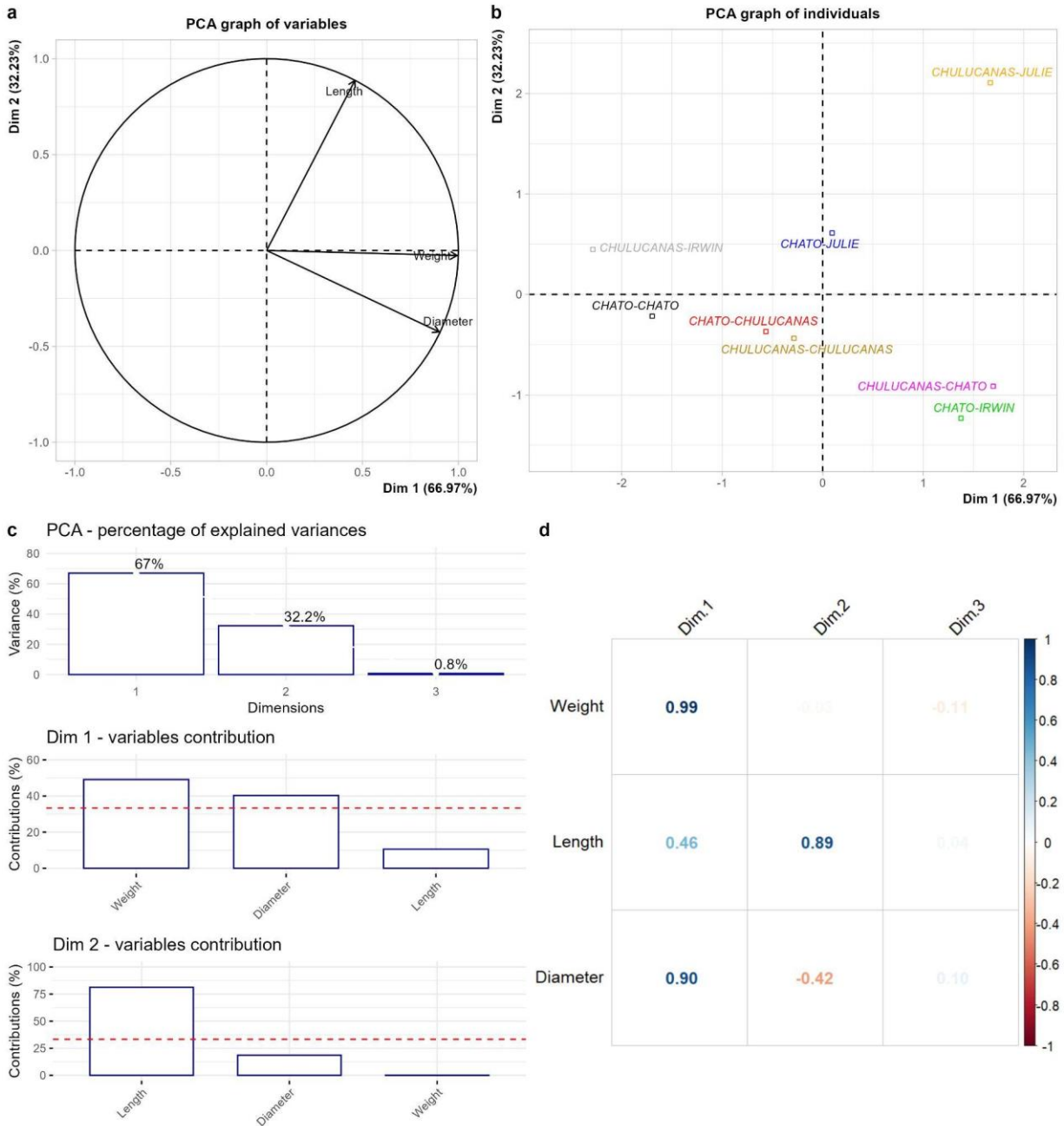266 were conducted (Figure 5, Supplementary Figure 2).

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 (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).

267   The first two components represent 99.21% of the cumulative variance, with 66.97% of the variance in dimension 1

268   and 32.23% in dimension 2 (Figure 5a, c). For dimension 1, the variables weight and diameter of the fruit contributed

269   the most to this dimension, with 49.14% and 40.32%, respectively, whereas the contribution of fruit length was 10.55%

270   (Figure 5a, c). In dimension 2, the variable fruit length had the greatest contribution, at 81.29%, compared with the

271   contributions of weight and fruit diameter, which were 0.07% and 18.64%, respectively (Figure 5a, c)

272   The vectors indicate the direction of the relationship between the variables, highlighting a notable degree of positive

273   correlation among the weight, length, and diameter of the fruits. Notably, there was a strong positive correlation for

274   fruit weight $r = 0.99$ and fruit diameter $r = 0.90$ with respect to dimension 1. Additionally, in dimension 2, the variable

275   fruit length has a strong positive correlation of $r = 0.89$ (Figure 5a, d).

276   On the other hand, it is observed that the 'Chulucanas'-'Julie' rootstock-interstock relationship is aligned with the

277   vector for fruit length, indicating that individuals with this graft exhibit better characteristics for this variable. In terms

278   of fruit weight, individuals with the 'Chulucanas'-'Chato' and 'Chato'-'Irwin' relationships presented the highest

279   values. In terms of fruit diameter, the 'Chulucanas'-'Chato' and 'Chato'-'Irwin' rootstock-interstock relationships

280   also presented the highest means (Figure 5b).

5   DISCUSSIONS

281

282   The mango is considered one of the most important export fruits in Peru. Sixty-six point seven percent (66.7%) of the

283   mango harvest is produced in the Piura department, making it the country's leading producer (Coral and Escobar-

284   Garcia 2021). Despite the large quantity of mango produced, there is still low productivity per unit area, which

285   significantly impacts exports. The use of rootstocks influences the growth of mango plants in terms of height, diameter,

286   and canopy volume, potentially inducing dwarfism in individuals and thereby increasing the planting density per

287   hectare (Dubey et al. 2021). This research evaluated the effects of rootstock and interstock on the agronomic

288   characteristics and fruit quality of mango. The growth and productivity parameters that determine the production of

289   mango in the San Lorenzo Valley, Piura, were assessed.

290   The interaction between rootstocks and interstocks plays a very important role in the process of obtaining crops with

291   favorable agronomic characteristics (Hamza et al. 2023); (El Shahawy et al. 2023); (Minja et al. 2017). In our study,

292   we evaluated the impact of interstocks and observed that the interaction influenced plant height (Figure 3, Figure 4).

293   The interaction of 'Chulucanas' rootstock with the interstocks 'Chulucanas', 'Irwin', and 'Julie' resulted in a reduction

294   in height. One possible factor explaining this decrease may be the size of the cultivars used, as is the case with 'Irwin',

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which produces plants with shorter heights (Wijethunga et al. 2023). Our results agree with those of the study by Minja et al. (2017), 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 El Shahawy et al. (2023), 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, 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. (2023), who evaluated three scion varieties ('Sinddhri,' 'Sufaid Chaunsa,' and 'Chenab Gold') grafted at three different heights. Their results indicated that scion variety significantly increased the number of sprouts produced. This difference may be attributed to the genetic variability among scion cultivars, as sprouting intensity in mango can vary considerably due to genetic factors (Emire et al. 2022). Therefore, it is presumed that the graft varieties used in their study exhibit greater genetic divergence than those employed in the present research. For flowering and fruit production, our results were primarily influenced by the agricultural season, with significant differences observed across the evaluated years. This suggests that environmental conditions or campaign-specific factors may have played a key role in mango productivity, regardless of the rootstock and interstock used. These differences may be due to changes in climate caused by the El Niño-Southern Oscillation (ENSO) phenomenon. As noted by Scuderi et al. (2023), environmental factors can influence the development of flowering and, consequently, the number of fruits produced during mango cultivation.

Rebolledo-Martínez et al. (2019) 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, Figure 4, Table 1).

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, Figure 5). The highest weight values were recorded with the 'Chulucanas'-Chato' and 'Chulucanas'-'Julie' combinations (Table 2); therefore, it can be assumed that 'Chulucanas' used as rootstock has a direct relationship with fruit weight. However, Shivran et al. (2023) 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 'Chulucanas' rootstock results in a greater fruit length than the combination on 'Chato' rootstock (Table 2). These results could be attributed to the fact that 'Chato', 'Irwin', and 'Julie' produce fruits of greater length than 'Chulucanas'. This aligns with the findings of Shivran et al. (2023) 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 rootstock cultivar (Dubey et al. 2021; Reddy et al. 2003; Smith et al. 2008).

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331 In our study, the lower mango yield observed in 2017—approximately 15% less than in 2018 and 2019—can be
332 attributed to the El Niño–Southern Oscillation (ENSO) event that year, which increased precipitation and temperature
333 in the San Lorenzo Valley (Figure 2). These climatic anomalies likely affected flowering and fruit development, as
334 supported by previous studies indicating that such conditions can reduce tree vigor, disrupt rootstock–scion
335 compatibility, and increase premature fruit drop (Dubey et al. 2021; Halder et al. 2024). Our results align with reports
336 highlighting the sensitivity of mango production to temperature and rainfall variability (Normand et al. 2015;
337 Ogunbode et al. 2024), emphasizing the need for climate-adaptive management strategies, particularly in regions like
338 Piura, where seasonal fluctuations and extreme weather events frequently impact agricultural productivity (Aldana et
339 al. 2021; Gouveia et al. 2023).

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

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

6 CONCLUSIONS

355 The use of rootstocks in combination with interstocks influences the agronomic characteristics of mango cultivation,
356 although it does not affect the biometrics of mango fruits. This study demonstrated that cultivars used affect plant
357 growth; however, nonsignificant differences in the biometric characteristics of the fruits were detected. The obtained
358 data confirm that interstocks can induce a dwarfing effect in plants, allowing for increased planting density per hectare.
359 This information regarding plant behavior based on the type of graft used can be valuable for optimizing the agronomic
360 management of mango cultivation in the Piura region of Peru.

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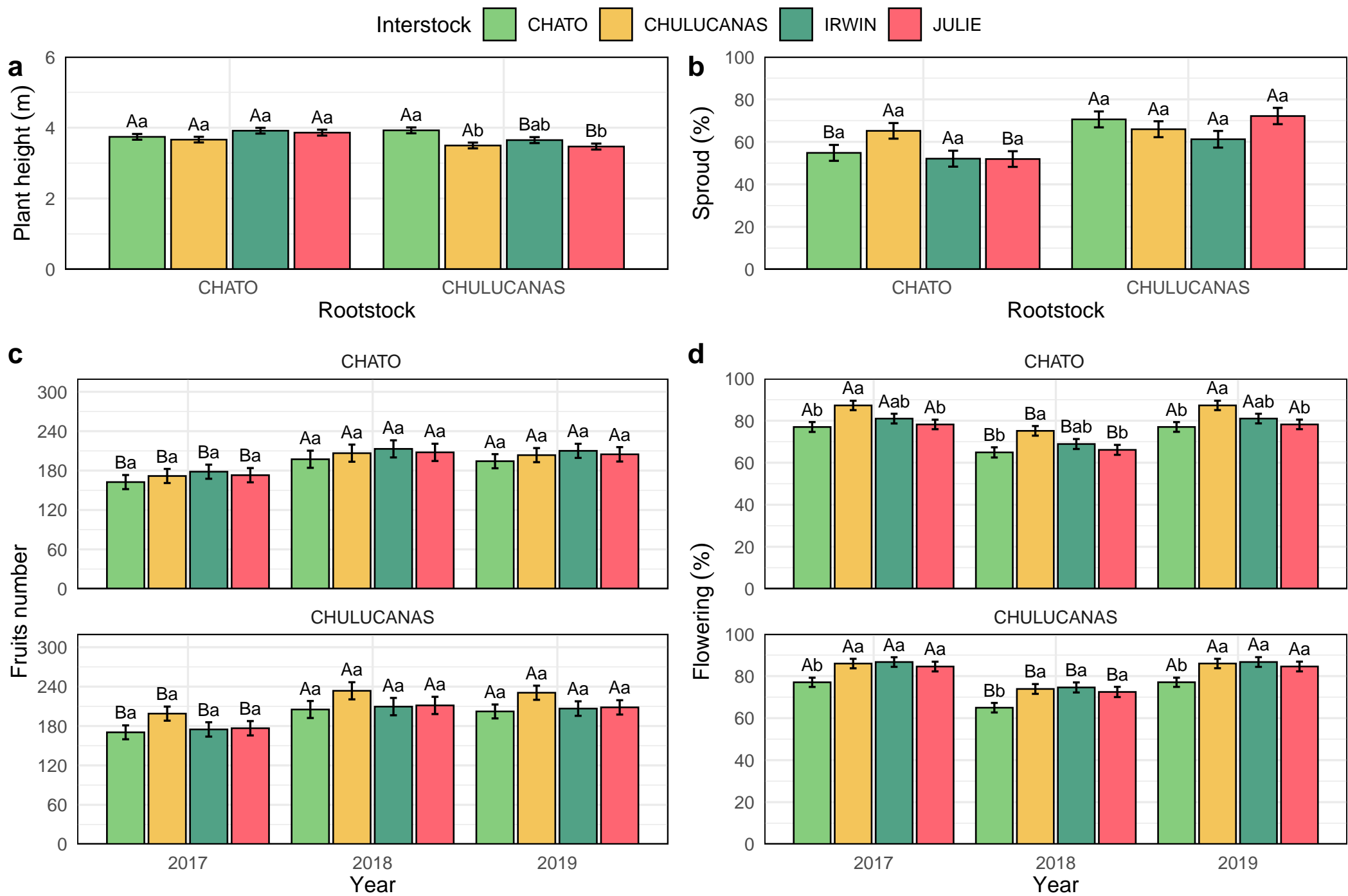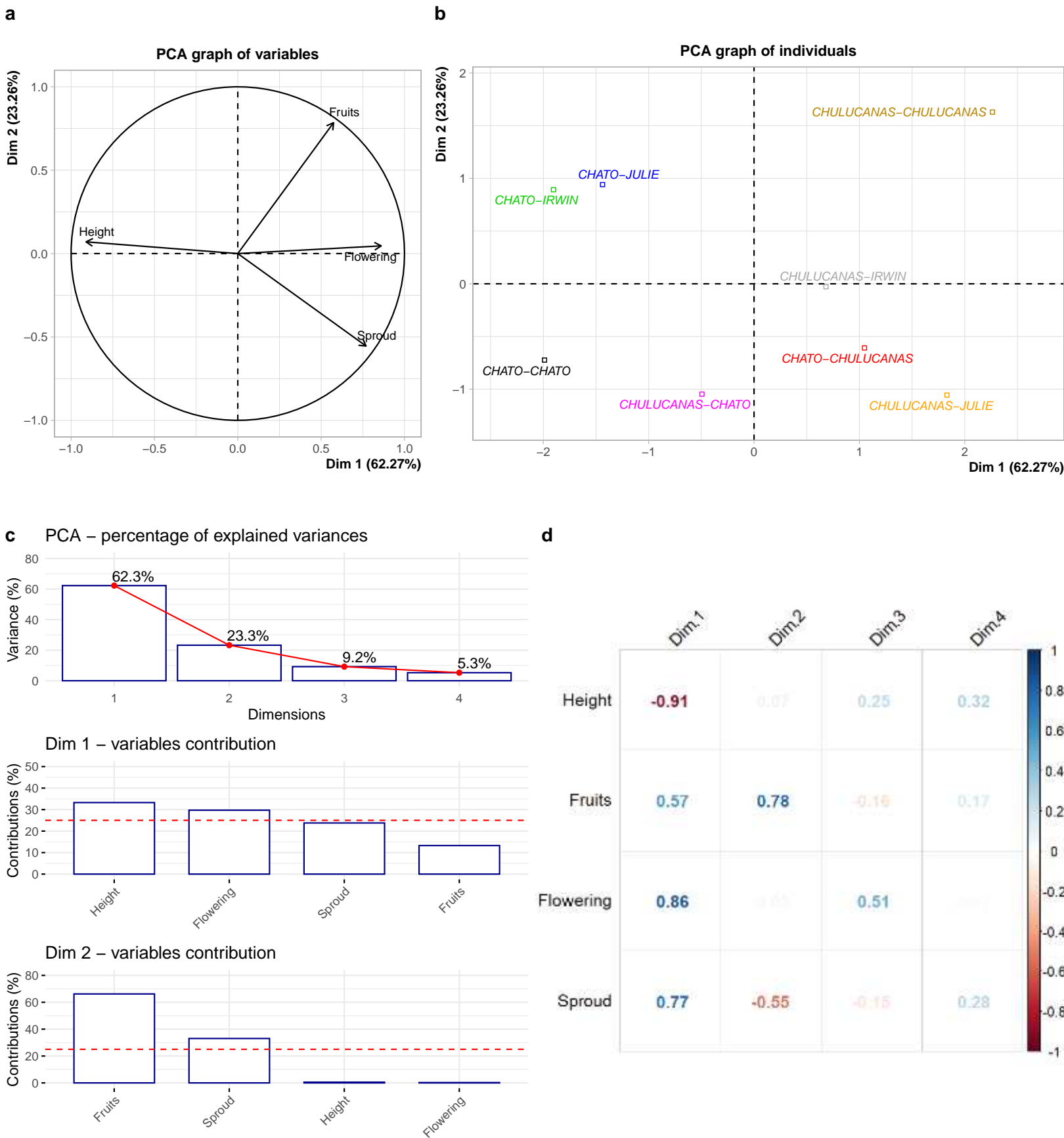
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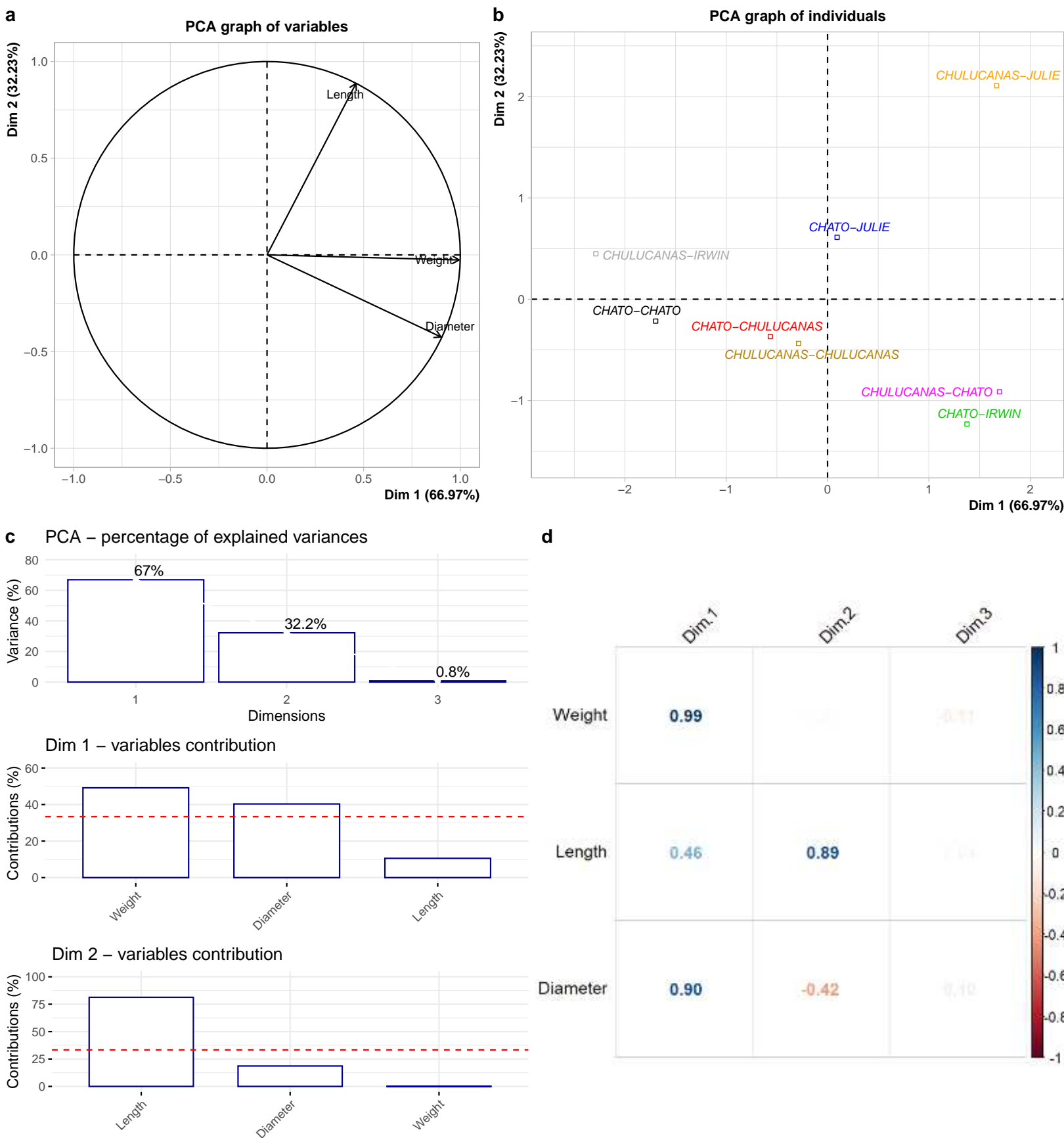487 Budding in Mango. Int J Pure App Biosci 6:575–586. https://doi.org/10.18782/2320-7051.6681
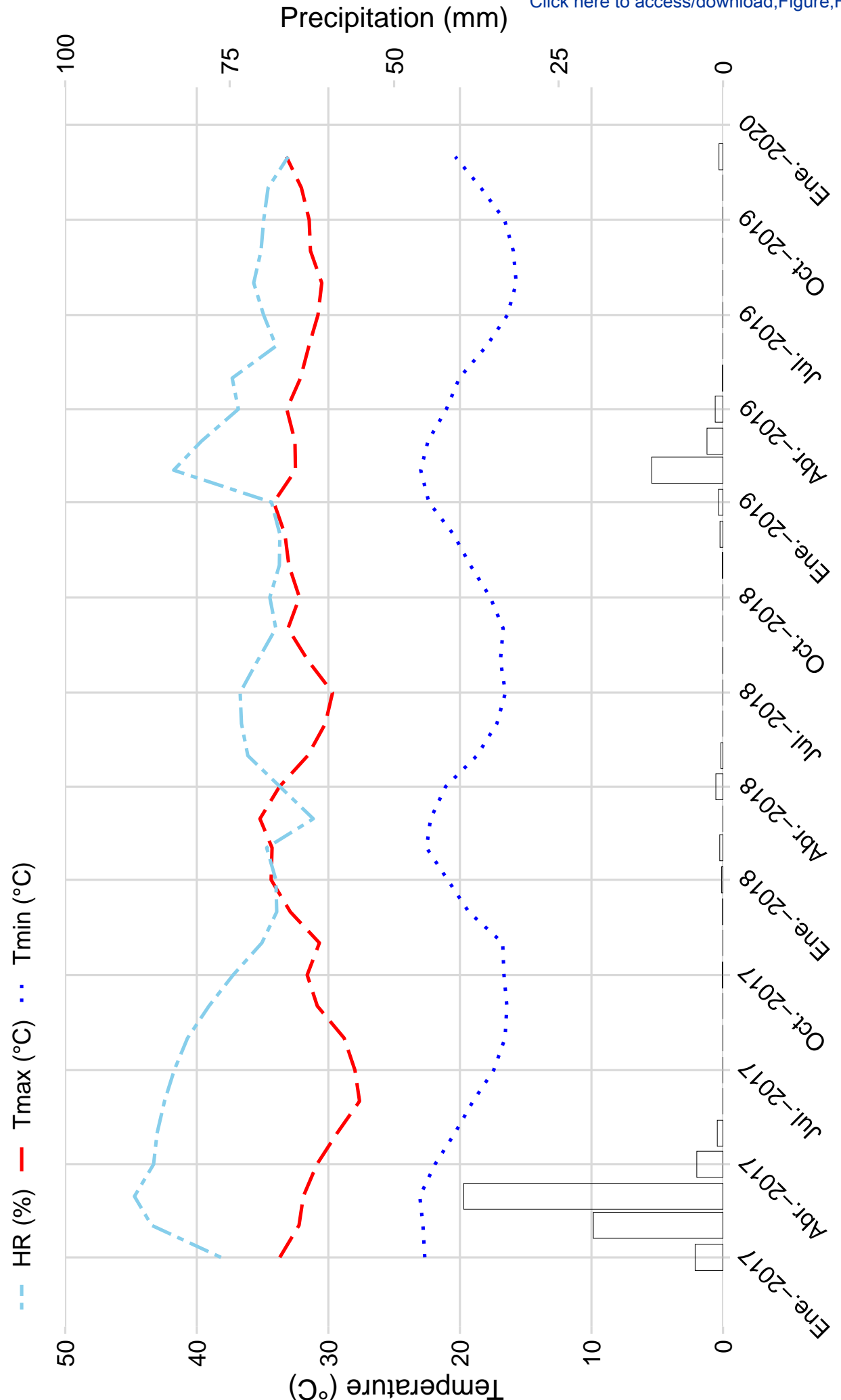
Figure 2

Figure 3

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Figure 4

a

b

c

d

Figure 5

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