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Research Article

Effect of Planting Density on the Agronomic Performance and Fruit Quality of Three Pineapple Cultivars (*Ananas comosus* L. Merr.)

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Pineapple is a crop of great importance for the economic stability of a large number of Peruvians; however, in areas experiencing low degrees of technological intervention, farmers generally adopt low planting densities. The objective of this study was to determine the effect of three plantation densities (35700, 47600, and 55500 plants ha^{-1}) on the agronomic performance and fruit quality of three pineapple cultivars ("Golden," "Smooth Cayenne," and "Santa Rosa" ecotype). The experiment was performed under a randomized complete block design (RCBD) in a factorial arrangement, and the data were subjected to analysis of variance and the Tukey test ($p < 0.05$). The results show significant differences in terms of plant height and D-leaf length, with "Golden" being the cultivar that achieved the best performance at the three planting densities. The diameter (11.77–13.29 cm) and weight of the fruit without a crown (1.48–1.85 kg) were not affected by the treatments; in contrast, the length and weight of the fruit with a crown did exhibit significant variations, highlighting the "Smooth Cayenne" cultivar and "Santa Rosa" ecotype at a density of 55500 plants ha^{-1}, respectively. The highest estimated yield (>100 t ha^{-1}) for the three pineapple cultivars was recorded at a density of 55500 plants ha^{-1}. The content of total soluble solids was higher in the "Golden" cultivar, but in general, all the fruits exceeded the established standards. Based on the results, it is recommended that farmers in the area and those with similar conditions establish a planting density of 55500 plants ha^{-1} because it improves the yield without damaging the quality of the fruit of the pineapple cultivars evaluated.

1. Introduction

The pineapple (*Ananas comosus* L. Merr.), originally from South America, is the most representative plant in the family Bromeliaceae. This tropical fruit is in great demand on the market and widely cultivated around the world; the principal pineapple-producing countries are Costa Rica, Philippines, Brazil, Thailand, and Indonesia [1]. This fruit is a rich source of phenolic compounds (flavonoids, carotenoids, and hydroxycinnamic acids) and is traditionally employed in dietary formulations for the prevention and management of cardiovascular and neurodegenerative diseases [2, 3].

In Peru, in 2019, the harvested area covered 15847 ha, and 567477 tons of pineapple were produced [4]. In the same year, a large portion of Peru's production was concentrated in the regions of Junín (77%), La Libertad (4%), and Loreto (3.5%), yielding an average of 37.2 tons per hectare [4]. In general, pineapple production has grown consistently around the country and has great socioeconomic importance as it generates employment and substantial income in favor of a large number of small producers.

However, in the Santa Rosa district (a producing area located in the Amazon region of northern Peru), pineapple production faces serious agricultural challenges due to the presence of pathogens and poor agronomic monitoring of the crop. Among the aforementioned factors is the adoption of sowing densities (<25000 plants ha^{-1}) has not adjusted to technological packages, as they take advantage of the crop's potential and the soil and climate conditions of the area; therefore, it generates a low production volume [5]. This deficiency causes important losses, mainly of which are to small farmers who cultivate this fruit as their main source of economic income.

An adequate sowing density depends, among other factors, on the type of crop, product target, level of mechanization, use of irrigation, or precipitation [6]. Importantly, high sowing densities of up to 70000 plants per hectare ensure a higher tonnage per unit area; conversely, lower densities generally allow larger fruits with higher market prices [6,7]. In this way, the economic profitability of the plot is related to selecting appropriate sowing densities, rationally using inputs, and soils with characteristics that meet the requirements of pineapple cultivation [7–9] because a high level of production and good fruit quality depend on these factors.

In addition, plant spacing in pineapple cultivation can influence plant growth, fruit development, and performance as a result of competition for nutrient, water, and light sources. In the study area, farmers have developed agricultural practices that follow ancient production trends; therefore, it is important to study agronomic practices that are adjusted to local conditions and those that improve pineapple production. In this context, the objective of the study was to determine the agronomic behavior and fruit quality of three pineapple cultivars ("Golden," "Smooth Cayenne," and "Santa Rosa" ecotype) in response to different spacings between plants, with the aim of determining the appropriate planting density to maximize yields and ensure the harvest of quality fruits.

2. Materials and Methods

2.1. Study Area. The field experiment took place from August 2016 to July 2018 in the district of Santa Rosa, Rodríguez de Mendoza Province, located in northern Peru. The experimental area is located between coordinates 6° 26′ 59.104″ south latitude and 77° 26′ 58.937″ west longitude with an altitude of 1832 meters above the sea level.

The study area does not present differentiated climatic seasons, but it is characterized by temperatures between 15°C and 22°C and rainfall over 1300 mm per year. During the experimental period, the average temperature was 17.97°C (with a cold period between August and November 2017), and the precipitation varied between a minimum of 40.50 mm in October 2016 and a maximum of 351.20 mm in May 2017 (Figure 1, data recorded by an OREGON Automatic Weather Station model WMR300PU).

The analysis of the physical and chemical properties of the soil was carried out in the Soil and Water Laboratory of the Instituto de Investigación para el Desarrollo Sustentable de Ceja de Selva (INDES-CES) of the Universidad Nacional Toribio Rodríguez de Mendoza de Amazonas (UNTRM). Twelve subsamples were collected at a depth of 0–20 cm, which were subsequently mixed and homogenized to obtain a single representative sample of the soil of the experimental area. The properties of the soil were a sandy loam texture, a pH of 4.74, an organic matter content of 6.67%, a P content of 2.83 ppm, a K content of 253.15 ppm, a cation exchange capacity (CEC) of 9.60 meq/100 g), and a base saturation of 37%. In relation to Ca and Mg, the soil presented contents of 2.15 and 0.41 meq/100 g, respectively.

2.2. Experimental Management. We used the suckers (250–350 g) of cultivars "Golden or MD2," "Smooth Cayenne," and "Santa Rosa" ecotype that were collected from nearby plots. The propagation material was disinfected in a fungicide solution (benlate 500 g 200 L^{-1} + fosetyl-Al 200 g 200 L^{-1}) and an insecticide solution (Prethor® 400 ml 200 L^{-1}) for 5 minutes and then immersed in a hormone solution (Root-Hor® 250 ml 200 L^{-1}). After 7 days (healing period), they were sown in a plot to which we had previously applied agricultural lime (3 t ha^{-1}), island guano (2 t ha^{-1}), and phosphate rock (1 t ha^{-1}).

It was fertilized by localized applications (per plant) of 4.2 g of urea (46% N), 1.3 g of diammonium phosphate (18% N and 46% P_2O_5), and 1.4 g of potassium chloride (60% K_2O); these applications were made from the second to the tenth month of sowing, with a frequency of 2 months. In addition, 3 foliar applications were made (fifth, seventh, and ninth months after sowing) with Nitrosol Hoja® (5 ml L^{-1}) and Fitobolic® (1.5 ml L^{-1}). Phytosanitary management took place from the vegetative phase to the reproductive phase (preflowering) with applications of chlorpyrifos (2 ml L^{-1} every 8 days) and copper sulfate pentahydrate (4 ml L^{-1} every 21 days), which were varied according to the incidence of pests or diseases. Flower induction (TIF) was performed out 11 months after sowing (July 2017); therefore, we prepared a solution of ethephon (1.5 ml L^{-1}), urea (25 g L^{-1}), and boron (1 g L^{-1}). To prevent fruit fly damage (*Melanoloma viatrix*), the fruit was bagged when we noticed the last flowers (January 2018) (Figure 2). Harvesting began in April and lasted until July 2018. Regarding weeding, a manual process was adopted throughout the growth stage of the crop.

2.3. Data Collection. The evaluated variables were plant height (cm), number of young leaves, D-leaf length (cm), fruit length (cm), average fruit diameter (cm), total fruit weight (+crown) (kg), commercial fruit weight (−crown) (kg), crown weight (kg), total soluble solid content (°Brix), and fruit extract pH. The total soluble solid content and pH were determined using a Pocket PAL-3 refractometer (Atago, Japan) and a HANNA HI2216 digital potentiometer (Hanna, USA), respectively. Data were collected from 16 central plants/fruit from each experimental unit. Furthermore, we determined the yield (t ha^{-1}), for which we used the average weight of the fruit and the density of sowing.

2.4. Experimental Design. The experiment was arranged under a randomized complete block design (RCBD) in a

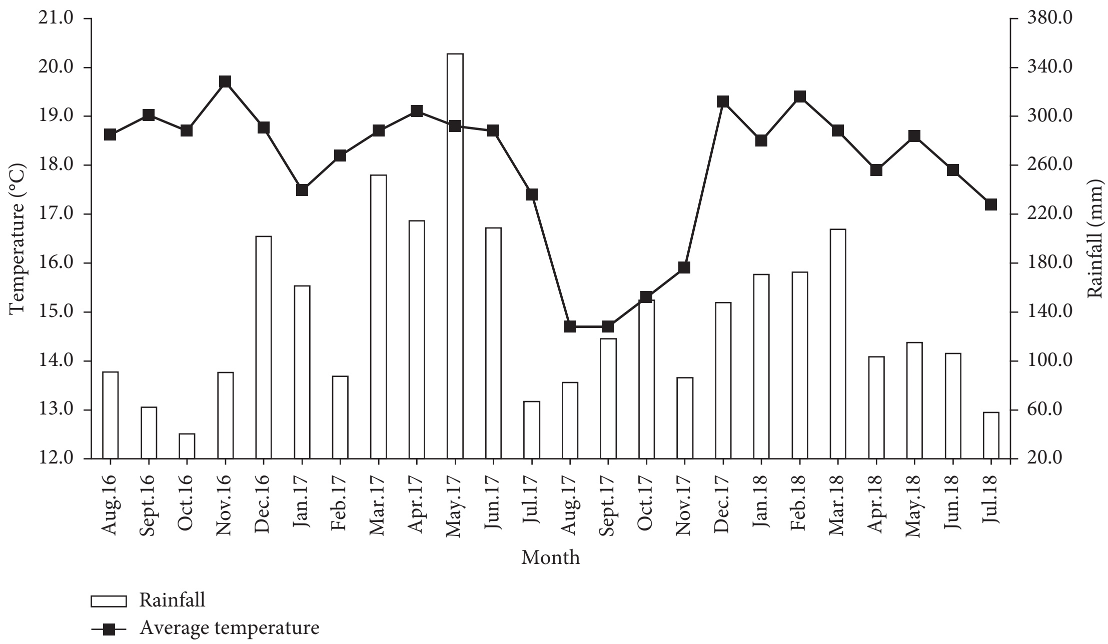


Figure 1: Monthly mean temperatures and rainfall from August 2016 through July 2018.

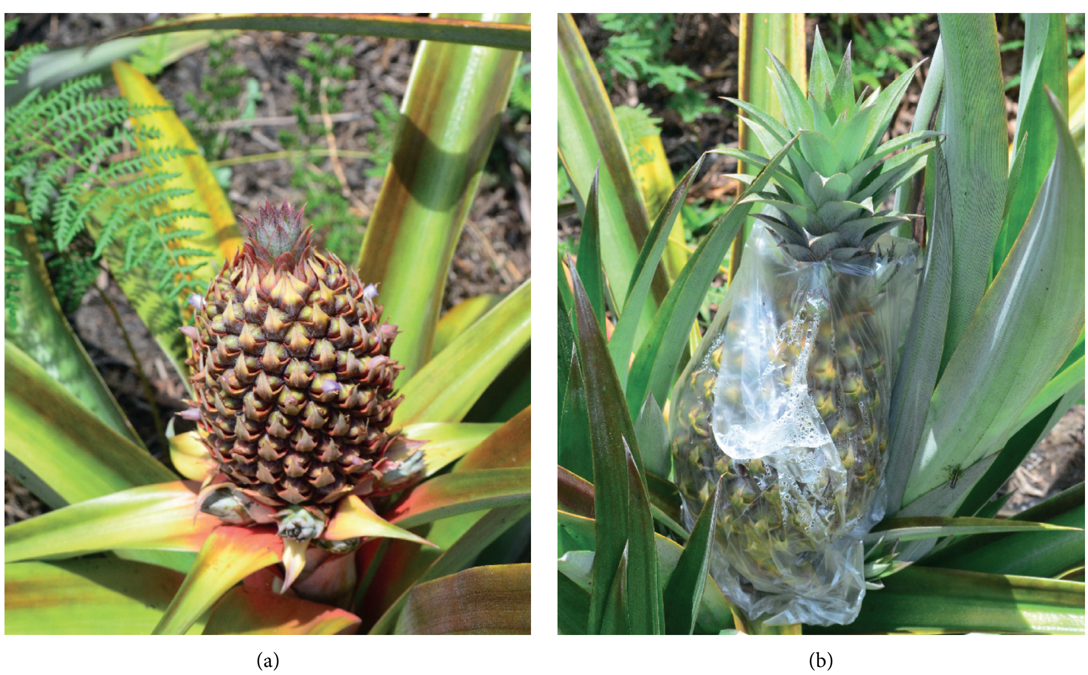


Figure 2: Physical control of fruit flies. (a) Last flowers present prior to the (b) bagging of pineapple fruit.

factorial arrangement with three repetitions. The treatments consisted of a combination of three planting densities (35700, 47600, and 55500 plants ha^{-1}) and three pineapple cultivars ("Golden," "Smooth Cayenne," and "Santa Rosa" ecotype). The experimental unit consisted of 144 plants distributed in 6 rows. It was planted in a double-row system taking into account distances between plants, rows and ridges of (a) $0.4 \times 0.4 \times 1$ m, (b) $0.3 \times 0.4 \times 1$ m, and (c) $0.3 \times 0.4 \times 0.8$ m, therefore, forming densities of 35700, 47600, and 55500 plants per hectare, respectively.

2.5. Statistical Analysis. The data were processed using analysis of variance (ANOVA), and the means were compared using the Tukey test ($p < 0.05$). We analyzed the data in the statistical software InfoStat version 2017.

3. Results

3.1. Morphological Characteristics of the Plant. After 10 months of planting, we evaluated the morphological characteristics of the crop. Our analysis indicates that the interaction of factors (cultivar x planting density) had a significant effect ($p < 0.05$) on plant height and D-leaf length, while the number of young leaves was not affected by the treatment. Table 1 shows that the "Golden" cultivar grew to the highest plant height (60.15 cm) and D-leaf length (64.83 cm) at a density of 35700 ha^{-1}, but regardless of the density of planting, it was the best performing cultivar for these variables; in fact, it exceeded the average of the treatments with the "Smooth Cayenne" cultivar and "Santa Rosa" ecotype. Although the number of young leaves did not differ significantly, Smooth Cayenne showed the highest number of leaves compared to the "Golden" cultivar and "Santa Rosa" ecotype.

3.2. Physicochemical Characteristics of the Fruits. Figure 3 illustrates the physical characteristics of the pineapple fruit of the three cultivars. The harvested pineapples were sown under three different sowing densities. As a result, data analysis indicated that the factors significantly ($p < 0.05$) influenced the fruit characteristics, with the exception of the diameter and weight of fruit without crowns (Table 2). As shown in Table 2, the fruit length ranged from 15.41 cm to 17.86 cm, where the highest values were recorded with the "Smooth Cayenne" cultivar at densities of 35700 and 55500 plants ha^{-1}, while the "Santa Rosa" ecotype had the lowest average at a density of 35700 plants ha^{-1}. In terms of the total fruit weight (+crown), the results indicate that fruits of the "Santa Rosa" ecotype were slightly heavier than those of the "Golden" and "Smooth Cayenne" cultivars. The fruit weight without crown (1.48–1.85 kg) and fruit diameter (11.77–13.29 cm) did not differ significantly between treatments but was noted that the fruits of the "Santa Rosa" ecotype were slightly weightier and had a larger diameter. Regarding the crown weight, "Golden fruits" had the heaviest crowns (0.19–0.22 kg), followed by "Santa Rosa" (0.18–0.19 kg) and "Smooth Cayenne" (0.12–0.17 kg).

The visual appearance of the pineapple cuts shows clear variation in flesh color among cultivars (Figure 4). Furthermore, in Figure 3, the core diameter of the fruit also differs; the "Santa Rosa" ecotype, for example, has a larger core diameter, followed by "Smooth Cayenne" and "Golden" (not shown). In general, both parameters may be considered indicators of the quality and acceptability of the fruit.

The chemical characteristics of the fruits are shown in Table 3. The results indicate that the total soluble solids content (°Brix) and pH of the juice varied significantly across the treatments ($p < 0.05$). For example, the total soluble solid contents (°Brix) were higher in treatments with "Golden" than in treatments with the "Santa Rosa" ecotype. The maximum pH value (3.61) was recorded in fruits of the "Santa Rosa" ecotype grown at a density of 47600 plants ha^{-1}, while the lowest values were found in the "Golden" cultivar.

3.3. Estimated Crop Yield. Table 4 shows significant differences ($p < 0.05$) for performance. The results indicate that there is a direct proportional relationship between planting density and yield, that is, yield increased as the number of plants per unit area increased, which was observed independently of the cultivar. In general, the estimated yield at a density of 55500 plants ha^{-1} was greater than 100 t ha^{-1}, while at a density of 35700 plants ha^{-1}, it was less than 70 t ha^{-1} (Table 4).

4. Discussion

4.1. Plant Growth Parameters. Our results show that plant height and D-leaf length differed significantly between treatments. However, "Golden," regardless of the planting density, expressed the best levels of these variables, suggesting that pineapple growth performance is influenced by the variety. Similar results were reported by Hung et al. [10], in which increased planting densities (between 57000 and 78000 plants ha^{-1}) did not influence the growth of "Smooth Cayenne." On the other hand, Delgado-Huertas and Arango-Wiesner [11] indicated that "Mitú" showed better growth than "Golden" and "Smooth Cayenne." In general, our results reveal that the genetic differences inherent to each cultivar have a strong influence on crop development. Nevertheless, the technical level of agricultural practices can significantly influence the expression of the crop's genetic potential [7, 12]. The records of the morphological characteristics of the pineapple plants reported in this study are lower than the values reached by "Queen" cultivar cultivated in three different ecosystems (freshwater peat, brackish peat, and alluvial soil), as they reached a height greater than 80 cm and D-leaf lengths over 65 cm [13]. The quantification of these morphological characteristics (including the number of leaves) is of great importance in pineapple cultivation because they are related to photosynthetic efficiency and fruit development [12–14].

Another key factor to be considered is climate conditions, which have a great influence on the growth of pineapples. Variations in temperature can lead to differentiated growth in pineapple plants [15], which may be affected when temperatures are below 15°C or above 32°C [16–18]. In general, a suitable temperature for pineapple growth is between 20°C and 30°C [16], but for optimal crop development, the temperature should be between 25°C and 32°C during the day and between 15°C and 20°C at night [19]. Therefore, temperature is a crucial factor for the successful development of crops and determines the suitable area for cultivation worldwide [15].

In this context, it is important to take into account climatic factors such as altitude and topography due to their association with temperature and solar irradiation parameters that are essential for crop growth and fruit development [20–22]. A high altitude together with cold nighttime temperatures may result in erect, straight, rigid, short, and less numerous leaves; in contrast, in hot (with temperatures above 25°C) and humid climates, prevalent in low altitude areas, leaves are numerous, wide, and flaccid [23, 24]. In this regard, pineapples can be cultivated up to 1800 m a.s.l.

Table 1: Effect of sowing density on the growth parameters of three pineapple cultivars.

Treatments Cultivar	Planting density (plants ha^{-1})	Plant height (cm)	Number of leaves	D-leaf length (cm)
	35700	60.15^{a}	16.48^{a}	64.83^{a}
Golden	47600	57.48^{ab}	16.15^{a}	60.04^{abc}
	55500	57.21^{abc}	16.69^{a}	61.46^{ab}
	35700	48.00^{e}	17.44^{a}	52.81^{d}
Smooth Cayenne	47600	54.10^{bcd}	17.08^{a}	53.54^{d}
	55500	50.19^{de}	17.46^{a}	55.73^{bcd}
	35700	51.88^{cde}	15.00^{a}	57.88^{bcd}
Santa Rosa ecotype	47600	50.00^{de}	15.02^{a}	54.29^{cd}
	55500	50.75^{de}	15.04^{a}	55.10^{cd}
CV (%)		15.82	10.03	17.23

Means with different letters in the same column indicate significant differences (Tukey, $p < 0.05$).

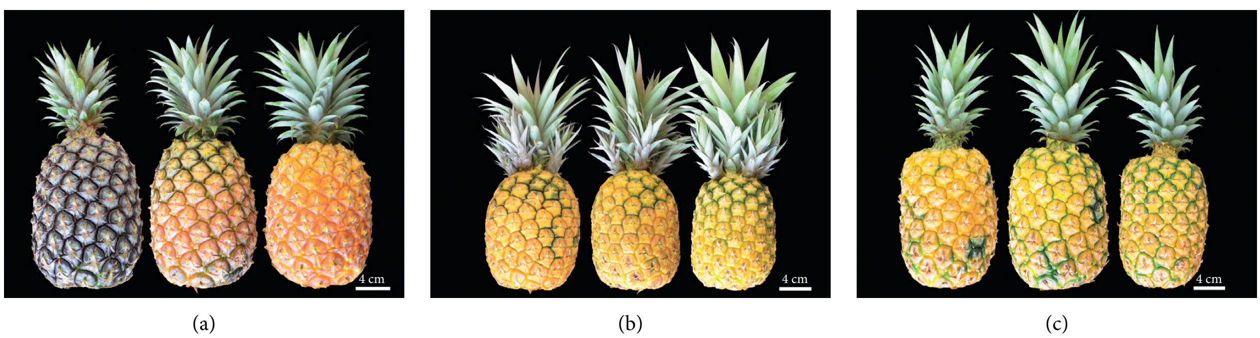


Figure 3: Fruits of the three pineapple cultivars harvested from established crops under three different sowing densities. (a) Smooth Cayenne, (b) Santa Rosa ecotype, and (c) Golden.

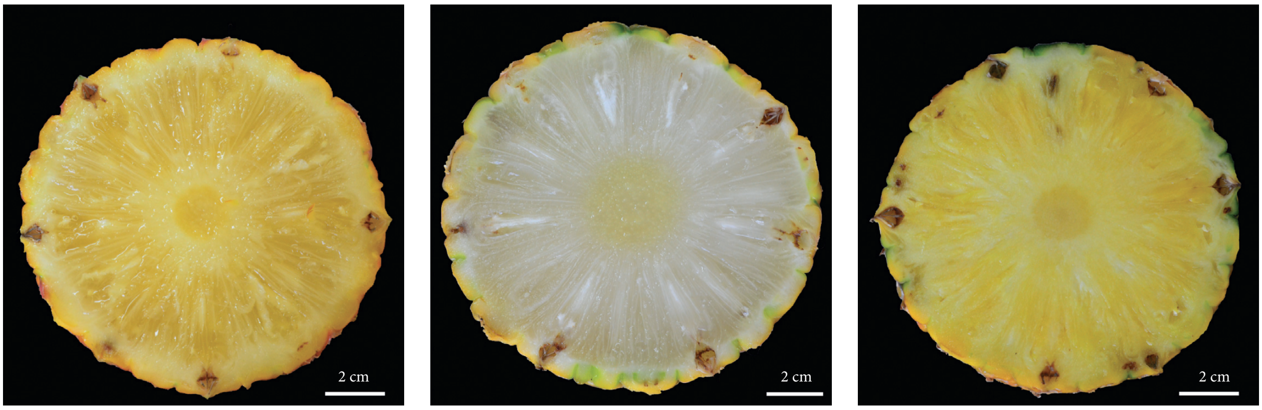
Table 2: Effect of sowing density on the physical characteristics of three pineapple cultivars.

Treatments Cultivar	Planting density (plants ha^{-1})	Fruit length (cm)	Fruit weight (kg) (+crown)	Fruit weight (kg) (−crown)	Crown weight (kg)	Average fruit diameter (cm)
	35700	15.89^{bc}	1.69^{c}	1.48^{a}	0.21ab	11.77^{a}
Golden	47600	16.74^{ab}	1.88^{ab}	1.66^{a}	0.22^{a}	12.04^{a}
	55500	16.73^{ab}	1.83^{bc}	1.64^{a}	0.19^{bc}	11.98^{a}
	35700	17.86^{a}	1.80^{bc}	1.67^{a}	0.13^{d}	11.97^{a}
Smooth Cayenne	47600	17.03^{ab}	1.83^{bc}	1.66^{a}	0.17^{c}	11.87^{a}
	55500	17.84^{a}	1.91^{ab}	1.79^{a}	0.12^{d}	12.22^{a}
	35700	15.41^{c}	1.92^{ab}	1.73^{a}	0.18^{bc}	13.29^{a}
Santa Rosa ecotype	47600	16.21^{bc}	1.89^{ab}	1.71^{a}	0.18^{bc}	13.26^{a}
	55500	16.28^{bc}	2.04^{a}	1.85^{a}	0.19^{bc}	13.28^{a}
CV (%)		9.51	12.97	14.61	19.70	4.98

Means with different letters in the same column indicate significant differences (Tukey, $p < 0.05$).

However, at this elevation, pineapple fruits can be more acidic; in contrast, low temperatures contribute to improving the quality of the fruit (uniform size) and induce flowering [25].

In addition, for productive areas without irrigation systems (e.g., this study area), rainfall exerts a great contribution. However, pineapple has botanical and physiological characteristics that give it tolerance to long periods of drought [26, 27]. Nevertheless, according to Généfol et al. [7], scarce and erratic rainfall may become a limiting factor for the development of pineapple; therefore, the density of sowing may have an important contribution due to the retention of humidity around the plant. In this context, according to Paull and Duarte [19], the optimal rainfall for pineapple cultivation should be in the range of 1000–1500 mm per year; its importance should not be measured by its total accumulation but rather by its distribution throughout the year. In general, the meteorological



(a) (b) (c)

Figure 4: Comparison of the pineapple cuts of (a) Smooth Cayenne, (b) Santa Rosa ecotype, and (c) Golden.

Table 3: Fruit chemical characteristics of three pineapple cultivars grown at different sowing densities.

Cultivar	Treatments Planting density (plants ha^{-1})	Total soluble solids (°Brix)	Juice pH
	35700	15.25^{a}	3.25^{c}
Golden	47600	14.46^{a}	3.26^{bc}
	55500	14.31^{a}	3.39^{abc}
	35700	12.84^{bc}	3.45^{abc}
Smooth Cayenne	47600	13.95^{ab}	3.42^{abc}
	55500	12.87^{bc}	3.54^{a}
	35700	12.09^{c}	3.51^{ab}
Santa Rosa ecotype	47600	12.21^{c}	3.61^{a}
	55500	12.12^{c}	3.48^{abc}
CV (%)		8.82	6.24

Means with different letters in the same column indicate significant differences (Tukey, $p < 0.05$).

Table 4: Estimated yield of three pineapple cultivars grown at different planting densities.

Cultivar	Treatments Planting density (plants ha^{-1})	Yield (t ha^{-1})
	35700	60.25^{c}
Golden	47600	89.61^{abc}
	55500	101.57^{ab}
	35700	64.23^{c}
Smooth Cayenne	47600	87.31^{abc}
	55500	106.27^{a}
	35700	68.37^{bc}
Santa Rosa ecotype	47600	90.12^{abc}
	55500	113.18^{a}
CV (%)		12.28

Means with different letters in the same column indicate significant differences (Tukey, $p < 0.05$).

conditions of the study area meet crop needs; moreover, it is a potentially important area for the commercial development of pineapple cultivation.

4.2. Physicochemical Characteristics of the Fruit. The evaluation of a pineapple's physicochemical parameters is not only of commercial importance but also of agroindustrial importance since they have an impact on the yield and determine the fruit's quality for processing. In commercial terms, the size and weight of the fruit are factors of great importance owing to the preference of consumers who prefer large fruits [28]. This market characteristic could mean compensation for the establishment of lower densities because they generally favor the development of fruits with better sizes and higher prices [7, 9]. However, achieving acceptable and desirable fruit characteristics for the consumer is the sum of various factors, such as crop management strategies and climatic conditions, as well as the availability of soils with optimum pH values. The latter is directly related to the availability of nutrients, which are required for plant growth and fruit formation [29, 30].

The fruit weight (+crown) presented significant variations according to the treatment, with values ranging from 1.69 kg to 2.04 kg per fruit. However, at the three plantation densities, the "Santa Rosa" ecotype showed a higher fruit weight (+crown), even though the commercial weight (−crown) was statistically the same across all treatments. Based on the commercial weight, pineapple fruits can be classified into three categories: category A (>1.7 kg), category B (1.3–1.6 kg), and category C (<1.3 kg) [9]. In this light, the "Santa Rosa" ecotype fruits (in the three densities) and "Smooth Cayenne" cultivar fruits (at 55500 plants) were classified as grade A, while the remaining fruits of other treatments were classified as grade B. The average weight of the fruits harvested in this study was higher than the weight reported for "Golden" pineapple fruits grown at densities of 50000 (1.61 kg) and 70000 (1.51 kg) plants ha^{-1} [7], also exceeding the weight of "Smooth Cayenne" fruits (<1.64 kg) harvested from a cultivation system associated with cassava plants [14].

On the other hand, the results clearly show that yield is strongly influenced by sowing density, a factor that naturally enables a greater number of fruits to be harvested. Similar results were reported by Leon and Kellon [8] who indicated that the yield (cv. "Golden") was greater at higher planting densities, notwithstanding having no effect on fruit weight (1.5–2 kg). Establishing high planting densities, between 50000 and more than 70000 plants per hectare, aims to obtain better yields to satisfy the growing demand for pineapple fruit and consequently increase profits [10, 31]. Conversely, low planting densities (close to 30000 plants ha^{-1}) are an alternative to low-input, mechanized systems [32]. In fact, when using high densities, manual practices are often difficult and impractical. Regarding fruit length, the results obtained are close to the values reported in other studies [12, 30]. In contrast, the diameter of fruits harvested in this study exceeds that reported for fruits of pineapple "Queen" cultivar, whose values were less than 10 cm [13].

Both the total soluble solid content (°Brix) and juice pH showed significant differences between treatments, but the cultivar with the highest TSS and lowest juice pH was that of "Golden." Notably, the values of these parameters were close to reported data on pineapple chemical characteristics throughout the experiment [12, 33]. Importantly, the TSS content and juice pH can be influenced by the ripening stage of the fruit and the harvesting season [33–36]. These factors can be used to determine the harvest time and manage the seasonality of the crop. In this study, the fruits presented pH values (3.25–3.54) lower than those reported in pineapple "Sarawak" cultivar (3.88) [36] and TSS (12.09–15.25) values lower than those registered in the "Golden" cultivar grown under different seedbed conditions (>16.80°Brix) [37]. However, the results demonstrated that the total soluble solids content exceeded the minimum acceptable content for fresh fruit markets (12°Brix) [34, 38], which together with pH are indicators of good quality of fruit sweetness and acidity [39, 40].

5. Conclusions

The results of the study show that increasing plantation densities (up to 55500 plants ha^{-1}) did not have significant effects on the weight (–crown) or diameter of pineapple fruits. The TSS contents and pH values of the harvested fruits varied due to the interaction of the cultivars and the sowing density, but in general, the fruits met the standards required for the market. Based on the results, it is recommended that farmers in the area increase their planting densities up to 55500 plants ha^{-1}, since it improves the yield of fruits ha^{-1} but without affecting the quality of the harvested fruit. On the other hand, the choice of the cultivar to be sown will be chosen by the farmer and the final market for production.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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