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Distribution of Fresh Pineapple (*Ananas comosus* MD-2) Biomass at Harvest of the Plant Crop Using Three Planting Materials

D. Zavala[1], H. Salas[1], J. Delgado[1], E. Corrales[2] and Mario Araya[3*]

[1]LIFE-RID/AMVAC LATAM, [2]Centro Agronómico Tropical de Investigación y Enseñanza-CATIE, [3]AMVAC Chemical Corporation

**Corresponding author*

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A B S T R A C T

In three propagative planting materials; stems shoots, slips and crowns, planted and grown in 20 L pots, the fresh pineapple (*Ananas comosus* MD-2) biomass was determined at harvest of the plant crop. Considering the main plant organs of the shoot system differences in weight of leaves ($P< 0.0001$), fruit ($P< 0.0001$) and stem ($P< 0.0001$) were found among planting materials. Plants coming from crowns showed lower weight of the three variables, differing from plants originating from slips and stem shoots, which were similar. Leaves weight varied between 2480.0 and 3527.5 g, fruit weight between 1264.0 and 1995.0 g, and stem weight between 553.0 and 868.5 g. Plant root weight that oscillated between 374.5 and 487.5 g was similar ($P= 0.0914$) among the three planting materials. For the stem shoots, a significant positive linear correlation was found between fruit and leaves weight ($r = 0.50$; $P= 0.0238$) and between root and leaves weight ($r= 0.76$; $P< 0.0001$). Also, a positive linear correlation for the crown plants was found between leaf and fruit weight ($r= 0.56$; $P= 0.0096$) as well as between root and leaves weight ($r = 0.74$; $P= 0.0001$). The plant organs-fractions contribution to the complete fresh plant biomass at harvest in descending order was: leaves between 2480.0 and 3527.5 g (between 49.4 and 50.1%), fruit between 1264.0 and 1995.0 g (between 25.6 and 28.8%), stem between 553.0 and 868.5 g (between 11.0 and 12.2%), roots between 374.5 and 487.5 g (5.2 and 8.1%), crown between 211.3 and 237.3 g (between 3.0 and 4.9%) and the slips between 11.3 and 94.0 g (between 0.2 and 1.2%). From the main plant organs-fractions (leaves, stem, fruit, roots), roots represent the smallest proportion but are responsible for anchorage, water and nutrients supply, and exchange of various growth substances with the shoots. This emphasizes the necessity to potentialize the maximum genetic expression of the root system of the planting material as well as maintaining its health and conservation. It is known that the pineapple root growth decreases after flower induction, with the maximum root mass reached at anthesis. On the other hand, pineapples roots do not regenerate or produce again if damaged or attacked by pests and diseases, and for those who run the plantation for one or two ratoon crops, it is essential to understand this fact, since their yield depends on the original root system developed during the plant crop.

Introduction

Pineapples (*Ananas comosus* MD-2) is an herbaceous, perennial, self-sterile, monocotyledonous plant that is cultivated in Costa Rica for fresh fruit export markets and is normally eaten as a dessert. Pineapple is also used as an ingredient in a wide range of foods, as a meat tenderizing agent, for medicinal purposes and for flavor and sweetener in alcoholic beverages. It is the second most important crop in Costa Rica after banana, with a planted area in 2023 of 53,000 ha (CANAPEP 2026), giving a total income in 2025 of US$ 1400 million (La República 2026). It is commercially produced locally for two harvests since the deterioration of the root system and declining of plants produces a reduction in fruit size and uniformity, resulting in yield profitability loss and compromising subsequent crop cycles. Three vegetative propagative materials are commonly used; stem shoots (suckers), slips and fruit crowns. Normally, growers prefer stem shoots as planting material, because of their higher development (more weight), availability and shorter crop cycle, followed by slips. The least preferred are fruit crowns, because even though it is mentioned that they emit more roots, they tend to be more susceptible to foliage diseases and take longer to reach harvest.

Growth is an irreversible increase in mass, weight or volume of a living organism, in its advancement towards maturity. Growth is achieved mainly as a result of photosynthesis with the reductions of respiration (Singh and Vaishya 2022). Growth analysis is a tool for determining, indirectly, a plant's photosynthetic efficiency, because it studies the ratio of leaf area to total biomass and the relative proportion of energy invested in producing the plant's different organs-sections. Then, being aware of the biomass partitioning in pineapple becomes essential for understanding the crop's growth and development, as well as for optimizing its production. Therefore, the present investigation evaluated and compared the fresh biomass of pineapple plant organs at harvest of the plant crop from three propagative materials grown outdoors in pots. The objective of this work is to provide information to aid in the knowledge of pineapple as ingredients for good agronomic management strategies to improve yield.

Materials and Methods

The experiment was set up in an open field area located at the Guácimo county, in the Limón province at an altitude of 67 meters above sea level, Costa Rica. Plastic pots of 33 cm diameter by 29 cm heigh, with four drainage holes of 1 cm-d in the bottom that fit a soil volume of 20 L were filled with soil from a commercial pineapple plantation and layout in a double-row block for each planting material (Figure 1A). Each planting material was grown separately, and no statistical design was used. The soil had 2.09% organic matter, a pH of 5.7, and extractable cations using Mehlich 3 extractant (Mehlich 1984): Ca 2.1, Mg 0.23, and K 0.05 $cmol^{(+)}\ L^{-1}$, and P 2.0, Zn 3.5, B 0.53, Cu 1.2, Fe 64.0, and Mn 54.0 mg ml^{-1}. The soil had a loamy sand texture (81% sand, 7% clay and 13% silt).

The propagative pineapples (*Ananas comosus* MD-2) material were stem shoots or suckers of 533 ± 5.6g, slips of 555 ± 7.7 g and crowns of 224 ± 7.6 g that were manually planted in each of the 20 pots (repetitions) for each planting material. As usual, the total water requirement was supplied by rainfall having an accumulated rainfall (February 2024 - March 2025) of 4310 mm evenly distributed throughout the period. April and March were the driest months with 127 and 241 mm, respectively. Mean daily maximum/minimum temperatures were 29.9/21.9 ºC.

Custom made 25-8-5-1.5-0.2-0.5-1.5-0.5 (N-P_2O_5-K_2O-MgO-B-Ca-S-Zn) granular fertilizer was applied at 8 g by pot 30 and 60 days after planting. Thereafter, every 15 days a mix of nutrients using a calibration of 2000 L of solution by hectare during the first six months and after in 4000 L of solution per hectare were applied with a simulating a spray boom (Figure 1B) application. The rate was adapted to the needs of the soil and the crop to complete 601.4 kg N, 147.6 kg P_2O_5, 529.2 kg K_2O, 76 kg MgO, 133.3 kg CaO, 119.3 kg S, 13.5 kg B, 8.5 kg Zn, 8.2 kg Fe and 1 kg Cu per hectare for the crop cycle. Weeds were controlled manually during the experimental period. The diseases were managed with applications of systemic and protective fungicides. These management practices (weed control, fungicide and fertilizer applications) were applied uniformly to the three planting materials.

Flower induction was done 266 days after planting with the following mixture: urea 46% N 1.25 kg ha^{-1} + 2.2 L Etephon 48SL ha^{-1} + Dewdrop 0.6 L ha^{-1} in 4000 L solution ha^{-1} and Greenplants B was added to raise the solution pH to 8. At harvest, 146 days after forcing, each plant was removed from the pot (Figure 2C-D) and placed in 1 m^2 metal table with a square metal mesh of 0.5 x 0.5 cm to wash the root system with a pressure washer (Figure 1E-F). Then, the organ or plant parts (roots, leaves, fruit, crown, stem, slips) by plant-repetition and planting material, were separated (Figure 2A) and left to dry off all remaining superficial water and weighed on a Pretul scale of 3 ± 0.001 kg (Figure 2B-F). After washing the root system of each plant, all the roots present on the square mesh were collected and weighed together with the root system of each plant. The number of green and dry leaves as well as the slips close to the fruit of each plant were registered. The axillary roots (Carr 2012, Sinclair 1993) from 10 stems of each planting material were removed and weighed on a Mainstays digital scale of 1 kg ± 1 g.

Weight data of each pineapple plant part (green leaves, dry leaves, fruit, stem, roots, axillary roots, crown and slips weight) as well as the number of green and dry leaves were submitted to ANOVA comparing the planting materials and mean separation by LSD. Then, each pineapple plant part weight (green leaves, dry leaves, fruit, stem, roots, crown and slips) was submitted to ANOVA withing each planting material and mean separation by LSD. A 95% confidence interval was estimated for the average percentage of root weight relative to the total biomass. The distribution assumptions of the error (normality and homogeneity of variance) were verified by analyzing the diagnostic graphs. The number of slips at harvest was analyzed with a generalized model approach, using the Poisson distribution function and logarithmic link function and mean separation by LSD. To validate the model fit, the ratio of the deviation to the residual degrees of freedom was calculated. A Pearson correlation analysis of fruit weight with root and leaves weight was run for each planting materials. All data were analyzed in Navure software.

Results and Discussion

Differences in weight of leaves ($P< 0.0001$), fruit ($P< 0.0001$), stem ($P< 0.0001$), and slips ($P< 0.0001$) were found among planting materials (stems, slips and crowns). In the four variables, the difference was related to the lower weight in the crowns differing from slips and stem shoots, which were similar. Leaves weight varied between 2480.0 and 3527.5 g, fruit weight between 1264.0 and 1995.0 g, stem weight between 553.0 and 868.5 g and slip weight between 11.3 and 94.0 g (Figure 3A, B, C and 4E). Plant root weight that oscillated between 374.5 and 487.5 g was similar ($P= 0.0914$) among planting materials (Figure 3D). Also, crown weight was similar ($P= 0.1226$) among planting materials varying between 211.3 and 237.3 g by plant (Figure 3E).

Axillary roots differed ($P< 0.0001$) among planting materials at harvest of the plant crop with the highest amount in the plants coming from stem shoots with 22.0 g, followed by slips with 15.6 g and lastly the crown with 3.52 g by plant (Figure 4A). Axillary roots represented 0.85, 3.1 and 5.55% of the total roots (soil or adventitious roots + axillary roots) for crowns, slips and stem shoots, respectively. The number of green ($P= 0.2057$) and dry ($P= 0.2151$) leaves at harvest was similar among planting materials and varied between 42.5 and 48.0 and between 3.9 and 5.7 by plant, respectively (Figure 4B, C). The number of slips was lower ($P= 0.0223$) in the plants originated from crowns with 0.4 vs 1.4 in the other (stem and slips) planting materials (Figure 4D). Correspondingly, the weight of these slips was lower ($P< 0.0001$) in the plants originated from crowns with 11.3 g vs 94.0 g in the stem shoots and 85.0 g in the slips (Figure 4E).

In the three planting materials, the plant organ biomass distribution followed the same trend (Figure 5). The organ or plant part with the greatest contribution was the leaves varying between 2480.0 and 3527.5 g (between 49.4 and 50.1% of the total plant), followed by the fruit which varied between 1264.0 and 1995.0 g (between 25.6 and 28.8%). Then follows the stem which fluctuated between 553.0 and 868.5 g (between 11.0 and 12.2%). The roots contribution was between 374.5 (5.2%) and 487.5 g (8.1%) of the total plant biomass. The proportion of the crown varied between 211.3 and 237.3 g (between 3.0 and 4.9%) and the slips between 11.3 and 94.0 g (between 0.2 and 1.2%).

For the plants coming from stem shoots, a significant positive linear correlation was found between fruit weight and leaves weight ($r = 0.50$; $P= 0.0238$) and between root weight and leaves weight ($r= 0.76$; $P< 0.0001$). Also, a positive linear correlation for the crown plants was found between leaf weight and fruit weight ($r= 0.56$; $P= 0.0096$) as well as between root weight and leaves weight ($r = 0.74$; $P= 0.0001$). For the slips the correlations were non-significant.

In this pineapple (*Ananas comosus* MD-2) pot plants, the plant part contribution in descending order was: leaves between 2480.0 and 3527.5 g (between 49.4 and 50.1%), fruit between 1264.0 and 1995.0 g (between 25.6 and 28.8%), stem between 553.0 and 868.5 g (between 11.0

and 12.2%), roots between 374.5 and 487.5 g (5.2 and 8.1%), crown between 211.3 and 237.3 g (between 3.0 and 4.9%) and the slips between 11.3 and 94.0 g (between 0.2 and 1.2%). This plant part distribution pattern agreed with that of fresh biomass reported by Py *et al.,* (1987) using Smooth Cayenne of leaves 2000 g (38.8%), fruit 1850 g (35.9%), stem 530 g (10.3%), roots 350 g (6.8%), crown 300 g (5.8%), and slips 120 g (2.3%) and even thought it was not mentioned, looks like that data are also of pot plants at harvest of the plant crop.

A similar distribution pattern of fresh biomass was found in commercial field conditions in Costa Rican by Hernández and Tello de Gracia (2011) using stem shoots (suckers) of MD-2 as planting material. At harvest of the plant crop they obtained a weight of leaves of 3033.5 g (51.1%), fruit 1795.0 g (30.2%), stem 687.8 g (11.6%), crown 388.5 g (6.54%) and roots of 35.5 g (0,5%). In a similar work by Cruz (2012) in the pineapple production area of Sarapiquí, Costa Rica in two farms A and B, with stem shoots (suckers) of MD-2 the fresh biomass of each organ at harvest of the plant crop was calculated as follows: leaves 3400.0 (54.7%) and 3031.4 g (52.8%), fruit 1744.1 (28.0%) and 1741.9 g (30.3%), stem 600.0 (9.6%) and 517.6 g (9.0%), crown 220.0 (3.5%) and 174.7 g (3.0%), slips 167.6 (2.7%) and 176.2 g (3.0%) and roots with 82.4 g (1.3%) and 91.9 g (1.6%), for farm A and B, respectively. Herrera *et al.,* (2022) in plantations on Inceptisol and Ultisol soil in Costa Rica, found that the mean root content of the plant at 6-8 months of age was 22 g (Inceptisol) and 23.5 g (Ultisol) per plant and estimated that the proportion of roots with respect to the plant weight (between 2.5 to 3 kg) at flower induction (8 months) would be 0.8 and 0.9% of the total plant weight, respectively.

The plant organs-fractions distribution followed the same trend in the three planting materials only differing in values. Always the organ with the greatest biomass contribution was the leaves followed by the fruit. The total number of leaves (green + dry) was similar among planting materials and varied between 46.4 and 53.7 by plant and agreed with that reported by Coppens-d´Eeckenbrugge and Leal (2003, 2018) and Bartholomew (2018) of between 40 and 80 by plant and disagreed with Carr (2012) who reported between 70 and 80 by plant. The similar root weight among the pot plants from different planting materials contrasts with Py *et al.,* (1987), Coppens-d´Eeckenbrugge and Leal (2003, 2018), Bartholomew (2018) and Carr (2012) who mentioned that crowns produce more roots than slips or shoots without given values.

Considering that photosynthesis is the physico-chemical process by which the leaves of plants use light energy and assimilate CO_2 to drive the synthesis of organic compounds, it is essential to promote good plant growth and healthy leaf area which could represent up to 54% of the total plant. Once decided to establish the plantation in a specific location, virtually nothing can be done to improve the availability of solar energy and CO_2, two elements for which growers do not pay and do not increase the crop production costs. Leaf growth and development depend on the nutrients and water uptake, which occurs primarily through the roots. This organ contributed only between 5.2 and 8.1% of the total plant when developed in pots, while in field conditions, the contribution varied between 0,5 and 1,6%. Nutrients and water may represent between 15 and 25% of the total production costs depending on the access to irrigation and the fertilizers applied.

This emphasizes the necessity to potentialize the maximum genetic expression of the root system of the planting material as well as maintaining its health and conservation. It is known that the pineapple root system consists of about 100 main-primary roots (Godfrey 1936), from which a system of lateral roots (secondary and tertiary roots) develops, the latter being progressively thinner and shorter. It is fundamental to consider that the pineapple root growth decreases after flower induction, with the maximum root mass reached at anthesis (Malézieux *et al.,* 2003, Carr 2012, Bartholomew 2018).

Futhermore, pineapples roots do not regenerate or produce again if damaged or attacked by pests and diseases (Rohrbach and Apt 1986, Petty *et al.,* 2002, Rohrback and Johnson 2003, Umble *et al.,* 2006, Paull and Duarte 2011, Nurfadhilah *et al.,* 2012, Rabie 2017), which results in a relatively fragile root system as mentioned by Py *et al.,* (1987). For those who run the plantation for one or two ratoon crops it is essential to understand this, since their yield depends on the original plant crop root system as indicated by Bartholomew and Kadzimin (1977) and Carr (2012).

From the main plant organs-fractions (leaves, stem, fruit, roots), the roots represent the smaller proportion of biomass partition.

Figure.1 A-F. A) Distribution of the pineapple (*Ananas comosus* MD-2) plants of each planting material (stem shoots or suckers, slips and crown) in a double-row block in the experimental site, B) spray boom simulator used for the application of fertilizer solutions and the control of pests and diseases, C) state of the plants at harvest, D) observation of the root system at harvest, E) washing of the root system with a pressure washer onto a 1 m^2 metal table with a square metal mesh of 0.5 x 0.5 cm, F) root system of the plants after washing.

Figure.2 A-G. A) Organs or fractions of the pineapple (*Ananas comosus* MD-2) plant, weighing of the B) root system, C) stem, D) fruit, E) crown, F) green and dry leaves, and G) axillary roots, reddish brown in colour, wrap around the stem of plants originated from stem shoots or suckers, slips and crowns.

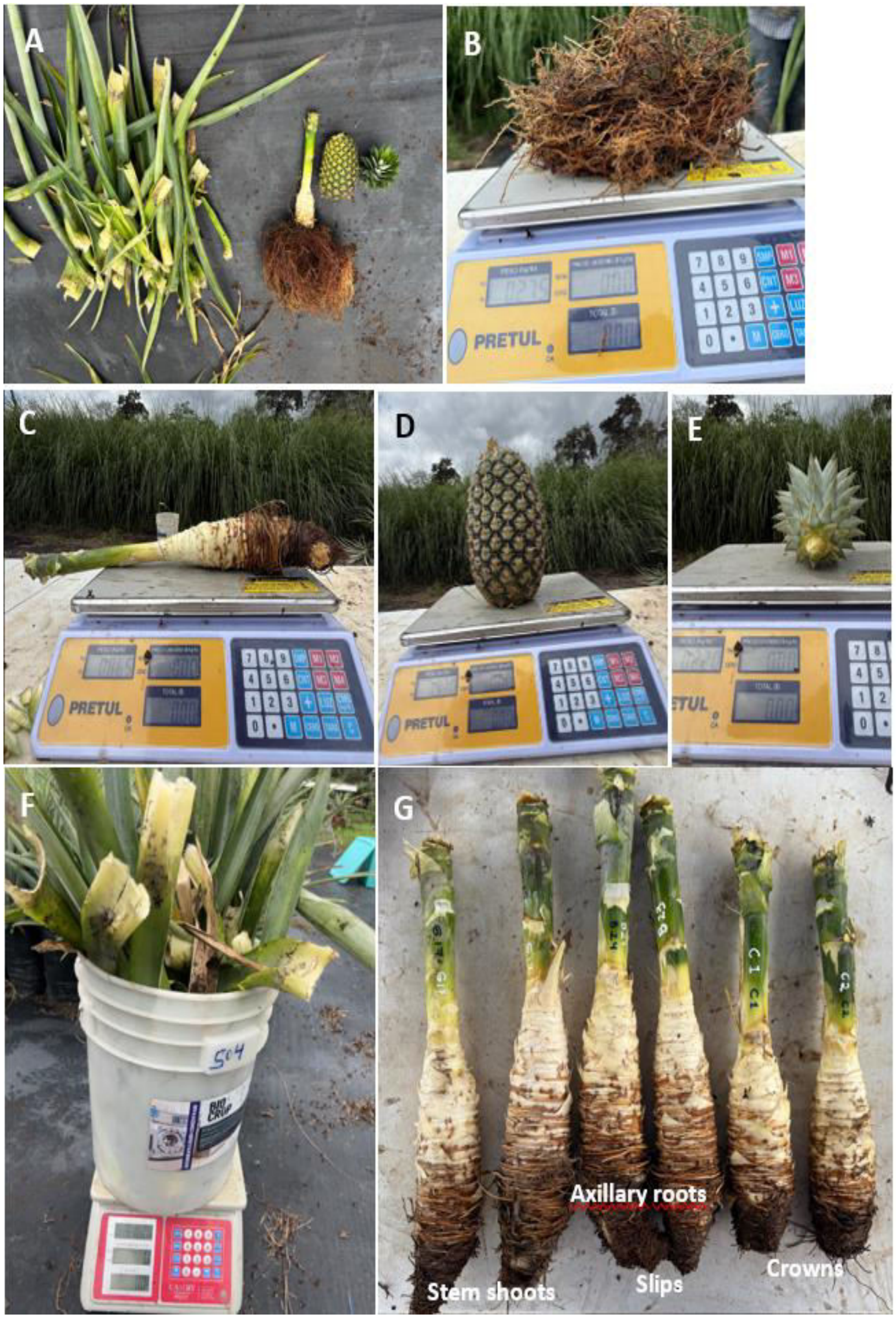


Figure.3 A-E. Weight (g) of A) leaves, B) fruit, C) stem, D) roots and E) crowns by pineapple (*Ananas comosus* MD-2) plant at harvest of the plant crop originated from different planting materials established in 20 L pots. Each bar is the means ± standard error of 20 plants. The letters above each bar in each graph correspond to the LSD mean separation.

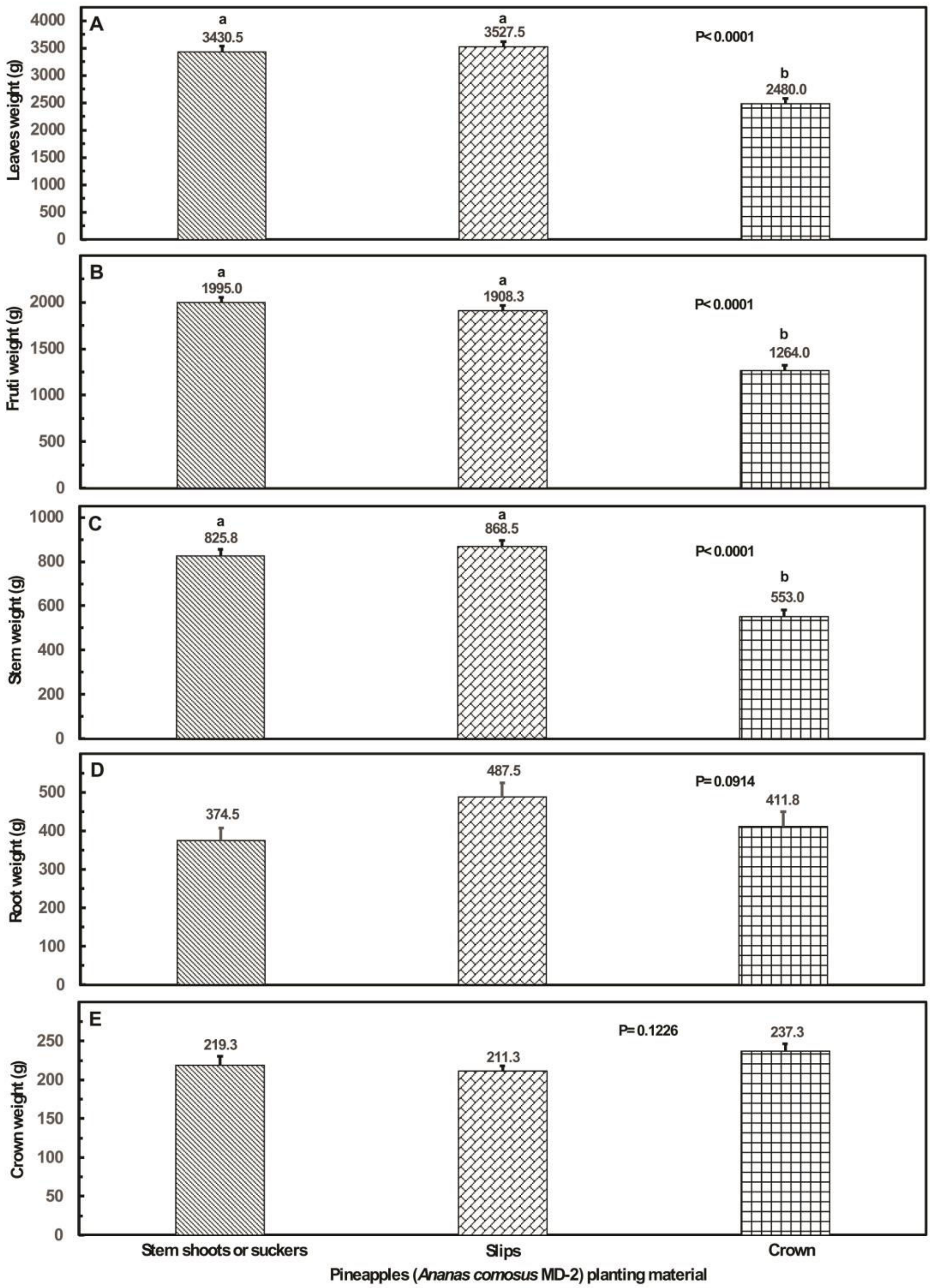


Figure.4 A-E. Weight (g) of A) axillary roots, number of B) green leaves, C) dry leaves, and D) slips and weight (g) of slips by plant of pineapple (*Ananas comosus* MD-2) originated from different planting materials at harvest of the plant crop established in 20 L pots. Each bar is the means ± standard error of 20 plants except for axillary roots, where is the means ± standard error of 10 plants. The letters above each bar in each graph correspond to the LSD mean separation.

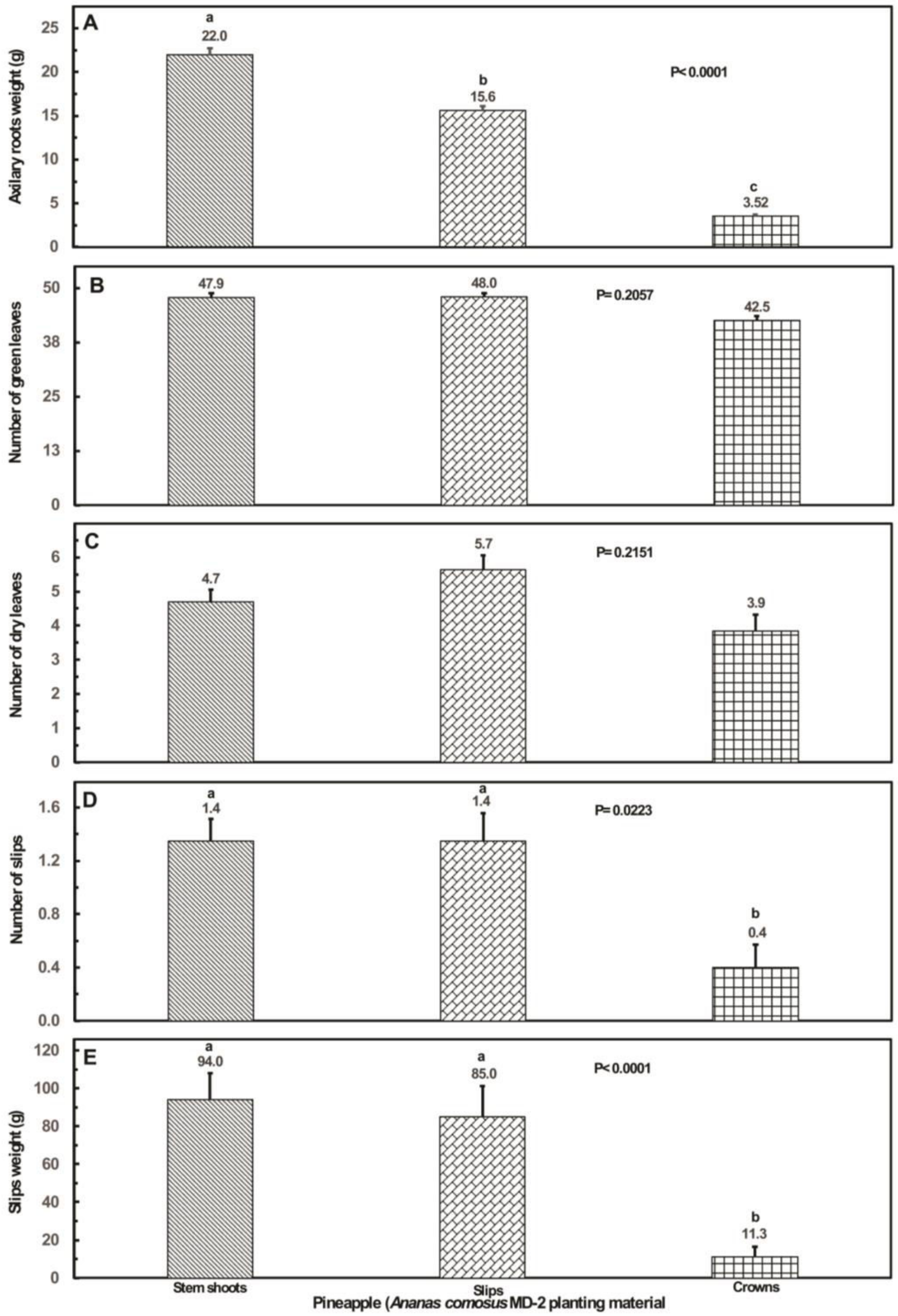
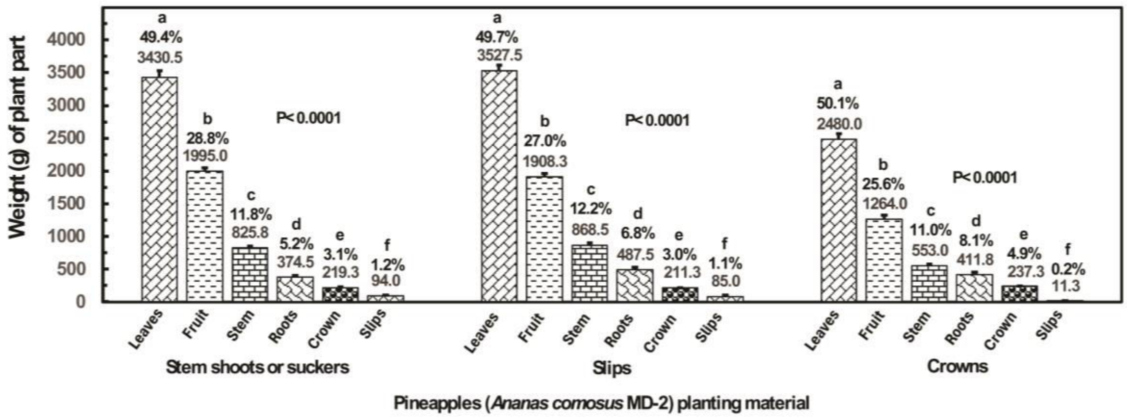


Figure.5 Weight (g) of each organ or plant fraction at harvest of the pineapple (*Ananas comosus* MD-2) plant crop originated from different planting materials cultivated in 20 L plastic pots. Each bar es the mean ± standard error of 20 repetitions. The percentage values above each bar are the contribution of that organ or fraction of the plant to the total plant biomass (sum of all organs or fractions or parts by plant) in each planting material. The letter above the % values correspond to the mean separation by LSD in each planting material.



Nevertheless, they are responsible for anchorage, water and nutrients supply, and exchange of various growth substances with the shoots including plant growth hormones such as: cytokins, abscisic acid, ethylene, gibberellins, auxins, and jasmonic acid (Itai 1996). According to Bartholomew (2018) high productivity of pineapple depends on successfully managing controllable factors such as water and nutrient supply and pests and diseases. Therefore, most agricultural investment (soil preparation, fertilization, irrigation scheduling, pest control) should be directed towards providing optimal conditions for root growth and its health. This is supported by the positive correlations found between fruit weight and leaves weight and between leaves weight and root weight on stem shoots and crowns, and in slips followed the same trend but without reaching significance.

Author Contributions

Zavala D: Investigation, writing original draft. Salas H: Validation, methodology, writing. Delgado J: Investigation, resources, writing, reviewing. Corrales E: Formal analysis, writing, review and editing. Araya M: Investigation, writing, reviewing.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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