Comunicata Scientiae
Horticultural Journal

ORIGINAL ARTICLE
published: 31 July 2024
https://doi.org/10.14295/CS.v15.4162

# Contribution of physical-chemical variables and passion fruit production in Baixo Acre

Rychaellen Silva de Brito[1]*, Lorena Yanet Cáceres Tomaya[1], Romeu de Carvalho Andrade Neto[2], Reginaldo Almeida Andrade[3], Pedro Henrique da Silva Carvalho[1], Viviane Pereira Chaves[1]

[1]Universidade Federal do Acre, Rio Branco-AC, Brasil
[2]Empresa Brasileira De Pesquisa Agropecuária, Rio Branco-AC, Brasil
[3]Universidade Federal de Rondônia, Rolim de Moura-RO, Brasil
*Corresponding author, e-mail: rychaellenbrito@gmail.com

## Abstract

This study investigated the production and physical and chemical characteristics of eight sour passion fruit genotypes cultivated in Baixo Acre, AC. Evaluation of fruit number (FN), productivity (PRO), longitudinal diameter, transverse diameter (LD and TD), peel thickness (PT), average fruit mass (AFM), pulp mass (PM), juice yield (JY), soluble solids (SS), titratable acidity (TA), ratio, and pH of genotypes H1, H3, R, V1, V2, V3, V4, and V5 was performed. Univariate, multivariate, and Pearson's correlation analyses were performed. Univariate analyses revealed that the genotype H1 stood out in terms of AFM, JY, and PRO; H3 for TD, LD, JY, and pH; H1, H3, V1, and R for LD; H3 and V5 for pH; and V4 and V5 for NF. A strong positive correlation was observed among the physical variables AFM, PM, LD, and TD. Four genotypes groups were obtained for both genetic divergence and PCA. The H1 genotype presented higher productivity, and the H3 genotype presented better fruit physical attributes.

**Keywords:** *Passiflora edulis Sims*, phenotypic characteristics, western Amazonia

## Introduction

With advances in Brazilian agriculture, primary sectors such as fruit growing have gained prominence for income generation, and the expansion of cultivation areas directly promotes the development of agro-industries focused on processing fruit trees (Santos et al., 2017).

Passion fruit is of great relevance as a local crop due to the country's prominence worldwide as the largest producer and exporter of fruit (Botelho et al., 2019). This position has occurred through the dissemination of cultures throughout the territory, ensuring productivity capable of serving the consumer market in natura and processed fruit, even with variations in the productive potential between regions where edaphoclimatic conditions are distinct (Pereira et al., 2018).

Although cultures have been implemented in several localities, (Rosa et al., 2020) mentioned that the use of productive cultivars is limited by region because they do not adapt to different agroecosystems. Due to the precariousness of better-quality genetic material and cultivation techniques that establish a continuous crop, many orchards have low agronomic performance (Morais et al., 2020).

Given the magnitude of the culture exerted in the market and the difficulty in potentiating performance in some regions, research aimed at incorporating new cultivars has been implemented to provide producers with greater diversity among vegetative materials and within their edaphoclimatic limitations (Aguiar et al., 2015).

(Gonçalves et al., 2018) reported that companies such as Embrapa Cerrado have developed passion fruit cultivars with increased productivity when properly managed. Based on this principle, in 2015, after adaptation studies to regional cultural practices, Embrapa Acre

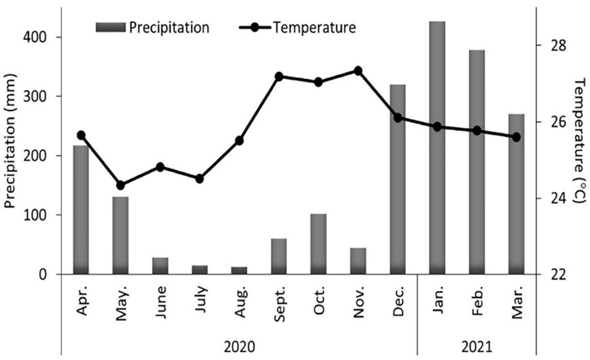

Received: 26 January 2023
Accepted: 10 April 2023

announced two new cultivars, BRS Gigante Amarelo and BRS Sol do Cerrado, as more productive than local varieties (Andrade Neto et al., 2015).

The appropriate application of selection methods for introducing new genotypes in the region is required to recommend new varieties and to adopt suitable cultivation techniques. Multivariate statistical analyses allow for the simultaneous synthesis of the information contained in a character set. Several methods can be used, including principal component analysis (PCA), canonical correlation, and clustering (Silva et al., 2017; Oliveira et al., 2017; D'Abadia et al., 2020). Thus, this study evaluated eight sour passion fruit genotypes' production and physical and chemical characteristics.

**Material and Methods**

The experiment was conducted from November 2019 to March 2021 in an area located in the municipality of Senador Guiomard, Acre, lot 061940 (latitude 10°05'40" S, longitude 67°36'19"" W, and altitude 236 m). According to the Köppen classification, the region's climate is Am (hot and humid), with an average temperature of 26°C, annual precipitation of 1,648.94 mm, and relative humidity of 83% (Alvares et al., 2013). (**Figure 1**) shows the average temperature and monthly average precipitation.




**Source:** National Institute of Meteorology, 2021.

**Figure 1.** Average monthly precipitation (mm) and average monthly temperature (°C) occurred during the evaluation period of the experiment.

The experiment was performed in the seedling production nursery of the Embrapa Acre experimental field, in Rio Branco, Acre state, Brazil (latitude 10°1'30" S, longitude 67°42'18" W, and altitude 185 m), from September 2019 to November 2019. In the field, technical recommendations described by (Andrade Neto et al., 2015) were followed for the cultivation of passion fruit regarding spacing, fertilization, pests, and disease control. Data collection was continuous from the first production inside the orchard between April 2020 and March 2021. In February 2021, the fruits were collected to evaluate physical and chemical attributes.

Eight passion fruit genotypes used in this study, V1, V2, V3, V4, V5, H1, H3, and R, were installed in a completely randomized design, allocated in two ranges with 20 plants divided into four replicates.

During the entire field experimental period, the number of fruits produced by each plant within each treatment was collected weekly. With these results, the annual productivity of the crop was calculated using the following equation: productivity = ((nfh/np) × afm × pd), where nfh = number of fruits harvested; np = number of plants; afm = average fruit mass (kg); and pd = planting density (800 plants per hectare). In addition to productivity, physical and chemical analyses of ten fruits per replicate were randomly determined at the Phytotechnics Laboratory in Rio Branco, the Federal University of Acre, when fruits presented a greater than 80% yellowish color in the peel.

Following the adapted methodology of (Silva et al., 2015), physical variables, such as transverse diameter (TD), longitudinal diameter (LD), and peel thickness (PT), were measured using a digital caliper. The average fruit mass (AFM), fruit mass (FM), and seedless pulp mass (SPM) were determined by weighing the samples on an analytical balance. Juice yield (JY) was evaluated based on the relationship between seedless pulp mass and fruit mass ([seedless pulp mass/fruit weight] × 100). The chemical variables of the soluble solids (SS) in Brix were determined by direct reading using a portable digital refractometer. The juice's titratable acidity (TA) was determined by titration with 0.1N NaOH solution, while the relationship of soluble solids/titratable acidity was determined as a ratio. The pH values were obtained by direct reading using a digital pH meter according to the methodology described by (Brasil, 2008).

The data were analyzed using univariate variance (F test) at 5% probability, including residual normality and homogeneity of variance tests. The means of the treatments were compared using the Scott-Knott test at 5% probability. In addition, Pearson correlation was used to demonstrate the linear relationship and the strength between the assessed quantitative characteristics.

Conversely, multivariate statistical techniques, such as principal component analysis (PCA) (Jolliffe, 1972) and clustering (Mardia et al., 1979), were performed to study the dissimilarity among the evaluated genotypes. The dissimilarity measure considered the average Euclidean distance after the hierarchical agglomeration method, known as the unweighted pair grouped, using the arithmetic average (UPGMA) method. Clustering was based on the genotype scores obtained from the principal components.

**Results and Discussion**

The analysis of variance showed a significant difference among all genotypes at 5% probability by the F test (**Table 1**) for all evaluated physical and chemical characteristics except pulp mass, peel thickness, soluble solids, titratable acidity, and ratio. Genetic variability was also observed among the genotypes for the characteristics considered, favoring genetic improvement programs for these genotypes or species.

It is worth commenting on the variables such as the pulp mass (PM), peel thickness (PT), soluble solids (SS), titratable acidity (TA), and the ratio. No significant differences among genotypes (Table 1) were observed in the chemical characteristics considered important. These variables often delimit the desired quality attributes in the industrial field. (Botelho et al., 2016) claim that the soluble solids/titratable acidity ratio (SS/TA) can stipulate whether the pulp is sweet or acidic.

For the commercialization of passion fruit pulp, the minimum value recommended for soluble solids is 11° Brix and titratable acidity of 2.5% (Brasil, 2018). According to (Botelho et al., 2017), high soluble solids are preferred in fruits intended for fresh consumption, as this characteristic indicates pulp sweetness. In addition, (Aguiar et al., 2015) indicated that titratable acidity is an important attribute for estimating the state of conservation of the pulp because when the reference value is satisfied, it is not necessary to add preservatives. The pulp itself may be able to maintain the quality and flavor of the juice.

**Table 1.** Analysis of variance for average fruit mass (AFM), transverse diameter (TD), longitudinal diameter (LD), pulp mass (PM), juice yield (JY), peel thickness (PT), soluble solids (SS), titratable acidity (TA), soluble solids/titratable acidity (Ratio), hydrogenionic potential (pH), fruit number (FN) and productivity (PRO) of eight passion fruit genotypes. Rio Branco, AC, 2021

| Variables | Fc | Men | Min | Max | CV(%) | CVg(%) | $h^2$(%) |
|---|---|---|---|---|---|---|---|
| AFM (g) | 8.06* | 244.31 | 184.51 | 331.20 | 15.04 | 19.98 | 87.59 |
| TD (mm) | 8.11* | 86.77 | 78.49 | 94.90 | 4.48 | 5.98 | 87.67 |
| LD (mm) | 16.15* | 98.83 | 87.76 | 111.70 | 4.40 | 8.57 | 93.81 |
| PM (g) | $2.07^{ns}$ | 765.26 | 607.18 | 895.30 | 16.68 | 8.64 | 51.77 |
| JY (%) | 3.17* | 32.22 | 23.79 | 37.80 | 14.60 | 10.76 | 68.47 |
| PT (mm) | $1.40^{ns}$ | 7.33 | 6.25 | 8.00 | 14.21 | 4.48 | 28.47 |
| SS (°Brix) | $1.10^{ns}$ | 13.71 | 12.65 | 15.10 | 11.70 | 1.92 | 9.72 |
| TA (%) | $2.05^{ns}$ | 4.44 | 4.13 | 4.90 | 9.15 | 4.69 | 51.29 |
| Ratio | $2.05^{ns}$ | 3.12 | 2.72 | 3.60 | 13.71 | 7.04 | 51.35 |
| pH | 6.44* | 2.82 | 2.77 | 2.90 | 1.07 | 1.25 | 84.47 |
| FN | 22.33* | 2452.68 | 1546.75 | 3135 | 8.55 | 19.74 | 95.52 |
| PRO(t $ha^{-1}$) | 8.58* | 46.83 | 32.81 | 66.83 | 14.61 | 20.13 | 88.35 |

* Significant and $^{ns}$ not signifier ($p < 0.05$) by the F-test; men: mean; min: minimum; max: maximum; CV: coefficient of variation; CVg: genotypic coefficient of variation; $h^2$: heritability in the broad sense.

According to the reference values required by the industry, it was found that all eight genotypes showed superiority concerning values of soluble solids between 12.65 and 15.10 Brix and titratable acidity of 4.13 to 4.90%, taking into account the specifications mentioned above.

Several studies focused on passion fruit have indicated high coefficient of variation values (Santos et al., 2017; Pereira et al., 2018; Cavichioli et al., 2020). (Pereira et al., 2018) characterized the fruits of different passion fruit species. They observed variation values ranging from 12.1 to 28.1%, whereas the values of our study varied between 1.07 and 16.88% (Table 1), highlighting that most of the assessed attributes revealed good experimental precision.

With regard to heritability, all non-significant variables had low heritability. (Chagas et al., 2016) reported that low heritability values might represent greater difficulty in propagating desirable characteristics for future generations due to environmental effects on the genotype. Using the genotypes researched in our study for the formation of new orchards, it is expected that the average fruit mass, longitudinal and transverse diameters, juice yield, pH, number of fruits, and productivity would be perpetuated, suggesting that the environment does not strongly influence these characteristics. The Scott-Knott test at 5% significance, when applied to the means of the significant characteristics, resulted in the formation of groups ranging from two to four genotypes, such as the longitudinal diameter (LD), juice yield (JY), transverse diameter (TD), and the number of fruits (NF), respectively (**Table 2**).

Regarding the transverse diameter, a variation between 78.49 mm (V2) and 94.90 (H1) mm was observed, whereas the longitudinal diameter ranged from 87.76 mm (V2) to 111.73 mm (H3). For these variables, the H3 genotype presented the best performance (Table 2). (Botelho et al., 2019) state that for the marketing of the sour passion fruit, the principal criterion for consumer selection is the diameters (longitudinal and transverse) because these are directly related to fruit mass and determine fruit shape. (Silva et al., 2017) report that in the search for new genotypes to be implemented, the physical fruit characteristics and productivity are essential for establishing a genotype in the market.

The average fruit mass ranged from 184.51 (V5) to 331.23 g (H1), whereas juice yield ranged from 23.79 (H1) to 37.81% (V5), as shown in (Table 2). Although the H1 genotype had a higher average fruit mass, it had the lowest juice yield. (Botelho et al., 2017) stated that regardless of whether the fruit is marketed in natura

**Table 2.** Comparison of average snags for average fruit mass (AFM), transverse diameter (TD), longitudinal diameter (LD), juice yield (JY), hydrogenonic potential (pH), fruit number (FN) and productivity (PRO) of eight passion fruit genotypes. Rio Branco, AC, 2021

| Genotypes | AFM(g) | TD(mm) | LD(mm) | JY(%) | pH | FN | PRO(t ha$^{-1}$) |
|---|---|---|---|---|---|---|---|
| H1 | 331.23a | 94.90 a | 106.46 b | 23.79 b | 2.81 c | 2538.75 b | 66.83 a |
| H3 | 264.51 b | 91.72 a | 111.73 a | 31.67 a | 2.87 a | 1546.75 d | 32.81 c |
| R | 292.46 b | 90.57 a | 104.76 b | 30.84 a | 2.83 b | 2127.75 c | 49.41 b |
| V1 | 260.68 b | 87.70 a | 101.91 b | 31.08 a | 2.83 b | 2250.00 c | 47.00 b |
| V2 | 189.02 c | 78.49 b | 87.76 d | 32.39 a | 2.78 c | 2528.25 b | 38.04 c |
| V3 | 227.50 c | 86.18 b | 96.81 c | 34.60 a | 2.77 c | 2525.00 b | 45.81 b |
| V4 | 204.56 c | 82.48 b | 89.28 d | 35.59 a | 2.84 b | 3135.00 a | 50.76 b |
| V5 | 184.51 c | 82.10 b | 91.91 d | 37.81 a | 2.88 a | 2970.00 a | 44.05 b |

Means followed by equal letters in the column do not differ from each other by the Scott-Knott test at 5% probability.

or processed, such variables are important during fruit selection.

The pH averaged 2.82, varying between 2.77 and 2.88, with genotypes H3 (2.87) and V5 (2.88) showing the best results. The values obtained in this study were above 2.7, which is the minimum value required by industry (Brasil, 2018). Notably, the lowest values are very close to the default values. pH influences the formation of organic acids and total sugars, increasing soluble solids and reducing the percentage of hydrogen-free ions in the pulp, reducing pH (D'Abadia et al., 2019).

Regarding the number of fruits harvested for each genotype, there is notable variability between genotypes, as evidenced by the formation of four groups, especially the V4 (3,135 fruits) and V5 (2,970 fruits) genotypes with the highest fruit production values (Table 2). It is estimated that for the H3 genotype, the number of fruits was directly influenced by the flowering period since late fruiting was observed in the field compared with other genotypes.

Three groups were formed based on productivity (Table 2). The first group was represented by the H1 genotype, with the highest mean value (66.83 t ha$^{-1}$); the second group was represented by genotypes R, V1, V3, V4, and V5, with intermediate yields ranging between 44.05 t ha$^{-1}$ and 50.76 t ha$^{-1}$ and the third by genotypes H3 and V2, with lower yields of 32.81 t ha$^{-1}$ and 38.04 t ha$^{-1}$, respectively. Regardless of genotype, the productivity presented here exceeds the national and Acre state averages in 2020, which produced 14.86 t ha$^{-1}$ and 8.87 t ha$^{-1}$, respectively (Ibge, 2021).

(Andrade Neto et al., 2015), when evaluating the genotypes Gigante Amarelo and Sol Cerrado under local conditions, obtained average productivity in the first year of 48 t ha$^{-1}$, close to that found in most genotypes studied in this work (Table 2), except for H1 (66,83 t ha$^{-1}$), which exceeded that average.

It is worth mentioning that many variables can be directly influenced by others, which implies that there may be a positive correlation when the effect of one characteristic potentiates the other or a negative correlation when the increase in one variable causes a decrease in another. In both cases, such findings can be used to potentiate certain characteristics, as shown by the Pearson correlation network in (**Figure 2**).

Based on the color of the connection line and its thickness, it was possible to detect the average fruit mass (AFM), pulp mass (PM), transverse diameter (TD), and longitudinal diameter (LD) revealed a strong positive correlation (green lines and strong intensity), between pairs of variables. In addition, there was a strong negative correlation (red lines) between the diameters (TD and LD) and the number of fruits (NF), demonstrating that increased fruit production tends to result in smaller fruit sizes. Smaller diameters would also reduce the average fruit mass (AFM) and pulp mass (PM).

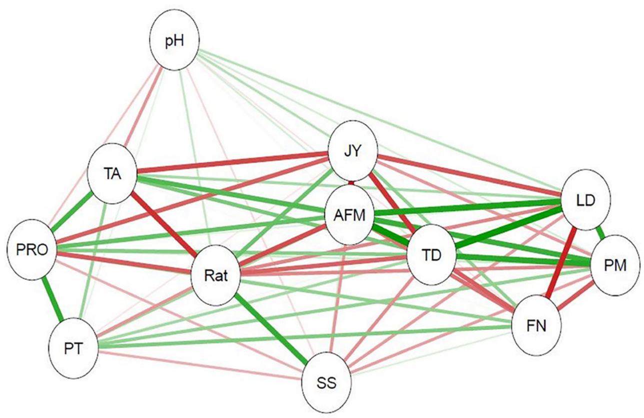



**Figure 2.** Correlation network between longitudinal diameter (LD), transverse diameter (TD), peel thickness (PT), average fruit mass (AFM), pulp mass (PM), juice yield (JY ), soluble solids (SS), titratable acidity (TA), soluble solids/titratable acidity ratio (Ratio), hydrogenonic potential (pH), fruit number (FN) and productivity (PRO) of passion fruit genotypes. Rio Branco, AC, 2021. The red and green lines represent negative and positive correlations, respectively, and the width of the line is proportional to the intensity of the correlation.

It was also observed that productivity was positively correlated with the average fruit mass (AFM), the number of fruits (NF), peel thickness (PT), and titratable acidity (TA). Conversely, for the chemical variables, the ratio (SS/AT) showed a high positive correlation with soluble solids (SS) and a strong negative correlation with titratable acidity (TA). In addition, it was possible to visualize a weak negative correlation with pH for both variables (SS and TA).

The correlations revealed here corroborate the results of (Silva et al., 2017), who reported that the fruit and pulp mass are directly influenced by fruit diameter, affecting orchard productivity. Strong correlations between chemical attributes and the ratio were expected, either negative or positive, as shown in (Figure 2).

Through principal component analysis (PCA), it is possible to reduce the number of observed variables that can be correlated with each other, simplifying the evaluation of the quality of passion fruit characteristics into a smaller set of variables (components) without much loss of information. Thus, PCA allows the identification of variables that can be redundant or of minimal contribution to the study of genetic variability. If followed by cluster analysis, adopting the Euclidean distance as a measure of dissimilarity and the UPGMA method, it is possible to bring together distinct groups of genetic similarity.

For the set of 12 variables mentioned in (Table 1), (Sneath & Sokal's, 1973) approach was adopted as a criterion for choosing the main components, in which the number of components must contain at least 70% of the total variance of the original data. This study found that principal components 1 and 2 (PC1 and PC2, respectively) explained 70.52% of the variance of the components assessed, with CP1 and CP2 explaining 48.78% and 21.74%, respectively (**Figure 3**).

The correlation coefficients revealed that for the main component 1, PC1, the variables with the greatest influence were those related to fruit quality, such as AFM, LD, TD, PM, JY, and the ratio, whose estimates were 0.97; 0,94; 0,83; 0,76; -0.80 and -0.78, respectively, while for PC2 only the variables FN and PRO influenced with high correlations of 0.85 and 0.75, respectively. Note that PC2 can be labeled as a component of fruit production. In addition, the effect of correlations between the other variables can be observed (Figure 3); that is, the smaller the measure of the angle formed between the vectors of two variables, the greater correlation will be between them, also confirming the high correlations shown in (Figure 2).

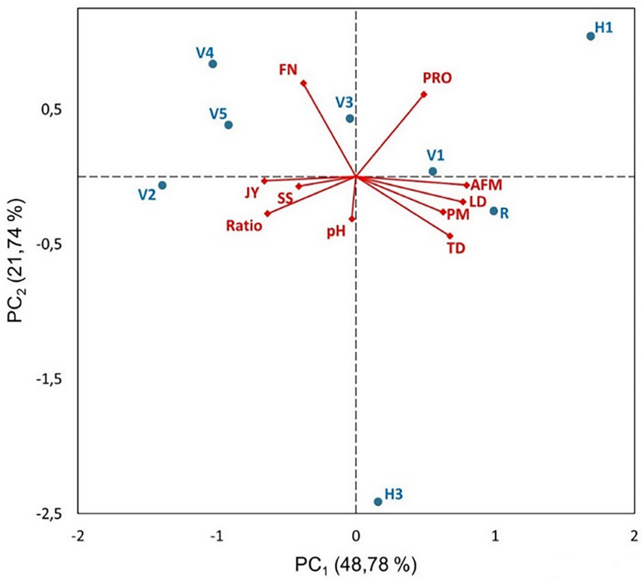



**Figure 3.** Main components considering the variables of longitudinal diameter (LD), transverse diameter (TD), average fruit mass (AFM) and pulp (PM), juice yield (JY), soluble solids/ titratable acidity ratio (Ratio), fruit number (FN) and productivity (PRO) associated with the eight passion fruit genotypes (H1, H3, R, V1, V2, V3, V4 e V5). Rio Branco, AC, 2021.

From (Figure 3), it is possible to visualize the genotypes that can be grouped if we consider the distance measurement as a group formation criterion. Thus, the mean values corresponding to the possible groups listed in (**Table 3**) were obtained.

When applying the above criteria for allocating genotypes in different groups, the first group (I) variables of juice yield, number of fruits, and ratios significantly contributed to the genotypes contained therein. However, these same genotypes did not express the best results for other fruit variables (Table 3). Similarly, the characteristics AFM, TD, LD, PM, and PRO. Finally, even though group IV performed well in the same variables as the groups mentioned above, it can be observed that the values related to production (FN and PRO) led to the inclusion of a single genotype in this group.

The results above generally corroborate those presented in Table 2, where there are established statistical comparisons and validate what was demonstrated univariately. (Oliveira et al., 2017) stated that the characteristics of the fruits contribute positively to phenotypic differentiation between genotypes and that selection techniques and groupings are important for the characterization and genetic diversity of passion fruit.

It is important to consider that the choice between the PC selection methods was based on each component's impact on determining promising genotypes. By adopting the method proposed by (Kaiser, 1958), there was an increase in the dimensioning of the total data variability, reaching 91.88%, and contained in

**Table 3.** Mean for groups I, II, III, IV in relation to the variables average fruit mass (MMF), transverse diameter (TD), longitudinal diameter (LD), pulp mass (PM), juice yield (JY), soluble solids/titratable acidity ratio (Ratio), fruit number (FN) and productivity (PRO). Rio Branco, AC, 2021

| Group | Genotype | AFM (g) | TD (mm) | LD (mm) | PM (g) | JY (%) | Ratio | FN | PRO (t ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| I | V2, V4, V5 | 192.69 | 81.02 | 89.65 | 670.85 | 35.26 | 3.35 | 2877.75 | 44.28 |
| II | V1, R, V3 | 260.21 | 88.15 | 101.16 | 832.92 | 32.17 | 2.92 | 2300.92 | 47.41 |
| III | H1 | 331.23 | 94.89 | 106.45 | 778.59 | 23.79 | 2.72 | 2538.75 | 66.83 |
| IV | H3 | 264.51 | 91.72 | 111.73 | 832.23 | 31.67 | 3.41 | 1546.75 | 32.81 |

addition to components 1 and 2, components 3 and 4, exerting 12.88% and 8.50%, respectively. According to the criteria presented by (Jolliffe, 1972), which recommends the disposal of the variables pulp mass (PM), titratable acidity (TA), and transverse diameter (TD), pulp mass has a high contribution within PC1, which is due to the existence of a high correlation between both variables, making it redundant.

Considering the scores obtained when using the first two main components, it should be noted that in the dendrogram, based on the measure of dissimilarity of the Euclidean distance and the UPGMA method, there is a separation and consequent formation of groups, starting from the most important variables (**Figure 4**). The formation of the four groups was like that observed in the univariate analysis for most variables. This finding was in accordance with the dispersion graph of the genotype scores (Figure 3), where H1 and H3 were identified in individual clusters.

The cluster evaluation given by the cophenetic coefficient, which considers the correlation between the estimated distances and those observed from the data, was 0.76, indicating a high correlation in group formation. Thus, the genotypes used can be classified into the following groups (**Table 4**):

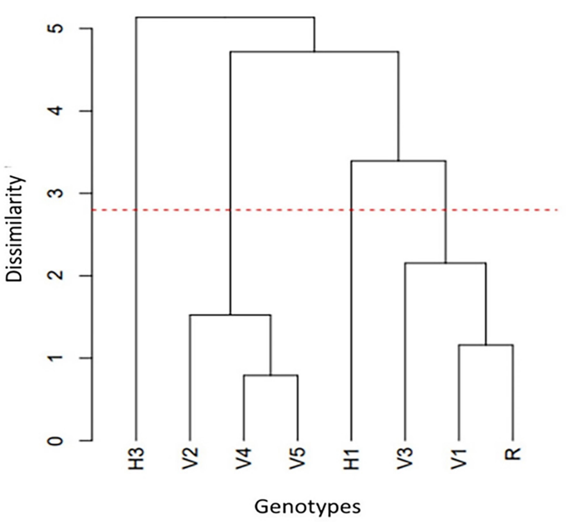



**Figure 4.** Dendrogram of dissimilarity among the 8 passion fruit genotypes, obtained by the UPGMA method based on euclidean distance, considering the scores of the first two main components. Genotypes: H1, H3, R, V1, V2, V3, V4 e V5. Rio Branco, AC, 2021.

**Table 4.** Demonstration of the groups formed after application of the Euclidean distance

| Groups | Genotypes |
|---|---|
| I | H3 |
| II | V2, V4 e V5 |
| III | H1 |
| IV | R, V1 e V3 |

## Conclusions

The variables of average fruit mass, longitudinal and transverse diameter, pulp mass, juice yield, ratio, number of fruits, and productivity contribute to genetic divergence. Genotypes H1 and H3 showed optimal productivity and physical characteristics, respectively, among the genotypes surveyed.

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**Conflict of Interest Statement:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.