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# Selection of umbu-cajazeira clones using the REML/BLUP

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## ABSTRACT

Genetic parameters and genotypic values of fruits from umbu-cajazeira clones were determined using the restricted maximum likelihood/best linear unbiased prediction (REML/BLUP) method, from the morphological, physicochemical and chemical characterization of fruits. The experiment was composed of six experimental clones, in three randomized complete block designs and three replicates per plot in an unbalanced arrangement in Ipanguaçu/RN, due to non-fructification of some clones of the experiment. Morphological, physicochemical and chemical characterization of 20 fruits of each clone was performed. The variance components for REML and medium components (BLUP), were estimated using the mixed model's method REML/BLUP. The three best clones selected were from Serra do Mel, Açu, and Carnaubais. The method used allowed selection of clones with high soluble solids content and pulp yield based on the genotypic value of clones. Fruit clones from Serra do Mel can be used for pulp processing or fresh consumption. The Açu clone showed a high pulp yield and is recommended pulp processing. Carnaubais, Alto do Rodrigues, and Ipanguaçu generated fruits for fresh consumption.

**Key words:** fresh consumption; genetic variability; mixed models; *Spondias* sp.

# *Seleção de clones de umbu-cajazeira utilizando REML/BLUP*

## RESUMO

Os parâmetros genéticos e os valores genotípicos de clones de umbu-cajazeira foram determinados utilizando o método REML/BLUP (restricted maximum likelihood/best linear unbiased prediction), a partir da caracterização morfológica, físico-química e química de frutos. O ensaio foi composto por seis clones experimentais, em delineamento blocos ao acaso com três blocos e três repetições por parcela em arranjo desbalanceado em Ipanguaçu/RN, devido a não frutificação de alguns clones do experimento. A caracterização morfológica, físico-química e química de vinte frutos de cada genótipo foi realizada. Os componentes de variância por REML e componentes de médias (BLUP) foram estimados via modelos mistos pelo método REML/BLUP. Os três melhores clones selecionados foram Serra do Mel, Açu e Carnaubais. O método utilizado permitiu a seleção de clones com alto teor de sólidos solúveis e rendimento de polpa, baseado no valor genotípico dos clones. Os frutos do clone Serra do Mel podem ser utilizados para o processamento de polpa e para o consumo in natura. O clone Açu apresentou elevado rendimento de polpa sendo recomendado para o processamento. Carnaubais, Alto do Rodrigues e Ipanguaçu apresentam frutos para o consumo ao natural.

**Palavras-chave:** consumo ao natural; variabilidade genética; modelos mistos; *Spondias* sp.

## Introduction

Umbu-cajazeira (*Spondias* sp.), of the Anacardiaceae family, is a perennial plant in the process of domestication. It is a natural, interspecific hybrid between the yellow mombim (*Spondias mombin* L.) and the umbu (*Spondias tuberosa* L. Arr.), and produces highly prized fruits primarily in the north and the northeast, as well as in other regions of Brazil (Lederman et al., 2008). There are only a few commercial orchards that supply umbu-cajazeira, and the supply depends on the extrativism and is also characterized by seasonality and failure to meet industry demands (Gondim et al., 2013).

According to Carvalho et al. (2008) and Santana et al. (2011), umbu-cajazeira fruit has considerable genetic and morphological variability in several regions of northeast Brazil. So, to protect this fruit against the predatory exploitation, the genetic characterization is required to identify and preserve the genetic variability among plants of the same species (Blank, 2011). Research on the genetic diversity of plants with vegetative propagation enables the identification of a clone of the selected genotype, thereby saving time and cost in breeding programs (Lira Júnior et al., 2008).

Nowadays, there has been limited research on the umbu-cajazeira fruit, and there have been no studies on the prediction of breeding values or estimation of variance components for the species. Thus, it is necessary to understand the genetic variability of this species by using the REML/BLUP methodology (restricted maximum likelihood/best linear unbiased prediction), an essential tool to improve perennial plants and contribute to the conservation of germplasm and selection of superior genotypes (Carvalho et al., 2008).

Balanced data and absence of fixed and random effects together in the same statistical model are prerequisites for the analysis of variance (ANOVA) method to produce unbiased results (Duarte et al., 2001). However, in most of the experiments on the breeding plant, the unbalanced data and the randomness of the genotypes are specific factors for the analysis data. Thus, the REML method has replaced the ANOVA method in many agronomic and forest experiments, since it allows the application of unbalanced data, non-orthogonal delineations and takes into account the relationship between treatments (Resende, 2007).

This study aimed to estimate the genetic parameters required for the selection of promising umbu-cajazeira clones from the *Spondias* germplasm bank for fresh fruit production and processing of pulp, using the mixed model method.

## Materials and Methods

The experimental area utilized in this study belongs to the Agricultural Research Company (EMPARN) in Ipanguaçu (5°29′54″ South and 36°51′18″ West, 16 m altitude), located in the state of Rio Grande do Norte. According to Thornthwaite's classification, the area has a type "E"- arid climate, with average annual rainfall of 590 mm, and average annual temperature of 31 °C.

The soil is the saline-sodic eutrophic alluvial type, highly fertile but limited due to its salt content (Embrapa, 2006). The research was conducted in February and November 2013.

In 2001, seven umbu-cajazeiras cuttings were collected from seven counties (Ipanguaçu, Açu, Alto do Rodrigues, Serra do Mel, Pendências, Carnaubais, and Parelhas) in the semiarid area, and were transplanted to create the Active Germplasm Bank of *Spondias* for EMPARN. A 10 × 10 m area was used, and irrigation was performed until the cuttings thrived entirely. Culture practices such as pruning and cleaning of the planted lines were conducted as required and pesticides were not used, as there were no signs of attacks by pests or diseases that could compromise the project.

Six umbu-cajazeira clones were selected for this analysis: Ipanguaçu, Açu, Alto do Rodrigues, Serra do Mel, Carnaubais, and Parelhas. The study did not include size, architecture, canopy form, plant phenology, or crown diameter of the umbu-cajazeira clones.

Initially, a preliminary visual selection of plants was performed based on the information on its early production and yield. Therefore, phenotypically undesirable plants were not evaluated, resulting in a total of 39 identified plants. The plant breeding method was a stratified mass selection to minimize environmental effects. The area was divided into three strata based on topography and types of soil. The design was a randomized block design with six treatments (six clones) and three replications (three blocks). The experimental plots contained three umbu-cajazeira plants. Some plants did not produce fruits, resulting in an unbalanced experiment.

Twenty fruits were collected in the same morning, all with the same degree of ripeness, which had fallen from the trees. To determine the physical and physicochemical characteristics of the fruits, the following evaluations were conducted: longitudinal diameter and transversal diameter; ratio by longitudinal diameter transversal, diameter fruit mass, pulp mass, shell mass, seed mass, total weight of 20 fruits; titratable acidity, with NaOH 0.1 M titration according to Instituto Adolfo Lutz (2008); pH, determined with digital potentiometer; soluble solids, determined with digital refractometer and expressed as ºBrix by AOAC (2002); vitamin C, using Tillmans method according to Strohecker & Henning (1967); ratio by soluble solids/titratable acidity; pulp yield, ratio pulp mass/fruit mass x100; and technological index, ratio soluble solids x pulp yield/100.

Morphological analyses were performed at the Postharvest Laboratory of the Federal Rural University of the Semi-Arid (UFERSA).

For statistical analyse the data of all three plants, the second model (randomized blocks, unrelated clones test, several plants per plot) (Resende, 2007) was used. The mixed model's equations (MME) allow for a fixed effect estimate (f) by ordinary least squares and prediction of random effects (a, e, c) by best linear unbiased prediction (BLUP) (Resende, 2002).

The mixed model analyses in experiments with unbalanced data do not test the effect regarding F test, which is the usual approach for variance analysis. In this case, for random effects, the likelihood ratio test (LRT) (Resende, 2007) is commonly used. The procedure creates a known table deviance analysis (ANADEV) similar to an analysis variance.

Variance components, genetic parameters, deviance analysis, genotypic values, and a new average for the REML/BLUP procedure, were estimated using the software SELEGEN – REML/BLUP (Resende, 2007).

## Results and Discussion

The genetic variation coefficient showed the genetic variability for the pulp mass, fruit mass, shell mass, technological index and the ratio of soluble solids/titratable acidity (Table 1). The experimental variation coefficient did not show high values, indicating that the variation is the result of genetic clones. A small variation coefficient reflects good experimental quality and leads to high accuracy values, promoting safety in the selection of superior umbu-cajazeira clones. The highest was the variation coefficient for pulp mass, which was probably generated by the seed slurry retention caused by manual pulping. Quantifying the variability in a germplasm bank is essential to establish a breeding program to obtain superior genotypes (Santos et al., 2008a).

Plants number of per plot resulted in a low coefficient to determine the effects of the plots ($c^2$parc) for all features with good experimental precision (Table 1). The reduced environmental variance among plots within the block confirms that the experimental design was sufficient for the objectives proposed in the analysis. It suggests that much of the variation between clones is genotypic in nature. A study by Maia et al. (2011) on the families of half-sib cupuaçu also showed low values for the coefficient of determination of plot effects on fruit mass and pulp mass, with values close to zero, and also revealed the existence of small environmental variation within plots. These results corroborate the findings of Farias Neto et al. (2008) who studied açaizeiro progenies.

Residual variance was also small in magnitude, as shown by the coefficient of relative variation and according to the number of repetitions adopted (Table 1). The coefficient of relative variation values greater than or equal to one indicates that these features can be easily managed for genetic gain (Vencovsky, 1987). All variables except seed mass and vitamin C may be useful for selection because most phenotypic variations are attributed to their genetic expression. Manfio et al. (2011) analyzed macaúba matrices and found the coefficient of relative variation values above unity.

High values of coefficient of relative variation compared to longitudinal diameter, transversal, the ratio of longitudinal/transversal diameter, fruit mass, pulp mass, technological index and pulp yield, indicated a high value of accuracy for these traits. Considering the low values obtained for standard deviations of prediction errors (SEP), it can be inferred that the selection accuracy of these traits will be high, similar to Maia et al. (2011).

Genetic variability among clones resulted in a high coefficient of individual heritability in a broad sense ($h^2g$) for longitudinal diameter, transversal, the ratio of longitudinal/transversal diameter, fruit mass, pulp mass, technological index and pulp yield (Table 1). It can be inferred that the reproduction mode by cutting off the clones evaluated could result in progenies with similar or superior performance to the parents.

**Table 1.** Estimates of genetic variance components (Vg), residual variance (Ve), individual phenotypic variance (Vf), environmental variance among plots (Vparc), heritability ± standard deviation of heritability ($h^2g$), coefficient of determination of the effects of plot ($c^2$parc), accuracy in the selection of clones ($r_{\hat{a}a}$), genetic variation coefficient (CVg), environmental variation coefficient (CVe), coefficient of relative variation (CVr = CVg / CVe), and standard deviation of genotypic value (SEP) of six umbu-cajazeira clones (*Spondias* sp.).

| | LD | TD | LD/TD | FM | PM | ShM | SM |
|---|---|---|---|---|---|---|---|
| | (mm) | | | (g) | | | |
| Vg | 9.28 | 9.37 | 0.00 | 16.60 | 11.80 | 0.37 | 0.00 |
| Vparc | 0.13 | 0.04 | 0.00 | 0.06 | 0.02 | 0.00 | 0.01 |
| Ve | 1.25 | 1.32 | 0.00 | 2.90 | 1.529 | 0.16 | 0.07 |
| Vf | 10.66 | 10.73 | 0.00 | 19.56 | 13.35 | 0.54 | 0.08 |
| $h^2g$ | 0.87±0.43 | 0.87±0.43 | 0.85 ±0.42 | 0.85 ± 0.42 | 0.88 ± 0.43 | 0.69±0.38 | 0.003±0.03 |
| $c^2$parc | 0.01 | 0.004 | 0.00 | 0.00 | 0.002 | 0.01 | 0.17 |
| $r_{\hat{a}a}$ | 99.03 | 99.15 | 99.05 | 99.00 | 99.25 | 97.50 | 15.03 |
| $CV_{gi}$ | 9.96 | 10.47 | 3.86 | 25.54 | 30.29 | 23.15 | 0.88 |
| $CV_e$ | 2.42 | 2.38 | 0.93 | 6.34 | 6.45 | 9.12 | 10.03 |
| $CV_r$ | 4.12 | 4.41 | 4.17 | 4.03 | 4.70 | 2.54 | 0.09 |
| SEP | 0.42 | 0.40 | 0.01 | 0.58 | 0.42 | 0.14 | 0.02 |
| Mean | 30.60 | 29.23 | 1.05 | 15.96 | 11.34 | 2.66 | 1.96 |

| | TA % citric acid | pH | SS | VITC in mg/100 g pulp | SS/TA | TI | PY |
|---|---|---|---|---|---|---|---|
| | | | | | | (%) | |
| Vg | 0.01 | 0.03 | 0.65 | 0.38 | 2.57 | 1.70 | 23.77 |
| Vparc | 0.00 | 0.00 | 0.01 | 0.01 | 0.03 | 0.03 | 0.59 |
| Ve | 0.02 | 0.02 | 0.48 | 1.75 | 2.02 | 0.25 | 4.89 |
| Vf | 0.03 | 0.05 | 1.14 | 2.13 | 4.61 | 1.98 | 29.25 |
| $h^2g$ | 0.44 ± 0.30 | 0.62 ± 0.36 | 0.57 ±0.34 | 0.17 ± 0.19 | 0.55 ± 0.34 | 0.85±0,42 | 0.81 ±0 .41 |
| $c^2$parc | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 |
| $r_{\hat{a}a}$ | 93.44 | 96.71 | 95.99 | 80.94 | 95.74 | 98.88 | 98.47 |
| $CV_{gi}$ | 10.62 | 6.26 | 5.09 | 4.53 | 11.43 | 11.68 | 6.96 |
| $CV_e$ | 7.01 | 2.85 | 2.57 | 5.69 | 5.97 | 3.05 | 2.13 |
| $CV_r$ | 1.52 | 2.20 | 1.98 | 0.80 | 1.92 | 3.83 | 3.27 |
| SEP | 0.04 | 0.04 | 0.23 | 0.36 | 0.46 | 0.19 | 0.85 |
| Mean | 1.15 | 2.68 | 15.88 | 13.54 | 14.02 | 11.16 | 70.06 |

Variables: longitudinal diameter (LD) and transversal diameter (TD), in mm, LD/TD, fruit mass (FM), pulp mass (PM), shell mass (ShM), and seed mass (SM) in grams, titratable acidity (TA) in % of citric acid, soluble solids (SS) in Brix, pH, SS/TA, vitamin C, in mg/100 g pulp, technological index (TI) in %, and pulp yield (YP), in %.

Seed mass and vitamin C resulted in much lower values for $h^2g$, rejecting the physical and chemical analysis. Compared to other fruits, umbu-caja has low vitamin C content, providing small variation about different individuals (Santos et al., 2008b). Maia et al.. (2011) also reported lower estimates of vitamin C and cupuaçu fruit seed mass. Estimates of genetic parameters in umbu-cajazeira do not exist. These results indicate the potential for selection within the experiment, with good prospects for genetic gain in future breeding programs.

The evaluated clones showed no significant differences using the LRT for 14 traits (data not shown). This indicates that it was not possible to identify genetic differences between the six umbu-cajazeira clones. In general, there was a little genetic variability among clones, according to the estimates of genotypic variation coefficients of individual heritability. This result can be explained by the fact that umbu-cajazeira spreads exclusively by vegetative means, creating little genetic variability, which is only obtained by natural mutations (Souza et al., 2006).

The accuracy of clone selection ($r_{\hat{a}a}$) is measured by the correlation between the actual value and the genotypic value estimated or predicted by experimental results (Resende & Duarte, 2007). The accuracy must be correlated with the heritability in breeding programs, thus ensuring a greater response to selection. In this study, both the accuracy values, as well as the heritability, were higher for most characteristics between umbu-cajazeira clones, showing that the choice could indicate clones with desirable characteristics.

Besides the seed mass and vitamin C, all other characteristics expressed high accuracy values ($r_{\hat{a}a} > 0.90$), indicating that the experimental accuracies were high. According to Resende & Duarte (2007), the values obtained are close to those recommended for the selection process in breeding programs, which requires $r_{\hat{a}a}$ values above 0.70. Considering the identity and quality standard (PIQ) for yellow mombin, a species of the same genus as umbu-cajazeira, the values found in this study for pH, titratable acidity, and soluble solids indicate that high precision values are within the recommended levels (Brazil, 2000).

Table 2 contains the physical and chemical traits of clones obtained by individual Blup. The REML/BLUP methodology estimated and/or predicted genotypic and new middle values. The genotypic values of each clone were achieved by adding the overall mean (u) to the genotypic effect (g). These values should be able to be selected by a breeder since these are the actual values to be predicted. The genetic gain was calculated concerning the average of the predicted effects of genetic vectors for each clone. The new average is the sum of the overall mean with genetic gain and indicates how much each clone should produce (on average) for commercial crops. The new average values, being close to the genotypic values, indicate a promising selection of clones (Borges et al., 2010).

Results indicated that the genotypic values were very close to the new average values. From the individual performance of each clone about its traits (pH, titratable acidity, and soluble solids), the first three clones were considered for selection. Considering the overlap of confidence intervals of the predicted genotypic values, several clones were statistically equal at the 95% confidence level (Table 2).

Serra do Mel clone was first in the ranking for transversal diameter characteristics, fruit mass, pulp mass, titratable acidity and vitamin C. It is noteworthy that for other features such as longitudinal/transversal diameter, pH, technological index and pulp yield, the Serra do Mel clone was ranked high. It had higher vitamin C content, larger fruit size, and weight, which are ideal features both for fruit processing and fresh consumption. It also expressed a little acidity rate, pH 2.6, soluble solids 16.14 Brix, technological index and pulp yield 11.7 and 72.87%, respectively. Freitas et al. (2015) analysing the same umbu-caja clones in Rio Grande do Norte indicate that Serra do Mel clone produced fruits with greater quality using analysis of variance (ANOVA).

Açu clone selection showed the characteristic ratio of 1 for longitudinal/transversal diameter, indicating the next round fruits, corresponding to 12.25 technological index and pulp yield equal to 74.2%, will have ideal features for pulp production. Even the Ipanguaçu clone, which had the best soluble solids/titratable acidity, was outperformed by the Carnaubais clone about other features for fresh consumption, such as fruit mass, soluble solids/titratable acidity, longitudinal diameter and transversal diameter. Alto do Rodrigues clone can be recommended for fresh use because of the high soluble solids content. These clones stood out in having fruits with high pulp production and meet the fresh consumption demand and processing of local agricultural industries, potentially increasing the family income in the Natal area, resulting in better sustainability for fieldworkers.

About the pulp yield, which is the most important feature for industrial processing, Açu, Serra do Mel, Alto do Rodrigues, and Carnaubais clones showed the greatest genotypic values, with a genetic gain of up to 4%. For agribusiness, genotypes that produce an above average income should be selected (Pinto et al., 2003). A genetic gain up to 2.9% was found for the fruit mass and pulp mass features. The other variables showed genetic gain values of less than one. The pulp yield results obtained in this study were higher than those obtained by Gondim et al. (2013) at 68.53%.

The longitudinal diameter and transversal diameter variables are important for the increased demand of umbu-cajazeira fruit. Two clones showed the longitudinal/transversal diameter characteristics (Carnaubais and Serra do Mel). Gondim et al. (2013) evaluated the quality of the umbu-caja fruits in Paraíba; length and diameter of fruits ranged between 36.9 and 44.9 and 30.4 mm and 36.1 mm, respectively. The results obtained in the present study are consistent with the range of values for the umbu-cajazeiras fruit size in existing literature (Pinto et al., 2003; Gondim et al., 2013).

PIQ for yellow mombim pulp showed that all clones, except for Parelhas, met the basic requirements established for fruit pulp processing, with a minimum pH of 2.2, titratable acidity above 0, 90 g $100^{-1}$ g of citric acid, soluble solids above 9.5, and Brix soluble solids/titrable acidity greater than 10, indicating a possibility to select clones for most features. Table 3 presents information on the quality of fruits for both fresh consumptions and processing pulp.

**Table 2.** Ranking of clones (ODR), clones (CL), genotypic value (u + g), and new middle (NV) of fourteen physical traits in six umbu-cajazeira clones (*Spondias* sp.).

| ORD | CL | u+g | IC | NV | ORD | CL | u+g | IC | NV |
|---|---|---|---|---|---|---|---|---|---|
| Longitudinal diameter | | | | | Transversal diameter | | | | |
| 1 | CAR | 32.72 | 30.1-35.3 | 32.72 | 1 | SER | 31.38 | 28.6-33.9 | 31.38 |
| 2 | SER | 32.34 | 29.7-34.9 | 32.53 | 2 | CAR | 31.14 | 28.5-33.7 | 31.26 |
| 3 | AÇU | 31.89 | 29.9-34.5 | 32.32 | 3 | ALT | 30.98 | 28.4-33.6 | 31.17 |
| 4 | ALT | 31.70 | 29.1-34.3 | 32.16 | 4 | AÇU | 30.87 | 28.3-33.5 | 31.09 |
| 5 | IPA | 30.22 | 27.6-32.8 | 31.77 | 5 | IPA | 26.86 | 24.3-29.4 | 30.25 |
| 6 | PAR | 24.72 | 22.1-27.3 | 30.60 | 6 | PAR | 24.13 | 21.5-26.7 | 29.23 |
| Longitudinal/Transversal diameter | | | | | Fruit mass | | | | |
| 1 | IPA | 1.13 | 1.1-1.2 | 1.13 | 1 | SER | 18.93 | 15.4-22.4 | 18.93 |
| 2 | CAR | 1.05 | 1.0-1.1 | 1.09 | 2 | CAR | 18.64 | 15.1-22.2 | 18.78 |
| 3 | SER | 1.03 | 0.9-1.1 | 1.07 | 3 | AÇU | 18.28 | 14.8-21.8 | 18.61 |
| 4 | ALT | 1.03 | 0.9-1.1 | 1.06 | 4 | ALT | 18.04 | 14.5-21.5 | 18.47 |
| 5 | AÇU | 1.03 | 0.9-1.1 | 1.05 | 5 | IPA | 12.36 | 8.9-15.7 | 17.25 |
| 6 | PAR | 1.02 | 0.9-1.0 | 1.05 | 6 | PAR | 9.49 | 5.9-13.0 | 15.96 |
| Pulp mass | | | | | Shell mass | | | | |
| 1 | SER | 13.85 | 10.9-16.7 | 13.85 | 1 | CAR | 3.30 | 2.71-3.88 | 3.30 |
| 2 | AÇU | 13.63 | 10.7-16.5 | 13.74 | 2 | SER | 3.07 | 2.50-3.63 | 3.18 |
| 3 | CAR | 13.22 | 10.3-16.1 | 13.57 | 3 | ALT | 2.97 | 2.39-3.54 | 3.11 |
| 4 | ALT | 13.13 | 10.2-16.0 | 13.46 | 4 | AÇU | 2.76 | 2.18-3.33 | 3.02 |
| 5 | IPA | 8.46 | 5.6-11.3 | 12.46 | 5 | PAR | 1.97 | 1.38-2.55 | 2.81 |
| 6 | PAR | 5.76 | 2.8-8.7 | 11.34 | 6 | IPA | 1.88 | 1.32-2.43 | 2.66 |
| Seed mass | | | | | Titratable acidity | | | | |
| 1 | CAR | 1.96 | 1.9-1.9 | 1.96 | 1 | SER | 1.27 | 1.1-1.4 | 1.27 |
| 2 | IPA | 1.96 | 1.9-1.9 | 1.96 | 2 | AÇU | 1.25 | 1.1- 1.4 | 1.26 |
| 3 | SER | 1.96 | 1.9-1.9 | 1.96 | 3 | ALT | 1.20 | 1.1-1.3 | 1.24 |
| 4 | ALT | 1.96 | 1.9-1.9 | 1.96 | 4 | PAR | 1.13 | 0.9-1.3 | 1.21 |
| 5 | AÇU | 1.96 | 1.9-1.9 | 1.96 | 5 | CAR | 1.09 | 0.9-1.2 | 1.19 |
| 6 | PAR | 1.96 | 1.9-1.9 | 1.96 | 6 | IPA | 0.98 | 0.8-1.1 | 1.15 |
| pH | | | | | Soluble solids | | | | |
| 1 | IPA | 2.96 | 2.8-3.11 | 2.96 | 1 | ALT | 16.50 | 15.6-17.3 | 16.50 |
| 2 | PAR | 2.74 | 2.6-2.9 | 2.85 | 2 | AÇU | 16.41 | 15.6-17.2 | 16.46 |
| 3 | SER | 2.66 | 2.5-2.8 | 2.79 | 3 | SER | 16.14 | 15.3-16.9 | 16.35 |
| 4 | ALT | 2.60 | 2.4-2.4 | 2.74 | 4 | IPA | 16.05 | 15.3-16.8 | 16.28 |
| 5 | CAR | 2.60 | 2.4-2.8 | 2.71 | 5 | CAR | 15.74 | 14.9-16.6 | 16.17 |
| 6 | AÇU | 2.49 | 2.3-2.6 | 2.68 | 6 | PAR | 14.43 | 16.5-15.2 | 15.88 |
| Vitamin C | | | | | Soluble solids/Titratable acidity | | | | |
| 1 | SER | 14.09 | 13.2-14.9 | 14.09 | 1 | IPA | 16.73 | 15.2-18.3 | 16.73 |
| 2 | CAR | 13.98 | 13.1-14.9 | 14.03 | 2 | CAR | 14.60 | 12.9-16.3 | 15.67 |
| 3 | IPA | 13.69 | 12.9-14.5 | 13.92 | 3 | ALT | 14.01 | 12.4-15.6 | 15.11 |
| 4 | PAR | 13.44 | 12.5-14.3 | 13.80 | 4 | AÇU | 13.09 | 11.5-14.7 | 14.61 |
| 5 | ALT | 13.14 | 12.3-14.0 | 13.67 | 5 | PAR | 12.98 | 11.3-14.6 | 14.28 |
| 6 | AÇU | 12.93 | 12.0-13.8 | 13.54 | 6 | SER | 12.72 | 11.1-14.3 | 14.02 |
| Pulp yield | | | | | Technological index | | | | |
| 1 | AÇU | 74.41 | 70.1-78.7 | 74.41 | 1 | AÇU | 12.25 | 11.1-13.4 | 12.25 |
| 2 | SER | 72.87 | 68.6-77.1 | 73.64 | 2 | ALT | 12.05 | 10.9-13.2 | 12.15 |
| 3 | ALT | 72.58 | 68.3-76.9 | 73.29 | 3 | SER | 11.79 | 10.7-12.9 | 12.03 |
| 4 | CAR | 70.75 | 66.4-75.1 | 72.65 | 4 | CAR | 11.12 | 9.9-12.2 | 11.80 |
| 5 | IPA | 68.50 | 64.3-72.7 | 71.82 | 5 | IPA | 11.00 | 9.8-12.1 | 11.64 |
| 6 | PAR | 61.24 | 56.9-65.6 | 70.06 | 6 | PAR | 8.74 | 7.6-9.8 | 11.16 |

Legend: AÇU (Açu), SER (Serra do Mel), ALT (Alto do Rodrigues), CAR (Carnaubais), IPA (Ipanguaçu), PAR (Parelhas).

**Table 3.** Reference to fruit quality of umbu-cajazeira (*Spondias* sp.) for fresh consumption and pulp processing, considering the identity and quality standard (PIQ) for yellow mombin (Brazil, 2000).

| Variables | Fresh consumption | Pulp processing |
|---|---|---|
| pH | high | between 2.2 ≥ x ≤3.5 |
| Titrable acidity | low | ≥0.90 g/100 g citric acid |
| Soluble solids | high | ≥9.5 ºBrix |
| Soluble solids/Titrable acidity | high | ≥10.0 |
| Pulp yield | - | ≥50% |
| Longitudinal/Transversal diameter | Round fruits | Round fruits |

Traits: pH: potential of hydrogen.

These clones stood out in producing fruits with a high potential for pulp production and can meet the demand for fresh fruit as well as local agricultural industries, thereby improving the economy and job security of the semiarid area.

Parelhas clone showed inferior quality compared to others, with smaller size and lower weight of fruits, and lower soluble solids content, low technological index, and lower SS/TA. Based on these features, this clone could be excluded from any breeding program in the early stages, because it has unfavorable selection characteristics.

Method REML/BLUP, being a mixed model, allowed a selection of clones based on the genotypic value and not on the phenotypic value, characteristic of the analysis of variance. It is necessary to increase the genetic variability in the EMPARN germplasm bank for *Spondias* through the creation of new umbu-cajazeiras for the semiarid regions. Because it is a lesser known species of Brazilian fruit tree, breeding should be aimed at increasing the quality and value of umbu-cajazeira fruits produced in north-eastern Brazil, improving characteristics such as resistance to pests and diseases, increased content in soluble solids composition, and increased productivity, contributing to the its quality, acceptability, and product competitiveness in the national market.

## Conclusions

Serra do Mel clone ranked first in all fruit quality traits and can be used both for pulp processing and for fresh consumption.

Açu clone has ideal features for pulp processing.

Carnaubais, Alto do Rodrigues and Ipanguaçu are recommended for fresh consumption.

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