

## Article

# New Sweet Potato Genotypes: Analysis of Agronomic Potential

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## Abstract

The quantification of genotype  $\times$  environment interaction is essential for recommending high-yielding genotypes for both favorable and unfavorable environments, thereby increasing production. This study aimed to evaluate the agronomic performance of sweet potato genotypes in the central–east and central–south regions of São Paulo. The experiments were conducted using a randomized block design with 9 plants per plot and 3 replications, consisting of 18 sweet potato genotypes and 3 commercial cultivars, totaling 21 treatments. The characteristics, such as commercial productivity, dry matter, chroma, hue, insect resistance, eyes, and lenticels showed genotype  $\times$  environment interaction for 77.78% of the variables. The maximum productivity of the genotypes ranged from 31.81 t/ha<sup>−1</sup> to 63.60 t/ha<sup>−1</sup>. Heritability was observed in 88.89% of the analyzed traits, with values ranging from 75.36% to 93.47%, indicating a significant genetic influence on the evaluated characteristics. Location 4 (first cycle in Botucatu, 20 December 2021) was superior and considered the most suitable for sweet potato cultivation. The genotypes CERAT60-05, CERAT56-23, CERAT60-26, and CERAT35-11 performed best, showing promise as new cultivars.

**Keywords:** *Ipomoea batatas*; genetic parameters; heritability



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## 1. Introduction

The sweet potato is an allogamous plant with a self-incompatibility mechanism that leads to cross-pollination and, consequently, a high degree of heterozygosity [1]. For the development of new cultivars, directed crosses require hybridization techniques, backcrossing, and incur high implementation costs. The sweet potato is one of the most consumed vegetables worldwide and ranks among the most important root crops, being cultivated in over 110 countries. It is a staple food in tropical countries, although it is also widely grown in subtropical and temperate regions [2,3].

China is the largest producer of sweet potatoes, with 51,629,135.1 t, followed by Malawi with 8,045,477.59 t, Tanzania with 4,514,919.3 t, Nigeria with 4,084,517.8 t, and Brazil with 925,618 t. Brazil ranks 14th among the world’s largest producers of sweet potatoes [4]. The leading producing states are São Paulo (160,514 t), Rio Grande do Sul (155,070 t),

and Ceará (116,668 t) [5]. Sweet potato cultivation is the sixth most planted vegetable in Brazil, producing 847,100 t and generating BRL 1413.645 million in production value in 2022 [5]. Over the past decade, both sweet potato production and the cultivated area have increased due to the rising demand for sweet potatoes, particularly for their nutritional characteristics, low glycemic index, and fiber content. The socioeconomic importance of the sweet potato has expanded cultivation and production, offering positive growth prospects for the industry [6].

Less nutritious and low-yield local cultivars are grown in Africa. At the International Potato Center (CIP), through the programs Sweetpotato Action for Security and Health in Africa (SASHA), Orange-fleshed Sweetpotato (OFSP), and Sweetpotato Genetic Advances and Innovative Seed Systems (SweetGAINS), studies have been conducted on biofortified cultivars with beta-carotene and anthocyanin content, and with higher productivity. More than 250 million preschool-aged children and approximately 19 million pregnant women suffer from caloric and vitamin A deficiencies [7,8]. With the introduction of biofortified cultivars, the daily vitamin A requirements have been met in regions of Eastern and Southern Africa, unlike in some West African countries [9]. The sweet potato has been reported to be a good potential source of phenolic compounds and antioxidants, and it has potential for preventing many chronic diseases, including cancer, cardiovascular diseases, and diabetes [10,11]. Despite its economic, nutritional, and social significance, investment in sweet potato cultivation in Brazil remains low due to its predominantly family-farming profile. Most farmers cultivate sweet potatoes with low technological input, resulting in yields below  $10 \text{ t ha}^{-1}$ , which reduces productivity and profitability [12,13]. High-tech cultivation with improved cultivars, irrigation, fertilization, and pest management can yield up to  $210 \text{ t ha}^{-1}$ .

The sweet potato is grown in almost all regions of Brazil due to its adaptability to different climates, such as equatorial, tropical, semi-arid, and subtropical, as well as to soils, its tolerance to drought, and its low production costs [14]. Advances in sweet potato research contribute directly to agricultural expansion, increased production, improved food quality, the promotion of sustainability, and the opening of new markets [15]. This increased demand stimulates the need for new research projects to improve sweet potato production worldwide. The genetic improvement of sweet potatoes has become a focal point in various research studies. Promising cultivars are available to both producers and consumers.

However, most research focuses on developing cultivars suited for fresh consumption. These cultivars must meet specific market requirements, including root shape and quality [16,17]. Genetic improvement studies have focused on enhancing both qualitative and quantitative traits. Institutions such as Embrapa, UNESP, UFLA, and UNOESTE have developed cultivars to meet national market demands. High-yielding, disease-resistant, pest-resistant, drought-tolerant, biofortified, and dual-purpose cultivars are examples, with sweet potato yields reaching up to  $120 \text{ t ha}^{-1}$  [18].

Inheritance pattern studies indicate that selecting high-yielding plants first and then evaluating them across multiple environments can enhance selection efficiency [19]. The variation in genotype performance due to environmental differences is called genotype  $\times$  environment interaction. This interaction occurs when cultivars do not behave consistently across different environments. It can be classified as simple, complex, or absent, depending on how cultivars respond to environmental changes [20]. In genetic terms, this interaction arises when gene contributions or expression levels vary across environments due to environmental influence or regulation.

Plant breeding programs consist of three phases, as follows: (1) developing a base population with high genetic variability and adaptation potential, (2) selecting segregating

families for maximum direct, indirect, or simultaneous gains in key traits, and (3) improving genetic material and recommending it for broad or specific regions. The average time to release a new sweet potato cultivar is 3.5 to 4 years, highlighting the importance of genotype  $\times$  environment interaction studies [21]. Given these factors, this study aimed to evaluate the agronomic performance of elite sweet potato genotypes in the regions of São Paulo.

## 2. Materials and Methods

The trials were conducted at the Faculty of Agricultural and Veterinary Sciences (FCAV), Jaboticabal Campus, and the Faculty of Agronomic Sciences (FCA). Jaboticabal (FCAV) is located at a latitude of 21°14'05" S, a longitude of 48°17'09" W, and an altitude of 615.01 m. The soil in the study area is classified as a Dark Red Eutrophic Latosol, with a clayey texture and gently undulating relief [22]. The maximum, the average, and minimum temperatures were 32 °C, 25 °C, and 14 °C, respectively, accompanied by a maximum precipitation of 275 mm, an average of 140 mm, and a minimum of 30 mm. Botucatu (FCA) is situated at a latitude of 22°44'52" S, longitude of 48°35'1" W, and an altitude of 740 m; the soil is classified as a Red Latosol with a medium texture [23]. The maximum temperature was 31 °C, with an average of 24 °C and a minimum of 20 °C, while precipitation levels reached a maximum of 260 mm, an average of 120 mm, and a minimum of 20 mm.

In Jaboticabal, the planting and harvest dates for the trials were as follows: first cycle (E1): planted on 17 December 2021 and harvested on 26 April 2022; second cycle (E2): planted on 21 February 2022 and harvested on 22 June 2022; third cycle (E3): planted on 2 April 2022 and harvested on 23 September 2022. In Botucatu, the planting and harvest dates were as follows: first cycle (E4): planted on 20 December 2021 and harvested on 20 April 2022; second cycle (E5): planted on 20 February 2022 and harvested on 24 June 2022; third cycle (E6): planted on 6 April 2022 and harvested on 21 July 2022.

A total of 21 sweet potato genotypes were evaluated, including 18 genotypes derived from advanced trials conducted since 2018 by NEOM (Nucleus for Studies in Horticulture and Breeding). These genotypes originated from botanical seeds obtained through non-directed crosses (Polycross) from the CIP-Mozambique (International Potato Center) breeding program. Three commercial sweet potato cultivars were included as controls (Table 1).

For genotype propagation, cuttings were taken from mother plants to prepare mini-stakes with two or three nodes, which were placed in 128-cell trays filled with substrate. The seedlings remained in a greenhouse for development. Irrigation was carried out via a sprinkler system, according to the needs of the seedlings, twice daily during the initial stage and once daily after establishment. Transplanting was performed into five-liter pots in the greenhouse, with the goal of producing sufficient cuttings for field trial establishment. Fertigation was applied to the pots once a week, using micro- and macronutrients, to ensure the production of vigorous shoots.

Soil chemical analyses were performed by collecting samples from a depth of 0–20 cm at random points in the areas where the trials were conducted. The results are presented in Table 2.

The soil was prepared by performing one aeration and two harrowings, followed by the construction of ridges measuring 40 cm in height and spaced 1.1 m apart. Basal fertilization was applied according to the recommendations of Boletim 100 [26], and consisted of 60 kg ha<sup>−1</sup> of P<sub>2</sub>O<sub>5</sub> (triple superphosphate), 90 kg ha<sup>−1</sup> of K<sub>2</sub>O (potassium chloride), and 30 kg ha<sup>−1</sup> of nitrogen. Cuttings measuring 30 cm in length were harvested from mother plants and planted with two-thirds of their length buried in the soil at a depth of approximately 20–25 cm, spaced 33 cm apart.

**Table 1.** Control cultivars (UNESP Maria Rita, Amélia, Beauregard).

| Cultivar         | Year of Release | Origin                                                   | Characteristics                                                                                          | Cycle (Days) | Productivity (t ha <sup>-1</sup> ) |
|------------------|-----------------|----------------------------------------------------------|----------------------------------------------------------------------------------------------------------|--------------|------------------------------------|
| UNESP Maria Rita | 2023            | UNESP-CERAT                                              | Has orange flesh with a high beta-carotene (vitamin A) content, cream-colored skin, and a fusiform shape | 120          | 40                                 |
| Amélia           | 2007            | Embrapa Clima Temperado                                  | Features a long, elliptical shape, light pink skin, and intermediate orange flesh                        | 120 to 140   | 32                                 |
| Beauregard       | 1987            | Louisiana Agricultural Experiment Station (LSU AgCenter) | Its roots are elongated, with reddish-purple skin                                                        | 120 to 150   | 23 to 29                           |

Source: Adapted from De [24,25].

**Table 2.** Chemical and physical characteristics of the soil used in the Jaboticabal and Botucatu experiments.

| Location    | pH                   | M.o.               | P                   | S  | Ca                     | Mg | Al | H + Al/SMP | SB   | CTC  | StB | B    | Cu  | Fe | Mn   | Zn  |
|-------------|----------------------|--------------------|---------------------|----|------------------------|----|----|------------|------|------|-----|------|-----|----|------|-----|
|             | (CaCl <sub>2</sub> ) | g dm <sup>-3</sup> | mg dm <sup>-3</sup> |    | mmolc dm <sup>-3</sup> |    |    |            | m%   |      |     |      |     |    |      |     |
| Jaboticabal | 5.8                  | 24                 | 37                  | 12 | 23                     | 10 | 0  | 20         | 36.2 | 56.1 | 65  | 0.26 | 5.0 | 20 | 20.1 | 3.8 |
| Botucatu    | 5.6                  | 21                 | 55                  | 15 | 26                     | 12 | 0  | 22         | 40.7 | 62.9 | 65  | 0.22 | 4.7 | 11 | 14.3 | 2.2 |

pH: Hydrogen potential; M.o.: molybdenum; P: phosphorus; S: sulfur; Ca: calcium; Mg: magnesium; K: potassium; Al: aluminum; H + Al: potential acidity; SMP: determined in buffer solution; SB: base sum, CTC: Cation exchange capacity; StB: base saturation; B: boron; Cu: copper; Fe: iron; Mn: manganese; and Zn: zinc. Source: Dango F.J.U.

Irrigation was carried out using a sprinkler system, adjusted according to the crop's needs. At 30 days after planting, a topdressing application of 30 kg ha<sup>-1</sup> of nitrogen (urea) was performed. Crop management included manual weeding and the application of the herbicide Verdict Max for weed control. For the control of *Diabrotica speciosa*, the insecticide cypermethrin (Nortox) was utilized.

In all experiments, harvesting was conducted 120 days after planting. The following parameters were evaluated:

- Productivity: mass of all roots harvested in the plot, subsequently converted to kg ha<sup>-1</sup>.
- Commercial root productivity (PC): mass of roots weighing more than 80 g.
- Total number of roots (TNR): number of roots harvested in the plot.
- Number of commercial roots (NCR): number of roots harvested in the plot with a mass equal to or greater than 80 g.
- Average root mass (ARM): obtained by dividing the total productivity by the total number of roots.
- Average commercial root mass (ACRM): obtained by dividing commercial productivity by the number of commercial roots.

- Root dry matter content (RDMC): samples of 0.3 kg of roots were ground and then dried in an oven at 65 °C until constant weight was achieved, for determination of dry matter content (%).
- Dry matter production (DMP): obtained by multiplying total productivity by the root dry matter content.

The classification of visual characteristics was assigned by three evaluators, as follows:

- General shape (FG): scores from 1 to 4 were assigned, where 1 = non-commercial shape with many deformities; 4 = fusiform shape [3].
- Insect resistance (IR): scores from 1 to 5 assigned based on the presence of galleries or holes in the roots: 1 = damage severely affecting commercial appearance; 5 = free from damage [3].
- Eyes (Ey): scores from 1 to 4, where 1 = many eyes; 4 = absence of eyes [3].
- Vein (Vein): scores from 0 to 1, where 0 = absence of veins; 1 = presence of veins [3].
- Lenticels (Len): scores from 1 to 4, where 1 = many lenticels; 4 = absence of lenticels [3].

Coloration: determined using a Colorimeter—CR-400® (Konica Minolta), São Paulo, Brazil.

- Chroma (CHROMA): saturation angle calculated as  $\sqrt{(a^*)^2 + (b^*)^2}$ .
- Munsell Hue (Hue): representation of color hue angle. Hue = IF (Hue2 < 0; Hue2 + 180; Hue2 + 0).

A joint analysis of the evaluated variables was performed. Subsequently, an analysis of variance (ANOVA) was conducted using Genes software, version 1990.2023.48, with a simple factorial design (fixed genotypes  $\times$  random environments) according to the following statistical model:  $Y_{ijk} = m + (B/A)_{jk} + G_i + A_j + GA_{ij} + \epsilon_{ijk}$ : observed value in the  $k$ -th  $i$ -th block, evaluated for the  $i$ -th genotype in the  $j$ -th environment;  $m$ : overall average of the tests;  $(B/A)_{jk}$ : effect of block  $k$  within environment  $j$ ;  $G_i$ : effect of the  $i$ -th genotype;  $A_j$ : effect of the  $j$ -th environment;  $GA_{ij}$ : effect of the interaction between genotype  $i$  and environment  $j$ ;  $\epsilon_{ijk}$ : random error associated with observation  $ijk$ .

For the variable vein, the data were transformed using  $\sqrt{(x + 0.5)}$ , due to the presence of zero values. After the analysis of variance, the Scott–Knott test at 5% probability was performed to identify superior genotypes within the six environments and to compare genotypes within the same environment. In the joint data analysis, the genotype by environment interaction was verified using the expected mean squares (E(QM)), considering the effects of genotypes as fixed, and the effects of blocks, environment, residual, and  $G \times E$  interaction as random, as proposed by Cruz et al. [19].

### 3. Results

The joint analysis of variance was significant for the evaluated variables; 77.78% showed significant genotype  $\times$  environment interaction. Significant interaction was observed in 77.78% of the cases for genotypes and 88.89% for the environment. Table 3 presents the summary of the joint variance analysis of the experiments evaluated in three environments (cycles) in Botucatu and three environments (cycles) in Jaboticabal, considering 21 genotypes.

**Table 3.** Summary of the joint variance analysis of the experiments conducted in Botucatu and Jaboticabal, considering 21 genotypes during 2021 and 2022, for the following traits: commercial productivity (PC), dry matter content (TMS), saturation angle (Chroma), color hue representation (Hue), general shape (GS), insect resistance (RI), eyes (Eye), veins (Vei), and lenticels (Len).

| FV                 | Mean Square |           |           |            |                    |                    |         |                    |         |
|--------------------|-------------|-----------|-----------|------------|--------------------|--------------------|---------|--------------------|---------|
|                    | PC          | TMS       | Chroma    | Hue        | FG                 | RI                 | Eye     | Vei                | Len     |
| Blocks/Environment | 0.22        | 35.04     | 2.73      | 38.11      | 1.44               | 0.45               | 0.21    | 0.02               | 0.18    |
| Environment        | 35.15 **    | 295.18 ** | 82.57 **  | 156.97 *   | 1.49 <sup>ns</sup> | 8.11 **            | 1.74 ** | 0.23 **            | 1.83 ** |
| Genotypes          | 18.80 **    | 114.85 ** | 407.98 ** | 2795.01 ** | 4.56 **            | 0.92 <sup>ns</sup> | 1.82 ** | 0.02 <sup>ns</sup> | 0.38 *  |
| GXE                | 3.64 **     | 19.33 **  | 91.05 **  | 182.42 **  | 0.74 <sup>ns</sup> | 0.56 **            | 0.45 ** | 0.03 <sup>ns</sup> | 0.18 *  |
| Residue            | 0.16        | 5.02      | 7.40      | 31.03      | 0.76               | 0.32               | 0.30    | 0.04               | 0.14    |
| Averages           | 15.09       | 26.6      | 42.22     | 68.10      | 3.17               | 3.91               | 3.01    | 0.75               | 3.16    |
| CV%                | 3.11        | 8.42      | 6.44      | 8.17       | 27.63              | 14.50              | 18.41   | 27.17              | 11.88   |

PC: commercial productivity (t ha<sup>-1</sup>); TMS: dry matter content (%); Chroma: saturation angle; Hue: color hue representation in the angle; FG: general shape (rated from 1 to 5); RI: insect resistance (rated from 1 to 5); Eye: eyes (rated from 1 to 5); Vei: veins (rated from 0 to 1); Len: lenticels (rated from 1 to 4); CV%: experimental coefficient of variation; <sup>ns</sup>: not significant by the F test; \* significant at 5% probability and \*\* significant at 1% probability by the T test; <sup>ns</sup>: not significant. Source: Dango F.J.U.

This study revealed high genetic variability for the evaluated traits, with higher values in genetic parameters, genotype  $\times$  environment interaction, and heritability for the traits Hue, Chroma, TMS, and PC. The genetic and relative coefficients of variation showed that the trait PC had the highest percentage. Table 4 presents estimate of genetic and environmental parameters, including genotypic variance ( $\sigma_g^2$ ), genotype  $\times$  environment variance ( $\sigma_{gxe}^2$ ), heritability ( $h^2$ ), genotype-environment coefficient of variation ( $\sigma_e^2$ ), genotypic coefficient of variation (CVg), environmental variance (CVe), and relative coefficient of variation (CVr).

**Table 4.** Estimates of genetic parameters in agronomic and qualitative traits of sweet potato.

|                  | PC    | TMS   | Chroma | Hue    | FG    | RI    | Eye   | Vei   | Len   |
|------------------|-------|-------|--------|--------|-------|-------|-------|-------|-------|
| $\sigma_g^2$     | 0.84  | 5.30  | 17.6   | 145.14 | 0.21  | 0.02  | 0.07  | -     | 0.01  |
| $\sigma_{gxe}^2$ | 1.10  | 4.54  | 26.55  | 48.06  | -     | 0.07  | 0.04  | -     | 0.01  |
| $\sigma_e^2$     | 0.16  | 5.02  | 7.4    | 31.03  | 0.76  | 0.32  | 0.30  | 0.40  | 0.14  |
| $h_{mc}^2$       | 80.59 | 83.16 | 77.68  | 93.47  | 83.79 | 39.05 | 75.36 | -     | 51.07 |
| $h_i^2$          | 39.84 | 35.67 | 34.14  | 64.72  | 21.86 | 39.05 | 17.82 | -     | 6.56  |
| CVg(%)           | 25.32 | 8.65  | 9.93   | 17.67  | 14.53 | 3.61  | 9.18  | -     | 3.31  |
| CVe(%)           | 11.22 | 8.42  | 6.44   | 8.17   | 27.63 | 14.55 | 18.41 | 27.17 | 11.88 |
| CVr(%)           | 2.25  | 1.02  | 1.54   | 2.16   | 0.52  | 0.24  | 0.49  | -     | 0.27  |
| Average          | 15.09 | 26.60 | 42.22  | 68.10  | 3.17  | 3.91  | 3.01  | 0     | 3.16  |

PC: commercial productivity; TMS: dry matter content; Chroma: color saturation angle; Hue: color tone angle; FG: general shape of root; RI: insect resistance; Eye: eyes; Vei: veins; Len: lenticels;  $\sigma_g^2$ : genotypic variance;  $\sigma_{gxe}^2$ : genotype  $\times$  environment interaction variance;  $\sigma_e^2$ : environmental variance;  $h_{mc}^2$ : average heritability of genotypes;  $h_i^2$ : individual heritability; CVg(%): genotypic variation coefficient; CVe(%): environmental variation coefficient; CVr = CVg/CVe: ratio between genetic and environmental variation coefficients. Source: Dango F.J.U.

Genotype  $\times$  environment interaction was observed in the Botucatu and Jaboticabal environments during the evaluated harvests. Commercial productivity showed genotype  $\times$  environment interaction, with the genotypes CERAT60-05, CERAT56-23, and CERAT51-30 standing out. These genotypes exceeded the Brazilian average of 15.17 t ha<sup>-1</sup>. Table 5 presents the means of sweet potato genotypes in Botucatu and Jaboticabal during the years 2021 and 2022 across three seasons for the evaluated traits.

**Table 5.** Average of sweet potato genotypes in Botucatu and Jaboticabal, in the years 2021 and 2022 for the following characteristics: commercial productivity (PC), dry matter content (TMS), saturation angle (Chroma), color hue representation at angle (Hue), general shape (FG), insect resistance (RI), eyes (Eye), veins (Vei), and lenticels (Len).

| Genotypes/Cultivars | Environment | PC (t ha <sup>-1</sup> ) | TMS (%)  | Chroma   | Hue      | FG      | RI      | Eye     | Vei     | Len     |
|---------------------|-------------|--------------------------|----------|----------|----------|---------|---------|---------|---------|---------|
| CERAT21-02          | E1          | 2.85 Bh                  | 30.94 Ba | 46.40 Aa | 75.34 Aa | 3.33 Ab | 4.50 Aa | 3.33 Aa | 0.00 Ba | 3.50 Aa |
|                     | E2          | 2.85 Bc                  | 31.15 Ba | 41.52 Bb | 77.09 Aa | 2.33 Aa | 1.83 Cc | 2.16 Bb | 0.00 Aa | 2.50 Bb |
|                     | E3          | 1.62 Bf                  | 36.14 Aa | 48.47 Aa | 75.68 Ab | 3.00 Aa | 3.16 Bb | 3.16 Aa | 0.00 Ba | 3.16 Aa |
|                     | E4          | 10.05 Ae                 | 27.08 Cc | 40.46 Bc | 72.32 Ab | 3.33 Ab | 4.50 Aa | 3.33 Aa | 0.00 Ba | 3.50 Aa |
|                     | E5          | 2.70 Be                  | 26.00 Cc | 43.97 Bb | 75.64 Aa | 2.83 Aa | 2.50 Bb | 2.50 Bb | 1.00 Aa | 2.50 Bb |
|                     | E6          | 1.63 Bd                  | 32.07 Ba | 43.12 Bb | 75.76 Ac | 3.16 Aa | 4.50 Aa | 3.50 Aa | 0.00 Aa | 3.33 Aa |
| CERAT21-06          | E1          | 6.0 Cg                   | 24.48 Bb | 45.48 Aa | 81.18 Aa | 3.66 Aa | 4.00 Aa | 4.00 Aa | 0.00 Aa | 3.66 Aa |
|                     | E2          | 21.45 Aa                 | 30.90 Aa | 46.29 Aa | 79.79 Aa | 3.33 Aa | 4.50 Aa | 2.83 Ba | 0.00 Ab | 3.16 Ba |
|                     | E3          | 26.20 Ab                 | 27.55 Ac | 48.81 Aa | 80.88 Aa | 3.83 Aa | 3.50 Aa | 2.66 Ba | 0.00 Aa | 2.66 Bb |
|                     | E4          | 26.10 Ac                 | 30.21 Ab | 43.58 Ab | 81.13 Aa | 3.66 Aa | 4.00 Aa | 4.00 Aa | 0.00 Aa | 3.66 Aa |
|                     | E5          | 6.30 Cd                  | 23.26 Bc | 45.95 Ab | 81.09 Aa | 3.50 Aa | 3.50 Aa | 3.16 Ba | 0.00 Ab | 3.16 Ba |
|                     | E6          | 12.85 Bb                 | 29.62 Aa | 49.12 Aa | 79.15 Ab | 3.83 Aa | 4.33 Aa | 3.00 Bb | 0.00 Aa | 3.00 Ba |
| UNESP Maria Rita    | E1          | 30.75 Ac                 | 30.39 Aa | 46.98 Ba | 77.11 Aa | 3.66 Aa | 3.83 Aa | 3.50 Aa | 0.00 Aa | 3.50 Aa |
|                     | E2          | 23.70 Ba                 | 19.65 Cc | 46.79 Ba | 75.44 Aa | 3.91 Aa | 3.91 Aa | 3.16 Aa | 0.00 Ab | 3.25 Aa |
|                     | E3          | 15.30 Cc                 | 26.89 Bc | 46.65 Ba | 73.83 Ab | 4.16 Aa | 4.00 Aa | 2.83 Aa | 0.00 Aa | 3.00 Ab |
|                     | E4          | 34.50 Ab                 | 25.05 Bd | 45.01 Bb | 75.14 Aa | 3.66 Aa | 3.83 Aa | 3.50 Aa | 0.00 Aa | 3.50 Aa |
|                     | E5          | 3.60 Ee                  | 22.83 Cc | 46.88 Aa | 75.27 Aa | 4.00 Aa | 4.16 Aa | 2.83 Aa | 0.00 Ac | 3.00 Aa |
|                     | E6          | 8.13 Dc                  | 26.24 Bb | 47.85 Ba | 74.83 Ac | 4.33 Aa | 4.50 Aa | 3.66 Aa | 0.00 Aa | 3.50 Aa |
| CERAT25-27          | E1          | 4.5 Bh                   | 32.14 Ba | 41.64 Ab | 68.47 Bb | 3.00 Ab | 4.00 Aa | 2.50 Ab | 0.00 Aa | 3.00 Aa |
|                     | E2          | 4.20 Bc                  | 27.96 Ca | 40.34 Ab | 61.45 Cb | 3.00 Aa | 3.66 Ba | 2.83 Aa | 0.00 Aa | 2.50 Bb |
|                     | E3          | 4.00 Cf                  | 35.95 Aa | 41.82 Ab | 69.45 Bc | 2.50 Ab | 3.50 Bb | 3.50 Aa | 0.00 Aa | 3.50 Aa |
|                     | E4          | 37.87 Ab                 | 29.45 Cb | 37.55 Ac | 56.72 Cc | 3.00 Ab | 4.00 Aa | 2.50 Ab | 0.00 Aa | 3.00 Aa |
|                     | E5          | 2.70 Be                  | 28.70 Cb | 42.93 Ab | 73.50 Ba | 2.83 Aa | 2.83 Bb | 2.33 Ab | 0.00 Ab | 2.33 Bb |
|                     | E6          | 2.17 Bd                  | 29.95 Ca | 43.19 Ab | 81.65 Ab | 2.83 Aa | 4.50 Aa | 2.83 Ab | 0.00 Aa | 3.16 Aa |
| CERAT31-12          | E1          | 38.4 Ab                  | 27.44 Ab | 49.48 Aa | 76.78 Aa | 4.16 Aa | 4.33 Aa | 3.50 Aa | 0.00 Aa | 3.50 Aa |
|                     | E2          | 18.30 Ba                 | 25.20 Ab | 48.27 Aa | 76.52 Aa | 4.50 Aa | 4.33 Aa | 3.33 Aa | 0.00 Aa | 3.33 Aa |
|                     | E3          | 6.87 Cd                  | 27.86 Ac | 50.91 Aa | 74.58 Ab | 3.00 Aa | 3.16 Bb | 3.16 Aa | 0.00 Aa | 2.83 Ab |
|                     | E4          | 31.95 Ab                 | 26.83 Ac | 49.63 Aa | 76.73 Aa | 4.16 Aa | 4.33 Aa | 3.50 Aa | 0.00 Aa | 3.50 Aa |
|                     | E5          | 23.40 Ba                 | 25.30 Ac | 44.60 Ab | 75.07 Aa | 3.16 Aa | 3.66 Ba | 2.83 Aa | 0.00 Ab | 3.00 Aa |
|                     | E6          | 5.67 Cc                  | 28.11 Aa | 47.93 Aa | 79.25 Ab | 3.16 Aa | 3.66 Ba | 3.33 Aa | 0.00 Aa | 3.16 Aa |

Table 5. Cont.

| Genotypes/Cultivars | Environment | PC (t ha <sup>-1</sup> ) | TMS (%)  | Chroma   | Hue      | FG      | RI      | Eye     | Vei     | Len     |
|---------------------|-------------|--------------------------|----------|----------|----------|---------|---------|---------|---------|---------|
| CERAT31-22          | E1          | 6.9 Bg                   | 30.19 Ba | 41.25 Aa | 70.70 Bb | 2.00 Ab | 4.66 Aa | 3.50 Aa | 0.00 Aa | 3.66 Aa |
|                     | E2          | 1.80 Cc                  | 23.76 Cb | 44.41 Ab | 81.05 Aa | 3.00 Aa | 3.33 Bb | 3.00 Aa | 0.00 Ab | 3.00 Bb |
|                     | E3          | 11.04 Bc                 | 28.24 Bc | 37.73 Bc | 67.53 Bc | 3.00 Aa | 3.33 Bb | 3.16 Aa | 0.00 Aa | 3.50 Aa |
|                     | E4          | 16.80 Ad                 | 33.90 Aa | 36.74 Bc | 66.11 Bb | 2.00 Ab | 4.66 Aa | 3.50 Aa | 0.00 Aa | 3.66 Aa |
|                     | E5          | 10.20 Bc                 | 23.13 Cc | 37.51 Bc | 68.52 Bb | 2.83 Aa | 3.00 Bb | 2.83 Aa | 0.00 Ab | 3.16 Ba |
|                     | E6          | 10.41 Bb                 | 24.23 Cb | 40.95 Ac | 68.45 Bc | 2.50 Aa | 4.00 Aa | 2.83 Ab | 0.00 Aa | 3.00 Ba |
| CERAT52-23          | E1          | 16.95 Be                 | 28.99 Aa | 50.76 Aa | 75.88 Aa | 4.33 Aa | 4.50 Aa | 3.33 Aa | 0.00 Aa | 3.50 Aa |
|                     | E2          | 9.15 Cb                  | 22.40 Bb | 47.34 Aa | 76.29 Aa | 4.33 Aa | 3.83 Aa | 3.00 Aa | 1.00 Aa | 3.33 Aa |
|                     | E3          | 5.19 Cd                  | 27.01 Ac | 48.67 Aa | 74.86 Ab | 3.33 Aa | 3.66 Aa | 3.00 Aa | 0.00 Aa | 3.33 Aa |
|                     | E4          | 23.40 Ac                 | 24.64 Bd | 47.28 Aa | 75.38 Aa | 4.33 Aa | 4.50 Aa | 3.33 Aa | 0.00 Aa | 3.50 Aa |
|                     | E5          | 6.30 Ce                  | 23.85 Bc | 39.03 Bc | 65.49 Ab | 3.50 Aa | 3.66 Aa | 3.00 Aa | 0.00 Ab | 3.00 Aa |
|                     | E6          | 1.68 Dd                  | 28.41 Aa | 41.51 Bc | 72.00 Ac | 3.50 Aa | 4.50 Aa | 3.50 Aa | 0.00 Aa | 3.33 Aa |
| CERAT55-20          | E1          | 13.20 Bf                 | 26.02 Bb | 49.34 Aa | 76.89 Aa | 2.66 Ab | 4.33 Aa | 2.16 Bb | 0.00 Aa | 3.00 Aa |
|                     | E2          | 9.30 Bb                  | 23.46 Cb | 46.44 Ba | 79.04 Aa | 2.83 Aa | 3.66 Aa | 2.00 Bb | 0.00 Ab | 2.83 Ab |
|                     | E3          | 29.49 Ab                 | 30.03 Ab | 50.91 Aa | 74.58 Ab | 4.00 Aa | 3.83 Aa | 3.16 Aa | 0.00 Aa | 3.00 Ab |
|                     | E4          | 28.42 Ac                 | 25.68 Bc | 46.86 Ba | 77.31 Aa | 2.66 Ab | 4.33 Aa | 2.16 Bb | 0.00 Aa | 3.00 Aa |
|                     | E5          | 26.70 Aa                 | 21.30 Cd | 45.66 Bb | 77.29 Aa | 3.00 Aa | 3.83 Aa | 2.16 Bb | 0.00 Ac | 2.83 Ab |
|                     | E6          | 7.26 Cc                  | 25.50 Bb | 45.59 Ba | 75.95 Ac | 2.00 Aa | 4.33 Aa | 3.00 Ab | 0.00 Aa | 3.00 Aa |
| CERAT56-23          | E1          | 43.8 Bb                  | 31.07 Aa | 36.75 Ac | 45.84 Ac | 3.50 Aa | 4.33 Aa | 2.66 Ab | 0.00 Ba | 3.16 Aa |
|                     | E2          | 21.00 Ca                 | 22.13 Bb | 36.55 Ac | 47.50 Ac | 3.66 Aa | 4.50 Aa | 2.50 Ab | 0.00 Aa | 3.50 Aa |
|                     | E3          | 8.14 Dd                  | 30.21 Ab | 37.61 Ac | 49.82 Ad | 3.50 Aa | 4.50 Aa | 3.66 Aa | 0.00 Ba | 3.50 Aa |
|                     | E4          | 56.85 Aa                 | 30.26 Ab | 30.33 Bd | 55.39 Ac | 3.50 Aa | 4.33 Aa | 2.66 Ab | 0.00 Ba | 3.16 Aa |
|                     | E5          | 27.30 Ca                 | 24.15 Bc | 33.67 Bd | 52.07 Ac | 3.16 Aa | 4.00 Aa | 3.66 Aa | 1.00 Aa | 3.50 Aa |
|                     | E6          | 6.66 Dc                  | 30.29 Aa | 37.35 Ac | 48.22 Ae | 2.83 Aa | 3.83 Aa | 2.83 Ab | 0.00 Ba | 2.66 Ba |
| CERAT60-05          | E1          | 52.20 Ba                 | 25.70 Ab | 41.86 Ab | 69.15 Bb | 4.33 Aa | 4.00 Aa | 2.66 Ab | 0.00 Ba | 3.16 Aa |
|                     | E2          | 27.30 Ca                 | 19.55 Bc | 39.11 Bb | 82.24 Aa | 3.16 Ba | 3.83 Aa | 2.83 Aa | 0.00 Bb | 2.66 Ab |
|                     | E3          | 29.02 Cb                 | 25.15 Ac | 42.80 Ab | 74.45 Bb | 2.16 Bb | 2.83 Bb | 3.00 Aa | 0.00 Ba | 3.00 Ab |
|                     | E4          | 63.60 Aa                 | 26.56 Ac | 37.06 Bc | 70.75 Bb | 4.33 Aa | 4.00 Aa | 2.66 Ab | 0.00 Ba | 3.16 Aa |
|                     | E5          | 24.45 Ca                 | 21.10 Bd | 36.35 Bc | 77.33 Ba | 4.00 Aa | 2.83 Bb | 2.16 Ab | 1.00 Aa | 2.66 Ab |
|                     | E6          | 11.92 Db                 | 25.77 Ab | 42.88 Ab | 84.94 Ab | 2.83 Ba | 3.66 Aa | 3.00 Ab | 0.00 Ba | 3.00 Aa |

Table 5. Cont.

| Genotypes/Cultivars | Environment | PC (t ha <sup>-1</sup> ) | TMS (%)  | Chroma   | Hue      | FG      | RI      | Eye     | Vei     | Len     |
|---------------------|-------------|--------------------------|----------|----------|----------|---------|---------|---------|---------|---------|
| CERAT60-07          | E1          | 23.70 Bd                 | 28.26 Ab | 40.82 Ab | 72.10 Aa | 4.33 Aa | 4.00 Aa | 2.66 Ab | 0.00 Ba | 3.16 Aa |
|                     | E2          | 10.65 Cb                 | 19.95 Bc | 40.38 Ab | 81.38 Aa | 3.16 Aa | 3.83 Aa | 2.83 Aa | 0.00 Bb | 2.66 Ab |
|                     | E3          | 13.41 Cc                 | 25.49 Ac | 43.29 Ab | 71.25 Ac | 3.33 Aa | 2.50 Bb | 2.50 Aa | 0.00 Aa | 3.16 Aa |
|                     | E4          | 39.45 Ab                 | 28.00 Ac | 41.44 Ab | 72.42 Ab | 4.33 Aa | 4.00 Aa | 2.66 Ab | 0.00 Ba | 3.16 Aa |
|                     | E5          | 21.75 Ba                 | 17.75 Bd | 42.65 Ab | 75.18 Aa | 4.00 Aa | 2.83 Bb | 2.16 Ab | 1.00 Aa | 2.66 Ab |
|                     | E6          | 6.30 Dc                  | 16.85 Bd | 43.92 Ab | 77.86 Ab | 2.83 Aa | 3.66 Aa | 3.00 Ab | 0.00 Ba | 3.00 Aa |
| CERAT60-26          | E1          | 34.50 Bc                 | 28.58 Ab | 37.44 Ac | 73.39 Ba | 4.16 Aa | 4.50 Aa | 3.00 Ab | 0.00 Aa | 3.16 Aa |
|                     | E2          | 13.80 Db                 | 24.40 Bb | 38.26 Ac | 78.52 Ba | 2.83 Aa | 3.00 Bb | 2.50 Ab | 0.00 Ab | 3.00 Ab |
|                     | E3          | 43.50 Aa                 | 26.40 Ac | 37.76 Ac | 88.82 Aa | 4.00 Aa | 3.16 Bb | 3.00 Aa | 0.00 Aa | 2.33 Bb |
|                     | E4          | 20.32 Cd                 | 30.70 Ab | 38.67 Ac | 76.64 Ba | 4.16 Aa | 4.50 Aa | 3.00 Ab | 0.00 Aa | 3.16 Aa |
|                     | E5          | 15.75 Cb                 | 22.35 Bc | 35.04 Bd | 84.80 Aa | 4.00 Aa | 4.33 Aa | 3.50 Aa | 0.00 Ac | 3.16 Aa |
|                     | E6          | 10.78 Db                 | 28.07 Aa | 32.78 Bd | 94.11 Aa | 3.83 Aa | 4.83 Aa | 3.83 Aa | 0.00 Aa | 2.66 Ba |
| BEAUREGARD          | E1          | 3.90 Bh                  | 26.32 Ab | 43.89 Ab | 63.51 Ab | 3.00 Ab | 4.00 Aa | 2.50 Ab | 0.00 Ba | 3.50 Aa |
|                     | E2          | 4.20 Bc                  | 17.45 Cc | 41.55 Ab | 61.05 Ab | 3.50 Aa | 4.33 Aa | 3.00 Aa | 0.00 Bb | 3.50 Aa |
|                     | E3          | 5.92 Bd                  | 20.55 Cd | 43.27 Ab | 60.47 Ac | 3.50 Aa | 3.50 Bb | 3.16 Aa | 0.00 Ba | 3.33 Aa |
|                     | E4          | 10.27 Ae                 | 21.87 Bd | 36.07 Bc | 59.60 Ac | 3.00 Ab | 4.00 Aa | 2.50 Ab | 0.00 Ba | 3.50 Aa |
|                     | E5          | 4.50 Be                  | 18.80 Cd | 33.32 Bd | 58.36 Ab | 2.50 Aa | 2.66 Bb | 2.50 Ab | 0.00 Ab | 2.50 Bb |
|                     | E6          | 1.75 Bd                  | 23.19 Bb | 39.32 Ac | 59.53 Ad | 2.83 Aa | 4.33 Aa | 3.16 Ab | 1.00 Aa | 3.33 Aa |
| CERAT24-02          | E1          | 32.12 Ac                 | 30.30 Aa | 49.35 Aa | 77.34 Aa | 3.33 Ab | 3.83 Aa | 3.16 Aa | 0.00 Aa | 3.33 Aa |
|                     | E2          | 6.66 Bb                  | 22.79 Bb | 44.77 Ba | 81.64 Aa | 3.83 Aa | 4.66 Aa | 2.33 Ab | 0.00 Ab | 3.00 Ab |
|                     | E3          | 8.30 Bd                  | 29.95 Ab | 44.07 Bb | 80.93 Aa | 3.83 Aa | 4.33 Aa | 3.50 Aa | 0.00 Aa | 3.16 Aa |
|                     | E4          | 31.06 Ab                 | 27.59 Ac | 47.46 Aa | 78.34 Aa | 3.33 Ab | 3.83 Aa | 3.16 Aa | 0.00 Aa | 3.33 Aa |
|                     | E5          | 31.81 Aa                 | 28.43 Ab | 44.96 Bb | 81.87 Aa | 3.16 Aa | 3.66 Aa | 3.00 Aa | 0.00 Ac | 2.83 Ab |
|                     | E6          | 5.30 Bc                  | 29.27 Aa | 42.57 Bb | 85.47 Ab | 3.33 Aa | 4.33 Aa | 3.16 Ab | 0.00 Aa | 2.83 Aa |
| CERAT25-01          | E1          | 7.87 Bg                  | 30.79 Aa | 36.49 Bc | 40.61 Cc | 3.83 Aa | 4.50 Aa | 3.33 Aa | 0.00 Aa | 3.16 Aa |
|                     | E2          | 16.89 Aa                 | 23.92 Bb | 43.33 Aa | 63.78 Ab | 4.00 Aa | 3.33 Ab | 2.83 Aa | 0.00 Ab | 3.33 Aa |
|                     | E3          | 1.37 Df                  | 28.50 Ac | 41.09 Ab | 46.53 Bd | 1.83 Bb | 3.83 Aa | 3.66 Aa | 0.00 Aa | 3.66 Aa |
|                     | E4          | 7.15 Be                  | 24.57 Bd | 31.80 Cd | 50.82 Bc | 3.83 Aa | 4.50 Aa | 3.33 Aa | 0.00 Aa | 3.16 Aa |
|                     | E5          | 10.00 Bd                 | 24.75 Bc | 36.79 Bc | 48.07 Bd | 3.66 Aa | 4.00 Aa | 3.00 Aa | 0.00 Ab | 3.16 Aa |
|                     | E6          | 2.72 Cd                  | 24.93 Bb | 38.70 Ac | 38.64 Cf | 2.33 Ba | 3.83 Aa | 2.83 Ab | 0.00 Aa | 3.33 Aa |

Table 5. Cont.

| Genotypes/Cultivars | Environment | PC (t ha <sup>-1</sup> ) | TMS (%)   | Chroma   | Hue      | FG      | RI      | Eye     | Vei     | Len     |
|---------------------|-------------|--------------------------|-----------|----------|----------|---------|---------|---------|---------|---------|
| CERAT35-02          | E1          | 6.36 Ag                  | 28.05 Ab  | 42.52 Ab | 79.22 Aa | 3.00 Ab | 4.50 Aa | 2.50 Ab | 0.00 Aa | 3.33 Aa |
|                     | E2          | 10.00 Ab                 | 21.27 Bc  | 37.07 Bc | 45.72 Bc | 2.83 Aa | 3.91 Aa | 2.75 Aa | 0.00 Ab | 3.33 Aa |
|                     | E3          | 2.51 Be                  | 25.31 Bc  | 42.33 Ab | 81.82 Aa | 2.60 Ab | 3.33 Bb | 3.00 Aa | 0.00 Aa | 3.33 Aa |
|                     | E4          | 4.83 Bf                  | 24.14 Bd  | 42.29 Ab | 77.73 Aa | 3.00 Ab | 4.50 Aa | 2.50 Ab | 0.00 Aa | 3.33 Aa |
|                     | E5          | 7.50 Ad                  | 24.02 Bc  | 45.07 Ab | 82.75 Aa | 2.33 Aa | 3.16 Bb | 2.50 Ab | 0.00 Ac | 2.66 Ab |
|                     | E6          | 6.06 Ac                  | 23.91 Bb  | 37.79 Bc | 82.48 Ab | 2.16 Aa | 4.16 Aa | 2.66 Ab | 0.00 Aa | 3.00 Aa |
| CERAT35-11          | E1          | 31.81 Ac                 | 27.22 Bb  | 39.42 Bc | 58.37 Bb | 2.66 Ab | 4.16 Aa | 4.16 Aa | 0.00 Ba | 3.16 Aa |
|                     | E2          | 22.12 Ba                 | 24.05 Cb  | 44.91 Aa | 67.89 Aa | 2.16 Aa | 4.33 Aa | 4.16 Aa | 0.00 Aa | 3.33 Aa |
|                     | E3          | 6.72 Dd                  | 30.06 Ab  | 38.60 Bc | 41.51 Cd | 2.16 Ab | 3.66 Aa | 3.83 Aa | 0.00 Ba | 3.50 Aa |
|                     | E4          | 16.22 Cd                 | 32.45 Aa  | 35.84 Cc | 51.67 Cc | 2.66 Ab | 4.16 Aa | 4.16 Aa | 0.00 Ba | 3.16 Aa |
|                     | E5          | 26.36 Aa                 | 30.41 Aa  | 32.89 Cd | 45.82 Cc | 2.33 Aa | 3.66 Aa | 2.83 Ba | 1.00 Aa | 3.16 Aa |
|                     | E6          | 28.33 Aa                 | 28.36 Ba  | 35.72 Cd | 46.77 Ce | 2.00 Aa | 3.33 Aa | 4.33 Aa | 0.00 Ba | 3.16 Aa |
| CERAT51-30          | E1          | 50.75 Aa                 | 26.92 Ab  | 42.07 Bb | 70.88 Ab | 2.66 Ab | 4.50 Aa | 3.33 Aa | 0.00 Aa | 3.50 Aa |
|                     | E2          | 11.21 Bb                 | 21.43 Bc  | 46.66 Aa | 74.98 Aa | 3.50 Aa | 4.33 Aa | 3.16 Aa | 0.00 Aa | 3.33 Aa |
|                     | E3          | 7.72 Bd                  | 28.36 Ac  | 45.90 Aa | 67.03 Ac | 2.83 Aa | 4.00 Aa | 3.16 Aa | 0.00 Aa | 3.33 Aa |
|                     | E4          | 8.51 Be                  | 24.62 Bd  | 38.61 Bc | 63.99 Ab | 2.66 Ab | 4.50 Aa | 3.33 Aa | 0.00 Aa | 3.50 Aa |
|                     | E5          | 9.39 Bd                  | 24.77 Bc  | 40.30 Bb | 65.26 Ab | 3.16 Aa | 4.16 Aa | 3.00 Aa | 0.00 Ac | 3.00 Aa |
|                     | E6          | 6.21 Bc                  | 24.92 Bb  | 46.45 Aa | 66.85 Ac | 2.66 Aa | 4.33 Aa | 3.33 Aa | 0.00 Aa | 3.00 Aa |
| CERAT60-22          | E1          | 10.60 Bf                 | 30.79 Aa  | 42.44 Ab | 74.57 Aa | 2.83 Ab | 4.16 Aa | 3.66 Aa | 0.00 Aa | 3.50 Aa |
|                     | E2          | 8.18 Bb                  | 21.17 Cc  | 39.80 Ab | 75.60 Aa | 2.33 Aa | 4.16 Aa | 3.50 Aa | 0.00 Ab | 3.66 Aa |
|                     | E3          | 4.25 Ce                  | 31.43 Ab  | 43.34 Ab | 72.54 Ab | 1.33 Ab | 3.16 Bb | 3.00 Aa | 0.00 Aa | 3.16 Aa |
|                     | E4          | 2.33 Cf                  | 23.90 Cd  | 39.81 Ac | 70.82 Ab | 2.83 Ab | 4.16 Aa | 3.66 Aa | 0.00 Aa | 3.50 Aa |
|                     | E5          | 14.09 Ac                 | 25.64 Cc  | 42.25 Ab | 80.64 Aa | 2.16 Aa | 3.16 Bb | 2.33 Bb | 0.00 Ab | 2.66 Bb |
|                     | E6          | 15.75 Ab                 | 27.38 Ba  | 38.91 Ac | 55.78 Bd | 2.16 Aa | 3.83 Aa | 2.00 Bb | 0.00 Aa | 3.33 Aa |
| CERAT60-25          | E1          | 11.81 Bf                 | 29.54 Ba  | 40.23 Ab | 36.75 Ac | 3.00 Ab | 4.50 Aa | 3.00 Ab | 0.00 Aa | 3.33 Aa |
|                     | E2          | 5.15 Cc                  | 20.79 Cc  | 34.78 Bc | 39.03 Ac | 3.16 Aa | 3.16 Bb | 2.50 Ab | 0.00 Aa | 3.00 Ab |
|                     | E3          | 6.09 Cd                  | 23.05 Cd  | 32.70 Bd | 33.51 Ae | 3.00 Aa | 3.83 Ba | 3.00 Aa | 0.00 Aa | 3.50 Aa |
|                     | E4          | 14.30 Ad                 | 32.66 Aa  | 34.83 Bc | 38.01 Ad | 3.00 Ab | 4.50 Aa | 3.00 Ab | 0.00 Aa | 3.33 Aa |
|                     | E5          | 13.33 Ac                 | 26. 96 Bb | 38.71 Ac | 36.89 Ad | 3.16 Aa | 3.33 Bb | 2.83 Aa | 0.00 Ab | 2.66 Ab |
|                     | E6          | 6.66 Cc                  | 21.26 Cc  | 39.55 Ac | 38.52 Af | 2.66 Aa | 3.66 Ba | 2.16 Ab | 0.00 Aa | 3.00 Aa |

Table 5. Cont.

| Genotypes/Cultivars | Environment | PC (t ha <sup>−1</sup> ) | TMS (%)  | Chroma   | Hue      | FG                 | RI                 | Eye     | Vei                | Len     |
|---------------------|-------------|--------------------------|----------|----------|----------|--------------------|--------------------|---------|--------------------|---------|
| AMÉLIA              | E1          | 24.62 Ad                 | 30.63 Ba | 41.05 Ab | 65.05 Ab | 2.00 Bb            | 4.50 Aa            | 2.66 Bb | 0.00 Aa            | 3.50 Aa |
|                     | E2          | 2.72 Cc                  | 28.92 Ba | 44.90 Aa | 71.34 Aa | 3.16 Aa            | 3.33 Ab            | 2.16 Bb | 0.00 Ab            | 3.16 Aa |
|                     | E3          | 2.00 Ce                  | 30.87 Bb | 36.97 Bc | 63.47 Ac | 3.66 Aa            | 3.66 Aa            | 3.16 Aa | 0.00 Aa            | 2.83 Ab |
|                     | E4          | 12.33 Bd                 | 34.62 Aa | 42.15 Ab | 69.70 Ab | 2.00 Bb            | 4.50 Aa            | 2.66 Bb | 0.00 Aa            | 3.50 Aa |
|                     | E5          | 11.36 Bc                 | 32.76 Aa | 39.17 Bc | 71.34 Ab | 3.00 Aa            | 4.00 Aa            | 3.50 Aa | 0.00 Ac            | 3.33 Aa |
|                     | E6          | 4.84 Cc                  | 30.90 Ba | 38.86 Bc | 67.89 Ac | 3.50 Aa            | 4.00 Aa            | 3.16 Ab | 0.00 Aa            | 2.83 Aa |
| CV%                 |             | 3.11                     | 8.42     | 6.44     | 8.17     | 27.63              | 14.50              | 18.41   | 27.17              | 11.88   |
| F                   | Genotype    | 5.15 **                  | 5.94 **  | 4.48 **  | 15.32 ** | 6.16 **            | 1.64 <sup>ns</sup> | 4.05 ** | 0.72 <sup>ns</sup> | 2.04 *  |
|                     | Environment | 156.14 **                | 84.22 ** | 30.25 ** | 4.11 *   | 1.03 <sup>ns</sup> | 17.72 **           | 8.29 ** | 8.88 **            | 9.77 ** |
|                     | GxE         | 22.07 **                 | 3.84 **  | 12.29 ** | 5.87 **  | 0.96 <sup>ns</sup> | 1.72 **            | 1.46 ** | 0.83 <sup>ns</sup> | 1.34 *  |

Scott and Knott mean grouping test at 5% probability. Means followed by the same uppercase letters vertically compare genotypes within the six environments. Means followed by the same lowercase letters vertically compare genotypes in the same environment. PC: commercial productivity (t ha<sup>−1</sup>); TMS: dry matter content (%); Chroma: saturation angle; Hue: color hue representation at angle; FG: general shape (rating from 1–5); RI: insect resistance (rating from 1–5); Eye: eyes (rating from 1–5); Vei: veins (rating from 0–1); Len: lenticels (rating from 1–4). Environment; E1: first cycle Jaboticabal; E2: second cycle Jaboticabal; E3: third cycle Jaboticabal; E4: first cycle Botucatu; E5: second cycle Botucatu; E6: third cycle Botucatu; CV%: coefficient of variation; F: Test F; genotype; environment; and genotype by environment interaction (GxE); ns: not significant by the F test; \* significant at 5% probability and \*\* significant at 1% probability by the T test; <sup>ns</sup>: not significant. Source: Dango F.J.U.

#### 4. Discussion

The experimental coefficient variation (CV%) ranged from 3.11% (PC) to 27.63% (FG), demonstrating high experimental precision based on the observed values in the trial set. The overall observed means were 15.09 t ha<sup>-1</sup> (PC), 26.6% (DMC), 42.22 (Chroma), 68.10 (Hue), 3.17 (FG), 3.91 (IR), 3.01 (Eye), 0.75 (Vein), and 3.16 (Len) (Table 3). The evaluation of nine orange-fleshed sweet potato cultivars under the conditions of Southwest and West Ethiopia showed a coefficient of variation (CV) of 19.40% in total fresh root yield, which includes both commercial production and non-commercial production, thus surpassing the value found in the present study [27]. Otoboni et al. [28], when evaluating 97 sweet potato genotypes during 2018 and 2019, reported experimental coefficient of variation (CV%) ranging from 4.30% (DMC) to 8.37% (PC), demonstrating high experimental precision in the trial set. This high precision is attributed to the evaluated genotypes being in an advanced selection stage. Such a situation is possible in crops where the traits studied are subterranean structures, which complicate environmental control and may lead to outlier observations around statistical parameters [29]. Cavalcante et al. [30] found CV values ranging from 8.87% to 22.20% when evaluating the productivity of sweet potato genotypes under different phosphorus doses. However, these values align with literature reports and confirm that root yield-related traits can vary according to the environment due to their quantitative inheritance, governed by multiple genes with strong environmental influence [31,32]. The qualitative traits showed CV values ranging from 3.11% (FG) to 27.17% (Vein). For insect resistance, the obtained CV was 14.50%, which is higher than the 8.5% reported [33].

The joint variance analysis was significant ( $p \leq 0.01$ ) for the environment in the traits PC, TMS, Chroma, Hue, RI, Olh, Vei, and Len, but not significant for FG. Regarding genotypes, significance was observed for PC, TMS, Chroma, Hue, FG, Eye, and Len, while RI and Vei were not significant. For the genotype  $\times$  environment interaction, the traits PC, TMS, Chroma, Hue, Eye, and Len were significant, whereas FG and Vei were not. Amaro et al. [31] also observed a significant interaction between cultivars and growing cycles for the number of commercial roots (NRC), a result that is consistent with the present study. The significant genotype  $\times$  environment interaction confirms the necessity of conducting further studies, highlighting the importance of adaptability and the stability analysis of genotypes [28]. The FG trait was not significant for the environment, as it is quantitatively inherited by only a few genes. In general, quantitative traits are influenced by multiple genes and are largely affected by environmental conditions. However, they still showed statistical differences and significance in the genotype  $\times$  environment interaction.

Genotypic variation ( $\sigma_g^2$ ) showed that the Hue characteristic was superior at 145.14, indicating greater genetic variability. For genotype  $\times$  environment variation ( $\sigma_{gxe}^2$ ), the Hue characteristic also stood out with 48.06 (Table 4). Similarly, for environmental variation ( $\sigma_e^2$ ), Hue was again superior with 31.01, showing the influence of environmental factors. In this study, the values of the genetic variation coefficients indicate a genetic variability of 88.9% for the characteristics evaluated in the Jaboticabal and Botucatu environments. According to Ebem et al. [34], the results indicate environmental variance of 23.56, genotype variance of 8.32, and genotype  $\times$  environment interaction of 9.16, which were highly significant ( $p < 0.01$ ) for the variable number of marketable roots, based on the evaluation of 41 sweet potato genotypes in two locations (Abakaliki and Osun State) over two years (2018 and 2019) in Nigeria (unlike the study that presented higher variance values). Among these, 11.11% of CVg values were above 20%; 22.22% of the traits were between 10% and 20%; and 66.67% were below 10%, demonstrating genetic variability favorable for selection in the characteristics PC, Hue, and FG, as they exhibited the highest values.

For commercial productivity (PC), the CVg was 25.32%, considering it is one of the main traits desired by breeders. The qualitative character of Hue, which represents the color tone angle and can indicate the presence of beta-carotene, had a CVg of 17.67%, making it an important characteristic for genotype selection. The general shape (FG) is a key trait observed by both breeders and farmers during the early and late stages of the breeding program, with a CVg of 14.3%, indicating genetic variability among the genotypes (Table 4). Otoboni et al. [28] evaluated 97 sweet potato genotypes and obtained results exceeding 19.14% CVg for root shape. Carmona et al. [35], evaluating 23 sweet potato genotypes, found a CVg of 16.60% for the general shape characteristic, which is close to the value observed in this study.

For the characteristics FG, RI, Eye, Vei, and Len, the genotypic coefficient of variation (CVg) did not exceed the environmental coefficient of variation (CVe). However, the quantitative traits were influenced by environmental conditions. The relative coefficient of variation (CVr) indicates the ratio between the genotypic coefficient of variation (CVg) and the environmental coefficient of variation (CVe). Values close to or greater than 1 indicate the predominance of genetic factors over environmental factors, responsible for the estimated variation in the experimental data. This parameter can be used as an indicative index of the ease of selecting genotypes for each character [28]. The CVr values estimated for the traits were as follows: commercial productivity 2.25, dry matter content 1.02, chroma 1.54, hue 2.16, general shape 0.52, insect resistance 0.24, eyes 0.49, and lenticels 0.27. Carmona et al. [35] found relative coefficient of variation (CVr) values greater than 1 for commercial productivity when evaluating sweet potato genotypes. However, lower values were obtained in this study, which were 0.63 for commercial productivity and 0.66 for general shape.

Heritability is one of the most important genetic parameters because it quantifies the fraction of phenotypic variation that is heritable, indicating the influence of genotype on phenotype [28]. Heritability is an estimate of the degree of variation in a phenotypic trait in a population, which is attributable to genetic variation among individuals in that population [36]. In this study, the average heritability of the genotypes ( $h_{mc}^2$ ) ranged from 39.05% (RI) to 93.47% (Hue), indicating the potential for success in selection, with higher percentage values yielding satisfactory genetic gains. The individual heritability ( $h_i^2$ ) values were low compared to the average heritability of the genotypes ( $h_{mc}^2$ ). According to Junior [37], data obtained from 10 sweet potato genotypes (originating from uncontrolled cross seeds at the Federal University of Viçosa) showed that flesh color had a higher broad-sense heritability ( $h^2a$ ) of 99.9% compared to the present study. This may be explained by the classification method used. However, Carmona [35] found values close to those in this study regarding broad-sense heritability ( $h^2a$ ), which indicated great potential for successful selection, in decreasing order, for the following variables: diameter (85.42%), stem length (85.34%), and commercial root productivity (81.55%). According to [38], a minimum of 80% is necessary to achieve satisfactory genetic gains through selection. Nevertheless, the estimates of heritability ( $h^2$ ), genotypic coefficient of variation (CVg), and the environmental coefficient of variation (CVe) were promising, even though their values relative to the relative coefficient of variation (CVr) were lower.

For the characteristic of commercial productivity, there was genotype–environment interaction. The superior genotypes were CERAT60-05 (63.30 t ha<sup>−1</sup>), CERAT56-23 (56.85 t ha<sup>−1</sup>), both from the summer cycle, first cycle of Botucatu (E4), and CERAT51-30 (50.75 t ha<sup>−1</sup>) from the first cycle of Jaboticabal (E1), showing statistically significant differences from the others (Table 5). The superior genotypes had average productivity values higher than those of China (22.22 t ha<sup>−1</sup>), Malawi (24.48 t ha<sup>−1</sup>), Tanzania (7.58 t ha<sup>−1</sup>), the United States of America (22.26 t ha<sup>−1</sup>), and Brazil (15.17 t ha<sup>−1</sup>) [4]. Gemechu

et al. [39] observed that the total root yield for the cultivars Napot-12 (55.8 t ha<sup>-1</sup>), Naspot-13 (47.55 t ha<sup>-1</sup>), and Dilla (44.31 t ha<sup>-1</sup>) benefited advantageously from the genotype-by-environment interaction under the conditions of Southwest and West Ethiopia. It is worth highlighting that the data obtained in the present study were significantly higher, as they considered only commercial production. Producers could achieve satisfactory gains (five to six times higher gains in productivity) by adopting high technological levels and utilizing the superior genotypes found in this study. Ringo et al. [40] observed that the highest number of commercial roots (NRC) was produced by the Beauregard cultivar in both cycles, with 3.3 kg pl<sup>-1</sup> (first cycle, 28 December) and 4.5 kg pl<sup>-1</sup> (second cycle, 3 November). The averages of commercial productivity ranged from 10.05 t ha<sup>-1</sup> to 63.30 t ha<sup>-1</sup>, with both values corresponding to genotypes from the first cycle of Botucatu (E4) (Table 5). Similar values were observed in the selection of the best genotypes for total root productivity, with values ranging between 33.11 t ha<sup>-1</sup> and 42.76 t ha<sup>-1</sup>, exceeding the average population productivity of 24.53 t ha<sup>-1</sup> in the work conducted by Costa [12] in the region of Minas Gerais, the municipality of Ijaci, working with sweet potato genotypes.

Daros et al. [41] observed variation in average commercial productivity by environment in the municipality of Campos dos Goytacazes, in the northern Fluminense region, with values ranging from 9,858.197 kg ha<sup>-1</sup> for the environment and area of the Colégio Estadual Agrícola Antônio Sarlo (CEAAS) to 14.53 t ha<sup>-1</sup> for the research support unit (UAP/97), while evaluating sweet potato genotypes. Similar averages were observed in this study. Dry matter content had a direct relationship with industrial yield, including ethanol production and chip production, highlighting the importance of selection based on this characteristic [28–42]. Dry matter content also exhibited genotype–environment interaction, with the superior genotypes being CERAT21-02 (36.14%), CERAT25-27 (35.97%) in the third cycle of Jaboticabal (E3), and CERAT31-22 (33.90%) in the first cycle of Botucatu (E4), showing statistically significant differences from the others (Table 5). Silva et al. [43] evaluated 16 clones and 3 sweet potato cultivars at the Agronomic Institute of Campinas; clones with statistically significant average dry matter percentages could be observed, such as IAC-38 (22.43%), IAC-216 (23.72%), IAC-459 (24.75%), IAC-604 (24.15%), IAC-737 (22.57%), and IAC-1063 (22.61). The mean values, as reported, were higher in the present study, demonstrating the superiority of the genotypes under evaluation. The analysis of nine cultivars in South Africa revealed dry matter values for the cultivars Ndou (25%), Khumo (23.7%), Monate (23.2%), and Ribbok (22.8%), showing lower values compared to the present study [11].

Color is one of the main attributes of food, being considered an indicator of quality and determining consumer acceptance. Chroma expresses color saturation or intensity. To evaluate this quality attribute, the highest averages that express color intensity were taken into account [44]. The Chroma variable scales range from 0 (green) to 60 (red), with values identifying the saturation of dark orange falling between 30 and 50. The values for this characteristic varied between 30.33 and 50.91 in the present study (Table 4). Velho [3], evaluating sweet potato genotypes, found Chroma values around 17.72, indicating that the samples showed low color saturation, tending toward yellow hues. For the Chroma characteristic, the superior genotypes were CERAT31-12, CERAT55-20, and CERAT52-23 in the third cycle of Jaboticabal (E3). The averages ranged from 50.91 to 50.76, with the first and second genotypes showing no variation (Table 5). The control cultivar, Beauregard, had an average of 43.89 in the first cycle of Jaboticabal (E1). Similar results were observed in genotypes CNPH1007 (49.00), CNPH1194 (54.00), CNPH1202 (47.06), and CNPH1205 (49.6) [45]. According to Laurie et al. [37], data from nine sweet potato cultivars in South Africa showed that, for the color variable (beta-carotene content), levels ranged from 10.27 to 3.67 mg/kg. Blesbok (10.27), Beauregard (7.33), Monate (6.33), and Ndou were the cultivars

that showed better performance compared to Bophelo and 199,062.1. The differences in the results, compared to the present study, may be explained by the method used to assess the color variable; in the present study, color was measured using a spectrophotometer, while Laurie et al. [11] employed the NIR (near-infrared) method.

Beta-carotene is an important precursor of vitamin A in the body and is associated with the yellow to red coloration of foods. The color tone is observed through the hue angle, which is considered on a scale of 30 to 50 [46]. For the hue characteristic, the superior genotypes were CERAT60-25 (33.51), CERAT35-11 (41.51) in the third cycle of Jaboticabal (E3), and CERAT25-01 (38.64) in the third cycle of Botucatu (E6) (Table 5). As the environment changed, their values varied due to soil divergence and, primarily, climate changes (summer and winter). The ideal temperature for sweet potato production is between 24 °C and 33 °C; productivity is higher in the summer cycle compared to the winter cycle due to lower temperatures that directly influence the development of the crop. Donado [45] observed that the hue angle values differed statistically among genotypes, with the highest value attributed to CNPH1202 (50.7) and the lowest value to CNPH1194 (46.1), close to the values observed in this study. When evaluating color tone, it should be noted that the genotype CERAT60-25 in the third cycle of Jaboticabal (E3) was superior, with hue averages ranging from 33.51 to 39.03. The averages obtained were close to the values observed in genotypes UGA34, UGA125, and UGA126, ranging from 34.48 to 37.24 [46].

Regarding root shape, there was no genotype–environment interaction. Typically, genotypes maintain their shape pattern regardless of the environment they are in. Their averages varied from 3 (irregular shape) to 4.50 (close to fusiform shape). The cultivars Beauregard and Amélia showed averages of 3.50 to 3.66 (increasing score classification) in this study, showing a desirable shape for the commercial market (Table 5). In a study conducted by Amaro et al. [31], in 2014, the authors found that the cultivars BRS Amélia, Brazlândia Branca, and BRS Cuia differentiated themselves from the others and received scores above 3.0 (decreasing score classification), indicating fewer desirable shapes for the market, while Beauregard received a score of 1.63 with a good shape [31]. The superior and recommended genotypes for commercialization are CERAT31-12 (second cycle Jaboticabal—E2), UNESP Maria Rita (third cycle Botucatu—E6), CERAT52-23, CERAT60-05, and CERAT60-07 (first cycle Jaboticabal—E1 and Botucatu—E4), with averages ranging from 4.33 to 4.50 in fusiform shape. Costa [12] evaluated the genotypes 2018-19-443, 2018-36-807, and 2018-19-464, finding that they were among the best in general shape, being close to fusiform, and had a moderate influence on commercialization, being rated as close to good, with an open root grouping.

For human consumption, it is important that, in addition to productivity characteristics, good quality characteristics such as shape and resistance to soil insects are offered [39]. The genotype by environment interaction was significant for insect resistance and non-significant for treatment. The environment influenced more than the genetic standard, as genotypes do not contain genes for insect resistance. The averages ranged from 3 (moderate damage affecting commercial appearance) to 4.66 (little to no damage). Barreto et al. [47] evaluated experimental genotypes, where there was a wide variation in the severity of damage caused by soil insects, highlighting genotypes BD#106, BD#58, and BD#22, with respective averages of 1.16, 1.43, and 1.58, not differing statistically from the resistant controls (Brazlândia Branca, Brazlândia Rosada, Brazlândia Roxa, and Palmas). The superior genotypes for insect resistance were CERAT21-06, UNESP Maria Rita, CERAT-25-27, CERAT21-02 (4.50) (third cycle Botucatu—E6), CERAT52-23, CERAT56-23, CERAT35-02, CERAT60-25 (first cycle Jaboticabal—E1 and first cycle Botucatu—E4), Amélia with an average of 4.50 (first cycle Botucatu—E4), and CERAT 24-02 with an average of 4.66 (second cycle Jaboticabal—E2) (Table 4). In 2014, the level of damage was sufficient to separate the

cultivars into two groups, with the most resistant cultivars being Beauregard, Brazlândia Rosada, Princesa, BRS Rubissol, and Brazlândia Roxa, with the latter receiving a score of 1.50, Amaro et al. [31] confirming the result obtained in the Amélia cultivar in this study.

Regarding the Eye characteristic, the averages for this trait ranged from 3 (few eyes) to 4 (absence of eyes). However, similar data were observed when evaluating sweet potato genotypes, with scores ranging from 0.04 to 0.32 for the 15 best genotypes, corresponding to the absence of eyes, with a decreasing score classification [12]. The cultivar Amélia was the only one showing a score of 4.0, being the best one for this characteristic, while the genotype CERAT56-23 (first cycle Botucatu—E4) was also superior, confirming the importance of shape in the industry. The characteristics of sweet potatoes have an impact on the development of the sector. In addition to agricultural productivity, it is necessary to consider quality attributes. From the characteristics evaluated in the present study, some can contribute to improving the performance of the sweet potato production chain, considering agronomic and economic parameters, which are fundamental for the crop's insertion in the market.

Regarding the presence of lenticels, the averages varied from 3.16 to 4, indicating few to no lenticels. There was a genotype by environment interaction for this characteristic, with the superior genotypes being CERAT21-06, CERAT31-22 (genotypes in the first cycle of Botucatu—E4), CERAT25-01 (third cycle of Jaboticabal—E3), and CERAT60-22 (second cycle of Jaboticabal—E2), all having an average score of 4, indicating the absence of lenticels (Table 4). The evaluation of the genotypes showed scores ranging from 0.88 to 1.26, corresponding to roots with few lenticels, with selection gains between  $-0.86$  and  $-0.48$ . The overall average of the population (1.74) indicated a moderate presence of lenticels, confirming the results obtained [12]. For the characteristics that did not show significant interaction between genotype and environment, such as the general shape and vein, the environment had no influence on them, remaining constant regardless of the environment. Regarding the characteristics of commercial productivity (PC), general shape (FG), insect resistance (RI), eyes (Eye), and lenticels (Len), the best location was Botucatu in the first cycle (E4). For the characteristics of hue, chroma, and dry matter content (TMS), the superior location was Jaboticabal in the third cycle (E-3), corresponding to 33.33%. Overall, the first cycle in Botucatu (E4), accounting for 55.5%, was superior compared to the other cycles for the evaluated characteristics.

In addition to the duration of the cycles of the materials, the edaphoclimatic conditions of the cultivation site, the planting time, the quality of the cuttings used, and the time the crop remains in the field, the genetic constituents of the cultivars and factors such as temperature, photoperiod, and incident solar radiation, which result in the interaction between genotypes and environments, directly affect the growth, development, and size of the roots and, consequently, the yield of the cultivars [35]. The summer cycle was superior to produce this crop, as it had higher temperatures compared to the winter cycle, since low temperatures delay the development of sweet potatoes and, consequently, reduce productivity. In Botucatu, due to its medium-textured soil, it showed greater efficiency in the development of sweet potatoes compared to the clayey soil of Jaboticabal.

## 5. Conclusions

The interaction between genotype and environment was evident in 76.78% of the evaluated characteristics. The first cycle in Botucatu (E4) was superior and the most appropriate for sweet potato cultivation. The genotypes CERAT60-05, CERAT56-23, CERAT60-26, and CERAT35-11 were the most promising in the evaluated environments.

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## Abbreviations

The following abbreviations are used in this manuscript:

|                |                                                                    |
|----------------|--------------------------------------------------------------------|
| Chroma         | Saturation Angle                                                   |
| E              | Environment                                                        |
| FG             | General Shape                                                      |
| Hue            | Color Hue Representation in the Angle                              |
| Len            | Lenticels                                                          |
| Olh            | Eyes                                                               |
| PC             | Commercial Productivity                                            |
| RI             | Insect Resistance                                                  |
| TMS            | Dry Matter Content                                                 |
| Vei            | Veins                                                              |
| CIP            | International Potato Center                                        |
| CERAT          | Center for Tropical Roots and Starches                             |
| SASHA          | Sweetpotato Action for Security and Health in Africa               |
| OFSP           | Orange-fleshed Sweetpotato                                         |
| SweetGAINS     | Sweet-potato Genetic Advances and Innovative Seed Systems          |
| Embrapa        | Brazilian Agricultural Research Corporation                        |
| UNESP          | São Paulo State University “Júlio de Mesquita Filho”               |
| UFLA           | Federal University of Lavras                                       |
| UNOESTE        | University of Western São Paulo                                    |
| FCAV           | Faculty of Agricultural and Veterinary Sciences Jaboticabal Campus |
| FCA            | Faculty of Agronomic Sciences                                      |
| E1-Jaboticabal | first cycle                                                        |
| E2-Jaboticabal | second cycle                                                       |
| E3-Jaboticabal | third cycle                                                        |
| E4-Botucatu    | first cycle                                                        |
| E5-Botucatu    | second cycle                                                       |
| E6-Botucatu    | third cycle                                                        |
| pH             | Hydrogen potential                                                 |
| M.o            | Molybdenum                                                         |
| P              | Phosphorus                                                         |
| S              | Sulfur                                                             |
| Ca             | Calcium                                                            |
| Mg             | Magnesium                                                          |
| K              | Potassium                                                          |
| Al             | Aluminum                                                           |

|        |                               |
|--------|-------------------------------|
| H + Al | Potential acidity             |
| SMP    | Determined in buffer solution |
| SB     | Base sum                      |
| CTC    | Cation exchange capacity      |
| StB    | Base Saturation               |
| B      | Boron                         |
| Cu     | Copper                        |
| Fe     | Iron                          |
| Mn     | Manganese                     |
| Zn     | Zinc                          |

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