Fruit productivity of "Pera" sweet orange grafted on different rootstocks in the mesoregion of Northeast Pará (Brazil)

Productividad de frutos en naranja dulce "Pera" injertada sobre diferentes portainjertos en la mesorregión del Nordeste de Pará (Brasil)

Gilberto Ken Iti Yokomizo[1]*, Kuang Hongyu[2], Fabio de Lima Gurgel[3], Walter dos Santos Soares Filho[4], Eduardo Augusto Girardi[4], and Orlando Sampaio Passos[4]

ABSTRACT

Citrus is among the most important cultivated species in the world. However, the Northern region of Brazil, despite its available cultivation, still presents incipient production and faces numerous environmental factors that require further study to mitigate the impact of genotype-by-environment interactions. To address this issue, an experiment was set up in the municipality of Capitão Poço, Pará, using a completely randomized block design to evaluate six graft/rootstock combinations with AMMI and GGE Biplot analyses. The variable assessed was total fruit weight (FW), that is the total of fruits produced by the plant, measured in kg, in the 2018, 2019, 2020, and 2021a (first half of the year) and 2021b (second half of the year) harvests. Superior rootstocks were 'Santa Cruz' Rangpur lime (*C.* x *limonia* Osbeck) (T1) and 'San Diego' citrandarin (TSK x TRENG-314) (T10). Although T1 and T10 had low stability in certain years, for ideotype aspect T1 was superior in relation to the other rootstocks and, despite the search for more promising materials, which here were the least stable, it must be accepted that there are risks, as there is no way to predict production in later years. Future research should identify which environmental factors favor fruit productivity and which generate instability in the Capitão Poço region.

Keywords: *Citrus sinensis* (L.) Osbeck, graphical analysis, stability, adaptability, genetic improvement, perennial plants, Amazon region.

RESUMEN

Los cítricos están entre las especies cultivadas más importantes del mundo, pero la región norte de Brasil, a pesar de su área disponible para el cultivo, aún tiene una producción incipiente y, por presentar infinitas combinaciones de efectos ambientales, se requieren estudios que puedan evaluar el efecto de la interacción genotipo x ambiente. Para abordar esta problemática, se estableció un experimento en el municipio de Capitão Poço del Estado de Pará siguiendo un diseño en bloques completamente al azar con el fin de evaluar seis combinaciones de injerto/portainjerto mediante un análisis gráfico AMMI y GGE Biplot. La variable evaluada fue peso total de los frutos (FW) que corresponde a la suma del total de frutos producidos por la planta, medido en kg, en las cosechas de 2018, 2019, 2020 y 2021a (primera mitad del año) y 2021b (segunda mitad del año). Los portainjertos más destacados fueron los de limón Rangpur "Santa Cruz" (*C.* x *limonia* Osbeck) (T1) y citrandarin "San Diego" (TSK x TRENG-314) (T10). Aunque T1 y T10 tuvieron baja estabilidad para ciertos años, para el aspecto ideotipo T1 fue superior con relación a los demás portainjertos y a pesar de la búsqueda de materiales más prometedores, que en este caso fueron los menos estables, es necesario aceptar que existen riesgos, ya que no es posible predecir la producción en años posteriores. Investigaciones futuras deberían identificar cuáles factores ambientales favorecen la productividad frutícola y cuáles generan inestabilidad en la región de Capitão Poço.

Palabras clave: *Citrus sinensis* (L.) Osbeck, análisis gráfico, estabilidad, adaptabilidad, mejoramiento genético, plantas perennes, región Amazónica.

Introduction

Citrus fruits have become among the most important cultivated species in the world, consumed fresh or processed into juices, sweets, and other by-products (Passos *et al.*, 2016; Silva *et al.*, 2016). In the North region of Brazil, orange production stands out in the State of Pará, which in 2021 harvested 14,200 ha, yielding 233,051 t, associated with an economic value of US$22 million and reaching an average yield of 16,412 kg ha^{-1}. Compared with other

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[1] Embrapa Amapá, Macapá, AP (Brazil).
[2] Universidade Federal de Mato Grosso, Cuiabá, MT (Brazil).
[3] Embrapa Amazônia Oriental, Belém, PA (Brazil).
[4] Embrapa Mandioca e Fruticultura, Cruz das Almas, BA (Brazil).
[*] Corresponding autor: gilberto.yokomizo@embrapa.br

regions, Pará represents almost the entire northern region of Brazil (IBGE, 2021).

Given the importance of citrus farming, several studies have examined the potential of and minimized the challenges of the national citrus chain, seeking to provide security and enable socioeconomic development (Borges & Costa, 2005; Pimentel *et al*., 2014). Among these studies, some evaluate scion/rootstock combinations resistant or tolerant to the principal biotic stresses (*e.g*., pests or diseases) and abiotic stresses (*e.g*., drought and high temperatures) (Bastos, Sombra, Andrade *et al*., 2017; Bastos, Sombra, Loureiro *et al*., 2017; Rodrigues *et al*., 2016; Silva & Vieira, 2015).

The enormous potential for expanding fruit cultivation areas in Brazil generates a phenomenon known as genotype-by-environment interaction (GxE). This interaction results in significant differences in plant performance across heterogeneous locations (Cruz *et al*., 2014). It is one of the main obstacles to plant selection.

In the manifestation of GxE interaction, the genotype's behavior becomes uncertain when changing from one location to another. This reaction reflects different responses of the same genes set to environmental changes (Muthoni *et al*., 2015). There is no way to eliminate GxE interaction, as it is associated with a physiological reaction existing in plants (Adewale *et al*., 2010). This event certainly disrupts the breeder's selection processes (Carvalho *et al*., 2016). One possible solution to mitigate the effects of this interaction is to identify plants with broad adaptability and good stability in different environments (Cruz *et al*., 2014).

Based on these particularities, plant genetic improvement programs usually aim to select several individuals with broad adaptation and stability, which can then be recommended for various environments (Malosetti *et al*., 2013). There are three ways for GxE interaction to occur: detecting cultivar(s) with specificity for each environment; detecting cultivar(s) with high phenotypic stability; and obtaining environmental stratifications (Ramalho *et al.,* 2024). However, to get these results, it is necessary to perform statistical or graphical analyses on the genotypes and environments under study.

A graphical methodology for visualizing and interpreting GxE interaction is called AMMI ("Additive Main Effects and Multiplicative Interaction Model"), where the generated graphs make it easy to discern different interaction patterns, allowing better prediction of results across different genotypes and environments used in the analyses (Silva, 2016). Additionally, it provides information to understand how different genetic materials behave in terms of stability and adaptability (Karimizadeh *et al*., 2016; Ramalho *et al*., 2024).

A second and essential methodological procedure for estimating the effects of the existing GxE interaction is the so-called GGE biplot, which graphically expresses in biplot format an overview of the grouping of environments or mega environments and the superior or inferior genotypic performance in specific environments; it also allows the selection of genotypes based on the average relationship vs. stability, and discrimination vs. representativeness; and also finding the genotype that is perfect and desired by researchers (ideotype) (Yan, 2001; Yan, 2011; Yan & Holland, 2010; Yan & Kang, 2003; Yan & Tinker, 2006).

In the northeastern region of Pará, the municipality of Capitão Poço and other adjacent municipalities in the Guamá microregion are home to the largest citrus-growing region in Pará (SECOM, 2021). However, there are no studies on the stability and adaptability of rootstocks relevant to genetic improvement programs used by local producers. This justifies the need to understand the behavior of different genotypes under local conditions. Based on this information and using AMMI and GGE biplot analyses, the objective of this study was to evaluate the effects of genotype-by-environment (GxE) interactions on early productivity of orange clones, aiming to identify superior genotypes in environmental variations.

Materials and methods

We conducted our research in the rural part of the municipality of Capitão Poço, located in the northeast region of the state of Pará, Brazil, 73 m a.s.l., 47º03'34'' W, 01º44'47'' S. This municipality has a temperature range that varies from 25.7°C to 26.9°C, with an annual average of 26.2ºC (Silva *et al*., 2011). According to the Köppen classification, the climate of the region is of the Am type (tropical monsoon climate), with annual precipitation around 2,500 mm, with a short dry season between September and November (monthly precipitation around 60 mm), and relative humidity of the air between 75% and 89% in the months with the least and most precipitation (Schwartz, 2007). The soil type is Dystrophic Yellow Latosol (Ribeiro *et al*., 2006). The experimental design used was randomized blocks with six rootstocks (Tab. 1), four replicates, and 5 plants per plot, spaced 4.0 m between plants and 5.5 m between rows, with irrigation only during the dry season (August - November).

TABLE 1. Rootstocks used for the scions of 'Pera' sweet orange tree [*Citrus sinensis* (L.) Osbeck]. Lima Farm, Capitão Poço, PA, Brazil.

Number	Rootstock description
T1	"Santa Cruz" Rangpur lime (*C.* × *limonia* Osbeck)
T7	Hybrid LVK (Volkamer lemon [*C.* × *volkameriana* (Risso) V. Ten. & Pasq.]) x LCR-010 (Rangpur lime)
T10	"San Diego" citrandarin (TSK [Sunki mandarin] × TRENG-314 [*P. trifoliata* cv. Swingle])
T12	BRS Pompeu (TSKC [Sunki mandarin] x CTSW-028 Citrumelo Swingle [*Citrus paradisi* × *Poncirus trifoliata*])
T13	TSKC (Sunki mandarin [C. Sunki (Hayata) hort. x Tanaka] x CTSW-033 (Citrumelo Swingle [*Citrus paradisi* × *Poncirus trifoliata*])
T16	'Riverside' citrandarin (TSKC x TRENG-264)

The rootstock seedlings were produced in a greenhouse with 50% shade; the seeds to produce six rootstocks were obtained from the active germplasm bank of Embrapa Cassava and Fruits (Cruz das Almas, Bahia, Brazil). When the rootstocks reached the appropriate diameter (about 1 cm), inverted T-type budding was performed using buds of ´Pera' sweet orange [*Citrus sinensis* (L.) Osbeck] and the planting was carried out when the seedlings were about 11 months old after grafting and 0.90 cm tall in a nursery located in Santa Luzia, 15 km from the municipality of Capitão Poço, PA. Specific cultural practices for citrus cultivation were carried out in accordance with farm practices, including monitoring and removing unwanted plants, crowning plants, creating basins around plants to allow for water accumulation during rainfall and for irrigation, and using mulch. Fertilization was performed according to Lima Farm's nutritional program, with 1 kg of thermophosphate (20% P_2O_5) and 1 kg of 9-9-19 NPK formulation per year.

The characteristic evaluated was the total weight of fruits (FW), that is the sum of the fruits produced by each plant measured in kilograms in 2018, 2019, 2020, and 2021a (first half of the year) and 2021b (second half of the year) when the plants were three years old. This characteristic was assessed since it results from all the others that involve productivity aspects (number of fruits, fruit weight, and fruit size); therefore, for the purposes of this research, the total fruit weight was considered sufficient to describe the behavior of the rootstocks.

AMMI

The statistical treatment of the data, including analysis of variance and analysis of stability and adaptability via the AMMI model, was performed using the R program version 3.4.1 (R Core Team, 2020).

The AMMI analysis, described by Duarte and Vencovsky (1999), was based on the model:

$$Y_{ij} = \mu + g_i + a_j + \sum_{k=1}^{n} \lambda_k \gamma_{ik} \alpha_{jk} + \rho_{ij} + \bar{\varepsilon}_{ij} \quad (1)$$

where Y_{ij} is the average response of the repetitions of the i-th progeny (i = 1, 2, 3, ..., g) in the j-th year (j = 1, 2, 3, ..., a); μ is the average of all progenies in all years (general average); g_i is the main effect of progeny "i"; a_j is the main effect of year "j"; λ_k, γ_{ik} and α_{jk} refer to the terms of the singular decomposition (SVD), also called principal component analysis (PCA), of the matrix $GE_{gxe}=\{(ge)_{ij}\}$, which expresses and captures the "pattern" regarding the interaction of progeny "i" with year "j"; ρ_{ij} represents the additional noise to be eliminated in the analysis, relative to the term routinely accepted as the interaction itself; and $\bar{\varepsilon}_{ij}$ is the experimental error, assuming i.i.d.~N(0, σ^2).

The AMMI analysis involves two steps: first, the main effects; then the additive part of the model (general mean, progeny, and year effects), adjusted by analysis of variance (ANOVA), generating a non-additivity residual $(\hat{ge})_{ij} = \bar{Y}_{ij} - \bar{Y}_{i.} - \bar{Y}_{.j} + Y_{..}$ That is, the ordinary least squares estimates of $(ge)_{ij}$; in the second step, the interaction (multiplicative part of the model) is adjusted using DVS or PCA applied to the matrix $GE_{gxe}=\{(g\hat{e})_{ij}\}$, resulting in the part named as "standard" (being the interaction – AMMI interaction), and the other denominated as "noise", which should be included in the residual in the analysis of variance.

To determine how many main axes should be considered to explain and graphically represent the interaction pattern, the criteria presented by Gauch Jr. and Zobel (1988) were adopted, where the proportion of the sum of squares SQ_{GxE} of the original interaction accumulated up to the n_{th} axis is considered:

$$\sum_{k=1}^{n} \lambda_k^2 / SQ_{GxE} \quad (2)$$

GGE Biplot

The GGE Biplot method, according to Yan *et al*. (2000), considers the main effect of progeny and its interaction with years, which are essential and considered concomitantly. The GGE Biplot model maintains G of GxE together in the format of two multiplicative terms, employing Equation 3:

$$Y_{ij} - \bar{y}_j = y_1\varepsilon_{i1}\rho_{j1} + y_2\varepsilon_{i2}\rho_{j2} + \varepsilon_{ij} \quad (3)$$

where Y_{ij} symbolizes the average performance of the i-th progeny in the j-th year; $\bar{y}_j$ symbolizes the overall average of the progenies for year j; $y_1\varepsilon_{i1}\rho_{j1}$ is equivalent to the first principal component (IPCA1) associated with the eigenvalue from IPCA1; $y_2\varepsilon_{i2}\rho_{j2}$ is comparable to the second principal component (IPCA2) associated with the eigenvalue from IPCA2; ε_{i1} and ε_{i2} symbolize the scores of the first and second principal component, respectively, of the i-th progeny; ρ_{j1} and ρ_{j2} symbolize the scores of the first and second principal component, respectively, for the j-th year; ε_{ij} is equivalent to the model error associated with the i-th progeny in the j-th year (Yan & Kang, 2003).

Additionally, the information ratio (IR) proposed by Yan and Tinker (2006) was estimated to assess whether the biplot is suitable for displaying the patterns in a double-entry table. This relationship is interpreted based on each PC axis (interaction axis of the principal components analysis): IR ≥ 1 or close to 1 indicates patterns (associations between years), and a PC with IR < 1 indicates the absence of any pattern or information. Therefore, a biplot of dimension 2 can adequately represent the patterns in the data only if the first two PCs have IR ≥ 1 or close to 1.

Results and discussion

In the summary of the analysis of variance (Tab. 2), in all scion/rootstock combinations (G), significance was observed by the F test, that is, there are distinct performances that are indicative of the presence of superior materials and differences also occurring for the years of evaluation, as well as in the GxE interaction. This allows the continuity of the statistical analyses through the AMMI and GGE Biplot methodologies.

The experimental coefficients of variation as classified by Gomes (2022) were much higher than those reported by Costa *et al.* (2021). It is important to note that this scale does not represent the reality of perennial species or many fruit trees, including the orange tree. Therefore, although this scale is helpful for general discussions of agricultural research results, it is inappropriate because the precision assessment depends on the response variable in the study.

An appropriate CV classification for citrus should consider this species' peculiarities, the characteristics being evaluated, the number of replicates, and the experimental design, among other essential aspects. This may be because some variables are naturally more variable among fruits from the same plant or because the measurements themselves tend to be less homogeneous (Silva *et al.*, 2011). Therefore, it is evident that the productivity component (FW) is a trait under quantitative genetic control, with phenotypic performance strongly influenced by environmental conditions and shaped by distinct gene complexes (Cruz, 2012; Maia *et al.*, 2010).

TABLE 2. Summary of the analysis of variance for scion/rootstock combinations in 'Pera' sweet orange trees, being years (E); repetitions within years R(E); genotypes (G), effect of the interaction between genotypes and years (GxE), acumulative percentage (PA), mean square (QM) of the first four component axes (PC1, PC2, PC3, and PC4) on fruit weight (FW, kg/plant). Capitão Poço, PA, Brazil.

	E	R(E)	G	GxE
GL	4	15	5	20
	37599**	652**	4409**	754**
CV	103.48			
Mean	12.20			
	PA	QM		
PC1	69.7	144.236[b]		
PC2	98.8	80.282[c]		
PC3	99.4	2.845[a]		
PC4	100.0	4.657[a]		

ns: not significant; **: significant at 1%; *: significant at 5% by F test.

[a]: not significant; [b]: significant at 1%; [c]: significant at 5% by the Fisher-Ford test.

Table 2 also provides a summary of the principal component analysis, where the first two axes (PC1 and PC2) accounted for more than 82%, which is higher than the value reported by Costa (2019) at 66%, Costa *et al.* (2021) at 69%, and Carvalho *et al.* (2020) at 66.71%. Therefore, the first axis captured a greater portion of the main effects.

The data accumulated here by the first two component axes can be considered sufficient, since Yang *et al.* (2009) state that the first two principal components should account for at least 60% of the total variance. Since the F_{Gollob} test indicates the significance of only the first two axes, it allows us to conclude that the AMMI analysis with these axes captures all variations attributed to genetic and environmental effects directly related to the interaction, while discarding the effects of noise or stochastic effects, which can significantly hinder the analysis interpretation (Maia *et al.*, 2009). Therefore, the AMMI2 model used here aligns with the standard for studying GxE interaction within a data set.

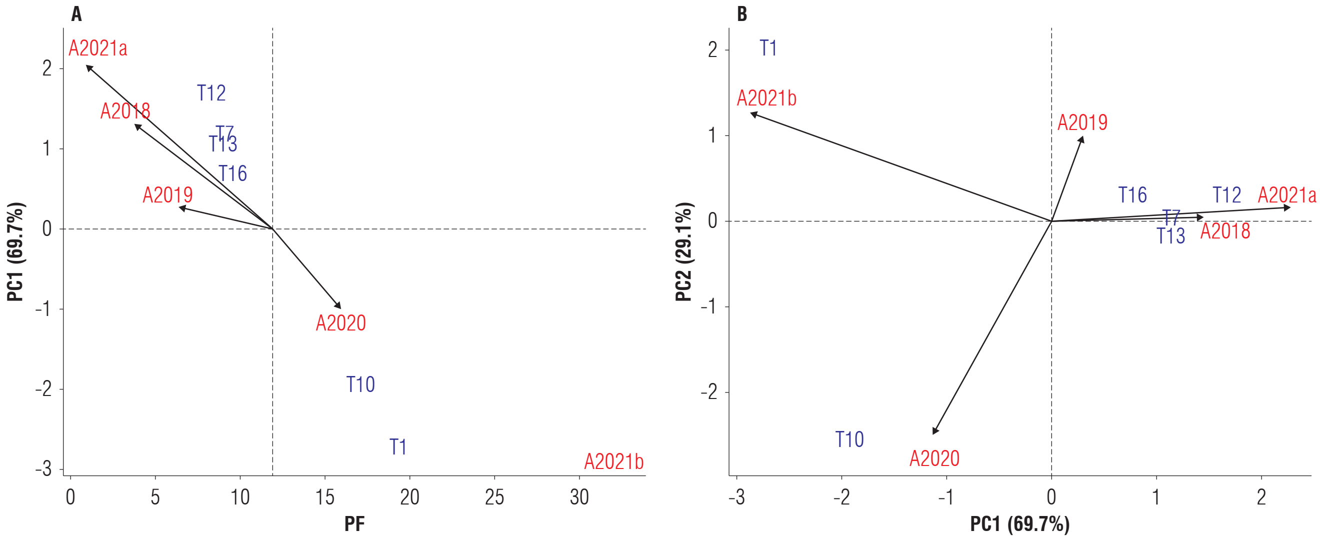

FIGURE 1. AMMI analysis for fruit weight (FW) trait. (A) Biplot AMMI1, means (x) vs. PC1 (y) and (B) Biplot AMMI2, PC1 (x) vs. PC2 (y), with environments corresponding to years for scion/rootstock combinations in 'Pera' sweet orange trees. Years are identified numerically, and combinations are recognized as T followed by a number. Capitão Poço, PA, Brazil.

In the AMMI1 analysis for FW (Fig. 1), T16 was the most stable material. Still, it contributed to the average, which is undesirable because it falls below the comparative average of all scion/rootstock combinations involved in the study. The materials with the most significant positive contributions (T1 and T10), unfortunately, exhibited instability, as evidenced by their distance from the horizontal axis and confirmed by the AMMI2 graph, which plots them far from the origin.

Based on graphic dispersion from scion/rootstock combinations, with different performances or contributions along the axes of the evaluated characteristics, it is possible to infer that materials with stability, specific adaptability, and better averages are valuable in genetic improvement programs. These results are consistent with those obtained by Carvalho *et al.* (2020), Ferrer *et al.* (2022), Huang *et al.* (2020), and Singh *et al.* (2023) in AMMI analysis.

In the GGE Biplot graphical analysis, summarized in the analysis of variance presented in Table 3, to verify the representativeness (PCs) of the treatment behavior, the first two axes account for a sum above 90%, exceeding the 60% minimum suggested by Yang *et al.* (2009). This confirms the reliability of the treatment performance distribution, which results from the G+GxE interaction and helps explain the total variation. The choice of a two-axis model, therefore, is satisfactory for portraying the behavior of the genetic material and the contribution of years, while disregarding potential noise or stochastic effects, which can cause distortions and make graph interpretation extremely difficult (Maia *et al.*, 2009). This model also exceeds the values reported by Costa (2019) (66%) and Costa *et al.* (2021) (69%).

Information ratios (IR) were also considered, with the first component axis showing values above 4 for all three characteristics, capturing almost all the contributions of genetic or non-environmental effects. In contrast, the second component reveals no clear pattern. Thus, a two-dimensional biplot portrays the data pattern, consistent with the approach defined by Yan and Tinker (2006). Consequently, the other component axes (PC3 and PC4) can be regarded as having only noise (IR<1), with no contribution to the interaction effect.

TABLE 3. Eigenvalues, explained variance (Ve%), cumulative explained variance (Va%), and information ratio (IR), considering the first four principal components (PCs), in fruit weight (FW, kg/plant) for scion/rootstock combinations in 'Pera' sweet orange trees. Capitão Poço, PA, Brazil.

Character	Parameters	PC1	PC2	PC3	PC4	PC5
FW	Eigenvalues	29.607	10.975	2.250	1.532	0.024
	Ve %	87.27	11.99	0.50	0.23	0.01
	Va %	87.27	99.26	99.76	99.99	100.00
	IR	4.36	0.60	0.03	0.01	0.00

In the graphical analysis of mega-environment identification and treatment specificity, we observed that for FW, no year was associated with T7, T13, T12, or T16, indicating no specificity in this aspect. In contrast, T10 was associated with 2020 and T1 with 2021b (Fig. 2).

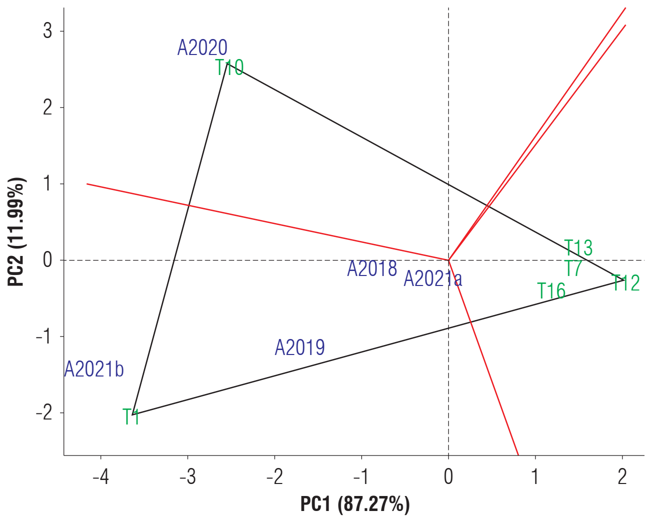

FIGURE 2. Indicative of which rootstocks performed best and in which years by GGE biplot ("Which-won-where") in fruit weight (FW) for scion/rootstock combinations in "Pera" sweet orange trees. Capitão Poço, PA, Brazil. The solid red lines delimit sectors that define the mega-environments.

Ideal test environments for identification and superior genotypes selection must possess both discriminative capacity and representativeness (Pereira *et al*., 2017). Environments with long vectors are the most discriminative, providing the most information about genotypes (Yan, 2016). The representative one is the one that forms the smallest angle with the average environment axis (EAM, the line that passes through the average environment and the biplot origin) and represents an average behavior across all environments. Therefore, in terms of the discriminative capacity, which aims to identify which sources of variation related to treatments and years have the most significant contribution to the variations, for FW (Fig. 3), the years 2019, 2020, and 2021b were the most discriminative, with treatments T1 and T10 also having an essential contribution in the total.

A second interpretation from the graphical analysis in Figure 3 is the identification of the year that represents the average of all others, effectively representing the average effect of all years. Thus, the year with the smallest angle relative to the EAM axis for FW was 2018, which was the average of all other years.

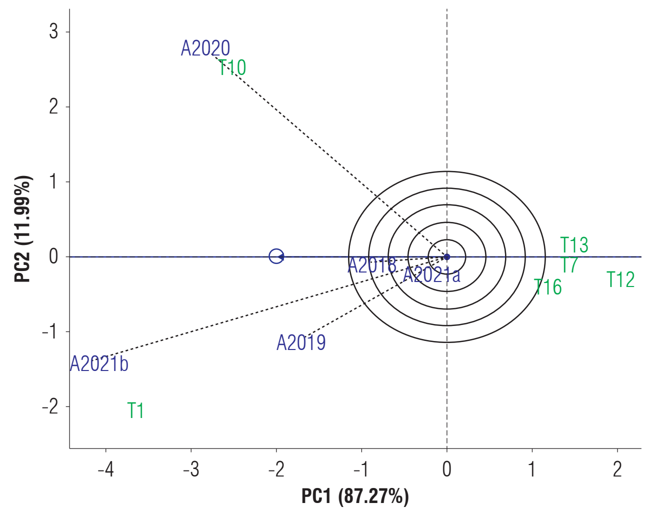

FIGURE 3. GGE biplot "discrimination and representativeness" to show the discrimination ability and representativeness of the test environments compared to the genetic materials in fruit weight (FW) for scion/rootstock combinations in 'Pera' sweet orange trees. Capitão Poço, PA, Brazil.

In Figure 4, the straight line (EAM) with an arrow indicates the scion/rootstock combinations that lie beyond the tip of the arrow are those that showed the highest average contribution among the materials evaluated (Yan, 2002; Yan, 2011). However, it is also noted that materials with longer vectors moving away from the EAM axis exhibit the least stability. Thus, in Figure 4 for FW, the treatments T7, T12, T13, and T16 were highly stable as indicated by their

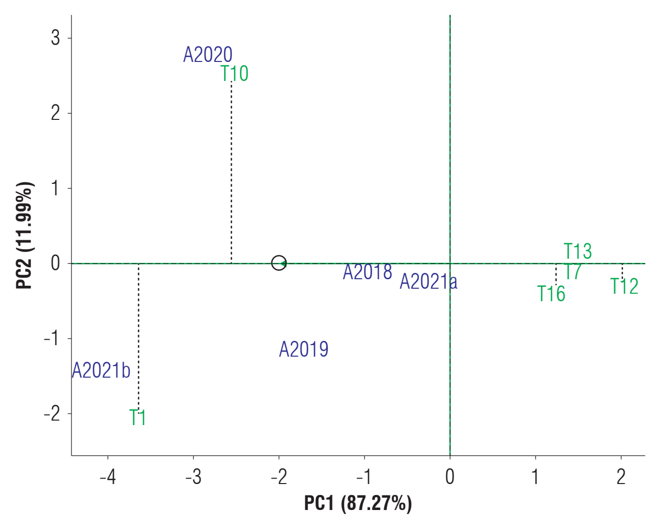

FIGURE 4. Average performance and stability of treatments by GGE biplot ("Average versus Stability") with environment mean axis (EAM) in fruit weight (FW) for scion/rootstock combinations in 'Pera' sweet orange trees. Capitão Poço, PA, Brazil.

proximity to the horizontal axis. Among the circles at the tip of the axis, those with the least stability were the ones with a positive contribution to the averages. This indicates that the environmental conditions generated different responses, with T1 and T10 exhibiting low stability and being more similar to genotypes with specific adaptability, due to their proximity to certain years.

A plant with above-average performance and high stability is the desired plant in genetic improvement programs and is called an “ideotype”, or simply the perfect plant, associating the better relations between productivity, disease resistance and stability (Trethowan, 2014) in each specific situation. Although it is only a representative model, its identification serves as a reference in comparison with other materials. The graphical analysis of the GGE Biplot, titled “Average versus Stability,” is an effective tool for identifying these ideotypes (Yan, 2011; Yan *et al*., 2007; Yan & Tinker, 2006).

The ideotype for the here-evaluated characteristic in the GGE Biplot (Fig. 5) is located at the center of the concentric circles; those plotted near this center or in the first circumcircles were considered promising. Thus, for FW, although T1 and T10 showed specificity and the greatest contributions to variation and were located in the circumcircles closest to the center, they were considered the best-performing ideotype among the materials evaluated.

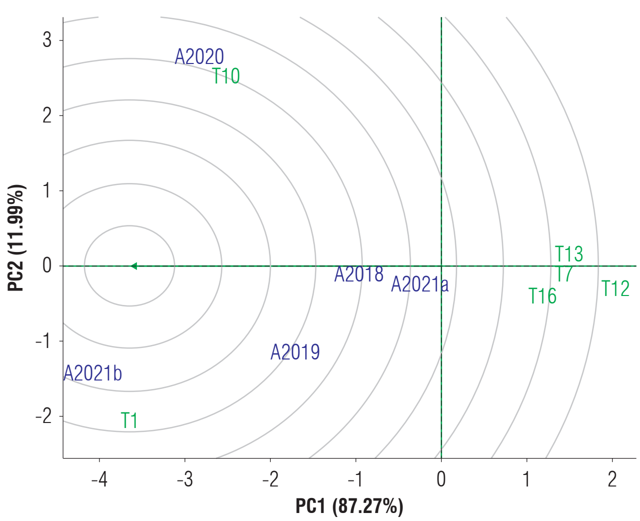

FIGURE 5. Classification of treatments in relation to ideotype (in the center of the concentric circles) by GGE biplot with environment-mean axis (EAM) in fruit weight (FW) for scion/rootstock combinations in ‘Pera’ sweet orange trees. Capitão Poço, PA, Brazil.

Citrus cultivation requires a variety of rootstocks for specific conditions, leading to differentiated performances in several characteristics, such as fruit quality and quantity, plant vigor and size, tolerance to abiotic factors, and resistance/tolerance to biotic factors (Medina *et al*., 2005; Santana *et al*., 2018). The results obtained here, selecting materials with greater stability, productivity, and a closer approach to the ideotype due to the presence of the GxE interaction, enabled the identification of promising clone/rootstock combinations. This study focused solely on fruit productivity, including components such as the number, weight, size, and quantity of fruits, again justifying its use here; however, in future research, evaluations of fruit quality and fruit harvest time should be added.

Conclusions

Comparing the results of AMMI and GGE Biplot analyses, the best rootstocks are “Santa Cruz” Rangpur lime (*C.* x *limonia* Osbeck) (T1) and “San Diego” citrandarin (TSK x TRENG-314) (T10).

The ideotype “Santa Cruz” Rangpur lime is shown to be closer to the target sought by genetic improvement.

“Santa Cruz” Rangpur lime presents low stability, which is a hindrance. Still, on the other hand, it appears to be specific to certain years.

In this situation, the breeder must choose the most promising materials in terms of positive contribution to the averages, even if it means sacrificing the desired stability.

Despite the search for more promising materials, which here were the least stable, it must be accepted that there are risks, as there is no way to predict production in later years.

Future research should identify which environmental factors favor fruit productivity and which generate instability in the Capitão Poço region of Brazil.

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Conflict of interest statement

The authors declare that there is no conflict of interests regarding the publication of this article.

Author´s contributions

Conceptualization: EAG, OSP, WSSF. Data curation and experimental evaluation: FLG. Formal analysis: KH. Funding acquisition: FLG, EAG, OSP, WSSF. Research: FLG.

Writing – original draft: GKIY. Writing – review & editing: FLG, KH, EAG, OSP, WSSF. All authors have read and approved the final version of the manuscript.

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