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Adaptability and stability of jabuticaba tree genotypes based on plant growth

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ABSTRACT. The aim of this work was to verify by means of adaptability and stability analyses which genotype of *Plinia* sp. (jabuticaba tree) is more adapted to orchard conditions, based on the measures of stem growth and primary shoots. During a three-year period, the initial growth of jabuticaba tree genotypes from the native fruit collection of the Experimental Station of the Universidade Tecnológica Federal do Paraná - Câmpus Dois Vizinhos was evaluated. These genotypes included seedlings from forest fragments of the southwestern region of Paraná State and some from Minas Gerais State, Brazil. Analysis of variance (ANOVA) was performed, in a 29 x 3 factorial design, with three replicates in each treatment. Phenotypic adaptability and genotypic stability were evaluated based on the data obtained by the following methods: Eberhart and Russell, Lin and Binns and the AMMI. The analyses were carried out through the computer programs GENES and Stability. The methods that were tested to determine the adaptability and stability of the growth behaviour of the jabuticaba tree did not present consistent patterns in the results. However, the genotype generally referred to as 'Vitorino' was the most suitable for open-air cultivation.

Keywords: Eberhart and Russel; Lin and Binns; AMMI; *Plinia* sp; jabuticaba tree; domestication.

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Introduction

The *Plinia* sp. (jabuticaba tree) originates in south central Brazil, occurring in practically every national territory with tropical and humid subtropical climates and areas with forests (Kinupp, Lisbôa, & Barros, 2011). In the southwestern region of Paraná State, the natural occurrence of *Plinia sp* (jabuticaba tree) is limited to some remaining forest sites, where human intervention has already occurred. This human intervention involves mainly the extractive exploitation of fruits, or in many places, native vegetation has been changed by pasture or husbandry (Citadin, Vicari, Silva, & Danner, 2005; Danner, Citadin, Sasso, & Tamazoni, 2010).

For the implementation of commercial orchards, *Plinia* sp. (jabuticaba tree) can be hard to cultivate when propagated by seed. This tree has a longer juvenile period that does not attract producers to cultivate it (Andrade & Martins, 2003). Therefore, it is necessary to understand this species better agronomically, through research on the methods of vegetative propagation, as well as the molecular characterization and phenotypic characteristics of the germplasm.

In this sense, it is important to select species or genotypes for cultivation that have adequate growth and vigour and, with quality fruit production.

To meet the needs of the producer, genetic improvement involves the selection of agronomic characteristics appropriate to the interest of the producer, with regularity in gene expression. Thus, studies involving the adaptability and stability of selected material are important to obtaining genetic material that maintain these selected characteristics over several years and in diverse environments.

To achieve this goal, the use of stability and adaptability analysis methods that take into account the interaction genotype x environment (G x E) and help the breeder to identify genotypes of more stable behaviour is important. Stability is the ability of a genotype to remain constant in its performance independent of the environment into which it is inserted, and adaptability refers to an individual's ability to respond positively to environmental conditions. These factors can be used as basis to use a new cultivar or to follow the breeding process (Cruz & Regazzi, 2001; Silva & Duarte, 2006).

There are several methods of determining phenotypic adaptability and stability and the difference between them, and these methods are related to biometric concepts and procedures to measure the interaction of G x E (Luz et al., 2018), being complementary to the analysis of variance of the data.

The models that can be used are procedures based on simple linear regression, such as the model of Eberhart and Russel (1966), non-parametric methods by the Lin and Binns (1988) model and the analysis of the main additive effects and multiplicative interaction (AMMI) described by Zobel, Wright, and Gauch (1988). These analyses will be important to observe the adaptive behaviour of *Plinia* sp. (jabuticaba tree) in orchards, where it is a fruit plant that is from forests where the environment had lower radiation in comparation the radiation under cultivated conditions. In addition, genotypes can present different behaviours when in cultivation.

The objective of this work was to verify the adaptive behaviour of *Plinia* sp. (jabuticaba tree) genotypes in orchard condition in terms of adaptability and stability analyses based on the measures of stem growth and primary shoots.

Material and methods

The study was carried out with *Plinia sp* (jabuticaba tree) genotypes from the collection of native fruit trees at the Experimental Station of Universidade Tecnológica Federal do Paraná – Câmpus Dois Vizinhos (latitude 25°41'49.47" S / longitude 53°5'41.46" W), with an altitude of approximately 520 m, in the southwestern region of Paraná State. The climate of the region, according to the classification of Köppen, is characterized as humid subtropical, type Cfa, with no defined dry season, and the average temperature of the warmer months is 22°C, and the cooler months range from -3,0°C and 18,0°C (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2013). The soil is classified as distroferric red nitosol (Bhering et al., 2008).

Twenty-nine jabuticaba fruit tree genotypes were planted in November 2009. These genotypes were obtained of the seeds of fragments of the Araucaria Forest, located in the southwestern region of Paraná, in the cities of Clevelândia, Vitorino, Chopinzinho, Coronel Vivida, Dois Vizinhos, and Pato Branco. The seeds from this region were classified as *Plinia cauliflora* (Danner, 2010). Additionally, there were genotypes from Imbituva City (*P. peruviana*), located in the south central region of Paraná State, and the genotypes were 'Silvestre' (*Plinia* sp.), 'Sabará' (*P. jaboticaba*), and Açú '(*P. cauliflora*) from the Universidade Federal de Viçosa, with altitudes ranging from 650 to 800 m.

The determination of the initial growth was performed every fortnight for three cycles (2012/2013, 2013/2014, and 2014/2015), and the stem and primary shoot lengths (cm) were obtained using a ruler in millimetres. The stem length was analysed from the base of the plant to the apex of the largest vertical bud. The primary shoot length (cm) was analysed from its beginning on the main stem to the apex of the stem.

The experimental design was completely randomized, in a factorial 29 x 3 (family x annual cycle) design, with three repetitions, with each genotype by plot.

Based on the values obtained for stem length and primary shoots (cm), genotypic adaptability and phenotypic stability evaluations were performed by the methods of Eberhart and Russell, where β_{1i} indicates adaptability and where β_{1i} = 1 indicates general or broad adaptability; β_{1i} > 1 indicated adaptability to favourable environments; and e β_{1i} < 1 indicates adaptability to unfavourable environments. Stability was determined by σ^2_{di}, where σ^2_{di} = 0 indicates high stability and σ^2_{di} = 1 indicates low stability (Cruz, Regazzi, & Carneiro, 2004; Eberhart & Russell, 1966). The Lin and Binns method is given by P_i, which indicates genotypic stability, and the smaller value is, the more stable the genotype (Lin & Binns, 1988), and by the additive main effects and multiplicative interaction analysis (AMMI) method to describe the mean response of genotype i, in terms of a single j with genotype (*gi*) and environment (*aj*) effects, which is multiplicative for the interaction effect (*ga*)*ij* (Zobel et al.,1988).

These analyses were performed used the GENES (Cruz, 2013) and Stability programs (UFLA, 2000).

Results and discussion

There was a significant effect among the *Plinia* sp. (jabuticaba tree) genotypes, by the F test (p < 0.01) for stem length and primary shoot length.

Based on the methodology of Eberhart and Russel (1966), genotypes that have general adaptability to the environment to which they are inserted have a linear regression coefficient equal to one (β_{1i} = 1), with high predictability of behaviour and a stability parameter equal to zero.

Thus, in Table 1, it was observed that the genotypes 'Clevelândia 1', 'Vitorino 7', and 'Coronel Vivida 4' had general adaptability in relation to stem growth. The Imbituva and Coronel Vivida 3 genotypes were more adapted to favourable environments followed by the 'Dois Vizinhos', 'Chopinzinho 2', and 'Clevelândia 2' genotypes. The other genotypes presented adaptability to the unfavourable environment for this same variable.

Table 1. Adaptability and stability of the 29 genotypes of *Plinia* sp. (jabuticaba tree) by the method of Eberhart and Russel.

	Stem				Primary shoots			
Gen.	Mean[1]	$\beta 1$[2]	σ^2[3]	R^2 (%)[4]	Mean[1]	$\beta 1$[2]	σ^2[3]	R^2 (%)[4]
CL1[5]	31.39	1.04	-16.94	98.08	115.21	0.98	-69.98	99.46
CL2	24.13	1.33	-17.22	99.97	104.97	0.67	-80.09	99.99
CL3	26.53	0.36	-17.17	96.87	110.9	0.90	-67.21	99.18
CL6	25.84	0.38	-17.20	98.50	134.64	1.04	-66.17	99.34
CL7	19.61	0.85	-17.23	99.96	105.08	0.89	-63.62	98.95
VI1	20.10	0.72	-16.67	92.73	117.97	1.07	-60.43	99.13
VI2	25.01	0.65	-17.10	97.74	132.92	1.51	-79.95	99.99
VI3	25.01	0.72	-17.02	97.21	127.83	1.16	-63.75	99.38
VI4	37.58	0.66	-17.21	99.76	139.47	1.35	-80.21	100.00
VI5	32.31	0.84	-16.71	94.92	128.41	1.13	-64.45	99.38
VI6	35.4	0.34	-16.85	80.08	121.01	1.02	-80.21	100.00
VI7	21.9	0.96	-17.07	98.78	123.64	1.18	-78.18	99.93
CH1	16.16	0.81	-16.93	96.77	117.91	0.97	-67.11	99.29
CH2	30.62	1.22	-16.78	97.84	112.46	1.10	-78.29	99.92
CH4	30.49	1.67	-17.19	99.90	120.54	0.97	-62.49	99.05
CV1	27.80	0.77	-17.15	98.98	129.79	1.40	-79.54	99.98
CV2	19.03	1.21	-17.12	99.46	118.84	1.25	-61.94	99.41
CV3	32.39	2.46	-17.16	99.91	96.52	0.91	-79.98	99.99
CV4	18.23	1.05	-17.13	99.37	107.86	1.10	-30.54	97.94
CV5	17.02	0.65	-17.23	99.98	97.56	0.56	-78.78	99.77
AS	17.94	0.69	-17.20	99.59	151.93	0.59	-76.66	99.48
SA1	32.37	0.3	-17.22	99.59	123.72	0.76	-65.71	98.73
SA2	23.52	0.56	-17.22	99.84	127.20	1.19	-2.9	97.28
PB1	16.76	0.64	-16.96	95.29	96.58	0.83	-78.39	99.86
PB4	19.78	0.92	-16.83	96.66	109.44	0.98	-79.38	99.96
SI	18.77	0.48	-16.57	83.03	105.44	1.08	-71.5	99.62
DV	15.92	1.18	-17.22	99.94	117.5	1.02	-70.79	99.54
AÇ	33.28	0.81	-17.18	99.40	102.78	0.97	-62.28	99.03
IM	28.71	4.71	-5.52	96.27	73.37	0.41	-72.85	97.80

[1]Average length of stem and primary shoots; [2]Regression coefficient; [3]Variance of regression deviations; [4]Determination coefficient; [5]CL1 - Clevelândia 1; CL2- Clevelândia 2; CL3 - Clevelândia 3; CL4 - Clevelândia 4; CL6 - Clevelândia 6; CL7 - Clevelândia 7; VPB1 - Vitorino 1; VI2 - Vitorino 2; VI3 - Vitorino 3; VPB4 - Vitorino 4; VI5 - Vitorino 5; VI6 - Vitorino 6; VI7 - Vitorino 7; FVPB1 - Chopinzinho 1; FVI2 - Chopinzinho 2; CH3 - Chopinzinho 3; CH4 - Chopinzinho 4; CH5 - Chopinzinho 5; CV1 - Coronel Vivida 1; CV2 - Coronel Vivida 2; CV3 - Coronel Vivida 3; CV4 - Coronel Vivida 4; CV5 - Coronel Vivida 5; SA - Sabará; SA1 - Sabará 1; SA2 - Sabará 2; PB1 - Pato Branco 1; PB4 - Pato Branco 4; SI - Silvestre; DV - Dois Vizinhos; AÇ - Açú; and IM - Imbituva.

For shoot length, the genotypes that were most adapted to location were 'Vitorino 2' and 'Vitorino 4', as well as 'Colonel Vivida 4', with 'Colonel Vivida 4' showing a broad adaptation genotype for the variable stem length. In this variable, a majority of the genotypes obtained this characteristic, with 'Coronel Vivida 5', 'Sabará', and 'Imbituva' being adapted to unfavourable environments (Table 1).

In both variables analysed, stability in all genotypes was lower than zero, demonstrating that the genotypes have high stability at the location they were inserted.

The stability of a genotype takes into account predictable behaviour in relation to the stimuli in the environment (Vencovsky & Barriga, 1992). This factor was demonstrated in that although the *Plinia* sp. (jabuticaba tree) genotypes of the Native Fruit collection had different origins, they maintained a pattern of growth.

In the model of Lin and Binns (1966), the estimates of the *Pi* parameter for the genotypes evaluated in the 3 growth cycles are represented in Table 2.

For the stem length variable, the five genotypes that showed adaptability to unfavourable $Pi_{(\text{unfavourble})}$ environments were 'Vitorino 4', 'Vitorino 6', 'Sabará', 'Açú', and 'Vitorino 5' genotypes, as their presented values of $Pi_{(\text{fav})}$ were smaller. For favourable environments, the five genotypes that presented lower values were 'Vitorino 4', 'Coronel Vivida 3', 'Vitorino 6', 'Açú', and 'Vitorino 5' (Table 2).

The highest stability (*Pi*) was observed in the 'Vitorino 4', 'Vitorino 6', 'Açú', 'Sabará 1', and 'Coronel Vivida 3' genotypes. The 'Vitorino 4', 'Vitorino 6', and 'Açú' genotypes presented greater stability and adaptability in the environment to which they were inserted in orchard conditions. Of these three genotypes, two (Vitorino denomination) came from the same location (Vitorino, Paraná State), demonstrating perhaps the possible existence of genes suitable for cultivation under orchard conditions.

For the variable length of shoots, the genotypes showed large variation in their values. For unfavourable environments, the genotype 'Sabará' presented a null value of adaptability to the environment. On the other hand, the 'Clevelândia 6', 'Vitorino 4', 'Sabará 1', and 'Vitorino 5' genotypes had the lowest values. For favourable environments, adaptability was higher for the 'Vitorino 4' genotype, also with a null value, and with 'Vitorino 2', 'Coronel Vivida 1', 'Sabará', and 'Clevelândia 6' genotypes (Table 2). In relation to stability, 'Sabará', 'Vitorino 4', 'Clevelândia 6', 'Vitorino 5', and 'Vitorino 2' were the genotypes that presented the lowest value by this methodology.

Table 2. Adaptability and stability of the 29 genotypes of *Plinia* sp. (jabuticaba tree) by the method of Lin and Binns.

	Stem				Primary shoots			
Gen.	Mean[(1)]	$Pi_{(desf)}$[(2)]	$Pi_{(g)}$[(3)]	$Pi_{(fav)}$[(4)]	Mean[(1)]	$Pi_{(desf)}$[(2)]	$Pi_{(g)}$[(3)]	$Pi_{(fav)}$[(4)]
CL1(5)	31.39	24.73	25.86	26.43	115.21	972.44	852.07	611.33
CL2	24.13	116.03	104.31	98.44	104.97	1178.56	1321.52	1607.45
CL3	26.53	52.02	74.14	85.2	110.90	1059.64	1036.96	991.61
CL6	25.84	60.13	82.61	93.84	134.64	331.74	251.54	91.13
CL7	19.61	171.74	180.1	184.27	105.08	1397.5	1311.41	1139.24
VI1	20.10	161.40	171.61	176.71	117.97	925.52	756.21	417.61
VI2	25.01	77.29	92.63	100.29	132.92	654.48	436.48	0.50
VI3	25.01	79.38	92.42	98.93	127.83	603.77	446.07	130.68
VI4	37.58	0.00	1.43	2.15	139.47	357.21	238.14	0.00
VI5	32.31	18.40	20.54	21.62	128.41	549.85	429.72	189.48
VI6	35.40	1.28	7.40	10.46	121.01	745.92	637.45	420.5
VI7	21.90	138.89	139.37	139.61	123.64	761.49	578.62	212.87
CH1	16.16	243.47	251.87	256.07	117.91	813.33	749.51	621.87
CH2	30.62	38.14	32.16	29.18	112.46	1166.48	989.28	634.87
CH4	30.49	47.37	33.24	26.17	120.54	714.14	653.95	533.56
CV1	27.80	52.36	58.74	61.94	129.79	680.88	465.78	35.56
CV2	19.03	203.35	191.04	184.89	118.84	1023	764.64	247.90
CV3	32.39	49.01	22.75	9.62	96.52	1861.49	1788.21	1641.65
CV4	18.23	206.05	206.75	207.1	107.86	1456.04	1201.75	693.16
CV5	17.02	211.49	232.91	243.62	97.56	1461.92	1743.02	2305.21
SA	17.94	194.05	213.27	222.88	151.93	0.00	27.74	83.21
SA1	32.37	9.10	21.34	27.46	123.72	474.31	536.22	660.06
SA2	23.52	95.22	114.25	123.77	127.2	631.11	491.47	212.18
PB1	16.76	220.5	238.98	248.23	96.58	1787.68	1779.85	1764.18
PB4	19.78	176.09	177.17	177.71	109.44	1225.66	1105.53	865.28
SI	18.77	174.85	197.81	209.29	105.44	1540.2	1315.22	865.28
DV	15.92	265.27	256.41	251.97	117.50	898.2	765.23	499.28
AÇ	33.28	11.68	14.73	16.25	102.78	1527.98	1445.38	1280.18
IM	28.71	167.45	76.85	31.55	73.37	2849.48	3489.45	4769.39

[(1)]Average length of stem and primary shoots; [(2)]Adaptability in an unfavourable environment; [(3)]Adaptability in a favourable environment; [(4)]Stability in the environment; [(5)]CL1 - Clevelândia 1; CL2 - Clevelândia 2; CL3 - Clevelândia 3; CL4 - Clevelândia 4; CL6 - Clevelândia 6; CL7 - Clevelândia 7; VI1 - Vitorino 1; VI2 - Vitorino 2; VI3 - Vitorino 3; VI4 - Vitorino 4; VI5 - Vitorino 5; VI6 - Vitorino 6; VI7 - Vitorino 7; FVPB1 - Chopinzinho 1; FVI2 - Chopinzinho 2; FVI3 - Chopinzinho 3; FVPB4 - Chopinzinho 4; FVI5 - Chopinzinho 5; CV1 - Coronel Vivida 1; CV2 - Coronel Vivida 2; CV3 - Coronel Vivida 3; CV4 – Coronel Vivida 4; CV5 - Coronel Vivida 5; SA - Sabará; SA1 - Sabará 1; SA2 - Sabará 2; PB1 - Pato Branco 1; PB4 - Pato Branco 4; SI - Silvestre; DV - Dois Vizinhos; AÇ - Açú; and IM - Imbituva.

The genotype 'Vitorino 4' was the only genotype that was repeated among the five most adapted and stable genotypes based on the Lin and Binns method for both variables.

For the AMMI methodology, in relation to stem length (Figure 1), the most adapted genotypes were represented in the biplot chart based on the first main component (IPCA 1) x the second main component (IPCA 2), where the points with the highest concentration next to the origin were 'Dois Vizinhos', 'Clevelândia 7', and 'Açú'. The genotypes 'Vitorino 6', 'Coronel Vivida 3' and 'Pato Branco 4' were the most stable for the variable shoot length (Figure 2). However, in both variables, the most distant genotype of the axis was Imbituva, whose origin is the south central part of Paraná State.

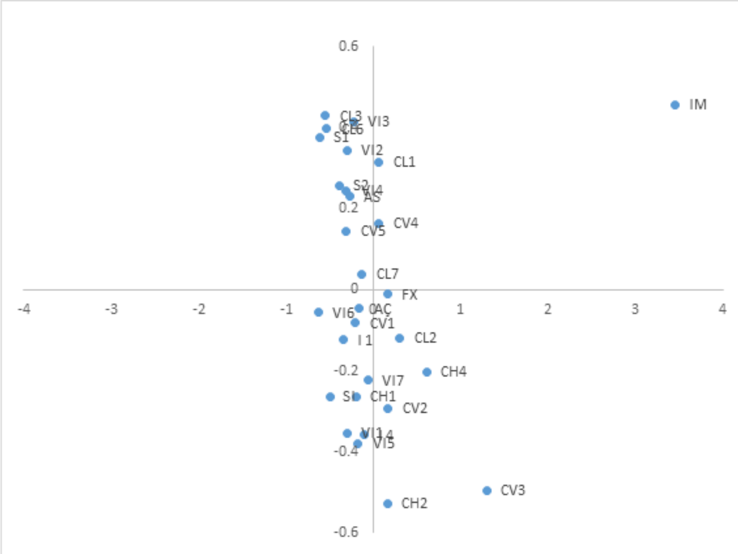

Figure 1. Adaptability and stability of the jaboticaba genotypes of the UTFPR native fruit trees, Câmpus Dois Vizinhos by the AMMI method for biplot stem length AMMI 2 - first main component (IPCA 1) x second main component (IPCA 2) for the genotypes CL1 - Clevelândia 1; CL2 - Clevelândia 2; CL3 - Clevelândia 3; CL6 - Clevelândia 6; CL7 - Clevelândia 7; VI1 - Vitorino 1; VI2 - Vitorino 2; VI3 - Vitorino 3; VI4 - Vitorino 4; VI5 - Vitorino 5; VI6 - Vitorino 6; VI7 - Vitorino 7; CH1 - Chopinzinho 1; CH - Chopinzinho 2; CH3 - Chopinzinho 3; CH4 - Chopinzinho 4; CH5 - Chopinzinho 5; CV1 - Coronel Vivida 1; CV2 - Coronel Vivida 2; CV3 - Coronel Vivida 3; CV4 - Coronel Vivida 4; CV5 - Coronel Vivida 5; SA - Sabará; SA1 - Sabará 1; SA2 - Sabará 2; PB1 - Pato Branco 1; PB4 - Pato Branco 4; SI - Silvestre; DV - Dois Vizinhos; AÇ –- Açú; and IM - Imbituva

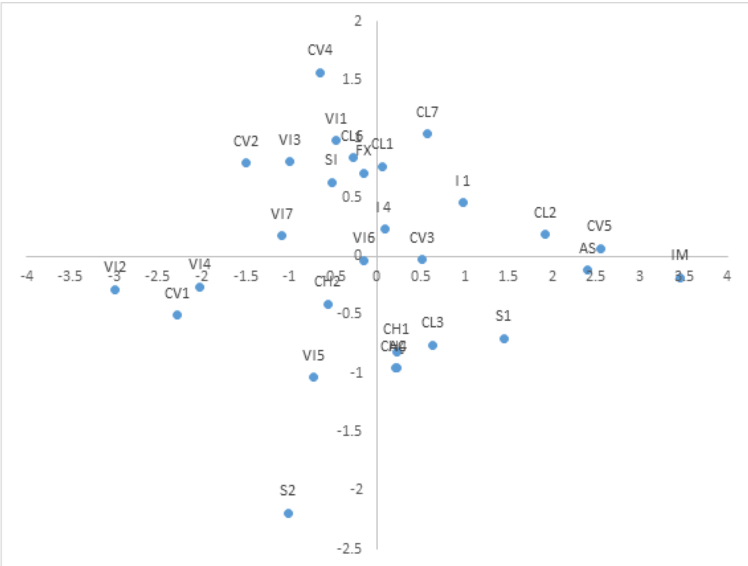

Figure 2. Adaptability and stability of the jaboticaba genotypes of the UTFPR native fruit trees, Campus Dois Vizinhos by the AMMI method for the length of the biplot shoots AMMI 2 - first main component (IPCA 1) x second main component (IPCA 2) for the genotypes CL1 - Clevelândia 1; CL2 - Clevelândia 2; CL3 - Clevelândia 3; CL6 - Clevelândia 6; CL7 - Clevelândia 7; VI1 - Vitorino 1; VI2 - Vitorino 2; VI3 - Vitorino 3; VI4 - Vitorino 4; VI5 - Vitorino 5; VI6 - Vitorino 6; VI7 - Vitorino 7; CH1 - Chopinzinho 1; CH2 - Chopinzinho 2; CH3 - Chopinzinho 3; CH4 - Chopinzinho 4; CH5 - Chopinzinho 5; CV1 - Coronel Vivida 1; CV2 - Coronel Vivida 2; CV3 - Coronel Vivida 3; CV4 - Coronel Vivida 4; CV5 - Coronel Vivida 5; SA - Sabará; SA1 - Sabará 1; SA2 - Sabará 2; PB1 - Pato Branco 1; PB4 - Pato Branco 4; SI - Silvestre; DV - Dois Vizinhos; AÇ –-Açú; and IM - Imbituva.

Regarding the methodologies adopted, it was observed that the results obtained did not have a pattern of response since both methodologies determined different genotypes as being more stable. However, genotypes from Vitorino were the most adapted and stable in orchard conditions, that is, for cultivated conditions. Thus, Vitorino could serve as material for a variety if they produce fruits with satisfactory sensory quality or as a possible parent to incorporate this adaptive capacity into other genotypes.

Several authors from different areas use these methodologies to estimate which genotype is most suitable for a crop, such as beans (Domingues, Ribeiro, Minetto, Souza, & Antunes, 2013; Pereira et al., 2009); eucalyptus (Santos et al., 2018) and soybean (Freiria et al, 2018), in a given location according to the desirable agronomic characteristics. These methods are now being used for the jabuticaba tree.

Conclusion

The methods tested for the adaptability and stability of the growth behaviour of the *Plinia* sp. (jabuticaba tree) did not present an even pattern in the results. The genotype 'Vitorino' presented the best results for both methods and was shown to be more suitable for open-air cultivation.

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