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Adaptability and stability of 'Valenciana' onion populations in the Brazilian tropical semi-arid

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Abstract

Brown onions of the 'Valenciana' type are not available for short-day growing conditions in the Northeast of Brazil. The goal of this study was to estimate parameters of adaptability and stability in order to release 'Valenciana' onion cultivars in the Northeast of Brazil. Eight populations of onions derived from a cross between 'Baia population' ×'Valcatorce INTA' and improved by recurrent selection were associated with six commercial onion cultivars, included as controls; they were evaluated in five experiments carried out in the municipalities of Petrolina, Pernambuco, Juazeiro, Bahia and Belém do São Francisco, Pernambuco. The experimental design was a randomized block design with three replications. Total and commercial bulb productions were evaluated for adaptability and stability parameters according to the methodologies of Eberhart and Russell, Lin and Binns and Main Effects and Multiplicative Interaction (AMMI). Significant genotype × environment interaction was observed for the two analysed variables. Eberhart & Russell and AMMI showed similar results for the overall cultivars, while some discrepancies were observed under the Lin & Binns method. The three methodologies produced concordant results for the 'Valenciana' onion types. The 25CA10 and T811CR13B'Valenciana'populations demonstrated broad adaptability and stability, associated with bulb production close to some cultivars and the commercial hybrid, and will be protected and released as new cultivars in the Northeast region of Brazil.

Keywords: *Allium cepa*; cultivars; genotype × environment interaction; recurrent selection.
Abbreviations: AMMI_ Main Effects and Multiplicative Interaction; Embrapa_ Brazilian Agricultural Research Corporation; G×E_ genotype and environment; IPA_ Instituto Agronômico de Pernambuco; PCI_ principal components; SAS GLM_ statistical analysis system general linear model.

Introduction

The onion (*Allium cepa* L.) is a vegetable of great economic importance for the states of Bahia and Pernambuco in the Brazilian Northeast, especially because of the climatic conditions of short days that allow for year-round cultivation (Souza et al., 2008). This region accounts for23.3% of national onion production where the largest producers are situated in the sub-median São Francisco valley (IBGE, 2015). The onion that is grown in the region is yellow type with fine cataphylls, the case being that 90% of the planted seeds are the result of the IPA (Instituto Agronômico de Pernambuco) genetic improvement program. The 'Valenciana' or "brown" onion differs from the yellow onion because it shows cataphylls of dark yellow colour with a great thickness and a better post-harvest quality, as well as a higher market price. Commercial 'Valenciana' cultivars have not been developed and adapted to the conditions of Brazil Northeast (Santos et al., 2010). The recommendation of an onion cultivar for a broad range of latitudes is limited by the interaction of genotype with the environmental conditions, mainly by photoperiod and temperature, which are essential to the bulbification process and the emission of the floral tassel respectively (Resende et al., 2010). According to Quartiero et al. (2014), the best cultivars are those that are developed in the target production region. A way to examine the genotype × environment interaction is to conduct a study on the adaptability and stability, which is of extreme importance to position the cultivars; it also helps to find genotypes that show a good performance in different environmental conditions (Hoogerheide et al., 2007).Adaptability is understood as the capacity of a genotype to take advantage of environmental conditions to maintain high productivity, while stability refers to the maintaining of productivity or the predictability in behaviour in diverse environments (Cruz et al., 2012). Among the numerous techniques, one of the most used methods to study adaptability and stability was developed by Eberhart and Russell (1966) based on the simple linear regression analysis. Other broadly applied methodology was proposed by Lin and

Binns (1988) and is based on non-parametric statistics in which the estimate of genotype stability is measured by the average square of the distance between the genotype average and the maximum average response for all environments. The Additive Main Effects and Multiplicative Interaction (AMMI) methodology combines, in one model, additive components for main effects (genotypes and environments) and multiplicative components for G × E interaction. Pereira et al. (2009) recommended simultaneous application of these methodologies in order to better understand the yield behaviour of populations or genotype in different environments. In the current study, parameters were estimated for adaptability and stability for eight improved 'Valenciana' populations by recurrent selection in order to release onion cultivars in the Northeast of Brazil.

Results

In the combined analysis, significant effects were observed for the genotype factors (G), environments (E) and for the genotype × interaction environment (G×E) (Table 1). The significance of the interaction indicates that the relative behaviour of the genotypes was distinctly influenced by the environmental conditions, which demands further studies about adaptability and stability in order to identify the genotypes that demonstrate good performance in different environmental conditions.

Commercial bulb yield

According to the methodology of Eberhart and Russell (1966), all the genotypes were classified as having a broad adaptability ($ß_1$=1), except for the cultivar BRS Alfa São Francisco that showed $ß_1$>1, which indicates that this population possesses an adaptability to favourable environments. In terms of stability of the studied populations, it was found that ten genotypes showed a high stability (σ^2_d=0), the case being that half of these obtained a medium productivity above the general average of 25.02 t ha^{-1} (Table2). According to the methodology of Lin and Binns (1988), the cultivar BRS Alfa São Francisco may be considered the most stable genotype in all environments for the commercial productivity of bulbs, which showed the lowest general values for P_i and for favourable environments. Based on this methodology, the population Alfa São Francisco TR C-IX, the cultivar IPA 11 and the 'Valenciana' populationT811CR13B also stood out. All types maintained reduced estimates for P_i (Table 2). According to the AMMI methodology, the interaction G × E was split into four principal components (CPI), and only the first CPI was statistically significant under *F*-test (p-value < 0.01), explaining 78.7% of commercial bulb yield (Table 1 and Figure 1). The experiment carried out at Bebedouro1 demonstrated the highest commercial bulb yield, with high instability, while Bebedouro2 and Belem1were the most stable sites for onion production (Figure 1).The populations Alfa São Francisco TR C-IX (#9) and Alfa São Francisco C-X (#10) showed the highest bulb yield, associated with high instability across the sites. Among the 'Valenciana' types, T811CR13B (#8) and 25CA10 (#4) showed the highest stability, associated with commercial bulb yield close to or above experimental bulb yield means, according to AMMI bi-plot (Figure 1).

Total bulb yield

In the Eberhart and Russell analysis (1966),only the control treatments BRS Alfa São Francisco and the hybrid demonstrated significant differences within the $ß_1$ parameter, $ß_1$>1 and $ß_1$<1, respectively, while the populations BRS Alfa São Francisco and Alfa São Francisco TR C-IX showed significant regression deviation. More than 85% of the examined populations showed an R^2estimate of over 80%, proving that the regressions satisfactorily explain the variations that occurred in the genotypes (Table 2).

According to the methodology of Lin and Binns (1988) (Table 2), the genotypes that showed the smallest P_i estimates were the BRS Alfa São Francisco, Alfa São Francisco TR Cycle IX, IPA 11, and the 'Valenciana' population T811CR13B. This same order was repeated for the P_i+ parameter in favourable environments, which are classified as genotypes with general adaption and stability for favourable environments.

According to the AMMI methodology, the interaction G × E was split into four principal components (CPI), and only the first CPI was statistically significant under *F*-test (p-value < 0.01), explaining 78.7% of commercial bulbs yield (Table 1 and Figure 1). The experiment carried out at Bebedouro1 showed the highest commercial bulb yield, with high instability, while Bebedouro2 and Belem1 were the most stable sites for onion production (Figure 1), as observed for commercial bulb yield.

The populations Alfa São Francisco TR C-IX (#9) and Alfa São Francisco C-X (#10) showed the highest bulb yield, associated with high instability across the sites. Among the 'Valenciana' types, T811CR13B (#8) and 25CA10 (#4) showed the highest stability, associated with commercial bulb yield close to or above the bulbs experimental yield means, according to AMMI bi-plot (Figure 1).

Discussion

This is one of the first studies to evaluate the genotype × environment interaction in the producing region of onions in the Northeast of Brazil. It is also the first study to evaluate onion populations of the 'Valenciana' type that were developed for the region with the final objective of protecting and releasing this type of onions to this region. Few studies about adaptability and stability have been published on onions in general and Golina et al. (2005) have been quoted mostly with ten populations examined during a six-year period in India.

The recommendation of onion genotypes for the region studied is complicated by the observation of the significance of the genotype × environment of combined analysis, given that a uniform recommendation cannot be made for all environments without considerable prejudice to the obtained production, which justifies conducting adaptability and stability analysis (Silveira et al., 2012), based on multiple complementary methodologies.

The three methods of adaptability and stability applied showed different results both for commercial and total bulb productivity: 1) The Eberhart and Russell (1966) and AMMI methodologies identified the IPA - 11 cultivar as the ideal genotype for the total and commercial productivity of bulbs; 2) the methodology of Lin and Binns (1988) identified the BRS Alfa São Francisco C-X and Alfa São Francisco TR C-IX, with the lowest estimates for both general P_i and P_i+ in favourable environments, as being ideal for this methodology.

According to Mendes et al. (2010), it is characteristic of the Lin and Binns (1988) methodology to reveal an increased correlation between high averages and genotypes with a general increased adaptability and phenotypic stability because it associates phenotypic stability to the smallest

Table 1. Commercial productivity (Procom) and total productivity (Prototal) ANOVA of 14 onion genotypes studied in five environments in the sub-median of the São Francisco River Valley, Brazil.

SV	DF	MS	
		Procom	Prototal
Blocks/environment	10	48.33	69.42
Genotypes (G)	13	574.87**	445.11**
Environments (E)	4	4131.54**	4798.94**
G × E	52	89.60**	81.33**
PCI1	16	127.03**	118.58**
PCI2	14	21.19^ns	17.10^ns
PC13	12	15.77^ns	7.86^ns
PC14	10	7.86^ns	5.02^ns
Error	156	32.41	29.91
Average		25.02	28.04
CV (%)		22.75	19.50
PCI1 (Cumulative %)		78.68	83.16
PCI2 (Cumulative %)		89.62	93.66
PC13 (Cumulative %)		96.95	97.80
PC14 (Cumulative %)		100.0	100.0

ns, *, ** = non-significant and significant at 5% and 1%, respectively, by *F*-test.

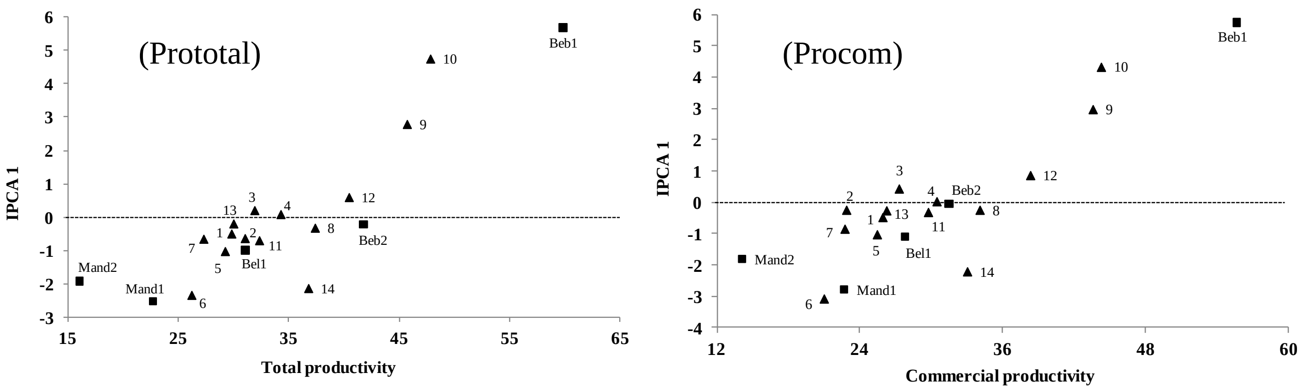

Fig 1. Bi-plot of AMMI for commercial productivity and total productivity of 14 onion genotypes (▲) examined in five environments (■) in the sub-median of the São Francisco River Valley, Brazil. 1 - T6 13 CR 15 – Bebedouro; 2 - T6 13 CR 15 – Bebedouro; 3 - T11 Botucatu; 4 - 25 CA 10 – Floresta; 5 - 17 CAI 1 – Canteiro; 6 - T11 Botucatu – Garagem; 7 - Cascuda Amarela SI – gaiola; 8 - T8 11 CR 13 – Mandacaru – A; 9 - Alfa São Francisco TR C-IX; 10 - Alfa SF C-X; 11 - IPA 10; 12 - IPA 11; 13 - IPA 12; 14 – Commercial Hybrid.

genotype deviations and takes all environments into consideration. This fact was observed for the Alfa São Francisco and Alfa São Francisco TR C-IX populations, which showed the largest bulb production. It should also be pointed out that this methodology is a non-parametric statistic, without presuppositions of statistic models such as data normality, while the methodology of Eberhart and Russell assumes data normality.

For the variables of total and commercial bulb productivity, the eight 'Valenciana' populations showed similar results under the three applied methodologies. The purple 'Valenciana' population T811CR13B stood out from the other 'Valenciana' types by all applied methodology. Another 'Valenciana' population that also showed superior behaviour was the yellow 'Valenciana'25CA10, which was classified as the sixth best genotype among the fourteen that were studied. On the other hand, the 'Valenciana' types T811CR13A, T11BotucatuB and Cascuda Amarela SI showed the highest estimates for P_i. They are, therefore, genotypes of low stability and adaptability, which indicates the necessity of additional recurrent selection cycles to reach production levels similar to the check cultivars.

It should be pointed out that the averages of some 'Valenciana' populations may have been negatively influenced by the fact that the evaluation periods of the experiments were those during which the highest temperatures of the region are reached. BRS Alfa São Francisco C-X and Alfa São Francisco TR C-IX cultivars were selected for high temperatures and the rainy period of the region, which partially explains the superior behaviour of these cultivars. The commercial hybrid behaved itself as one of high adaptability and stability in an unfavourable environment, and the results corroborate the findings based on the methods of Eberhart and Russell (1966) and AMMI. The average of commercial bulbs from the hybrid was, however, inferior to the averages of the genotypes BRS Alfa São Francisco C-X, Alfa São Francisco TR C-IX and IPA11, which indicates the superiority of these open-pollinated populations in relation to the hybrid in high temperature conditions and in the presence of pluviometric precipitation that is normally observed at the end and at the beginning of the year in the region. The 'Valenciana' population T811CR13Bwas also classified in the same production group of bulbs of the commercial hybrid, which shows the potential of this population for the region.

Taking the three applied methods into consideration to examine the adaptability and stability, the behaviour of the 'Valenciana' genotypes was generally satisfactory, which indicates a real possibility to recommend cultivars with the

Table 2. Estimations of adaptability and stability parameters of 14 onion genotypes for commercial productivity (Procom) and total productivity of bulbs (Prototal) based on the methodologies of Eberhart and Russell (1966) and Lin and Binns (1988).

Genotypes	Average (t ha^{-1})	Eberhart & Russel (1966)			Lin &Binns (1988)	
		$ß_1$	σ^2_d	R^2 (%)	P_i	P_i+
Procom						
T613CR15	25.90^{C}	0.93^{**}	4.23^{**}	96.89	350.05	708.33
T811CR13A	22.85^{C}	0.91^{**}	48.31^{**}	73.62	428.85	787.93
T11Botucatu A	27.27^{C}	1.08^{**}	2.60^{**}	99.31	295.15	578.76
25CA10	30.44^{B}	1.05^{**}	6.46^{**}	94.41	237.73	500.71
17CAI	25.43^{C}	0.79^{**}	4.69^{**}	94.40	387.80	813.83
T11Botucatu B	20.97^{C}	0.40^{**}	41.00^{**}	41.32	609.93	1343.83
Cascuda Amarela SI	22.72^{C}	0.81^{**}	0.65^{*}	89.66	447.27	889.11
T811CR13B	34.06^{B}	0.94^{**}	5.93^{**}	96.04	184.20	411.95
Alfa São Francisco TR C-IX	43.55^{A}	1.59^{**}	56.98^{**}	84.52	30.63	34.38
BRS Alfa São Francisco C-X	44.25^{A}	1.93^{**}	15.19^{**}	96.21	22.51	32.16
FranciscanaIPA 10	29.72^{B}	0.91^{**}	1.90^{**}	92.41	268.27	571.03
ValeOuroIPA11	38.30^{A}	1.15^{**}	18.16^{**}	88.77	111.64	256.77
Brisa IPA12	26.22^{C}	0.93^{**}	12.57^{**}	96.10	346.32	731.34
Commercial hybrid	33.01^{B}	0.57^{**}	24.23^{**}	46.57	289.72	709.15
Overall average	30.34					
Prototal						
T613CR15	29.88^{C}	0.91^{**}	1.02^{**}	98.93	342.91	718.10
T811CR13A	31.00^{C}	0.91^{**}	22.85^{**}	87.50	323.46	653.88
T11Botucatu A	31.87^{C}	1.04^{*}	1.66^{**}	98.27	277.05	556.50
25CA10	34.24^{C}	1.04^{*}	5.09^{**}	95.42	231.47	497.85
17CAI	29.20^{C}	0.81^{**}	3.62^{**}	96.64	382.72	817.69
T11Botucatu B	26.16^{C}	0.61^{**}	25.32^{**}	78.01	522.20	1148.01
Cascuda Amarela SI	27.25^{C}	0.91^{**}	5.85^{**}	87.32	411.24	814.65
T811CR13B	37.35^{B}	0.94^{**}	7.16^{**}	95.62	193.22	439.61
Alfa São Francisco TR C-IX	45.69^{A}	1.54^{**}	20.84^{**}	92.41	41.03	61.41
BRS Alfa São Francisco C-X	47.80^{A}	1.84^{**}	55.73^{**}	93.41	16.41	16.87
Franciscana IPA 10	32.30^{C}	0.86^{**}	1.67^{**}	93.02	302.08	659.52
ValeOuroIPA11	40.43^{B}	1.05^{**}	23.08^{**}	87.07	135.82	317.19
Brisa IPA12	29.96^{C}	0.91^{**}	9.76^{**}	96.88	332.34	705.75
Commercial hybrid	36.75^{B}	0.61^{**}	19.90^{**}	59.13	285.72	703.52
Overall average	34.26					

^{ns}, * and ** = non-significant and significant at 1% and 5%, respectively, by *F*-test. Averages followed by the same letter in the column belong to the same group by the Scott-Knott test at 5% probability.

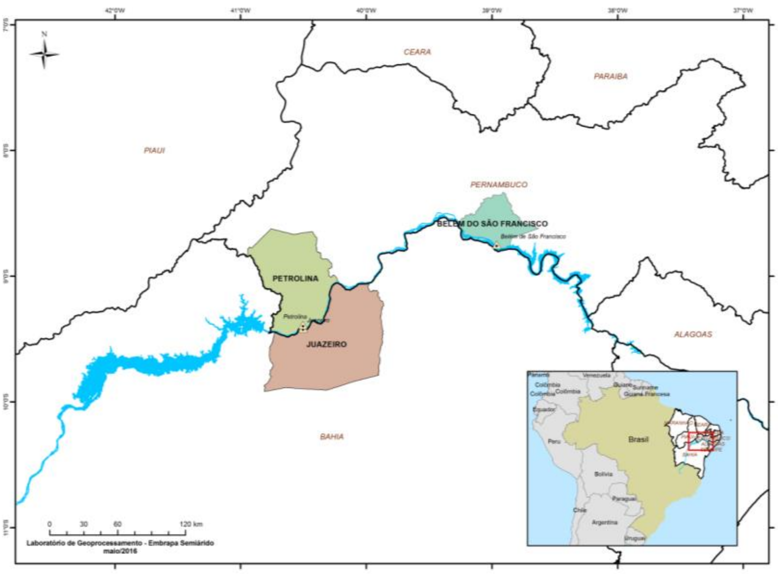

Fig 2. Location in Brazil Northeast of municipalities Petrolina, Juazeiro and Belém do São Francisco where14 onion populations were evaluated.

Table 3. Provenance and colour of the bulbs of onion genotypes examined in five environments in the Northeast of Brazil.

Genotypes	Provenance	Type-color
T6 13 CR 15	Embrapa Semiárido	Purple 'Valenciana'
T8 11 CR 13 A	Embrapa Semiárido	Purple 'Valenciana'
T11Botucatu A	Embrapa Semiárido	Yellow 'Valenciana'
25 CA 10	Embrapa Semiárido	Yellow 'Valenciana'
17 CAI	Embrapa Semiárido	Yellow 'Valenciana'
T11Botucatu B	Embrapa Semiárido	Yellow 'Valenciana'
Cascuda Amarela SI	Embrapa Semiárido	Yellow 'Valenciana'
T8 11 CR 13 B	Embrapa Semiárido	Purple 'Valenciana'
Alfa São Francisco TR C-IX	Embrapa Semiárido	Yellow Baia
BRS Alfa São Francisco C-X	Embrapa Semiárido	Yellow Baia
Franciscana IPA 10	IPA	Purple Baia
ValeOuroIPA11	IPA	Yellow Baia
Brisa IPA12	IPA	Yellow Baia
Commercial hybrid	-	Yellow Grano

'Valenciana' characteristics for short-day conditions in Brazil's Northeast.

The 'Valenciana' populations T811CR13B and 25CA10 show commercial and total productivities close to or above 25 t ha^{-1}, having been grouped with two cultivars and one commercial hybrid by the Scott-Knott test, and were classified by the three applied methodologies, as genotypes of good elevated adaptability and stability and should be released as new cultivars for the region of the São Francisco Valley. Additional cycles of recurrent selection, however, are recommended to increase the production potential of these 'Valenciana' type populations in the Northeast of Brazil.

Materials and methods

Sites and conduction of Experiment

The experiments were conducted in the municipalities of Petrolina, Pernambuco, Juazeiro, Bahia and Belém do São Francisco, Pernambuco, totalling five environmental conditions (Figure 1). The municipality of Petrolina is located at an altitude of 365.5 m, latitude 09º09'S and longitude 40º22'W, while the municipality of Juazeiro is situated at an altitude of 350 m, latitude09°24'S and longitude 40°26'W. The experiments in these municipalities were carried out at the experimental areas of Embrapa Semiárido, and the first experiment was carried out in the period of October 2013 to January 2014 and the second from October 2014 to January 2015. In Belém do São Francisco, the experiment was carried out at the IPA (Instituto Agronômico de Pernambuco) in the period of October 2014 until January 2015. This municipality is situated at an altitude of 305 m, latitude 08°45'S and longitude 38°57'W. The experimental design adopted in all experiments was a randomized complete block design with 14 treatments and three replications, with a spacing of 0.10 m among plants and 0.10 m among lines. Onion seedlings transplanting was performed 30 days after sowing, when the seedlings were15 to 20 cm higher. Crop management practices recommended for commercial onions fields were applied, including fertilization of 800 kg ha^{-1} NPK of the mixture 06-24-12, before transplanting in the field by hand. N and K were also applied during the plant development, consisting of 100 kg ha^{-1} of N divided in five applications, and 60 kg ha^{-1} of K divided in two applications, until 50 days after seedlings transplanting.

Plant Material

The treatments consisted of eight 'Valenciana' onion populations (Table 3) improved at Petrolina, Pernambuco by Embrapa Semiárido. These populations were derived by recurrent phenotypic selection from CNPH 6400 base population, which resulted from a cross between a 'Baia' population ×'Valcatorce INTA'. Four cycles of selection were performed at Brasilia, by Embrapa Vegetables, and ten cycles of selection were concluded at Petrolina, by Embrapa Tropical Semi-Arid. The populations Alfa São Francisco TRC-IX, which is resistant to *Thrips tabaci*, was also included as the control treatment, along with the commercial cultivars BRS Alfa São Francisco C-X, Fraciscana IPA - 10, Vale Ouro IPA - 11, Brisa IPA - 12 and a commercial hybrid. Two characteristics were examined: a. commercial productivity (Procom) – obtained by the total weight of the bulbs with a transversal diameter greater than 35 mm, with data in t ha^{-1}; b. total productivity (Prototal) obtained by the total weight of the bulbs harvested from the plot, with data intha^{-1}.

Statistical analysis

The total bulb production data were corrected by covariance based on the average plant stand of experimental units of each experiment. A factor was generated to adjust the commercial bulb production to correct for possible failures during seedlings transplanting in the field by hand.

After individual analyses of variance by the SAS GLM procedure (SAS, 1989), the combined analyses were carried out by considering the value smaller than seven for the ratio between the larger and the smaller error mean square as an indication of the homogeneity of the five experiments. The adaptability and stability parameters were estimated for the commercial and total productivities according to the methodologies of Eberhart and Russell (1966) and Lin and Binns (1988) with the Genes software (Cruz, 2009).

The methodology proposed by Eberhart and Russell (1966) is based on linear regression analysis and takes the average productivity of each genotype as an adaptability parameter: the linear regression coefficient ($ß_1$), which is used as the standard response of the genotype to different environments; the stability is evaluated by the variation of the regression deviation (σ^2_d) and by the determination coefficient (R^2).

The methodology proposed by Lin and Binns (1988) is based on non-parametric statistics.

The P_i parameter describes the genotype stability, which is defined as the mean square of the distance between genotype *i* and the genotype presenting the strongest response. In addition, the P_i+ parameter provides information about favourable environments. Genotypes presenting low values are those with the best performance in such contrasting environments.

The Additive Main Effects and Multiplicative Interaction (AMMI) methodology combines, in one model, additive components for main effects (genotypes and environments) and multiplicative components for G × E interaction. A matrix is built with new variables which are independent of one another and which capture G × E interactions. The first two AMMIs are enough to capture the majority of G × E variance and to allow for interpretation through bi-plots. It is a useful means of identifying high-yield, largely adapted genotypes and defining the so-called agronomic zoning (Duarte and Vencovsky, 1999).

Conclusion

Significant genotype × environment interaction for total and commercial bulb production among the five evaluation sites in Brazil's Northeast was observed. Eberhart and Russell and AMMI showed similar results for the overall cultivars, while some discrepancies were observed for the Lin and Binns method. The three methodologies showed concordant results for the 'Valenciana' onion types.

The 25CA10 and T811CR13B'Valenciana' populations showed broad adaptability and stability, associated with bulb production close to some cultivars and the commercial hybrid, and will be protected and released as new cultivars for the Northeast of Brazil.

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