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ARTICLE

Bayesian segmented regression model to evaluate the adaptability and stability of maize in Northeastern Brazil

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Abstract: *Although maize is one of the main crops in the Northeast region, yield is still considered low when compared to other regions. One of the main solutions to increasing yield is the selection of cultivars adapted to the conditions of the Northeast region. Thus, the present study aims to use the Bayesian segmented regression model to evaluate the adaptability and stability of maize. The experiment was set up in a randomized block design with two repetitions, where 25 maize hybrids were evaluated in different states. Initially, the analysis of variance was performed. Then, the Bayesian approach of the segmented regression method was used to select the hybrids regarding adaptability and stability. There was a difference between the genotypes indicated using the a priori distribution and those indicated by the minimally informative a priori distribution. Hybrids 20A55HX, 2B433HX, 2B512HX, and P2830H were considered ideal for the Northeast region.*

Keywords: *Bayes factor, Genotype x environment interaction, Informative priori,* Zea mays *L.*

INTRODUCTION

Maize is a crop with great economic and social importance, and for this reason it is studied worldwide. Brazil, the third largest producer in the world, with a production of 115.6 million tons and a planted area of 21.3 million hectares, has maize as one of the main commodities being cultivated under different environmental conditions and, according to the National Supply Company (CONAB 2018, 2022), in 20 years its production increased by 193.55%.

In the Northeast region, this crop is widely used in human diet because it is a source of carbohydrates, vitamin B1, magnesium, potassium, phosphorus, copper, and other important nutrients. In addition, it has a wide variety of uses (grain, greens, silage, popcorn, etc.) and it is the main raw material for feed production, where the entire structure of the plant is used, with the grains employed as the main source of energy and the vegetative parts in the production of silage (Artuzo et al. 2019, EMBRAPA 2023).

Due to the different forms of application, maize is a traditional crop in the Northeast and is the target of several research projects that aim to increase yield through the selection of cultivars adapted to the soil and climate conditions

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of the cultivation region, thus allowing better development and yield, since despite the importance of this crop for the Brazilian Northeast, yield is still considered low. The National Supply Company (CONAB 2022) estimates that for 2023 the planted area will be 3.300 million hectares and production could reach 11,438.5 tons. Research focused on the selection of genotypes with good adaptability and stability aims to increase yield and thus is of fundamental importance since they directly influence production costs and determine the effectiveness of the cultivar.

Among the different methodologies used to evaluate the adaptability and stability of maize genotypes for the growing region, the Bayesian segmented regression analysis has stood out for having greater rigor (Nascimento et al. 2020, Oliveira et al. 2020). This approach uses prior distributions that incorporate additional information, considered useful, about the parameters of interest in the estimation process.

In these parameters, interpreted as random variables, the probability models allow relevant initial information to be shown. As a result, there is a better identification of the genotype considered ideal, i.e., the one that has high yield, good adaptability, and low sensitivity to environmental adversities. Given the above, the objective of the present study is to use the Bayesian segmented regression model to evaluate adaptability and stability in maize.

MATERIAL AND METHODS

Conducting the experiment

Twenty-five maize hybrids from public and private companies were evaluated during the 2014 and 2015 agricultural seasons in the states of Sergipe (Nossa Senhora das Dores, Frei Paulo and Umbaúba), Alagoas (Arapiraca), Piauí (Teresina) and Maranhão (São Raimundo das Mangabeiras) (Table 1). The experimental areas in the cities of Teresina and São Raimundo das Mangabeiras were divided into two environments each, characterized by differences related to sowing and harvest dates and geographical data. Thus, according to the differences existing in the evaluation sites, a total of eight environments were considered (Table 2).

The experiments were implemented using a randomized block design, with two repetitions, where each plot was composed of four 5.0 m long rows, spaced 0.70 m x 0.20 m between and within rows, respectively. Sowing was done manually and, 15 days after emergence, the plants were thinned, totaling 100 plants per plot. At harvest, only the two central rows of each plot were evaluated to determine yield. The fertilizers used followed the guidelines of the soil analysis results for each experimental area. Irrigation was not used and weed and pest control was done according to the needs of the crop in each region.

Statistical analysis

For the analyses, the environments were considered random. Initially, the analysis of variance was performed for each trial, and after verifying the homogeneity of the residual variances using Hartley's (1950) maximum F test, we proceeded to the joint analysis of variance. The joint analysis was carried out considering the model:

$y_{ijk} = \mu + {}^{r}/_{e_{k(j)}} + e_j + y_l + g_i + ey_{jl} + ge_{ij} + gy_{il} + gey_{ijl} + \varepsilon_{ijlk}$, , where y_{ijk} is the phenotypic mean; μ is the overall mean; $\frac{r}{ek(j)}$ is the effect of the kth repetition in the jth environment; g_i is the fixed effect of the ith genotype; e_j is the effect of the jth environment Normally and Independently Distributed - NID$(0, \sigma^2_e)$; ge_{ij} and gy_{il} are the effect of the interaction of the ith genotype in the jth environment NID $(0, \sigma^2_{ge})$ and lst year NID $(0, \sigma^2_{gy})$, respectively; gey_{ijl} is the ith genotype in the jth environment in the lst year NID $(0, \sigma^2_{gey})$; and ε_{ijlk} is the experimental error, NID $(0, \sigma^2_{\varepsilon})$.

After verifying the significance of variance components related to the interaction term between genotypes and environments, we proceeded to the analysis of adaptability and phenotypic stability, through the Bayesian approach of the segmented regression method proposed by Cruz et al. (1989). This approach, described in Nascimento et al. (2020), is summarized below. The Bayesian segmented regression model is given by:

$$y_{ij} = \beta_{i0} + \beta_{i1} I_j + \beta_{i2} T(I_j) + e_{ij}$$

where: y_{ij} is the response of genotype i in environment j; β_{i0} is the mean response of genotype i; β_{i1} is the linear regression coefficient related to the unfavorable environments; β_{i2} represents the change in slope from the first to

Table 1. List of hybrid maize cultivars and their respective origins, types, cycles, colors, grain textures and companies

Nº	Cultivar	Transgenic/ conventional	Type[1]	Cycle[2]	Grain color[3]	Grain texture[4]	Seed company
1	20A55HX	Transgenic	TH	E	OR	SMHARD	Morgan
2	2B433HX	Transgenic	TH	EE	Y/OR	SMDENT	Dow Agro
3	2B512HX	Transgenic	TH	E	OR	SMDENT	Dow Agro
4	2B587HX	Transgenic	SH	E	Y/OR	SMDENT	Dow Agro
5	2B604HX	Transgenic	SHm	E	OR	SMHARD	Dow Agro
6	2B610PW	Transgenic	SH	E	Y/OR	SMDENT	Dow Agro
7	2B707HX	Transgenic	SH	E	OR	SMHARD	Dow Agro
8	2B710HX	Transgenic	SH	E	Y/OR	SMHARD	Dow Agro
9	2B810PW	Transgenic	SH	N	OR	SMDENT	Brevant
10	30A16HX	Transgenic	SH	E	Y/OR	SMHARD	Morgan
11	30A37HX	Transgenic	SH	EE	Y/OR	SMHARD	Morgan
12	30A91HX	Transgenic	SHm	E	Y/OR	SMHARD	Morgan
13	30A95HX	Transgenic	TH	E	OR	SMHARD	Morgan
14	SG6030YG	Transgenic	SH	E	OR	SMHARD	Monsanto
15	LG6038PRO	Transgenic	SH	E	Y/OR	SMHARD	Limagrain
16	LG 6304PRO	Transgenic	HS	E	Y	SMHARD	Limagrain
17	BR206	Transgenic	DH	E	OR/R	SMDENT	Embrapa
18	NS90PRO	Transgenic	HS	E	OR	SMHARD	Nidera
19	NS92PRO	Transgenic	HS	E	OR	SMHARD	Dow Agro
20	P2830H	Transgenic	HS	EE	OR	SMHARD	Du Pont
21	P3646H	Conventional	HS	E	OR	SMHARD	Du Pont
22	XB7116	Conventional	TH	E	OR	SMHARD	Semeali
23	XB8010	Conventional	DH	EE	OR	HARD	Semeali
24	XB8018	Conventional	DH	EE	OR	SMHARD	Semeali
25	XB8030	Conventional	DH	E	OR	SMHARD	Semeali

[1] DH = Double hybrid; TH = Triple hybrid; SHm = Modified single hybrid; [2] N = normal; EE = Extra early; E = Early; [3] OR = Orange; R = Reddish; Y = Yellow; [4] SMDENT = Semi-dent; SMHARD = Semi-hard.

Table 2. Edaphoclimatic characteristics of the experiments evaluated in the 2014 and 2015 seasons

Location	**Latitude** (S)	**Longitude** (W)	**Altitude** (m)	**Average rainfall** (mm)	**Average temperature** (°C)	**Soil type**
Nossa Senhora das Dores	10°30’	37°13’	200	670	25	Oxisol
Frei Paulo	10°51’	37°53’	272	613	26	Inceptisol
Umbaúba	12°22’	37°40’	109	997	24	Ultisol
Arapiraca	09°08’	36°09’	241	589	26	Inceptisol
Teresina 1	05°02’	42°47’	69	1.231	28	Ultisol
Teresina 2	05°02’	42°47’	80	1.031	28	Entisol
São Raimundo das Mangabeiras 1	06°49’	45°24’	515	718	26	Ultisol
São Raimundo das Mangabeiras 2	07°32’	45°46’	501	657	26	Ultisol

the second regime; $\beta_{i1} + \beta_{i2}$ is the linear response to the favorable environments; I_j is the coded environmental index; $T(I_j) = 0$, if $I_j \leq 0$, or $T(I_j) = I_j - \bar{I}_+$ if $I_j > 0$ and $\bar{I}_+$ is mean of the coded environmental index considering only environments with positive index; and e_{ij} is the error term, NID $(0, \sigma^2)$.

The prior distributions for the parameters ($\beta_{i0}, \beta_{i1}, \beta_{i2}, \sigma^2_{ie}$) were the same presented by Nascimento et al. (2020), that is, $\beta_{i0}, \mu_{\beta i0}, \sigma^2_{\beta i0} \sim N(\mu_{\beta i0}, \sigma^2_{\beta i0})$; $\beta_{i1}, \mu_{\beta i1}, \sigma^2_{\beta i1} \sim N(\mu_{\beta i1}, \sigma^2_{\beta i1})$; $\beta_{i2}, \mu_{\beta i2}, \sigma^2_{\beta i2} \sim N(\mu_{\beta i2}, \sigma_{\beta i2})$ and $1/\sigma^2_{ie} = \tau_{ie}\ \alpha_1, \beta_1 \sim Gamma(\alpha_i, \beta_i)$, where $\mu_{\beta i0}, \sigma_{\beta i0}, \mu_{\beta i1}, \sigma^2_{\beta i2}, \mu_{\beta i2}, \sigma^2_{\beta i2}$ and α_i, β_i are the known parameters.

The model’s goodness of fit was assessed through DIC (Deviance Information Criterion). Models with lower DIC are preferred. To perform the comparison, two models were fitted. Model 1 (M1) was characterized by minimally informative prior distributions. Specifically, the hyperparameters were defined as follows:

$\beta_{i0}|\mu_{\beta i0}, \sigma^2_{\beta i0} \sim N(\mu_{\beta i0} = 0, \sigma^2_{\beta i0} = 100000)$, $\beta_{i1}|\mu_{\beta i1}, \sigma^2_{\beta i1} \sim \mathrm{N}(\mu_{\beta i1} = 0, \sigma^2_{\beta i1} = 100000)$, $\beta_{i2}|\mu_{\beta i2}, \sigma^2_{\beta i2} \sim N(\mu_{\beta i2} = 0, \sigma^2_{\beta i2} = 100000)$ and $\tau_{ie}|\alpha_i, \beta_i \sim Gamma\ (\alpha_i = 0.001, \beta_i = 0.001)$. Model 2 (M2) used the estimates obtained of frequentist analysis of segmented model as information to define the hyperparameters (Nascimento et al. 2020, Oliveira et al. 2020).

The inferences about the parameters were obtained using Markov chain Monte Carlo (MCMC) approach to obtain the posterior marginal distributions for each parameter. A total of 100,000 iterations were considered, with burn-in of 10,000 and thinned every five iterations. In each chain, the posterior mean, standard deviation, 95% credibility intervals, and convergence criterion statistics were analyzed (Raffery and Lewis 1992). The analyses were performed with the help of R software (R Development Core Team 2022), through the rbugs (Yan 2001) and boa (Smith 2007) packages.

RESULTS AND DISCUSSION

In this study, we aimed to exploit the potential nonlinear pattern of genotype responses to environmental variation. To do that, we used the Bayesian segmented regression model which makes it possible to find the “ideal” genotype which shows high yield performance and high stability to adverse conditions.

The coefficient of variation (CV%) showed a value of 9.29, which is considered within the acceptable limits for the maize crop, since according to BRASIL (2012) the CV value must be less than or equal to 20% for soybean, wheat, bean, maize, and sorghum crops (Table 3). Therefore, the result obtained in this research indicated greater reliability in mean estimates, as indicated by optimal experimental precision. Moreover, the analysis of variance for grain yield showed a significant result ($p \leq 0.01$) of the variation factor environment x years. This result indicates that the environments showed climate differences in the different years of evaluation.

The effects of genotypes x environments and genotypes x years indicated inconsistent performance of the hybrids in different locations and years. These results highlight the difficulty of recommending these cultivars for wide cultivation, which requires an isolated recommendation for a specific planting location. These results corroborate those found by Afférri et al. (2020), Ferreira and Hongyu (2018), and Santos et al. (2019), who found in their studies difficulty in recommending cultivars with broad adaptability and good stability, the recommendation being made according to the specific environment.

The difficulty in recommending the ideal genotypes for a given environment occurs due to the effect of the environment on the expression of the characteristics, a factor responsible for reducing the correlation between phenotypic and genotypic values (Gauch 2013). This inconstancy in the classification of genotypes highlights the need for a detailed study of their behavior in each environment.

To do so, Bayesian analysis was performed considering the minimally informative a priori distributions by the method of Cruz et al. (1989), revealing that, of the genotypes evaluated, six were considered of general adaptation ($\beta_{i1} = 1$) (Table 4). Of these, only P2830H showed a linear response to favorable environments greater than 1 ($\beta_{i1} + \beta_{i2} > 1$) and high average yield ($\beta_{i0} > \bar{\mu}$). Thus, this genotype responds well to environmental improvement, which makes it suitable for producers who employ a high level of technology. Similar results were obtained by Carvalho et al. (2017) and Cardoso et al. (2014) when evaluating maize hybrids in the northeast and mid-north regions.

Regarding the stability parameter, (σ^2_{di}), classify the genotypes as having high adaptability when they have values equal to zero, or low predictability when values are greater than zero. However, coefficients of determination (R^2) can be greater than 80%, indicating that the degree of predictability should not be affected by the values of the stability parameter (Cruz et al. 1989). Thus, the hybrid P2830H was considered to have good stability because, despite exhibiting values of σ^2_{di} different from zero, it

Table 3. Joint analysis of the mean grain production of 25 hybrid maize cultivars tested in eight localities of Northeastern Brazil

Sources of variation	df	Mean square
Repetition (Environment)	8	1071341.00*
Environment	7	147953017.00**
Years	1	112616937.00**
Genotypes (G)	24	35284708.00**
Environments*Years	7	47954732.00**
Genotypes*Environments	168	2986173.00**
Genotypes*Years	24	19700012.00**
Genotypes*Environments*Years	165	2451459.00**
Error	388	668174.00
CV (%)	9.29	
Mean (kg ha^{-1})	8792.01	

**Significant at 0.01 probability level by F test.

Table 4. Estimates for the a posteriori mean and credibility intervals (95%) for the stability and adaptability parameters, coefficient of determination and deviance information criterion considering minimally informative prior distributions

Genotype	Informative a priori distributions													
	LB	$\widehat{\beta_{i0}}$	UP	LB	$\widehat{\beta_{i1}}$	UP	LB	$\widehat{\beta_{i1}} + \widehat{\beta_{i2}}$	UP	LB	$\hat{\sigma}^2_{di}$	UP	R^2	DIC
20A55PW	9372.00	9372.00	9372.00	0.58	0.92	1.92	2.17	2.69	4.25	5,266,000.00	6,760,216.78	12,030,000.00	83.73	249.64
2B433PW	10370.00	10370.00	10370.00	0.53	0.86	1.85	1.90	2.42	3.95	5,022,000.00	6,449,207.00	11,470,250.00	92.26	247.99
2B512PW	9961.00	9961.00	9961.00	0.55	0.88	1.88	2.56	3.09	4.64	5,169,000.00	6,635,433.61	11,820,000.00	90.70	248.99
2B587PW	8172.00	8172.00	8172.00	0.59	0.93	1.95	-1.18	-0.65	0.90	5,298,000.00	6,805,127.56	12,120,000.00	69.25	249.86
2B604PW	8234.00	8234.00	8234.00	0.67	0.99	1.95	-0.03	0.48	1.99	4,767,000.00	6,122,220.00	10,890,250.00	100.00	246.13
2B610PW	7792.00	7792.00	7792.00	0.63	0.96	1.92	-1.29	-0.77	0.74	4,750,000.00	6,102,740.42	10,890,250.00	100.00	246.00
2B707PW	10570.00	10570.00	10570.00	1.06	1.40	2.40	2.03	2.55	4.10	5,236,000.00	6,721,105.81	11,970,000.00	87.89	249.44
2B710PW	9837.00	9837.00	9837.00	0.77	1.11	2.11	2.90	3.42	4.97	5,184,000.00	6,654,256.11	11,850,250.00	93.37	249.09
2B810PW	8561.00	8561.00	8561.00	1.01	1.33	2.29	-0.16	0.35	1.86	4,718,000.00	6,060,007.47	10,780,250.00	100.00	245.75
30A16PW	10090.00	10090.00	10090.00	1.24	1.56	2.53	2.42	2.93	4.45	4,815,000.00	6,181,211.11	11,010,000.00	100.00	246.47
30A37PW	7942.00	7942.00	7942.00	0.27	0.60	1.58	-0.91	-0.39	1.14	4,948,000.00	6,356,046.81	11,310,000.00	80.62	247.48
30A91PW	8729.00	8728.97	8729.00	0.90	1.24	2.24	-0.73	-0.21	1.33	5,137,000.00	6,599,422.67	11,740,250.00	82.80	248.80
30A95PW	9700.00	9700.00	9700.00	0.86	1.20	2.20	1.83	2.35	3.90	5,179,000.00	6,649,577.75	11,830,000.00	86.79	249.07
6030PRO	7626.00	7626.00	7626.00	0.62	0.96	1.96	-0.45	0.07	1.62	5,136,000.00	6,596,999.00	11,730,250.00	75.57	248.79
6038PRO	9799.00	9799.00	9799.00	0.74	1.07	2.06	0.92	1.44	2.98	5,045,000.00	6,475,957.56	11,520,000.00	86.25	248.14
6304PRO	6151.00	6151.00	6151.00	0.83	1.26	2.52	-2.45	-1.85	-0.10	8,633,000.00	11,126,898.17	19,950,250.00	100.00	264.56
BR206	6245.00	6245.00	6245.00	0.44	0.78	1.78	-1.25	-0.72	0.82	5,028,000.00	6,447,393.17	11,370,000.00	100.00	248.05
NS90PRO	8062.00	8062.00	8062.00	0.58	0.91	1.89	-0.77	-0.26	1.27	4,926,000.00	6,328,173.44	11,260,000.00	88.55	247.32
NS92PRO	8250.00	8250.00	8250.00	0.72	1.05	2.01	-0.40	0.11	1.63	4,815,000.00	6,184,478.44	11,010,000.00	98.78	246.49
P2830H	9616.00	9616.00	9616.00	0.60	0.92	1.90	3.68	4.19	5.72	4,918,000.00	6,313,714.86	11,250,000.00	100.00	247.24
P3646YH	8767.00	8767.00	8767.00	0.74	1.10	2.15	0.63	1.16	2.75	5,764,000.00	7,399,909.78	13,170,000.00	59.74	252.66
XB7116	7284.00	7284.00	7284.00	0.43	0.75	1.73	-1.12	-0.60	0.92	4,886,000.00	6,276,177.44	11,160,000.00	91.94	247.02
XB8010	7007.00	7007.00	7007.00	0.40	0.73	1.71	-0.75	-0.23	1.29	4,937,000.00	6,342,220.42	11,280,250.00	84.57	247.40
XB8018	8959.00	8959.00	8959.00	0.49	0.82	1.80	1.88	2.40	3.93	4,997,000.00	6,417,347.31	11,420,000.00	93.26	247.82
XB8030	7096.00	7096.00	7096.00	0.35	0.67	1.63	0.26	0.77	2.28	4,724,000.00	6,067,672.97	10,800,250.00	100.00	245.80

LB Lower Bound, $\widehat{\beta_{i0}}$ is the mean response of genotype, UP Upper Bound, $\widehat{\beta_{i1}}$ is the linear regression coefficient related to the unfavorable environments, $\widehat{\beta_{i1}} + \widehat{\beta_{i2}}$ is the linear response to the favorable environments, $\hat{\sigma}^2_{di}$ is the stability parameter, R^2 is the coefficient of determination, and DIC is the deviance information criterion.

Table 5. Estimates for the a posteriori mean and credibility intervals (95%) for the stability and adaptability parameters, coefficient of determination and deviance information criterion considering minimally informative prior distributions

Genotype	Minimally informative a priori distributions													
	LB	$\widehat{\beta}_{i0}$	UP	LB	$\widehat{\beta}_{i1}$	UP	LB	$\widehat{\beta}_{i1} + \widehat{\beta}_{i2}$	UP	LB	$\hat{\sigma}^2_{di}$	UP	R^2	DIC
20A55PW	9125.00	9372.19	10160.00	0.76	0.96	1.60	1.84	− 2.38	4.07	1,429,000.00	2,173,111.98	5,149,000.00	72.99	242.53
2B433PW	10170.00	10367.87	11000.00	0.74	0.90	1.42	1.71	2.15	3.52	940,800.00	1,430,954.52	3,390,000.00	77.28	236.68
2B512PW	9731.00	9960.87	10690.00	0.75	0.93	1.52	2.25	2.75	4.32	1,226,000.00	1,865,491.17	4,420,000.00	77.43	240.40
2B587PW	7917.00	8172.10	8981.00	0.71	0.92	1.57	− 1.10	− 0.55	1.20	1,522,000.00	2,314,970.00	5,486,000.00	59.31	243.42
2B604PW	8097.00	8233.91	8669.00	0.89	1.00	1.35	0.14	0.43	1.37	439,600.00	668,599.44	1,584,000.00	83.28	226.03
2B610PW	7660.00	7791.92	8211.00	0.84	0.95	1.28	− 0.99	− 0.70	0.20	404,000.00	613,799.19	1,444,000.00	83.62	224.83
2B707PW	10330.00	10571.99	11340.00	1.25	1.45	2.06	1.70	2.23	3.88	1,365,000.00	2,075,874.92	4,918,000.00	81.45	241.89
2B710PW	9606.00	9837.22	10570.00	0.98	1.17	1.76	2.53	3.04	4.62	1,247,000.00	1,897,407.49	4,496,000.00	81.96	240.63
2B810PW	8440.00	8561.47	8944.00	1.24	1.34	1.65	0.06	0.33	1.15	341,075.00	518,735.76	1,229,000.00	91.65	222.48
30A16PW	9941.00	10088.80	10560.00	1.49	1.61	1.99	2.29	2.61	3.62	507,900.00	772,512.85	1,830,000.00	93.49	228.05
30A37PW	7756.00	7942.42	8533.00	0.44	0.59	1.07	− 0.76	− 0.36	0.92	811,075.00	1,233,576.66	2,923,000.00	54.64	234.61
30A91PW	8501.00	8728.40	9442.00	1.04	1.23	1.80	− 0.64	− 0.15	1.40	1,200,000.00	1,825,865.59	4,317,000.00	73.78	240.07
30A95PW	9468.00	9700.44	10440.00	1.05	1.24	1.84	1.58	2.08	3.67	1,260,000.00	1,916,209.16	4,540,000.00	78.80	240.77
LG6030PRO	7400.00	7626.35	8343.00	0.77	0.95	1.53	− 0.40	0.09	1.63	1,194,000.00	1,815,941.39	4,303,000.00	64.59	240.02
LG6038PRO	9593.00	9799.14	10450.00	0.93	1.10	1.63	0.79	1.23	2.64	991,400.00	1,507,863.04	3,573,000.00	76.09	237.42
LG6304PRO	8393.00	8529.95	8962.00	0.77	0.88	1.23	0.87	1.16	2.10	433,900.00	659,924.34	1,564,000.00	82.67	225.85
BR206	6716.00	6870.56	7359.00	0.59	0.72	1.11	− 0.77	− 0.44	0.62	554,500.00	843,380.44	1,999,000.00	69.37	229.28
NS90PRO	7881.00	8062.24	8636.00	0.76	0.91	1.37	− 0.64	− 0.24	1.00	767,000.00	1,166,601.61	2,764,025.00	71.21	233.82
NS92PRO	8098.00	8250.50	8732.00	0.93	1.05	1.44	− 0.23	0.10	1.14	538,900.00	819,602.90	1,942,000.00	81.50	228.88
P2830H	9443.00	9616.11	10160.00	0.84	0.98	1.42	3.39	3.77	4.95	700,000.00	1,064,797.50	2,523,000.00	89.72	232.55
P3646YH	8442.00	8767.04	9796.00	0.86	1.12	1.95	0.30	1.00	3.23	2,464,000.00	3,747,103.64	8,878,000.00	58.77	250.16
XB7116	7113.00	7284.54	7827.00	0.61	0.75	1.19	− 0.91	− 0.54	0.63	683,700.00	1,039,809.16	2,464,000.00	67.27	232.21
XB8010	6823.00	7007.02	7589.02	0.58	0.73	1.20	− 0.60	− 0.20	1.06	789,100.00	1,200,246.48	2,844,000.00	62.36	234.22
XB8018	8764.00	8959.30	9579.00	0.70	0.86	1.36	1.72	2.14	3.48	891,600.00	1,356,141.11	3,213,000.00	77.15	235.93
XB8030	6973.00	7095.77	7485.00	0.58	0.68	1.00	0.42	0.69	1.53	352,000.00	535,376.58	1,269,000.00	76.96	222.92

LB Lower Bound, $\widehat{\beta}_{i0}$ is the mean response of genotype, UP Upper Bound, $\widehat{\beta}_{i1}$ is the linear regression coefficient related to the unfavorable environments, $\widehat{\beta}_{i1} + \widehat{\beta}_{i2}$ is the linear response to the favorable environments, $\hat{\sigma}^2_{di}$ is the stability parameter, R^2 is the coefficient of determination, and DIC is the deviance information criterion.

showed R^2 greater than 80%.

The genotypes 2B707HX, 2B710HX, 30A16HX, 30A95HX, and LG6038PRO were shown to be specifically adapted to favorable environments ($\beta_{i1} > 1$, $\beta_{i1} + \beta_{i2} > 1$ and $\beta_{i0} > \overline{\mu}$). However, early cultivars develop faster, allowing harvest in less time and maintaining the quality of the grains. Thus, these hybrids may be indicated for northeastern environments since early maize cultivars are consistent with the short planting window of this region, developing well with rainfed agriculture even if a lower level of technology is made available.

Furthermore, hybrids 2B707HX, 2B710HX, and 30A16HX showed high stability when facing environmental variations, confirming that they can be a good indication since the Northeast region has variability, especially regarding temperature, precipitation, and physical and chemical properties of the soil. As for unfavorable environments, hybrids 2A55HX, 2B587HX, and 2B610HX were selected. However, only the last-mentioned showed high stability and is therefore indicated for farmers who use little technology in the production system.

The genotypes considered ideal, i.e., those with above average yield, good adaptability to unfavorable environments, and responsiveness to environmental improvement ($\beta_{i0} > \overline{\mu}$, $\beta_{i1} > 1$ and $\beta_{i1} + \beta_{i2} > 1$), were 2B433HX and 2B512HX. These, in turn, could be suitable for farmers in the Northeast with any level of farming technology.

The analysis considering the a priori information allowed a more rigorous discrimination, thus obtaining greater precision in the indication of the hybrids (Table 5). According to this analysis, only two hybrids showed a linear regression coefficient for unfavorable environments equal to 1 ($\beta_{i1} = 1$). In addition, five were found to be specifically adapted to favorable environments ($\beta_{i1} > 1$, $\beta_{i1} + \beta_{i2} > 1$ and $\beta_{i0} > \overline{\mu}$) and with good stability, including 30A95HX, disagreeing with the analysis considering the minimally informative a priori distributions that considered it unstable.

The hybrids considered ideal were 20A55HX, 2B433HX, 2B512HX and P2830. Finally, no hybrid showing good adaptability and stability to unfavorable environments was indicated. This greater rigor of the analysis considering the a priori information was also observed by Oliveira et al. (2020) and Nascimento et al. (2020).

In general, this superiority obtained in accuracy occurs due to the smaller credibility interval obtained. As a consequence, it is possible to estimate the parameters with greater precision, allowing a more reliable selection of the hybrids to be indicated to the farmers.

CONCLUSIONS

Hybrids 20A55HX, 2B433HX, 2B512HX, and P2830H were considered ideal for cultivation in the Northeast region.

The results obtained using the a priori distribution proved to be more accurate than those derived from the minimally informative a priori distribution.

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