DIFFERENTIAL RESPONSE OF TROPICAL, TEMPERATE, AND TEMPERATE × TROPICAL MAIZE HYBRIDS IN YIELD AND STARCH CONTENT TO ENVIRONMENTAL VARIABILITY IN CHACO PROVINCE

RESPOSTA DIFERENCIAL DE HÍBRIDOS DE MILHO TROPICAIS, TEMPERADOS E TEMPERADOS × TROPICAIS NO RENDIMENTO E TEOR DE AMIDO À VARIABILIDADE AMBIENTAL NA PROVÍNCIA DO CHACO

RESPUESTA DIFERENCIAL EN RENDIMIENTO Y CONTENIDO DE ALMIDÓN DE HÍBRIDOS DE MAÍZ TROPICALES, TEMPLADOS Y TEMPLADO × TROPICAL FRENTE A VARIACIONES AMBIENTALES EN LA PROVINCIA DEL CHACO

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ABSTRACT

Chaco Province (Argentina) is characterized by extensive arable land and marked environmental heterogeneity, which directly impact productive development and enable high maize production levels. Although previous studies have compared average yields among hybrids, understanding the response of different genetic groups to environmental variability remains essential. This study analyzed the differential response in grain yield and starch content of tropical, temperate × tropical, and temperate maize hybrids grown across different locations in the province, considering edaphic and climatic conditions based on previously published data. Results indicated that the temperate group achieved the highest average grain yield (82.20 qq/ha) and a high starch content (73.48%), although its performance varied depending on environmental conditions. The tropical group showed a lower average grain yield (70.71 qq/ha) but exhibited differential responses, particularly in environments with variations in precipitation and soil type. Overall, the results suggest that hybrid selection should not rely solely on average yield but also on adaptation to specific environmental conditions. Environmental factors such as precipitation (308–820 mm) and soil characteristics (organic matter: 0.40–1.50%) influenced the expression of the genetic potential of each group. It is concluded that a significant interaction exists between genetic group and environment, which is critical for the recommendation of hybrid materials across the different productive subregions of Chaco.

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Keywords: Maize (*Zea mays L.*). Hybrids. Grain. Yield. Starch Content. Genotype × Environment Interaction.

RESUMO

A Província do Chaco (Argentina) caracteriza-se por extensas áreas agricultáveis e marcada heterogeneidade ambiental, fatores que impactam diretamente o desenvolvimento produtivo e possibilitam elevados níveis de produção de milho. Embora estudos anteriores tenham comparado os rendimentos médios entre híbridos, compreender a resposta de diferentes grupos genéticos à variabilidade ambiental continua sendo essencial. Este estudo analisou a resposta diferencial no rendimento de grãos e no teor de amido de híbridos de milho tropicais, temperados × tropicais e temperados cultivados em diferentes localidades da província, considerando as condições edáficas e climáticas com base em dados previamente publicados. Os resultados indicaram que o grupo temperado apresentou o maior rendimento médio de grãos (82,20 qq/ha) e elevado teor de amido (73,48%), embora seu desempenho tenha variado de acordo com as condições ambientais. O grupo tropical apresentou menor rendimento médio de grãos (70,71 qq/ha), mas demonstrou respostas diferenciais, especialmente em ambientes com variações de precipitação e tipo de solo. De modo geral, os resultados sugerem que a seleção de híbridos não deve se basear apenas no rendimento médio, mas também na adaptação às condições ambientais específicas. Fatores ambientais, como precipitação (308–820 mm) e características do solo (matéria orgânica: 0,40–1,50%), influenciaram a expressão do potencial genético de cada grupo. Conclui-se que existe interação significativa entre grupo genético e ambiente, fator essencial para a recomendação de materiais híbridos nas diferentes sub-regiões produtivas do Chaco.

Palavras-chave: Milho (*Zea mays L.*). Híbridos. Grãos. Rendimento. Teor de Amido. Interação Genótipo × Ambiente.

RESUMEN

La provincia del Chaco (Argentina) presenta amplias superficies cultivables y una marcada heterogeneidad ambiental, que generan un impacto directo en el desarrollo productivo y permiten alcanzar altos volúmenes de producción de maíz. Si bien estudios previos han comparado rendimientos promedio entre híbridos, resulta fundamental comprender la respuesta de los distintos grupos genéticos frente a la variabilidad ambiental. En este trabajo se analizó la respuesta diferencial en rendimiento en grano y contenido de almidón de híbridos de maíz tropicales, templado × tropical y templados, cultivados en distintas localidades de la provincia, considerando condiciones edáficas y climáticas a partir de datos previamente publicados. Los resultados indicaron que el grupo templado presentó el mayor rendimiento promedio en grano (82,20 qq/ha) y un alto contenido de almidón (73,48 %), aunque con variaciones en su desempeño según el ambiente. El grupo tropical mostró un menor rendimiento promedio (70,71 qq/ha), pero evidenció respuestas diferenciales, particularmente en ambientes con variaciones en la precipitación y el tipo de suelo. En conjunto, los resultados sugieren que la elección del híbrido no debe basarse únicamente en el rendimiento promedio, sino también en su adaptación a condiciones específicas. Factores ambientales como la precipitación (308–820 mm) y las características edáficas (materia orgánica: 0,40–1,50 %) influyeron en la expresión del potencial genético. Se concluye que existe una interacción significativa entre el grupo genético y el ambiente, lo cual resulta clave para la recomendación de materiales híbridos en las distintas subregiones productivas del Chaco.

Palabras clave: Maíz (*Zea mays L.*). Híbridos. Rendimiento de Grano. Contenido de Almidón. Interacción Genotipo × Ambiente.

1 INTRODUCTION

The challenge for agricultural production in Argentina lies in seizing the opportunity to supply the growing global demand for food and renewable energy [1]. In this context, corn occupies a strategic role, both in crop rotation and as a source of raw material for various production chains [1].

The province of Chaco is an extra-Pampas region relevant in corn production [2], although its planted area and production levels are strongly conditioned by climatic factors [3]. In this framework, the development of hybrids has made it possible to improve genetic characteristics associated with yield and tolerance to adverse conditions [4, 5], including biotic [6] and abiotic factors such as water availability [7] and herbicide tolerance [8].

Grain yield and quality are determined by genotype, environment, and their interaction (G×E) [9, 10]. Environmental factors such as temperature [11, 13, 15] and solar radiation [12] influence crop growth and grain composition, particularly characteristics such as starch content and structure [14]. The quality of the grain, including components such as starch, protein and oil, is key to its industrial use [16, 17].

In this sense, sustainable regional development [19] promotes the addition of value to primary production. The use of corn for bioenergy generation in northern Argentina represents an alternative to strengthen the value chain, contribute to sustainability, and generate employment [19], although its implementation depends on appropriate policy frameworks [20].

Previous studies carried out in the province of Chaco have compared the average yield and starch content of different hybrids. However, the marked environmental variability within the province [Tables 2 and 3] makes it necessary to advance in the analysis of the differential response of genetic materials, beyond the average values. In particular, it is relevant to understand how different groups of hybrids (tropical, temperate × tropical and temperate) respond to this environmental heterogeneity.

The objective of this study was to analyze the differential response in grain yield and starch content of groups of maize hybrids (tropical, temperate × tropical and temperate) to environmental variations in different localities of the province of Chaco, using previously reported group average data.

2 DEVELOPMENT AND METHODOLOGY

This analysis was based on data collected from a previous comparative study conducted in Chaco Province, Argentina. In this study, planting blocks with maize genetic materials classified into three groups were evaluated: tropical, temperate × tropical and temperate (Table

1), implanted in various agricultural farms located between Latitude 26° 00' 46.4" and 27° 57' 45.72" S, and Longitude 60° 08' 36.76" and 61° 41' 19.28" W (Figure 1).

Figure 1

Georeferencing

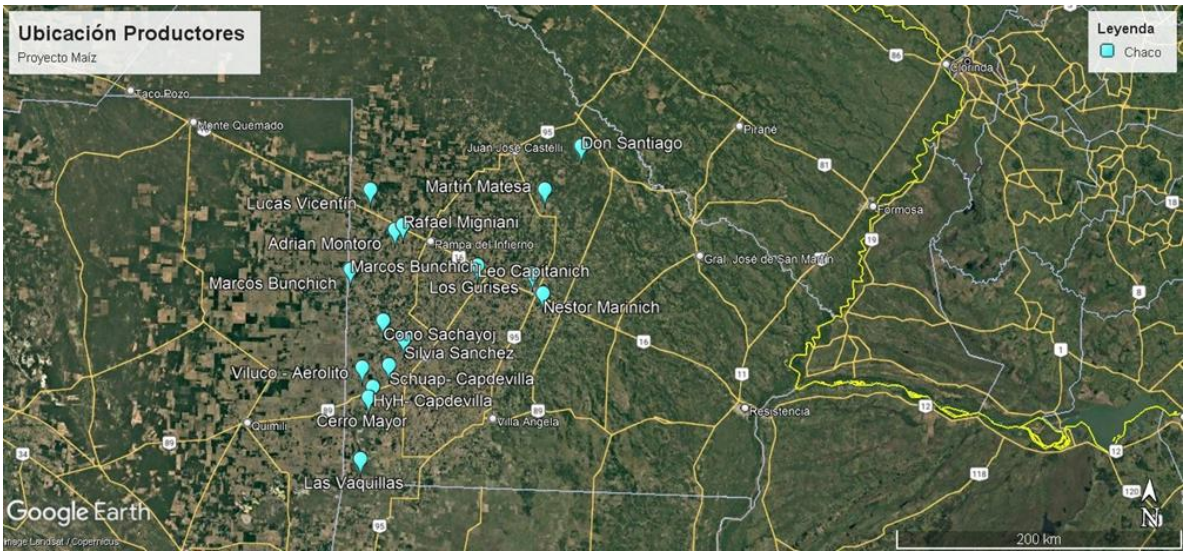

Table 1

Types of Materials Used

Tropical	Temperate x Tropical	Temperate
DK390VT3P	DK7910VT3P	DK7210VT3P
NK139VIP3	LT795VT3P	DK7310VT3P
P30F53HXRR2	2A120PW	2M510PW

Source: Authors.

The environmental conditions of the experimental sites were characterized by meteorological variables, including mean temperature, precipitation and effective heliophany (Table 2), and edaphic variables, such as organic matter content, nitrogen, phosphorus and soil pH (Table 3).

Table 2

Meteorological Data of Localities of the Province of Chaco

Locations	Average Temperature (°C)	Rainfall (mm)	Effective Heliophany (hs)
Los Frentones (AM)	22,64	308	7,367

Long Camp (LC)	24,40	353	7,367
Dead River (LV)	22,64	707	7,367
Pampa del Infierno (MG)	23,48	360	6,873
Pampa del Infierno (LG)	23,48	360	6,873
Las Breñas (MB)	24,4	413	7,367
Tres Isletas (Ma)	24,02	642	6,873
Tres Isletas (DS)	24,02	820	6,873
P. R. Sáenz Peña (NM)	24,03	433	6,873
Beautiful Field (CM)	23,67	441	7,367
Charata (SS)	24,4	336	7,367
Gen. Capdevila (Sch)	24,35	384	7,367
General Capdevila (HyH)	24,35	447	7,367
General Capdevila (VL)	24,35	420	7,367

Source: Authors.

Table 3

Soil Data

Location	Producer	Soil Factors			
		Matt. Organic [%]	Nitrogen [ppm]	Phosphorus [ppm]	pH
The Frentones	AM	0,40	0,07	77,00	7,30
Long Camp	LC	0,42	0,07	13,10	7,00
Dead River	LV	0,56	0,08	63,50	6,70
Pampa del Infierno	LG	1,27	0,15	67,10	7,50
Pampa del Infierno	MG	0,40	0,07	77,00	7,30
Las Breñas	MB	1,00	0,12	58,55	6,45
Three Islets	Ma	0,56	0,08	63,50	6,70
Three Islets	DS	0,58	0,09	65,50	6,70
P. R. Sáenz Peña	NM	1,50	0,12	55,80	7,60
Beautiful Countryside	C M	0,83	0,08	49,00	7,30
Charata	Sa	0,77	0,10	74.20	6,50
General Capdevila	Sch	1,07	0,09	64,34	7,04
General Capdevila	HyH	1,29	0,13	59,90	7,60
General Capdevila	VL	1,12	0,13	46,40	6,90

Source: Authors.

For the present study, we used only average data by group of hybrids and locality, corresponding to: (I) grain yield (qq/ha) (Table 4), and (II) starch content (%) (Table 5).

Table 4

Average Yield in qq/ha by Localities

Locations	Average Yield (qq/ha)			Average
	Tropical	Temperate x Tropical	Temperate	
Los Frentones (AM)	73,07	72,51	75,76	73,78
Long Camp (LC)	60,44	57,43	68,16	62,01
Dead River (LV)	81,23	84,76	91,28	85,76
Pampa del Infierno (LG)	72,23	86,99	94,35	84,52
Pampa del Infierno (MG)	66,17	61,73	75,03	67,64
Las Breñas (MB)	68,78	75,55	85,3	76,54
Tres Isletas (Ma)	36,81	56,37	46,84	46,67
Tres Isletas (DS)	68,50	62,72	61,92	64,38
P. R. Sáenz Peña	50,49	50,10	57,73	52,77
Beautiful Field (C M)	69,5	76,17	98,94	81,54
Charata (SS)	84,69	89,42	84,85	86,32
Gen. Capdevila (Sch)	90,09	87,78	107,05	94,97
General Capdevila (HyH)	86,37	94,77	103,64	94,93
General Capdevila (VL)	81,51	85,01	100,00	88,84
Average	**70,71**	**74,38**	**82,20**	**75,76**

Source: Authors.

Table 5

Average Starch Content of the Hybrids Tested

Locations	Tropical	Temperate x Tropical	Temperate	Average
The Frentones	74,28	73,27	74,32	73,96
Long Camp	75,48	74,53	73,44	74,48
Dead River	69,57	70,57	73,10	71,08
Pampa del Infierno	71,22	73,05	73,65	72,64
Las Breñas	73,53	73,69	73,18	73,47
Three Islets	75,21	74,43	73,75	74,46

Sáenz Peña	74,56	73,75	73,22	73,84
Beautiful Countryside	72,39	72,32	74,66	73,12
Charata	69,99	71,05	72,52	71,19
General Capdevila	71,84	70,73	72,95	71,84
Average	72,81	72,74	73,48	**73,01**

Source: Authors.

The differential response of the hybrid groups to environmental variability was evaluated by:

- Visual analysis, examining patterns of yield and starch content between localities, with emphasis on changes in the relative ranking of groups.
- Quantification of variability, by calculating the standard deviation (SD) and the coefficient of variation (CV) for each genetic group, as indicators of response stability.
- Qualitative correlation analysis, relating the relative performance of the groups with the environmental characteristics of each locality, in order to identify factors potentially associated with the observed variation.

It should be noted that the analysis was carried out at the level of groups of hybrids, using average values. Consequently, inferences about stability and differential response correspond to the mean behavior of each group and not to individual hybrids.

3 RESULTS AND DISCUSSION

The data on grain yield (Table 4) and starch content (Table 5) constitute the basis for the analysis of the differential response of the groups of hybrids to environmental variability.

In terms of yield, the temperate group presented the highest general average (82.20 qq/ha), surpassing the temperate × tropical group (74.38 qq/ha) and the tropical group (70.71 qq/ha). However, the magnitude of this superiority varied between localities, evidencing a marked genotype × environment (G×E) interaction. In high-potential environments, such as Río Muerto, Pampa del Infierno (LG) and localities of General Capdevila, the temperate group reached the highest yield values. In contrast, in more restrictive environments, such as Tres Isletas (Ma) and Campo Largo, yields were lower and differences between groups were reduced, with changes in the relative ranking being observed.

The variability of yield between environments, estimated by standard deviation, was greater in the temperate group (≈17.8 qq/ha), compared to the temperate × tropical (≈12.6

qq/ha) and the tropical (≈14.6 qq/ha) groups. This result suggests that, although the temperate group has greater productive potential, it also exhibits greater sensitivity to environmental conditions, which reinforces the existence of a significant G×E interaction.

In relation to starch content, the differences between groups were less marked. The average values were similar between temperate (73.48%), tropical (72.81%) and temperate × tropical (72.74%), with no evidence of a consistently higher group in all localities. However, occasional variations were observed, such as in Campo Largo, where the tropical group reached the highest starch content, and in Hermoso Campo, where the temperate group presented the highest values.

The variability of starch content was considerably lower than that of yield, especially in the temperate group (SD ≈ 0.8 %), indicating greater stability of this quality variable in the face of environmental changes. In this sense, the relationship between yield and starch content was not direct, since high-performance environments were not necessarily associated with higher starch contents.

The joint analysis with the environmental variables (Tables 2 and 3) did not show simple associations between a single factor (such as precipitation or organic matter content) and the performance of the groups. For example, localities with high rainfall, such as Tres Isletas (DS), did not systematically present the highest yields, while environments with low levels of organic matter showed variable responses. Likewise, in General Capdevila, the high yields observed in all groups, despite edaphic variations, suggest the influence of other local or management factors not considered.

Taken together, these results confirm that the response of hybrid groups is determined by a complex interaction between climatic, edaphic, and management factors, in accordance with what has been reported in the literature [9, 10, 15]. The temperate group tends to maximize its potential in favorable environments, while the tropical and temperate × tropical groups present more variable responses, which could be associated with differences in adaptation and phenotypic plasticity.

It should be noted that the use of group averages constitutes a limitation for interpretation at the level of individual hybrids. However, the results obtained are relevant from the agronomic point of view, since they indicate that the classification by genetic origin (tropical vs. temperate) has implications in the adaptation to the environmental heterogeneity of the province of Chaco.

4 CONCLUSIONS

The analysis of the response of groups of maize hybrids in different localities of the province of Chaco showed a significant interaction between the genetic group and the environment (G×E).

The temperate group presented the highest average yield, although it also showed the greatest variability between environments, indicating a greater sensitivity to environmental conditions. In contrast, the starch content was relatively similar between groups, with the temperate group standing out for its greater stability in this variable.

No simple relationships were identified between isolated environmental factors and the differential response of the groups, suggesting a complex interaction of multiple variables that modulate the expression of genetic potential.

From a productive perspective, the selection of hybrids in the province of Chaco must consider not only the average yield, but also the specific adaptation to the environmental conditions of each locality.

Finally, while this study provides evidence at the group level, scaled analyses of individual hybrids are required to deepen the assessment of stability and specific adaptation.

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