THE PROTEIN PRODUCTION POTENTIAL OF SOME MAIZE HYBRIDS

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Abstract

Maize hybrids, provided by Research and Development Agricultural Station-ARDS Suceava, were tested in comparative crop, under the specific conditions of the Western Plain of Romania. Field experiments were carried out in the ARDS Lovrin. Twenty maize hybrids were tested (SV_1 to SV_20, experimental codes). The protein content of the grains (Pro, %) was evaluated. The protein content varied between Pro = 9.45±0.09% (SV_13), and Pro = 12.40±0.12% (SV_17). Comparative analysis between hybrids (PHC), led to 190 combinations. There were 45 statistically significant positive differences; 13 differences with $p<0.05$ level (*), eight differences with $p<0.01$ level (**), and 24 differences with $p<0.001$ level (***). There were 19 negative differences with statistical certainty; two differences with $p<0.05$ level (o), three differences at the $p<0.01$ level (oo), and 14 differences at the $p<0.001$ level (ooo). In relation to the mean value ($Pro\_m = 10.69\pm0.18\%$), some hybrids presented higher values (nine hybrids), and other hybrds presented lower values (11 hybrids). Significant increase in protein growth was recorded by hybrid SV_17 ($\Delta Pro = 1.71\%$), followed by hybrid SV_5 ($\Delta Pro = 1.46\%$). Maize hybrids with genetic advantage for protein production have been identified, for breeding programs and agricultural practice.

Key words: *comparative analysis, maize genotypes, proteic crops, protein yield increase*

INTRODUCTION

Quality sources for protein intake in human nutrition, it is necessary to ensure a balanced supply of various nutrients such as dietary fiber, mineral elements, and vitamins [17].

Balanced protein consumption in human nutrition, in relation to age categories and the specifics of socio-economic activities, is necessary for human health [7, 17, 24].

Food and dietary approaches for the human population aim to promote health in relation to the age structure and dynamics of the human population [14]. The authors have studied the importance regarding high-quality protein intake in some recommended dietary. Plant proteins are of high interest as sustainable protein sources for human nutrition [14]. The demand for food resources increased in the context of human population growth, and proteins are of great importance [1]. For a balanced human diet, protein is a vital macronutrient [4].

Associated to the need for proteins in human nutrition, and the different diets that were adopted, there have been an increasing demand for plant-based proteins [11]. Proteins from plant sources have gained increasing demand for human nutrition, and growth trends are predicted for the coming decades [13]. Plant proteins represent a good source of essential amino acids, mineral elements, and nutritional principles for human diets [13]. Proteins from plant sources are increasingly promoted for various nutritional, human health, and environmental reasons [4].

There has been an increasing demand for plant proteins worldwide, which are considered a "key component" of balanced diets [2]. Different categories of crop plants, such as legumes, oilseeds, cereals, have been considered as protein sources, and different methods for extracting proteins from plant sources have been studied [2].

Various crop plants are important sources of vegetable protein, particularly through the high protein content in their seeds [6]. Through the presence of different species of protein plants in the structure of crop plants, they contribute to increasing biological diversity and increasing the sustainability of agricultural ecosystems [6]. Three categories of crop plants are in focus as main sources of protein, namely legumes, oilseeds, and cereals [4].

The plant-based protein industry is experiencing a growing trend, and protein crops present a series of economic and ecological benefits in agricultural ecosystems [19]. Attention is paid to improving genotypes of plants cultivated for protein production, with the aim of benefiting farmers by cultivating these categories of plants [19].

Maize is a crop of interest for protein, and different genetic systems in maize are being studied to obtain quality proteins [15]. Maize is a multifunctional crop, with a major contribution to global agri-food systems [8]. In many countries, maize is a staple food for a significant part of the world's population [5]. Evaluating the influence of climatic conditions and optimizing crop technologies and management practices, associated with high-performance genotypes, are considered necessary to increase yields and quality indices in maize crop [3, 5, 10, 21, 22].

This research evaluated the protein content of seeds in a group of maize hybrids (20 hybrids) originating from ARDS Suceava, and tested in comparative crops under pedo-climatic conditions characteristic of the Western Plain, located at ARDS Lovrin, Romania.

MATERIALS AND METHODS

Experimental protocols and collaborations between research stations provide for the comparative testing of crop plant genotypes created within a research station under specific conditions in another area of the country. In the present study, twenty maize hybrids, provided from ARDS Suceava, were cultivated and tested under specific climate and soil conditions within ARDS Lovrin. The genotypes were noted with SV_1 to SV_20 trials codes.

The research was conducted in the 2023-2024 agricultural year, under non-irrigated crop conditions. Climatic conditions are presented in Figure 1.

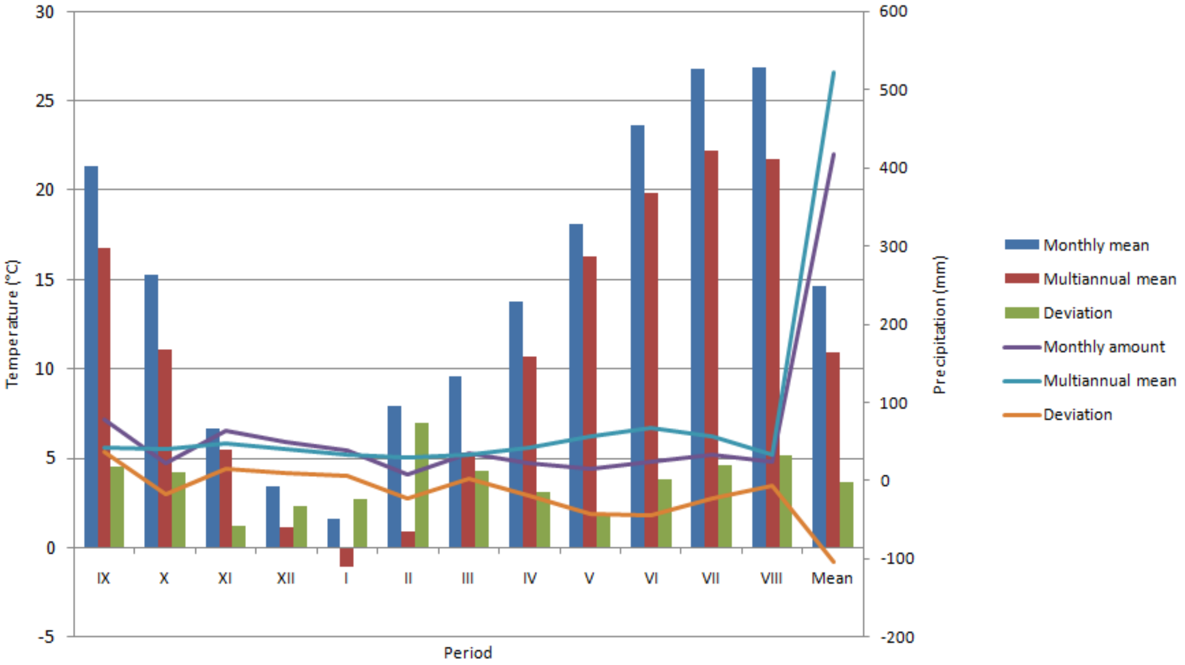

Fig. 1. Climatic conditions during the study period
Source: Original data, ARDS Lovrin Weather Station.

The location of the experiment was on a plot with chernozem soil, with medium fertility. A classic soil working system was used (plowing, disk, combine harrowing) for land preparation. Complex mineral fertilizers (15/15/15) were applied for soil fertilization, before sowing (250 kg ha^{-1}). Additionally, in vegetation, ammonium nitrate was applied (200 kg ha^{-1}). In the first decade of April, corn hybrids were sown. Repetitions were provided for each hybrid. Protection of corn crops from weeds was done by pre-emergence herbicides and by mechanical and manual work during the vegetation period.

The grain production was harvested at plant maturity [16], on each hybrid and replicates. Protein content (Pro, %) was determined based on sub-sampling from kernels production, for each genotype.

For the comparative analysis of corn hybrids, in terms of grain protein content, the calculation module in EXCEL, the PAST software [9] and JASP [12] were used.

RESULTS AND DISCUSSIONS

The tested maize hybrids benefited from uniform soil conditions (cambic chernozem) and climate, and expressed the genetic potential for protein content. Protein content values between Pro = 9.45±0.09% (hybrid SV_13) and Pro = 12.40±0.12% (hybrid SV_17) were recorded (Table 1).

Table 1. Protein content values of the tested corn hybrids

Maize hybrid	Protein (%)	Std. Error (SE)	Maize hybrid	Protein (%)	Std. Error (SE)
SV_1	11.50	±0.35	SV_11	10.65	±0.09
SV_2	10.30	±0.29	SV_12	10.30	±0.12
SV_3	10.85	±0.32	SV_13	9.45	±0.09
SV_4	10.45	±0.38	SV_14	11.25	±0.14
SV_5	12.15	±0.03	SV_15	10.40	±0.12
SV_6	10.70	±0.06	SV_16	9.55	±0.14
SV_7	11.05	±0.09	SV_17	12.40	±0.12
SV_8	11.15	±0.43	SV_18	11.30	±0.17
SV_9	10.55	±0.03	SV_19	9.65	±0.09
SV_10	10.15	±0.03	SV_20	10.05	±0.09

Source: Original data.

The Anova test applied certified the presence of the variance, as well as the reliability of the experimental data (Table 2).

Table 2. Results of Anova Test

Cases	Sum of Squares	df	Mean Square	F	p
Trial	35.554	19	1.871	15.841	< .001
Residuals	4.725	40	0.118		

Source: Original data.

A comparative analysis of maize hybrids was performed, based on the protein content accumulated in the grains.

Each hybrid was analyzed against the other hybrids in the comparative crop (Post Hoc Comparisons - PHC), to find out how the hybrids position themselves among themselves, in relation to the protein content. 190 combinations of comparative analysis resulted. The results safety and the significance of differences are presented in Table 3.

For the reliability of the results, the thresholds $p<0.05$ (symbol * for positive differences; symbol o for negative differences), $p<0.01$ (symbol ** for positive differences; symbol oo for negative differences), respectively $p<0.001$ (symbol *** for positive differences; symbol ooo for negative differences) were considered.

Positive differences were recorded, with statistical safety, for some comparative analyses; thirteen differences at the $p<0.05$ level (*), eight differences at the $p<0.01$ level (**), and 24 differences at the $p<0.001$ (***) level. Negative differences, in conditions of statistical safety, were recorded in the case of nineteen comparisons; in two situations with $p<0.05$ level (o), in three situations with $p<0.01$ level (oo), and in fourteen situations at $p<0.001$ level (ooo). Differences without statistical safety (ns) were also identified, for 126 comparative analyses. Of the total number of analyses, those that marked hybrids with high protein content, which showed genetic advantages for this quality index, were considered important, compared to the other hybrids.

Considering the results of the PHC analysis, in which the positioning of the hybrids was found based on protein content, with statistically significant differences among the 190 comparative analyses, it was also considered appropriate to analyze the hybrids in comparison with the average value at the experiment level.

Table 3. Results of the comparative analysis between corn hybrids, in relation to protein content

	SV_2	SV_3	SV_4	SV_5	SV_6	SV_7	SV_8	SV_9	SV_10	SV_11	SV_12	SV_13	SV_14	SV_15	SV_16	SV_17	SV_18	SV_19	SV_20
SV_1	0.014	0.713	0.056	0.713	0.362	0.983	0.999	0.129	0.003	0.266	0.014	< .001	1.000	0.036	< .001	0.188	1.000	< .001	0.001
	*	ns	ns	ns	ns	ns	ns	ns	**	ns	*	***	ns	*	***	ns	ns	***	**
SV_2		0.9	1.000	< .001	0.995	0.473	0.266	1.000	1.000	0.999	1.000	0.266	0.129	1.000	0.473	< .001	0.086	0.713	1.000
		ns	ns	ooo	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ooo	ns	ns	ns
SV_3			0.995	0.005	1.000	1.000	1.000	1.000	0.594	1.000	0.900	0.002	0.995	0.983	0.005	< .001	0.983	0.014	0.362
			ns	oo	ns	ns	ns	ns	ns	ns	ns	**	ns	ns	**	ooo	ns	*	ns
SV_4				< .001	1.000	0.818	0.594	1.000	1.000	1.000	1.000	0.086	0.362	1.000	0.188	< .001	0.266	0.362	0.995
				ooo	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ooo	ns	ns	ns
SV_5					0.001	0.036	0.086	< .001	< .001	< .001	< .001	< .001	0.188	< .001	< .001	1.000	0.266	< .001	< .001
					**	*	ns	***	***	***	***	***	ns	***	***	ns	ns	***	***
SV_6						0.999	0.983	1.000	0.900	1.000	0.995	0.008	0.900	1.000	0.022	< .001	0.818	0.056	0.713
						ns	ns	ns	ns	ns	ns	**	ns	ns	*	ooo	ns	ns	ns
SV_7							1.000	0.953	0.188	0.995	0.473	< .001	1.000	0.713	< .001	0.003	1.000	0.002	0.086
							ns	ns	ns	ns	ns	***	ns	ns	***	oo	ns	**	ns
SV_8								0.818	0.086	0.953	0.266	< .001	1.000	0.473	< .001	0.008	1.000	< .001	0.036
								ns	ns	ns	ns	***	ns	ns	***	oo	ns	***	*
SV_9									0.995	1.000	1.000	0.036	0.594	1.000	0.086	< .001	0.473	0.188	0.953
									ns	ns	ns	*	ns	ns	ns	ooo	ns	ns	ns
SV_10										0.953	1.000	0.594	0.036	1.000	0.818	< .001	0.022	0.953	1.000
										ns	ns	ns	o	ns	ns	ooo	o	ns	ns
SV_11											0.999	0.014	0.818	1.000	0.036	< .001	0.713	0.086	0.818
											ns	*	ns	ns	*	ooo	ns	ns	ns
SV_12												0.266	0.129	1.000	0.473	< .001	0.086	0.713	1.000
												ns	ns	ns	ns	ooo	ns	ns	ns
SV_13													< .001	0.129	1.000	< .001	< .001	1.000	0.818
													ooo	ns	ns	ooo	ooo	ns	ns
SV_14														0.266	< .001	0.022	1.000	< .001	0.014
														ns	***	o	ns	***	*
SV_15															0.266	< .001	0.188	0.473	0.999
															ns	ooo	ns	ns	ns
SV_16																< .001	< .001	1.000	0.953
																ooo	ooo	ns	ns
SV_17																	0.036	< .001	< .001
																	*	***	***
SV_18																		< .001	0.008
																		***	**
SV_19																			0.995
																			ns

Source: Original data.

The protein content mean value ($\overline{\text{Pro}}$), at the experimental level, was $\overline{\text{Pro}} = 10.69 \pm 0.18\%$. Compared to calculated mean value, nine hybrids provided positive differences, with an increase in protein content (ΔPro) ranging between ΔPro = 0.01% (SV_6) and ΔPro = 1.71% (SV_17). Eleven hybrids recorded a negative increase in protein content, with values ranging between ΔPro = -0.04% (SV_11) and ΔPro = -1.24% (SV_13). Hybrids SV_5 and SV_17 presented a positive increase, at a p<0.001 level. In the case of some hybrids, the differences fell within the limits of the standard error, SE = ±0.18% (e.g. SV_3, SV_6, SV_9, SV_11) (Figure 2).

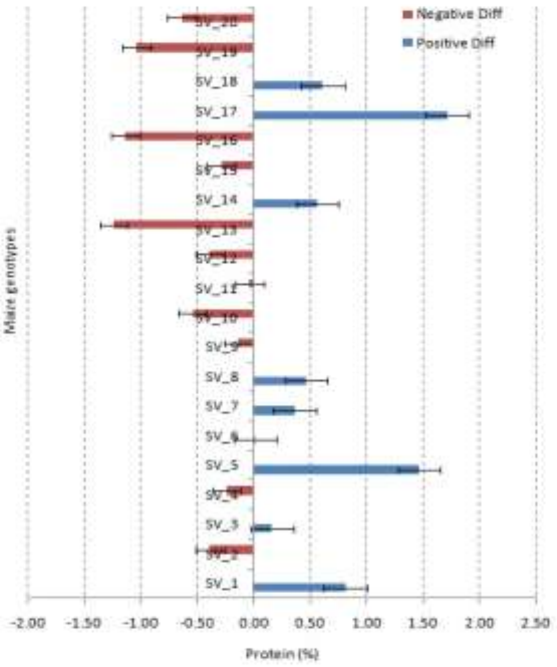

Fig. 2. Distribution of differences in protein content in corn hybrids, relative to the mean value of the experiment
Source: Original figure.

Based on the descriptive statistical analysis, quartile thresholds were generated and the corn hybrids were grouped by quartiles, in relation to the protein content in the grains (Figure 3). The upper quartiles included the hybrids SV_17, SV_5, SV_1, SV_18 and SV_14, with high protein content values. The lower quartile included the hybrids SV_10, SV_20, SV_19, SV_16, and SV_13, respectively, with protein content lower than the 10.99% threshold. The middle quartile included 10 hybrids, respectively SV_8, SV_7, SV_3, SV_6, SV_11, SV_9, SV_4, SV_15, SV_2, and SV_12.

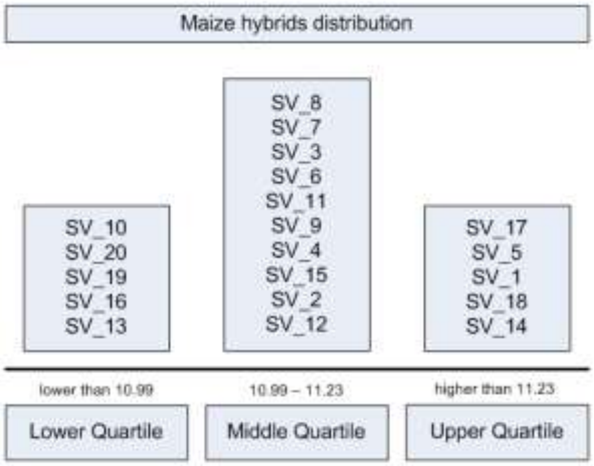

Fig. 3. Quartile distribution of maize hybrids, in relation to grain protein content
Source: Original figure.

A ranking of the maize hybrids was made based on the protein content of the kernels. The hierarchical diagram in Figure 4 resulted, with the distribution of the corn hybrids in the confidence interval in Figure 5, in the scattergram format.

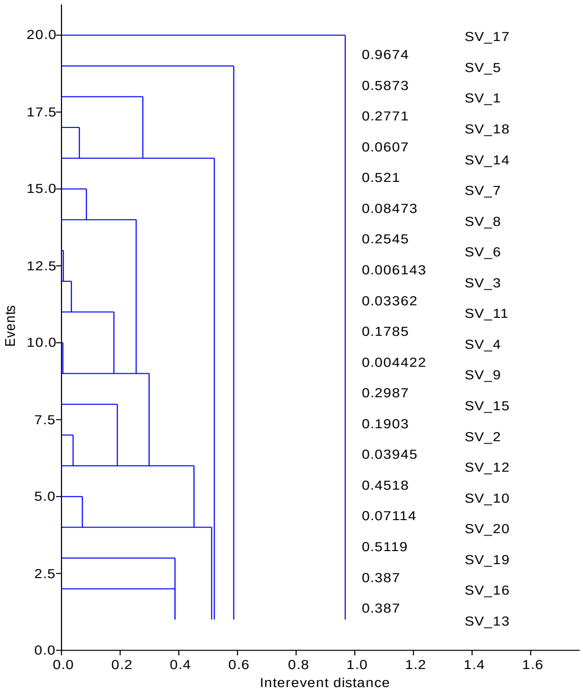

Fig. 4. Maize hybrid ranking chart based on protein content
Source: Original figure.

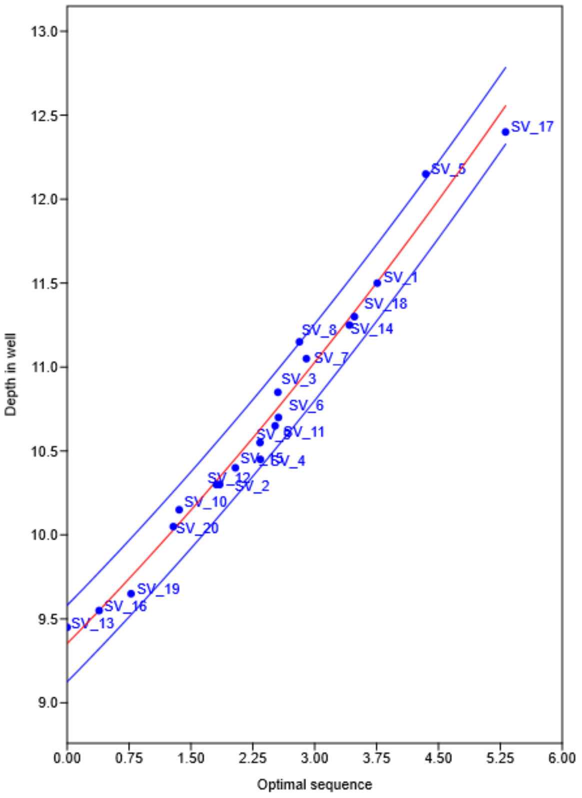

Fig. 5. Scattergrams of maize hybrids distribution
Source: Original figure.

The protein content in protein crops and the quality of proteins, especially in essential amino acids (Lys, Trp in cereals; Met in legumes) has presented and continues to present interest from economic and humanitarian perspectives [23]. The authors presented the importance of methods based on genetic approaches, on biotechnologies, which, complemented with technological measures, lead to a high and quality protein content in protein crops [23].

Associated with population growth and demand for food resources, there has been a need to find technologies to ensure accessible proteins for human consumption, and the production of vegetable protein represents a possible solution [1].

Vegetable proteins are found in varying proportions in different diets, and protein sources are represented by a wide range of plant species [18].

Maize protein yield was analyzed in relation to various agrotechnical and climatic elements [20]. The authors recorded the variation of protein content significantly with climatic conditions during the growing season in a seven-year study. Significantly lower protein content was recorded in drought years and high temperatures [20].

Nitrogen fertilization before sowing, and localized fertilization with NP complexes in the plant row, significantly contributed to increasing the protein content in corn kernels [20].

In the context of the present study, the genetic potential for protein production in the 20 hybrids in comparative culture was analyzed.

The hybrids in the upper quartile were analyzed and discussed both in terms of position within the quartile, as well as in relation to the other hybrids in the comparative crop.

The first position was occupied by the hybrid SV_17 with a protein content of Pro = 12.40±0.12%. Five hybrids were included in the upper quartiles (Figure 3). These five maize hybrids (SV_17, SV_5, SV_1, SV_18, and SV_14) showed genetic advantage for protein content, compared to the other hybrids tested.

Within the upper quartile, the hybrid SV_17 presented differences at the $p<0.05$ level compared to the hybrids SV_14 and SV_18. Compared to the hybrids SV_1 and SV_5, the differences did not present statistical significance. In the case of the other hybrids grouped in the upper quartile, differences were observed, but without statistical significance.

Across the entire collection of maize hybrids tested in comparative crop, maize hybrid SV_17 presented statistically significant differences, compared to the most of the hybrids tested, except for SV_1 and SV_5 hybrids. The SV_5 maize hybrid presented statistically significant differences, compared to 14 tested hybrids. The SV_1 maize hybrid registered statistically significant differences compared to eight tested hybrids. The SV_18 maize hybrid and the SV_14 maize hybrid presented statistically significant differences compared to six tested hybrids.

Ten hybrids were included in the middle quartile (Figure 2). Hybrid SV_8 (first position in the middle quartile) compared to the hybrids in the upper quartiles had a lower protein content, but with differences without statistical certainty (Table 3). Hybrid SV_7 (second position in the middle quartile) presented differences at the $p<0.05$ level with hybrid SV_5, at the $p<0.01$ level with hybrid SV_17, and differences without statistical certainty with the other hybrids in the upper quartiles. Hybrid SV_3 (third position in the middle quartile) presented differences at $p<0.01$ levels compared to hybrid SV_5, at $p<0.001$ level compared to hybrid SV_17 and differences without statistical certainty compared to the other hybrids in the upper quartile. Hybrid SV_6 (fourth position in the middle quartile) showed differences at the $p<0.01$ level compared to hybrid SV_5, at the $p<0.001$ level compared to hybrid SV_17 and differences without statistical certainty compared to the other hybrids in the upper quartile. Hybrid SV_11 (fifth position in the middle quartile) showed differences at the $p<0.001$ level compared to hybrids SV_5 and SV_17, and differences without statistical certainty compared to the other hybrids in the upper quartile. These hybrids require attention in future studies, as they show differences in protein content, with statistical certainty, only compared to two hybrids in the upper quartiles, and differences without statistical certainty compared to three hybrids in the respective quartile. The other five hybrids in the middle quartile presented negative differences in protein content compared to three hybrids in the upper quartile, within statistical safety. Maize hybrids in the lower quartile recorded low protein content under the study conditions, but can be further evaluated for other morphological and physiological traits and agronomic characteristics.

CONCLUSIONS

By the protein content in the grains, the maize hybrids expressed differentiated protein production potential under uniform cultivation conditions, in terms of environmental and technological factors. Based on the protein content, five hybrids were positioned in the upper quartile, with values above the threshold of 11.23% protein, five hybrids were positioned in the lower quartile, with values lower than the threshold of 10.99% protein, and ten hybrids were positioned in the middle quartile. The highest protein content was recorded for the SV_17 hybrid (Pro = 12.40±0.12%), followed by the SV_5 hybrid (Pro = 12.15±0.03%).

The comparative analysis led to 190 combinations, of which 45 comparative analyses with positive differences and 19 analyses with negative differences, in conditions of statistical safety.

Compared to the average value at the experiment level ($\overline{Pro} = 10.69 \pm 0.18\%$), the nine hybrids provided positive differences, with an increase in protein content (ΔPro) ranging between ΔPro = 0.01% (SV_6) and ΔPro = 1.71% (SV_17).

Maize hybrids in the upper quartile are of high interest for the corn breeding program, as a source of valuable genotypes, but at the same time they are also important for agricultural practice for the purpose of comparative testing in different pedoclimatic conditions and promotion for farmers.

ACKNOWLEDGEMENTS

The present data were generated following the implementation of the ADER 2.1.2 project.

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