

Linear associations among phenological, morphological, productive, and energetic-nutritional traits in corn

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Abstract – The objective of this work was to verify if there is linear dependence between the phenological, morphological, and productive traits and the energetic-nutritional ones in early maturing and super-early maturing corn genotypes. A total of 36 early maturing and 22 super-early maturing corn genotypes were evaluated in a randomized complete block design with three replicates, and the phenological, morphological, productive, and energetic-nutritional traits were measured. The matrix of phenotypic correlation coefficients among traits was determined; the multicollinearity diagnosis was carried out within each group of traits; and the canonical correlation analysis was performed. Linear dependence was observed between the groups of phenological, morphological, and productive traits and of the energetic-nutritional ones. In early maturing genotypes, significant canonical correlation shows the existence of linear dependence between the morphological and energetic-nutritional traits. The significant canonical pair shows that taller plants have lower amylose contents in the grains and reduced nitrogen-corrected apparent metabolizable energy. In super-early maturing genotypes, significant canonical correlations of the phenological, morphological, and productive traits with the energetic-nutritional ones indicate that a greater number of days from sowing to female flowering and ear insertion height, as well as a lower number of ears, increase ether extract contents in the grains.

Index terms: *Zea mays*, chemical composition, multivariate analysis.

Associações lineares entre caracteres fenológicos, morfológicos, produtivos e nutricionais energéticos em milho

Resumo – O objetivo deste trabalho foi verificar se há dependência linear entre caracteres fenológicos, morfológicos e produtivos e os nutricionais energéticos, em genótipos de milho de ciclo precoce e superprecoce. Foram avaliados 36 genótipos de milho de ciclo precoce e 22 de ciclo superprecoce, em delineamento de blocos ao acaso, com três repetições, tendo-se mensurado caracteres fenológicos, morfológicos, produtivos e nutricionais energéticos. Foi determinada a matriz de coeficientes de correlação fenotípica entre os caracteres; realizado o diagnóstico de multicolinearidade em cada grupo de caracteres; e feita a análise de correlação canônica. Observou-se dependência linear entre os grupos de caracteres fenológicos, morfológicos e produtivos e os de caracteres nutricionais energéticos. Em genótipos de ciclo precoce, a correlação canônica significativa mostra a existência de dependência linear entre os caracteres morfológicos e os nutricionais energéticos. O par canônico significativo mostra que plantas mais altas apresentam menor teor de amilose nos grãos e redução da energia metabolizável aparente corrigida para nitrogênio. Em genótipos de ciclo superprecoce, as correlações canônicas significativas dos caracteres fenológicos, morfológicos e produtivos com os nutricionais energéticos indicam que os aumentos no número de dias da semeadura até o florescimento feminino e na altura de inserção da espiga, bem como a redução no número de espigas, proporcionam maior teor de extrato etéreo nos grãos.

Termos para indexação: *Zea mays*, composição química, análise multivariada.

Introduction

Corn (*Zea mays* L.) is the most used energetic ingredient in animal diets, with 80% of the total production in Brazil being directed for this purpose

(Oliveira et al., 2011). Knowledge of the nutritional and energetic contents of corn grains, including metabolizable energy, ether extract, starch, and amylose, is important in animal feeding formulations, because it enables fulfilling nutritional requirements

and supplying the correct balance of nutrients in the animal diet (Silva et al., 2008).

Corn grain is widely used in human and animal diets, being the major ingredient in the latter due to its high energy content. Therefore, variations in the energetic composition of corn grain may, for example, significantly affect the profitability of swine production, since it directly affects feed conversion (Dozier et al., 2011). For this reason, studies on the chemical and energetic characterization of corn have been performed to assess the performance of swine (Li et al., 2014), broilers, and laying hens (Moore et al., 2008).

Among the energetic constituents present in the corn grain, the apparent metabolizable energy is the best way to describe the real energy available in feeds. Although apparent metabolizable energy is not a nutrient itself, it corresponds to the energy produced when nutrients are oxidized in the metabolism, aiming for the best animal performance. Other sources of energy in grains include: ether extract, which is known as crude fat and is located in the germ of the corn kernel; and starch, which is one of the main individual components present in the corn grain and a primary source of energy, since it is a carbohydrate reserve constituted by amylose and amylopectin (Li et al., 2008; Idikut et al., 2009). Amylose and amylopectin contents in grains determine starch digestibility and rate of degradation, showing that grains with lower amylose contents have greater digestibility. These contents may be evaluated through indirect methods, such as near-infrared reflectance spectroscopy (NIRS), which, according to Dale et al. (2010), is a quick and accurate non-destructive technique that preserves the integrity of the samples.

In plant breeding programs, the nutritional characterization of grains is essential, especially when determining crosses with improved genetic traits for use in animal feeds, in order to obtain better efficiency and minimize production costs. This shows that the study of the phenological, morphological, productive, and energetic-nutritional traits of corn is important for the early identification of traits, including those in the field, which are indicative of grain nutritional quality.

The knowledge of the association between the phenological, morphological, productive, and energetic-nutritional traits in early maturing and super-early maturing corn genotypes allows assessing

linear dependence among traits and the magnitude of the association. Another way to evaluate the association between two groups of traits is by the canonical correlation analysis, which is performed in a multidimensional way, so that the correlation between these combinations is maximized (Cruz & Carneiro, 2006).

The canonical correlation analysis is a multivariate technique used in exploratory studies to describe the association between groups of traits (X and Y). In this technique, each pair of canonical variables defines a canonical function, and the number of canonical functions that can be obtained is equal to the number of traits of the smallest group. For example, if the smallest group comprises three traits, the number of canonical functions is three, with the first canonical pair presenting the greatest existing correlation among the groups of traits (Hair Jr. et al., 2009).

There are several known studies on the associations among corn traits (Malik et al., 2005; Moore et al., 2008; Moradi & Azarpour, 2011; Li et al., 2014; Nataraj et al., 2014). However, researches on the association of the groups of phenological, morphological, and productive traits with those of energetic-nutritional ones by canonical correlations are practically nonexistent.

The objective of this work was to verify if there is linear dependence among the phenological, morphological, and productive traits and the energetic-nutritional ones in early maturing and super-early maturing corn genotypes.

Materials and Methods

The data used were originated from two experiments with corn, carried out during the 2009/2010 agricultural year, in the experimental area of the Department of Plant Sciences of Universidade Federal de Santa Maria, in the state of Rio Grande do Sul, Brazil (29°42'S, 53°49'W, at an altitude of 95 m). One experiment was composed of 36 early maturing corn genotypes and the other one of 22 super-early maturing corn genotypes. The assessed genotypes belong to the network for the evaluation of corn genotypes of the state of Rio Grande do Sul, Brazil, coordinated by Fundação Estadual de Pesquisa Agropecuária.

The commercial names of the 36 early maturing corn genotypes studied were the following: 20A55, 30A91, ATL 200, BM 207, BM 822, CD 321,

CO 327, CO 388, DKB 245, Dx 510, 2B655, 2B688, PMS 0219A54, FTH 404, FTH 900, CEP M 128, CEP M 130, CEP M 143, GNZ 2005, GNZ 2728, GNZX 0744, KSP 1356, KSP 3246, BX 945, BG7060, P 30B39, SHX 5121, SHX 7222, SHX 7323, XB 6012, XBX 70202, AG 8025, AG 9040, P 30R50, AG 5011, and AG 2020. The commercial names of the 22 super-early maturing corn genotypes evaluated were: BM 911, Dx 915, 2B433, PMS 3919, PMS 1635A08, FTH 960, GNZ 0729, GNZ 9505, BX 898, HS 79707, PRE 12S12, PRE 22D11, PRE 22S11, PRE 22T10, RBX 79, SHS 7090, SHX 7111, AG 9045, BALU 7690, SG 6302, AG 9020, and BG7060. The complete description of all these genotypes has already been presented by Alves et al. (2015).

In both experiments, the experimental design was a randomized complete block with three replicates. The experimental units were composed of two 5-m length rows, spaced at 0.80 m between rows and at 0.20 m between plants in the row. The sowing procedure was carried out manually on 10/26/2009, with base fertilization of 37.5 kg ha⁻¹ N, 150 kg ha⁻¹ P₂O₅, and 150 kg ha⁻¹ K₂O. Plant emergence occurred between 11/1/2009 and 11/3/2009, and the population was adjusted by thinning to 62,500 plants per hectare. For topdressing fertilization, 200 kg ha⁻¹ N were split in three applications, when the plants presented three, five, and ten leaves.

The phenological and morphological traits were measured in every genotype in every experimental unit in the field. The obtained phenological traits were: number of days from sowing until male flowering (MF) and number of days from sowing until female flowering (FF), when 50% of the plants of the plot showed male and female flowering, respectively. The morphological traits determined in all plants of the plot were: plant height at harvest (PH), in centimeters; ear insertion height at harvest (EH), in centimeters; and relative ear placement (EP=EH/PH). The harvest of corn ears was carried out on 3/15/2010, and, simultaneously, the following productive traits were measured: number of plants (NP) per hectare; number of ears (NE) per hectare; ear index (EI=NE/NP); ear weight (EW), in Mg ha⁻¹; grain yield (GY) at 13% humidity, in Mg ha⁻¹; and 1,000-grain weight (TGW), in grams.

Afterwards, 500-g corn grain samples from each plot were separated and stored in a paper bag, then taken to a forced-air circulation oven until 10% humidity.

After drying, the grains were ground in a MA-630 micro-mill (Marconi Equipamentos Para Laboratórios Ltda., Piracicaba, SP, Brazil), in order to obtain a sample with granulometry between 0.30 and 0.50 mm. Each ground sample was stored in a hermetically-closed package until the moment of grain nutritional analyses. These samples were used to determine the following energetic-nutritional traits: nitrogen-corrected apparent metabolizable energy (AMEn), in kcal kg⁻¹; as well as ether extract (EE), starch (ST), and amylose (AML), all in raw matter percentage. The quantification of EE, ST, and AMEn concentrations was performed using NIRS with analytical calibration, CEAN 010, (Adisseo Brasil Nutrição Animal Ltda., São Paulo, SP, Brazil). AML concentration was determined by iodometry, according to Martinez & Cuevas (1989), with the dissolution, gelatinization, acidification, and addition of iodine solution, which forms a complex with the starch, and was measured using a spectrophotometer at 620 nm.

The assumptions of the mathematical model were tested in each group of traits. The normality of errors was checked through the Kolmogorov-Smirnov test (Campos, 1983), and the homogeneity of residual variances by Bartlett's test (Steel et al., 1997). In addition, selective accuracy (SA) was estimated by the equation $SA = (1 - (1/Fc))^{0.5}$, in which Fc is the F-test value, used to evaluate the experimental accuracy, in alignment with the limits recommended by Resende & Duarte (2007). SA can alternatively be obtained by the square root of heritability and is considered: very high, when $SA \geq 0.90$; high, when $0.70 \leq SA < 0.90$; moderate, when $0.50 \leq SA < 0.70$; and low, when $SA < 0.50$. Moreover, the analysis of variance was carried out at 5% probability, and the phenotypic correlation coefficients (r) were estimated among 15 traits. The significance of r was also verified through Student's t-test, at 5% probability, for the experiments with early and super-early maturing corn genotypes. Subsequently, the diagnosis of multicollinearity was made within each group of traits (phenological, morphological, productive, and energetic-nutritional) for both experiments.

The methods used to verify the magnitude of the multicollinearity of the phenotypic correlation matrix were the condition number (CN) and the variance inflation factor (VIF). The CN is the ratio between the largest and the smallest eigenvalue of the correlation

matrix, and it was used as a decision criterion, according to the classification proposed by Montgomery & Peck (1982) and described by Cruz & Carneiro (2006): if $CN \leq 100$, there is a weak multicollinearity among traits; if $100 < CN < 1,000$, a moderate to strong one; and if $CN \geq 1,000$, a severe one. In the case of a moderate to strong or severe multicollinearity, it is necessary to eliminate highly correlated traits. The VIF represents how the coefficient of variation (CV) is inflated compared with what it would be if it was not correlated with any other trait of the model. VIF values lower than 10 are considered appropriate, indicating the absence of multicollinearity, whereas those above 10 show a high collinearity degree among traits (Kutner et al., 2005).

Next, the canonical correlation analysis was performed for the early and super-early maturing corn genotypes. The groups of traits were correlated as follows: phenological (MF and FF) and energetic-nutritional (AMEn, EE, ST, and AML); morphological (PH and EH) and energetic-nutritional (AMEn, EE, ST, and AML); and productive (NP, NE, GY, and TGW) and energetic-nutritional (AMEn, EE, ST, and AML). The association measurements among the groups of traits were presented through canonical pairs, followed by their canonical coefficients. To evaluate the significance of the canonical associations, a chi-square statistical test was used, at 5% probability (Cruz & Carneiro, 2006). The statistical analyzes were carried out using the Genes software (Universidade Federal de Viçosa, Viçosa, MG, Brazil) and Microsoft Office Excel.

Results and Discussion

The normality of errors checked through the Kolmogorov-Smirnov test showed that all measured traits had normal distribution in early maturing genotypes. In super-early maturing ones, only the trait NP did not have a normal distribution. It should be noted that in 10 and 13 of the 15 traits measured in early maturing and super-early maturing genotypes, respectively, the residual variances were homogeneous according to Bartlett's chi-square test (Tables 1 and 2), confirming the obtained results.

The analysis of variance of the phenological, morphological, productive, and energetic-nutritional traits revealed genetic variability between early maturing and super-early maturing genotypes

(Table 1). This type of study is of utmost importance, because the wide variability found among these traits enables the identification of those that are promising for corn genetic breeding programs through indirect selection. Given this variability, it may be inferred that these genotypes can be used in the process of selecting appropriate crosses between divergent genotypes.

The average values for each trait evaluated in the present study, compared with those found in the literature, are indicative of significant variability (Alves et al., 2014, 2015). The existence of variability is a plant breeding premise and creates the possibility of crosses between individuals through plant breeding strategies, in order to obtain improvements in energy nutritional quality without compromising grain yield.

Overall, the CV in the two experiments was low, indicating high experimental precision. Only the productive traits EW and GY showed medium CV values in both experiments (Tables 1 and 2). According to the precision statistics, the SA, Fc, and CV statistical tests confirmed the good experimental precision of the experiments. However, Cargnelutti Filho & Storek (2009), while studying corn, found that SA and Fc were the most adequate statistical tests for the inference of precision of the experiments.

The multicollinearity diagnostics, inferred from the phenotypic correlation matrix in each group of traits, showed a CN less than 100 and a VIF less than 10, indicating a weak multicollinearity for the phenological traits in the early maturing and super-early maturing genotypes. For both genotypes, the morphological traits showed high multicollinearity, whereas the trait EP had to be removed because it was highly correlated with EH. Regarding productive traits, EI and EW were excluded, since they showed multicollinearity problems. In contrast, the removal of traits in the energetic-nutritional group was not required.

The presence of correlation between the phenological, morphological, and productive traits and the energetic-nutritional ones of the early maturing and super-early maturing genotypes was confirmed through the phenotypic correlation matrix. In early maturing genotypes, the estimates of phenotypic correlation ranged from $r = -0.847$ between FF and EI and between FF and NE to $r = 0.993$ between EW and GY (Table 3). A positive correlation among EW and GY ($r = 0.64$) was also found by Mhoswa et al. (2016). In super-early maturing genotypes, the estimates of

phenotypic correlation ranged from $r = -0.873$ between FF and EI to $r = 0.991$ between EW and GY. From these estimates, it was concluded that there are traits in corn that show linear dependence and that may be used in indirect selection.

The results obtained in the present study suggest that, in early maturing genotypes, MF and FF are negatively correlated with traits from the productive group, i.e., NP, NE, EI, EW, and GY; the exception is TGW, which showed no correlation. In super-early maturing genotypes, MF and FF are negatively correlated with the productive traits NE, EI, EW, GY, and TGW; the exception is NP, which showed a slight positive correlation with MF ($r = 0.149$) and no correlation with FF ($r = 0.024$) (Table 3). These results are in agreement with those of Malik et al. (2005), Bekele & Rao (2014), and Ullah et al. (2016). The early maturing and super-early maturing genotypes showed a positive correlation between TGW and GY ($r = 0.370$ and $r = 0.346$, respectively). Prakash et al. (2006), Begum et al. (2016), Nardino et al. (2016), and Ullah et

al. (2016) also reported positive correlations between these traits.

The correlation between GY and ST was of $r = -0.141$ in the early maturing genotypes and of $r = 0.029$ in the super-early maturing genotypes (Table 3). These results are in alignment with those observed by Prakash et al. (2006), but differ from those of Idikut et al. (2009), who found a positive and nonsignificant correlation of $r = 0.486$. GY showed a positive correlation with TGW and EW in early maturing and super-early maturing genotypes (Table 3). These results are similar to those reported by Ghimire & Timsina (2015). EW showed a positive correlation of $r = 0.993$ and $r = 0.991$ with GY for early maturing and super-early maturing genotypes, respectively, corroborating the results of Mhoswa et al. (2016) and Ghimire & Timsina (2015).

In early maturing genotypes, the correlations between MF and EE and between FF and EE were of $r = 0.234$ and $r = 0.314$, respectively. In super-early maturing genotypes, the correlation between MF and EE was of $r = 0.617$, and between FF and EE of $r = 0.674$ (Table 3). However, a positive correlation with

Table 1. F-test value (Fc) of the analysis of variance for genotype effect, p-value of the Kolmogorov-Smirnov test for normality of error distribution (Norm), and p-value of Bartlett's chi-square test for homogeneity of residual variances (Homog) for the phenological, morphological, productive, and energetic-nutritional traits of 36 early maturing corn (*Zea mays*) genotypes in the agricultural year of 2009/2010.

Traits ⁽¹⁾	Fc	Mean	Minimum	Maximum	CV ⁽²⁾	SA ⁽³⁾	Norm	Homog
MF	8.91*	74.28	65.00	88.00	2.76	0.94	0.8434	0.3423
FF	16.11*	80.19	69.00	94.00	2.70	0.97	0.7841	0.7966
PH	2.84*	187.04	155.32	230.07	5.24	0.81	0.8325	0.1355
EH	5.29*	96.33	66.68	132.61	8.68	0.90	0.8992	0.2033
EP	17.42*	0.51	0.42	0.63	4.00	0.97	0.3841	0.0366
NP	1.66*	63.044	50.000	67.500	4.17	0.63	0.2451	0.0017
NE	7.03*	55.277	37.500	67.500	6.89	0.93	0.8161	0.6803
EI	6.01*	0.88	0.63	1.02	6.46	0.91	0.9622	0.6223
EW	7.44*	6.13	2.73	9.69	12.46	0.93	0.3940	0.0008
GY	8.15*	5.00	2.15	8.34	13.32	0.94	0.6425	0.0003
TGW	6.59*	265.16	186.72	322.42	5.91	0.92	0.9951	0.7323
AMEn	7.51*	3.435	3.382	3.479	0.37	0.93	0.8304	0.1850
EE	7.17*	3.76	3.37	4.18	2.58	0.93	0.7544	0.0777
ST	1.27	68.64	64.57	73.65	2.05	0.46	0.4647	0.0155
AML	5.33*	28.96	26.83	31.47	1.93	0.90	0.4109	0.3791

⁽¹⁾Phenological: MF, number of days from sowing until male flowering; and FF, number of days from sowing until female flowering. Morphological: PH, plant height, in centimeters; EH, ear insertion height, in centimeters; and EP, ear placement (EP = EH/PH). Productive: NP, number of plants per hectare; NE, number of ears per hectare; EI, ear index; EW, ear weight, in Mg ha⁻¹; GY, grain yield, in Mg ha⁻¹; and TGW, 1,000-grain weight, in grams. Energetic-nutritional: AMEn, nitrogen-corrected apparent metabolizable energy, in kcal kg⁻¹; EE, ether extract, in raw matter percentage (%RM); ST, starch, in %RM; and AML, amylose, in %RM. *Significant difference by the F-test, at 5% probability. ⁽²⁾CV, coefficient of variation. ⁽³⁾SA, selective accuracy, whose class limits were established by Resende & Duarte (2007) as: very high, when SA ≥ 0.90 ; high, when $0.70 \leq SA < 0.90$; moderate, when $0.50 \leq SA < 0.70$; and low, when SA < 0.50 .

Table 2. F-test value (Fc) of the analysis of variance for genotype effect, p-value of the Kolmogorov-Smirnov test for normality of error distribution (Norm), and p-value of Bartlett’s chi-square test for homogeneity of residual variances (Homog) for the phenological, morphological, productive, and energetic-nutritional traits of 22 super-early maturing corn (*Zea mays*) genotypes in the agricultural year of 2009/2010.

Traits ⁽¹⁾	Fc	Mean	Minimum	Maximum	CV ⁽²⁾	SA ⁽³⁾	Norm	Homog
MF	13.63*	72.12	66.00	82.00	2.17	0.96	0.0682	0.9001
FF	24.52*	77.18	69.00	87.00	2.14	0.98	0.5338	0.8676
PH	5.82*	202.27	178.15	223.51	3.33	0.91	0.8691	0.2538
EH	13.33*	104.97	80.08	127.20	4.77	0.96	0.8202	0.5512
EP	33.62*	0.52	0.43	0.59	2.34	0.99	0.6099	0.6195
NP	2.27*	62.632	58.750	66.250	1.86	0.75	0.0055	0.1988
NE	6.06*	58.522	42.500	65.000	4.72	0.91	0.8920	0.1282
EI	5.36*	0.93	0.68	1.02	4.85	0.90	0.7959	0.0244
EW	6.87*	7.27	3.97	9.89	10.32	0.92	0.7668	0.9624
GY	8.98*	5.92	3.09	8.23	10.64	0.94	0.6643	0.9375
TGW	3.28*	268.51	212.37	341.91	7.51	0.83	0.9942	0.2278
AMEn	20.75*	3.416	3.332	3.473	0.29	0.98	0.9793	0.3741
EE	12.70*	3.72	3.21	4.09	2.69	0.96	0.3952	0.0155
ST	2.62*	68.92	65.75	72.22	1.63	0.79	0.7942	0.3676
AML	6.90*	28.61	26.04	30.68	2.15	0.92	0.8725	0.3511

⁽¹⁾Phenological: MF, number of days from sowing until male flowering; and FF, number of days from sowing until female flowering. Morphological: PH, plant height, in centimeters; EH, ear insertion height, in centimeters; and EP, ear placement (EP = EH/PH). Productive: NP, number of plants per hectare; NE, number of ears per hectare; EI, ear index; EW, ear weight, in Mg ha⁻¹; GY, grain yield, in Mg ha⁻¹; and TGW, 1,000-grain weight, in grams. Energetic-nutritional: AMEn, nitrogen-corrected apparent metabolizable energy, in kcal kg⁻¹; EE, ether extract, in raw matter percentage (%RM); ST, starch, in %RM; and AML, amylose, in %RM. *Significant difference by the F-test, at 5% probability. ⁽²⁾CV, coefficient of variation. ⁽³⁾SA, selective accuracy, whose class limits were established by Resende & Duarte (2007) as: very high, when SA ≥0.90; high, when 0.70 ≤ SA <0.90; moderate, when 0.50 ≤ SA <0.70; and low, when SA <0.50.

Table 3. Estimates of the phenotypic⁽¹⁾ correlation coefficients among the phenological, morphological, productive, and energetic-nutritional traits of 36 early maturing corn (*Zea mays*) genotypes (above diagonal) and 22 super-early maturing corn genotypes (below diagonal) in the agricultural year of 2009/2010.

Traits ⁽²⁾	MF	FF	PH	EH	EP	NP	NE	EI	EW	GY	TGW	AMEn	EE	ST	AML
MF		0.868*	0.081	0.301	0.297	-0.431*	-0.728*	-0.709*	-0.528*	-0.509*	0.058	0.216	0.234	0.037	-0.281
FF	0.892*		0.141	0.173	0.107	-0.428*	-0.847*	-0.847*	-0.687*	-0.699*	0.081	0.198	0.314	-0.017	-0.359*
PH	0.432*	0.402		0.580*	0.169	-0.028	-0.183	-0.207	0.064	0.064	0.358*	0.065	0.308	-0.074	-0.413*
EH	0.779*	0.732*	0.674*		0.900*	-0.129	-0.215	-0.201	0.006	0.023	0.233	0.388*	0.311	0.053	-0.066
EP	0.747*	0.704*	0.255	0.886*		-0.130	-0.132	-0.102	-0.001	0.017	0.092	0.421*	0.214	0.095	0.147
NP	0.149	0.024	-0.012	0.002	0.028		0.599*	0.373*	0.476*	0.466*	0.059	-0.211	-0.231	-0.009	0.169
NE	-0.601*	-0.838*	-0.195	-0.548*	-0.586*	0.259		0.966*	0.820*	0.805*	-0.006	-0.292	-0.242	-0.134	0.307
EI	-0.658*	-0.873*	-0.206	-0.571*	-0.613*	0.021	0.971*		0.799*	0.783*	-0.024	-0.267	-0.202	-0.144	0.306
EW	-0.525*	-0.721*	-0.044	-0.403	-0.493*	0.230	0.817*	0.788*		0.993*	0.368*	-0.252	-0.122	-0.188	0.202
GY	-0.542*	-0.757*	-0.069	-0.426	-0.509*	0.223	0.852*	0.826*	0.991*		0.370*	-0.244	-0.170	-0.141	0.216
TGW	-0.301	-0.245	0.127	0.018	-0.054	0.043	0.141	0.136	0.393	0.346		0.083	0.109	-0.040	-0.107
AMEn	0.405	0.489*	0.395	0.618*	0.572*	0.096	-0.440*	-0.480*	-0.120	-0.203	0.466*		0.523*	0.041	-0.072
EE	0.617*	0.674*	0.312	0.668*	0.681*	0.198	-0.592*	-0.661*	-0.319	-0.388	0.264	0.896*		-0.341*	-0.347*
ST	-0.092	-0.188	0.019	-0.034	-0.067	-0.298	0.192	0.270	0.017	0.029	0.240	0.111	0.086		0.246
AML	0.201	0.284	0.181	0.387	0.416	-0.223	-0.313	-0.270	-0.121	-0.171	0.044	0.575*	0.377	-0.108	

⁽¹⁾Value greater than |0.341| for early maturing corn genotypes and greater than |0.432| for super-early maturing corn genotypes is significant by Student’s t-test, at 5% probability, with 34 and 20 degrees of freedom, respectively. ⁽²⁾Phenological: MF, number of days from sowing until male flowering; and FF, number of days from sowing until female flowering. Morphological: PH, plant height, in centimeters; EH, ear insertion height, in centimeters; and EP, ear placement (EP = EH/PH). Productive: NP, number of plants per hectare; NE, number of ears per hectare; EI, ear index; EW, ear weight, in Mg ha⁻¹; GY, grain yield, in Mg ha⁻¹; and TGW, 1,000-grain weight, in grams. Energetic-nutritional: AMEn, nitrogen-corrected apparent metabolizable energy, in kcal kg⁻¹; EE, ether extract, in raw matter percentage (%RM); ST, starch, in %RM; and AML, amylose, in %RM. *Significant coefficient by Student’s t-test, at 5% probability.

low magnitude among these traits was also observed by Wali et al. (2006) and Chukwu et al. (2013). This shows that for early and super-early maturing corn genotypes, the greater the MF and FF, the greater will be the EE contents in the grains.

In early maturing genotypes, the correlation between the morphological and energetic-nutritional traits constitutes the first significant canonical pair ($r = 0.545$), at 5% probability (Table 4). The significant canonical pair showed that taller plants have lower amylose contents in the grains and reduced nitrogen-corrected apparent metabolizable energy. This suggests that it is possible to verify the morphological traits of early maturing genotypes that indicate energetic quality in corn grains. It was observed that the canonical correlations established by the chi-square test based on phenological versus energetic-nutritional traits and on productive versus energetic-nutritional traits were nonsignificant. Therefore, it can be inferred that the considered groups are independent, i.e., they do not show linear dependence among traits.

In super-early maturing genotypes, the phenological traits were associated with the energetic-nutritional ones in the first significant canonical pair ($r = 0.779$), at 5% probability (Table 5). The significant canonical pair showed that the greater the number of days from sowing until FF, the greater were the ether extract contents in the grains. Significant canonical correlation ($r = 0.736$) was observed between the morphological and energetic-nutritional traits only for the first canonical pair. In this case, the significant canonical pair indicates that plants with greater ear height have greater ether extract contents in the grains.

In contrast, the association between productive and energetic-nutritional traits contributed to two significant canonical pairs: the first with a canonical correlation of $r = 0.900$ and the second with a canonical correlation of $r = 0.733$ (Table 5). The first significant canonical pair showed that the lower the number of ears, the greater were the ether extract contents in the grains. The second significant canonical pair indicated greater nitrogen-corrected apparent metabolizable energy in corn grains with increasing TGW. The productive traits NE and TGW can be used for the orientation of corn breeding programs through indirect selection.

The canonical correlation analysis showed that morphological versus energetic-nutritional traits

Table 4. Correlations and canonical coefficients estimated between the phenological and energetic-nutritional, morphological and energetic-nutritional, and productive and energetic-nutritional traits of 36 early maturing corn (*Zea mays*) genotypes in the agricultural year of 2009/2010.

Traits ⁽¹⁾	Canonical pairs			
	1 st	2 nd		
	Phenological			
MF	-0.220	1.999		
FF	1.185	-1.625		
	Energetic-nutritional			
AMEn	0.078	0.985		
EE	0.544	-0.686		
ST	0.293	0.349		
AML	-0.708	-0.125		
Canonical correlation (r)	0.438	0.170		
χ^2	7.650	0.925		
Degree of freedom	8	3		
Traits	Canonical pairs			
	1 st	2 nd		
	Morphological			
PH	1.178	0.345		
EH	-0.964	0.760		
	Energetic-nutritional			
AMEn	-0.735	0.420		
EE	0.256	0.618		
ST	0.049	0.304		
AML	-0.751	-0.303		
Canonical correlation (r)	0.545*	0.408		
χ^2	16.811	5.726		
Degree of freedom	8	3		
Traits	Canonical pairs			
	1 st	2 nd	3 rd	4 th
	Productive			
NP	0.022	1.151	-0.333	0.389
NE	0.656	-0.922	1.631	1.020
GY	0.357	0.151	-1.775	-1.219
TGW	-0.370	-0.521	0.130	1.127
	Energetic-nutritional			
AMEn	-0.453	-0.003	0.673	0.920
EE	-0.246	-0.743	-0.076	-1.105
ST	-0.485	0.564	0.235	-0.794
AML	0.669	-0.399	0.682	-0.318
Canonical correlation (r)	0.482	0.157	0.064	0.031
χ^2	8.977	0.911	0.154	0.030
Degree of freedom	16	9	4	1

⁽¹⁾Phenological: MF, number of days from sowing until male flowering; and FF, number of days from sowing until female flowering. Energetic-nutritional: AMEn, nitrogen-corrected apparent metabolizable energy, in kcal kg⁻¹; EE, ether extract, in raw matter percentage (%RM); ST, starch, in %RM; and AML, amylose, in %RM. Morphological: PH, plant height, in centimeters; and EH, ear insertion height, in centimeters. Productive: NP, number of plants per hectare; NE, number of ears per hectare; GY, grain yield, in Mg ha⁻¹; and TGW, 1,000-grain weight, in grams. *Significant by the chi-square test, at 5% probability.

Table 5. Correlations and canonical coefficients estimated between the phenological and energetic-nutritional, morphological and energetic-nutritional, and productive and energetic-nutritional traits of 22 super-early maturing corn (*Zea mays*) genotypes in the agricultural year of 2009/2010.

Traits ⁽¹⁾	Canonical pairs			
	1 st	2 nd		
	Phenological			
MF	0.194	2.203		
FF	0.823	-2.052		
	Energetic-nutritional			
AMEn	-1.133	-1.816		
EE	1.784	1.445		
ST	-0.217	0.724		
AML	0.306	0.091		
Canonical correlation (r)	0.779*	0.288		
χ^2	17.829	1.512		
Degree of freedom	8	3		
Traits	Canonical pairs			
	1 st	2 nd		
	Morphological			
PH	-0.554	1.235		
EH	1.286	-0.423		
	Energetic-nutritional			
AMEn	-0.765	2.691		
EE	1.465	-1.864		
ST	-0.070	-0.109		
AML	0.420	-0.695		
Canonical correlation (r)	0.736*	0.371		
χ^2	16.233	2.596		
Degree of freedom	8	3		
Traits	Canonical pairs			
	1 st	2 nd	3 rd	4 th
	Productive			
NP	0.671	0.020	0.581	0.533
NE	-1.392	0.123	-0.202	1.453
GY	0.622	-0.104	0.928	-1.798
TGW	-0.016	1.016	-0.337	0.337
	Energetic-nutritional			
AMEn	-0.260	2.495	1.053	-0.735
EE	1.126	-1.627	-1.066	0.990
ST	-0.586	0.133	-0.748	0.393
AML	-0.139	-0.781	-0.854	-0.704
Canonical correlation (r)	0.900*	0.733*	0.421	0.316
χ^2	45.033	17.676	4.945	1.731
Degree of freedom	16	9	4	1

⁽¹⁾Phenological: MF, number of days from sowing until male flowering; and FF, number of days from sowing until female flowering. Energetic-nutritional: AMEn, nitrogen-corrected apparent metabolizable energy, in kcal kg⁻¹; EE, ether extract, in raw matter percentage (%RM); ST, starch, in %RM; and AML, amylose, in %RM. Morphological: PH, plant height, in centimeters; and EH, ear insertion height, in centimeters. Productive: NP, number of plants per hectare; NE, number of ears per hectare; GY, grain yield, in Mg ha⁻¹; and TGW, 1,000-grain weight, in grams. *Significant by the chi-square test, at 5% probability.

in early maturing genotypes, and phenological, morphological, and productive versus energetic-nutritional traits in super-early maturing genotypes are dependent, indicating linear relation among the traits studied. The existence of variability among genotypes and the use of phenotypic correlation allow inferring that it is possible to indirectly identify traits that are indicative of energetic-nutritional quality in corn grains, even in the field. This identification of traits is possible because the majority of the phenotypic correlation is genetic. These data are important in plant breeding programs that aim to identify plants with greater nutritional grain quality, focusing on animal nutrition.

Conclusions

1. In early maturing corn (*Zea mays*) genotypes, the significant canonical correlation shows the existence of linear dependence between the morphological and energetic-nutritional traits, whereas the significant canonical pair shows that taller plants have lower amylose contents in the grains and reduced nitrogen-corrected apparent metabolizable energy.

2. In super-early maturing corn genotypes, significant canonical correlations of the phenological, morphological, and productive traits with the energetic-nutritional ones show that a greater number of days from sowing to female flowering and ear insertion height, as well as a lower number of ears, increase ether extract contents in the grains.

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