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CANONICAL CORRELATIONS BETWEEN MORPHOLOGICAL AND PRODUCTION TRAITS IN SPECIAL TYPES OF RICE[1]

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ABSTRACT - The rich genetic diversity and wide adaptation of rice (*Oryza sativa* L.) to different environments provide fundamental resources for its conservation and improvement. The analysis of canonical correlations can be used to increase the efficiency of selecting superior genotypes, as several traits are evaluated simultaneously. Thus, this study aimed to compare morphoagronomic traits and estimate the magnitude of the association and interdependence between two groups of traits in genotypes of special types of rice. The experiment was carried out between November 2020 and April 2021 at the Department of Plant Science of the Federal Rural University of Rio de Janeiro (UFRRJ), Seropédica – RJ. The experimental design consisted of randomized blocks, with four replications. Seventeen genotypes were evaluated, five of them consisting of white rice and eleven special types of rice. Two groups of variables were used to determine the canonical correlations, with group I composed of four morphological traits and group II composed of four yield components. Significant differences ($P<0.01$) were observed between genotypes for the eight evaluated traits. The first, second, and third pairs showed significant canonical correlations at a 5% probability, demonstrating that these groups are not independent. The selection of superior genotypes for production can be based on choosing plants with higher flag leaf thickness, higher height, and lower flag leaf angle.

Keywords: *Oryza sativa* L. Multivariate analysis; Plant breeding.

CORRELAÇÕES CANÔNICAS ENTRE CARACTERÍSTICAS MORFOLÓGICAS E DE PRODUÇÃO EM TIPOS ESPECIAIS DE ARROZ

RESUMO - A rica diversidade genética e ampla adaptação a diversos ambientes observadas na cultura do arroz (*Oryza sativa* L.) fornecem recursos fundamentais para conservação e melhoramento do cereal. A análise de correlações canônicas pode ser utilizada para aumentar a eficiência de seleção de genótipos superiores, pois várias características são avaliadas simultaneamente. Diante do exposto, este trabalho teve por objetivo comparar características morfoagronômicas e estimar a magnitude da associação e interdependência entre dois grupos de características em genótipos de tipos especiais de arroz. O ensaio foi realizado entre novembro de 2020 e abril de 2021, no Departamento de Fitotecnia da Universidade Federal Rural do Rio de Janeiro (UFRRJ), Seropédica – RJ. O delineamento experimental foi o de blocos ao acaso, com quatro repetições. Foram avaliados dezessete genótipos, dos quais cinco de arroz branco e onze de tipos especiais. Para a determinação das correlações canônicas foram utilizados dois grupos de variáveis, sendo o grupo I composto por quatro características morfológicas e o grupo II composto por quatro componentes da produção. Houve diferenças significativas ($P<0,01$) entre os genótipos para as oito características avaliadas. O primeiro, o segundo e terceiro pares apresentaram correlações canônicas significativas a 5% de probabilidade, demonstrando que esses grupos não são independentes. A seleção de genótipos superiores, para produção, pode basear-se na escolha de plantas com maior espessura da folha bandeira, maior altura e menor ângulo da folha bandeira.

Palavras-chave: *Oryza sativa* L. Análise multivariada. Melhoramento de plantas.

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INTRODUCTION

Rice (*Oryza sativa* L.) is a basic and essential food in the composition of a healthy diet, considered a primary source of energy and proteins. The numerous varieties of cultivated rice have different and unique characteristics of flavor, color, aroma, nutrients, chemical composition, and cooking properties. Red rice is one of the special types of rice. The pigmented pericarp is associated with a remarkable antioxidant activity due to the presence of specific bioactive phytochemicals. These varieties have high levels of iron, essential amino acids, and fibers present in the grains, in addition to an important source of proanthocyanidins (red), making them functional due to their antioxidant capacity (GHASEMZADEH et al., 2018; STRECK et al., 2019; SILVA et al., 2020).

Phenotypic and genotypic aspects diverge within the same species, thus reflecting on plant development and yield. The yield of a given crop is the result of the expression and association of different components, and the degree of this association can be determined by correlations that allow the identification of indirect selection criteria that increase yield (STRECK et al., 2019). When associated, the morphological, physiological, and genetic diversity of the different cultivars can provide essential information and resources for the development of new cultivars with stable production that adapts well to the most diverse growing conditions (HOUR et al., 2020).

The analysis of canonical correlations is a technique that allows evaluating a set of phenotypic data useful for the knowledge of the available germplasm, the magnitude, and direction of genetic effects that control a certain characteristic, demonstrating associations between two groups of variables, allowing inferences to be made as to how much the alteration of a given trait can influence the others (CRUZ; CARNEIRO; REGAZZI, 2014). Canonical correlation analysis has been used in different crops, such as soybean (PEREIRA et al., 2017), elephant grass (MENEZES et al., 2014), wheat (CARVALHO et al., 2015), and quinoa (VERGARA et al., 2021), among others (CRUZ; CARNEIRO; REGAZZI, 2014).

Thus, this study aimed to compare morphoagronomic traits and estimate the magnitude of association and interdependence between two groups of traits in genotypes of special types of rice.

MATERIAL AND METHODS

Implementation of the experimental test

The experiment was carried out in a greenhouse at the Sector of Large Crops of the Department of Plant Science of the Federal Rural University of Rio de Janeiro (UFRRJ), located in the municipality of Seropédica, RJ (22°45′ S and 43°41′ W; 35-40 m of altitude). The regional climate fits into the type Aw – Tropical climate, according to the Köppen (1948) classification, characterized by a rainy season in the summer, from November to April, and a clear dry season in the winter, from May to October, with July being the driest month.

Sowing was carried out on November 10, 2020, in 5 L pots, with a density of five seeds per pot. The pots were kept under protection in a greenhouse covered with a shade screen, and drip irrigation was used as a supplement to the rainfall regime. Thinning was performed 15 days after sowing (DAS), keeping two plants per pot. The substrate used to fill the pots was obtained through the homogenization of sandy-textured soil, cured manure, and red clay at the 2:1:1 ratio. Fertilization was performed with the NPK formulation 15-15-20 at 59, 74, and 90 DAS. Figure 1 shows the minimum, mean, and maximum temperature and precipitation values.

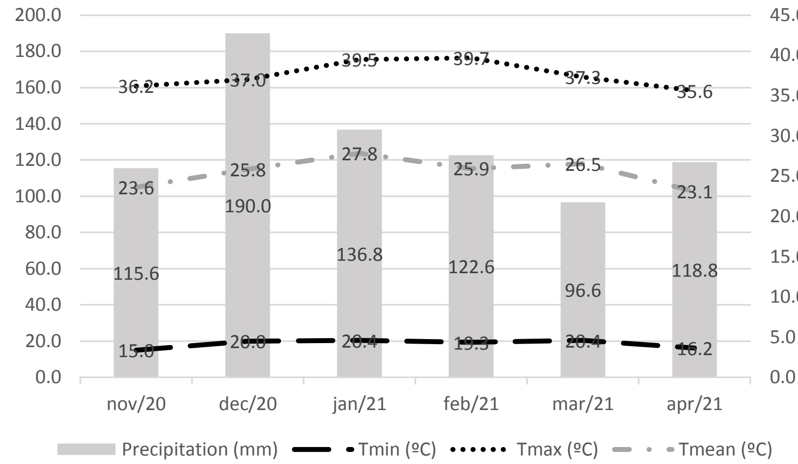

Figure 1. Minimum, mean, and maximum temperatures and precipitation (mm) recorded during the experimental period (Seropédica, RJ, 2020/2021). Source: National Institute of Meteorology (INMET, 2021).

The experimental design consisted of randomized blocks, with four replications and 17 treatments. The experimental unit consisted of pots with two rice plants.

The evaluations started in December 2020 when the first genotype showed full flowering at 44 DAS and lasted until April 2020 with the harvest of the last genotype. Seventeen rice genotypes were evaluated in this experiment (Table 1).

Table 1. Identification of the 17 rice genotypes and their respective origins.

Number	Code	Types	Origins
1	IAC 201	White	Agronomic Institute of Campinas
2	BRS Esmeralda	White	Embrapa
3	IAC 500	Aromatic	Agronomic Institute of Campinas
4	IAC 109	White	Agronomic Institute of Campinas
5	ENA AR1901	Short-grain rice	Palhoça - SC
6	ENA AR1902	Arboreal rice	Palhoça - SC
7	ENA AR2001	Red	Seropédica - RJ
8	ENA AR1903	Carolina Gold	Rio de Janeiro - RJ
9	ENA AR1904	Duborskian	Rio de Janeiro - RJ
10	ENA AR2002	Needle yellow	Porto União - SC
11	ENA AR2003	Short-grain rice	Palhoça – SC
12	ENA AR1905	Aromatic red	Rio de Janeiro - RJ
13	ENA AR1601	Red	Seropédica - RJ
14	ENA AR1602	Red	Virgínia - MG
15	BRS 901	Red	Embrapa (Teresina – PI)
16	BRS 902	Red	Embrapa (Teresina – PI)
17	ENA AR1906	Blue Bonnet	Rio de Janeiro - RJ

Evaluated traits

a) Flag leaf length (FLL, in cm): the length of the flag leaf was measured after anthesis from the ligule to the tip of the leaf blade in two leaves of two stems taken at random.

b) Flag leaf thickness (FLT, in mm): two leaves of two stems were taken at random, which had the widest portion of the flag leaf measured.

c) Flag leaf angle (FLA): measurement of the angle of connection between the flag leaf blade (last to appear on the stem) and the axis of the main panicle of two samples taken at random evaluated at anthesis (opening of the flower buds).

d) Plant height (HGT, in cm): distance from the soil surface to the end of the tallest tiller panicle in a sampling of two plants from grain filling.

e) Number of viable tillers (NVT): the number of tillers with at least one viable spikelet was counted.

f) Percentage of fertile spikelets (%FS): two panicles were taken at random to obtain the relationship between the number of fertile spikelets, with full grains, and the total number of spikelets in each panicle.

g) Hundred-grain weight (HGW, in g): one hundred grains with husks at 13% moisture were counted in two panicles taken at random in each plot, being subsequently weighed to determine the mean weight.

h) Yield (YLD, in g plant^{-1}): the total yield of grains with husk of each plant was weighed at 13% moisture.

i) Full flowering (FF): days elapsed between the effective sowing date (when the seeds are moistened or pre-soaked for the first time) and the date when 80% of the plants have flowers.

j) Crop cycle (maturation, CC): days elapsed from the effective planting to the point of harvest, that is, the date when 80% of the grains in the panicles are fully mature. Rice cultivars were classified according to the cycle as early (< 120 days), medium (121 to 135 days), semi-late (136 to 150 days), and late (over 150 days).

The grains were harvested manually at the end of the cycle and subjected to drying until they reached 13% moisture.

Genetic-statistical analyses

The means were compared after analysis of variance using the Scott-Knott test (P<0.01). The diagnosis of multicollinearity was performed. Two groups of variables were used to determine the canonical correlations, with group I composed of morphological traits: flag leaf length (FLL), flag leaf thickness (FLT), flag leaf angle (ANG), and plant height (HGT); and group II composed of yield components: number of viable tillers (NVT), percentage of fertile spikelets (%FS), hundred-grain weight (HGW), and yield (YLD). The traits full flowering (FF) and crop cycle (CC) were excluded from the correlation estimates. The significance between the groups of traits was evaluated based on the chi-square statistics (CRUZ; CARNEIRO; REGAZZI, 2012). Statistical analyses were performed using the Genes software (CRUZ, 2013).

RESULTS AND DISCUSSION

Table 2 shows the mean values of full flowering, crop cycle, and three morphological traits evaluated in the 17 rice genotypes. The white rice and special rice genotypes showed cycle variations ranging from early to late under the edaphoclimatic conditions in which the experiment was carried out.

The genotype ENA AR 1905 reached full flowering at 51 days after planting, followed by the genotype ENA AR1904 at 53 days after planting. The genotypes IAC 109 (111 days) and ENA AR1906 (112 days) showed the longest time to reach the date when 80% of the plants had flowers. The shortest crop cycle was observed for the genotypes IAC 201, ENA AR 1904, ENA AR 2002, and ENA AR 1905 (119 days), which were classified as early. The genotypes IAC109, BRS 902, and ENA AR1906 (158 days) showed the highest number of days elapsed from planting to harvest and were classified as late.

The sowing date may influence the cycle length of rice cultivars. According to Freitas et al. (2006), cultivars with contrasting cycles, when sown at different times, vary in the number of days after emergence to present a certain number of expanded leaves at the same phenological stage. The total crop cycle is reduced as sowing is delayed.

Early genotypes usually show lower percentages of grain yield reduction under adverse environmental conditions, such as high temperatures and water deficit. However, the reduction in the total cycle due to the improvement must be carried out in a way that does not affect the cultivar production. According to Streck et al. (2006), the reduction in the cycle may drastically reduce the number of leaves in the main stem. The reduction in leaf area can also affect the accumulation of photoassimilates reserves in the stem, which would be translocated to the grains.

Table 2. Mean values of five traits evaluated in 17 rice genotypes.

Genotypes	FF (days)	CC (days)	CLL	FLT	FLA
IAC 201	67	119	58.25 a	17.67 b	3.37 b
BRS Esmeralda	75	135	49.20 b	16.63 b	2.67 c
IAC 500	77	125	37.42 c	20.14 a	2.75 c
IAC 109	112	158	19.05 e	12.09 d	2.00 c
ENA AR1901	75	123	43.42 d	20.23 a	3.25 b
ENA AR1902	94	123	32.2 d	20.45 a	2.62 c
ENA AR2001	93	125	25.11 d	13.79 c	2.69 c
ENA AR1903	91	133	27.77 d	14.96 c	3.37 b
ENA AR1904	53	119	48.2 b	14.45 c	4.62 a
ENA AR2002	76	119	39.52 c	18.52 b	2.50 c
ENA AR2003	67	129	48.92 b	18.18 b	4.00 a
ENA AR1905	51	119	27.30 d	11.28 d	3.75 b
ENA AR1601	102	142	24.17 d	13.67 c	2.62 c
ENA AR1602	98	129	22.75 d	12.84 d	1.69 c
BRS 901	92	133	15.44 e	12.73 d	2.87 c
BRS 902	108	158	18.41 e	11.72 d	2.81 c
ENA AR1906	111	158	28.63 d	15.52 c	3.00 c
Mean	-	-	33.28	15.58	2.80
CV (%)	-	-	14.34	7.30	20.83

FF: full flowering; CC: crop cycle; FLL: flag leaf length, in cm; FLT: flag leaf thickness, in mm; FLA: flag leaf angle. Means followed by the same letter in the column do not differ from each other according to the Scott-Knott test at a 1% probability.

Significant differences ($p<0.01$) were observed for all ten evaluated traits, showing variability between the evaluated genotypes (Tables 2 and 3). The estimate of the experimental error relative to the overall mean of the experiment is expressed by the coefficient of variation (CV), in which the lower the CV estimate, the higher the experimental precision and vice versa. Quantitative traits tend to have high CV values as they are highly influenced by environmental conditions (STRECK et al., 2019). The CV values ranged from 2.8% for the trait flag leaf angle (FLA) to 27.99% for the trait number of viable tillers (NVT).

The cultivar IAC201 had the longest flag leaf length (FLL), with a mean value of 58.25 cm. The genotypes ENA AR1904 and ENA AR2003 showed the highest flag leaf angle (FLA), with a value of 4.62° and 4.0°, respectively. The genotypes IAC 500, ENA AR1901, and ENA AR1901 had the highest mean values for flag leaf thickness (FLT), with values of 20.14, 20.23, and 20.45 mm, respectively (Table 2). The estimates of phenotypic correlations indicated a trend for genotypes with higher FLA to present higher FLL, with the correlation between both traits being 0.66 ($P<0.01$). However, a negative phenotypic correlation of −0.76 ($P<0.05$) was observed between the traits FLT and the percentage of fertile spikelets (%FS). It means that the higher the FLT, the lower the %FS (Table 4).

Plants with traditional architecture, that is, tall, long, broad, and decumbent leaves have a lower genetic potential for production than plants with modern architecture. According to Santos et al. (2017), rice planting under flood irrigation, in which the cultivars have modern architecture and high yield potential, presented a positive correlation between tillering and the specific leaf area, shoot biomass, and leaf area index and, therefore, an increase in yield. Plants under this rice production system are less subject to adverse conditions, such as water deficit, compared to the rainfed system.

The genotypes ENA AR1903 and ENA AR1602 showed the highest plant height (HGT), with values of 125.17 and 118.84 cm, respectively (Table 3). This trait is highly influenced by environmental conditions. Lopes et al. (2017) found that nitrogen doses increased the plant height of two irrigated rice cultivars (Irga 424 and Epagri 116), but without resulting in plant lodging. Sangoi et al. (2014) observed that the cultivar Epagri 106 had the smallest height at two evaluation sites (Itajaí and Pouso Redondo, Santa Catarina), which was related to the higher precocity of the cultivar. The genotypes ENA AR2001 and ENA AR1905 presented the highest number of viable tillers (NVT) and were among the genotypes with the lowest HGT, that is, 73.10 and 77.80 cm, respectively. However, no significant phenotypic correlation was observed between both traits (Table 4).

Table 3. Mean values of five traits evaluated in 17 rice genotypes.

Genotypes	HGT	NVT	%FS	HGW	YLD
IAC 201	102.71 b	14.00 b	65.76 b	2.38 e	15.12 b
BRS Esmeralda	85.75 c	7.67 c	33.30 d	2.42 e	8.50 c
IAC 500	72.50 d	14.50 b	7.28 e	2.68 d	7.04 c
IAC 109	83.17 c	16.50 b	84.40 a	2.71 d	21.33 a
ENA AR1901	83.87 c	15.50 b	51.71 c	4.29 a	8.62 c
ENA AR1902	67.61 d	11.12 c	12.60 e	2.45 e	6.12 c
ENA AR2001	73.10 d	27.25 a	69.59 b	2.04 e	27.00 a
ENA AR1903	125.17 a	11.87 c	81.61 a	2.93 d	22.72 a
ENA AR1904	100.49 b	15.87 b	84.12 a	3.32 c	15.85 b
ENA AR2002	85.21 c	12.62 c	53.96 c	2.94 d	10.06 c
ENA AR2003	108.80 b	8.83 c	66.02 b	3.65 b	8.50 c
ENA AR1905	77.80 d	25.37 a	68.65 b	2.64 d	10.10 c
ENA AR1601	106.12 b	19.00 b	66.17 b	2.38 e	16.76 b
ENA AR1602	118.84 a	15.62 b	90.43 a	2.80 d	23.26 a
BRS 901	87.94 c	16.25 b	73.26 a	2.39 e	19.90 a
BRS 902	68.37 d	10.00 c	82.12 a	2.76 d	12.82 c
ENA AR1906	109.90 b	11.17 c	77.04 a	3.16 c	12.17 c
Mean	91.61	14.89	62.83	2.82	14.45
CV (%)	8.96	27.99	13.75	8.64	27.27

HGT: plant height, in cm; NVT: number of viable tillers; %FS: Percentage of fertile spikelets; HGW: hundred-grain weight, in g; YLD: yield, in g plant^{-1}. Means followed by the same letters in the column do not differ from each other according to the Scott-Knott test at a 1% probability.

A negative phenotypic correlation of −0.64 was found between the traits FLT and yield per plant (YLD). However, a positive phenotypic correlation of 0.69 was observed between the percentage of fertile spikelets (%FS) and YLD (Table 4). Alvarez, Crusciol and Nascente (2012) analyzed the growth and yield of upland rice cultivars and found that the highest crop yield was more related to the spikelet fertility and thousand-grain weight than to the leaf area index. However, no significant phenotypic correlation was observed in the present study between HGW and YLD.

The genotypes IAC 109, ENA AR2001, ENA AR1903, ENA AR1602, and BRS 901 showed higher YLD, with values of 21.33, 27.00, 22.72, 23.26, and 19.90 g plant^{-1}, respectively. Three out of these five genotypes are red. Red rice genotypes under rainfed conditions have similar yields to rainfed white rice cultivars, but they present lower yields under irrigated conditions compared to cultivars recommended for this production system (MENEZES et al., 2012). This result does not corroborate what was observed in the present study relative to production per plant, as the white rice cultivar IAC 109 is recommended for flood-irrigated cultivation. Except for the genotype ENA AR2001, the other four genotypes showed higher %FS. The short-grain ENA AR1901 genotype showed the highest (HGW), with a value of 4.29 g but among the lowest values of %FS and YLD (Table 3).

Table 4. Matrix of phenotypic correlations between morphological traits (group I) and yield components (group II) in 17 rice genotypes.

	FLT	FLA	HGT	NVT	%FS	HGW	YLD
FLL	0.47^{ns}	0.11 ^{ns}	-0.12 ^{ns}	-0.44 ^{ns}	-0.76 **	0.36 ^{ns}	-0.64 **
FLT		0.66 **	-0.44 ^{ns}	0.38 ^{ns}	0.21 ^{ns}	0.37 ^{ns}	-0.36 ^{ns}
FLA			0.16 ^{ns}	-0.00 ^{ns}	-0.22 ^{ns}	0.42 ^{ns}	-0.26 ^{ns}
HGT				-0.21 ^{ns}	0.52 *	0.25 ^{ns}	0.36 ^{ns}
NVT					-0.20 ^{ns}	-0.32 ^{ns}	0.47 ^{ns}
%FS						0.11^{ns}	0.69 **
HGW							-0.36 ^{ns}

FLL: flag leaf length, in cm; FLT: flag leaf thickness, in mm; FLA: flag leaf angle; HGT: plant height, in cm; NVT: number of viable tillers; %FS: percentage of fertile spikelets; HGW: hundred-grain weight, in g; YLD: yield, in g plant^{-1}. ^{ns} Not significant, ** and * significant at 1 and 5% probability by the t-test.

The genotypes with the highest YLD showed no flowering period of less than 90 days, that is, with flowering in February when the mean temperature reduced to 25.9 °C when compared to the mean temperature in January of 27.8 °C (Figure 1). Light and temperature affected rice yield mainly through their effects on the total number of grains and their fertility (ZHOU et al., 2006). XU et al. (2020) observed that the Hap2 allele was present in 93.9% of accessions from regions with a mean annual temperature above 29 °C. In contrast, the Hap1 allele was found in 96.1% of accessions from regions with a mean annual temperature below 18 °C. Similar geographic distribution was observed when tracing the distribution of the SLG1-Hap1/Hap2 allele in germplasm from medium-temperature regions. These results suggest that Hap1 and Hap2 from SLG1 may have a potential contribution to rice adaptations at different temperatures.

Multicollinearity occurs when variables are correlated with each other. Multicollinearity at levels considered moderate to severe and variances associated with certain estimators can assume excessively high values, generating inappropriate results (CRUZ; CARNEIRO; REGAZZI, 2014). Condition number (CN) in the present study was 68.91, indicating weak multicollinearity.

The canonical correlation aims to describe and predict the relationship between two sets of variables (NAYAK et al., 2018). A significance of 5% probability was observed for the first three canonical pairs by the X^2 test. According to the coefficients of the first pair, the increase in FLT determined the increase in HGW and YLD determined the reduction in %FS and NVT, with a higher intensity for the %FS reduction. Regarding the second canonical pair, the increase in HGT also determined the increase in HGW, while YLD determined a reduction in %FS and NVT, with a higher intensity for the YLD reduction. TANG et al. (2021) found relatively high correlations between yield with plant height and leaf area index, indicating that these two traits had a higher effect on yield (Table 5).

The third canonical pair showed that genotypes with higher FLA tended to have lower YLD, which is probably related to the capture of light energy. Genotypes with higher FLA tended to have higher HGW because the evaluated red and short-grain rice genotypes presented a more traditional architecture. However, three red rice genotypes were among those with the highest YLD probably due to the high %FS (Table 3). A higher FLA had less effect on NVT (Table 5).

Table 5. Canonical correlations and estimated canonical pairs between morphological traits (group I) and yield components (group II) in 17 rice genotypes.

Characters	Canonical Pairs			
	1st	2nd	3rd	4th
FLL	- 0.12411	0.10257	-0.21356	1.58403
FLT	0.97883	0.35254	0.20388	-0.59716
FLA	0.03101	-0.58143	0.99485	-0.80427
HGT	-0.26086	0.91482	0.35938	-0.21691
NVT	-0.893	-0.94346	0.15067	0.64896
%FS	-1.1048	-0.54922	0.61707	0.86485
HGW	0.44453	0.46985	0.68817	-0.84502
YLD	0.2285	1.33511	-0.59413	-1.0642
R	0.9321*	0.6442*	0.5449*	0.1180^{ns}

FLL: flag leaf length, in cm; FLT: flag leaf thickness, in mm; FLA: flag leaf angle; HGT: plant height, in cm; NVT: number of viable tillers; %FS: percentage of fertile spikelets; HGW: hundred-grain weight, in g; YLD: yield, in g plant^{-1}. ^{ns} Not significant, * significant at 5% probability by the chi-square test.

CONCLUSIONS

A negative phenotypic correlation was observed between production per plant and flag leaf thickness, whereas a positive correlation was found between production per plant and the percentage of fertile spikelets.

The higher flag leaf thickness and plant height determined the production of a lower number of viable tillers and percentage of fertile spikelets and higher hundred-grain weight and production per plant.

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