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Morphophysiological and developmental parameters of maize varieties

Giovani Felipe de Oliveira Neves[a], Bruno Sena de Brito[a], Tallys Vinícius Vicente Januário[a], Eucledes Domingos dos Santos Junior[a], Lucas Aparecido Manzani Lisboa[a,b*]

[a] Educational Foundation of Andradina, Brazil
[a,b] São Paulo State University, Brazil
[*] Autor correspondente (lucas@fea.br)

INFO

Keywords
Zea mays L
plant development
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ABSTRACT

Knowing the characteristics of maize varieties becomes a strategy for an adequate crop planning, in order to extract the maximum agronomic power of each variety. The objective of this work is to know the morphophysiological and developmental parameters of maize varieties. The experiment was conducted in August 2021, in Faculdades Integradas Stella Maris (FISMA), located in the Municipality of Andradina, State of São Paulo. The design was entirely randomized, where six maize varieties were grown: XB 8010; AG 1051; Cateto Paraguay; Sweet Maize (Paraguay Soup); White Maize and Asteca Mole and with four repetitions, totaling 20 plots or pots. The hybrid varieties showed better development characteristics. The criolla variety Asteca Mole presented lower developmental characteristics. Stomatal density and functionality were expressed in an antagonistic way. Maize varieties did not present differences in internal morphology in the leaves. Correlations were found between the morphophysiological and developmental parameters in the maize varieties.

Palavras-chaves
Zea mays L
desenvolvimento vegetal
fisiologia vegetal
morfologia vegetal
melhoramento genético

RESUMO

Parâmetros morfofisiológicos e de desenvolvimento de variedades de milho
Conhecer as características de variedades de milho torna uma estratégia para o um planejamento de adequado de safra, a fim de extrair o máximo do poder agronômica de cada variedade. O objetivo desse trabalho é conhecer os parâmetros morfofisiológicos e de desenvolvimento de variedades de milho. O experimento foi realizado em agosto de 2021, nas Faculdades Integradas Stella Maris (FISMA), localizada no Município de Andradina, Estado de São Paulo. O delineamento foi inteiramente casualizado, onde foram cultivadas seis variedades de milho: XB 8010; AG 1051; Cateto Paraguai; Milho Doce (Sopa Paraguai); Milho Branco e Asteca Mole e com quatro repetições, totalizando 20 parcelas ou vasos. As variedades híbridas apresentam melhores características de desenvolvimento. A variedade crioula Asteca Mole apresentou menores características de desenvolvimento. A densidade e funcionalidade estomática se expressaram de maneira antagônica. As variedades de milho não apresentaram diferenças na morfologia interna nas folhas. Foram encontradas correlações entre os parâmetros morfofisiológicos com os de desenvolvimento nas variedades de milho.

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INTRODUCTION

Maize (*Zea mays* L.) stands out among crops in cereal crops worldwide. It is widely grown in various climatic conditions due to its contribution it plays in the economic balance of the country (Hassan et al., 2018). It is one of the most efficient energy-storing plants existing in nature, because from a seed with a mass of 0.3 g will emerge a plant, usually over 2.0 m tall in a short time of about nine weeks. In the following months, this plant can produce 600 to 1,000 seeds similar to the one from which it originated (Vazquez et al., 2012).

Its stanchion-like roots favor the fixation of the plant stem for a better absorption of mineral salts, and the endosperm of the grain is an important source of carbohydrates and proteins. However, the vegetative and flowering period of maize can vary according to climatic factors and varietal characteristics (Silva et al., 2021). Its stalk is cylindrical, reaching an average of 2 m, with nodes and internodes, and when the vegetative stage ceases, it ends in a male inflorescence (stem). From each node above the ground emerge leaves that are 90 cm long and about 7-9 cm wide, and when the vegetative state ceases, in the axils, the female inflorescence (spike) emerges, marking the reproductive stage. Below ground, from the nodes emerge roots of the fasciculate type, characteristic of grasses (Vazquez et al., 2012, Liu et al., 2021).

Maize has undergone a long domestication process through genetic improvement programs in research centers (Chen et al., 2022), where the understanding of the interactions of environmental variations with the characteristics of plant development has become an important tool in order to achieve maximum productivity of the crop, where some characteristics are expressed with greater intensity, or even have high correlation between them, and thus passing this information through the heritability of their offspring, thus studies show that some anatomical characteristics such as cuticle thickness and vessel diameters have this ability to be expressed in future generations and thus emerging new varieties more adapted (Bongard-Pierce et al., 1996; McCubbina and Braunab, 2021).

With a more in-depth analysis of these anatomical characteristics, researchers can make better decisions when choosing maize genitors. This fact is that native varieties can be an alternative for the search of important characteristics to obtain new hybrids, so that hybridization can express the characteristics chosen in the environment where the plant was inserted, thus requiring our botanical classifications based on the new characteristics expressed (Galarreta and Alvarez, 2001).

The objective of this work is to know the morphophysiological and developmental parameters of native varieties and hybrids of maize.

MATERIAL AND METHODS

Installation and conduct of the experiment

The experiment was carried out in August 2021, at Faculdades Integradas Stella Maris (FISMA), located in the Municipality of Andradina, State of São Paulo. The design was completely randomized, where six maize varieties were cultivated.: XB 8010, AG 1051, Cateto Paraguai, Milho Doce (Sopa Paraguai), Milho Branco e Asteca Mole and with four replications, totaling 20 plots or pots.

The pots had a volumetric capacity of five dm^{-3} and were filled with soil originating from the 0-0.3 m layer classified as Hypoferric Red Latosol (Embrapa, 2013) and present the following chemical attributes as shown in Table 1.

Table 1 - Chemical attributes of the soil at the time of installation of the experiment. Andradina, 2021.

pH	OM	P	K	Ca	Mg	H+Al	Al	SB	CTC	V%	m%
$CaCl_2$	g dm^{-3}	mg dm^{-3}	--------------------- mmol$_c$ dm^{-3} --------------------								
3.9	18	2.0	1.6	5.0	3.0	42	11	9.6	51.6	19	53

OM: Organic matter; SB: Sum of bases; V%: Base saturation; m%: Saturation by aluminum

The soil was fertilized according to the requirements of the maize crop according to Raij et al. (1996). And six viable seeds of the cultivar were planted five centimeters deep. During the experiment, all vessels were irrigated until reaching field capacity and all cultural treatments were carried out.

Development parameters

At 30 days after planting, the following variables were determined: plant height (PH) determined using a ruler graduated in millimeters; stem diameter (SD) determined using a caliper graduated in millimeters; number of leaves (NL) determined by direct counting on the plant. The dry mass of aerial part and dry mass of root (DMAP and MSR) were determined by drying in a circulation oven and air renewal at a constant temperature of 65 °C until reaching constant weight.

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Chlorophyll Parameters

The concentrations of chlorophylls A and B (Chloro A and B) were determined by direct reading with the use of the ClorofiLog® device (Falker), given the values in SPAD index (PARRY et al., 2014) and later converted into absolute values of the pigments as described by Chang and Troughton (1972).

Morphological parameters

A fragment of the middle third of the first fully expanded leaf was collected from the apex of the plant. All the fragments received the relevant procedures for dehydration, diaphanization, inclusion and blocking, and with the aid of a microtome, cross sections of 10.0 µm were carried out in each tissue fragment, where they were stained with safranin. The slides were observed under an optical microscope with a camera attached to perform measurements of histological variables through an image program, calibrated with a microscopic ruler at the same magnification, where the following tissues were measured: leaf phloem diameter (PD); leaf xylem diameter (XD), sheath cell diameter (SCD) and adaxial and abaxial epidermis thickness (ADET and ABET) (Kraus and Arduim, 1997). For all variables, ten measurements were performed per slide, totaling 40 measurements per treatment.

The impression was also performed on the inferior or abaxial epidermal surface of the collected leaf fragments using cyanoacrylate ester, to determine the stomatal functionality of the inferior or abaxial surface (SF) and stomatal density of the inferior or abaxial surface (DEN) (Carlquist, 1975; Castro et al., 2009). For all variables, 10 measurements were performed per slide. The plots were represented by the average value obtained from the measurements of each characteristic.

Statistical analysis

For statistical evaluation, the variables were submitted to normality tests using the Shapiro-Wilk test. Tukey at 5% probability (Banzatto and Kronka, 2013), a Pearson correlation was also performed using the statistical program RStudio (Team, 2019)).

RESULTS AND DISCUSSION

There was no significant difference for plant height among maize varieties. However, a statistical difference was observed for stem diameter among maize varieties, where XB 8010 showed an increase of approximately 33.66% compared to Asteca Mole variety that showed lower average as shown in Figure 1 and Table 2.

Table 2 - Statistical analysis of plant height (PH); stem diameter (SD); number of leaves (NL); dry mass of aerial part (DMAP) and dry mass of root (DMR) of maize varieties. Andradina, 2021.

	PH(cm)	SD(cm)	NL	DMAP(g)	DMR(g)
p value	0.1219ns	0.0001**	0.0424*	0.0071**	0.0053**
OA	55.50	0.80	7.25	1.31	5.77
SD	6.04	0.08	1.06	0.43	2.15
SEM	3.02	0.04	0.53	0.21	1.07
CV (%)	10.89	10.72	14.75	33.20	37.28

** - significant at the 1% probability level ($p<0.01$); * – significant at the 5% probability level ($0.01=<p<0.05$); ns - not significant ($p>=0.05$); OA: overall average; SD: standard deviation; SEM: standard error of the mean; CV: coefficient of variation.

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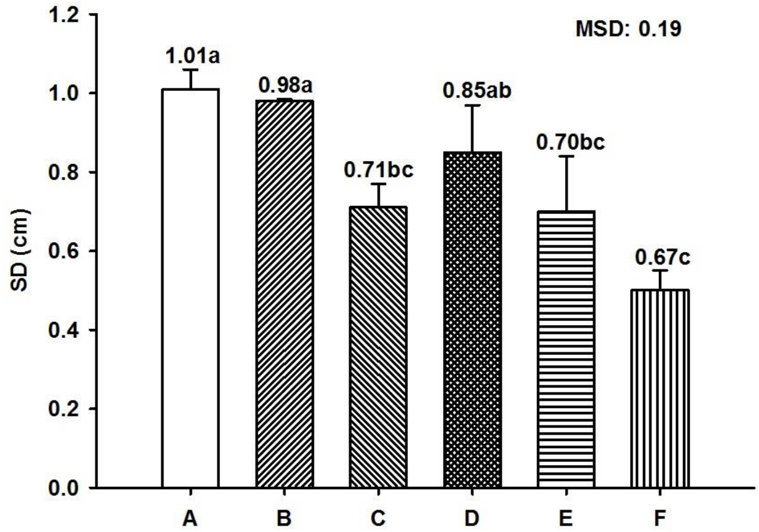

Figure 1 - Mean values of stem diameter (SD) of maize varieties. A – XB 8010; B – AG 1051; C – Cateto Paraguai; D – Milho Doce (Sopa Paraguai); E – Milho Branco and F – Asteca Mole. MSD: minimal significant difference. The means followed by the same letter do not differ statistically from each other. The Tukey Test was applied at the level of 5% probability.

Maize stem diameter is directly related to plant support and energy storage, where reduced diameters compromise plant support and may cause lodging and/or breakage, in addition to reducing its contribution during the grain filling phase (Ebertz et al., 2019), but when some maize variety is intended for forage production, a very thick stalk can negatively affect silage production because of the difficulty in cutting and grinding that machinery can face (Klein et al., 2018). Correlations were observed between plant height with some morphophysiological and developmental parameters after cultivation of the maize varieties as shown in Figure 2 and their linear regressions presented in Table 3.

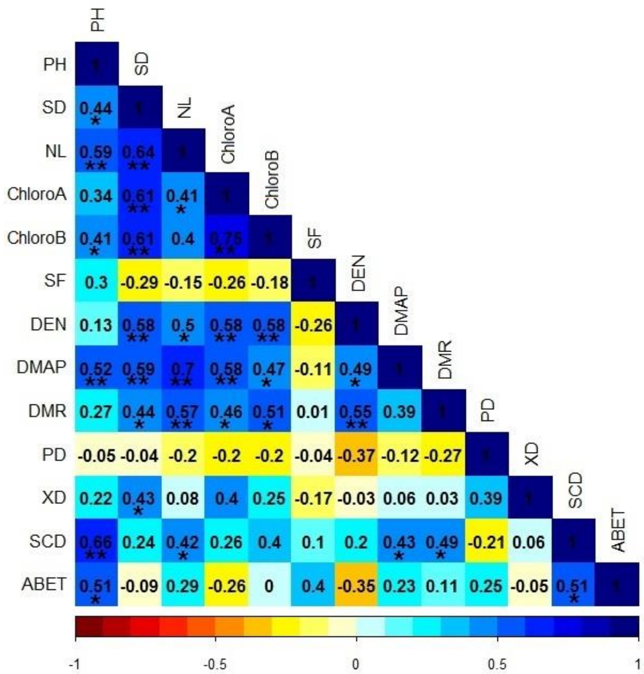

Figure 2 - Pearson's correlation between the variables analyzed in the maize varieties. Andradina, 2022. SP.

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PH - Plant height; SD - Stem diameter; NL - Number of leaves; ChloroA and B – Chloro-phylls; SF - Stomatal functionality; DEN - Stomatal density; DMAP - Dry mass of aerial part; DMR - Dry mass of root; PD - Phloem diameter; XD - Xylem diameter; SCD - Sheath cell diameter and ABET - abaxial epidermis thickness. Andradina, SP, 2020. ** – significant at the 1% probability level (p<0.01); * – significant at the 5% probability level (0.01=<p<0.05).

Table 3 - Matrix of significant linear regressions of Pearson interactions of the variables analyzed in maize varieties. Andradina, 2021.

y=	a+bx	p value	R^2
PH	42.1191539 + 16.5878258SD	0.0337*	0.1962
	33.8395062 + 2.98765432NL	0.0024**	0.3451
	37.9629710 + 0.33293415ChlB	0.0431*	0.1709
	47.7506531 + 5.90955479DMAP	0.0084**	0.2662
	30.7625874 + 1.72948585SCD	0.0005**	0.4403
	42.7522886 + 0.85831133ABET	0.0089**	0.2617
SD	0.18012346 + 0.08641975NL	0.0014**	0.4049
	-0.2242420 + 0.00384488ChlA	0.0019**	0.3760
	0.12017492 + 0.01303280ChlB	0.0025**	0.3672
	0.41762431 + 0.00441989DEN	0.0044**	0.3390
	0.57053997 + 0.18006726DMAP	0.0030**	0.3467
	0.66185939 + 0.02509019DMR	0.0420*	0.1901
	0.28289135 + 0.01496572XD	0.0323*	0.1864
NL	4.80964340 + 0.02772476DEN	0.0128*	0.2460
	4.18321760 + 0.21441033SCD	0.0415*	0.1750
ChlA	203.642963 + 8.89407407NL	0.0443*	0.1686
	131.757092 + 2.58889541ChlB	0.0001**	0. 5698
	205.836489 + 0.70765645DEN	0.0025**	0.3417
ChlB	34.5658011 + 0.20572818DEN	0.0043**	0.3397
DMAP	-0.9397821 + 0.31049753NL	0.0002**	0.4889
	-1.8795176 + 0.01190058ChloroA	0.0043**	0.3369
	-0.4129749 + 0.03273521ChloroB	0.0289*	0.2167
	0.24623666 + 0.01210041DEN	0.0164*	0.2377
	0.86684536 + 0.02749784SCD	0.0106*	0.2466
DMR	-4.0195691 + 1.35048827NL	0.0020**	0.3274
	-7.8055662 + 0.05063697ChloroA	0.0198*	0.2159
	-4.2962451 + 0.19113195ChloroB	0.0145*	0.2615
	-2.6413051 + 0.58816891SCD	0.0162*	0.2365
SCD	9.42994534 + 0.32812824ABET	0.0098**	0.2599

PH - Plant height; SD - Stem diameter; NL - Number of leaves; ChloroA and B – Chlorophylls; SF - Sto-matal functionality; DEN - Stomatal density; DMAP - Dry mass of aerial part; DMR - Dry mass of root; PD - Phloem diameter; XD - Xylem diameter; SCD - Sheath cell diameter and ABET - abaxial epidermis thickness. Andradina, SP, 2020. ** – significant at the 1% probability level (p<0.01); * – significant at the 5% probability level (0.01=<p<0.05).

The maize varieties differed statistically for the number of leaves, where again the variety XB 8010 stood out among them, with 28.57% more leaves compared to the varieties Cateto Paraguay and Asteca mole that had the lowest number of leaves as shown in Figure 3. Plants with more leaves provide greater leaf area, thus ensuring better coverage in the square meter, thus ensuring greater

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soil protection, and can also ensure greater accumulation of dry mass (Afolabi et al., 2020).

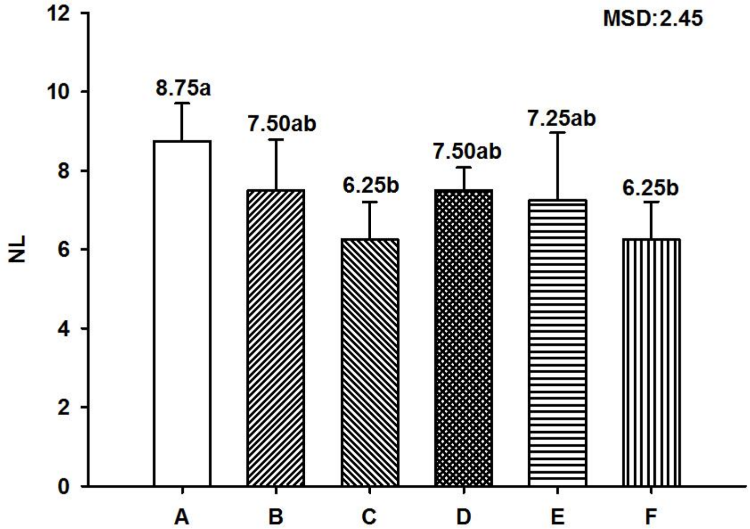

Figure 3 - Mean values of number leaf (NL) of maize varieties. A - XB 8010; B – AG 1051; C - Ca-teto Paraguai; D - Milho Doce (Sopa Paraguai); E - Milho Branco and F - Asteca Mole. MSD: mini-mal significant difference. The means followed by the same letter do not differ statistically from each other. The Tukey Test was applied at the level of 5% probability.

Again the variety XB 8010 showed the highest averages for dry mass of the aerial part ($p<0.001$), implying a superior difference of approximately 59.34% compared to the variety Asteca Mole as observed in Figure 4. Plants that show greater development ensures greater productivity per area, this fact, provides for varieties of agronomic interests for the production of silage, better performance during their cultivation, it is also worth noting that the quality of the final dry matter is intrinsically linked to the accumulation of minerals, protein and energy, which ensures better animal performance (Gaj et al., 2020).

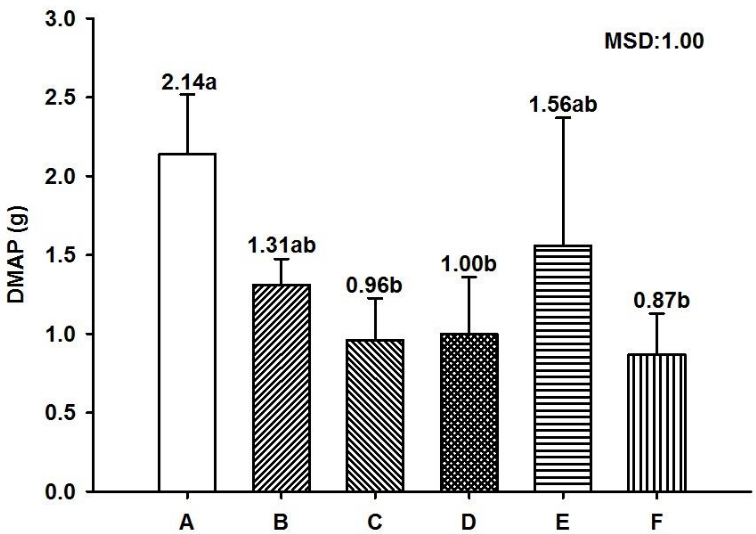

Figure 4 - Mean values of dry mass of aerial part (DMAP) of maize varieties. A - XB 8010; B - AG 1051; C -

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Cateto Paraguai; D - Milho Doce (Sopa Paraguai); E - Milho Branco and F - Asteca Mole. MSD: minimal significant difference. The means followed by the same letter do not differ statistically from each other. The Tukey Test was applied at the level of 5% probability.

A statistical difference was found between maize varieties for root dry mass, where again variety XB 8010 stood out with a difference of approximately 60.37% higher compared to variety Asteca Mole as shown in Figure 5. A high root development provides the plant with a greater exploration in the deeper layers of soil, and thus ensures a greater tolerance to water stress, and consequently guarantees a greater absorption of nutrients, which prevents nutritional disruption leading to an imbalance in the physiology of the plant (Chukwudi et al., 2021). Chlorophyll contents correlate with development parameters as shown in Figure 2, and thus, with increasing concentration, it provides greater development as seen in Table 3.

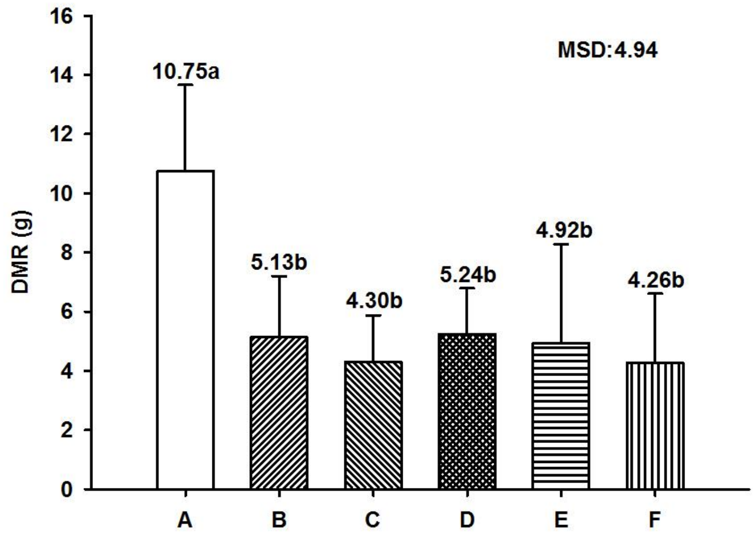

Figure 5 - Mean values of dry mass of root (DMR) of maize varieties. A - XB 8010; B – AG 1051; C - Cateto Paraguai; D - Milho Doce (Sopa Paraguai); E - Milho Branco and F - Asteca Mole. MSD: minimal significant difference. The means followed by the same letter do not differ statistically from each other. The Tukey Test was applied at the level of 5% probability.

A statistical difference was found among maize varieties for the concentrations of chlorophylls in the leaves as shown in Table 4. The highest Chlorophyll A and Chlorophyll B averages were presented by variety XB 8010, with an increase of 23.15% and 27.61% respectively, compared to the varieties that presented the lowest averages, as shown in Figure 6.

Table 4 – Statistical analysis of chlorophylls (Chloro A and B), stomatal functionality (SF) and stomatal density (DEN) of the maize varieties. Andradina, 2021.

	ChloroA(μmol m^{-2})	ChloroB(μmol m^{-2})	SF	DEN(nº/mm)
p value	0.0014**	0.0011**	0.0520**	0.0172**
OA	268.12	52.67	2.86	88.02
SD	19.21	5.43	0.43	19.08
SEM	9.60	2.71	0.21	9.54
CV (%)	7.16	10.30	15.34	21.67

** - significant at the 1% probability level (p<0.01); * – significant at the 5% probabil-ity level (0.01=<p<0.05); ns – not significant (p>=0.05); OA: overall average; SD: standard deviation; SEM: standard error of the mean; CV: coefficient of variation.

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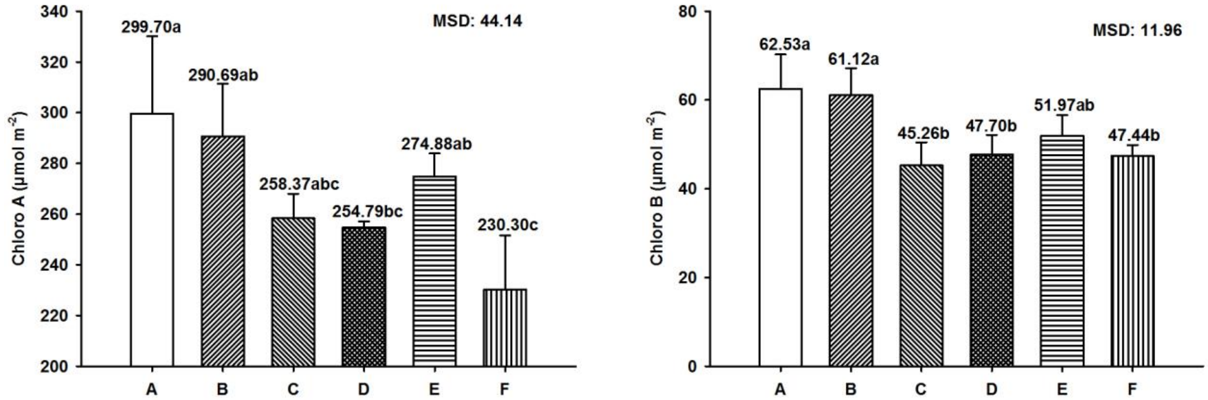

Figure 6 – Mean values of chlorophyll A and B (Chloro A and B) of maize varieties. A – XB 8010; B – AG 1051; C – Cateto Paraguai; D – Milho Doce (Sopa Paraguai); E – Milho Branco and F – Asteca Mole. MSD: minimal significant difference. The means followed by the same let-ter do not differ statistically from each other. The Tukey Test was applied at the level of 5% probability.

These differences in chlorophyll concentrations between the varieties were already expected, because the varieties that underwent a genetic improvement as XB 8010 and AG 1051 showed a more pronounced green coloration when compared to the varieties that did not undergo this improvement (Chiango et al., 2021). It is worth noting that the contents of chlorophyll and other pigments are used to estimate the photosynthetic potential of plants, due to its direct connection with the absorption and transfer of light energy and also the growth and adaptation of plants to different environments (Chang and Troughton, 1972; Ramazan et al., 2021).

The Asteca Mole variety showed the highest average for stomatal functionality, with 37.10% more compared to the Cateto Paraguay variety that showed the lowest average, as shown in Figure 7.

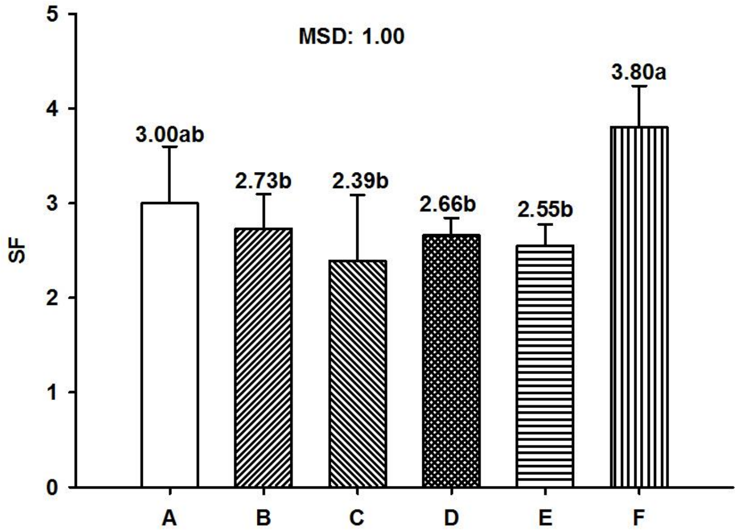

Figure 7 - Mean values of stomatal functionality (SF) of maize varieties. A - XB 8010; B - AG 1051; C - Cateto Paraguai; D - Milho Doce (Sopa Paraguai); E - Milho Branco and F - Asteca Mole. MSD: minimal significant difference. The means fol-lowed by the same letter do not differ statistically from each other. The Tukey Test was applied at the level of 5% probability.

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However, for stomatal density, the variety XB 8010 showed the highest average, this implied a difference of approximately 47.36% compared to the variety Asteca Mole that showed the lowest average as shown in Figure 8.
These evaluated stomatal parameters act in an antagonistic way between them, that is, the higher the stomatal functionality, which implies a larger stomata, the lower the stomatal density, because smaller stomata will have a higher number per square millimeter (Castro et al., 2009). Thus, a doubt is created, in which future studies will have to answer, because some lines of research indicate that the stomatal density ensures greater efficiency in the photosynthetic rate of plants, and also a very large stomatal opening may favor the chemical and biological contamination of plants (Shrestha et al., 2021; Manjunatha et al., 2019; Aono et al., 2021.

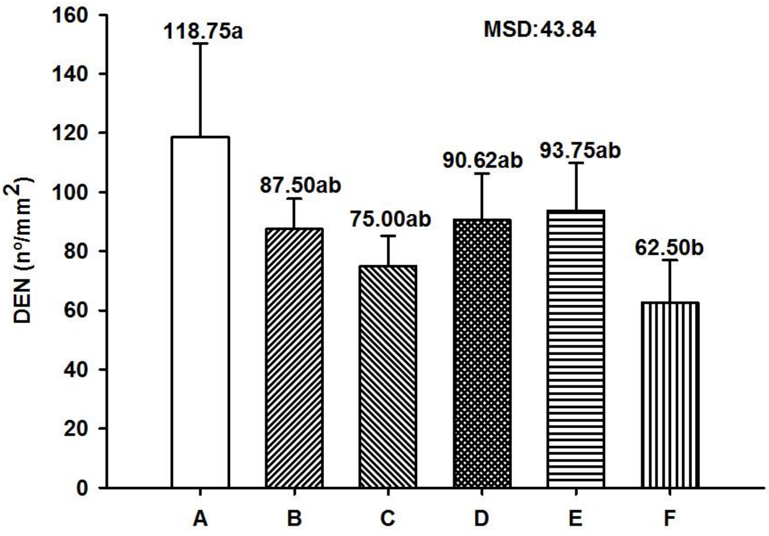

Figure 8 - Mean values of stomatal density (DEN) of maize varieties. A - XB 8010; B – AG 1051; C - Cateto Paraguai; D - Milho Doce (Sopa Paraguai); E - Milho Branco and F - Asteca Mole. MSD: minimal significant difference. The means followed by the same letter do not differ statisti-cally from each other. The Tukey Test was applied at the level of 5% probability.

No statistical differences were observed among the leaf morphological variables of the maize varieties as presented in Table 5. It is worth pointing out the importance of evaluations of the internal tissues of maize, because the major changes can be observed at the cellular level and thus imply in a greater understanding in the heritability of the characteristics among the maize varieties.

Table 5 - Statistical analysis of leaf phloem diameter (PD); leaf xylem diameter (XD), sheath cell diameter (SCD) and abaxial epidermis thickness (ABET) of the maize varieties. Andradina, 2021.

	PD(µm)	XD(µm)	SCD(µm)	ABET(µm)
p value	0.4991ns	0.1839ns	0.0658ns	0.0949ns
OA	8.15	34.99	14.30	14.85
SD	1.15	4.65	2.18	0.0949
SEM	0.57	2.32	1.09	14.85
CV (%)	14.19	13.31	15.30	23.28

** - significant at the 1% probability level (p<0.01); * – significant at the 5% probability level (0.01=<p<0.05); ns – not significant (p>=0.05); OA: overall average; SD: standard deviation; SEM: standard error of the mean; CV: coefficient of variation.

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CONCLUSIONS

The hybrid varieties showed better development characteristics. The criolla variety Asteca Mole presented lower developmental characteristics. tomatal density and functionality were expressed in an antagonistic way. Maize varieties did not present differences in internal morphology in the leaves. Correlations were found between the morphophysiological and developmental parameters in the maize varieties.

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