

Vigor of maize seeds determined by a free image analysis system¹

Vigor de sementes de milho determinado por sistema livre de análise de imagens

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ABSTRACT - New and refined technologies based on computerized procedures create the potential for automating laboratory evaluations, constituting an alternative to reduce costs and increase the decision-making capacity regarding the destination of seed lots. The objective of this study was to evaluate the efficiency of the *Sistema de Análise de Plântulas (SAPL®)* free digital image processing software of seedlings in characterizing the physiological potential of maize seeds in comparison with information provided by vigor tests recommended for this species. Ten lots of maize seeds were submitted to germination, first germination count, germination speed index, seedling emergence, cold test and electrical conductivity. The results of these tests were compared with the data obtained from the image analysis, which evaluated the development of seedlings at three and five days counted from the beginning of the germination test, by obtaining values of seedling length, growth, development uniformity, vigor index and corrected strength index. *SAPL®* is a consistent and promising alternative for evaluating the physiological potential of maize seeds, presenting a high correlation of its variables with the traditional tests used. The evaluation can be performed on the third and fifth day after the germination test is installed.

Key words: SAPL®. Seed technology. Physiological potential. *Zea mays*.

RESUMO - Novas e refinadas tecnologias, baseadas em procedimentos computadorizados, criam potencial para automatização de avaliações laboratoriais, alternativa para a redução de custos e aumento da capacidade de tomada de decisão quanto ao destino de lotes de sementes. O presente trabalho teve como objetivo avaliar a eficiência do software de processamento digital de imagens de plântulas, o SAPL®, na caracterização do potencial fisiológico de sementes de milho, em comparação com informações fornecidas por testes de vigor recomendados para essa espécie. Dez lotes de sementes de milho foram submetidos às avaliações de germinação, primeira contagem de germinação, índice de velocidade de germinação, emergência de plântulas, teste de frio e condutividade elétrica. Os resultados desses testes foram comparados com os dados obtidos com a análise de imagem, que avaliou o desenvolvimento de plântulas aos três e cinco dias, contados a partir do início do teste de germinação, mediante a obtenção de valores de comprimento de plântulas, índice de crescimento, uniformidade de desenvolvimento, índice de vigor e índice de vigor corrigido. O SAPL® é uma alternativa consistente e promissora para avaliação do potencial fisiológico de sementes de milho, tendo apresentado alta correlação de suas variáveis com os testes tradicionais utilizados. A avaliação pode ser realizada no terceiro e quinto dia após a instalação do teste de germinação.

Palavras-chave: SAPL®. Tecnologia de sementes. Potencial fisiológico. *Zea mays*.

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INTRODUCTION

Maize is a highly representative crop in the Brazilian seed market and has an effective demand of approximately 250 thousand tons of seeds per year (ASSOCIAÇÃO BRASILEIRA DE SEMENTES, 2017). For this, it is necessary that the commercial seeds are healthy and present high physiological potential.

The evaluation of the physiological potential aims to identify differences between seed lots in terms of their performance and subsidizes information which contributes to decision-making regarding the destination of seed lots. This evaluation is usually done through the germination test and complemented by vigor tests, mainly because the germination test can overestimate the physiological potential of the seeds when performed under controlled conditions (SILVA; CICERO, 2014).

The vigor test is a more sensitive measure of seed physiological quality and it is understandable that their evaluation requires a more rigorous control of the test variables and interpretation criteria to obtain consistent results (MARCOS FILHO, 2015). However, although the tests are performed by trained analysts, the evaluations are time-consuming and subject to subjective interpretations, which can lead to large errors.

In this sense, image analysis techniques associated to seed vigor tests appears as an important and potential method to be used, offering greater efficiency to the evaluation procedure involved. Recent works carried out using the SVIS[®] (ALVARENGA; MARCOS-FILHO; GOMES JUNIOR, 2012), SAS[®] (PINTO *et al.*, 2015) and Vigor-S[®] (CASTAN; GOMES-JUNIOR; MARCOS-FILHO, 2018) systems demonstrated the efficiency of analyzing seedling images in evaluating the physiological quality of maize seeds and presented themselves as valuable digital image processing tools capable of making inferences about seed vigor in an automated way. However, the acquisition of these systems requires cost, either due to the software or the specific equipment to obtain the images, which restricts their use to only a few research centers and seed analysis laboratories.

To make high-throughput image analysis methods more accessible, free software programs and low-cost equipment can be used to acquire, process and generate image data (MEDEIROS; PEREIRA, 2018). Among the free alternatives available for this purpose is the Seedling Analysis System (*Sistema de Análise de Plântulas - SAPL[®]*). SAPL[®] consists of digital image processing software for evaluating seed vigor based on seedling growth. The software generates measures of seedling length and vigor indexes from images obtained through seedling photographs. The images can be acquired through digital cameras and low-cost smartphones, among other

devices, and can be performed in any place with adequate lighting.

The objective of the present work was to evaluate the efficiency of a digital seedling image processing software program (SAPL[®]) in characterizing the physiological potential of maize seeds in comparison with information provided by vigor tests recommended for this species.

MATERIAL AND METHODS

Ten lots of maize seeds, Potiguar variety, obtained from the Agricultural Research Company of Rio Grande do Norte (EMPARN), were evaluated through traditional tests used to evaluate the quality of seeds and by digital image processing software of seedling images obtained by digital photography.

The germination test, first germination count, germination speed index, seedling emergence, cold test and electrical conductivity were used as traditional tests. In order to compare the results of these traditionally used tests in analyzing seeds with those obtained by the software, root length, coleoptile length and whole seedlings were obtained, as well as growth rates, uniformity, vigor and corrected vigor from digital image processing of seedlings by the SAPL[®] program.

Seed moisture was determined prior to the germination and vigor tests, being carried out by the oven method at 105 ± 3 °C for 24 hours (BRASIL, 2009), with two replicates for each lot. Results were expressed as percentage of moisture per lot.

The germination test was conducted with four replicates of 50 seeds per lot on rolls of germinating paper, moistened with distilled water in the amount of water equivalent to 2.5 times the dry paper mass. The rolls were placed inside plastic bags and kept in a B.O.D. chamber at 25 °C for seven days. The evaluations were carried out according to the Rules for Seed Analysis (BRASIL, 2009), and the results were then expressed as average percentage of normal seedlings for each lot. The first germination count was performed on the fourth day after sowing.

The germination speed index (GSI) was performed together with the germination test, and daily counts of normal seedlings were performed after sowing. The GSI was calculated using the formula proposed by Maguire (1962).

The emergence test was conducted with four replicates of 50 seeds in multi-cell expanded polystyrene trays with one seed per cell being filled with washed sand, irrigated daily with the same volume per cell and kept in a greenhouse. The final emergence evaluation

was performed 14 days after sowing, when the total emergence of the seedlings occurred, expressing the result in percentage.

The soil free test was conducted with four replicates of 50 seeds on rolls of paper moistened with an amount of distilled water equivalent to 2.5 times the weight of the paper. After seeding, the rolls were placed inside plastic bags, sealed with adhesive tape and kept in a humid chamber at 10 °C for seven days. After this period, the rolls were removed from the plastic bags and transferred to a germinator at 25 °C where they remained for four days, when the number of normal seedlings was determined (KRZYANANOWSKI; VIEIRA; FRANÇA-NETO, 1999).

In the electrical conductivity test, four replicates of 50 seeds per lot were weighed in a 0.01 g precision scale and placed in plastic cups containing 75 ml of distilled water in germination chambers at 25 °C for 24 hours. After this period, the electrical conductivity of the solution was determined with a conductivity meter and the mean values were calculated and expressed in $\mu\text{S} \cdot \text{cm}^{-1} \cdot \text{g}^{-1}$ of seed (VIEIRA; KRZYANOWSKI, 1999).

SAPL[®] software was used for computerized analysis. The seeds were initially put to germinate following the methodology proposed by (NAKAGAWA *et al.*, 1999), aiming at forming seedlings. Four replicates of 20 maize seeds per lot were used for each specific evaluation day, distributed on a line drawn in the upper third of the germination paper in the longitudinal direction. The seeds were positioned so that the hilum was directed to the bottom of the paper and the rolls were packed in plastic bags, then placed vertically in the germinator for periods of three and five days at 25 °C. Seedling roots were removed from the seedlings when necessary at the end of each period, leaving only the primary root, and

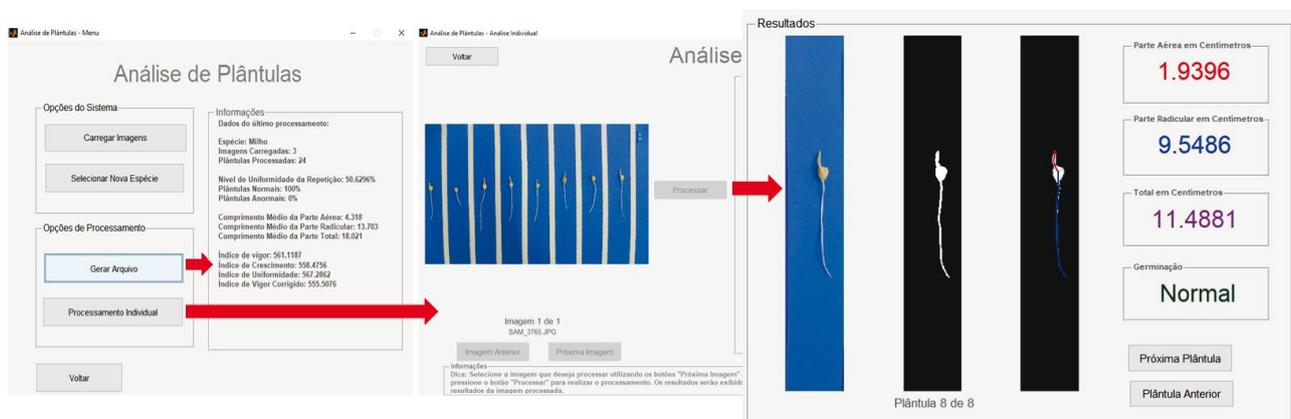
were then transferred from the germinating paper to a blue staining ethylene-vinyl acetate (EVA) sheet (40 x 60 cm) containing nine cells of five centimeters wide, divided by white bands. The upper corner of the first cell on the right was used for the metric (two points equidistant in 1 cm), and the rest of the cells were individually occupied by each seedling.

Image acquisition was carried out by photographs using a Samsung DV300F digital camera maintained at fixed height and field vision (40 cm). The images were obtained in JPEG format, with a resolution of 10 megapixels. The images were then stored and inserted into the default file selected for the maize option of the SAPL[®] software installed on a HP Compaq Pro 6305 SFF Windows 7 Professional computer. Afterwards, the growth value and uniformity contribution to the vigor index calculation (70 and 30%, respectively) was completed. After recording the initial values, the seedling images were loaded by repetition and lot.

Each original seedling image was analyzed by means of its white silhouette with black background (binary image) in the digital image processing by the software. The shoot and radicular demarcation was represented in red and blue, respectively, and then the individual length value of each seedling was obtained (Figure 1). The software also provided measurements of the length of the primary root, shoot or coleoptile, whole seedlings, as well as uniformity, growth, vigor and corrected vigor indexes. These indices were defined by Sako *et al.* (2001), except for the corrected vigor index, being expressed by the following equation: $\text{CVI} = (0.7 \cdot \text{GI} + 0.3 \cdot \text{UI}) \cdot \text{Germination}(\%) / 100$, in which CVI = corrected vigor index; GI = growth index; UI = uniformity index.

The results were automatically saved in a spreadsheet file through the selection of “processing

Figure 1 - Individual processing screen of maize seedlings with three days; detail of seedling number eight with the primary root (blue) and the coleoptile (red)



options> Generate file” (Figure 1), and archived in the folder corresponding to the analyzed repetition.

Statistical analysis was conducted in a completely randomized design with four replicates per treatment. The data were submitted to analysis of variance and the means were compared by the Scott Knott test ($p \leq 0.05$) when a significant effect of the treatments was verified. The data of the variables obtained in the traditional tests and by means of images were also correlated by Pearson’s correlation coefficient (r , $p \leq 0.05$). R software was used for statistical analyzes (R CORE TEAM, 2017).

RESULTS AND DISCUSSION

Physiological potential by traditional analysis

It was possible to observe performance differences between the lots in all the tests used in the physiological characterization of the lots by the traditional tests. The moisture degree results varied between lots of 8.5 to 11.5% (Table 1). According to Marcos-Filho (2016), low variation in moisture between the lots is necessary in order to compare them simultaneously with respect to their physiological quality, without this difference in moisture compromising the quality of the analyzes and an establishment of comparisons.

The germination test found that six of the ten lots (lots 1, 3, 4, 5, 8 and 9) presented values greater than or

equal to 85% of germination, being the minimum value established for the commercialization of maize seeds in Brazil (BRASIL, 2013). Among the lots of marketable seeds, the test enabled identifying quality differences at two levels, where the seeds of lots 1, 3, 8 and 9 presented higher germination percentages ($\geq 99\%$), while lots 4 and 5 presented lower germination of 90 and 92%, respectively. The other lots had germination outside commercialized standards (Table 1).

From the vigor tests classified as physiological, the first germination test showed similar behavior to that observed in the germination test, while the germination speed index showed some variations of the lot position in relation to the previous test. In general, lot 3 was more vigorous than the other lots in these tests (Table 1). The germination and the time required for it to occur are an expression of the speed with which the metabolic systems and the functionality of the embryonic developmental structures resume their functioning satisfactorily (PESSARAKLI, 2014); thus, high values of the percentage of germinated seedlings per unit of time expresses a high physiological quality of the seeds.

Better performance by lots 1, 8 and 9 was observed in the seedling emergence test with an emerged seedling percentage equal to or greater than 92%. The test enabled categorizing five levels of vigor, as well as the germination.

The results obtained from the evaluation of the cold test showed better separation of the lots at different

Table 1 - Average results obtained in the evaluation of the physiological potential of maize seeds by traditional tests

Lots	DM	G	FGC	E	CT	GSI	EC
			%			Index	($\mu\text{S}\cdot\text{cm}^{-1}\cdot\text{g}^{-1}$)
1	8.5	99 a	98 a	99 a	94 b	27.15 b	6.58 d
2	10.5	75 d	72 d	64 c	70 d	21.37 d	7.87 d
3	8.5	99 a	99 a	49 d	93 b	31.54 a	11.26 c
4	9.2	92 b	91 b	83 b	80 c	22.17 d	7.37 d
5	8.5	90 b	89 b	69 c	85 c	21.96 d	7.47 d
6	10.6	84 c	83 c	45 d	58 e	24.94 c	14.07 b
7	11.5	27 e	19 e	6 e	22 g	5.17 e	25.89 a
8	11.2	99 a	99 a	97 a	100 a	29.25 b	7.15 d
9	11.4	99 a	99 a	92 a	100 a	27.50 b	7.36 d
10	11.3	30 e	21 e	10 e	38 f	5.61 e	15.02 b
F	-	152*	247*	136*	156*	140*	336*
CV (%)	-	5.66	5.16	9.39	5.89	7.16	6.00

*Significant by the F-test ($p < 0.05$). Means followed by the same letter in the column did not differ by Scott Knott’s test ($p < 0.05$). CV. = coefficient of variation; DM: degree of moisture; G: germination; FGC: first germination count; E: emergence; CT: cold test; GSI: germination speed index; EC: electrical conductivity

levels of vigor, with the test being considered more sensitive than the others used. It was verified that a ranking occurred for seven levels of vigor for the tested lots, in which lots 8 and 9 stood out with better performance. Maize is a summer crop and therefore presents high sensitivity at low temperatures, and germination can consequently be affected by this factor. Thus, seeds with higher physiological quality present greater capacity to overcome the imposed stress (GRZYBOWSKI; VIEIRA; PANOBIANCO, 2015).

It was possible to categorize the lots into a few levels of vigor when compared to the other tests used by the electrical conductivity test in the initial characterization (Table 1). According to Steiner *et al.* (2011), the electrical conductivity test presents limitations in identifying lots with intermediate level of vigor, and these lots can express similar behavior those of high vigor or low vigor. However, electrical conductivity offers advantages among other tests routinely used such as the fact that it is a rapid test and it can detect the first symptom of seed deterioration, i.e. a loss in the structural integrity of the seed cell membranes (NOGUEIRA *et al.*, 2013).

Physiological potential via computerized system

Analyzing the seedling images enabled identifying differences in physiological potential between lots by means of some evaluated parameters, considerably reducing the time spent for evaluations. In the first evaluation (carried out on the third day after the start of the germination test),

it was noticed that lots 8 and 9 stood out with higher performance in the average primary root length and total seedling length tests, while lower performances were found in lots 7 and 10 (Table 2), corroborating the results obtained in the initial characterization from the traditional vigor tests (Table 1).

Some variations were detected in the performance of lots which stood out in the initial physiological characterization, such as for lot 3 in which the seedling length tests and the indexes which evaluate performance from using the software obtained lower performance when compared to the germination test, first germination count, germination speed index and cold test. According to Nakagawa *et al.* (1999), the lot had a high germination percentage, but a low average seedling length value, which is possibly related to other intrinsic characteristics of the genetics and physiological quality of the seeds. The lot behavior may vary between the physiological evaluation tests on seeds, since they measure different characteristics (PINTO *et al.*, 2015) which evolve at different rates.

It was possible to identify that only lots 9, 8 and 6 presented longer coleoptile lengths than the other lots, only forming two groups. Thus, this variable was less sensitive in identifying differences in the vigor of the evaluated lots. Thus, it was observed that the length of the primary root was more efficient in discriminating vigor than the coleoptile length in the evaluation performed on the third day.

Table 2 - Parameters generated by *SAPL*® on the third day of evaluation for maize seeds

Lots	Three-day-old seedlings						
	Coleoptile mm	Root mm	Full seedling Mm	Growth	Uniformity	Vigor	Corrected Vigor
				-----Index-----			
1	1.29 b	7.60 b	8.89 b	256 b	829 c	428 c	423 b
2	1.46 b	6.04 c	7.5 c	210 c	884 b	412 c	310 e
3	1.16 b	5.73 c	6.88 c	195 c	827 c	385 d	381 c
4	1.43 b	4.74 d	6.18 d	169 c	896 b	387 d	356 d
5	1.34 b	4.16 e	5.5 d	150 d	907 b	377 d	339 d
6	2.75 a	6.99 b	9.74 b	259 b	909 b	454 b	380 c
7	1.59 b	1.66 f	3.25 e	76 e	970 a	344 e	94 f
8	2.92 a	12.43 a	15.35 a	430 a	941 a	584 a	581 a
9	2.86 a	11.70 a	14.55 a	407 a	935 a	565 a	560 a
10	1.29 b	2.28 f	3.57 e	91 e	930 a	343 e	105 f
F	41.26*	92.57*	87.50*	90.71*	7.41*	61.13*	187.72*
CV (%)	12.47	11.68	10.86	11.14	3.77	5.06	6.64

*Significant by the F-test ($p < 0.05$). Means followed by the same letter in the column did not differ by Scott Knott's test ($p < 0.05$). CV. = coefficient of variation

Dias *et al.* (2015) found that root length measurement by image analysis provides reliable data compared to conventional analysis tests. Total length as a discrimination parameter was similar to the grouping performed through root length.

For the indices obtained from the software on the third day of evaluation, the growth index was more representative to qualify the lots in relation to the uniformity index. The growth index was similar to the classification by the traditional analyzes, also showing lots 8 and 9 as having the greatest vigor. Seedling growth slows as the seed decays. Thus, the deterioration puts the lots at different levels of vigor, and the small growth rate of deteriorated maize seeds is related to the decrease in the expansion and cellular division of the growth areas (SVEINSDOTTIR, 2009).

However, the uniformity index provided by the *SAPL*[®] alone was not effective in discriminating the vigor of the maize seed lots nor in reproducing the classification order of the traditional tests used in the characterization of the lots. Despite having different lengths, the lots maintained a uniform growth rate within the same lot, which may have led to a low discriminatory performance by the uniformity index (MEDEIROS; PEREIRA, 2018). Pinto *et al.* (2015) observed that the uniformity index calculated by the *SAS*[®] software did not obtain satisfactory results for the classification of the physiological quality of maize seeds. Similar results were also found by Medeiros and Pereira (2018) using the *SAPL*[®] program for soybean seeds.

On the other hand, the vigor index presented marginal discriminatory capacity of the lots when also carried out with seedlings of three days, but with a superior performance to the uniformity index. Caldeira *et al.* (2014) also did not find significant differences in the vigor and uniformity indexes calculated by the *SVIS*[®] software in evaluating the quality of sunflower seeds, demonstrating the necessity for better adaptation of this variable provided by the software for the studied species in that condition.

Greater sensitivity to categorizing the lots in terms of vigor was observed for the corrected vigor index. Corrected vigor is an index which integrates the growth and uniformity ratios of seedling development to lot germination, so that there is a more cohesive fit between viability and vigor. According to Nakagawa *et al.* (1999), this link between germination and seedling length enables a more coherent assessment of the lot's physiological quality.

In the second evaluation (Table 3) performed on the fifth day of germination, it was verified that the root and coleoptile lengths and total lengths of the seedlings were able to differentiate the lots. However, coleoptile length was the least efficient parameter in this differentiation. The variables of root and whole seedling length enabled classifying 5 groups with notoriety for lot 9, considered of better performance, followed by lots 8 and 1, then decreasing until the lots which presented worse performance, being lot 7 and 10. The seeds in lots 7 and 10 possibly presented advanced physiological deterioration

Table 3 - Parameters generated by the *SAPL*[®] program on the fifth day of evaluation for maize seeds

Lots	Five-day-old seedlings						
	Coleoptile mm	Root mm	Full seedling mm	Growth	Uniformity	Vigor	Corrected Vigor
-----Index-----							
1	7.68 a	18.74 a	26.41 a	700 a	909	763 b	755 b
2	6.98 b	13.35 b	20.33 b	522 b	927	644 c	484 d
3	6.53 b	9.29 c	15.83 c	389 c	916	547 d	542 d
4	8.13 a	13.29 b	21.42 b	538 b	935	657 c	604 c
5	8.08 a	15.2 b	23.27 b	596 b	931	697 c	628 c
6	8.18 a	11.79 b	19.96 b	492 b	931	624 c	524 d
7	4.79 e	4.12 d	8.91 d	202 d	870	402 e	110 e
8	8.55 a	20.11 a	28.66 a	756 a	904	800 b	797 b
9	9.02 a	21.88 a	30.89 a	818 a	958	860 a	851 a
10	4.69 e	3.54 d	8.23 d	182 d	948	412 e	126 e
F	11.85*	34.08*	39.34*	38.0*	0.53 ^{ns}	43.11*	103.42*
CV (%)	12.07	16.29	11.94	13.43	7.33	7.26	9.21

*Significant by the F-test ($p < 0.05$). Means followed by the same letter in the column did not differ by Scott Knott's test ($p < 0.05$). CV. = coefficient of variation

with high EC values and low GSI values being observed (Table 1); moreover, as also reported by Rocha, Silva and Cícero (2015), in which low performance seeds were related to delays in the cell membrane system restructuring, this caused an impact on metabolic rates with reductions in mitochondrial efficiency, energy release and slower germination and seedling growth.

A very similar differentiation for the growth index obtained from *SAPL*[®] was observed to that obtained in the total seedling length parameter, as there were no significant differences in categorization between the lots for the uniformity index. In an evaluation of seeds by image analysis, Marcos Filho, Kikuti and Lima (2009) found that it is necessary to use more sensitive parameters for lots with high vigor to detect differences in lot quality, since uniformity is a desired characteristic, but did not present discriminatory capacity.

The results obtained for the vigor and corrected vigor indexes in five-day-old maize seedlings were more accurate and consistent for classifying vigor when compared to the results of the traditional vigor tests used, with it being possible to show lots with better and worse performance. In the present study, it was observed that

the seedlings presented higher growth rates and higher mobilization rates of the reserve components for resuming growth of the embryonic axis and their structures (DAN *et al.*, 1987). On the contrary, the low vigor can be related to the delay in the metabolic processes, which are reflected in the lower growth of seedlings and their components (SCHUCH *et al.*, 1999).

It was possible to observe significant correlations from the Pearson correlation analysis (Table 4) between the variables generated by the traditional tests and by the seedling analysis system in the two days in which the seedling images processed by the software were obtained. The evaluations performed on the third day only indicate the coleoptile length and uniformity variables as those which did not present significant correlation with any of the traditional tests. When evaluating wheat seedlings by manual methods and by computerized analysis using the Matlab[®] mathematical tool, Brunet *et al.* (2016) also did not observe a significant correlation between the seedling shoot and the other routine tests applied.

On the fifth day after the start of the germination test, there were significant and high correlations for most of the variables except the uniformity index, which did

Table 4 - Pearson's correlation (r) between the variables generated from the traditional seed analysis and the digital image processing with *SAPL*[®] from seedlings of ten lots of maize seeds

SAPL [®]	Traditional Tests					
	G (%)	FGC (%)	GSI	E (%)	EC ($\mu\text{S}\cdot\text{cm}^{-1}\cdot\text{g}^{-1}$)	CT (%)
Third day of evaluation						
CL (mm)	0.29 ^{ns}	0.30 ^{ns}	0.34 ^{ns}	0.33 ^{ns}	-0.11 ^{ns}	0.24 ^{ns}
RL (mm)	0.72*	0.72*	0.75*	0.78**	-0.61 ^{ns}	0.76*
TL (mm)	0.67*	0.67*	0.71*	0.73*	-0.54 ^{ns}	0.70*
GI	0.70*	0.70*	0.73*	0.75*	-0.57 ^{ns}	0.73*
UI	-0.54 ^{ns}	-0.54 ^{ns}	-0.57 ^{ns}	-0.35 ^{ns}	0.49 ^{ns}	-0.49 ^{ns}
VI	0.60 ^{ns}	0.60 ^{ns}	0.62 ^{ns}	0.69*	-0.49 ^{ns}	0.64*
CVI	0.91**	0.91**	0.90**	0.89**	-0.75*	0.91**
Fifth day of evaluation						
CL (mm)	0.88**	0.89**	0.81**	0.88**	-0.76*	0.81**
RL (mm)	0.83**	0.83**	0.77**	0.95**	-0.79**	0.86**
TL (mm)	0.85**	0.85**	0.79**	0.95**	-0.80**	0.87**
GI	0.85**	0.84**	0.78**	0.95**	-0.80**	0.87**
UI	0.27 ^{ns}	0.27 ^{ns}	0.21 ^{ns}	0.25 ^{ns}	-0.55 ^{ns}	0.31 ^{ns}
VI	0.85**	0.84**	0.78**	0.95**	-0.81**	0.87**
CVI	0.94**	0.94**	0.89*	0.96**	-0.83**	0.95**

^{ns} not significant, **, * significant at 1 and 5% probability. Germination = G; first germination count = FGC; emergency = E; cold test = CT; germination speed index = GSI; electrical conductivity = EC; coleoptile length = CL; primary root length = RL; total length of seedlings = TL; growth index = GI; uniformity index = UI; vigor index = VI; corrected vigor index = CVI

not show a significant correlation with the traditional tests (Table 4). Although the high correlation indicates a linear relationship between two random characteristics, its interpretation must integrate variables directly related to the biological phenomenon (LEAL *et al.*, 2012), and to establish coherence and complementation of the parameters to be obtained in the computerized analysis of seedlings. According to Albuquerque *et al.* (2008), reducing the number of characteristics evaluated in future experiments may be decided with a linear correlation analysis, as great dependence between the variables is observed.

The results obtained in this work demonstrated a high coherence between the results obtained in the analysis by the traditional tests and the parameters generated by the *SAPL*[®] computerized system, which enables including this methodology to evaluate the quality of maize seeds. The use of *SAPL*[®] still has many advantages, such as greater speed in obtaining the results, greater reliability, precision, less subjectivity and reduced costs in the analyzes, as well as still archiving images for later analyzes.

CONCLUSION

The computerized analysis of seedling images enables efficient classification of lots and evaluating the physiological quality of the seeds in an equivalent and consistent way with the results of the analyses performed by the traditional seed tests to determine the physiological potential. The evaluation can be performed on the third and fifth day after the germination test.

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