The impact of transmission on maize seed deposition in pneumatic dispensers

O impacto da transmissão na deposição de sementes de milho em dosadores pneumáticos

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Received May 31, 2023 and approved in October 5, 2023

ABSTRACT

The proper distribution of maize seeds in pneumatic dispensers is essential for high-quality sowing operations. To enhance seed distribution accuracy, advanced pneumatic mechanisms utilizing new electrically driven dosing devices have been developed, as mechanical mechanisms often lead to distribution errors. Consequently, it becomes imperative to assess the impact of these mechanisms, particularly concerning operational speed. This study aims to evaluate the transmission performance of pneumatic dispensers when depositing maize seeds at varying operating speeds. The experiment was conducted on a static simulation bench, employing a completely randomized design and assessing two seed distribution mechanisms at speeds of 5.0, 7.0, 9.0, 11.0, and 13.0 km h^{-1}. Parameters analyzed included acceptable spacing, double failure, coefficient of variation, and precision index, gathered from five repetitions of 250 consecutive seed depositions. The results suggest that the independent electrically driven dosing mechanism outperforms the pneumatic dosing mechanism with mechanical transmission in terms of acceptable spacing (1.27), missing spacing (0.85), and accuracy index (1.31). However, it is crucial to note that an increase in operating speed negatively impacts seed quality for both dispenser drive mechanisms.

Index terms: Acceptable spacing; missing spacing; precision index; electric dosing mechanism.

RESUMO

A distribuição adequada das sementes de milho em dispensadores pneumáticos é essencial para uma semeadura de alta qualidade. Para melhorar a precisão da distribuição de sementes, foram desenvolvidos mecanismos pneumáticos avançados que utilizam novos dispositivos de dosagem acionados eletricamente, uma vez que os mecanismos mecânicos muitas vezes levam a erros de distribuição. Consequentemente, torna-se imperativo avaliar o impacto destes mecanismos, particularmente no que diz respeito à velocidade operacional. Este estudo tem como objetivo avaliar o desempenho da transmissão de dispensadores pneumáticos na deposição de sementes de milho em diversas velocidades de operação. O experimento foi conduzido em bancada de simulação estática, empregando delineamento inteiramente casualizado e avaliando dois mecanismos de distribuição de sementes nas velocidades de 5,0, 7,0, 9,0, 11,0 e 13,0 km h^{-1}. Os parâmetros analisados incluíram espaçamento aceitável, falha dupla, coeficiente de variação e índice de precisão, obtidos a partir de cinco repetições de 250 deposições consecutivas de sementes. Os resultados sugerem que o mecanismo de dosagem independente acionado eletricamente supera o mecanismo de dosagem pneumático com transmissão mecânica em termos de espaçamento aceitável (1,27), espaçamento ausente (0,85) e índice de precisão (1,31). No entanto, é crucial observar que um aumento na velocidade operacional impacta negativamente a qualidade da semente para ambos os mecanismos de acionamento do dispensador.

Termos para indexação: Espaçamento aceitável; falta de espaçamento; índice de precisão; mecanismo de dosagem elétrico.

INTRODUCTION

Precision agriculture is based on improving the interaction between soil and machine operations, with the goal of increasing profitability, reducing waste, and preserving the environment's quality (Berger et al., 2023).

Among the critical factors for success in crop cultivation, the sowing operation plays a pivotal role. Precision seeders aim to distribute individual seeds evenly at consistent intervals without depth variations within sowing lines, ensuring input savings and high crop yields (Ismail; Ismail; Elsisi, 2022). It is essential to employ

seeds of reliable origin and efficient dosing mechanisms (Moreno et al., 2023).

Currently, pneumatic dispensers have a significant presence in the Brazilian market (Savi et al., 2023), offering a wide range of technologies and specialized companies. These dosing mechanisms excel in capturing and ejecting seeds uniformly, minimizing mechanical damage to the seeds. Nevertheless, despite improvements in deposition devices, mechanical transmission systems continue to dominate (Sun et al., 2022).

In the mechanical transmission system, dispensers are driven through the seeder's solidary shaft. This setup leads to interactions between wheelsets and soil, including slippage, resulting in variations that cause uneven seed distribution. Additionally, components like chains and gears can generate errors that hinder the operation (Wang et al., 2021; Tony Thomas et al., 2022).

To address these issues, electrical transmission systems are increasingly employed. These systems activate mechanisms via electric motors, establishing synchronization between the dosing system and the mechanized unit (Wang et al., 2022). Consequently, dispensers equipped with electronic controllers are used to mitigate the impact of factors inherent to traditional mechanical transmission systems, such as wheel slippage and friction, which negatively affect sowing quality (Khadatkar et al., 2021).

Hence, beyond the construction parameters of dosing mechanisms, other factors, such as transmission type and operational speed, influence seed distribution in the soil (Hensh et al., 2021). This underscores the importance of studies focused on understanding these parameters.

The objective of this study is to evaluate the transmission performance of pneumatic dispensers when depositing maize seeds at various operating speeds.

MATERIAL AND METHODS

The experiment was conducted in June 2022 in the Tractor Adequation Laboratory (LATA) at the Federal University of Paraná (UFPR), Curitiba, Paraná, Brazil, using a static seeding bench (Figure 1) as described by Savi et al. (2023). This bench simulated the longitudinal distribution of seeds in the sowing furrow for subsequent evaluation.

The experiment evaluated two pneumatic dosing mechanisms: the Selenium Electric model (J. Assy™), driven by its own 24-volt electric motor with a 62:1 transmission ratio, and the Selenium model (J. Assy™), which was attached to the drive shaft of a 0.25 kW power reducer motor with a 25:1 transmission ratio from Sew

Eurodrive Inc.™. The latter was managed through a frequency inverter (CFW300, Weg Inc.™) integrated into the experimental bench.

Each mechanism utilized the Apollo disk with 28 holes (4.5 mm in diameter), along with its corresponding singulator. During operation, a vacuum of 4.98 kPa was generated using a radial compressor model CR-3 88 IBRAM (Indústria Brasileira de Máquinas™). This compressor had a maximum air flow capacity of 0.022 m^3 s^{-1} and a vacuum strength of 12.75 kPa.
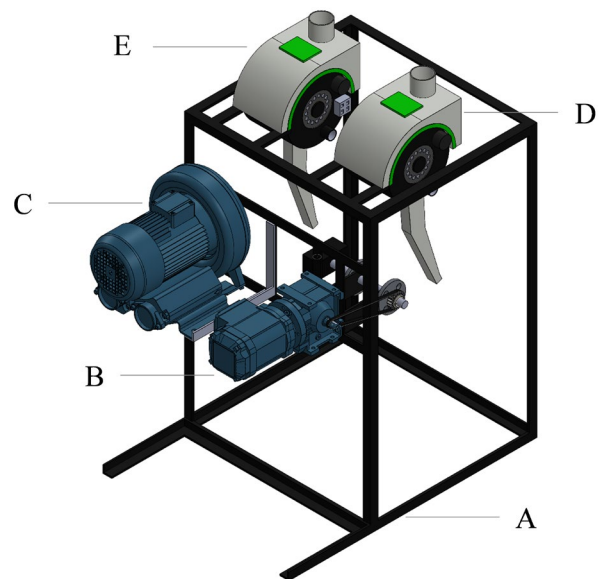

Figure 1: Isometric projection of the workbench: metal structure (A), gearmotor and shaft-pulley transmission set (B), radial electric vacuum compressor (C), conventional pneumatic dosing mechanism (D), and pneumatic dosing mechanism with an electric motor (E).

An optical position sensor model PM 400 (Dickey John™), positioned in the middle section of the conductive tube, performed individual readings of the deposited seeds. The sensor featured three LED lamps as a light source and a photoelectric sensor atop a photovoltaic cell. The sensor signal was converted into rectangular pulses based on its reflection angle and signal strength was adjusted according to its depth level.

The bench incorporated a data acquisition system (DAS), equipped with a printed circuit board designed in Proteus 8.1 software (Labcenter Electronics™) and created using the LPKF Protomat 93s™ milling machine. This DAS was connected to an ATmega328 microcontroller (Atmel™) with a 16 MHz clock speed and a 10-bit

analog-to-digital converter. Data acquisition occurred when seeds passed through the optical sensor connected to the DAS, and the acquired data were transferred and stored electronically.

The experiment employed a completely randomized design, assessing two metering mechanisms (Selenium model and Selenium Electric model) at different operational speeds (5.0, 7.0, 9.0, 11.0, and 13.0 km h^{-1}). For each treatment, five repetitions were conducted, with each repetition involving 250 consecutive spacings, totaling 12,500 experimental units. Data collection continued until 2,000 seeds had been deposited, and each repetition was extracted from the median for subsequent statistical analysis.

The maize seeds used were of the Anhembi variety, suitable for sowing, with a minimum purity and germination rate of 98% and 85%, respectively. They were distributed with a sowing density of 90,036.01 seeds ha^{-1}, maintaining a spacing of 0.25 m between plants and 0.45 m between rows, considering the characteristics of the seeds.

The methodology for dimensional measurements followed the approach proposed by Soyoye, Ademosun and Agbetoye (2018). A total of 100 sample units were assessed using a digital caliper with a precision of 0.0001 m to ensure accurate measurements of the sample units' dimensions.

To determine the weight of one thousand grains, a semi-analytical scale was used. The average weight of a triple sample comprising 300 maize seeds was measured using this scale, providing an accurate estimate of the weight of one thousand grains.

The angle of repose of the seeds was determined following the method described by Al-Hashemi et al. (2018). This involved adding graphite at a dosage of 4.0 g kg^{-1} to the seeds. The angle of repose was calculated by taking the inverse tangent of the height of the seed pile in relation to the distance it was deposited on a flat surface.

The physical characteristics of the maize seeds were as follows: length of 11.62 mm, width of 7.49 mm, thickness of 4.43 mm, sphericity of 62.80 mm, weight of one thousand grains of 305.10 g, and an angle of repose of 28.29°.

By adhering to these established methodologies, the researchers obtained reliable and standardized measurements for the dimensional characteristics, weight, and angle of repose of the maize seeds in the study. The following parameters were used to assess homogeneity: percentage acceptable spacing (As), double deposition (D$_D$), and missing spacing (M$_S$); coefficient of variation (C$_V$), precision index (P$_I$), and singulation (I$_S$). Seeder performance indicators are presented in Table 1 (ISO 7256/1, 1984).

Table 1: Limit values for classifying the performance of precision seeders.

Spacing (%)			Classification
A$_S$	D$_D$	M$_S$	
>98.6	<0.7	<0.7	Excelent
>90.4 a 98.6	≥0.7 a <4.8	≥0.7 a <4.8	Good
≥82.3 a ≤90.4	≥4.8 a ≤7.7	≥4.8 a ≤10.0	Regular
<82.3	>7.7	>10.0	Unsatisfactory

Acceptable spacing (As), double deposition (D$_D$) and missing spacing (M$_S$).

According to Cay et al. (2018), the P$_I$ quantifies the variability of distribution relative to the theoretical spacing (Equation 1), disregarding D$_D$ and M$_S$. Higher P$_I$ values indicate greater non-uniformity with respect to the target spacing. P$_I$ values should not exceed the suggested 29% limit for precision seeders (Nejadi; Raoufat, 2013).

$$P_I = \left(\frac{\sigma}{X_{ideal}} \right) x100 \qquad (1)$$

P$_I$ – Precision index, %;
σ – standard deviation of acceptable spacing, m; It is,
Xideal – ideal spacing, m.

The collected data underwent normality testing utilizing the Shapiro-Wilk test, and homogeneity of variance was assessed using the Brown-Forsythe test. Following the confirmation of these assumptions, the data were subjected to an analysis of variance (ANOVA). In instances where differences were observed, the means were compared using Tukey's test, with a significance level set at p ≤ 0.05 for qualitative factors associated with the dosing mechanism. For quantitative factors such as distribution velocity and their interactions, regression analyses were conducted. The models with the highest R^2 values and significant parameters (p ≤ 0.05) were selected using the SigmaPlot 12 software developed by Systat Software™. This rigorous methodology ensured the appropriate statistical analysis and the selection of the most suitable models for the provided dataset.

RESULTS AND DISCUSSION

Table 2 provides a summary of the results of the analysis of variance and the Tukey test applied to the data obtained, revealing that there was no need to transform the means for all the variables studied. This indicates

normality (Shapiro-Wilk) and homogeneity (Brown-Forsythe) in the data. Additionally, all coefficients of variation were categorized as stable according to Ferreira's (2018) classification.

The evaluation results reveal that the electric dispenser exhibits a 1.27-fold advantage over the conventional dispenser in achieving acceptable spacing. Furthermore, the electric dispenser reduces the occurrence of missing spacings by 0.85 in comparison to its conventional counterpart. These findings underscore the superior performance of the electric dispenser in maintaining precise and consistent spacing between objects or components. By minimizing errors and ensuring accurate dispensing, the electric dispenser contributes to enhanced quality control and efficiency across various applications.

Regarding the Precision Index, there was a decrease of 1.31 in the values for the mechanism equipped with a dedicated motor, indicating a higher level of operational quality in this system. However, no significant differences were found in the parameters of double deposition and coefficient of variation between the two types of dispensers evaluated.

Both dosing mechanisms were classified as Good, following the classification proposed by ISO 7256/1 (1984). The electric dispenser displayed superiority in terms of acceptable and flawed spacing and accuracy index. This superiority is attributed to the operational principle of the electric dispenser, which is driven by a dedicated motor, promoting uniformity in energy transmission (Wang et al., 2022).

In the evaluations of double deposition and coefficient of variation, no differences were observed. This may indicate that these parameters are not influenced by the change in the transmission system but rather by the intrinsic characteristics of the technology used, as well as the quality and uniformity of the seeds (Sun et al., 2022).

Regarding the operational speeds employed and their impact on the results obtained, variations in this factor do influence A_S, D_D, M_S, and P_I. However, the coefficient of variation remained unaffected and did not differ between the adopted speeds.

The data presented in Figure 2 depict the deposition parameters in relation to the operational speeds employed. In all cases, a second-order polynomial trend was evident, with a coefficient of determination (R^2) exceeding 87%.

Table 2: Analysis of variance and mean test for maize seed deposition.

Analyzes	Variables				
	A_S	D_D	M_S	C_V	P_I
	(%)				
Normality					
SW	0.762	0.703	0.815	0.363	0.899
Homogeneity					
BF	0.061	0.173	0.216	0.223	0.411
Test F					
DS	8.005**	1.692[NS]	15.778**	0.172[NS]	176.171**
S	71.473**	63.391**	44.738**	0.694[NS]	113.573**
DS x S	2.169**	0.640[NS]	3.817**	0.997[NS]	18.943**
C_V (%)					
	1.80	5.93	5.37	6.06	3.49
Test of averages - Dispenser					
Conventional	95.74 B	1.86	1.97 B	14.26	11.54 B
Electric	97.01 A	2.28	1.12 A	15.22	10.23 A

Variables: Dispenser (DS), distribution speed (S), acceptable spacing (A_S), double spacing (D_D), missing spacing (M_S), coefficient of variation (C_V) and precision index (P_I). Shapiro-Wilk normality test: SW ≤ 0.05 – Data abnormality; SW > 0.05 – Normality in the data. Brown-Forsythe test for homogeneity of variance: BF ≤ 0.05 – Heterogeneous variance; BF > 0.05 – Homogeneous variances. Analysis of variance F test (ANOVA): NS – Not significant; * (p ≤ 0.05) and ** (p ≤ 0.01). C_V (%) – Coefficient of variation. In each column, for each factor, means followed by different capital letters differ from each other by Tukey's test" (p ≤ 0.05).
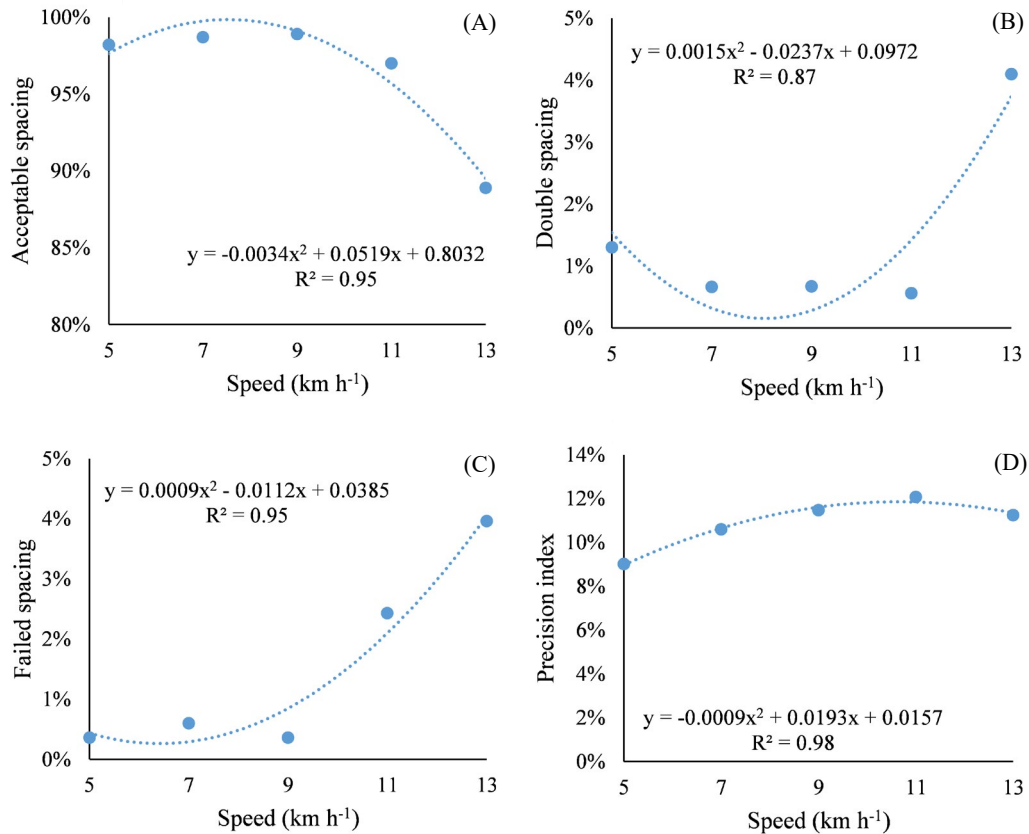
Figure 2: Acceptable spacing (A), double deposition (B), missing spacing (C) and precision index (D).

Upon examining the data presented in Figure 2, it becomes apparent that as the operational speed increases, there is a corresponding decrease in the percentage of acceptable spacing. This trend aligns with the observed relationships between speed and the incidence of double and missing spacing, which both show an increase as speed rises. Furthermore, there is a noticeable inclination towards higher accuracy rates at elevated speeds.

In summary, operational speed plays a pivotal role in determining sowing quality. A higher operational speed leads to a greater occurrence of errors, including both M_S or D_D, as well as a reduced proportion of A_S. This results in a less uniform distribution of seeds, a phenomenon also noted by Fanigliulo et al. (2022), who examined the correlation between operational speed and the dosing mechanism's effectiveness in seed deposition.

This behavior can be attributed to the decreased capacity of the seeder to handle variations in crop topography, as mentioned by Parihar et al. (2022). Additionally, the system responsible for seed acquisition,

transport, and deposition is compromised with the increase in operational speed.

Regarding the relationship between the dosing mechanism and operational speed, differences were observed in the parameters of acceptable spacing, failures, and precision index. However, there were no significant differences in terms of double deposition and coefficient of variation. The dispensers tested at various sowing speeds exhibit a second-order polynomial behavior (Figure 3), with a coefficient of determination (R^2) exceeding 90% for the conventional dispenser and surpassing 94% for the electric dispenser.

As the speed increases, particularly beyond 8 km/h, the proportion of acceptable spacing decreases for both types of metering mechanisms. However, this decrease is more pronounced in the mechanical dispenser, whereas the electric dispenser exhibits a more stable variation at higher speeds.

Higher speeds also lead to a greater occurrence of failures in seed deposition. Starting from 6 km h^{-1}, there is a noticeable superiority of the mechanism driven by

electronic components, and this advantage intensifies with higher speeds. This disparity underscores the impact of mechanical components involved in the energy transfer from the joint axis to the mechanical mechanism, which is influenced by friction among parts and variations in the movement of the mechanized assembly (Xia et al., 2023).

Initially, at the lowest speeds studied, the electric dispenser has an advantage in terms of the precision index. However, as the speed increases, this parameter is more adversely affected in the electric dispenser, to the point where values become similar at 13 km h⁻¹. This outcome indicates that the advantage of the transmission technology is more significant at lower speeds, owing to the influence of other factors related to the operation of the dispensers (Yang et al., 2022).

The electric dispenser consistently outperformed the conventional dispenser in terms of A_S, M_S and P_I. When comparing data between the mechanisms, it becomes evident that the disparity increases with the rise in speed, particularly in the A_S and M_S parameters. This can be attributed to the principles of energy transmission inherent to each technology. The conventional dispenser relies on the stability of the wheelset concerning the ground, which affects axis movement, along with the interactions among mechanical parts, introducing friction and inherent errors associated with the equipment's architecture (Chen et al., 2022).

Consequently, the dispenser driven by a dedicated motor offers operational advantages, both in favorable conditions and especially in adverse situations. This corroborates the benefits outlined by Sharaby et al. (2019), who highlighted the qualities and broad range of metering mechanisms driven by electric motors in comparison to conventional drive systems.

Additionally, it is worth noting the simplicity of system maintenance, as it does not require specific attention to chains, transmission shafts, drive wheels, clutch systems, or sprockets. This contributes to a more straightforward and uncomplicated maintenance process.
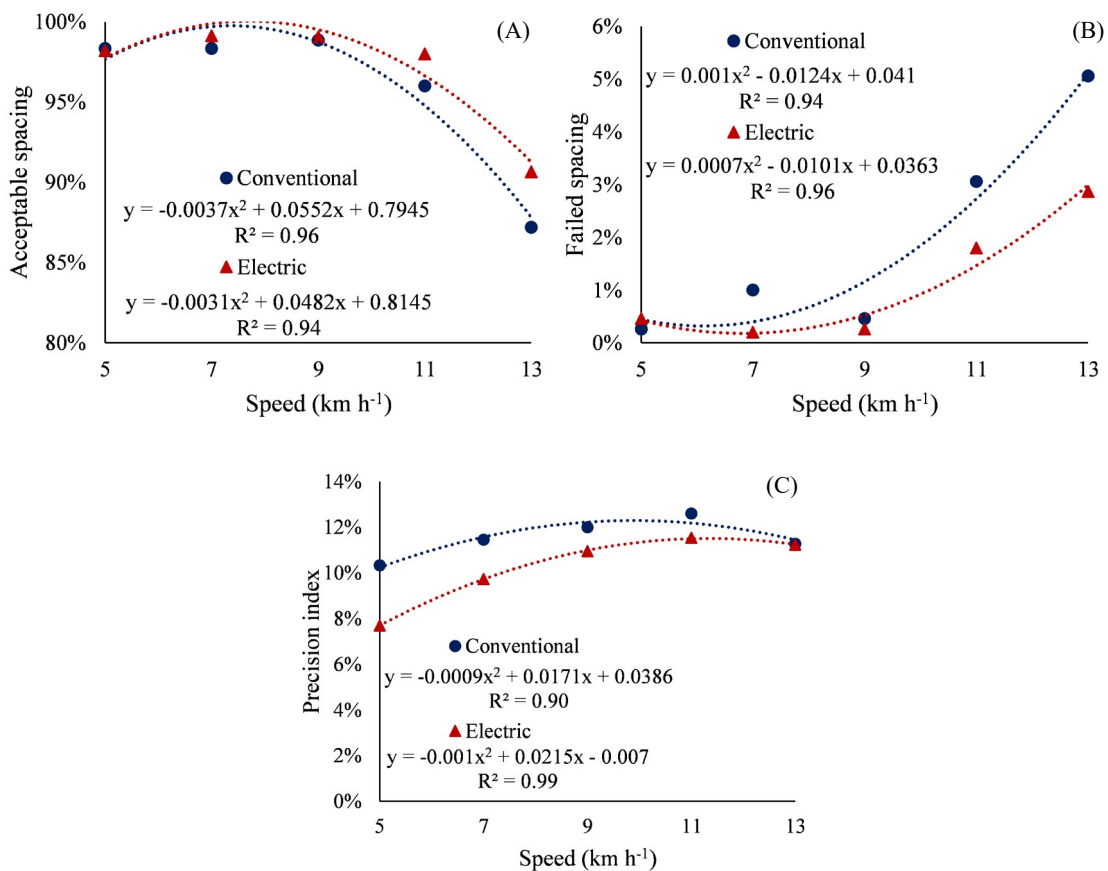

Figure 3: Acceptable spacing (A), missing spacing (B) and precision index (C).

CONCLUSIONS

The electric dosing mechanism demonstrated superiority over the conventional dosing mechanism in the parameters of acceptable spacing, missing spacing, and precision index. However, the increase in operational speed compromises sowing quality in both evaluated dosing mechanisms.

AUTHOR CONTRIBUTION

Conceptual idea: Zimmermann, G.G.; Jasper, S.P.; Methodology design: Jasper, S.P.; Zimmermann, G.G.; Data collection: Moreno, F.G.; Ingles, F.A.; Data analysis and interpretation: Zimmermann, G.G.; Teixeira, R.S., and Writing and editing: Mendonça, W.S.; Teixeira, R.S.; Ingles, F.A; Zimmermann, G.G.

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