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Industrial corn seed treatment processes on seed quality during storage

Abstract – The objective of this work was to evaluate the effects of industrial seed treatment processes and of the stratification of the applied components on the physiological and functional quality of corn (*Zea mays*) seeds during storage. SYN555 VIP hybrid corn seeds from the same batch were subjected to 12 treatments, involving the application of insecticides, fungicide, polymer, and finishing powder at three different stages of the treatment process. The physiological quality of the seeds was evaluated using germination and vigor tests during the storage periods of 0, 6, 12, and 21 months. Functional quality was evaluated using the dust-off, plantability, and run-off tests. The treatments affected corn seed quality. The use of fungicide and polymer in the first stage of the treatment process helps to preserve seed vigor, especially after 12 months of storage. The treatment with fungicide, polymer, insecticide, and powder is recommended because it favors the maintenance of seed vigor for up to 12 months of storage, similarly to the treatment with only fungicide and polymer. The functional quality of the treatments is not influenced by the seed treatment processes with component stratification.

Index terms: *Zea mays*, functional quality, phytotoxicity, seed deterioration, seed quality.

Processos industriais de tratamento de sementes de milho sobre a qualidade das sementes durante o armazenamento

Resumo – O objetivo deste trabalho foi avaliar os efeitos dos processos industriais de tratamento de sementes e da estratificação dos componentes aplicados sobre a qualidade fisiológica e funcional de sementes de milho (*Zea mays*) durante o armazenamento. Sementes do milho híbrido SYN555 VIP do mesmo lote foram submetidas a 12 tratamentos, envolvendo a aplicação de inseticidas, fungicida, polímero e pó de acabamento em três diferentes estágios do processo de tratamento. A qualidade fisiológica das sementes foi avaliada por meio de testes de germinação e vigor ao longo dos períodos de armazenamento de 0, 6, 12, e 21 meses. Já a qualidade funcional das sementes foi avaliada por meio de testes de desprendimento de poeira, plantabilidade e recobrimento. Os tratamentos afetaram a qualidade das sementes de milho. O uso de fungicida e polímero no primeiro estágio do processo de tratamento auxilia na preservação do vigor da semente, principalmente após 12 meses de armazenamento. O tratamento com fungicida, polímero, inseticida e pó é recomendado, pois favorece a manutenção do vigor das sementes por até 12 meses de armazenamento, semelhantemente ao tratamento com apenas fungicida e polímero. A qualidade funcional dos tratamentos não é influenciada pelos processos de tratamento de sementes com estratificação de componentes.

Termos para indexação: *Zea mays*, qualidade funcional, fitotoxidez, deterioração de sementes, qualidade de sementes.

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Introduction

The use of high-quality corn (*Zea mays* L.) seeds is essential for the proper initial development of plants, contributing to the achievement of high yields (Reis et al., 2022). However, productivity can be affected by the occurrence of pests and pathogens, requiring a viable alternative to mitigate potential harmful effects and protect seeds and seedlings, such as chemical seed treatment with phytosanitary products (Brustolin et al., 2017). This technique has gained prominence in the domain of seed production and technology as it involves the application of phytosanitary products, dyes, coatings, polymers, or other additives that preserve seed performance, allowing crops to reach their full potential under field conditions (Carvalho et al., 2022).

Seed treatment processes can essentially occur on-farm, near the time of sowing, or at the seed processing unit of producing companies (Reis et al., 2023). The latter process, known as industrial seed treatment, has grown significantly as it provides logistical advantages to the producer and ensures a better coating and distribution of the active ingredients in phytosanitary products through specific technologies (Medeiros et al., 2023).

For logistical and technical reasons, it is common for the production, processing, and treatment of hybrid corn seeds to occur several months before the sowing period, requiring treated seed batches to be stored for extended periods (Oliveira et al., 2020; Moraes et al., 2022). However, there are reports indicating that certain products used in seed treatment, such as key insecticidal molecules employed for pest management during early growth stages (Utono & Adamu, 2023), may cause phytotoxicity over time, negatively impacting corn seed quality (Moraes et al., 2022).

Despite the known benefits of seed treatments (Medeiros et al., 2023), there is still a lack of information regarding the optimal treatment process, the tolerance period for storing treated seeds, and the potential damages that treatments may cause to the physiological quality and functional properties of the seeds. Such challenges have driven the demand for the development of innovations in products and application processes for seed treatment using phytosanitary products (Oliveira et al., 2021).

The objective of this work was to evaluate the effects of industrial seed treatment processes and of the stratification of the applied components on the physiological and functional quality of corn seeds during storage.

Materials and Methods

The experiment was conducted at two institutions in Brazil: at the Central Laboratory for Seed Research (CLSR) of Escola de Ciências Agrárias de Lavras, at Universidade Federal de Lavras, in the municipality of Lavras, in the state of Minas Gerais; and at the Syngenta Seedcare Institute, in the municipality of Holambra, in the state of São Paulo.

The experiment used a completely randomized design in a 12 × 4 factorial arrangement, comprising 12 industrial treatment processes (T1 to T12) and four storage periods (immediately after the treatments and after 6, 12, and 21 months of storage). Two types of assessment were carried out, one for physiological performance, and another for physical-functional properties.

Physiological performance was evaluated at the CLSR. Four tests were carried out for each combination of treatment and storage period: two for germination (moistened rolled paper towels and moistened rolled paper towels + vermiculite) and two for vigor (cold test and accelerated aging test), all in four replicates (n = 768). The experimental unit was 50 seeds.

The analysis of physical-functional properties was carried out at the Syngenta Seedcare Institute. The dust-off (particle detachment), plantability, and abrasion resistance by coating quantification (rub-off) laboratory tests were performed once immediately after the treatments. The used sample sizes were: two replicates of 100 g seeds for each treatment, one sample of 1.0 kg seeds per treatment, and four replicates of 50 seeds for each treatment, respectively.

Corn seeds from the SYN555 VIP3 hybrid (Syngenta, Basel, Switzerland) were subjected to different industrial seed treatments processes, varying in the sequence of used products and in the stages of application.

The used products were: the Maxim Quattro fungicide (Syngenta, Basel, Switzerland), containing azoxystrobin 1.5% m/v, thiabendazole 30.0% m/v, fludioxonil 3.8% m/v, and metalaxyl-M 3.0% m/v; the Fortenza 600 insecticide (Syngenta, Basel, Switzerland), with cyantraniliprole 60% m/v; the Cruiser 600 insecticide (Syngenta, Basel, Switzerland), with thiamethoxam 60% m/v; and the Disco AG Red L-450 polymer (Incotec, Enkuizen, Netherlands). In some treatments, the Biogloss finishing powder (Biogrow, Santiago, Chile) or mechanical ventilation drying was used between the stages of liquid-product application; the treatments that used insecticides received both. The rate of finishing powder was 20 g per 60,000 seeds, and the drying wind speed was 17.51 knots per kilogram of seed for 10 s. The rates of the Maxim Quattro fungicide, Fortenza 600 insecticide, Cruizer 600 insecticide, and Disco AG Red L-450 polymer applied per 60,000 seeds were 20, 40, 70, and 110 mL, respectively. The seed treatments (Table 1) were performed at the CLSR, using the Arktos L-5k batch-type seed treatment machine (Momesso, Birigui, SP, Brazil) at a mixing speed of 304 rpm. Each treatment was conducted in one to three stages that lasted 10 s.

After the treatments, the seeds were packed in multi-layered paper bags and stored at ambient temperature and relative humidity at the CLSR. During the storage period, from September 2020 to June 2022, temperature and relative humidity were recorded daily using a data logger. Maximum, minimum, and mean temperature were 28.5, 9.5, and 21.3°C, respectively, and mean relative humidity was 70%.

For germination, seeds were sown on paper towels moistened with distilled water at an amount equivalent to 2.5 times the weight of the paper. The rolls were placed in the EL006 Mangelsdorf-type germinator (Eletrolab Ltda., São Paulo, SP, Brazil) at a temperature of 25°C. Evaluations were conducted on the seventh day, following the criteria established by the rules for seed testing (Brasil, 2025).

Germination on rolled paper + vermiculite followed the methodology described by Rocha et al. (2023). Counting of normal seedlings was done on the seventh day according to the rules for seed testing (Brasil, 2025).

The cold test was conducted in trays filled up with a substrate composed of a mixture of sand and soil at a 2:1 ratio (v/v). The substrate was irrigated until reaching 60% of its water-holding capacity. After sowing, the trays were kept in a cold chamber at 10°C for seven days and, then, transferred to a plant growth chamber at 25°C, with a 12 hour photoperiod for seven more days. After growing in the chamber, normal emerged seedlings were counted, and the results were expressed as percentage (Cicero & Vieira, 2020).

The accelerated aging test was conducted using transparent polystyrene containers containing 40 mL distilled water. A suspended screen was attached inside the container and covered with a single layer of seeds, kept in a biochemical oxygen demand chamber at 41°C for 96 hours (Marcos-Filho, 2020). Then, the seeds were sown in the same substrate used in the cold test, and evaluated for the emergence of normal seedlings seven days after sowing (Rocha et al., 2025).

The dust-off test was conducted as described in Reis et al. (2023). The results were expressed as grams of dust per 60,000 seeds.

Table 1. Description of the seed treatments, used products(1), and application stages.

Treatment	1st stage	2nd stage	3rd stage	Summary
T1	F + P	-	-	F + P
T2	F + I + P (mix)	-	-	Mix
T3	F + I + P (mix)	PW	-	Mix + powder
T4	F + I + P (mix)	D	-	Mix + drying
T5	F + P	I	-	F+P/insecticide
T6	F + P	PW	I	F + P + powder + insecticide
T7	F + P	D	I	F + P + drying + insecticide
T8	F + P	I	PW	F + P + insecticide + powder
T9	F + P	I	D	F + P + insecticide + drying
T10	I	F+P	-	Insecticide + F + P
T11	I	PW	F+P	Insecticide + powder + F + P
T12	I	D	F+P	Insecticide + drying + F + P

(1)F, fungicide; P, polymer; I, insecticide; PW, finishing powder; and D, drying.

The plantability test used the STF-80 planting simulator (Momesso Birigui, SP, Brazil), adapted with the John Deere 1200 series mini seed hopper planter box (Deere & Company, Horizontina, RS, Brazil) and equipped with the CornCounter MW laser sensor (Syneltro, Birrwil, Switzerland) to measure seed distribution during sowing under controlled conditions. The equipment features a microwave cavity oscillating at 1.6 GHz, and a phase-locked loop circuit used to detect frequency changes as seeds pass through the sensor. A computer connected to the laser sensor outputs a data log with measurements of the quality of feed index and percentages of skips, doubles, and multiples (Syneltro, 2024).

Abrasion resistance was evaluated through coating quantification. The GroundEye S800 seed analysis system (Tbit Tecnologia S.A., Lavras, MG, Brazil) was used to capture high-resolution images before and after the abrasion cycles. The images were processed at the CLSR for coating assessment according to the method proposed by Medeiros et al. (2023). For abrasion simulation, the PTF 20E/ER device (Pharma Test, Hainburg, Germany) was used, consisting of two transparent polymer cylinders with polished internal surfaces rotating around their axis. A sample of 300 g seeds was weighed and subjected to the action of the device for 6 min, at 50 rpm, totaling 300 abrasion cycles.

The physiological quality data were subjected to the statistical analysis. To treat discrepant values (outliers), the maximum tolerance criteria proposed by Miles (1963) were used. Then, the data were subjected to Levene's, Shapiro-Wilk's, and Durbin-Watson's tests for verification of homoscedasticity, normality, and independence of errors, respectively, at 5% probability. All assumptions were met. To compare means, the data were subjected to the factorial analysis of variance (ANOVA) at 5% probability, using the F-test. Mean grouping was conducted using Scott-Knott's test ($\alpha = 0.05$). Linear regression was performed, and the obtained models that showed the highest coefficient of determination (R^2) were selected. The physical-functional results were subjected to different analyses, i.e., particle detachment and plantability to the descriptive analysis of the means, and abrasion resistance to the same factorial ANOVA and mean grouping analyses used for physiological data. All analyses were carried out using the R, version 4.1.2, software (R Core Team, 2016) and the ExpDes package (Ferreira et al., 2014).

Results and Discussion

The ANOVA showed significant differences ($p < 0.05$) for means of seed treatment and storage periods, as well as a significant interaction between them. The coefficient of variation ranged from 1.2 to 6.0%.

Storage period influenced seed germination percentage, with a notable highlight at 21 months of storage, when the highest mean germination rate of 97% was observed in T1 (Table 2). The remaining batches that were treated with insecticides at any stage in T2 to T12 showed values ranging from 87 to 95%. However, all batches met the minimum germination standard of 85% required for commercialization, in accordance with the Brazilian legislation (Brasil, 2013). In the seed industry, it is a trend to select initial high-quality seed batches for treatment to ensure a successful seedling establishment in the field, accompanied by a high added value in production and an advanced technology in industrial corn seed treatment (Pereira et al., 2019; Medeiros et al., 2021, 2023). Germination showed a monthly reduction of 0.16% in T1 (Table 2), but of 0.49% in the treatments with insecticides according to the sum of the coefficients from T2 to T12 divided by 11.

In general, germination was higher on rolled paper + vermiculite than only on rolled paper in the same storage period (Tables 3 and 2, respectively). The use of vermiculite between papers in the germination test reduced the concentration of phytosanitary products in direct contact with the seeds, minimizing the potential phytotoxicity of the insecticides, which may have helped to reveal the true physiological quality of the treated seeds (Rocha et al., 2020, 2023; Carvalho et al., 2024).

Regarding germination on vermiculite, differences in the treatment results were observed after 21 months of storage, when batches from T2 to T12 treated with insecticides showed a reduction of 8 to 10% in germination compared with those from T1 (Table 3), as also noted for germination on rolled paper (Table 2). At 21 months of storage under ambient temperature, in addition to the insecticides, the application of fungicide + polymer in the first stage in T8 and T9 (Table 3 and Table 2, respectively) was considered the best chemical treatment. This indicates that product stratification during seed treatment processes influenced seed quality.

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Lorenzetti et al. (2014) also reported a pronounced reduction in corn seed germination when using neonicotinoid insecticides, including imidacloprid + thiodicarb and especially thiamethoxam, under temperature from 20 to 30°C and relative humidity around 60%. Another study showed that the deterioration process of seeds kept in suboptimal conditions was exacerbated due to oxidative stress

Table 2. Mean germination of corn (*Zea mays*) seeds on moistened paper towels when subjected to 12 treatments (T1 to T12) after 0, 6, 12 and 21 months of storage, in addition to linear regression equations of germination (y) during the storage period (x), and values of the coefficient of determination (R^2) for the evaluation of goodness of fit[(1)].

Treatment[(2)]	Germination (%) during storage time in months				Regression	
	0[ns]	6[ns]	12	21	Equation	R^2
T1	100	100	100 a	97 a	y = 100 - 0.160x	0.806
T2	100	100	99 a	87 e	y = 102 - 0.597x	0.728
T3	99	99	100 a	89 d	y = 101 - 0.455x	0.660
T4	100	100	100 a	92 c	y = 101 - 0.366x	0.698
T5	100	100	100 a	88 e	y = 102 - 0.564x	0.670
T6	100	99	99 a	86 e	y = 102 - 0.651x	0.728
T7	100	100	99 a	86 e	y = 102 - 0.640x	0.755
T8	100	100	99 a	91 c	y = 101 - 0.422x	0.784
T9	100	99	100 a	95 b	y = 100 - 0.238x	0.732
T10	100	100	98 a	92 c	y = 101 - 0.372x	0.820
T11	100	100	99 a	90 d	y = 102 - 0.477x	0.773
T12	100	99	96 b	87 e	y = 101 - 0.650x	0.926

[(1)]Means followed by different letters in the same column indicate a significant difference according to Scott-Knott's test ($\alpha = 0.05$). [ns]Nonsignificant. [(2)]T1, fungicide + polymer (FP); T2, fungicide + insecticide + polymer (mix); T3, mix + powder; T4, mix + drying; T5, FP + insecticide; T6, FP + powder + insecticide; T7, FP + drying + insecticide; T8, FP + insecticide + powder; T9, FP + insecticide + drying; T10, insecticide + FP; T11, insecticide + powder + FP; and T12, insecticide + drying + FP.

Table 3. Mean germination of corn (*Zea mays*) seeds on rolled paper + vermiculite when subjected to 12 treatments (T1 to T12) after 0, 6, 12 and 21 months of storage, in addition to linear regression equations of germination (y) during the storage period (x), and values of the coefficient of determination (R^2) for the evaluation of goodness of fit[(1)].

Treatment[(2)]	Germination (%) during storage time in months				Regression	
	0[ns]	6[ns]	12[ns]	21	Equation	R^2
T1	100	100	100	96 a	y = 101 - 0.187x	0.701
T2	100	99	99	89 d	y = 101 - 0.492x	0.773
T3	100	100	98	89 d	y = 102 - 0.513x	0.793
T4	100	100	100	89 d	y = 102 - 0.511x	0.735
T5	99	100	99	90 d	y = 101 - 0.460x	0.695
T6	100	100	100	91 c	y = 102 - 0.425x	0.742
T7	100	100	99	89 d	y = 102 - 0.520x	0.802
T8	100	99	99	93 b	y = 101 - 0.344x	0.799
T9	100	100	100	91 c	y = 102 - 0.449x	0.740
T10	100	100	100	91 c	y = 102 - 0.421x	0.701
T11	100	100	99	92 c	y = 102 - 0.407x	0.785
T12	100	98	99	88 d	y = 101 - 0.544x	0.789

[(1)]Means followed by different letters in the same column indicate a significant difference according to Scott-Knott's test ($\alpha = 0.05$). [ns]Nonsignificant. [(2)]T1, fungicide + polymer (FP); T2, fungicide + insecticide + polymer (mix); T3, mix + powder; T4, mix + drying; T5, FP + insecticide; T6, FP + powder + insecticide; T7, FP + drying + insecticide; T8, FP + insecticide + powder; T9, FP + insecticide + drying; T10, insecticide + FP; T11, insecticide + powder + FP; and T12, insecticide + drying + FP.

and metabolic changes, such as cell membrane disintegration, which negatively affected germination and vigor (Jeevan Kumar et al., 2015). Moraes et al. (2022) concluded that such deterioration is intensified when seeds are treated with insecticides.

The cold test allowed grouping the industrial treatment processes at the 21 month storage mark (Table 4). Similar to what was observed in the other germination and vigor tests, in general, T1 and four (T6, T7, T8, and T9) out of five treatments with fungicide + polymer applied in the first stage exhibited a lower deterioration by the end of the storage period, with germination ranging from 88 to 92%. This suggests that this process can mitigate phytotoxic effects during storage when insecticides are used for pest control. The worst values, ranging from 80 to 82%, were verified when products were applied as a mixture or when the insecticide was applied in the first stage.

Deterioration during storage occurred linearly in all treatments, but at different intensities. In the cold test, T1 showed a decrease in emergence of 0.394% per month, considered a desirable rate, whereas seeds treated with fungicide + polymer in the first stage presented a mean reduction of 0.533% per month; the exception was T8, with a seed deterioration rate of 0.377% per month, close to that of T1 (Table 4). The mean reduction of the treatments involving mixed applications (T2, T3, and T4) and insecticide application in the first stage (T10, T11, and T12) was of 0.85% per month. T4 and T10 presented the worst results, with monthly reductions of 0.942 and 0.879%, respectively. It seems that the use of insecticide in the first stage may have accelerated seed deterioration, which is a significant finding given the observed relationship between an initial strong seedling development and field yield performance for high-vigor seed batches (Reis et al., 2022).

In the accelerated aging test, vigor followed similar trends to those verified in the cold test, showing significant differences at 12 months. T1 did not differ from T5, T6, and T9 with fungicide + polymer in the first stage and, exceptionally, from T12, which were superior to the other treatments. However, this trend did not hold at the end of the storage period, when T1 was superior to all others, reaching 45% germination (Table 5). At 21 months of storage, all batches treated with fungicide + polymer in the first stage showed vigor from 24 to 28%, superior to that of the treatments with insecticides applied in the first stage (T2, T3, T4, and T10), whose values were below 20%.

Table 4. Mean germination of corn (*Zea mays*) seeds on substrate subjected to 12 treatments (T1 to T12) following the cold test after 0, 6, 12 and 21 months of storage, in addition to linear regression equations of germination (y) during the storage period (x), and values of the coefficient of determination (R^2) for the evaluation of goodness of fit[(1)].

Treatment[(2)]	Germination (%) during storage time in months				Regression	
	0 ^{ns}	6 ^{ns}	12 ^{ns}	21	Equation	R^2
T1	100	100	100	92 a	y = 101 - 0.394x	0.745
T2	100	99	97	84 b	y = 102 - 0.788x	0.853
T3	99	96	94	81 c	y = 100 - 0.821x	0.888
T4	100	97	95	80 c	y = 102 - 0.942x	0.883
T5	100	97	96	85 b	y = 101 - 0.692x	0.893
T6	100	99	97	88 a	y = 101 - 0.594x	0.900
T7	100	100	96	90 a	y = 101 - 0.533x	0.920
T8	99	99	97	91 a	y = 100 - 0.377x	0.850
T9	100	98	97	90 a	y = 100 - 0.472x	0.914
T10	100	100	98	81 c	y = 103 - 0.879x	0.760
T11	100	99	97	82 c	y = 103 - 0.857x	0.802
T12	99	99	96	83 b	y = 102 - 0.780x	0.847

[(1)]Means followed by different letters in the same column indicate a significant difference according to Scott-Knott's test ($\alpha = 0.05$). ^{ns}Nonsignificant. [(2)]T1, fungicide + polymer (FP); T2, fungicide + insecticide + polymer (mix); T3, mix + powder; T4, mix + drying; T5, FP + insecticide; T6, FP + powder + insecticide; T7, FP + drying + insecticide; T8, FP + insecticide + powder; T9, FP + insecticide + drying; T10, insecticide + FP; T11, insecticide + powder + FP; and T12, insecticide + drying + FP.

During storage, all industrial seed treatment processes exhibited a linear deterioration over the storage period (Table 5). The lowest reduction was 2.55% per month in T1, followed by 3.41% per month in T5 to T9, in which fungicide + polymer were applied in the first stage. Mean reduction was 3.59% per month in T10 to T12, with insecticide application in the first stage, reaching 4.07% per month in T2 to T4, with all phytosanitary products mixed and applied in the first stage. This result reinforces that using insecticides in the first stage of application accelerates deterioration over the storage period.

Mariucci et al. (2018) observed a reduction in the vigor of corn seeds treated with combined products such as neonicotinoid insecticides and inoculants. When the deterioration process is more advanced, damage to structures, such as cell membranes and growth regions of the seedling, can negatively affect physiological performance (Marcos-Filho, 2015). Carvalho et al. (2020) found that the treatment with thiamethoxam caused phytotoxicity in soybean [*Glycine max* (L.) Merr.] seeds, resulting in a reduction in seedling length. For this reason, the authors concluded that characteristics such as seedling and root length should be considered when evaluating the occurrence of phytotoxicity in treated seeds. A possible explanation for this reduction in vigor is the different effect of chemical groups of insecticides on seeds. For instance, systemic insecticides from the anthranilic diamide chemical group, such as cyantraniliprole, exhibit a high selectivity and a low phytotoxicity (Li et al., 2022).

The application of active ingredients affected the maintenance of the quality of the treated corn seeds. The use of fungicide + polymer in the first stage may have created a protective layer that prevented the direct contact between the insecticide and the seed, helping to maintain vigor and mitigate phytotoxicity in the seeds and, subsequently, in the seedlings during germination. However, further studies are necessary to confirm this hypothesis.

T8 and T9 proved to be adequate alternatives for maintaining the physiological quality of the treated and stored corn seeds based on the results of the germination and vigor tests. These operational procedures are relatively simpler to implement than the other stratification and application procedures tested in the present study, such as drying and mechanical ventilation between layers, which had no effect on the formation of a protective layer.

The seed treatment processes affected the functional quality parameters of each treatment. For drying powder as the last coating, the highest particle detachment values were 0.78 and 0.10 g dust per 60,000 seeds in T8 and T3,

Table 5. Mean germination of corn (*Zea mays*) seeds on substrate subjected to 12 treatments (T1 to T12) following accelerated aging after 0, 6, 12 and 21 months of storage, in addition to linear regression equations of germination (y) during the storage period (x), and values of the coefficient of determination (R^2) for the evaluation of goodness of fit(1).

Treatment(2)	Germination (%) during storage time in months				Regression	
	0ns	6ns	12	21	Equation	R^2
T1	100	97	95 a	45 a	y = 109 - 2.550x	0.763
T2	99	95	91 b	13 d	y = 114 - 4.039x	0.771
T3	99	95	90 b	06 e	y = 115 - 4.363x	0.770
T4	100	94	91 b	18 c	y = 112 - 3.794x	0.780
T5	100	95	94 a	26 b	y = 112 - 3.420x	0.752
T6	100	96	96 a	24 b	y = 113 - 3.498x	0.735
T7	98	94	88 b	28 b	y = 109 - 3.260x	0.814
T8	98	95	90 b	25 b	y = 111 - 3.430x	0.780
T9	100	95	93 a	26 b	y = 112 - 3.417x	0.768
T10	99	95	89 b	19 c	y = 113 - 3.741x	0.790
T11	99	94	88 b	26 b	y = 110 - 3.410x	0.830
T12	98	93	92 a	20 c	y = 111 - 3.630x	0.752

(1)Means followed by different letters in the same column indicate a significant difference according to Scott-Knott's test (α = 0.05). nsNonsignificant. (2)T1, fungicide + polymer (FP); T2, fungicide + insecticide + polymer (mix); T3, mix + powder; T4, mix + drying; T5, FP + insecticide; T6, FP + powder + insecticide; T7, FP + drying + insecticide; T8, FP + insecticide + powder; T9, FP + insecticide + drying; T10, insecticide + FP; T11, insecticide + powder + FP; and T12, insecticide + drying + FP.

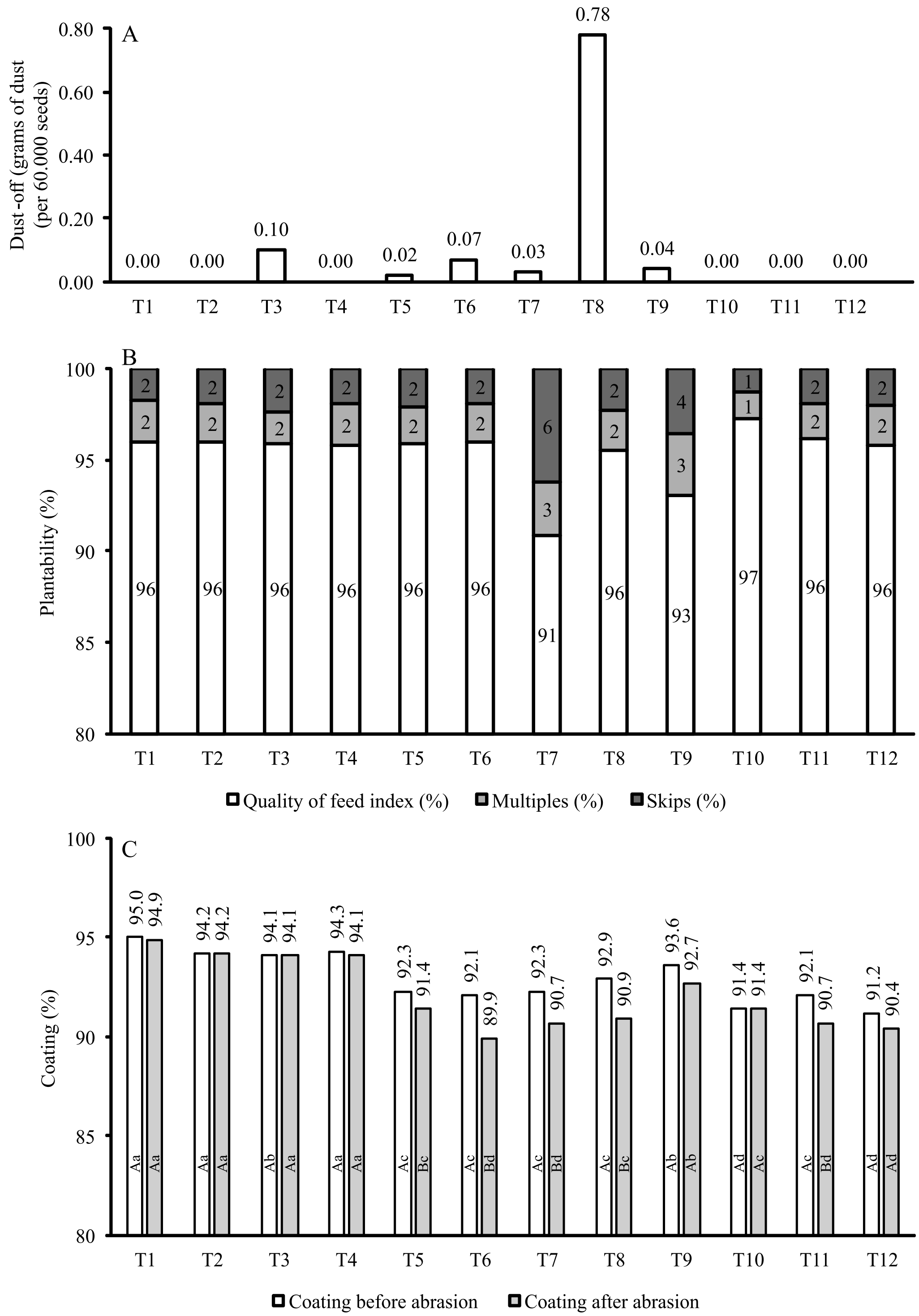

Figure 1. Grouping of the means of the dust-off (A), plantability (B), and abrasion resistance by coating quantification (C) tests applied to corn (*Zea mays*) seeds subjected to different seed treatments (T1 to T12). T1, fungicide + polymer (FP); T2, fungicide + insecticide + polymer (mix); T3, mix + powder; T4, mix + drying; T5, FP + insecticide; T6, FP + powder + insecticide; T7, FP + drying + insecticide; T8, FP + insecticide + powder; T9, FP + insecticide + drying; T10, insecticide + FP; T11, insecticide + powder + FP; and T12, insecticide + drying + FP. Means followed by different letters indicate a significant difference according to Scott-Knott's test (α = 0.05), where lowercase letters compare means between treatments with the same type of abrasion and uppercase letters compare means before and after abrasion.

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respectively (Figure 1 A). The Euroseeds STAT Dust Working Group (2011) suggests a maximum amount of 0.75 g dust per 100,000 seeds, meaning that the limit recommended for 60,000 seeds would be up to 0.45 g. In the present study, only the first treatment exceeded this limit. However, in most cases, the dust consisted mainly of drying powder rather than detached phytosanitary products, which would be more concerning due to product loss and environmental issues. The detachment of drying powder can be attributed to its low weight and isolated application in the last stage, reducing its contact with the seed, which allowed it to be mixed with the treatment solution, facilitating its detachment from the seed during testing.

The plantability test showed a quality of feed index of around 96%. Only T7 and T9 had values below 96%, i.e., 91 and 93%, respectively, which were still satisfactory (Figure 1 B). A possible explanation for the latter results is polymer application in the first stage, combined with the use of drying by ventilation. This process may have made seed surface rougher, compromising the quality of feed index. Regarding plantability, Rontani et al. (2020) added that the uniformity of seed spacing per unit area is essential for the crop to express its full potential.

Comparing seed coating before and after the abrasion resistance test, a slight reduction was observed, reaching a maximum of 2% (Figure 1 C). The main reductions, between 1 and 2%, occurred in the treatments with fungicide + polymer in the first (T5 to T9) and third (T11 and T12) stages. Although the use of polymers improves coverage, finishing, and product adhesion to seeds (Ludwig et al., 2011), in the third stage, the substance's efficiency in maintaining coating was also low. This is an indicative that more studies on this variable are required.

Conducting the evaluated tests is important since, during seed handling processes, such as chemical treatment, packaging, storage, transportation, and sowing, friction occurs between the seeds themselves and between them and the package. This friction can lead to a reduction in coating and in the rate of active ingredients per seed, with a consequent decrease in their efficiency due to product detachment (Medeiros et al., 2023).

The impairment caused by abrasion observed in the present study was very subtle, as the overall average coating before the test was 93%, reducing only to 92% afterwards, which indicates a good adequacy of the industrial seed treatment processes. According to the criteria for corn seeds proposed by Medeiros et al. (2023), all treatments presented a satisfactory to good coating ≥ 90% or a score of 5. Overall, none of the functional quality variables studied would hinder the use of stratified seed treatment processes.

Conclusions

1. The arrangement of active ingredients in the seed chemical treatment process affects the maintenance of corn (*Zea mays*) seed quality during storage.
2. The treatment with fungicide + polymer + insecticide + powder is recommended to promote vigor maintenance up to 12 months of storage, showing similar results to those of the treatment with only fungicide + polymer.
3. The use of insecticides in the first stage of application, either alone or in mixtures, intensifies the phytotoxicity and deterioration of stored corn seeds, particularly after 21 months of storage.
4. The functional quality of the treatments is not influenced by the industrial seed treatment processes with component stratification.

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