

Temperatures and periods of drying delay and quality of corn seeds harvested on the ears¹

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ABSTRACT – Seeds harvested on the ears have high moisture content. On that account, this study aimed at evaluating the loss of physiological quality of corn seeds harvested on the ears, as a function of different drying-delay times. Hybrid corn ears were harvested at 31% moisture and then had their drying postponed for 0, 12, 24 and 36 h, while subjected to temperatures of 30, 40, 50 and 60 °C. The physiological quality was evaluated after 0, 4, 8 and 12 months of storage. A completely randomized design was employed, in a 4 x 4 x 4 factorial scheme, with four replications. In addition, a study was performed in a seed-processing unit, reporting the average waiting time before drying and the temperatures of all loads of a corn hybrid received at the facility. The physiological quality was not affected by temperatures below 40 °C, considering 36 h of waiting before drying. At 50 °C during the drying delay, the germination was impaired 36 h afterward, and the vigor was compromised after 24 h, with the damage effects intensifying as the storage advanced. At the temperature of 60 °C, the deficits in germination and vigor occurred within the first hours of drying delay.

Index terms: drying delay, germination, transport, vigor, *Zea mays*.

Temperaturas e períodos de espera pela secagem e qualidade de sementes de milho colhidas em espigas

RESUMO – Sementes colhidas em espiga possuem elevados teores de água. Assim, o objetivo neste trabalho foi avaliar a perda de qualidade fisiológica de sementes de milho colhidas em espiga, em função do retardamento de secagem. As espigas de milho híbrido foram colhidas com 31% de umidade e submetidas ao atraso da secagem por 0, 12, 24 e 36 horas, sob as temperaturas de 30, 40, 50 e 60 °C. As avaliações da qualidade fisiológica foram realizadas aos 0, 4, 8 e 12 meses de armazenamento. Utilizou-se o delineamento inteiramente casualizado, em um esquema fatorial 4 x 4 x 4, com quatro repetições. Adicionalmente, foi realizado um levantamento do tempo médio até a secagem e temperatura de todas as cargas de um híbrido recebidas em uma unidade de beneficiamento de sementes. A qualidade fisiológica não foi afetada pelas temperaturas abaixo de 40 °C, considerando-se 36 horas de espera até a secagem. Com a temperatura no retardamento da secagem de 50 °C, a germinação foi prejudicada com 36 horas e o vigor com 24 horas de atraso, e os danos foram maiores com o avanço do armazenamento. Para a temperatura de 60 °C, as perdas de qualidade ocorrem nas primeiras horas de retardamento de secagem.

Termos para indexação: germinação, retardamento de secagem, transporte, vigor, *Zea mays*.

Introduction

The seed market annually moves large sums of money worldwide. Within the segment, corn hybrids have a significant economic representation, with high rates of certified-seed

usage (between 90% and 92%) (Lima and Borém, 2018).

Hybrid seeds of top physiological quality are essential for properly establishing plant stands and also for guaranteeing high yields (Mondo et al., 2012). In addition, due to the economic relevance and the fierce competition among the

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numerous seed-processing companies, the production of hybrid seeds often employs highly sophisticated technology.

Most of the harvest of hybrid corn seeds is executed near the physiological maturity phase, so that to minimize the harmful effects of in-field storage. However, this practice must be followed by artificial drying, in order to delay the deterioration process, characterized by an increase in respiratory activity and the consumption of seed reserves (Peske and Villela, 2012; Vergara et al., 2018).

Some special attention must be paid during the harvesting of the seeds, as the success or failure of the following steps (drying and storage) are directly linked to the conservation of the product (Peske and Hamer, 1997; Afonso-Júnior and Corrêa, 2000; Khatun et al., 2009). An early harvest helps to keep the quality of corn seeds, as they get less exposed to pest, diseases and adverse climatic conditions related to air humidity and temperature. Nevertheless, this measure is only feasible when the seeds are reaped on the ears, state in which the seeds usually have a moisture content rounding 35% – or even 40%, in some cases (Ferreira et al., 2013).

The preservation of seeds during and after harvest is challenging, once various factors might compromise their physiological health. The main issues are related to temperature, relative humidity of the air and moisture content of the product. Together, they account for the deterioration intensity (Carvalho and Nakagawa, 2012; Shaban, 2013).

Ferreira et al. (2015) investigated corn seeds harvested with 30%, 40% and 45% moisture contents. They noticed a more substantial expression of enzymes related to aerobic and anaerobic respiration (malate dehydrogenase – MDH, and alcohol dehydrogenase – ADH, respectively) in those seeds bearing higher water content. According to Castro et al. (2017), the more expressed MDH is, the more intense the respiratory activity and, consequently, the faster the deterioration of grains occurs.

At high air temperatures and elevated relative humidity levels, postponing the drying process favors the depreciation of seeds. Castro et al. (2015) confirmed that the vigor of seeds of a specific corn line was indeed much affected in such circumstances, but they did not consider the latent damages originated throughout storage. This important aspect must be reckoned, as many conditions can become evident only during sowing, that is, after the storage period.

Even after drying and processing, the quality of seeds is prone to decay, and this phenomenon may considerably intensify under non-controlled storage conditions (Timóteo and Marcos-Filho, 2013). On the other hand, in a monitored environment, which includes refrigeration and humidity regulation, seeds are more likely to retain their physiological

quality for longer (Carvalho et al., 2014).

Given the economic value of hybrid corn seeds and the scarcity of scientific information on production parameters, it is imperative to study the aspects related to seed moisture and quality physiological, total time spent before drying, temperature of the ear mass, and other relevant storage aspects. Despite being conducted on experimental scales, these investigations should reflect real situations faced by seed companies. Thus, it was aimed at evaluate the loss of physiological quality of corn seeds harvested on the ears as a function of the waiting time (between harvest and drying) and distinct temperatures in the mass of ears, and the effects of these factors throughout the storage period.

Material and Methods

The experiment was carried out in the laboratory of corn production research and in the processing unit, both belonging to the company Syngenta, based in the Brazilian state of *Minas Gerais* (MG), in the cities of *Uberlândia* and *Ituiutaba*, respectively.

Hybrid corn ears were manually collected from a single production field, in *Uberlândia* (MG), at the moisture content of 31%. The seeds were subsequently subjected to various waiting-time simulations (before drying), at different temperatures.

Four replications sets, each containing 20 corn ears with the husk, were stowed in Raschel bags, made of high-density polyethylene – which allows balancing temperature and humidity with the surroundings. Next, they were placed inside BOD chambers set at 30, 40, 50 or 60 °C, without lighting nor ventilation. They remained there until the drying process, for four distinct periods: 0, 12, 24 and 36 h. By the end of each time, the husks were removed by hand, and the ears were dried in a forced-convection oven at 35 °C, until the moisture content reached 13%. Then, they were manually threshed and the seeds were sorted with the aid of sieves sized 18 to 22, free from impurities. Next, they were treated with the recommended dose of Maxim Advanced® (Metalaxyl + Thiabendazole + Fludioxonil), K-Obiol® (Deltamethrin) and Actellic® (Pirimiphos-methyl). Lastly, they were packed in multilayer kraft paper bags and stored inside a cold chamber with controlled temperature (10 °C) and relative humidity (54%) for 12 months.

The physiological quality was assessed during storage at 0, 4, 8 and 12 months, when the seeds were tested by germination and accelerated aging tests. These analyses employed four replicates of 50 seeds and were carried out as follows:

Germination: seeds were sown over germitest paper rolls, moistened with distilled water at the proportion of 2.5 times the

substrate weight. They were kept in a germinator set at 25 °C for seven days, when the number of normal seedlings was counted (Brasil, 2009). The results were expressed in percentage.

Vigor (accelerated aging test): 40 mL of water were added into adapted gerboxes, and the seeds were evenly distributed over the inner screen, without overlaying them. Later, the boxes were put inside a BOD chamber with the temperature controlled at 42 °C for 96 h (Vieira and Carvalho, 1994). They were arranged so as not to occupy the entire surface of the trays of the BOD. After the incubation period, the seeds were subjected to the germination test, as previously described.

The testing followed a completely randomized design (CRD), in a 4 x 4 x 4 factorial scheme – corresponding to four waiting periods (before drying), four temperatures (in the waiting environment) and four storage times – in four replications. The data were subjected to analyses of variance, handled by the software Sisvar® (Ferreira, 2014), at a 5% probability level by F test. When pertinent, the means were sorted by the Scott-Knott test at a 5% probability level, or adjusted to polynomial regressions models, choosing the significant model with the highest coefficient of determination and biological correlation.

Additionally, a supplementary descriptive study of a real-scale operation was carried out *in situ*, in a corn seed processing unit (SPU) located in *Ituiutaba* (MG). This survey monitored and reported all loads of a specific corn hybrid received by the facility in the crop year of 2017/18. For this matter, the following aspects were considered: average temperature of the mass of corn ears in the load (in °C), total time spent in the trucks (from harvest to the unloading at the SPU, in h), and total time until drying (from harvest, in h). These data were plotted in graphs with the aid of the software JMP 13.0. They were introduced and explored descriptively, in contrast with the information obtained in the laboratory experiments.

Results and Discussion

Separately, the storage time, waiting temperature and waiting period before drying led to different germination percentages and seed vigor results. Additionally, the interaction among these three variables significantly influenced seed vigor, whereas the temperature and the duration of the waiting phase had a jointly effect on germination (Table 1).

The germination assessed during storage displayed a quadratic effect, with a high determination coefficient and little variation in magnitude (Figure 1a), as evidenced by the low coefficient of variation (Table 1). There was a decrease in the average germination throughout storage, which ranged from

Table 1. Analysis of variance of the germination and vigor results of corn seeds, that had been subjected to drying delay for different times and at various temperatures and to subsequent storage.

Variable	DF	Mean square values	
		Germination	Vigor
Storage (S)	3	47.29**	72.22**
Waiting temperature (T)	3	41262.47**	45140.05**
Drying delay (D)	3	7964.78**	9325.85**
S*T	9	4.07	42.96**
S*D	9	3.89	30.75**
T*D	9	7211.92**	7465.75**
S*T*D	27	4.33	21.99**
Residue	192	7.51	5.98
CV (%)		3.31	3.07
Mean (%)		83	79.8

*Significant at a 5% probability level, according to the F test ($p < 0.05$).

**Significant at a 1% probability level, according to the F test ($p < 0.01$).

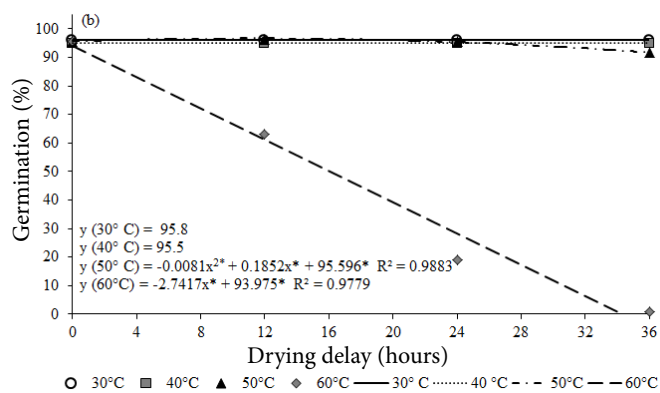
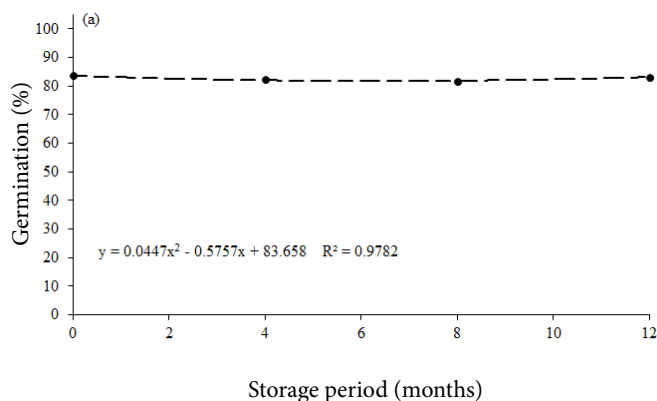


Figure 1. Germination (%) of corn seeds as a function of (a) the storage period and (b) the duration and temperature during the drying delay.

84%, in the beginning, to 82%, 6.54 months later, when the lowest rate was estimated. Even the storage in a cold chamber compromised the germination of corn seeds over time.

Monitoring temperature and humidity inside warehouses is strongly advisable to preserve corn seeds, as their deterioration generally happens at a slower pace under controlled conditions (Timóteo and Marcos-Filho, 2013; Lorenzetti, 2017). Therefore, the storage ambient directly affects the final quality of seed lots, which usually retain their physiological potential for longer once kept in a refrigerated, humidity-controlled environment (Carvalho et al., 2014).

Seeds that had their drying postponed for 12 or 24 h showed depreciation of germination only when the highest temperature, 60 °C (Table 2). As the waiting time prior to drying extended for 36 h, the germination was impaired at 50 °C, and it got as low as 1% at 60 °C. The temperature of 60 °C during the drying delay also damaged seed viability of a line of corn (Castro et al., 2015).

Regarding the germination as a function of the temperature and waiting time before drying, a quadratic model was adjusted to 50 °C and a linear one was applied to 60 °C, with coefficients of determination equal to 0.9883 and 0.9779, respectively (Figure 1b). Up to 36 h of waiting, the temperatures under 40 °C did not damage the germination of hybrid corn seeds reaped on the ear with high moisture content (31%). Thus, this condition represents a maximum feasible limit to be used for protecting the quality between the harvest and drying steps.

At 50 °C, the interval before drying caused a reduction in the germination percentage in delay longer than 24 h, having the effects been potentialized by the end of 36 h (Figure 1b). At 60 °C, a downward linear effect was detected, implying that the longer the waiting time, the lower the seed germination. In this situation, seed degradation happened more prominently within the first hours of delay, when it caused a germination loss of 2.7% per hour of waiting. This fact reaffirms the importance of drying the seeds as soon as possible after their harvest, especially in seasons, geographical regions and conditions that favor the occurrence of high temperatures.

By postponing drying in corn seeds, Rangel et al. (2003) verified an immediate loss in their physiological quality. Notably, at 60 °C, the respiration rate increased, and the deterioration accelerated. Likewise, while pondering various conditions of initial moisture content and drying delay, Castro et al. (2015) also verified a germination loss in seeds of a line of corn exposed to 60 °C. At lower values (20 °C and 40 °C), the adverse effects occurred only when the seeds started the delay time with a higher moisture content (48%).

As for the effect of the temperature during the drying delay on seed vigor (Table 3), no difference was noticed at first

(0 h), but the divergences started to become evident after 12 h of waiting. At the lowest temperature (30 °C), the initial vigor analysis, prior to storage and after 12 h of waiting, scored 95%. This value was superior to the equivalent ones, tested at higher temperatures, and such tendency occurred in other analyses over the storage time (Table 3). After 12 h of drying delay, considering the storage for 4 months, no difference was noticed between the temperatures of 40 °C and 50 °C. After 8 months, the temperatures of 30 °C and 50 °C provided similar

Table 2. Germination (%) of corn seeds harvested on the ears and subjected to different waiting times and temperatures prior to drying.

Waiting temperature (°C)	Drying delay (h)			
	0	12	24	36
30	96 a	96 a	96 a	96 a
40	96 a	96 a	96 a	95 a
50	96 a	96 a	96 a	92 b
60	96 a	63 b	19 b	1 c

*Means followed by the same letter, in the column, do not differ at a 5% probability level, according to the Scott-Knott test.

Table 3. Vigor of corn seeds evaluated via accelerated aging, after they had been subjected to different waiting times and temperatures prior to drying, and also to different storage periods.

Storage (months)	Waiting temperature (°C)	Drying delay (h)*			
		0	12	24	36
0	30	95 a	95 a	96 a	89 b
	40	95 a	88 b	92 b	92 a
	50	95 a	90 b	85 c	86 b
	60	95 a	60 c	9 d	0 c
4	30	96 a	98 a	95 a	96 a
	40	96 a	94 b	94 a	93 a
	50	96 a	91 b	90 b	89 b
	60	96 a	57 c	8 c	1 c
8	30	92 a	95 a	93 a	91 a
	40	92 a	92 b	94 a	92 a
	50	92 a	97 a	95 a	82 b
	60	92 a	62 c	10 b	1 c
12	30	95 a	97 a	98 a	96 a
	40	95 a	99 a	96 a	96 a
	50	95 a	92 b	96 a	88 b
	60	95 a	54 c	4 b	1 c

*Means followed by the same letter in the column, within each storage period, do not differ at a 5% probability level, according to the Scott-Knott test.

vigor levels. With 12 months, in turn, there was a reduction in the seed vigor evaluated at 50 °C, even after the shortest delay (12 h). At this interval, the deterioration was very intense at 60 °C in all storage periods.

Within 24 h of drying delay (Table 3), the degradation was more prominent at 60 °C – after certain storage times, however, it was conspicuous even at 50 °C. These occurrences accentuated after 36 h of drying delay. In general, for all storage periods considered, the temperatures of 30 °C and 40 °C did not weaken seed vigor, whereas an initial decay was noticeable at 50 °C and a total deterioration prevailed at 60 °C.

Overall, temperatures up to 40 °C during drying delay did not affect the viability of corn seeds. As for their vigor, at 50 °C there was an initial degradation, which got stronger at 60 °C. Castro et al. (2015) verified changes in seed vigor of a line of corn after the drying delay, even at lower temperatures (20 °C and 40 °C), especially when those seeds had been collected with moisture contents above 34.2%.

When they carried out the drying delay at 30 °C or 40 °C, the vigor levels remained high (between 92% and 96%) even after 4, 8 and 12 months of storage (Figure 2).

At the beginning of storage, the temperature of 50 °C led to the low vigor value of 85%, considering the waiting period of 36 h prior to drying (Figure 2a). After 8 and 12 months of storage (Figures 2c and 2d), a quadratic effect with a sharp decline trend was detected in the vigor of seeds subjected to 24 h of drying delay. After 4 months of storage at 50 °C (Figure 2b), the vigor degradation complied with a decreasing linear effect, with the vigor diminishing by 1.9% every 10 h of delay.

Regarding the temperature of 60 °C, a downward linear effect was observable in all storage periods (Figure 2), with relevant losses in the first hours of delay. In the earliest storage (Figure 2a), every hour of delay implied in a 2.78% reduction in vigor, which zeroed after 32.57 h. After 4 and 8 months of storage (Figures 2b and 2c), seed vigor decayed at rates of 2.79% and 2.71% per hour of delay, becoming null after 32.41 and 33.17 h, respectively. After 12 months of storage (Figure 2d), seeds suffered 2.78% of depreciation per hour of delay, and the complete loss of vigor happened after 31.74 h. Therefore, in all storage periods appraised, the temperature of 60 °C provoked total depletion of vigor within approximately 32 h of drying delay. This fact reinforces the

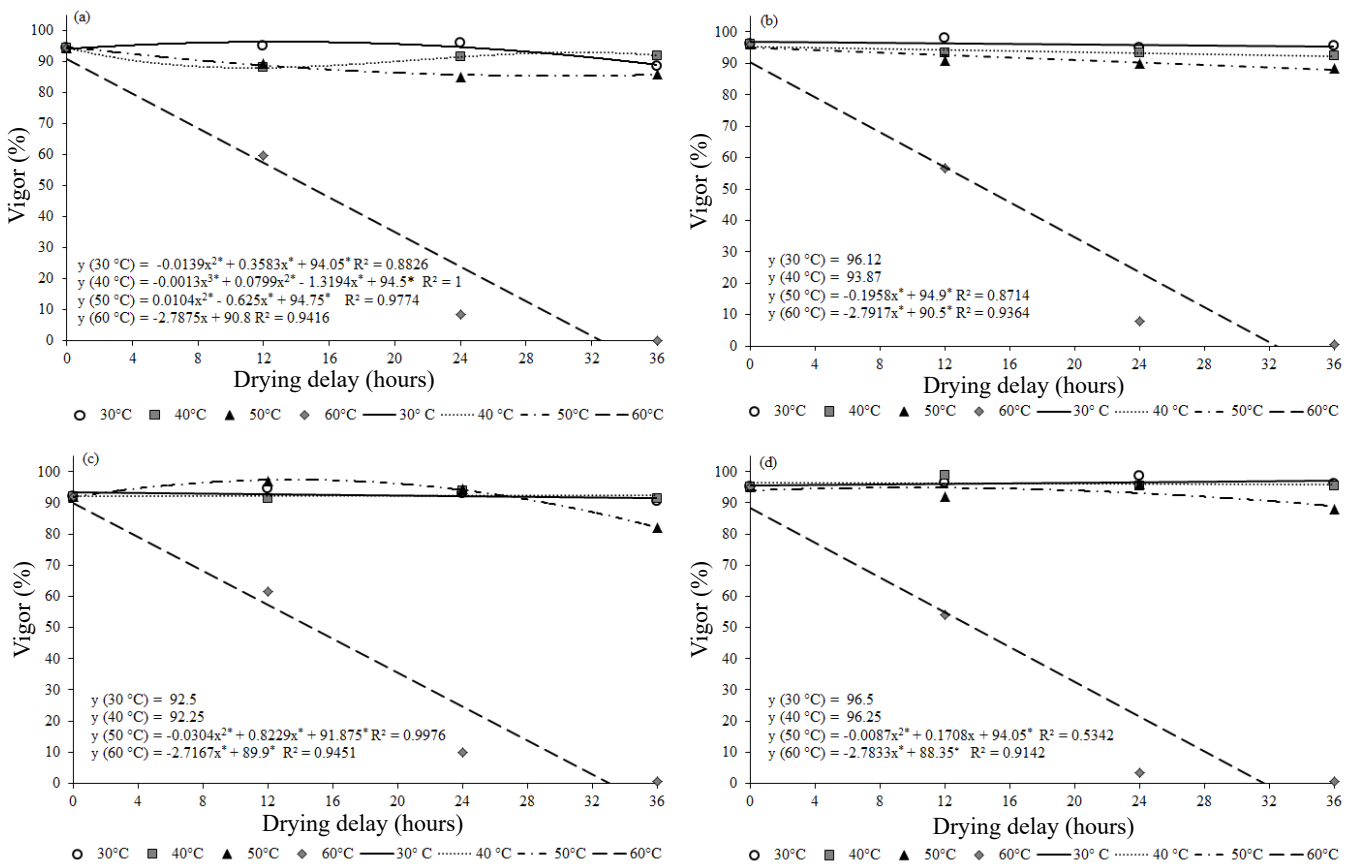


Figure 2. Vigor of corn seeds, assessed via accelerated aging, as a function of the drying delay duration, at different temperatures and after (a) 0, (b) 4, (c) 8 and (d) 12 months of storage.

importance of drying seeds right after harvested, especially when temperatures over 40 °C are involved.

At 60 °C, both deterioration and respiration accelerate, with consequent consumption of reserves, protein denaturation and isoenzymic alterations, which overall impair the physiology of seeds (Rangel et al., 2003). Lopes et al. (2017) correlate the enzymes α - and β -amylase with seed quality. At high temperatures, they denature, drastically compromising the potential of seed lots, as they are responsible for processes such as the hydrolysis of starch and the catalysis of maltose and dextrans, which are crucial for maintaining the physiological quality of seeds.

Regarding the temperatures of 30 °C (Figure 3a) and 40 °C (Figure 3b) during the waiting before drying, all vigor values rounded close or above 90%, even as the storage progressed to up to 12 months. At 50 °C and 36 h of drying delay (Figure 3c), seeds showed high vigor before the 4th month of storage but, past this point, this feature started to decline. This might have happened due to the latency of some physical harms caused to cells and tissues of the seeds. At 60 °C (Figure 3d), in drying delays equal to or longer than 24 h, the vigor percentages were

low from the beginning of storage – at 36 h of waiting, it almost zeroed. At a shorter delay (12 h), an intermediate vigor was verified, but the effects of the damages intensified as the storage approached its end.

Lowering the temperature minimizes the speed of biochemical and metabolic reactions in corn seeds. It therefore reduces the mobilization, transport and synthesis of reserves in the embryonic axis (Paraginski et al., 2015). In addition to the temperature during the waiting period, the drying system itself can engender some damages and physiological alterations that diminish the quality of the lot. These adverse effects are likely to escalate during storage (Vergara et al., 2018).

In general terms, temperatures below 40 °C and waiting times shorter than 36 h did not impair the physiological potential of the seeds, so these conditions can be employed as adequate limits for controlling quality. At higher temperatures prior to drying (50 °C and 60 °C), the harm caused to seed physiology was noticeable, even within a few hours of delay in some cases. The transport from the farms to the seed-processing units is a critical phase, as seeds reaped on the ears

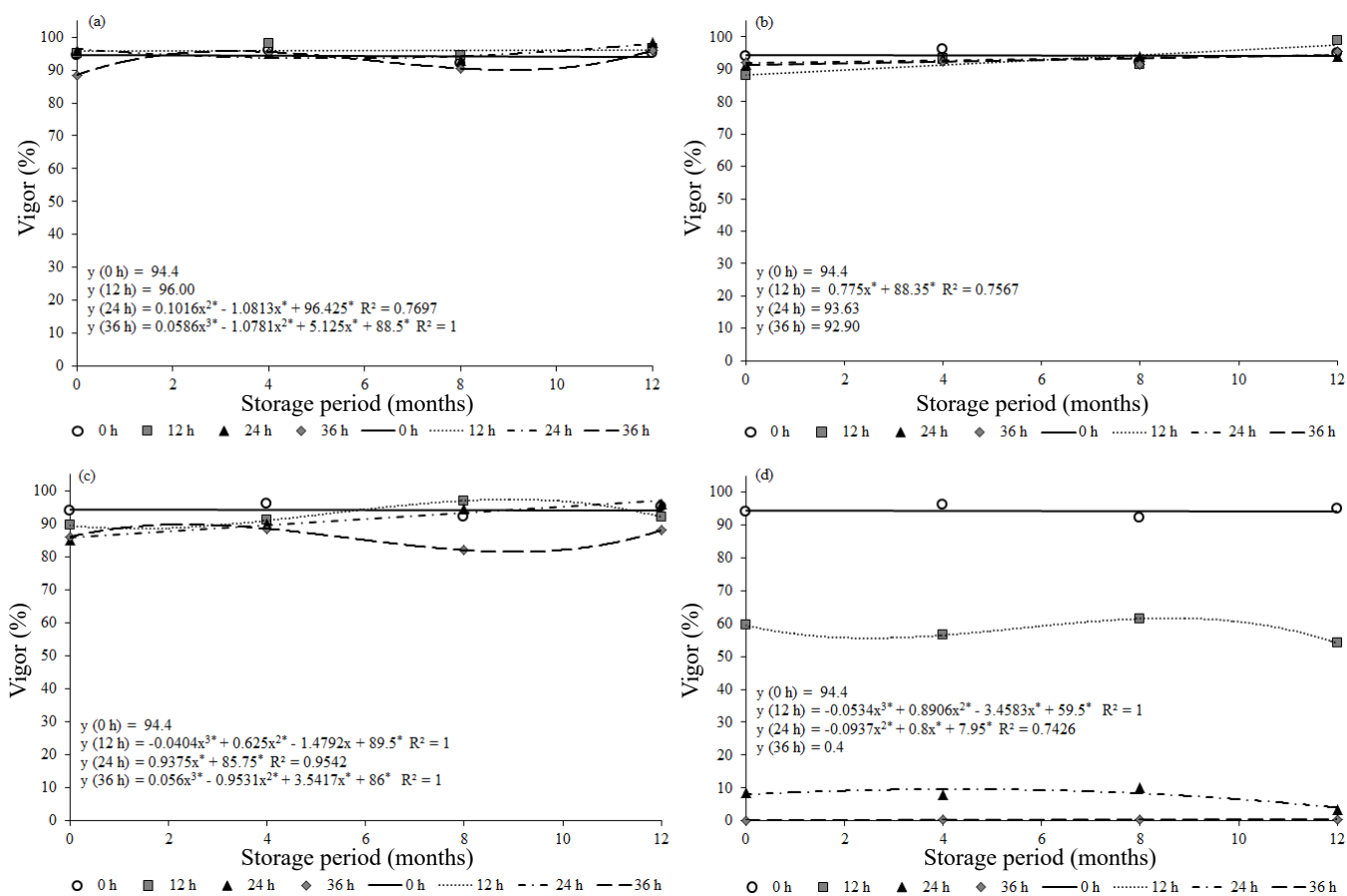


Figure 3. Vigor of corn seeds, assessed via accelerated aging, as a function of the storage time and drying delay period, at temperatures prior to drying (a) 30 °C, (b) 40 °C, (c) 50 °C and (d) 60 °C.

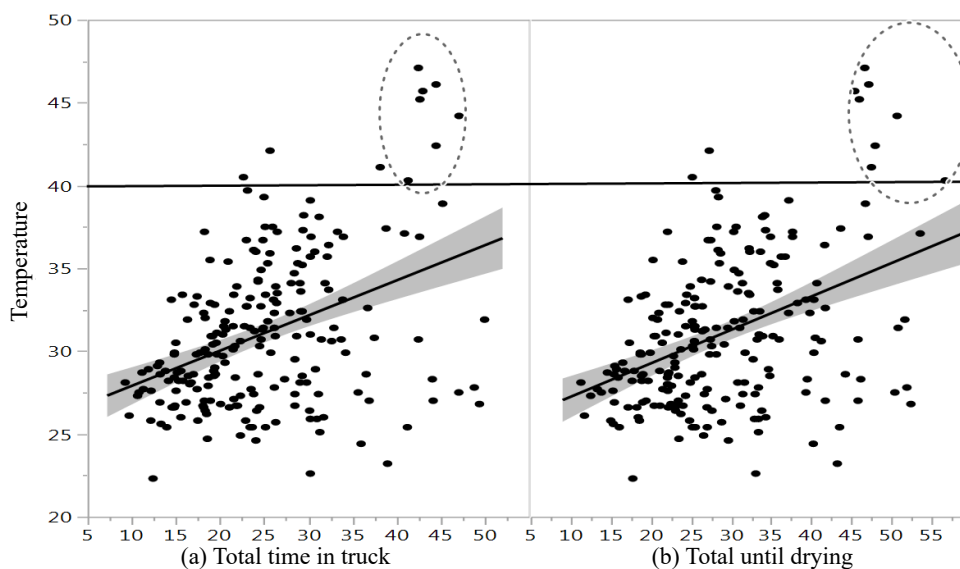


Figure 4. Temperatures ($^{\circ}\text{C}$) in the mass of corn ears, of each load received at the corn seed processing unit (SPU), as a function of (a) the total time spent in the truck (h) and (b) total time before drying.

usually have high moisture content and intense metabolic activity. These factors, in association with an environment with little ventilation, exposed to strong sunlight incidence that raise the temperature inside the mass of ears, tend to boost deterioration. On that account, drying the seeds is a measure that should be executed as early as possible.

The real-scale study conducted at a seed-processing unit monitored a total of 217 trucks (loads) transporting corn ears to drying (Figure 4). In this survey, a rising linear trend was observed, once the longer it took to dry the seeds, the higher the registered temperatures were. For that reason, it is necessary to draw strategies to attenuate the effect of excessively hot temperatures (above 40°C) in the mass of corn ears, as they directly influence seed quality. These actions might include frequently gauging the temperature of each load (during the transport and also throughout the waiting period before unloading) and establishing an unloading scale that prioritizes the trucks with higher temperatures.

The results showed that seeds spent from 9.27 to 50 h inside the trucks, producing a rising linear trend: the longer this span, the higher the temperature in the mass of corn ears (Figure 4a). In turn, the total waiting period before drying ranged between 11.28 and 51.67 h, also with a general linear trend (Figure 4b). Most of the loads that exceeded the maximum limit of 40°C had faced drying delay, generally which had lasted more than 40 h (Figure 4). These observations support the need for drying corn seeds as soon as possible, especially when they are harvest on the ears, with high moisture contents.

Conclusions

Both germination and seed vigor are not affected by the temperature in the mass of corn ears harvested at 31% moisture content – considering the maximum limits of 40°C and 36 h of drying delay.

At 50°C , the germination is compromised with 36 h of drying delay. Seed vigor is early affected during the waiting period (24 h), and the losses tend to increase as the storage progresses.

At 60°C , both germination and seed vigor decrease within the first hours of drying delay.

Acknowledgments

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