Research, Society and Development, v. 11, n. 15, e565111537071, 2022
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v11i15.37071

Alternative method of maize grain quality maintenance for small farmers through hermetic storage

Método alternativo de manutenção da qualidade do grão de milho para pequenos agricultores através do armazenamento hermético

Método alternativo de mantenimiento de la calidad del grano de maíz para pequeños agricultores a través del almacenamiento hermético

Received: 10/26/2022 | Revised: 11/16/2022 | Accepted: 11/19/2022 | Published: 11/26/2022

Maksaila Soares Gomes da Silva
ORCID: https://orcid.org/0000-0001-7669-9979
Federal Institute of Maranhão, Brazil
E-mail: maksailasoares@outlook.com
Gutierres Nelson Silva
ORCID: https://orcid.org/0000-0002-4272-0634
Federal Institute of Mato Grosso do Sul, Brazil
E-mail: gutierres.silva@ifms.edu.br
Míria Grasiele Casado da Silva
ORCID: https://orcid.org/0000-0003-2122-2027
Universidade Federal de Viçosa, Brazil
E-mail: miriag.silva@ufv.br
Adalberto Hipólito Sousa
ORCID: https://orcid.org/0000-0002-3089-2762
Universidade Federal do Acre, Brazil
E-mail: adalbertohipolito@hotmail.com
Douglas Rafael e Silva Barbosa
ORCID: https://orcid.org/0000-0003-0234-773X
Federal Institute of Maranhão, Brazil
E-mail: douglas.barbosa@ifma.edu.br
Lêda Rita D` Antonino Faroni
ORCID: https://orcid.org/0000-0001-8648-5034
Universidade Federal de Viçosa, Brazil
E-mail: lfaroni@gmail.com
Kesleyane Pereira Camilo
ORCID: https://orcid.org/0000-0002-7538-4163
Universidade Federal de Viçosa, Brazil
E-mail: kesleyane.camilo@ufv.br
Paloma Vieira Brás
ORCID: https://orcid.org/0000-0002-3985-0411
Universidade Federal de Viçosa, Brazil
E-mail: paloma.bras@ufv.br
Ana Carolina Melo Ribeiro
ORCID: https://orcid.org/0000-0003-0891-2445
Universidade Federal de Viçosa, Brazil
E-mail: ana.carolina7@ufv.br
Marcela Silva Carvalho
ORCID: https://orcid.org/0000-0002-8996-5743
Federal Institute of Mato Grosso do Sul, Brazil
E-mail: marcelasc.eng@gmail.com

Abstract
In many countries, small corn producers generally have technological limitations during storage. hermetic storage with use of PET bottles stands out as an alternative. The objective of this study was to evaluate the hermetic storage of corn in polyethylene silo bags and PET bottles as an alternative for small producers. Maize grains were stored in polyethylene silo bags, polyethylene terephthalate (PET) bottles and glass recipients for 0, 15, 30, 45, and 60 days. Were used four repetitions for each treatment. Were evaluated the traits: infestation by insect pests (%); water content (% bu.); bulk density (kg 100 L^{-1}); electrical conductivity (µS cm^{-1} g^{-1}); percentage of germination (%). The insect species that infested the corn kernels under hermetic and non-hermetic conditions was only *Sitophilus zeamais*. PET bottles presented the lowest percentage of infestation among the storage containers, followed by silo bags, both

presented the maximum percentages of 0.65% and 30%, respectively. Water content, bulk density, electrical conductivity e percentage of germination of the maize were preserved in both hermetic storage systems that were tested for 60 days. The use of PET bottles control *S. zeamais* and preserve the quality of maize for at least 60 days of storage. Our study concludes that hermetic storage in PET bottles can be particularly useful and important for small farmers.
Keywords: Hermetic Storage; *Zea mays*; Stored grains.

Resumo
Em muitos países, os pequenos produtores de milho geralmente apresentam limitações tecnológicas durante o armazenamento. O armazenamento hermético com uso de garrafas PET destaca-se como alternativa. O objetivo deste trabalho foi avaliar o armazenamento hermético de milho em silo-sacos de polietileno e garrafas PET como alternativa para pequenos produtores. Os grãos de milho foram armazenados em silos de polietileno, garrafas de polietileno tereftalato (PET) e recipientes de vidro por 0, 15, 30, 45 e 60 dias. Foram utilizadas quatro repetições para cada tratamento. Foram avaliadas as características: infestação por insetos-praga (%); teor de água (% bu.); densidade aparente (kg 100 L-1); condutividade elétrica (µS cm^{-1} g^{-1}); porcentagem de germinação (%). A espécie de inseto que infestou os grãos de milho em condições herméticas e não herméticas foi apenas *Sitophilus zeamais*. As garrafas PET apresentaram o menor percentual de infestação entre os recipientes de armazenamento, seguidos dos silo bags, ambos com percentuais máximos de 0,65% e 30%, respectivamente. Teor de água, densidade do solo, condutividade elétrica e porcentagem de germinação do milho foram preservados em ambos os sistemas de armazenamento hermético testados por 60 dias. O uso de garrafas PET controla o *S. zeamais* e preserva a qualidade do milho por no mínimo 60 dias de armazenamento. Nosso estudo conclui que o armazenamento hermético em garrafas PET pode ser particularmente útil e importante para pequenos agricultores.
Palavras-chave: Armazenamento hermético; *Zea mays*; Grãos armazenados.

Resumen
En muchos países, los pequeños productores de maíz generalmente tienen limitaciones tecnológicas durante el almacenamiento. Se destaca como alternativa el almacenamiento hermético con uso de botellas PET. El objetivo de este estudio fue evaluar el almacenamiento hermético de maíz en silo bolsas de polietileno y botellas PET como alternativa para pequeños productores. Los granos de maíz se almacenaron en silos bolsas de polietileno, botellas de tereftalato de polietileno (PET) y recipientes de vidrio durante 0, 15, 30, 45 y 60 días. Se utilizaron cuatro repeticiones para cada tratamiento. Se evaluaron los rasgos: infestación por insectos plaga (%); contenido de agua (% bu.); densidad aparente (kg 100 L-1); conductividad eléctrica (µS cm^{-1} g^{-1}); porcentaje de germinación (%). La especie de insecto que infestó los granos de maíz en condiciones herméticas y no herméticas fue únicamente *Sitophilus zeamais*. Las botellas de PET presentaron el menor porcentaje de infestación entre los envases de almacenamiento, seguidas de las bolsas de silo, ambas presentaron los porcentajes máximos de 0,65% y 30%, respectivamente. El contenido de agua, la densidad aparente, la conductividad eléctrica y el porcentaje de germinación del maíz se conservaron en ambos sistemas de almacenamiento hermético que se probaron durante 60 días. El uso de botellas de PET controla *S. zeamais* y preserva la calidad del maíz durante al menos 60 días de almacenamiento. Nuestro estudio concluye que el almacenamiento hermético en botellas de PET puede ser particularmente útil e importante para los pequeños agricultores.
Palabras clave: Almacenamiento hermético; *Zea mays*; Granos almacenados.

1. Introduction

Corn (*Zea mays* L.) is one of the main crops produced by small farmers worldwide (Acheampong et al. 2019). It is the second most-produced grain in Brazil, with a production estimate of approximately 98.5 million tons for the 2018/2019 harvest. This production represents an increase of 22.0% compared to last season (CONAB 2019).

Despite the increase in maize production, significant losses occur during the storage stage, with post-harvest losses of maize reaching up to 36% (Tefera 2012). This is a challenge for many farmers in developing countries (Abass et al. 2014), who generally carry out grain storage using traditional methods (Lane & Woloshuk 2017).

Losses during maize storage are caused by both biotic and abiotic factors (Suleiman et al. 2018). Among the biotic factors, we highlight pest insects, which are responsible for large economic losses of stored grains (Silva et al. 2012). Regarding corn storage in tropical and subtropical countries including Brazil, *Sitophilus zeamais* Mots., 1855 (Coleoptera: Curculionidae) is an important pest (Kaguchia et al. 2018; Baoua et al. 2014). It can reduce the nutritional value, germination percentage, weight, and commercialization of the grains (Frazão et al. 2018; Khakata et al. 2018).

S. zeamais is controlled mainly using fumigant phosphine (PH_3) and pyrethroid, and organophosphorus insecticides (Vélez et al. 2019; Walker et al. 2018). However, the continuous and indiscriminate use of these insecticides over the years has favored the development of populations of insect pests resistant to these products and is creating concerns regarding environmental pollution and carcinogenicity (Kaguchia et al. 2018).

In Brazil, small corn farmers usually have technological limitations surrounding storage. This necessitates either selling soon after harvesting, when prices are still low, or drying the beans in the sun, leaving the ears directly on the ground to later store in inadequate conditions. Compared to the above methods, hermetic storage stands out as a superior alternative for the storage of maize by small farmers.

Hermetic storage of grains limits gas exchange and prevents the grains from losing moisture. This results in a modification in the grains' internal atmosphere, which can deplete oxygen and create an anaerobic environment that is unfavorable to the growth and development of pest insects (Sanon et al. 2011; Walker et al. 2018). The hermetically sealed polyethylene silo bags stand out as an alternative for grain storage to meet the high demand for storage units at the farm level (Freitas et al. 2016; Jones et al. 2011). The material of the silo bags is composed of three layers of high-density polyethylene, whose functions are to reflect ultraviolet rays, preserve the plastic and increase its resistance, and help maintain the temperature of the stored product (Freitas et al. 2016; Santos et al. 2010).

The use of alternative containers to store grains may be an option for small farmers to meet specific needs such as small harvesting or storage in smaller portions in order to separate seeds from grains (Williams et al. 2017). An example of an alternative container for use as hermetic storage is polyethylene terephthalate (PET) bottles. The objective of this study was to evaluate the hermetic storage of corn in polyethylene silo bags and PET bottles as an alternative for small producers.

2. Methodology

The experiment was conducted at a municipality located at 4°27′18″ S and 43°53′09″ W (Gr.), at an altitude of 43 m above sea level. The characteristics of the maize tested are shown in Table 1.

Table 1 - Initial characterization of corn grains.

Analysis	Value
Infestation by insect pests (%)	0.00±0.00*
Moisture content (% bu.)	11.74±0.08
Bulk density (kg 100 L^{-1})	82.20±0.54
Electric conductivity (µS cm^{-1} g^{-1})	17.41±0.08
Germination (%)	95.00±0.00

*(Mean± SE). Source: Authors.

The corn was packed in polyethylene silo bags and polyethylene terephthalate (PET) bottles. The bags had a 500-g capacity and were made of the same 250-mm thick plastic used for the manufacture of Silox ™ (DuPont) silo bags. The bags were made of a three-layer plastic and were black on the inner side and white on the outer side with UV stabilizers. The bags were hermetically sealed with a multi-use sealing machine (hot bar 40/60 cm). The plastic layers are a mixture of high dense (HDPE) and low dense polyethylene (LDPE). The plastic bottles were reused transparent soda bottles with a 0.6-L capacity and a 270-mm thickness. These were properly closed with a screw cap and sealed with beeswax to avoid gaseous torques. For the control treatment, the grains were placed in transparent glass containers with a 1.2-L capacity and closed with an organza fabric. The organza cloth was used to allow gas exchange between the ambient and inter-granular atmospheres, as well as to prevent the exit or entry of insects into the containers. In each sample unit were placed 50 non-sexed adults of *Sitophilus zeamais* (3 to 4 weeks old).

The corn was stored in the silo bags, PET bottles, and in the control containers for 0, 15, 30, 45, and 60 days in climatic chambers at a temperature of 25 ± 2°C and relative humidity of 70 ± 5%. Every 15 days, four packages of each treatment were opened to carry out analyses of infestation by insect pests, water content, apparent specific mass, percentage of germination, and electrical conductivity.

To evaluate the degree of infestation by pest insects, three samples of 100 corn grains, randomly removed from each treatment, were immersed in water for 24 h (a sufficient time to soften the grains). After this time, the grains were removed from the water, dried on filter paper, cut, and examined individually. Grains containing young adult forms and/or pest insect exit holes were considered infested, as recommended by the Rules for Seed Analysis (Brasil 2009).

The water content of the grains was determined by the standard greenhouse method, according to ASAE (2004) standards, which suggest the use of a forced air circulation oven at 130 ± 1°C for 72 h. The weighing was done in a 0.01-g resolution scale and the analyses were performed in triplicate, with the results being expressed on a wet basis.

The bulk density was determined in a hectolitric scale, model PH Determiner (DPH) (Balanças Dalle Molle Ltda), with a capacity of one quarter of a liter (250 mL). The analyses were performed according to the methodology described by the Rules for Seed Analysis (Brasil 2009).

The germination test was performed according to the Rules for Seed Analysis (Brasil 2009), by using four replicates of 50 grains per treatment. The substrate used was paper germitest, moistened with distilled water in the proportion of 2.5 times the weight of the paper. The corn kernels were placed on two leaves of the germinating paper, later covered by another sheet of the same paper, and then wrapped into rolls. The rollers were placed vertically within a germinator and maintained at a temperature of 25 ± 1°C. The final count was done after nine days, considering the normal seedlings, and the data were expressed as a mean percentage of germination.

Electrical conductivity of the solution containing the beans was measured using the cup system or mass conductivity (Vieira et al. 2002). The tests were performed with three replicates of 50 grains from each sample unit. The grains were weighed in an analytical balance with a precision of 0.01 g and placed in 200-mL plastic cups. Deionized water (75 mL) was then added to each cup. Afterward, the cups were placed in the climatic chamber type BOD, at 25°C, for 24 h. Immediately after this period, the cups were removed from the chamber for the measurements. The electrical conductivity of the grains was expressed in $\mu S\ cm^{-1}\ g^{-1}$.

The experiment was carried out using a completely randomized design, in a subdivided plots scheme, with four replications. The plots consisted of storage systems (silo bags, PET bottles, and control containers), and the subplots consisted of the storage periods (0, 15, 30, 45, and 60 days). Data were submitted to covariance analysis ($P < 0.05$). As the interaction between the storage conditions and the storage periods was significant, the data were unfolded. The values obtained were submitted to regression analysis as a function of time.

The regression models were chosen based on the significance of the regression coefficients, by using the t-test, coefficient of determination (R^2), and biological phenomenon. Because of the biological interest of this study, we opted to the unfold the data regardless of the degrees of interaction significance. Pearson's correlation coefficient ($P < 0.05$) was estimated between the insect infestation index and the water content, bulk density, percentage of germination, and electrical conductivity of corn grains.

(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v11i15.37071

3. Results and Discussion

The results regarding the initial characterization (zero storage time) of corn grains are presented in Table 1. In general, the insect infestation index was significantly influenced (P <0.05) by the treatments (control, silo bag and PET bottle), for all storage periods (Table 2). The control treatment presented mean values of insect infestation (P <0.05) statistically higher han the hermetic treatments in the storage periods of 15, 30, 45 and 60 days. The use of silo bag and PET bottle did not affect (P <0.05) the rate of insect infestation at storage periods of 15, 30, 45 and 60 days.

Table 2 - Means (±SE) Infestation, moisture content, bulk density, electric conductivity and germination of corn grains in different period and hermetic conditions of storage.

SP (days)	Infestation (%)		
	Control	**Silo bags**	**PET bottles**
0	0.00a	0.00a	0.00a
15	3.50a	1.25b	1.00b
30	27.50a	1.25b	1.00b
45	75.75a	1.25b	0.75b
60	100.00a	0.75b	0.75b
SP (days)	**Moisture content (%)**		
	Control	**Silo bags**	**PET bottles**
0	11.74a	11.74a	11.74a
15	12.44a	11.13b	11.28b
30	13.85a	11.18b	11.45b
45	14.19a	11.66b	11.66b
60	14.75a	11.79b	11.89b
SP (days)	**Bulk density (kg 100 L^{-1})**		
	Control	**Silo bags**	**PET bottles**
0	82.20a	82.20a	82.20a
15	79.64a	80.79a	81.06a
30	77.18b	79.91a	80.76a
45	72.77b	80.30a	80.25a
60	61.63b	79.34a	79.53a
SP (days)	**Electric conductivity (μS cm^{-1} g^{-1})**		
	Control	**Silo bags**	**PET bottles**
0	17.41a	17.41a	17.41a
15	38.37a	17.56b	17.76b
30	40.44a	19.66b	19.40b
45	45.10a	19.74b	20.06b
60	104.09a	19.79b	19.96b
SP (days)	**Germination (%)**		
	Control	**Silo bags**	**PET bottles**
0	95.00a	95.00a	95.00a
15	64.50b	93.00a	93.50a
30	55.50b	89.50a	89.50a
45	16.50b	87.50a	88.00a
60	0.00b	80.00a	79.50a

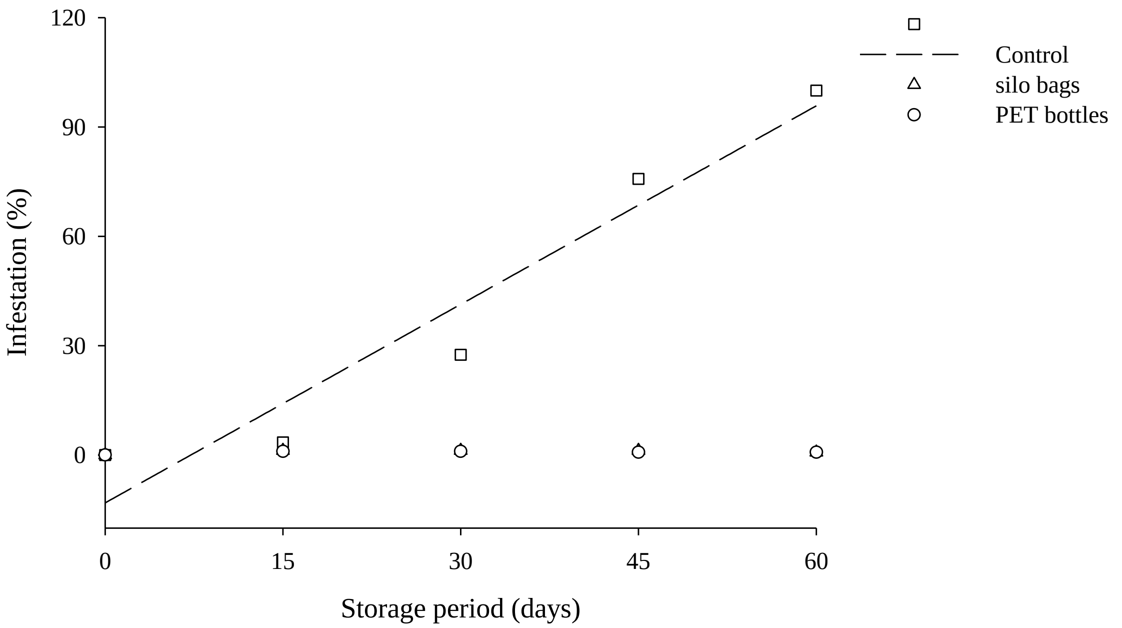
* Means followed by the same letter in the row for each variable do not differ from each other by the Tukey test (P <0.05); SP Storage period; SE standard error. Source: Authors.

The insect species that infested the corn kernels under hermetic and non-hermetic conditions was only *S. zeamais*. This weevil is the main stored-grain pest in tropical regions (Oliveira et al. 2018). An analogous result was verified by Lane and Woloshuk (2017), who studied the effectiveness of hermetic sacks for corn storage and observed that after three months of storage, the predominant insect was *S. zeamais*.

PET bottles and silo bags presented insect infestation percentage close to zero in all storage periods (Figure 1, Table 2 and 3). In the control treatment, the degree of infestation increased significantly (P<0.05), corresponding to a 100% increase of infestation throughout the storage of up to 60 days (Figure 1 and Table 2 and 3). Suleiman et al. (2018) studied the effect of *S.*

zeamais on maize quality during hermetic and non-hermetic storage and verified 100% mortality of insects after 60 days of storage under hermetic storage conditions. According to these authors, the hermetic treatment was observed to have a greater decrease of oxygen and a higher accumulation of carbon dioxide than those in other treatments, confirming that treatments that contained insects consumed more oxygen compared to the treatments without insects.

Figure 1 - Percentage of maize infested by *Sitophilus zeamais*, stored in silo bags (□), PET bottles (○), and control containers (Δ) during 60 days of storage. The symbols represent the means of replicates, and the line represents the adjusted model.



Source: Authors.

Table 3 - Mathematical models used to represent the variation in the qualitative characteristics of maize hermetically stored for 60 days, and the mean values of the characteristics that did not significantly vary depending on the rate of infestation in each storage system.

Variable	Storage	Equation or mean	df_{error}	*F*	*P*	R^2
	CO*	$\hat{y}$= -13,10 +1,81x	3	40.76	<0.01	0.93
Infestation	SB	-	-	-	-	-
	PB	-	-	-	-	-
	CO	$\hat{y}$= 11,84+0.05x	3	62.76	<0.01	0.95
Moisture content	SB	$\hat{y}$=11,65-0.03x+0.0006x^2	2	2.88	=0.25	0.74
	PB	$\hat{y}$=11.67-0.02x+0.0005x^2	2	4.51	=0.18	0.81
	CO	$\hat{y}$=84.29–0.32x	3	22.47	<0.01	0.88
Bulk density	SB	$\hat{y}$=81.75–0.04x	3	13.71	<0.05	0.82
	PB	$\hat{y}$=81.99–0.04x	3	71.74	<0.01	0.95
	CO	$\hat{y}$=93.90–1.58x	3	109.70	<0.01	0.97
Germination	SB	$\hat{y}$=96.10–0.23x	3	39.90	<0.01	0.93
	PB	$\hat{y}$=96.40–0.24x	3	27.61	<0.01	0.90
	CO	$\hat{y}$=13,06+1.20x	3	9.82	<0.05	0.76
Electrical conductivity	SB	$\hat{y}$=17.44+0.04x	3	11.55	<0.05	0.79
	PB	$\hat{y}$=17.43+0.04x	2	21.56	<0.05	0.87

* CO = control; SB = silo bags; PB = PET bottles. Source: Authors.

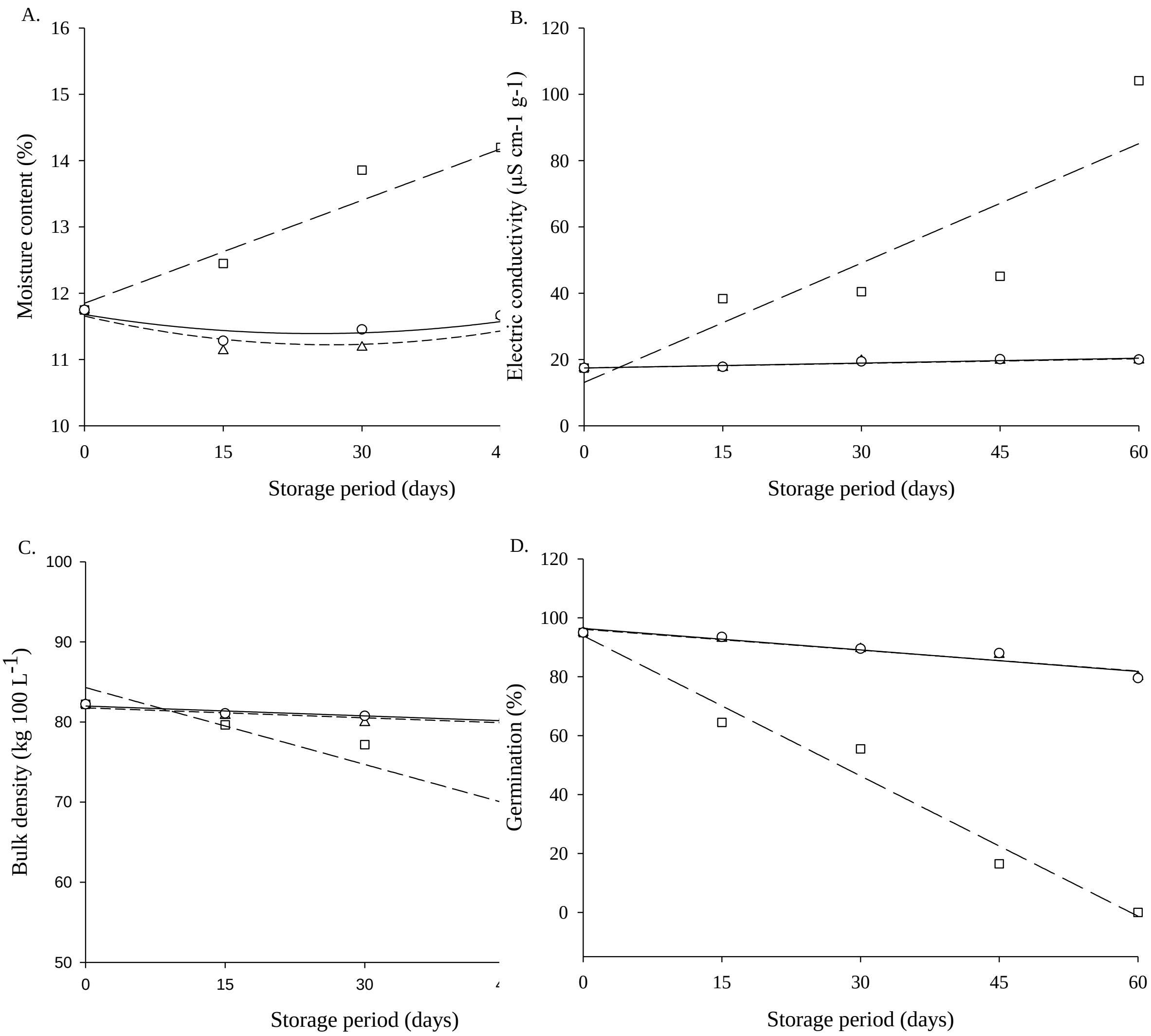
In the present study, we found a infestation index near to zero in hermetic treatments, probably due to the low oxygen content and the accumulation of carbon dioxide under these conditions. For Williams et al. (2017), the rapid consumption of oxygen by insects is the driving force of much of the protective action of hermetic storage, since conditions within the sealed vials reach limiting oxygen levels within a relatively short period of time.

The water content of corn grains showed significant variation (P <0.05) between treatments (Table 2). It was also observed that corn grains in the control treatment presented mean value statistically higher n all storage periods, compared to hermetic treatments.

One of the main causes associated with loss of grain quality during storage is an increase in high water content (Freitas et al. 2016). The water content of maize varied with the increase in the storage period in all treatments (Figure 2A and Table 3), although this increase was significant only in the non-hermetic treatment. Similar results were reported by Silva et al. (2018), who studied hermetic storage as an alternative to control *Callosobruchus maculatus* and maintenance of the quality of the cowpea, verified that the treatments with the bag-type silo and the PET bottle presented only a small increase in the water content, while the control treatment (non-hermetic condition) showed a significant increase in the water content of the grains.

The bulk density of corn grains presented lower mean values (P <0.05) in the control treatment, compared to grains of hermetic treatments (Table 2). The bulk density (Figure 2C and Table 3) decreased significantly during the time of storage of corn in all treatments, except for the hermetic treatments, in which this reduction was negligible. In the non-hermetic treatment, there was a reduction of 25.02% during 60 days of storage.

Figure 2 - Moisture content (A), electrical conductivity (B), bulk density (C), and germination (D) of maize stored in silo bags (Δ), PET bottles (○), and control containers (□) during 60 days of storage. The symbols represent the means, and the lines represent the adjusted regression models.



Source: Authors.

This low reduction of bulk density in hermetic treatments was also elucidated by Silva et al. (2018), who studied the effect of hermetic conditions on cowpea storage. The increase in water content and the significant decrease in bulk density within the non-hermetic treatment can be explained by the high infestation of *S. zeamais* in this treatment. According to Ribeiro et al. (2015), *S. zeamais* infestations can substantially reduce weight and increase grain water content, providing conditions favorable to the growth of microorganisms, resulting in higher post-harvest losses.

Germination in non-hermetic treatment also decreased significantly over the storage period (P <0.05) (Figure 2D and Table 3), reaching 100% reduction after 60 days of storage. Hermetic treatments showed germination rate during 60 days of storage, approximately of 80%. Similar results were reported by Williams et al. (2017), where they observed that corn germination decreased in all treatments (hermetic and non-hermetic) after eight months of storageAccording to these same authors, the highest germination rate was observed in the treatment with sealed plastic bottles not infested with insects (83.25 ± 3.6%). The bulk density and germination of maize presented a high relation with the degree of infestation of *S. zeamais*, with the hermetic storage method producing the smallest reduction of apparent specific mass and germination of the grains.

In previous studies, the hermetic system has been shown to better maintain grain quality owing to the lower respiratory rate that is associated with the reduction of insect infestation (Scariot et al., 2018). The low insect infestation observed in the present study in the hermetic storage is probably due to the reduction in gas exchanges within this environment. The reduction in gaseous exchange in plastic bottles is probably due to the physical properties of polyethylene terephthalate (PET) plastic polymer. This plastic polymer has oxygen permeability rates similar to high density polyethylene (HDPE), which is used to make PICS hermetically sealed bags (Williams et al., 2017).

There was a significant variation in electrical conductivity between treatments (P <0.05), this variation was significantly higher in the non-hermetic treatment, with an increase of 83.27% (Figure 2B and Table 3). Scariot et al. (2018) studied the quality of wheat grains stored in a hermetic and conventional system and found that the electrical conductivity of wheat increased over time for both storage systems but was lower in the hermetic system compared to the conventional system. Insect infestation causes an increase in electrical conductivity due to insects tearing the integument, resulting in an increase in water and microorganism content (Vieira et al. 2002; Freitas et al. 2016).

There were significant correlations between the infestation degree of *S. zeamais* and the qualitative variables of maize in the control storage systems (non-hermetic) (P <0.01) (Table 4). There was no significant correlation between the infestation degree of *S. zeamais* and the qualitative variables of maize in hermetic storage systems, except for the Bulk density variable in silo bag treatment. This demonstrated that the hermetic treatments (PET bottle and silo bag) maintained the qualitative characteristics of corn during 60 days of storage.

Table 4 - Correlations between infestations by *Sitophilus zeamais* and the qualitative variables of maize stored for 60 days in different storage systems.

Variable	Infestation by *S. zeamais*								
	Control			Silo bags			PET bottles		
	n	r	*P*	N	r	*P*	n	r	*P*
Moisture content	20	0.79	<0.01	20	-0.20	=0.38	20	-0.08	=0.71
Bulk density	20	–0.93	<0.01	20	–0.45	<0.05	20	–0.37	=0.11
Germination	20	–0.96	<0.01	20	–0.30	=0.20	20	–0.28	=0.22
Electrical conductivity	20	0.84	<0.01	20	0.29	=0.20	20	0.24	=0.30

Source: Authors.

Our study concludes that hermetic storage in PET bottles can be particularly useful and important for small farmers. The volume that is typically reserved for seeds is relatively small compared to the harvested volume (Walsh et al. 2014) and may not be suitable for storage in larger hermetic containers, such as silo bags. For these purposes, plastic bottles may serve as appropriate alternative containers (Williams et al. 2017). Even if the farmer does not have the financial resources to buy the PET bottles, the general availability of plastic waste throughout the urban–rural spectrum in Brazil will facilitate the use of these containers. As a result, these discarded bottles can be cleaned and reused.

4. Conclusion

The use of PET bottles control *S. zeamais* and preserve the quality of maize for at least 60 days of storage. Therefore, hermetic storage in PET bottles can be particularly useful and important for small farmers.

(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v11i15.37071

References

Abass, A. B., Ndunguru, G., Mamiro, P., Alenkhe, B., Mlingi, N., & Bekunda, M. (2014) Post-harvest food losses in a maize-based farming system of semi-arid savannah area of Tanzania. *J. Stored Prod. Res.* https://doi.org/10.1016/j.jspr.2013.12.004

Acheampong, A., Ayertey, J. N., Eziah, V. Y., & Ifie, B. E. (2019) Susceptibility of selected maize seed genotypes to *Sitophilus zeamais* (Coleoptera: Curculionidae). *J. Stored Prod. Res.* https://doi.org/10.1016/j.jspr.2019.01.003

ASAE, Moisture Measurement – Unground Grain and Seeds. (2004) American Society of Agricultural Engineers, St. Joseph, USA

Baoua, I. B., Amadou, L., Ousmane, B., Baributsa, D., & Murdock, L. L. (2014) PICS bags for post-harvest storage of maize grain in West Africa. *J. Stored Prod. Res.* https://doi.org/10.1016/j.jspr.2014.03.001

Brasil, *Regras para análise de sementes*/Ministério da Agricultura, Pecuária e Abastecimento . (2009) Secretaria de Defesa Agropecuária. Mapa/ACS, Brasília

Companhia Nacional de Abastecimento- CONAB. (2019) *Acompanhamento de safra brasileira de grãos*, Safra 2018/19: décimo levantamento. Brasília: CONAB. 113 p

Frazão, C. A. V., Silva, P. R. R., Almeida, W. A., Pontual, E. V., Cruz, G. S., Napoleão, T. H., & França, S. M. (2018) Resistance of maize cultivars to *Sitophilus zeamais* (Coleoptera: Curculionidae). *Arq. Inst. Biol.* (Sao. Paulo). https://doi.org/10.1590/1808-1657000552017

Freitas, R. S., Faroni, L. R. A., & Sousa, A. H. (2016) Hermetic storage for control of common bean weevil, *Acanthoscelides obtectus* (Say). *J. Stored Prod. Res.* https://doi.org/10.1016/j.jspr.2015.12.004

Jones, M., Alexander, C., & Lowenberg-Deboer, J. (2011) *Profitability of hermetic purdue iproved crop storage (PICS) bags for African common bean producers*, Dept . of Agricultural Economics, Purdue University.

Kaguchia, S. M., Gitahi, S. M., Thoruwa, C. L., Birgen, J. K., & Hassanali, A. (2018) Bioefficacy of selected plant extracts against *Sitophilus zeamais* on post-harvest management of *Zea mays*. J. *Phytopharm*. 7, 384–391.

Khakata, S., Mbute, F. N., Chemining'wa, G. N., Mwimali, M., Karanja, J., Harvey, J., & Mwololo, J. K. (2018) Post-harvest evaluation of selected inbred lines to maize weevil *Sitophilus zeamais* resistance. *J. Plant Breed. Crop Sci*. https://doi.org/10.5897/jpbcs2017.0646

Lane, B., & Woloshuk, C. (2017) Impact of storage environment on the efficacy of hermetic storage bags. *J. Stored Prod. Res*. https://doi.org/10.1016/j.jspr.2017.03.008

Oliveira, A. P., Santos, A. A., Santana, A. S., Lima, A. P. S., Melo, C. R., Santana, E. D. R., Sampaio, T. S., Blank, A. F., Araújo, A. P. A., Cristaldo, P. F., & Bacci, L. (2018) Essential oil of *Lippia sidoides* and its major compound thymol: Toxicity and walking response of populations of *Sitophilus zeamais* (Coleoptera: Curculionidae). *Crop Prot*. https://doi.org/10.1016/j.cropro.2018.05.011

Ribeiro, L. P., Ansante, T. F., Niculau, E. S., Pavarini, R., Silva, M. F. G. F., Seffrin, R. C., & Vendramim, J. D. (2015) *Pimenta pseudocaryophyllus* derivatives: extraction methods and bioactivity against *Sitophilus zeamais* Motschulsky (Coleoptera: Curculionidae). *Neotrop. Entomol.* https://doi.org/10.1007/s13744-015-0321-6

Sanon, A., Dabiré-Binso, L. C., & Ba, N. M. (2011) Triple-bagging of cowpeas within high density polyethylene bags to control the cowpea beetle *Callosobruchus maculatus* F. (Coleoptera: Bruchidae). *J. Stored Prod. Res*. https://doi.org/10.1016/j.jspr.2011.02.003

Santos, S. B., Martins, M. A., D'Antonino Faroni, L. R., Junior, V. R., & Dhingra, O. D. (2010) Quality of maize grains treated with allyl isothiocyanate stored in hermetic bags. *J. Stored Prod. Res.* https://doi.org/10.1016/j.jspr.2009.11.003

Scariot, M. A., Radünz, L. L., Dionello, R. G., Toni, J. R., Mossi, A. J., & Reichert Júnior, F. W. (2018) Quality of wheat grains harvested with different moisture contents and stored in hermetic and conventional system. *J. Stored Prod. Res*. https://doi.org/10.1016/j.jspr.2017.11.005

Silva, G. N., Faroni, L. R. A., Sousa, A. H., & Freitas, R. S. (2012) Bioactivity of *Jatropha curcas* L. to insect pests of stored products. *J. Stored Prod. Res.* https://doi.org/10.1016/j.jspr.2011.10.009

Silva, M. G. C., Silva, G. N., Sousa, A. H., Freitas, R. S., Silva, M. S. G., & Abreu, A. O. (2018) Hermetic storage as an alternative for controlling *Callosobruchus maculatus* (Coleoptera: Chrysomelidae) and preserving the quality of cowpeas. *J. Stored Prod. Res*. https://doi.org/10.1016/j.jspr.2018.05.010

Suleiman, R., Bern, C. J., Brumm, T. J., & Rosentrater, K. A. (2018) Impact of moisture content and maize weevils on maize quality during hermetic and non-hermetic storage. *J. Stored Prod. Res.* https://doi.org/10.1016/j.jspr.2018.05.007

Taylor, P., Cesari, I., Arsenak, M., Ballen, D., Abad, M., Fernández, A., Milano, B., Ruiz, M. C., Williams, B., & Michelangeli, F. (2006) Evaluation of Venezuelan medicinal plant extracts for antitumor and antiprotease activities. *Pharm. Biol*. https://doi.org/10.1080/13880200600748119

Tefera, T. (2012) Post-harvest losses in African maize in the face of increasing food shortage. *Food Secur*. https://doi.org/10.1007/s12571-012-0182-3

Vélez, M., Bernardes, R. C., Barbosa, W. F., Santos, J. C., & Guedes, R. N. C. (2019) Walking activity and dispersal on deltamethrin- and spinosad-treated grains by the maize weevil *Sitophilus zeamais*. *Crop Prot*. https://doi.org/10.1016/j.cropro.2018.12.013

Vieira, R. D., Penariol, A. L., Perecin, D., & Panobianco, M. (2002) Condutividade elétrica e teor de água inicial das sementes de soja. Pesqui. *Agropecu. Bras*. https://doi.org/10.1590/S0100-204X2002000900018

Walker, S., Jaime, R., Kagot, V., & Probst, C. (2018) Comparative effects of hermetic and traditional storage devices on maize grain: Mycotoxin development, insect infestation and grain quality. *J. Stored Prod. Res*. https://doi.org/10.1016/j.jspr.2018.02.002

Walsh, S., Potts, M., Remington, T., Sperling, L., & Turner, A. (2014) Seed Storage Brief: *Defining Seed Quality and Principles of Seed Storage in a Smallholder Context*. Catholic Relief Services, Nairobi.

Williams, S. B., Murdock, L. L., & Baributsa, D. (2017) Safe storage of maize in alternative hermetic containers. *J. Stored Prod. Res.* https://doi.org/10.1016/j.jspr.2016.12.008