ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.28, n.11, e282159, 2024
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v28n11e282159

Original Article

Storage and quality of landrace cowpea grains stored in silo bags[1]

Armazenamento e qualidade dos grãos de variedades crioulas de feijão-caupi em silo bolsa

Mayara A. D. e Silva[2], Lucas M. Lopes[2], Adalberto H. de Sousa[2*], Lêda R. A. Faroni[3], Rychaellen S. de Brito[4], Malena Lima[5] & Reginaldo A. Andrade[6]

[1] Research developed at Universidade Federal do Acre, Rio Branco, AC, Brazil
[2] Universidade Federal do Acre/Centro de Ciências Biológicas e da Natureza, Rio Branco, AC, Brazil
[3] Universidade Federal de Viçosa/Departamento de Engenharia Agrícola, Viçosa, MG, Brazil
[4] Instituto Federal de Educação, Ciência e Tecnologia do Acre/Campus Sena Madureira, Sena Madureira, AC, Brazil
[5] Instituto de Defesa Agropecuária e Florestal do Estado do Acre, Rio Branco, AC, Brazil
[6] Instituto Federal de Educação, Ciência e Tecnologia do Amazonas/ Campus Coari, Coari, AM, Brazil

HIGHLIGHTS:
Storage in silo bags preserves the quality of landrace cowpea grains for up to 120 days.
Infestation by Zabrotes subfaciatus was controlled by the storage of landrace cowpea grains in silo bags.
Silo bags are an airtight alternative to mitigate the environmental effects that lead to the deterioration of cowpea grains.

ABSTRACT: Storage is one of the main stages during grain production. The present study was conducted to evaluate the use of silo bags as an alternative for storing landrace cowpea grains. The experiment used samples of the Arigozinho, Manteiguinha, and Quarentão cowpea varieties from Cruzeiro do Sul - Acre, harvested in the 2021 crop season. The samples (500 g) were stored in raffia and silo bags for 30, 60, 90, and 120 days. The experimental design was completely randomized, arranged in a split-plot-in-time scheme (2 × 5) with four replicates. Storage conditions represented the plots: silo bags and raffia bags. The subplots comprised five storage conditions: 0, 30, 60, 90, and 120 days for each landrace cowpea variety. The insect species identified in all varieties was *Zabrotes subfasciatus*, with infestation ranging from 49% to 98% in raffia bags and less than 10% in silo bags over 120 days. A depreciation in grain quality was observed during storage in raffia bags. There was increase in electrical conductivity, fluctuations in water content, and reductions in bulk density and germination due to the higher degree of infestation in all the investigated varieties. The grains stored in silo bags showed minimal variations over the 120 days, maintaining their initial quality throughout the storage period. The bag silo storage system is an effective alternative for controlling *Z. subfasciatus* and maintaining the grain quality of the varieties Arigozinho, Manteiguinha, and Quarentão for a period of up to 120 days.

Key words: *Vigna unguiculata*, modified atmosphere, alternative control, weevil

RESUMO: O armazenamento é uma etapa crucial durante a produção de grãos. Este trabalho foi realizado com o objetivo de avaliar o uso de silo bolsa como alternativa no armazenamento de grãos crioulos de feijão-caupi. Para o estudo utilizou-se amostras de feijão-caupi, das variedades Arigozinho, Manteiguinha e Quarentão, procedentes do município de Cruzeiro do Sul - Acre, safra 2021. As amostras de 500 g foram armazenadas em silos bolsa e sacos de ráfia, durante 30, 60, 90, 120 dias. O experimento foi inteiramente casualizado, com parcelas subdivididas no tempo (2 × 5), com quatro repetições. As parcelas foram as condições de armazenamento: silo bolsa e sacos de ráfia, e as subparcelas, os períodos de armazenamento: 0, 30, 60, 90 e 120 dias para cada variedade crioula de feijão-caupi. *Zabrotes subfasciatus* foi identificado em todas as variedades, com infestações de 49 a 98% em sacos de ráfia e inferiores a 10% em silo bolsa ao longo de 120 dias. Foi observado a depreciação na qualidade dos grãos durante o período de armazenamento em sacos de ráfia. Houve aumento na condutividade elétrica, flutuações no teor de água, redução da massa específica aparente e na germinação, devido ao maior grau de infestação em todas as variedades investigadas. Os grãos em silo bolsa apresentaram mínimas variações e mantiveram a qualidade inicial durante 120 dias. O armazenamento em silo bolsa é eficaz no controle de *Z. subfasciatus* e na manutenção da qualidade dos grãos das variedades Arigozinho, Manteiguinha e Quarentão por até 120 dias.

Palavras-chave: *Vigna unguiculata*, atmosfera modificada, controle alternativo, gorgulho

• Ref. 282159 – Received 10 Jan, 2024
* Corresponding author - E-mail: adalberto.sousa@ufac.br
• Accepted 09 Jun, 2024 • Published 29 Jun, 2024
Editors: Geovani Soares de Lima & Walter Esfrain Pereira

Introduction

Cowpea (*Vigna unguiculata* L.) is a crop that gathers some of the main components of the food diet in the North and Northeast regions of Brazil (Souza et al., 2020; Silva et al., 2023). Cowpea possesses several desirable attributes for a food crop, including high contents of proteins, food fibers, minerals, and antioxidants such as iron and zinc, and low lipid contents (Oliveira et al., 2021; Sousa et al., 2021).

Storage is one of the most important steps in dry grain production, as it preserves the nutritional value of grains and seed quality for future cultivation (Lorini, 2018). The storage period is influenced by a series of factors, including infestation by pest insects, responsible for most quantitative and qualitative losses in grain mass (Gomes et al., 2022). Pest insect attacks can reduce grain weight, germinative capacity, and nutritional quality (Hamzavi et al., 2022; Martins et al., 2024).

Zabrotes subfasciatus (Boheman) is one of the main pest insect species affecting stored cowpea grains (Toledo et al., 2013; Lopes et al., 2018; Nascimento et al., 2020). The larvae build galleries in the integument, resulting in grain mass and quality losses and reducing seed germination (Queiroga et al., 2012). In particular, the *Vigna* genus has no recommendations from competent bodies regarding using chemicals to control pest insects during storage (MAPA, 2022). In this scenario, alternatives such as hermetic storage systems are effective in protecting grains against infestation by harmful agents and maintaining quality in several species (Coradi et al., 2020; Magalhães & Sousa, 2020; Kuyu et al., 2022).

Due to the wide genetic diversity and the possible responsiveness of the various available options, alternative methods for phytosanitary management and grain preservation during storage have been increasingly sought (Abreu et al., 2022).

The study was conducted to evaluate the use of silo bags as an alternative to control *Zabrotes subfasciatus* and preserve the quality of landrace cowpea grains for 120 days.

Material and Methods

The experiment was conducted at the Integrated Pest Management Laboratory of the Federal University of Acre – Campus Universitário, in Rio Branco - AC (9° 57’ 22.9” S, 67° 52’ 00.5” W, and 160 m of altitude) from November 2021 to March 2022.

The experimental design was completely randomized, arranged in a split-plot-in-time (2 × 5) scheme with four replicates. Storage conditions represented the plots: silo bag and raffia bags, whereas the subplots consisted of five storage times (0, 30, 60, 90, and 120 days at 25 ± 1.5 °C and relative air humidity of 76 ± 12.5%) of three landrace cowpea variety (Arigozinho, Manteiguinha, and Quarentão).

Grains from the 2021 crop season were used in the experiment, purchased from the municipal market of Cruzeiro do Sul – AC (7° 38’ 11.1” S, 72° 40’ 08.8” W, and 182 m of altitude). The grains were packed in polypropylene bags and transported to the Integrated Pest Management Laboratory, after which they were characterized according to the variables analyzed (Table 1).

Table 1. Initial characterization of cowpea grains (*Vigna unguiculata* L.)

Variables analyzed	Varieties		
	Arigozinho	Manteiguinha	Quarentão
Infestation (%)	1.50	4.50	2.50
Water content (% w.b.)	8.83	12.47	9.17
Bulk density (kg m^{-3})	682.00	745.00	702.00
Germination (%)	86.50	73.00	79.00
Electrical conductivity (µS cm^{-1} g^{-1})	24.28	29.50	50.93

Tests were conducted to evaluate grain quality in three landrace cowpea varieties: Arigozinho, Manteiguinha, and Quarentão. Initially, the grains were packed to contain 500.00 g of grains per replicate in each treatment: raffia bags and silo bags. The raffia bags were made of braided polypropylene threads, which allow gas exchange between the inside and the outside of the bags. The silo bags were manufactured with 20.00 cm × 24.00 cm dimensions using 250.00 mm thick polyethylene tarps (Silox TM/DuPont). The bags had three layers, black inside and white outside, hermetically sealed with a sewing machine (40.00 cm hot bar).

Two samples of 100 grains for each replicate were used to quantify the percentage of grains damaged by insects. These samples were randomly withdrawn from each treatment and immersed in water for 24 hours, a sufficient time to soften the grains. Then, the water was removed, and the grains were dried in filter paper, cut, and examined individually. The grains with eggs, larvae, pupae, adults, or insect exit holes were considered damaged. The results were expressed as a percentage after obtaining the means of the two samples for each replication (BRASIL, 2009).

The grain water content (% w.b.), was determined by the oven method. Samples of 30 g were used in triplicate for each of the four replications of the treatment. The container was weighed with its lid, then with the grains, and then the samples were oven-dried at 105 ± 3 °C for 24 hours. After this period, the samples were weighed in an analytical balance (0.001 g) (BRASIL, 2009). The results obtained were expressed as percentages on a wet basis, according to Eq. 1.

$$\%\text{water}(W) = \frac{100 \cdot (P - p)}{P - t} \tag{1}$$

where:

P - initial weight, the weight of the container and its lid plus the wet seed weight;

p - final weight, the weight of the container and its lid plus the dry seed weight; and,

t - tare, the weight of the container plus its lid;

The bulk density (kg m^{-3}) was determined with a hectoliter scale with a capacity of one-quarter of a liter (250.00 mL). The measurements were performed in triplicate for each replication and estimated the arithmetic mean. The hectoliter weight was determined according to the RAS methodology (BRASIL, 2009), Eq. 2.

$$HW = \frac{WOB \cdot 100}{VB} \tag{2}$$

where:

HW - hectoliter weight;

WOB - weight obtained in the balance; and,

VB - volume in the balance.

The germination (%) test was conducted according to the criteria contained in the Rules for Seed Analysis guidelines (BRASIL, 2009) by establishing four samples of 50 seeds, totaling 200 seeds per replication and four replications per treatment. The substrate consisted of germination paper (Germitest) sheets moistened with distilled water in a proportion of 2.5 times the weight of the dry paper. The seeds were laid on two paper sheets and then covered with a third one, after which they were closed in a roll. Then, the rolls were stored vertically in a BOD incubator and kept at 25 ± 1 °C. The initial count was performed after eight days, and the results were expressed as mean germination percentage by considering the germinated seeds that emitted the primary root and shoot and were apparently healthy.

The electrical conductivity (μS cm^{-1} g^{-1}) was determined using three samples of 50 grains, one for each of the four replicates. The grains were weighed in an analytical balance (0.01 g), immersed in 75.00 mL of deionized water in 180 mL cups, and kept in a BOD incubator at 25 °C for 24 hours. After this period, the electrical conductivity was read using a conductivity meter, and the results obtained were divided by the mass of 50 seeds and expressed as μS.$cm^{-1}g^{-1}$ o seeds (Silva et al., 2013).

The presence of outlier data was initially verified, followed by the normality of residuals and homogeneity of variances tests. Upon meeting the assumptions, the data were subjected to the analysis of variance at $p \leq 0.05$ using the ExpDes.pt package of software R (Ferreira et al., 2018). The means of storage were compared by the Tukey test at $p \leq 0.05$. The data from the storage time was submitted to regression analysis. The regression graphs were constructed using the software SigmaPlot, version 10.0 (SPSS, 2006).

Results and Discussion

The infestation by pest insects in cowpea beans ranged significantly over the storage period and between the storage systems, with a significant interaction between both factors (Table 2).

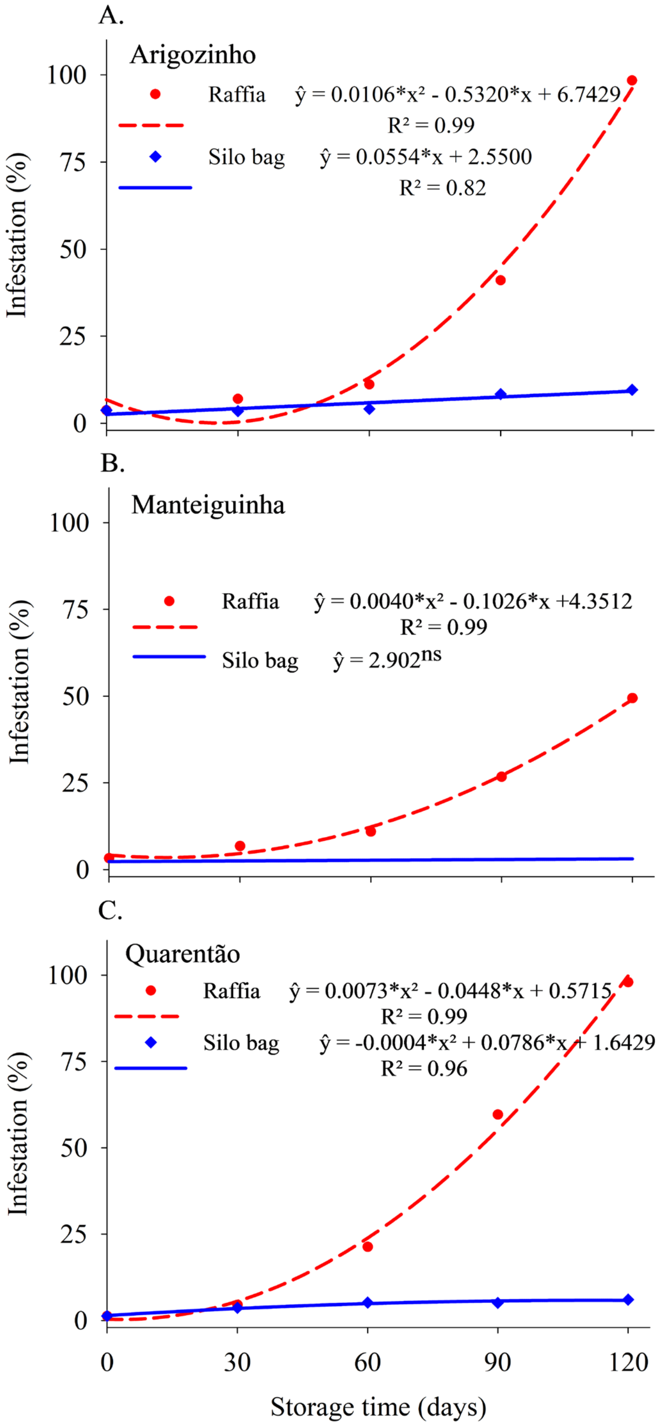
Table 2. Summary of the analysis of variance of infestation in grains from three landrace cowpea varieties over 120 days of storage in raffia and silo bags

Source of variation	DF	Mean squares		
		Arigozinho	Manteiguinha	Quarentão
Storage	1	6956.40**	2795.58 **	10653.60 **
Error 1	6	2.20	0.60	2.50
Period	4	3616.70**	759.70 **	3634.50 **
Storage × Period	4	2762.00**	685.72 **	3158.40 **
Error 2	24	2.00	2.41	1.20
Total	39			
CV 1		7.72	6.87	7.60
CV 2		7.34	13.78	5.37

** Significant at $p \leq 0.01$ according to the F-Test; DF - Degrees of freedom; CV - Coefficient of variation

Regression models were adjusted for the characteristics that showed significant variation between the storage time and storage type. When no significance was identified, the mean values replaced the equations (Figure 1). Once the equations were fitted, comparisons between the types of storage for each period are shown in Table 3.

It is noted that regardless of the cowpea variety, the storage in raffia bags shows positive quadratic results to explain the estimated data. For the Arigozinho variety, an increase in infestation is observed only after 25 days, a period longer than the Manteiguinha variety, which is estimated to increase after



* - Significant at $p \leq 0.05$ by F test; ns - Not significant by F test

Figure 1. Infestation of grains of three landrace cowpea varieties stored in different systems (raffia bags and silo bags) according to the storage time

Table 3. Infestation in grains of three landrace cowpea varieties stored in raffia bags and silo bags in each storage period

Variable	Storage (days)	Arigozinho		Manteiguinha		Quarentão	
		Raffia	Silo bag	Raffia	Silo bag	Raffia	Silo bag
Infestation (%)	0	3.75 a	3.75 a	3.50 a	3.50 a	1.50 a	1.50 a
	30	7.00 a	3.50 b	7.00 a	1.57 a	4.75 a	3.87 a
	60	11.13 a	4.13 b	11.12 a	2.75 b	21.50 a	5.37 b
	90	41.00 a	8.38 b	26.92 a	2.82 b	59.75 a	5.30 b
	120	98.38 a	9.63 b	49.58 a	3.87 b	98.00 a	6.25 b

Means followed by the same letter in the lines do not differ statistically by the Tukey test at $p \leq 0.05$

12 days. For the Quarentão variety, this increase in infestation occurs after 3 days. For grains stored in silo bags, the infestation percentages are lower compared to those stored in raffia bags. For the Arigozinho variety, the equation that best represents the estimated data is a positive linear equation; thus, the longer the storage time, the higher the infestation. However, within the time studied, infestation percentages remain below 25%

The low oxygen environment in hermetic silo bags is hostile to most insects that infest stored grains. This anoxic condition directly affects the respiration of insects, leading to their inactivity or death. This mechanism is supported by studies such as that of Mutungi et al. (2014), where the reduction of oxygen and the increase of carbon dioxide in hermetic systems suppress the activity and development of pests.

The dynamic present in the hermetic method, based on the principle of oxygen depletion and the corresponding increase in carbon dioxide, suppressing the development of aerobic organisms, can cause the death of insects or change their cycles, resulting in inactivity, interruption of population growth, and desiccation and eventual death of eggs, larvae, and pupae (Silva et al., 2018; Mesele et al., 2022). The infestation percentages for both landrace varieties of cowpea beans showed better responses over the 120 days of storage in the silo bag system. For the Arigozinho variety, the difference is 88.78% (Raffia bag: 98.38; Silo bag: 9.63; $p \leq 0.05$); for the Manteiguinha variety, the difference is 45.71% (Raffia bag: 49.58; Silo bag: 3.87; $p \leq 0.05$), and for the Quarentão variety, the difference is 91.50% (Raffia bag: 98.00; Silo bag: 6.50; $p \leq 0.05$). It is noteworthy that during the 120 days of storage, the grain quality in terms of infestation degree is preserved when stored in silo bags (Figure 1 and Table 3). Similar responses were observed by Silva et al. (2018) when they evaluated the behavior of two hermetic storage methods compared to a non-hermetic method. The authors reported that the grains stored in non-hermetic packages showed a significant increase in the infestation degree, corresponding to 100% during the whole storage period of 120 days, contrary to the response observed in the hermetic system, both in silo bags and PET plastic bottles, which achieved the infestation percentages of 1.00 and 7.50%, respectively.

The use of hermetic silo bags can significantly reduce the reliance on chemical insecticides, promoting a more sustainable and safe approach to pest management in grain storage (Odjo et al., 2020). Silva et al. (2018) observed that this approach not only effectively controls pests but also preserves the quality of the grains, highlighting the relevance of these systems for both small and large producers seeking economical and eco-friendly storage methods.

The presence or absence of infestation directly influences grain quality. In that regard, several authors highlight that qualitative variables such as the apparent density, electrical conductivity, water content, and germination are interconnected with the percentage of insects, and the higher the degree of infestation, the lower grain quality and, consequently, the lower the product's price (Silva et al., 2018; Ngwenyama et al., 2020; Kuyu et al., 2022; Mesele et al., 2022).

The water content in cowpea beans varied significantly over the storage period and between the storage systems, with a significant interaction between both factors (Table 4).

Regression models were adjusted for characteristics that exhibited significant variation across different storage times and storage types. When no significant variation was identified, the equations were substituted with mean values (Figure 2). Once the equations were adjusted, comparisons between the types of storage for each period are shown in Table 5.

It is noted that regardless of the variety studied, the storage in raffia bags shows positive quadratic results for explaining the estimated data in all tested varieties. There was an increase in the water content of grains from the Arigozinho and Manteiguinha varieties in the same period despite being different varieties (after 42 days), while the Quarentão variety had a more accelerated increase in water content after 14 days of storage.

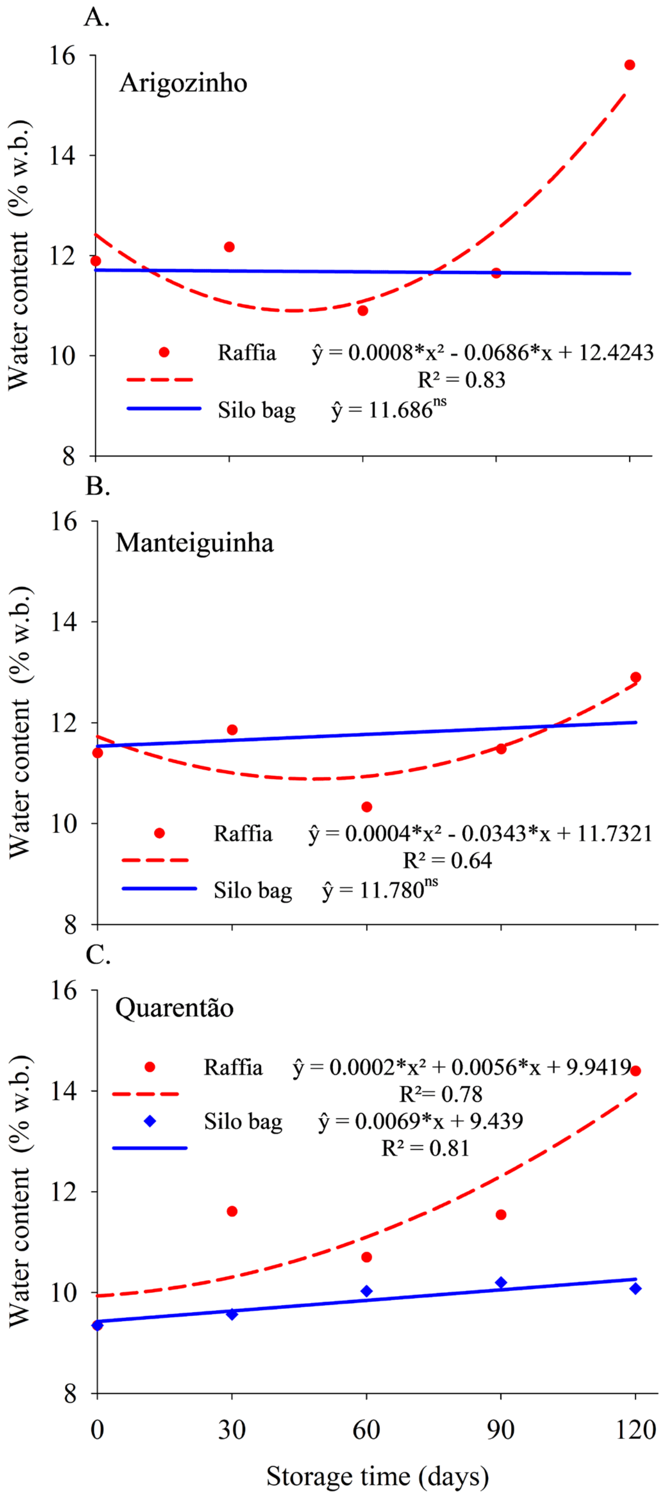
For grains stored in silo bags, the lowest percentages of water content are estimated compared to those stored in raffia bags. For the Quarentão variety, the equation that best represents the estimated data is a positive linear equation; thus, the longer the storage period, the higher the water content. However, over the storage time, water content remains below 12% for Arigozinho and Manteiguinha and below 10% for Quarentão.

The grains stored in silo bags remained with minimum oscillations during the 120 days (Figure 2) but became variable when stored in raffia bags, showing an increase over time ($p \leq 0.05$). The permeability of raffia bags allows for water content exchanges with the external environment, which can lead to

Table 4. Summary of the analysis of variance of water content of grains from three landrace cowpea varieties over 120 days of storage in raffia and silo bags

Source of variation	DF	Mean squares		
		Arigozinho	Manteiguinha	Quarentão
Storage	1	6.52 **	0.35 ^{ns}	28.01 **
Error 1	6	0.16	0.07	0.22
Period	4	7.89 **	2.15 **	8.67 **
Storage × Period	4	6.86 **	1.41 **	5.51 **
Error 2	24	0.06	0.08	0.12
Total	39			
CV 1		3.35	2.25	4.34
CV 2		2.09	2.43	3.19

** Significant at $p \leq 0.01$ according to the F-Test; ^{ns} - Not significant; DF - Degrees of freedom; CV - Coefficient of variation



* - Significant at $p \leq 0.05$ by F test; ns - Not significant by F test

Figure 2. Water content of cowpea grains of three landrace cowpea varieties stored in different systems (raffia and silo bags) according to the storage time

undesirable fluctuations in the grain's water content. These fluctuations are harmful as they can promote the growth of pathogens and pest insects. Kuyu et al. (2022) demonstrated that hermetic systems maintain stable water content, protecting the grains from environmental variations and reducing the possibility of deterioration. This corroborates the results presented in this paper for the three investigated landrace varieties.

The water content values of the grains stored in silo bags showed the lowest increases compared to the raffia bag system after 120 days of storage. The results corroborate Magalhães & Sousa (2020), who observed a considerable increase in the water content of common beans stored under non-hermetic conditions. On the other hand, the hermetic system showed no significant variation over 120 days.

The means between systems and the response for both varieties were similar, with the water content of the Arigozinho variety in raffia bags increasing by 4.04% (raffia bag: 15.81; silo bag: 11.77; $p \leq 0.05$), 0.91% in the Manteiguinha variety (raffia bags: 12.91; silo bag: 12.00; $p \leq 0.05$), and 4.31% in the Quarentão variety (raffia bag: 14.4; silo bag: 10.09; $p \leq 0.05$) (Table 5). The stability of water content in silo bags can result in grains of better quality and higher market value. Magalhães & Sousa (2020) noted that the preserved quality of grains can directly influence the market price, as grains with less deterioration and better storage quality are preferred by consumers and have less rejection during processing.

The increase in the water content in conventional storage systems could be related to the possible migration of external water into storage facilities since these allow air circulation (Mesele et al., 2022). Kuyu et al. (2022) compared different storage methods and observed similar behavior in grains of common bean, maize, wheat, and sorghum, with both storage methods (jute and polypropylene bags) showing a water content of approximately 13% over seven months of storage. The authors stated that, as time progresses, water increases in the grain environment due to the porous structure of bags in traditional systems, increasing the water content and accelerating the metabolic dynamic.

The bulk density in cowpea beans varied significantly over the storage period and between the storage systems, with a significant interaction between both factors (Table 6).

Regression models were adjusted for characteristics that showed significant variation over the storage time and storage types. When no significant variation was found, the equations were replaced with average values (Figure 3). Once the equations were adjusted, comparisons between the types of storage for each period are shown in Table 7.

Table 5. Water content in grains of three landrace cowpea varieties stored in raffia bags and silo bags in each storage period

Variable	Storage (days)	Arigozinho		Manteiguinha		Quarentão	
		Raffia	Silo bag	Raffia	Silo bag	Raffia	Silo bag
Water content (% w. b.)	0	11.90 a	11.90 a	11.41 a	11.41 a	9.36 a	9.36 a
	30	12.18 a	11.59 b	11.87 a	11.86 a	11.62 a	9.58 b
	60	10.91 b	11.49 a	10.34 b	11.77 a	10.71 a	10.04 b
	90	11.66 a	11.68 a	11.49 b	11.86 a	11.55 a	10.21 b
	120	15.81 a	11.77 b	12.91 a	12.00 b	14.40 a	10.09 b

Means followed by the same letter in the lines do not differ statistically by the Tukey test at $p \leq 0.05$

Table 6. Analysis of variance of cowpea bean bulk density in the three landrace varieties during 120 days of storage in raffia and silo bag

Source of variation	DF	Mean squares		
		Arigozinho	Manteiguinha	Quarentão
Storage	1	26860.90 **	1109.55 **	31621.50 **
Error 1	6	21.30	63.22	71.70
Period	4	14284.80 **	346.05 **	15997.00 **
Storage × Period	4	15427.30 **	210.39 **	16098.50 **
Error 2	24	53.30	40.13	58.60
Total	39			
CV 1		0.70	1.07	1.26
CV 2		1.11	0.85	1.14

** Significant at $p \leq 0.01$ according to the F test; DF - Degrees of freedom; CV - Coefficient of variation

It is noted that regardless of the variety studied, the storage in raffia bags shows negative quadratic results for explaining the estimated data in the three varieties. The Arigozinho and Quarentão varieties began to show a reduction in bulk density during the same period (after 31 days), while Manteiguinha showed a reduction in bulk density starting from 60 days. For grains stored in silo bags over 120 days, similar behaviors were observed in all varieties. Although there was significant variation, there was no marked increase in the loss of bulk density of grains (Figure 3 and Table 7).

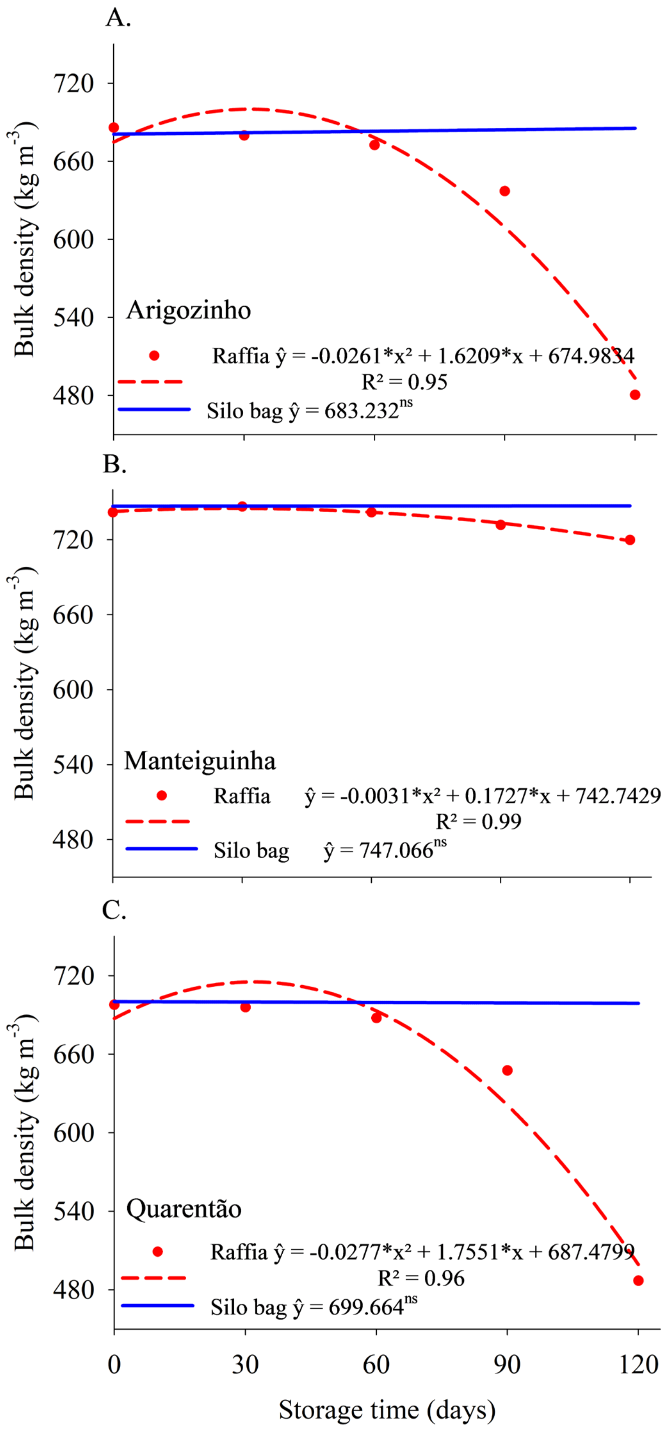
The presence of insects and the increase in water content in jute bags contribute to the loss of dry matter and the physical structure of the grains, resulting in a decrease in bulk density. Momanyi et al. (2022) and Ngwenyama et al. (2020) directly associate this reduction with physical deterioration and the metabolic activity of the insects and the grains themselves, which consume nutrients and alter the physical integrity of the grains.

In the comparison between storage systems, there were similar responses between varieties, with all showing a reduction in grain mass after 120 days of storage, with a reduction of 204.97 kg m^{-3} for the Arigozinho variety (raffia bag: 481.03; silo bag: 686.00; $p \leq 0.05$), 27.33 kg m^{-3} for the Manteiguinha variety (raffia bag: 720.00; silo bag: 747.33; $p \leq 0.05$), and 213.16 kg m^{-3} for the Quarentão variety (raffia bag: 487.50; silo bag: 700.66; $p \leq 0.05$) (Table 5).

Magalhães & Sousa (2020) reported that losses in bulk density during grain storage are usually associated with the increase in the water content and the presence of insects, which, however, favors grain degradation and results in reduced physical and nutritional quality, corroborating the results of the present study.

The germination in cowpea beans ranged significantly over the storage period and between the storage systems, with a significant interaction between both factors (Table 8).

Regression models were adjusted for the characteristics that showed significant variation between the storage time



* - Significant at $p \leq 0.05$ by F test; ns - Not significant by F test

Figure 3. Bulk density of grains of three landrace cowpea varieties stored in different systems (raffia bags and silo bags) according to the storage time

Table 7. Bulk density of grains of three landrace cowpea varieties stored in raffia bags and silo bags in each storage period

Variable	Storage (days)	Arigozinho		Manteiguinha		Quarentão	
		Raffia	Silo bag	Raffia	Silo bag	Raffia	Silo bag
Bulk density (kg dm^{-3})	0	686.00 a	680.00 a	742.00 a	742.00 a	698.00 a	698.00 a
	30	680.00 a	684.00 a	746.67 a	752.00 a	696.00 a	705.33 a
	60	672.67 b	682.83 a	742.00 b	752.00 a	687.83 a	697.66 a
	90	637.33 b	683.33 a	732.00 b	742.00 a	647.83 b	696.67 a
	120	481.03 b	686.00 a	720.00 b	747.33 a	487.50 b	700.66 a

Means followed by the same letter in the rows do not differ statistically by Tukey's test at $p \leq 0.05$

Table 8. Summary of the analysis of variance of seed germination of three landrace cowpea varieties during 120 days of storage in raffia and silo bag

Source of variation	DF	Mean squares		
		Arigozinho	Manteiguinha	Quarentão
Storage	1	4445.10 **	774.40 **	3525.00 **
Error 1	6	0.80	25.13	2.60
Period	4	1943.80 **	301.70 **	1238.40 **
Storage × Period	4	1841.90 **	254.10 **	1174.00 **
Error 2	24	4.80	10.52	6.60
Total	39			
CV 1		1.00	5.36	1.88
CV 2		2.50	3.47	2.97

** Significant at $p \leq 0.01$ according to the F-Test; DF - Degrees of freedom; CV - Coefficient of variation

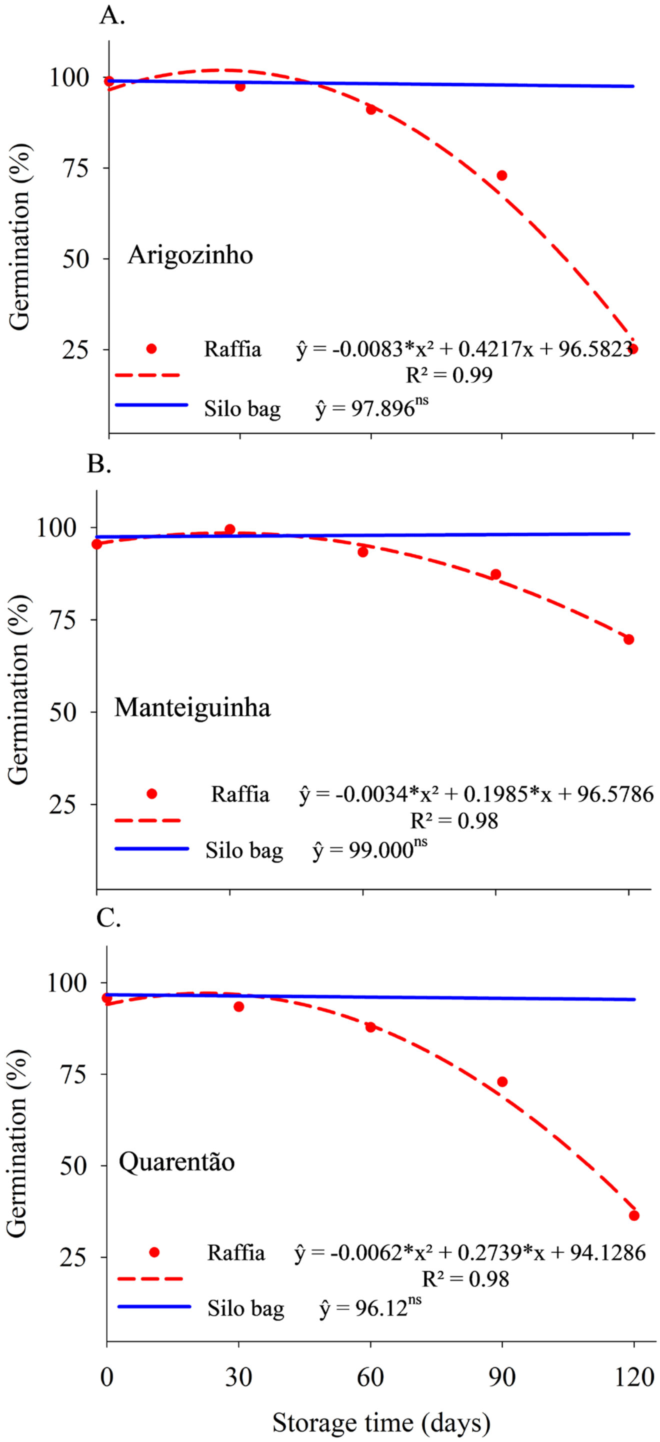
and storage type. When no significance was found, the mean values replaced the equations (Figure 4). Once the equations were adjusted, comparisons between the types of storage for each period are shown in Table 9.

Over the storage, seed germination of the three cowpea varieties stored in raffia bags was lower ($p \leq 0.05$) than those stored in silo bags. There was an interaction between the storage type × storage time and the germination rate affected by the storage time. There were significant losses over the 120 days when the grains were stored in raffia bags, with expressive reductions from 25, 29, and 22 days of storage for the Arigozinho, Manteiguinha, and Quarentão varieties, respectively (Figure 4 and Table 9).

When examining storage systems, the silo bag system showed high efficiency by showing the best performance in the preservation of grain quality and vigor after 120 days (Table 9). A high germination rate is essential to ensure future yield. Grains that maintain their germination capacity are crucial for food security, especially in regions dependent on subsistence agriculture. The use of silo bags can be a key strategy to preserve seeds for future cultivations, as observed by Silva et al. (2018).

There were similar responses for the varieties, with all showing superior results in the germination test when stored in solo bags, and worse results when stored in raffia bags, with a difference between systems of 72.55% for the Arigozinho variety (raffia bag: 25.33%; silo bag: 97.88%; $p \leq 0.05$), 27.12% for the Manteiguinha variety (raffia bag: 69.75%; silo bag: 96.87%; $p \leq 0.05$), and 59.87% for the Quarentão variety (raffia bag: 36.50%; silo bag: 96.37%; $p \leq 0.05$). In studies with common bean varieties and using hermetic bags, Magalhães & Sousa (2020) observed that the germination percentage is affected by the storage time and is influenced by the storage system. The authors noted that hermetic bags (silo bags and PET plastic bottles) promoted the best responses over 120 days compared to the non-hermetic treatment.

The germination capacity is a critical indicator of the quality and viability of grains. The deterioration observed in



* - Significant at $p \leq 0.05$ by F test; ^{ns} - Not significant by F test

Figure 4. Seed germination of three landrace cowpea varieties stored in different systems (raffia bags and silo bags) according to the storage time

Table 9. Seed germination of three landrace cowpea varieties stored in raffia bags and silo bags in each storage period

Variable	Storage (days)	Arigozinho		Manteiguinha		Quarentão	
		Raffia	Silo bag	Raffia	Silo bag	Raffia	Silo bag
Germination (%)	0	98.88 a	98.88 a	95.50 a	95.50 a	95.87 a	95.87 a
	30	97.50 a	99.13 a	99.50 a	99.37 a	93.50 b	97.87 a
	60	91.13 b	98.00 a	93.37 b	99.12 a	87.87 b	96.87 a
	90	73.00 b	97.38 a	87.37 b	98.62 a	73.00 b	93.62 a
	120	25.33 b	97.88 a	69.75 b	96.87 a	36.50 b	96.37 a

Means followed by the same letter in the line do not differ statistically by the Tukey test at $p \leq 0.05$

jute bags can be attributed to insect activity and water-induced degradation. Kuyu et al. (2022) and Mesele et al. (2022) show that the preservation of germination in silo bags is linked to internal environmental stability, which keeps the grains in an almost inert state, preserving their viability and planting potential.

The germination is intimately related to the physiological potential of the seed. Storage is meant to preserve, for a long time, the initial quality of the product until its use. Silva et al. (2018) reported the efficiency of hermetic storage in cowpea cultivars aiming at quality control and infestation against bruchids; they reported that the results for non-hermetic storage were expressive, reaching a 100% reduction in germination.

The electrical conductivity in cowpea beans varied significantly over the storage period and between the storage systems, with a significant interaction between both factors (Table 10).

The results for the electrical conductivity of cowpea grains during storage are shown in Figure 5 (Table 11).

Significant interaction was found between the storage systems and storage time, with the electrical conductivity values being affected by storage time, depending on the storage system used. The results indicate smaller variations during storage for treatments that used silo bags as a storage system, also stressing that the results were lower for this variable compared to raffia bags. As a result, the greater the electrolytic leaching of cellular solutes, the lower the vigor of the evaluated grains and the higher the electrical conductivity values.

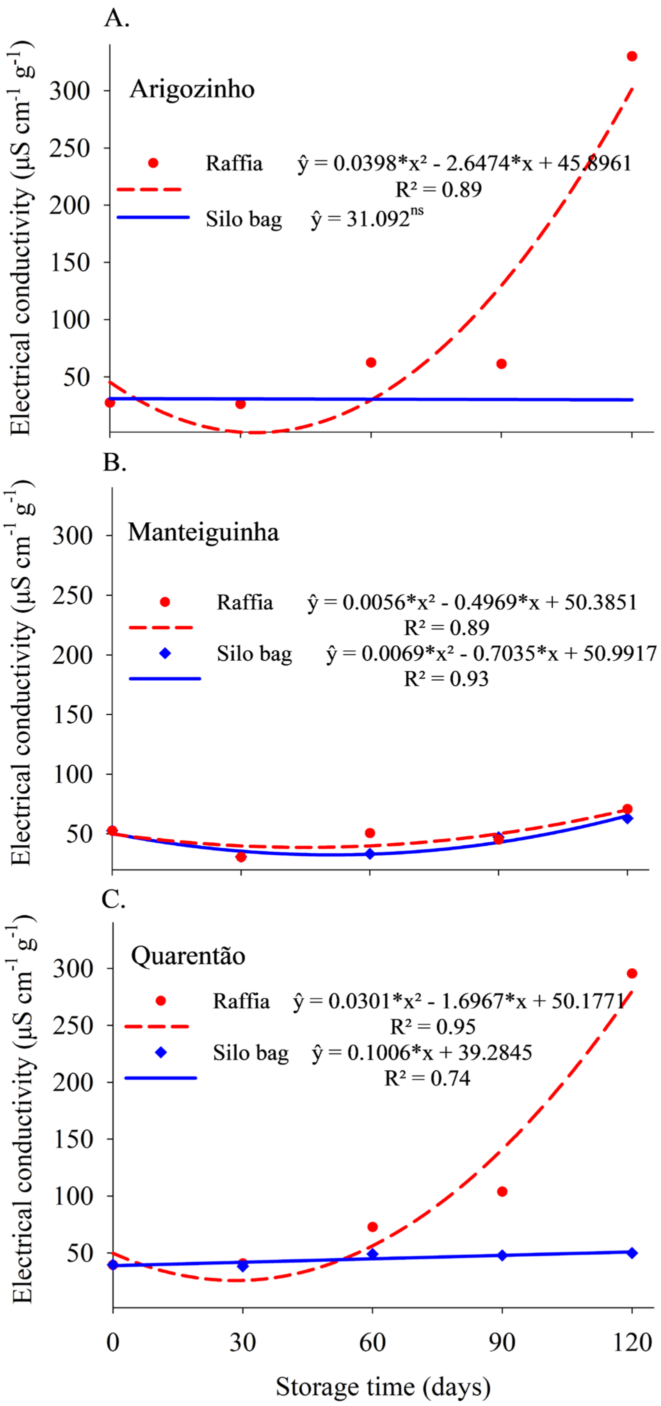
Furthermore, after 120 days, the difference between storage systems was 299.01 μS cm^{-1} g^{-1} for the Arigozinho variety (raffia bag: 330.15; silo bag: 31.14; $p \leq 0.05$), 7.85 μS cm^{-1} g^{-1} for the Manteiguinha variety (raffia bag: 71.39; silo bag: 63.54; $p \leq 0.05$), and 245.34 μS cm^{-1} g^{-1} for the Quarentão variety (raffia bag: 295.62; silo bag: 50.28; $p \leq 0.05$).

Table 10. Summary of the analysis of variance of electrical conductivity of grains of three landrace varieties during 120 days of storage in raffia and silo bag

Source of variation	DF	Mean squares		
		Arigozinho	Manteiguinha	Quarentão
Storage	1	50319.00 **	211.55 *	42966.00 **
Error 1	6	24.00	28.25	29.00
Period	4	33056.00 **	1433.61 **	24378.00 **
Storage × Period	4	33267.00 **	130.35 *	21210.00 **
Error 2	24	11.00	34.06	11.00
Total	39			
CV 1		7.33	11.01	6.86
CV 2		5.07	12.09	4.20

** Significant at $p \leq 0.01$ according to the F-Test; * Significant at Significant at $p \leq 0.05$ according to the F-Test; DF - Degrees of freedom; CV - Coefficient of variation

High electrical conductivity in raffia bags suggests greater leaching of solutes due to cell disruption caused by insects and



* - Significant at $p \leq 0.05$ by F test; ^{ns} - Not significant by F test

Figure 5. Electrical conductivity of grains of three landrace varieties stored in different systems (raffia bags and silo bags) according to the storage time

Table 11. Electrical conductivity of grains of three landrace cowpea varieties stored in raffia bags and silo bags in each storage period

Variable	Storage (days)	Arigozinho		Manteiguinha		Quarentão	
		Raffia	Silo bag	Raffia	Silo bag	Raffia	Silo bag
Electrical conductivity (μS cm^{-1} g^{-1})	0	28.13 a	28.13 a	53.27 a	53.27 a	39.95 a	39.97 a
	30	26.94 b	37.31 a	31.17 a	31.44 a	41.30 a	38.65 a
	60	63.08 a	30.04 b	51.18 a	33.83 b	73.21 a	49.49 b
	90	61.85 a	28.84 b	45.81 a	47.75 a	104.26 a	48.21 b
	120	330.15 a	31.14 b	71.39 a	63.54 a	295.62 a	50.28 b

Means followed by the same letter in the rows do not differ statistically by the Tukey test at $p \leq 0.05$

water absorption. This process is an indicator of low seed vigor, as highlighted by Prado et al. (2019), who associate higher electrical conductivity with the loss of seed vigor and viability. According to Magalhães & Sousa (2020), storage in silo bags is an effective alternative for maintaining the quality of common bean grains in terms of water, infestation, germination, electrical conductivity, and specific mass for up to 120 days.

Grains with high electrical conductivity are less desirable for agriculture and sale, indicating greater deterioration. The stability of cellular solutes in silo bags, as observed in the results for the three landrace varieties of cowpea, suggests superior preservation of the integrity and vigor of the grains compared to those stored in raffia bags, which is crucial for maintaining quality during extended storage times.

Silva et al. (2018) indicated the use of silo bags and hermetically sealed PET plastic bottles as an alternative for controlling insect pests and preserving the quality of grains of the BRS Guariba cowpea cultivar during 120 days of storage. The researchers observed a significant correlation, indicating that the water content and electrical conductivity of cowpeas increase as the infestation rate increases, thus confirming that infestation causes an increase in electrical conductivity values caused by the rupture of the integument and the increase in water content due to metabolic dynamics.

Overall, the results emphasize the superiority of hermetic storage in silo bags over raffia bags in maintaining the quality of cowpea grains. Hermetic systems minimize insect infestation, stabilize water content, preserve bulk density and germination, and maintain low electrical conductivity, proving a robust solution for grain storage. Therefore, transitioning to hermetic storage technologies is recommended to improve post-harvest grain preservation, contributing to food security and reducing losses in the production chain.

Conclusions

1. Hermetic storage of landrace cowpea varieties seeds in silo bags is a safe and efficient alternative to control infestation by *Zabrotes subfasciatus* for up to 120 days.
2. Silo bags maintain the water content, bulk density, germination, and electrical conductivity of the Arigozinho, Manteiguinha, and Quarentão landrace cowpea varieties for up to 120 days.

Contribution of authors: Mayara A. D. e Silva, Lucas M. Lopes, Adalberto H. de Sousa, and Lêda R. A. Faroni elaborated and established the experimental design of the research. Mayara A. D. e Silva, Lucas M. Lopes, Rychaellen S. de Brito, Malena Lima, and Reginaldo A. Andrade conducted the experiments. Mayara A. D. e Silva, Lucas M. Lopes, Adalberto H. de Sousa, Lêda R. D'A. Faroni, Rychaellen S. de Brito, Malena Lima, and Reginaldo A. Andrade wrote the first version of the manuscript. Mayara A. D. e Silva, Lucas M. Lopes, Adalberto H. de Sousa, and Rychaellen S. de Brito made corrections and edited the manuscript. All authors approved the manuscript.

Supplementary documents: There are no supplementary sources.

Conflict of interest: The authors declare no conflict of interest.

Financing statement: There was no funding for this research.

Acknowledgments: To the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - CAPES and the Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq for the funding and scholarships.

Literature Cited

Abreu, A. O.; Faroni, L. R. D'A.; Silva, M. V. de A.; Sousa, A. H. de; Alencar, E. R. de; Silva, G. N. Ozone as an alternative fumigant for controlling Callosobruchus maculatus (F.) (Coleoptera: Chrysomelidae) in cowpea beans. Journal of Stored Products Research, v.97, e101969, 2022. https://doi.org/10.1016/j.jspr.2022.101969

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. Regras para análise de sementes. Brasília, MAPA, 2009. 399p.

Coradi, P. C.; Lima, R. E.; Padia, C. L.; Alves, C. Z.; Teodoro, P. E.; Candido, A. C. da S. Soybean seed storage: packaging technologies and conditions of storage environments. Journal of Stored Products Research, v.89, e101709, 2020. https://doi.org/10.1016/j.jspr.2020.101709

Ferreira, E. B.; Cavalcanti, P. P.; Nogueira, D. A. ExpDes.pt: pacote experimental designs (portuguese). R package version 1.2.0, 2018. Available on: <https://CRAN.R-project.org/package=ExpDes.pt>. Accessed on: Jun. 2022.

Gomes, C. D. L.; Sá, J. M. de; Godoy, M. S. de; Molina-Rugama, A. J.; Oliveira, L. L. de; Pastori, P. L. Bioactivity of plant extracts from caatinga on cowpea weevil, *Callosobruchus maculatus* (Coleoptera: Chrysomelidae: Bruchinae). Revista Brasileira de Engenharia Agrícola e Ambiental, v.26, p.541-546, 2022. http://dx.doi.org/10.1590/1807-1929/agriambi.v26n7p541-546

Hamzavi, F.; Naseri, B.; Hassanpour, M.; Razmjou, J.; Golizadeh, A. Biology and life table parameters of *Callosobruchus maculatus* (F.) on *Vigna unguiculata* (L.) Walp. fertilized with some mineral- and bio-fertilizers. Journal of Stored Products Research, v.97, e101978, 2022. https://doi.org/10.1016/j.jspr.2022.101978

Kuyu, C. G.; Yetenayet, B. T.; Mohammed, A.; Mengesh, A.; Mpagalile J. J. Evaluation of different grain storage technologies against storage insect pests over an extended storage time. Journal of Stored Products Research, v.96, e101945, 2022. https://doi.org/10.1016/j.jspr.2022.101945

Lopes, L. M.; Sousa, A. H. Santos, V. B.; Silva, G. N.; Abreu, A. O. Development rates of *Callosobruchus maculatus* (Coleoptera: Chrysomelidae) in landrace cowpea varieties occurring in southwestern Amazonia. Journal of Stored Products Research, v.76, p.111-115, 2018. https://doi.org/10.1016/j.jspr.2018.01.008

Lorini, I. Descrição, biologia e danos das principais pragas de grãos e sementes armazenadas. In: Lorini, I.; Miike, L. H.; Scussel, V. M.; Faroni, L. R. D'A. Armazenagem de grãos. Jundiaí: Instituto Bio Geneziz. 2018, Cap.4.1, p.363-381.

Magalhães, V. B.; Sousa, A. H. de. Quality of white Gurgutuba creole beans stored in silo bolsas and PET bottles. Revista Agrogeoambiental, v.12, p.91-104, 2020. https://doi.org/10.18406/2316-1817v12n320201465

MAPA - Ministério da Agricultura, Pecuária e Abastecimento. Brasília: MAPA, 2022. Available on: < https://agrofit.agricultura.gov.br/>. Accessed on: May 2022.

Martins, S. P.; Silva, G. N.; Sousa, A. H. de; Barbosa, D. R. e S.; Silva, R. A. da; Ducatti, K. R.; Donegá, M. A.; Santos, E. F. dos; Carvalho, M. S.; Queiroz, M. V. B. M. de. Cowpea storage: Can small farmers use polyethylene terephthalate bottles and wood ash as an alternative to avoid damage caused by *Callosobruchus maculatus*? Journal of Stored Products Research, v.106, e102301, 2024. https://doi.org/10.1016/j.jspr.2024.102301

Mesele, T.; Dibaba, K.; Garbaba, C. A.; Mendesil, E. Effectiveness of different storage structures for the management of Mexican bean weevil, *Zabrotes subfasciatus* (Boheman) (Coleoptera: bruchidae) on stored common bean, *Phaseolus vulgaris* L. (Fabaceae). Journal of Stored Products Research, v.96, e101928, 2022. https://doi.org/10.1016/j.jspr.2022.101928

Momanyi, M. R.; Nduko, J. M.; Omwamba, M. Effect of hermetic Purdue Improved Crop Storage (PICS) bolsa on chemical and anti-nutritional properties of common Bean (*Phaseolus vulgaris* L.) varieties during storage. Current Research in Food Science, v.5, p.107-116, 2022. https://doi.org/10.1016/j.crfs.2021.12.014

Mutungi, C. M.; Affognon, H.; Njoroge, A. W.; Baributsa, D.; Murdock, L. L. Storage of mung bean (*Vigna radiata* [L.] Wilczek) and pigeonpea grains (*Cajanus cajan* [L.] Millsp) in hermetic triple-layer bolsas stops losses caused by *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae). Journal of Stored Products Research, v.27, p.239-243, 2014. https://doi.org/10.1016/j.jspr.2014.03.004

Nascimento, J. M. do; Lopes, L. M.; Rocha, J. F.; Santos, V. B. dos; Sousa, A. H. de. Population development of bean weevils (Coleoptera: Chrysomelidae: Bruchinae) in landrace varieties of cowpeas and common beans. Florida Entomologist, v.103, p.215-220, 2020. https://doi.org/10.1653/024.103.0210

Ngwenyama, P.; Mvumi, B. M.; Nyanga, L. K.; Stathers, T. E.; Siziba, S. Comparative performance of five hermetic bolsa brands during on-farm smallholder cowpea (*Vigna unguiculata* L. Walp) storage. Journal of Stored Products Research, v.88, e101658, 2020. https://doi.org/10.1016/j.jspr.2020.101658

Odjo, S.; Burgueño, J.; Rivers, A.; Verhulst, N. Hermetic storage technologies reduce maize pest damage in smallholder farming systems in Mexico. Journal of Stored Products Research, v.88, e101664, 2020. https://doi.org/10.1016/j.jspr.2020.101664

Oliveira, A. M. C. de; Melo Neto, B.; Rocha, M. de M.; Silva, M. R. da; Oliveira, M. R. Produção de alimentos na base do feijão-caupi (*Vigna unguiculata*): importância nutricional e benefícios para a saúde. Research, Society and Development, v.10, e56101416054, 2021. https://doi.org/10.33448/rsd-v10i14.16054

Prado, J. P. do; Krzyzanowski, F. C.; Martins, C. C.; Vieira, R. D. Physiological potential of soybean seeds and its relationshipto electrical conductivity. Journal of Seed Science, v.41, p.407-415, 2019. https://doi.org/10.1590/2317-1545v41n4214988

Queiroga, M. de F. C. de; Gomes, J. P.; Almeida, F. de A. C.; Pessoa, E. B.; Alves, N. M. C. Aplicação de óleo no controle de *Zabrotes subfasciatus* e na germinação de *Phaseolus vulgaris*. Revista Brasileira de Engenharia Agrícola e Ambiental, v.16, p.777-783, 2012. https://doi.org/10.1590/S1415-43662012000700011

Silva, L. S. da; Carvalho, A. J. de; Siqueira, W. da C.; Rocha, M. de M.; Borges, J. B.; Barbosa, E. da S.; Barbosa, J. A. E. Physical properties of grains of cowpea genotypes. Revista Brasileira de Engenharia Agrícola e Ambiental, v.27, p.216-222, 2023. https://doi.org/10.1590/1807-1929/agriambi.v27n3p216-222

Silva, M. G. C.; Silva, G. N.; Sousa, A. H. de; Freitas, R. S.; Silva, M. S. G.; Abreu, A. O. Hermetic storage as an alternative for controlling *Callosobruchus maculatus* (Coleoptera: Chrysomelidae) and preserving the quality of cowpeas. Journal of Stored Products Research, v.78, p.27-31, 2018. https://doi.org/10.1016/j.jspr.2018.05.010

Silva, S. S. da; Vieira, R. D.; Grzybowski, C. R. de S.; Carvalho, T. C. de; Panobianco, M. Electrical conductivity of different common bean seeds genotypes. Journal of Seed Science, v.35, p.216-224, 2013. https://www.scielo.br/j/jss/a/wdwVhGGQQP45gjVSdVFGPJP/?format=pdf&lang=en

Sousa, G. A.; Hernandes, E. E.; Damasceno, S. S.; Mattar, E. P. L.; Siviero, A. Qualidade de feijão-caupi crioulo do Alto Juruá armazenado em embalagem a vácuo. Revista Conexão na Amazônia, v.2, p.21-39, 2021. https://periodicos.ifac.edu.br/index.php/revistarca/article/view/80

Souza, P. J. O. P.; Farias, V. D. da S.; Pinto, J. V. N.; Nunes, H. G. G. C.; Souza, E. B. de; Fraisse, C. W. Yield gap in cowpea plants as function of water déficits during reproductive stage. Revista Brasileira de Engenharia Agrícola e Ambiental, v.24, p.372-378, 2020. https://doi.org/10.1590/1807-1929/agriambi.v24n6p372-378

SPSS. Sigma plot user's guide, version 10.0. Chicago: SPSS, 2006.

Toledo, A. V. K.; Fontes, L. da S.; Barbosa, D. R. e S.; Silva, P. R. R.; Neves, J. A.; Melo, R. de S. Resistance of Cowpea Genotypes to *Zabrotes subfasciatus* (Boheman, 1833) (Coleoptera: Chrysomelidae: Bruchinae). Journal of Agricultural Science, v.5, p.83-90, 2013. http://dx.doi.org/10.5539/jas.v5n5p83