The present study aims to evaluate the effectiveness of high-density polyethylene container combined or not with Super Grain Bag for cowpea grain storage. The experiments were conducted on-station and on-farm. The storage systems tested included high-density polyethylene container (PC), Super Grain Bag (SGB), and polypropylene bag (PB). The insect infestation level and grain damage were determined monthly for 6 months at on-station and every 2 months for 8 months at on-farm trials. Acceptability test of the stored grain was carried out at the end of on-station trials with farmers. Naturally infested grain was used, with an initial infestation level of 117 insects/kg and a percentage of damaged grain of 27%. After 6 months of storage on-station, PB resulted in an increase of insect infestation to above 1300 insects/kg of cowpea grain and an increase of damaged grain to 79%. In the SGB and PC, the number of insects increased to 573 and 364 insects/kg, while the grain damage increased to 40% and 36%, respectively. After 4 months of storage the SGB was perforated by insects, compromising its hermeticity. The combination of PC with SGB (PC + SGB) reduced the proliferation of insects and grain damage, resulting in 257 insects/kg and 34%, respectively. The farmers highly accepted grain stored at PC and PC + SGB systems. The on-farm trials confirmed the effectiveness of the polyethylene container on limiting insects multiplication and grain damage. Thus, the polyethylene container, associated or not with Super Grain Bag, showed to be effective for storage and preservation of cowpea grain, making it suitable for smallholder farmers, thereby reducing cowpea grain losses during storage.

KEYWORDS
cowpea, polyethylene container, smallholder famers, Super Grain Bag
INTRODUCTION

Cowpea, *Vigna unguiculata* (L.) Walp, is one of the most important crops in Africa. It provides an excellent protein supplement to the lower content and quality of protein of cereals or roots and tubers often consumed in most resource-poor households (Chiulele, Mwangi, Tongoona, Ehlers, & Ndeve, 2011). However, during storage, the grain is heavily attacked by insects such as the bruchid cowpea weevil, *Callosobruchus maculatus* (Fabricius) (Coleoptera: Chrysomelidae: Bruchinae), causing high losses (Adebayo, 2016; Baoua, Amadou, Margam, & Murdock, 2012; Jackal & Daoust, 1986; Moussa, Lowenberg-DeBoer, Fulton, & Boys, 2011). Infestation by insects occurs before harvest, and grain destruction continues during drying and storage, not lasting more than 3 months after harvest under smallholder farmers’ storage conditions (Baributsa, Lowenberg-DeBoer, Murdock, & Moussa, 2010). Although precise data are not available, losses of up to 30%-70% has been recorded on stored cowpea in the absence of insect pest control measures (Yakubu, Mbonu, & Nda, 2012).

Most smallholder farmers in Africa store their cowpea grains using a range of traditional methods including wood ash, botanical extracts, sand, granaries made from local materials (bamboo and clay), and polypropylene bags (Mutungi, Affognon, Njoroge, Baributsa, & Murdock, 2014; Tiroesele, Thomas, & Seketene, 2015). These methods are flawed by structural and functional inadequacies, and their use is often limited to small quantities for household consumption. Improving grain storage methods could contribute to the reduction of postharvest losses (PHL) and may have a significant impact on farmers livelihoods. Furthermore, a reduction in PHL can improve food security, increase farmers' income by avoiding seasonal price fluctuation, and improve the nutrition of the rural communities. The use of improved storage structure is particularly important in developing countries where crop production is once a year due to unimodal rainfall pattern coupled with the shortage of irrigation infrastructures (Kotu, Abass, Hoeschle-Zeledon, Mbwambo, & Bekunda, 2019).

Methods of preservation of grains under hermetic storage conditions emerge as a feasible and cost-efficient strategy to be adopted in developing countries (Mutambuki, Affognon, Likhayo, & Baributsa, 2019). The respiration of the product, mounds and insects inside hermetic containers leads to oxygen depletion and carbon dioxide accumulation, resulting in insects death (Mutungi et al., 2014; Navarro, Donahaye, & Fishman, 1994; Ognakossan, Tounou, Lamboni, & Hell, 2013). The CO₂-rich and O₂-poor atmosphere also reduces the development of aerobic fungi, mycotoxins accumulation, and grain metabolic activity resulting in a reduction of oxidation, favoring preservation (Likhayo, Bruce, Tefera, & Mueke, 2018). Containers such as Purdue Improved Cowpea Storage (PICS) (Baoua, Amadou, Lowenberg-DeBoer, & Murdock, 2013; Baoua et al., 2012; Baributsa et al., 2010; Murdock, Margam, Baoua, Balfe, & Shade, 2012) and Super Grain Bag GrainPro Inc. (SGB) (Baoua et al., 2013) have been tested and have shown to be effective in protecting cowpea grains against insects. However, SGB and PICS bags are not exempt from damage during handling, and insects can perforate the bags compromising its hermeticity (Anankware, Ofori, Nuamah, Oluwole, & Bonu-Ire, 2013; Baoua et al., 2013; García-Lara, Ortiz-Islas, & Villers, 2013; Mutungi et al., 2014).

Metal silos are other hermetic containers that have been shown effective against grain storage insects (Chigoverah & Mvumi, 2016). Metal silos have an additional advantage of protecting the grain against rodents and can last for over 30 years if properly handled (Kimatu, McConchie, Xie, & Nguluu, 2012). These containers are suitable for smallholder farmers and are under dissemination in some sub-Saharan African countries (De Groote et al., 2013). Nevertheless, the adoption level has been slower due to the lack of continued manufacturing, reducing its availability leading to relatively high price (Gitonga, De Groote, Kassie, & Tefera, 2013).

As a result of the above described scenario, the present study aims to evaluate the effectiveness of high-density polyethylene container in cowpea grain storage. This container is manufactured by Mozambique Company Plastex and is usually used for water storage. The container is characterized by having solid walls and a tight lid, which may create hermetic conditions if well sealed. Thus, this container has the potential to reduce the proliferation of insects during cowpea storage thereby contributing to the reduction of grain postharvest losses.

MATERIAL AND METHODS

2.1 Treatments

For this study, four storage systems were set up, namely, (i) Super Grain Bags (SGB), 50 kg capacity, supplied by GrainPro, Inc., USA, associated with polypropylene bags, (ii) high-density polyethylene containers (PC), 60 L, locally known as bidão, supplied by Plastex Lda, Mozambique, (iii) high-density polyethylene containers associated with Super Grain Bags (PC-SGB), and (iv) polypropylene bags (PB), 50 kg capacity, used as a control treatment. Figure 1 illustrates the storage containers used in this experiment.

2.2 Experimental set up

Two sets of the experiment were conducted, one on-station and another on-farm. The on-station experiment was established at seed storage room of Agriculture Authority of Manjacaze district, Mozambique, at ambient temperature. A completely randomized design was used to arrange the treatments. The storage containers were placed on wood pallets to avoid direct contact with the ground. Three replications were used for each structure, and data collection was carried out monthly for 6 months.

The on-farm trials were established at farmers’ houses, involving a total of nine small-scale farmers. Farmers for on-farm trials were...
chosen from three villages of Manjacaze district, namely, Chizavane, Tavane, and Macuacua, with three farmers at each site. Each farmer was given one storage system of each type. For on-farm trials, data collection was carried out every 2 months for 8 months with the direct participation of farmers.

For on-station trials, cowpea grain not treated with any pesticide and locally purchased was used. At arrival, the grain was thoroughly mixed and homogenized as one batch. The polypropylene bags (PB) and Super Grain Bags (SGB) inserted inside the PB were loaded with 45 kg of cowpea grain while the polyethylene container (PC) and PC + SGB combination were loaded with 50 kg of cowpea grain. The PB and SGB were tied after the removal of excess air, and in the PC, a candle was placed inside the container, for the depletion of oxygen, and closed with a lid. In the PC + SGB combination, the SGB was inserted inside the PC, and the cowpea grain was loaded inside the SGB then tied and the PC closed.

### 2.3 Grain sampling

Grain sampling during the experiment was done as recommended in ISO-24333:2009 Cereals and cereal products – Sampling. Several subsamples were taken and mixed thoroughly totaling 1 kg used for analysis. The samples were taken from the top, middle, and bottom of the storage containers using double tube sampling spears. The following data were collected during the on-station experiment: grain moisture content, insect infestation level, percentage of damaged grain, and sensory evaluation. Samples were transported from the experimental site to the laboratory in paper bags. For on-farm trials, the gathered data included insect infestation level and percentage of damaged grain, and the analysis were done in the local of trial involving farmers.

### 2.4 Grain moisture content

Moisture content was measured according to the ISO-712:2009 Cereals and cereal products – Determination of moisture content – Reference method. Two subsamples of 5 g per replication were collected from the working sample, dried in an oven at 105°C to constant weight, for at least 3 h, and then reweighed (Guenha et al., 2014). The determination of moisture content for on-station trials was done monthly, while for on-farm, it was done just at the beginning of the trial to confirm if the grain was sufficiently dried for storage.

### 2.5 Insect infestation level

Grain samples (1 kg) were collected, and the number of adult insects (live and dead altogether) was immediately recorded at the location of the experiment, as previously reported by Covele et al. (2020). For on-station trials, the infestation level was recorded monthly, whereas, for on-farm trials, it was done every 2 months. The infestation level was determined by dividing the number of adult insects by the grain sample weight.

### 2.6 Damaged grain

For damage grain evaluation, the method previously reported by Guenha et al. (2014) was used. Four replicates of 100 seeds per replicate were taken after batch mixing. The grains were carefully examined using a hand magnifier and separated in two lots: (i) damaged (hole in the seed) and (ii) not damaged by insects, and each lot was then counted. The damaged grain percentage was calculated using the following formula:

\[
\% \text{ damaged grain} = \frac{d}{e} \times 100
\]

where “d” is the number of damaged grains and “e” the total number of grains.

### 2.7 Sensory evaluation of stored grain

Sampling for sensory evaluation was done once after 6 months of storage in on-station trials. Grain from different storage containers was submitted to the acceptability test among local smallholder farmers. A total of 28 evaluators, of which 46% were women, participated in the sensory evaluation, using the “Attribute difference tests” Hedonic ratings. The attributes tested were (i) appearance of uncooked grain and (ii) taste of cooked grain. For the cooked samples, about 2 kg of grains from each storage system was boiled in water.
(4 L) until the desired softness of the grain was obtained. Still water was provided to the panelist between samples testing.

To evaluate the acceptability of each of the tested attributes, scores were assigned as shown in Table 1.

2.8 Data analysis

All gathered data were organized using Microsoft Excel (2018). Two-way factorial ANOVA was used to test the effect of type of storage system and period, and the interaction of both factors in grain moisture content, insect density, damaged grain, as suggested by Covele et al. (2020) and Guenha et al. (2014). Data from the sensory evaluation were analyzed using one-way ANOVA to test the effect of storage system on consumer’s attribute scores (Korus, Banaï, & Korus, 2017). When significant differences were observed, Tukey’s multiple comparisons test was used to separate treatment means (p < 0.05). Both ANOVA and Tukey’s test were conducted under 95% of confidence limits. The tests were conducted using SPSS 20.0 software (SPSS Inc., Chicago, IL, USA).

3 RESULTS

3.1 On-station trials

3.1.1 Moisture content of cowpea grain

The mean moisture content of cowpea grain at the beginning of the experiment was 13%. After 30 days of storage, for the grain stored at polypropylene bag, the moisture content increased significantly (p < 0.05) reaching a peak of 14.5%. On the other hand, under the same period, no significant change was observed in the moisture content of the grain stored in hermetic systems (Table 2). From 30 to 90 days of storage, we observed a significant decrease of moisture content by 21% for the grain held in polypropylene bags (p < 0.05), and henceforth, it showed a reasonably constant pattern achieving around 11.5% at the end of the storage period. No significant difference was observed in the moisture content of the grain stored in polyethylene container alone or associated with Super Grain Bags in the first 90 days of storage (p > 0.05). After 180 days of storage, no significant difference was observed in the moisture content of the grain stored in polypropylene bags, polyethylene container alone and associated with Super Grain Bag (p > 0.05). The Super Grain was the only storage system that kept grain moisture content stable along the storage period.

3.1.2 Insect infestation level

Naturally infested cowpea grain was used in the experiment. Cowpea weevil, Callosobruchus maculatus (F.) (Coleoptera: Chrysomelidae: Bruchidae), was the dominant insect species during storage. Since the counting of insects was done in the field (not in laboratory conditions), it was not possible to perform an accurate separation of larvae, live and dead adults. Therefore, the total number of insects, including both live and dead insects, was considered (Figure 2). The initial infestation level was 117 insects/kg of cowpea grain. There were significant differences (p < 0.05) of infestation level between the storage systems and period. After 30 days of storage, the insect infestation level in the polypropylene bag increased significantly (p < 0.001) by fivefold, reaching 595 insects/kg. Under the same period, we observed a significant increase in the number of insects in polyethylene container associated with the Super Grain Bag (PC + SGB), reaching 195 insects/kg of cowpea grain, which represents 66% increase compared with the initial infestation level. No significant increase was observed in the infestation level in Super Grain Bag and polyethylene container used alone after 90 days of storage.

After 90 days of storage, the infestation level in the polypropylene bags increased more than tenfold compared with the beginning of the experiment, and thereafter, it showed a slightly steady pattern until termination of the trials when the maximum accountable insects number (around 1300 insect/kg) was attained. For the same period, the insect density on the SGB storage system also started to increase from 425 insects/kg on the third month to around 573 insects/kg on the sixth month. From 120 days of storage, we observed white spots and some holes at the internal surface of the Super Grain Bags, which compromised in some extent the hermeticity of the bags, allowing insects multiplication. The lowest increase rate of insect population was observed for the grain stored in polyethylene container associated with the Super Grain Bag (PC + SGB), reaching 195 insects/kg of cowpea grain, which represents 66% increase compared with the initial infestation level.

3.1.3 Cowpea grain damage

At the beginning of the experiment, about 27% of the grain was already damaged by insects (Figure 3). There were significant differences among the storage systems and along the storage period within the same storage system. For cowpea grain stored in polypropylene bags, the percentage of damaged grain increased significantly

### TABLE 1 Scores assigned to various sensory attributes of cowpea food products

| Appearance          | Taste                  | Score number |
|---------------------|------------------------|--------------|
| Very good           | Like very much         | 9            |
| Good                | Like                    | 8            |
| Moderately good     | Like moderately        | 7            |
| Slightly good       | Slightly like          | 6            |
| Not good not bad    | Do not like and do not dislike | 5  |
| Slightly bad        | Slightly dislike       | 4            |
| Moderately bad      | Moderately dislike     | 3            |
| Bad                 | Dislike                | 2            |
| Very bad            | Dislike very much      | 1            |
after 30 days of storage, reaching 41.7%. In contrast, grain held in all hermetic storage systems was stable in the first 2 months, with no significant increase in the level of damage. For Super Grain Bag, significant grain damage was achieved after 90 days of storage with 35.5% of grain showing damages by insects, an increase of initial infestation level by 31%. For polyethylene system used alone or in

**TABLE 2** Mean values (±SE) of cowpea grain moisture content stored in different storage systems for 6 months

| Storage structure | Storage period (days) | 0       | 30      | 60      | 90      | 120     | 180     |
|-------------------|-----------------------|---------|---------|---------|---------|---------|---------|
| PB                | 13.1 ± 0.18Aa         | 14.5 ± 0.23Ca | 13.2 ± 0.15Aa | 11.5 ± 0.28Ba | 11.4 ± 0.09Ba | 11.5 ± 0.16Ba |
| SGB               | 13.1 ± 0.18ABa        | 12.6 ± 0.16AAb | 13.6 ± 0.01Aa | 12.6 ± 0.04ABb | 12.3 ± 0.23Ab | 12.5 ± 0.04ABb |
| PC                | 13.1 ± 0.18Aa         | 13.5 ± 0.08Ab | 13.4 ± 0.26Aa | 12.0 ± 0.21Ab | 11.1 ± 0.06Bb | 11.6 ± 0.09Ba |
| PC + SGB          | 13.1 ± 0.18Aa         | 12.6 ± 0.34ABb | 12.7 ± 0.33AAb | 11.9 ± 0.11Bab | 12.1 ± 0.09Bab | 12.0 ± 0.04Bab |

Note: Different uppercase letter in rows and lowercase in columns show statistically significant differences.
Abbreviations: PB, polypropylene bags; PC, polyethylene container; PC + SGB, polyethylene container associated with Super Grain Bag; SGB = Super Grain Bags.

**FIGURE 2** Number of adult insects per kg of cowpea grain stored in four storage systems for 180 days

**FIGURE 3** Percentage of damaged cowpea grain stored in different storage containers for 180 days; PB = polypropylene bag; SGB = Super Grain Bag; PC = polyethylene container; PC + SGB = polyethylene container in association with the Super Grain Bag. Different uppercase letter shows significant differences between storage containers in the same period, while different lowercase letters represent significant differences between the storage times for a storage structure.
association with Super Grain Bag, the grain damage was only significant after 120 days of storage with 32.5% and 30.2%, respectively, but it remained stable henceforth until the end of the trial at 180 days of storage. About 79.0% of the grain stored in polypropylene bags was damaged by insects at the termination of storage (180 days), representing about double of the damage observed in hermetic storage systems. Correlation analysis showed a significant positive relationship between the infestation level and the percentage of damaged grain ($r = 0.98$, $p < 0.001$).

3.1.4 Sensory evaluation

Sensory evaluation of the grain was carried out at the end of on-station trials to analyze the effect of the storage containers on the acceptability of the grain by farmers. Two attributes were evaluated, the appearance of uncooked grain and taste of cooked grain. The result of appearance acceptability shows the highest appreciation for the grain stored on the polyethylene container associated with the Super Grain Bag (Figure 4), with over 85% of the evaluator considering the appearance at least moderately good after 6 months of storage, while none evaluator considered the grain appearance bad. The grain stored in polypropylene bag had the lowest score on the appearance appreciation, with over 89% of the panelist considering the grain appearance bad. The grain stored in polypropylene bag had the lowest score on the appearance appreciation, with over 89% of the panelist considering the grain appearance bad after the storage period. The panelist gave acceptable appearance quality for the grain stored on Super Grain Bag and polyethylene container for 6 months, which mean acceptable preservation of physical appearance quality of the grain compared with that stored on polypropylene bag. When used separately, Super Grain Bag and polyethylene container did not show significant differences in terms of the preservation of grain appearance.

Similar result trend was obtained for the attribute taste of the cooked cowpea grain (Figure 5). Grain stored at polypropylene bags was considered not eatable at all and was not included for the tests. Whereas the cooked grains stored at Super Grain Bags and polyethylene containers, after 6 months of storage, were still acceptable for eating, with a score above 5. The highest taste acceptability was obtained on the cooked cowpea grains stored at the PC + SGB storage system, with over 42% of the evaluators considering the grain still highly acceptable for eating (a score of 9).

3.2 On-farm trials

Data collected from on-farm trials were the infestation level (Figure 6) and the percentage of grain damage (Figure 7). Like on-station trials, locally purchased grain was used in on-farm trials. The grain used for on-farm trials had slightly different initial infestation level and percentage of grain damage for different trials sites, and both parameters were lower when compared with the cowpea grain used on-station. After 60 days of storage, the infestation level and percentage of grain damage in polypropylene bags showed the lowest increasing rate in Tavane, increasing by over 12-fold and sevenfold, respectively. For the same period, the infestation level and percentage of grain damage in Chizavane and Macuacua increased by over 25-fold and 11-fold, respectively. On the other hand, a lower increasing rate of insect population and damage level was observed for the grain stored in hermetic systems.

From 120 days of storage to the termination of the trial at 240 days, the level of infestation level and grain damage in polypropylene bags and Super Grain Bag did not differ significantly in Chizavane ($p < 0.05$), with infestation level above 1000 insects/kg and 100% of the grain showing damage by insects. In Tavane and Macuaca, a similar trend was observed after 180 days of storage. The polyethylene container showed a better performance than the Super Grain Bag and polypropylene bag in preserving the grain against insect attack since it significantly reduced the growth rate of the population.
of insects along 240 days of storage, with grain damage level below 20% in all storage sites. The polyethylene container associated with the Super Grain Bags was the most effective storage system as it suppressed the growth of insects and reduced the physical damage of cowpea grain, with no significant variations for both parameters along 240 days of storage.
The initial grain moisture content for on-station trials was around 13%, which is at the upper limit of the recommended moisture content for safe storage of cowpea grain (Yakubu et al., 2012). A slight fluctuation in grain moisture was observed in polypropylene bag, polyethylene container associated or not with the Super Grain Bag between 30 and 120 days of storage. When used alone, the Super Grain Bag did not show a significant variation in the moisture content along the storage period, which is consistent with previous studies.

**FIGURE 7** Level of grain damage of for the different storage systems evaluated with farmers for cowpea grain for a period of 8 months. (a) Chizavane site, (b) Tavane site, and (c) Macuacua site.
was identified as the primary insect pest of *Callosobruchus maculatus*. 

Changes in the moisture content of the cowpea grain stored in hermetic storage systems can partly be ascribed to seasonal changes of temperature and relative humidity in the local area of storage. The trials were set up during the hot and rainy season, and the grain may have absorbed humidity from the environment since the relative humidity was high. As the season shifted from the rainy weather conditions to dry, the stored grain tended to lose its moisture content. Previous studies have also reported variation in the moisture content of the grain stored in polypropylene bags to adjust with the environmental conditions (Aboagye, Darko, & Banadda, 2017; Chigoverah & Mvumi, 2016; Walker, Jaime, Kagot, & Probst, 2018).

The fluctuation of moisture content in hermetic storage systems has also been reported in previous studies and has been partly attributed to intermittent opening of the storage containers for grain sampling (Baoua, Amadou, Ousmane, Baributsa, & Murdock, 2014; Chigoverah & Mvumi, 2016; Covele et al., 2020). However, no sound explanation could be offered for the differences in the fluctuation of moisture content of the grain stored in Super Grain Bag when used alone and when associated with the polyethylene container, especially considering that, when used alone, the Super Grain Bag was perforated by insects after 4 months of storage. The perforation of the plastic liner by insects compromises its hermeticity and allows interaction between the stored grain and the outside environment, which could potentially result in moisture content variation. In contrast to our findings, Aboagye et al., (2017) did not observe any significant change in the moisture content of the cowpea grain stored in hermetic systems for 12 weeks.

Naturally infested grain was used in the experiment, and *Callosobruchus maculatus* was identified as the primary insect pest of stored cowpea grain, which corroborates with previous studies (Ngwenyama, Mvumi, Nyanga, Stathers, & Siziba, 2020; Sanon, Dabiré-Binso, & Ba, 2011). Polypropylene bags showed the highest rate of insect multiplication achieving at the termination of the experiment 11-fold of the initial insect population. On the contrary, the polyethylene container showed to be effective in limiting the multiplication of insects, achieving the best performance when combined with the Super Grain Bag, with only twofold increase in insect population after 180 days of storage. Covele et al. (2020) also reported a reduction on insect population in paddy rice stored in high-density polyethylene containers of different sizes for 12 months, while for grain stored in polypropylene bags the population of insects increased by eightfold over the storage period. Insect population increase in polyethylene container associated with Super Grain Bag is most likely to be a result of insect death making them easy to capture or to already existing larvae that developed to adult during the storage period.

After 4 months of storage, the Super Grain Bag was perforated by insects compromising its hermeticity and leading to an increase in the infestation level. Similar results were reported by García-Lara et al., (2013) and Baoua et al., (2013) for cowpea grain stored in Super Grain Bags and PICS infested with *C. maculatus*. Due to insect perforations, the Super Grain Bag was the least effective hermetic system, with an increase of insect population by fivefold along the storage period. However, the insect population in these bags was still half of that observed in polypropylene bags, as insect multiplication was delayed before insects perforated the bags. Insects perforating the bags during storage may come from inside or outside the grain bulks. Therefore, initial disinfection of the grain before storage as well as maintaining the store environment clean are essential practices to improve grain preservation using hermetic plastic bags. We also observed white spots in Super Grain Bags, which could be the eggs or the larvae of *C. maculatus* (Beck & Blumer, 2014).

This study shows that the use of high-density polyethylene container represents an enormous potential for cowpea grain protection against *C. maculatus*. This container could also protect the grain against rodents and insect’s perforation during storage. The control of insect multiplication using hermetic containers is a result of oxygen depletion and carbon dioxide accumulation inside the container due to the respiration process of insects, fungi, and grain (Williams, Murdock, & Baributsa, 2017). The efficacy of hermetic systems in controlling insect multiplication during grain storage has been reported for several commodities (Abass et al., 2018; Lane & Woloshuk, 2017; Likhayo, Bruce, Mutambuki, Tefera, & Mueke, 2016; Sanon et al., 2011; Tola, Muleta, & Hofacker, 2020).

The percentage of damaged grain almost tripled during 180 days of storage for the grain held in polypropylene bags, which corroborates with the fact that high insect infestation level was recorded in polypropylene bags. In hermetic storage, the damaged grain level showed an increase by 26% to 48%, with the Super Grain Bag presenting the highest percentage of damaged grain, which parallels the fact that this container showed the highest infestation level amongst the hermetic systems. As previously reported by Singano, Mvumi, and Stathers (2019), insect infestation level during storage is positively correlated with grain damage and weight loss. The increase in damaged grain in hermetic systems underlines the need for initial disinfestation before the grain is stored. Insects may cause damages in the grain before the level of oxygen is reduced enough to deter their multiplication. Also, totally hermetic conditions may not have been achieved due to intermittent opening for grain sampling, as also reported in previous reports (Abass et al., 2018). Insects were not eradicated during storage using hermetic systems, so they could cause some level of damage on the grain.

Grain damage during storage could cause problems for both farmers and traders. The damage represents a lost opportunity due to the reduction in grain quality, which will result in farmers selling their grain at a lower price. Extensive damage makes the grain unfit for human consumption, making it unsellable. In cowpea, it has been shown that bruchid damage may attract price reduction in the order...
of 0.1%–0.5% for every unit increase in the number of holes in 100 seeds in Ghana and Cameroon markets (Langyintuo, Ntoukam, Murdock, Lowenberg-DeBoer, & Miller, 2004). In Tanzania markets, common beans were also demonstrated to attract an average price discount of 2.3% in every additional hole caused by bruchids in 100 bean grains (Mishili, Temu, Fulton, & Lowenberg-DeBoer, 2011). This could be eventually fixed by sorting out damaged grain before putting it in the market but will represent a loss in the weight of available grain for selling, resulting in economic loss. The use of hermetic containers could be an alternative to reduce the losses during storage and could bring an additional advantage to the environment by dispensing the use of pesticide to protect the grain against insects during storage.

Cowpea grain stored under hermetic conditions was highly accepted by smallholder farmers, as demonstrated by the sensory evaluation analysis for the appearance of uncooked grain and taste of cooked grain. On the other hand, the appearance of the grain held in polypropylene bags was considered unfit for consumption after 6 months of storage. The high acceptance of grain stored in hermetic systems is a result of lower insects’ multiplication which in turn reduced the percentage of damaged grain, making it more appealing to farmers. A study on maize storage has reported that the use of hermetic systems preserved grain appearance after 30 months of storage, while the appearance was negatively affected for the grain stored in polypropylene bags (Villers, Bruin, & Navarro, 2006).

Trials on cowpea grain storage systems were also carried out under smallholder farmers’ condition. Grain from different sources was used, so there was some variation in the initial infestation and damage level. Also, the type of grain used may be different since smallholder farmers tend to use a mix of grains coming from different sources as seed. Despite these variations in the grain quality, on-farm trials using grain from farmers are necessary to evaluate the technology and see how it performs where it is most needed.

The on-farm trials confirmed the effectiveness of the containers under evaluation to limit the multiplication of insects and reduce grain damage level during storage. Storage of cowpea grains not treated with pesticides needs to be done under hermetic conditions, and the resistance of the containers used to be punctured by insects and other pests such as rodents is an advantage. The high-density polyethylene container, when properly sealed, could be an alternative for long-term cowpea grain storage under smallholder farmers’ conditions, especially for women since it does not need to be repaired every year like the traditional silos. The container, if well preserved, can be used for more than 10 years, according to the manufacturer company. For long periods of storage, the container can be associated with Super Grain Bag since it makes a double action on creating hermetic conditions. The container also protected the Super Grain Bag against shocks that could result in the damage on the bag. This storage system can be classified as environmentally friendly and can contribute to fulfilling the consumer increase demand for chemical-free products, as it does not require the use of pesticides. In the Mozambique market, the container comes in the size of 60, 100, and 210 L.

In this study, the effectiveness of the storage systems on preserving seed quality was not tested. However, farmers involved in on-farm trials used the remaining grain stored in the polyethylene container alone and associated with Super Grain Bag storage system as seed and reported an acceptable germination rate. Therefore, the possibility to use these containers to preserve cowpea seed should be evaluated. The Super Grain Bag is suitable for the storage of grain for short periods (less than 3 months). Nevertheless, a much longer period of storage can be attained with Super Grain Bag if soon after harvest the grain is dried, thrashed, cleaned, and packed.

5 | CONCLUSIONS

From the results of the trials, both on-station and on-farm, it can be concluded that the high-density polyethylene container with or without the combination with Super Grain Bag is an effective system for the preservation of cowpea grain by limiting insect multiplication and the percentage of damaged grain. Also, the grains stored in polyethylene container for 6 months was highly accepted by the farmers, while grains stored in polypropylene bags had a very low acceptability. The polyethylene container could create hermetic condition and is resistant to be punctured by insects, necessary pre-conditions for the storage of cowpea grain. The use of this container can contribute to the reduction of the current level of postharvest losses under smallholder farmers, which is essential to improve farmers livelihood and food security. Further research is required to assess the effectiveness of hermetic storage containers under evaluation to minimize fungal growth and to maintain the grain germination potential and vigor, as the majority of smallholder farmers in sub-Saharan African countries use grain from previous harvest as seed.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest in this manuscript.

AUTHOR CONTRIBUTIONS

Lucas D. Tivana: formal analysis, conception and design of study, analysis and/or interpretation of data, drafting the manuscript, supervision, and funds acquisition. Rafael J. Nguenha: formal analysis, conception and design of study, analysis and/or interpretation of data, and revising the manuscript critically for important intellectual content. Paula Viola: methodology and conduction of the study. Isabel Monjane: methodology and conduction of the study. Nswana Kafwamfwa: conception and design of study, analysis and/or interpretation of data, and funds acquisition.
ETHICS APPROVAL
Informed consent was obtained at the time of data collection. The grain used for sensory evaluation, the only study that involved human participants, was bought locally, and prepared by the participants. The preparation of the grain did not involve the addition of any chemical additive. Furthermore, no data that could be used to identify the participants are presented in this report.

DATA AVAILABILITY STATEMENT
The datasets generated during and/or analyzed during the current research are available from the corresponding author on request.

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