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Capillary cooling technology with forced-air cross ventilation: an eco-friendly onion storage technology

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Abstract

The objective of this study was to develop a solar-powered forced air-ventilated onion storage system (FAVS) with capillary cooling technology and to compare the effectiveness of the system with other common onion storage practices. Onion is one of the economically important crops that suffer significant postharvest losses due to inadequate storage conditions. A FAVS unit (2300×1200×3400 mm) with a 3000 kg total capacity (1000 kg/layer) was designed and fabricated and compared with three conventional methods such as Traditional Storage (TDS), Net Sack Storage (SNS), and Jute Sack Storage (SJS). BARI Piaj-4 was kept in bulk condition for 120 days, and data of physiological weight loss (PWL), decay percentage, moisture content, total soluble solids (TSS), firmness, and fungal infection were measured at 30-day intervals. A 130-watt solar panel charges a battery that runs ten 6-watt exhaust fans all day. Side exhaust fans intake fresh air from outside to remove surface moisture from the onion as capillary action, while the exhaust fan on top sucks hot air from the FAVS system. The FAVS system outperformed, with the lowest decay (4.43%) and fungal infection (4.33%) compared to TDS (8.12% and 8.10%), SNS (8.80% and 8.90%), and SJS (9.27% and 9.37%). FAVS maintained the highest and most stable moisture content (75.37%), while physiological weight loss remained below 4%, which is significantly less than traditional methods (9%). Furthermore, the system showed minimum reductions in firmness (0.32%) and TSS (1.37%), indicating better quality storage. The findings support the adoption of FAVS as an effective and environmentally friendly alternative to traditional onion storage practices.

Keywords

Forced Air Ventilation; Onion Storage; Physiological Weight Loss; Postharvest Losses; Total Soluble Solids (TSS).

Introduction

Around the world, the onion (Allium cepa) is the most widely consumed bulb crop. The onion is thought to have originated in Asia, although it is now grown in almost every country on the planet (Ochar et al., 2023). Although onions are usually used as a spice in various meals due to their distinct flavor and pungency, they also play an important part in human nutrition due to their therapeutic characteristics (Singh and Khar, 2022). Onions are often planted during the cool-dry season and kept throughout the year. Worldwide production of onions was 100 million metric tons (MMT), and the production area of onions was 4.95 million ha in 2019 (USDA FAS, 2021). In terms of productivity, among major onion-producing countries, China tops the list with 67.25 ton/ha, followed by the USA, Spain, Japan, the Netherlands, Iran, Egypt, Mexico, Turkey, and Brazil with 53.91, 52.06, 47.55, 43.13, 34.0, 32.18, 29.13, 26.76, and 21.38 ton/ha, respectively (FAO, 2017). However, in terms of total production, China ranks first (40 MMT), followed by India (22.8 MMT) (USDA FAS, 2021). Onion is the most widely grown spice crop in Bangladesh, with 1.8 MMT produced annually on 0.178 million hectares (BBS, 2020). However, production cannot keep up with the rising demand for onions. On the other hand, inadequate postharvest management and unsuitable preservation practices are believed to waste 35–40% of the onion (Fatih, 2018). In general, weight loss and rotting (decay) losses were determined to be 20 to 25 percent and 10 to 13 percent, respectively (Siva et al., 2017; Adhikari et al., 2021).

Although the onion is a low-perishable crop, improper storage causes deterioration of the onion bulb due to rotting, sprouting, and physiological weight loss (Singh et al., 2021; Wang et al., 2019). The respiration rate in onions upturns decomposition and sprouting, while heat generation increases moisture loss and lowers their shelf life during storage (Kaka et al., 2019; Selivanova et al., 2019). Post-harvest processes and storage environments such as temperature, relative humidity, and air composition are fundamental factors in supervising and reducing the water losses (Barzigar et al., 2025; Ali et al., 2018). Imoukhuede & Ale (2015) conducted a study about storage structures with different roofs where they found that the basket kept at room temperature proved to be the best for storing onions compared to those with tin, thatched, and iron roofs. The onions are stored in conventional

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storage structures with no aeration at the bottom, which results in their bruising and decaying (Kiran et al., 2024).

However, onions stored in fully ventilated conditions at the bottom and sides with a raised structure above ground reduced the storage losses from 70.0 to 99.2% during five months of storage (Mandake et al., 2023). Sun et al. (2020) detected rotting in onions, particularly small and localized roots, by a transmittance system. Kiran (2024) stated that storage conditions are critical for regulating the rate of sprouting, rooting, and transpiration and thereby extending the shelf life of onion bulbs, while post-harvest handling, including storage temperature and relative humidity, is important to maintain the quality of onion bulbs (Samota et al., 2025). Onion cold storage is uncommon, and growers usually store onions using conventional techniques (Belo et al., 2023); in comparison, storing onion bulbs at high temperatures (18-21ºC) leads to increasing losses (Kakade, 2023).

In Bangladesh, onions are stored in the open air, where temperature and humidity are difficult to control (Abdullah-Al et al., 2024). Farmers store onions in conventional methods under shelters at ambient temperatures due to a lack of suitable storage facilities (Abdullah-Al et al., 2024). Onion postharvest loss is higher with this traditional storage strategy (Falola et al., 2022). As a result, a large volume of onions is imported from India and other countries throughout the year to address the onion shortage. Moisture loss from onion bulbs is increased at room temperatures over 27°C, according to Naqash et al. (2021).

Hot and humid storage conditions make onion bulbs more likely to develop problems like black mold (Aspergillus niger), bacterial soft rot (*Pseudomonas gladioli*), and other diseases (Gulandaz et al., 2024). Increased respiration with heat generation promotes onion regrowth during storage, but it also increases moisture loss from the bulb, reducing shelf life (Sharma et al., 2025). Cultivar, storage regime, and temperature have all been shown to have a substantial impact on onion storage life (Wakchaure et al., 2023).

One of the most critical steps in onion post-harvest technologies is onion curing (Muhie, 2022). Curing is the process of drying the bulb's thin outer layers to develop one or more complete outer skins. These outer skins serve as a barrier to water loss and infection by fungi such as Botrytis allii (neck rot). Several research studies on onion preservation have discovered that curing reduces the rate of respiration and suppresses sprouting and decomposition, hence preserving the quality of the onion and extending its shelf life (Ghulam, 2013). Low-cost farm-level storage technology is necessary to improve the shelf life of onions, enhance their marketability, and ensure that fresh onions are available to consumers at a fair price throughout the year (Dileep et al., 2024).

Consumers must accept dry onions with a robust texture. During storage, the texture and dry matter content of onions both deteriorate, lowering their market value (Akinwotu et al., 2025). Due to respiration and the loss of components necessary for respiration, the bulb dry matter content decreases during storage, and onions become softer (Chávez-Mendoza & Guevara-Aguilar, 2025). The hardness of onions is determined by firmness and total soluble solids (TSS) (Singh et al., 2021). The respiration rate is inversely related to the firmness and total soluble solids (TSS) (Islam et al., 2018). During storage, the total soluble solids (TSS) and hardness decreased, whereas respiration rate and total infection rose (Islam et al., 2019). For that reason, firmness and TSS of onion are considered indicators of the respiration rate of onion in this study; besides this, moisture content, physiological weight loss (PWL), and decay percentage are also considered to identify the appropriate onion storage system at the farm level.

Therefore, it's critical to understand how to keep onion bulbs for longer periods of time without deteriorating at the farm level, as well as to design structures to do so. The objectives of this research are to design a solar-powered, forced-air ventilated onion storage system and to compare the effectiveness of the system with other common storage methods.

Materials and methods

A solar-powered, forced-air ventilated onion storage was designed by SolidWorks 2016 software using specific methodological steps. According to objectives, FAVS, TDS, SNS, and SJS were designed and fabricated. Three 10 kg net bags are set in each layer of solar storage, traditional storage, net, and jute bag storage for sample data collection. The storage bin was fabricated from mild steel and plastic net, which is covered with a bamboo mat structure, and besides, the roof is shaded with asbestos tin.

The FAVS structure was made up of a steel frame and wrapped with a thin plastic net, which ensures aeration throughout the onion. The dimensions of the storage bin were L×W×H (2300×1200×3400) mm, layer-to-layer spacing was 865 mm, soil-to-layer spacing was 605 mm, the capacity of the bin was 3000 kg, and the capacity of each layer was 1000 kg.

The height of the onion on each shelf of storage was 762 mm. The steel structure was attached with a bamboo frame and bamboo mat walls on four sides. The floor was dressed in herringbone brick, and the roof was covered with asbestos. In two ventilation tunnels, exhaust fans (6 watts) were used in each layer to exhaust the warm air through the forced ventilation process.

Four exhaust fans (6 watts) were used just under the roof for ensuring continuous airflow inside the storage. A solar panel of 130 W and a 12 V battery are used to operate the fans. The spacing between each compartment was 0.60 m for the provision of air circulation. Figure 1(a) illustrates the 3D view of the FAVS, and Figure 1(b) represents the pictorial view of the FAVS system.

The TDS structure was made up of bamboo mat walls on three sides, and the upper side is open, which is placed under the shed with the help of bamboo. In this structure, natural ventilation was provided. The dimension of the traditional storage structure was randomly taken to be 2500×2000×1000 mm (L×W×H), which was exemplified in Figure 2. Traders usually keep their onions in jute or net sacks to sell them in the market. Onions in the net and jute are damaged due to improper management. For treatments 3 and 4, the net and jute bag were maintained as the traders' practices. The capacity of the jute and net bag was 50 kg each, which is shown in Figure 3.

(a)

(b)

Figure 1. 3D view (a) and pictorial view (b) of the FAVS system.

Figure 2. Traditional storage structure, i.e., farmers' practices for onion storage (Pictorial view)

Figure 3. Shows onions stored in net (a) and jute sacks (b) according to traders' practices.

Outside the machine laboratory of the Bangladesh Agricultural Research Institute's Farm Machinery & Post-harvest Processing Engineering Division in Gazipur, a solar-powered forced-air ventilated onion storage system was installed. The experiment took place on April 1, 2018, and lasted for 120 days and the same period of 2019 as well.

The onion variety used in the present study was BARI Piaj-4 because of its availability and popularity among farmers. In Bangladesh, farmers typically cultivate this onion variety using standard practices. We transplanted it at the end of December and harvested it at the end of March. In this study, preparation of the onion sample was carried out by sorting and cleaning to get uniform and good-quality onions, which were used for storage at different storage conditions.

Curing is the process of keeping an onion under natural aeration for 24 hours (Chattha et al., 2020). Freshly harvested onions are extremely perishable due to their heated surface, thin skin, and high moisture content. One of the most important ways to reduce post-harvest losses is onion curing. It's a natural wound-healing process in onions that replaces and strengthens damaged parts by producing a corky coating that prevents water loss and decay organism infection.

The principle of Completely Randomized Design (CRD) with 4 treatments and 3 replications was considered for experimentation. The experimental data collection was started on 1st April 2018 and continued up to August 2018, and this experiment also continued during the same period of 2019. The air temperature above three shelves inside the storage was recorded by a data logger. Airflow through the bin, relative humidity of air inside the bin, and ambient air temperature were measured. A sample onion was taken at 30-day intervals from each shelf to find out the decay, moisture content, physiological weight loss, total soluble solid (TSS), and firmness. The collected data were analyzed for meaningful interpretation.

The onion was stored in bulk condition in solar-powered FAVS, and three 10 kg net sacks of onion were placed on each shelf to examine the stored onion after a 30-day interval as per the loading pattern shown in Figure 4(a). In total, 3000 kg of onions were loaded into the FAVS system for experimentation. For TDS (Farmer's Practice), 3000 kg of onions were kept on bamboo mats in open surroundings. Three 10 kg net sacks of onion were placed in each replication to examine the stored onion after a 30-day interval as per the loading pattern shown in Figure 4(b). According to traders' practices, usually stored in local markets, 3000 kg of onions were kept in jute and net sacks each, which have a 50 kg capacity respectively. The loaded sacks are kept in a pile under a shed. Three 10 kg net sacks of onion were placed in each replication to examine the stored onion after a 30-day interval.

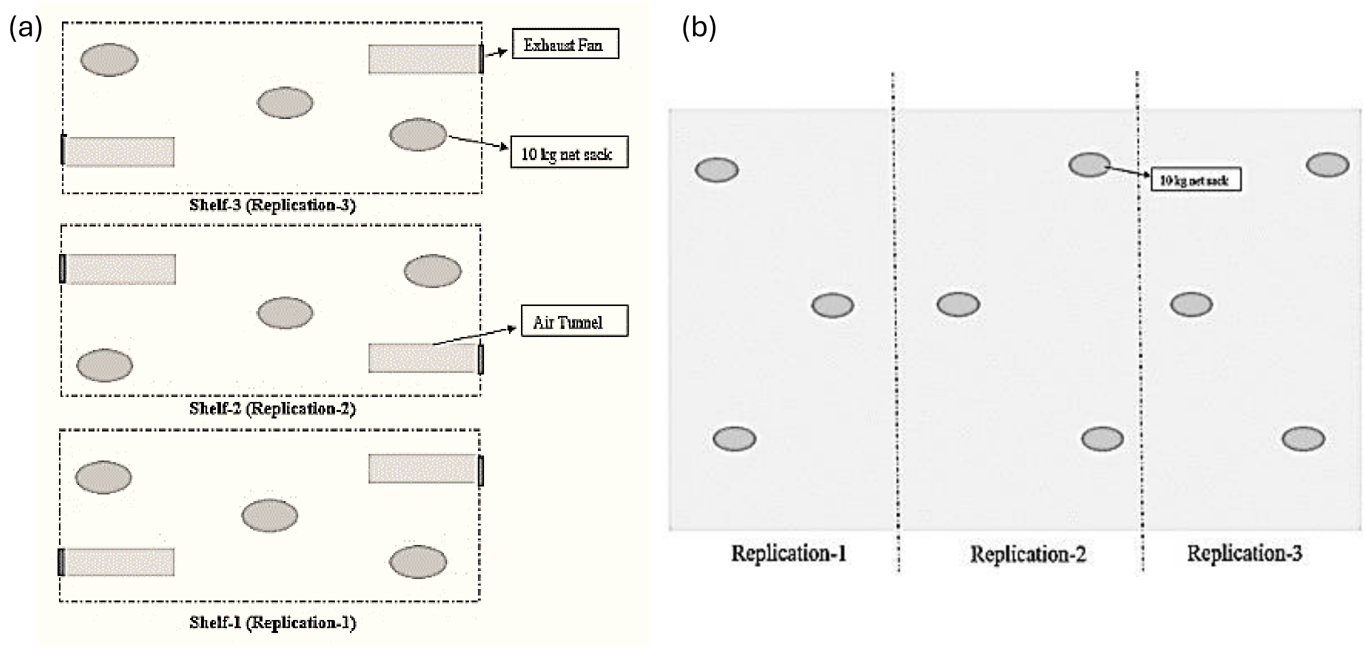

Figure 4. Allocation of onion samples (10 kg net sack) in the solar-powered FAVS system (a) and the traditional storage system (b).

Several performance indicators were used for this experiment. For moisture content, the 1 mm thick slices of onion were placed on perforated stainless-steel trays and dried in a hot air oven at 105°C for 6 hours (AOAC, 1990). The samples were recorded and weighed on an electronic balance and replicated. The moisture content was calculated using the following Eq. 1 (Attkan et al., 2024).

$$MC(wb\%) = (W_i - W_o)/(W_i) \times 100 \quad (1)$$

Where, W_i, initial weight; W_o, Oven dry weight

Before and after storing onions in a storage structure, onions were weighed in an electronic balance. Physiological loss in onion weight was calculated by the following (eq. 2) (Forotaghe et al., 2021).

$$PWL(\%) = (W_i - W_f)/W_i \times 100 \quad (2)$$

Where, W_i, initial weight; W_f, final weight

The decayed bulbs from the different storage methods were taken out and weighed at 15-day intervals in an electronic balance, and the decay percentage was calculated from the initial weight and the decayed bulbs' weight as given in (eq. 3) (Shelake et al., 2024). It is expressed in percentage.

$$Decay(\%) = W_{db}/W_{ti} \times 100 \quad [3]$$

Where, W_{db}, the decayed bulb weight and W_{ti}, initial weight of the total onion.

All statistical analyses in this experiment were carried out using the statistical package "R-3.4.4" for Windows Version 2010. Analysis of variance (ANOVA) and coefficient of variance (CV) between mean values were calculated at a 5% significance level.

Results and discussion

Curing of onion

Curing is an important post-harvest technology where excess moisture is removed from the outer skin of the onion to minimize the post-harvest losses because of sprouting, rooting, and rotting (Nabi et al., 2013). Onions are highly perishable if the outer skin is not cured out properly (Bezabih et al. 2017). The quality parameters for both fresh and cured onions are detailed in Table 1. As a result of the curing process of onions, the quality parameters such as firmness and total soluble solids (TSS) were increased significantly, while moisture content was decreased nominally.

Table 1. Quality parameters of fresh and cured onion samples.

Particulars	Fresh onion	Cured onion
Moisture content, % (wb)	78.3	76.8
Firmness (N)	3.86	3.98
Total soluble solid (TSS)	12.65	12.91

Temperature and relative humidity of storage period

Ambient temperature in all the storage structures was found to be almost similar to the storage period. The maximum ambient temperature of 35ºC was recorded in the jute sack storage system, followed by the traditional, net sack, and forced-air ventilated storage systems (Figure 5a). An increasing trend was observed for relative humidity in all three types of storage methods. The relative humidity of 79% was perceived to be highest in the jute sack storage system, followed by the traditional, net sack, and forced-air ventilated storage systems (Figure 5b). The increase and variation in temperature and humidity can be attributed to the firmness and TSS of onion bulbs.

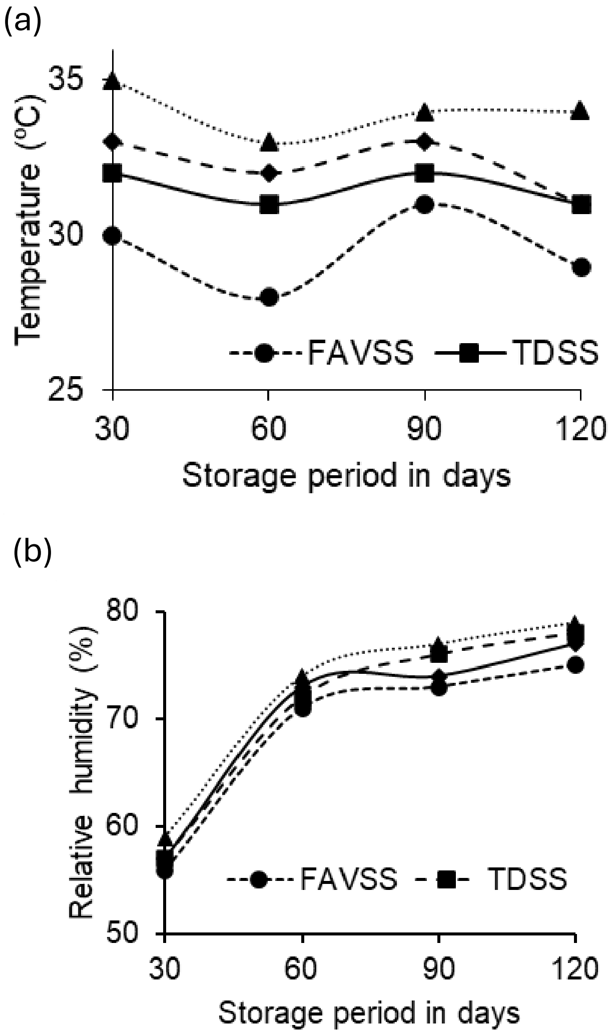

Figure 5. Temperature (a) and Relative humidity (b) for different storage System over the period.

Decay percentage of stored onion

A significant difference was observed in decay percentages among the treatments of the onion storage system. After 120 days, the forced-air ventilated storage system observed the significantly lowest decay at 4.43%, but the traditional storage system and the net and jute bag storage system were observed to have 8.12%, 8.80%, and 9.27% decay, respectively (Table 2). The results indicated that all the treatments were significant at the five percent level (Table 2). In this study, the forced-air ventilated storage structure recorded minimum decay due to good aeration and temperature inside the structure compared to the natural ventilated structure, net, and jute sack storage system. Similar results were expressed by Vishwakarma et al. (2022). The results indicated that the variables and their interactions for all the treatments were statistically significant.

A significant difference was observed in decay percentage with days in the forced-air ventilated storage system. The minimum and maximum decay percentages witnessed from 30 days to 120 days are 0.83% and 5.59%, respectively (Figure 7). Whereas literature showed that within a 90-day storage period, the minimum and maximum decay percent of stored onion bulbs in a forced ventilated storage structure was recorded as 3.8% and 13%, respectively (Shankar, 2022). For that reason, we can consider a solar-powered forced-air ventilated storage system to reduce decay percentage.

Decay percentages of onion with respect to treatment and storage period (days) were statistically analyzed and presented in Table 3. The results indicated that the variables storage period (days) and their interactions for all the treatments were significant at the one percent level. This indicates that the storage period affects the decay percentage of the onion storage system, i.e., when the storage period increases, decay percentages of stored onions also increase exponentially.

Figure 6 illustrated that all the decay percentages show a linear relationship with days. The highest decay % was found in jute sack storage, but the lowest decay % was found in FAVS after 30 days. But after 120 days, height decay % was observed in traditional farmer's practices, while decay % in FAVS remained constantly low. After a 60-day storage period, decay % was found stable in all treatments individually.

Table 2. Moisture content and decay of onion in terms of treatment after 120 days.

Treatment	Decay %	Moisture %
Forced air ventilated storage	4.43 c	75.37 a
Traditional Storage system	8.12 b	72.36 b
Stored in net sack	8.80 a	68.58 b
Stored in Jute sack	9.27 a	70.89 b
CV, %	7.956	6.37

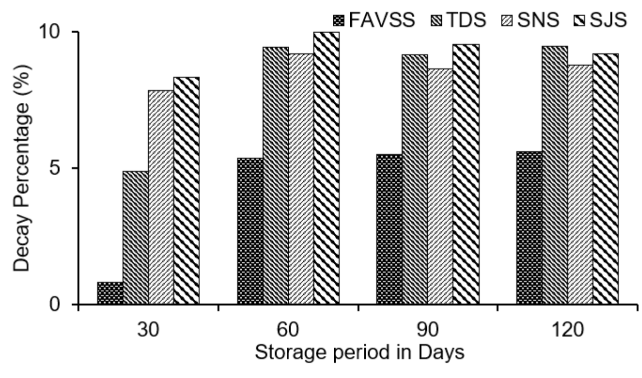

Figure 6. Decay % of onion among treatments.

Table 3. ANOVA table for Decay Percentage.

	Df	Sum Sq	Mean Sq	F value	Pr (>F)	
Trt	3	174.01	58	156.413	< 2e-16	**
Days	3	75.18	25.06	67.581	6.13E-14	**
Trt: Days	9	27.58	3.06	8.263	3.13E-06	**
Residuals	32	11.87	0.37			

** Significant at 1% level; **Significant at 5% level

Moisture content among the treatment

In this study, the forced-air ventilated storage system observed the highest moisture content (75.37%) compared to the moisture content % of the traditional storage system, net and jute bag storage systems, which were 72.36%, 68.58%, and 70.89%, respectively, after 120 days (Table 2). On the other hand, literature focused on the minimum and maximum value of moisture content in natural storage structure and forced ventilated storage, which was 79.57% and 82.49% and 79.80% and 79.85%, respectively, after 90 days (Shankar, 2017). The decrease in moisture content of the onion indicates the increase in ambient temperature as well as the increase in physiological loss in weight of the onion bulb. The moisture content of onions with respect to storage system and storage period was illustrated in Figure 7.

Moisture content deviation affects the physiological loss of onions in stored condition (Kim et al., 2024). Petropoulos et al. (2017) indicated that water loss is the key limiting factor that defines the length of the storage, because excessive water loss results in both bulb weight loss and quality loss that affect the marketability of the product. Minimum deviation of moisture content (less than 5%) is perceived in the forced-air ventilated storage system compared to the other treatments, and the highest deviation is observed (almost 20%) in the jute sack storage system. So, a lower decay % was observed in the forced-air ventilated storage system due to minimum deviation of moisture content.

The moisture content of onions with respect to treatment and storage period (days) was statistically analyzed and presented in Table 4. The results indicated that the variables are significant, but their interactions for all the treatments were not significant at the one percent level. Because moisture content can't affect the storage period.

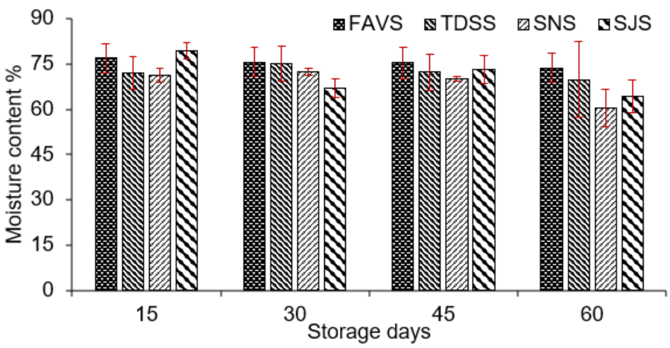

Figure 7. Moisture content % among treatments.

Table 4. ANOVA table for moisture content.

	Df	Sum Sq	Mean Sq	F-value	Pr(>F)	
Trt	3	291.2	97.06	4.632	0.00843	**
Days	3	401.8	133.93	6.392	0.00162	**
Trt:Days	9	329.2	36.58	1.746	0.11883	**
Residuals	32	670.5	20.95			

** Significant at 1% level; **Significant at 5% level

Physiological weight loss amongst the treatment

Onion bulbs in storage undergo loss in weight due to physiological changes like moisture loss, rotting, and nutritional and other biochemical changes resulting in desiccation. Weight loss in bulbs was found to increase with an increase in the storage period in onion (Sharma et al., 2020). The present study focused on minimum and maximum physiological weight loss and found less than 2% and less than 4% for onions stored in a FAVS system for 120 days (Figure 8). But maximum physiological weight loss (9%) is found in the traditional storage system. Similar studies were also observed; a 6% weight loss was found in onion bulbs stored at room temperature and 3% in cold storage as compared to fresh cultivated onion bulbs after three months (90 days) (Eun et al., 2012). Whereas Ali et al. (2021) also reported that physiological weight loss in onion bulbs was observed to be more under the traditional open ground method than those of nylon bags. Moreover, the net and jute sack storage system in ambient temperature for a 120-day storage period has shown a significant impact on physiological weight loss. The forced-air ventilated storage structure recorded the lowest physiological weight loss due to proper aeration, which decreased the temperature inside the structure.

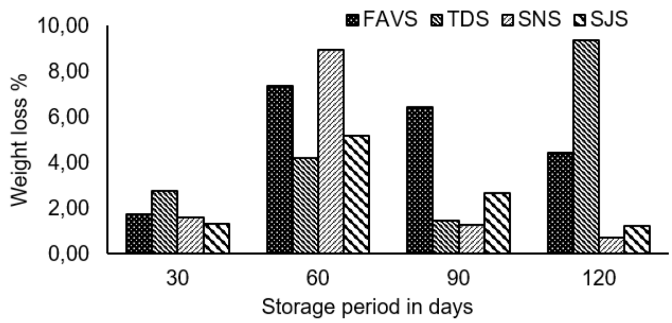

Figure 8. Physiological weight loss among treatments.

Total soluble content

The total soluble solids (TSS) are inversely related to respiration rate. TSS reduced from 13.85% to 12.48%, 11.89%, 11.45%, and 11.54% under the forced air ventilated storage system, traditional storage, net sack, and jute sack within 120 days, respectively (Fig. 12). However, the TSS reduced from 13.6% to 9.9% (i.e., the difference is 3.7%) for FAVS and 10.7% for the natural storage system, respectively (Soomro et al., 2016). But the minimum total soluble solids (TSS) difference (1.37%) is found in the forced air ventilated storage system compared to the other treatments (Figure 9).

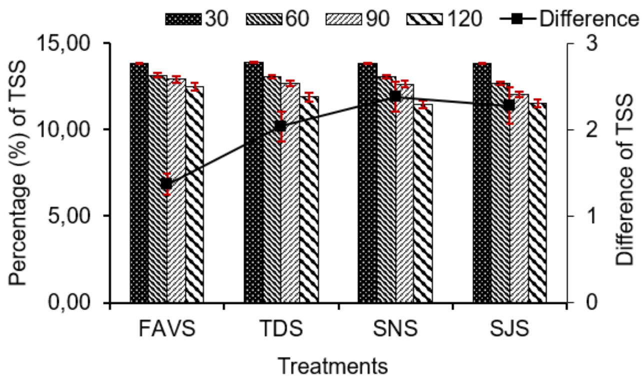

Figure 9. Total soluble solid (TSS) among treatments.

Firmness among treatments

Firmness is an acute characteristic of onion crops, especially in dry bulb onions, which are stored for long periods. Dry matter content (TSS) was also correlated to bulb firmness. Firmness is inversely related to respiration rate (Islam et al. 2018). This study found that firmness decreased gradually among all treatments during the 120-day storage period (Figure 10). Similar results were found by Rodrigues et al. (2012) for the onions kept for 3 and 6 months of storage; they reported that firmness tended to decrease with increasing days of storage. Firmness difference in forced-air ventilated storage was found to be a minimum of 0.32% compared to traditional storage (0.50%), net sack (0.82%), and jute sack (0.90%), respectively. A related observation was found in Vishwakarma et al., 2022, for the maximum difference in firmness was observed with high temperature, resulting in rapid degradation of quality of onion bulbs. So, forced-air ventilated storage is more competent than any other system in terms of firmness.

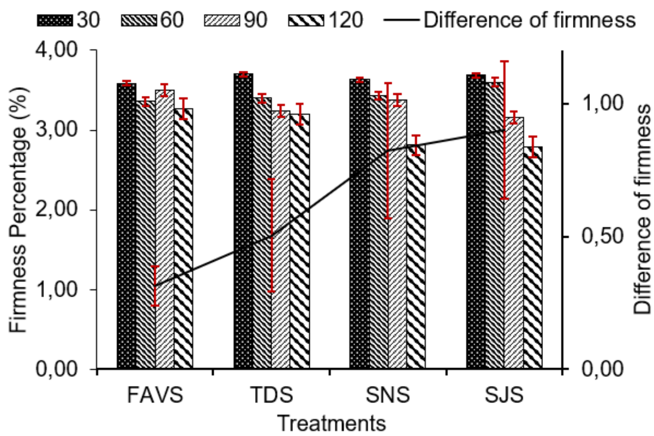

Figure 10. Firmness among treatments.

Fungal infection

The efficiency of different onion storage methods in controlling fungal infection is presented in Table 5, which includes the mean infection percentage, standard deviation (SD), and 95% confidence interval (CI), respectively. The FAVS system provided the lowest fungal infection rate (4.33%) with the lowest standard deviation (0.40) and a narrow confidence interval (3.83–4.83), indicating high consistency and reliability. In contrast, the TDS (8.10%), SNS (8.90%), and SJS (9.37%) methods showed higher infection rates, more variability (higher SD), and wider confidence intervals. The underlying CIs among the TDS, SNS, and SJS methods showed no significant differences among them. On the other hand, the CI of FAVS does not interfere with other methods, representing a clear statistical and practical superiority in reducing fungal infections during onion storage, focusing on its potential as an effective solution to reduce post-harvest losses.

Table 5. The table represents fungal infection percentages of four different onion storage methods, besides their standard deviations (SD) and 95% confidence intervals (CI).

Storage Method	Fungal Infection (%)	Standard Deviation (SD)	Confidence Interval (95%)
FAVS System	4.33	0.40	3.83 - 4.83
TDS	8.10	0.75	7.62 - 8.92
SNS	8.90	0.88	8.10 - 9.70
SJS	9.37	0.93	8.27 – 10.37

The study showed that onions kept in a Forced Air Ventilated Storage (FAVS) unit stayed in far better condition than those stored by the old methods, such as traditional dry storage (TDS), net sacks (SNS), or jute sacks (SJS), over a period of 120 days. FAVS bulbs held more moisture content (75.37%), had a lower decay percentage (4.43%), and had a minimum physiological weight loss under 2%, while the other methods represent more losses. These works coincide with the findings of Kiaya (2014) and Adhikari & Joshi (2021), who said steady airflow and exact humidity curb spoilage by slowing microbes and evaporation. FAVS also recorded the lowest fungal attack at 4.33%, with a tight confidence interval (CI) and small standard deviation (SD), representing statistical and practical superiority. The same trend was observed by Siva et al. (2022), who connected stable temperature and humidity in forced-ventilation rooms with better onion storage. Additional tests demonstrated that FAVS maintained the firmness of onions and retained a greater amount of total soluble solids (TSS), which are essential for their shelf life and customer appeal. The only noticeable decreases were firmness, which decreased by 0.32%, and TSS, which decreased by 1.37%. These decreases were significantly less severe than those observed in other systems. Vu et al. (2023) and Al-Gaadi et al. (2024) observed similar findings, indicating that lower respiration rates and lower temperatures slow down the spoilage of onions. In fine, forced-air ventilation not only limits fungal growth and rot but also preserves qualities better than standard storage methods.

Conclusions

These results collectively suggest that the FAVS system provides a controlled microenvironment that effectively minimizes spoilage factors such as moisture loss, microbial infection, and physical degradation. This aligns with previous findings that highlight the role of stable airflow, humidity, and temperature in reducing post-harvest losses and maintaining produce quality.

Although additional evaluations, such as economic feasibility, detailed fungal species profiling, and colorimetric analyses, could further validate its applicability, the performance of FAVS indicates that it is a viable, farmer-friendly solution for post-harvest onion storage, especially in humid and monsoon-prone regions. Integrating simple moisture absorbents like silica gel bags during the rainy season could further enhance the effectiveness of this system. Thus, the FAVS approach holds promise as a sustainable and scalable storage solution for improving onion post-harvest management and reducing economic losses in smallholder agricultural systems.

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