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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; SP-12(8): 1969-1983

www.thepharmajournal.com
Received: 09-06-2023
Accepted: 16-07-2023

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Different onion storage structures: Dimensions, materials and effects on the quality of onions: A review

SR Kakade, VP Kad, GN Shelke, GB Yenge and KJ Kamble

Abstract
Onions (*Allium cepa* L.) are one of the most well-known and commonly eaten bulbs. It is grown in India throughout three crop seasons (Kharif, late-Kharif, and Rabi). Onion storage is critical to ensuring that onions remain available in the market throughout the year. The major loss after harvest is caused by the forms identified with bulb dormancy physiology, such as growth and establishment, which usually occur during long-term storage or post-staining and add weight loss, degradation of visual appearance, quality changes, and, in severe cases, absolute production losses. Onion storage is a multifaceted subject involving several strategies varying from location to location. This review investigates the changes in the size details and materials of the various onion storage structures and the influence of long-term storage on onion quality parameters such as physiological loss in weight, sprouting, and rotting.

Keywords: Dimensions, onions, Kharif, late-Kharif, Rabi, *Allium cepa* L.

1. Introduction

Onion (*Allium cepa* L.) is considered the "Kitchen Queen" [1] and occupies a prominent position among the most popular and consumed bulbs of vegetables. It has been grown for centuries-without evidence of wild ancestors. It is believed to have origins in the harsh regions of Turkmenistan and northern Iran, and the southwest of Asia is considered an essential center for adaptation and diversity. Other regions with great diversity, such as the Mediterranean, are important reference points [2, 3].

In India, onions are the world's second-largest commercial vegetable crop after China. China, India, and the United States account for 52% of global onion production, totaling $8.7 billion in 2017 [4]. Storage plays an essential role in China's post-harvest losses, but in India, onions lost in storage and marketing account for about 42% of the total losses [5, 6]. Unlike in developed countries, most of the losses after harvesting occur at the level of retailers, food service and consumers, and developing countries have suffered significant losses during the storage and marketing process, resulting in nearly half of the total losses from production to retail sites [6].

The onion cultivation in India covers about 1196.30 thousand hectares, producing 21402.41 thousand metric tons in 2017-2018. However, India's productivity, at 16 metric tons/hectare, lags far behind that of countries like the Republic of Korea (66.16 t/ha), the USA (56.13 t/ha), Spain (55.21 t/ha), the Netherlands (64.51 t/ha), and Myanmar (46.64 t/ha) [7].

It grows in a cold season, so onions need optimal temperatures between 12.8 and 23°C during the growing season. The formation of the bulk requires a long day and even higher temperatures (20-25 °C). The diversity of onion varieties depends on the adaptation of the light period and temperature, the storage life of bulbs, the content of matter, taste and skin colour. Because of the high-water content of onions, onions are considered semi-perishable vegetables sensitive to storage conditions [8].

Post-harvest losses in onion storage are a significant concern. The factors such as unscientific storage structures, storage temperature, relative humidity, handling methods, and storage duration contribute to losses. The obstacles of storage include sprouting, deterioration, and physiological weight loss [9, 10]. To mitigate these issues, better post-harvest technologies and storage structures are essential. Extending the storage life of onions would lead to better financial rewards for growers and dealers [11]. In conclusion, onions hold significant importance in agriculture and food consumption worldwide. India is one of the top producers, but there is an opportunity for productivity and post-harvest processing improvement to lower losses and boost farmers and dealers' profitability. Better storage methods and technologies are crucial to minimize post-harvest losses in onion storage structures [12].

With the goal of minimizing deterioration rates, extensive research is being conducted to explore various onion storage methods. This review paper focuses on two main aspects: storage conditions and the impact of storage structures on the storability of onions. By thoroughly reviewing these factors, it aims to identify the most suitable facilities to reduce storage deterioration effectively.

2. Optimal storage conditions for onion

The storage environment significantly impacts the storage life and the loss of onion during storage. Various authors investigated different storage conditions, as shown in Table 1, and designed structures that effectively reduced physiological weight loss, undesirable sprouting, and the decay of stored onion bulbs. On a global scale, storing onions was not a prevalent practice from a trade perspective [13]. However, the need for storage has increased with growing domestic and export demands. Two temperature conditions have been identified with low losses: high-temperature storage (25-30 ºC) and low-temperature storage (0-20 ºC). Maintaining humidity at 65 to 70% yields the best results in both temperature conditions. High-temperature storage (25-30 ºC) leads to higher storage losses (30-35%) but minimal storage costs, whereas low-temperature storage (0-20 ºC) results in minimum losses (0.5%) but higher storage expenses [14].

The high temperature of the ambient storage structure (above 25 °C) causes significant weight loss, while the low temperature (above 10 °C) reduces the loss of sprouts. High humidity also plays an important role. Tripathi and Lawande (2019) [14] reported that reducing humidity improves storage conditions, while low humidity increases weight loss. Small-scale atmospheric storage is usually inexpensive for individual farmers to use at home. However, because the third world, especially without adequate storage facilities, suffers from high levels of loss of fresh weight (sprouting, decay) and quality (reduction of dry matter, sugar and vitamin C content), it is not recommended for large-scale storage, as Sharma *et al.*, (2014) emphasized [15].

For long-term storage, proper storage requirements include minimum temperatures (0 to 5 °C) and medium to strong relative humidity (60 to 70% RH), as mentioned by [16] and [17]. On the other hand, higher temperatures (above 25 °C) hinder sprouting and development in warm climates due to enzyme inactivity, as observed by Ward, (1976) [18], but result in significant water and quality losses due to dehydration and rotting.

Changes in chemical structure, sprouting, rooting, and water losses significantly contribute to the deterioration of onion bulb quality during processing. The proper storage conditions (temperature and humidity) are crucial for maintaining high-quality post-harvest retention of onions. Sprouting, rooting, and transpiration all play a role in determining the shelf life of onions [16, 17, 19].

Table 1: Different storage conditions for onion

Sr. No.	Temp. (ºC)	RH (%)	Storage Duration	Effects	Reference
1	25-30 ºC			This maintains dormancy and inhibits upper sprouting, but high temperatures also increase respiration rate, dryness and rotting.	[18]
2	Below 10 ºC			These slow down biological processes	[20]
3	0-5 ºC or 25-30 ºC	55-70%			[21, 22]
	27 ± 2 °C	60-65%			
4	0-2˚C	65-70%	4 Month	In cold storage, the overall storage losses for onion variety N-2-4-1 were only 5%.	[23]
5	27 ± 2 °C	60 to 65% with air circulation system	4 Month	Total loss of 7.14%	[24]

3. Storage structures

The availability of suitable storage facilities is crucial in the post-harvest handling of onions, as it significantly extends their storage life. Although many local onion storage systems exist as shown in Table 2 to 10, a major drawback is inadequate aeration. However, through extensive knowledge and subsequent studies, it has been demonstrated that low-cost structures can be designed to benefit onion farmers [25].

Temporary structures for the storage of onions were made with wooden boards with a covered roof and a covered roof with polyethene. The sides were built using pea sticks or wheat straw; in many cases, the floor was raised but made of Kouchcha. The semi-permanent structures were constructed with wooden logs or galvanized iron tubes/angles. Most of these structures are built on high Kuchcha or large sand platforms. The side walls were made of pigeon leaves, bamboo, and bamboo, and most semi-permanent buildings had manganese tiles as roof material.

In addition, permanent structures have been built with galvanized iron pipes, angles, and RCC columns. These buildings' roofs were made of galvanized iron or asbestos sheets, and the sides were made of wooden bantams, chain links and bamboo. Regarding storage capacity, 40 percent of many temporary and semi-permanent structures had less than 10 tons capacity [26, 27]. This review paper includes the details of traditional onion storage methods, advanced traditional structures, and atmospheric-controlled onion storage structures.

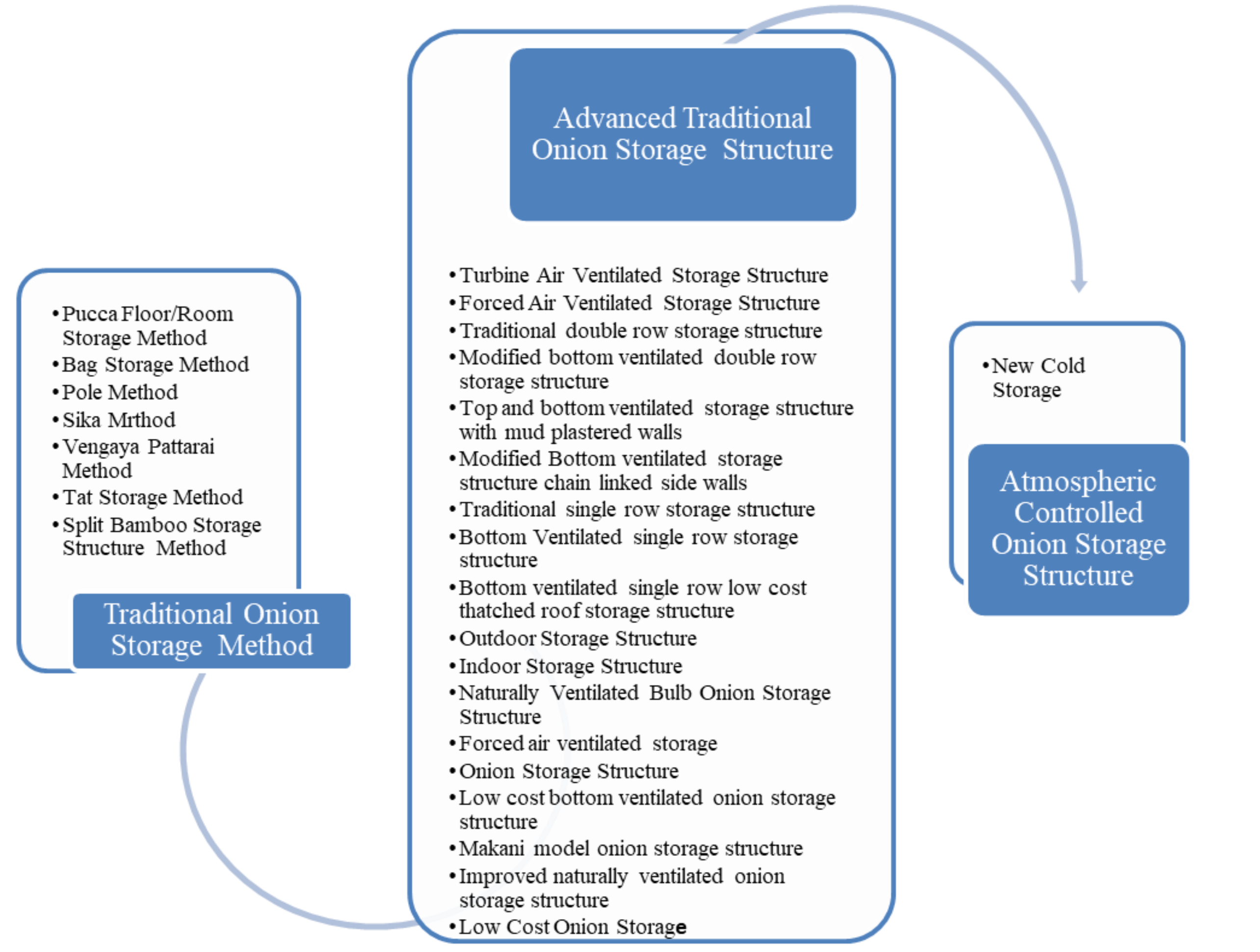

Fig 1: Different existing onion storage structures

3.1 Traditional onion storage structure method

3.1.1 Pucca floor/room storage

In a study by Deka *et al.* (1995) [28] on the effects of different storage methods over 150 days, it was found that using dry sand on the pucca floor was the most effective method for minimizing physiological weight loss, rotting, sprouting, and overall weight loss. In Sudan, onions were traditionally stored in mud or straw cottages as shown in Plate 1. These cottages were designed in a manner that allowed the prevailing wind to ventilate the stored onions effectively [29].

3.1.2 Bag storage

According to Iordachescu & Nihailescu, (1979), [30] the onions stored in bags showed losses of 17.2 percent over a 180-day period as shown in Plate 2.

3.1.3 Pole method

The leaves were used to bind cured bulbs into bunches and arrange them in a circle on a pole to ensure ample aeration as shown in Plate 3. This method is advantageous as it prevents the spread of disease by enabling early detection and removal of infected bulbs. Additionally, it facilitates easy storage while allowing the release of any remaining disease, making it particularly useful for long-term storage [31].

3.1.4 Sika method

The bulb bunches and leaves were hung on poles to ensure sufficient aeration as shown in Plate 4. Like the pole technique, they inspected both poles and bulbs for rot during storage and discarded any showing signs of decay. However, the hanging storage system proved effective only for a limited period of 45 days [32].

3.1.5 Vengaya Pattarai

The Vengaya Pattarai, rectangular stones placed in level fields, act as a barrier between rocks spaced 2 feet apart. A specially crafted neem wooden board is laid over the stones, while hand-woven bamboo mats cover three sides. The onions are stored within this system, and the fourth side is covered with jute gunny bags or bamboo sheets for the farmer's convenience [33]. To protect the onions from rain and excessive sunlight, the top portion of the Pattarai is filled with coconut thatches, promoting airflow within the stored onions as shown in Plate 5.

3.1.6 Tat storage

Singh & Singh, (1973) [34] found that storing onions with a brick foundation in tats resulted in better preservation compared to other local storage methods as shown in Plate 6.

3.1.7 Split bamboo storage structure

Krishnamurthy *et al.*, (1987) [25] found the split bamboo storage system with a central opening to be the most effective, showing the least spoilage and sprouting during storage. This system allowed for storing 100 to 800 kg of onion bulbs. It comprised two concentric bamboo structures with varying diameters, and the central hollow space on a platform provided excellent aeration, resulting in minimal losses as shown in Plate 7.

Plate 1: Pucca Floor/Room Storage Method

Plate 2: Bag Storage Method

Plate 3: Pole Method

Plate 4: Sika Method

Plate 5: Vengaya Pattarai Method

Plate 6: Tat Storage Method

Plate 7: Split bamboo storage structure

3.2 Advanced Traditional Onion Storage Structure

3.2.1 Turbine Air Ventilated Storage Structure

Wind turbines play a crucial role in maintaining air conditioning by drawing in air from inside the building. Especially useful at night, floor vents facilitate adequate ventilation. A turbine air ventilator is positioned atop a turbine air-ventilated storage structure. The rotor spins as warm air circulates within the storage space, creating upward air movement [31]. The turbine is mounted on the roof ridge of the storage structure, and the ventilator operates without consuming any electricity as shown in Plate 8.

Plate 8: Turbine air ventilated storage structure

3.2.2 Forced air ventilated storage structure

Perforated central systems with a lower blower are used in naturally ventilated or forced air-ventilated structures. In traditional single-layer storage structures, forced air ventilation systems are operated using a blower and a hole pipe. By forcing air ventilation, physiological weight loss in the perforated central structure decreased from 10% to 5% after storage for three months [31] as shown in Plate 9.

Plate 9: Forced air ventilated storage structure

Seven-onion storage structures including Traditional double row storage structure, modified bottom ventilated storage structure, Top and bottom ventilated storage structure with mud-plastered walls, modified bottom ventilated storage structure with chain-linked side walls, Traditional single row storage structure, modified bottom ventilated single row storage structure, Bottom ventilated single row low-cost thatched roof storage structure is built and constructed at NRC Onion and Garlic as shown in Plate 10, 11, 12, 13. Tripathi & Lawande, (2016) [13] reported these systems are based on storage structures that store onions in different parts of the country. The information on dimensional, material, quantitative, and qualitative losses related to these systems is described below in the Table 2.

Table 2: Details of material and dimensions of storage structures

1	Type of Structure	Traditional double row storage structure	Modified bottom ventilated double row storage structure	Top and bottom ventilated storage structure with mud plastered walls	Modified Bottom ventilated storage structure chain linked side walls	Traditional single row storage structure	Bottom Ventilated single row storage structure	Bottom ventilated single row low-cost thatched roof storage structure
2	**Dimensions (m)**							
	a. Length(m)	9.60	9.9	9.9	9.9	5.0	5.0	4.9
	b. Width(m)	7.5	6.0	4.75	3.6	1.2	1.2	1.2
	c. Centre Height	3.50	4.5	4.0	4.0	2.2	2.2	1.9
	d. Side Height(m)	2.25	2.25	2.25	2.25	1.2	1.2	1.6
3	**Construction Materials**							
	e. Roof	Asbestos	Asbestos with extended roof	Asbestos	Asbestos	Mangalore tiles	Mangalore tiles	Sugarcane leaves/thatch
	f. Side Wall	Wooden Bantam	Wooden Bantam	Split bamboo plastered with mud	Chain link	Split bamboo	Split bamboo	Split bamboo
	g. Floor	PCC	Wooden bantam with C channel support	Wooden bantam with C channel support	Wooden bantam with C channel support	PCC	Split bamboo with C channel support	Split bamboo with C channel support
	h. Foundation	PCC	RCC Pillar	RCC Pillar	RCC Pillar	PCC	Grouted C Channel	Brick Support
4	Losses: - (%) Quantitative Losses	46.11	37.69	23.82	37.30	38.10	33.88	28.66
	Qualitative Losses	5.21	11.06	13.75	8.88	7.86	9.87	3.46
5	Storage Capacity (tones)	38	42	31	25	5	5	5
6	Expected Life (Years)	20	20	20	20	20	20	5
7	Reference	[13]						

Plate 10: Top and bottom ventilated storage structure with mud-plastered walls

Plate 11: Bottom ventilated single row low-cost thatched roof storage structure

Plate 12: Modified Bottom ventilated storage structure chain linked side walls

Plate 13: Top and bottom ventilated storage structure with mud plastered walls

Table 3: Details of material and dimensions of outdoor storage structure

1	**Types of Structure Outdoor storage structure**		
2	**Dimensions**		
	a. Length (ft)	10	
	b. Breadth(ft)	15	
	c. Height(ft)	-	
	d. Bottom Ventilation (ft)	3	To prevent insect invasion and moisture contact
3	Structure Shape	Rectangular as shown in Plate 14.	
4	Roofing Shape	Triangular	Suitable ventilation and prevention of water stagnation during the rainy season
5	**Construction Materials**		
6	a. Side Wall	Iron mesh	To prevent foreign bodies from entering and to provide suitable air circulation.
	b. flooring	Wooden reapers	Give Ventilation
6	Storage period	3 months	
7	System Used	Naturally Ventilated	
8	Reference	[35]	

Table 4: Details of material and dimensions of indoor storage structure

1	**Types of Structure Indoor storage structure**		
2	**Dimensions**		
	a. Length (ft)	3	
	b. Breadth(ft)	1.5	
	c. Height(ft)		
	d. Bottom Ventilation (ft)	1	To prevent moisture humidity and the introduction of any pests
3	Structure Shape	Rectangular as shown in Plate 15.	
4	Roofing Shape	Rectangular	
5	Construction Materials		
6	a. Side Wall	Iron mesh	To give proper ventilation
	b. flooring	Wooden reapers	To give ventilation
6	Storage period	3 Month	
7	System Used	Naturally Ventilated	
8	Reference	[35]	

Plate 14: Outdoor Storage Structure

Plate 15: Indoor Storage Structure

Table 5: Details of material and dimensions of naturally ventilated bulb onion storage structure

1	**Types of Structure**	**Naturally Ventilated Bulb Onion Storage Structure**	
2	**Dimensions**		
	a. Shelves Size (cm)	25 and 125	
	b. Breadth(cm)	90	
	c. Height(cm)	-	
	d. Bottom Ventilation (cm)	70	For down ventilation
3	Structure Shape	Rectangular as shown in Fig 2.	
4	Roofing Shape	Triangular	
5	Construction Materials		
6	a. Side Wall	Mud Block	
	b. Onion flooring	Shelves	
	c. Roof	Thatched grass	
7	Storage period	80 Days	
8	Storage Capacity (Tonnes)	1.4	
9	Losses (%)	68.51%	
10	System Used	Naturally Ventilated	
11	Reference	[8]	

Table 6: Details of Material and Dimensions of Forced air ventilated storage

1	**Types of Structure Forced air ventilated storage**	
2	**Dimensions**	
	a. Length (m)	1.8
	b. Breadth(m)	1.0
	c. Height(m)	2
	d. Bottom Ventilation (cm)	45
3	Structure Shape	Rectangular as shown in Plate 16.
4	Roofing Shape	Triangular
5	**Construction Materials**	
6	a. Side Wall	Split areca wood
	b. Framework	Casuarinas wooden pole frame
	c. Onion flooring	Split areca wood
	d. Roof	Dried coconut thatches
7	Storage period	90 Days
8	Storage Capacity (Kg)	200Kg
9	Losses (%)	PWL- 27.41%
10	System Used	A blower and perforated pipe are used to create forced air circulation.
11	Reference	[36]

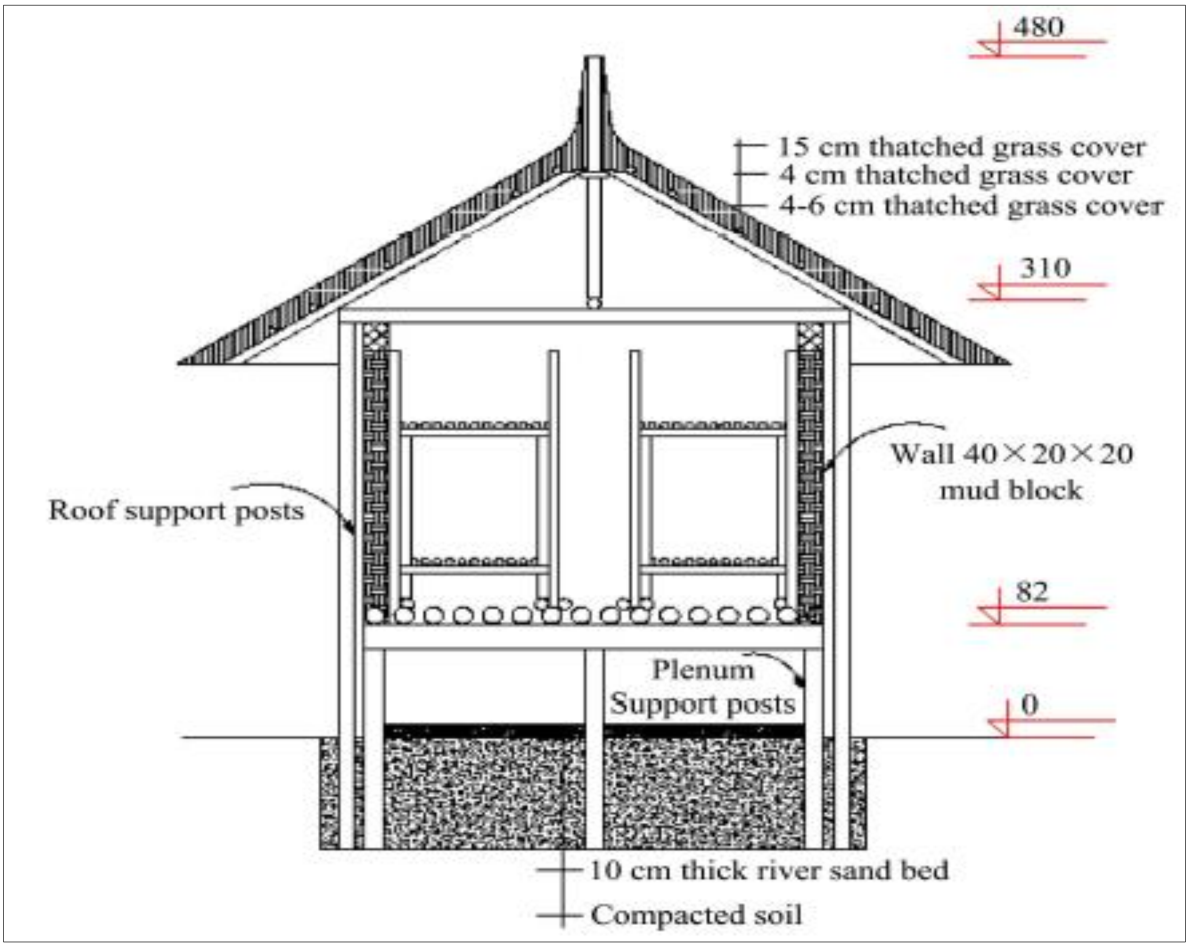

Fig 2: Naturally ventilated bulb onion storage structure

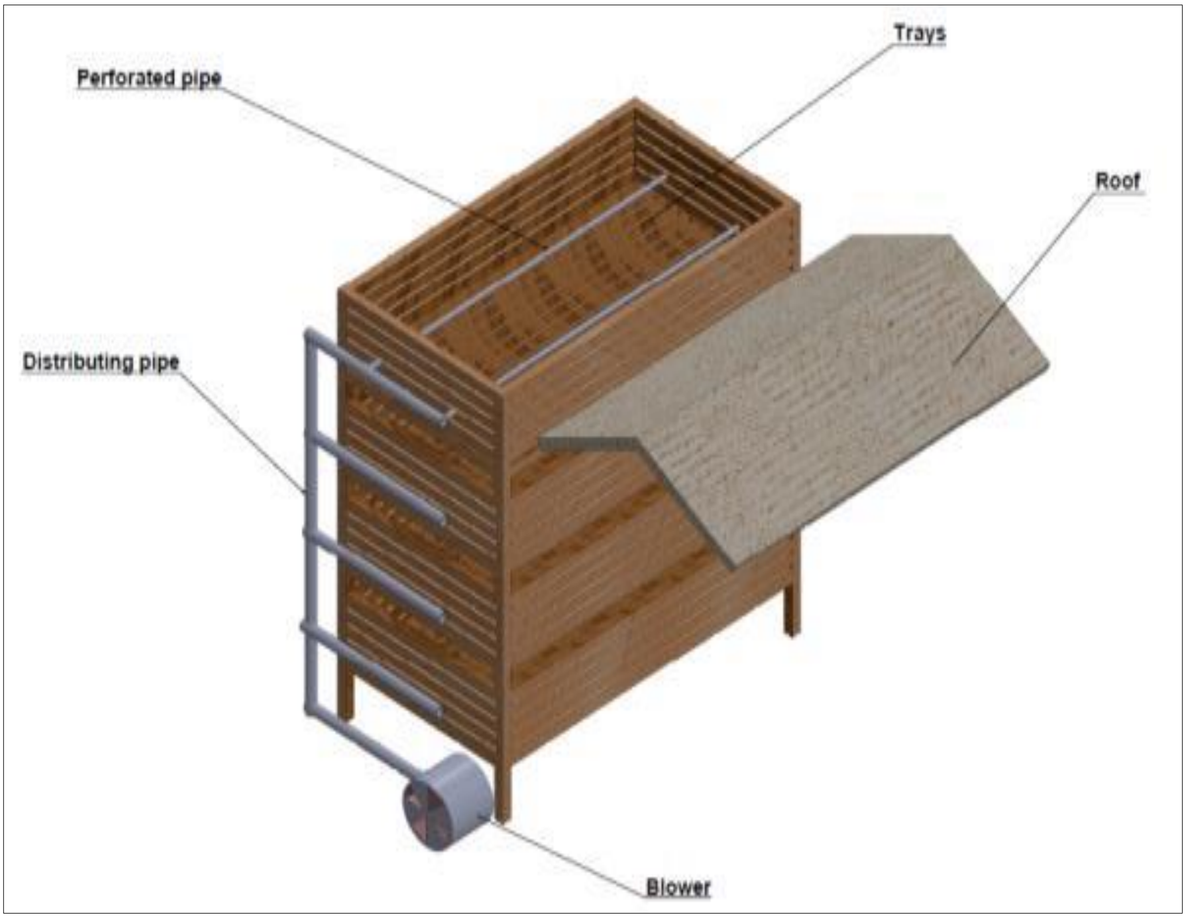

Plate 16: Forced air ventilated storage

Table 7: Details of material and dimensions of onion storage structure

1	**Types of Structure Onion storage structure**		
2	**Dimensions**		
3	a. Length (mm)	2000	As shown in Fig 3.
	b. Breadth (mm)	1800	
	c. Height (mm)	1900	
	d. Bottom Ventilation (mm)	-	
4	**Construction Materials**		
5	a. Side Wall	Wire mesh	To allow the required amount ventilation & optimum heat flow out of the structure
	b. Onion flooring	Wire mesh	For ventilation
	c. Framework	Wood	To avoid much expense and for high durability
	d. Roof	Asbestos sheet	Low heat absorption
6	Storage period	61 Days	
7	Storage Capacity (Tonnes)		
8	Losses (%)	PLW – 5.91%	
9	System Used	Adequate ventilation under ambient environment condition	
10	Reference	[37]	

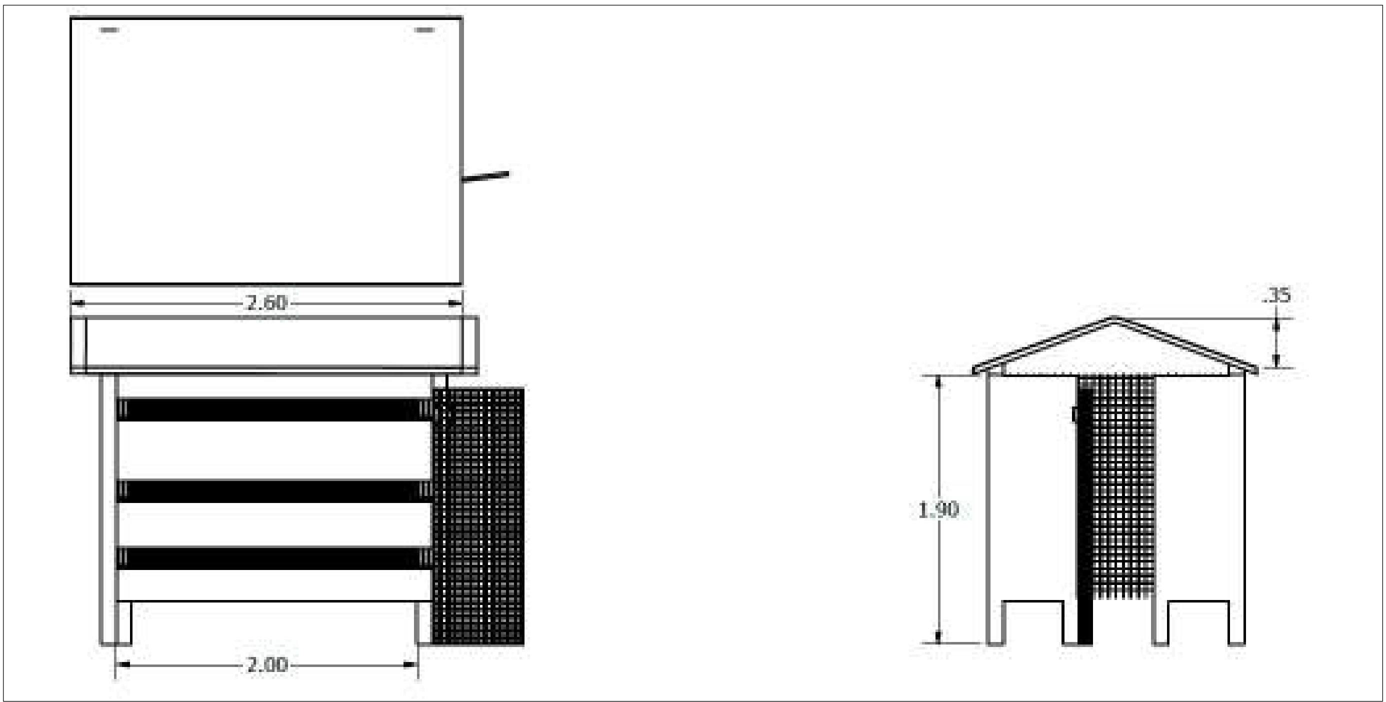

Fig 3: Onion storage structure

Table 8: Details of material and dimensions of low-cost bottom ventilated onion storage structure

1	**Types of Structure Low-cost bottom ventilated onion storage structure**	
2	**Dimensions**	
	a. Length (m)	5
	b. Breadth(m)	1.2
	c. Side height(m)	1.5
	d. Center Height(m)	1.9
	e. Bottom Ventilation (cm)	30
3	Structure Shape	Rectangular as shown in Plate 17
4	Roofing Shape	Triangular
5	**Construction Materials**	
6	a. Side Wall	Split bamboo with angle support
	b. Framework	Round bamboo
	c. Onion flooring	Split bamboo bantam supported on brick block
	d. Roof	Sugarcane leaves supported by bamboo bantam
	e. Foundation	Brick support
7	Storage period	6 months
8	Storage Capacity (Tonne)	5
9	Losses (%) Quantitative Losses	35.17
	Qualitative Losses	3.63
10	System Used	Naturally Ventilated
11	Reference	[13]

Table 9: Details of material and dimensions of Makani model onion storage structure

1	**Types of Structure Makani model onion storage structure**	
2	**Dimensions**	
	a. Length (ft)	18
	b. Breadth(ft)	9
	c. Side height(ft)	2
	d. Bottom Ventilation (ft)	2
3	Structure Shape	Rectangular as shown in fig 4
4	Roofing Shape	Triangular
5	**Construction Materials**	
6	a. Side Wall	With the help and assistance of the Iron angle, the Stalk (kara)
	b. Framework	Iron angles material
	c. Onion flooring	Iron angle & stalk bed
	d. Roof	Thick thatched grass material for hest resistant
7	Storage period	4 Month
8	Storage Capacity (Tonne)	90 Bags of Onion
9	Losses (%) PLW	11%
	Rotting	2.49%
10	System Used	Naturally Ventilated
11	Reference	[38]

Plate 17: Low-cost bottom ventilated onion storage structure

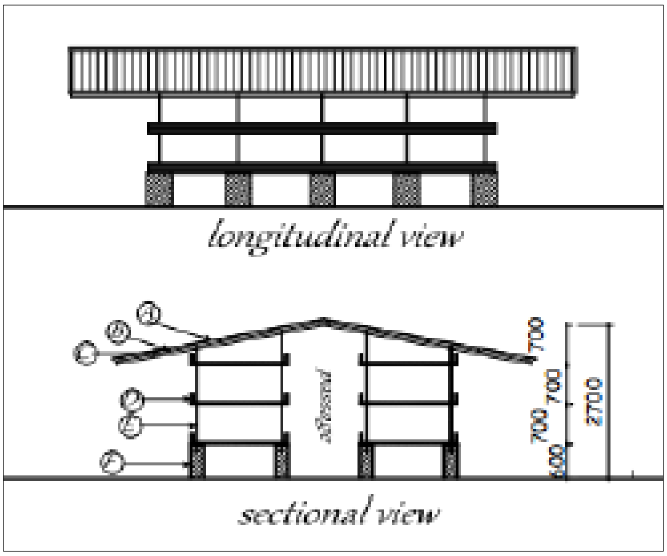

Fig 4: Makani model onion storage structure

Table 10: Details of material and dimensions of improved naturally ventilated onion storage structure

1	**Types of Structure Improved naturally ventilated onion storage structure**	
2	**Dimensions**	
	a. Length (m)	3
	b. Breadth(m)	2.5
	c. height(m)	2
	d. Bottom Ventilation (cm)	25
3	Structure Shape	Rectangular as shown in plate 18
4	Roofing Shape	Triangular
5	**Construction Materials**	
6	a. Side Wall	'Zana' mats made of grass
	b. Framework	It is built of local resources, including sand, cement, corn trees, wire mesh and grasses.
	c. Onion flooring	Sandcrete blocks
	d. Roof	Wood coated in dried grass, weaved with maize stalks and knitted
7	Storage period	6 Month
8	Storage Capacity (Kg)	125.1 Kg
9	System Used	Naturally Ventilated
10	Reference	[39]

Plate 18: Improved naturally ventilated onion storage structure

3.2.3 Low-cost onion storage

The modern onion storage system is 600 square feet in size and can store more than 50 tonnes of onions. It has a wire mesh foundation that rises 15 cm above the ground. Nearly six exhaust fans are in use for maintaining and preventing the onions from rotting, dry and cold. Since this kind of storage facility is accessible for purchase, it is less expensive than commercially available ones as shown in plate 19. This works out to be almost Rs.25, 000 per user per individual.

3.3 Atmospheric controlled onion storage structure

3.3.1 New cold storage

A well-engineered onion storage system that maintains a temperature and relative humidity of 27 ± 2 °C and 60 to 65% was designed to reduce onion storage loss while maintaining control conditions as shown in fig 5. (https://icar.org.in/content/onion-cold-storage-potential-stabilize-price-fluctuation)

Plate 19: Low-cost onion storage

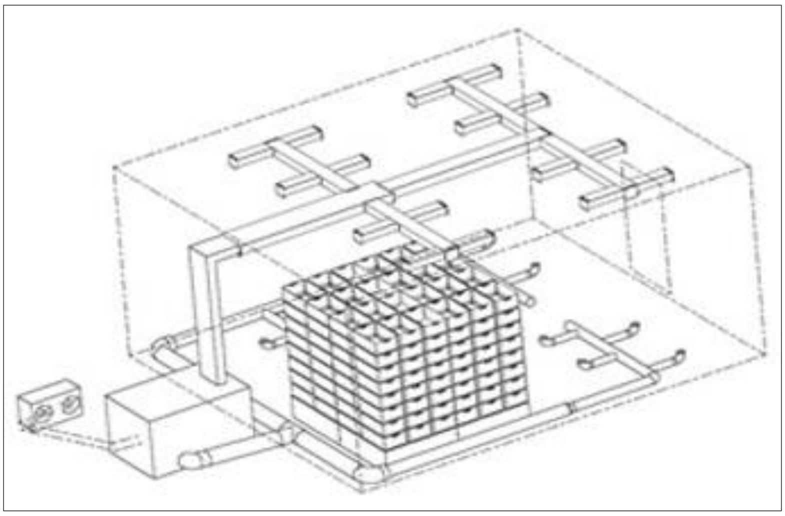

Fig 5: New cold storage

4. Post–harvest losses

In most tropical countries, onions are stored at ambient temperature due to high storage losses. 40–50% of the stored onions are reported to never meet the customer due to various forms of loss. It is estimated that 16 to 35% of onions are lost after harvest due to deterioration [40]. Traditionally, the losses in tropical areas were higher than estimated [41]. These losses include physiological weight loss (PLW), i.e., moisture loss and shrinkage (30–40%), decay (10–12%), and sprouting (8–10%). This further weight loss is caused by an increase in the average temperature and a decrease in humidity during the healing period. In the moist months, the loss of rotting is high. The onion sprouts begin when the bulb sleeps down, and the temperature drops below 20 ºC.

4.1 Physiological loss in weight (PLW)

The onion is a large bulb filled with up to 90% water. It is a medium that releases and absorbs water through breathing and transpiration. The storage environment controls the rate of water loss. Temperature, humidity, and ventilation affect storage [42]. The storage time depends on the loss of water; unnecessary water loss reduces the products' weight and marketability. Pre-harvest conditions, such as treatment method and duration, can affect the rate of water loss during storage [43]. Post-harvest and storage conditions (temperature, humidity, and air composition) are crucial for maintaining and reducing water loss and providing long storage times [17]. Damages help to accelerate weight loss by increasing respiration rates. In tropical climates, weight loss can reach 6% per month if stored under favourable conditions. Storage loss increases with storage time due to rotting and sprouting [23]. The weight of onions stored at ambient temperatures decreased by 23%, while the weight of onions stored at low temperatures (0–2 ºC) decreased by 4.0% for four months. The weight loss of onions increases with storage time and changes in temperature, relative humidity, and precipitation [44]. During storage, physiological weight loss was the leading cause of enormous loss, reaching between 20 and 87% [45]. The rate of water loss may be due to high temperatures and low humidity during storage. The Kharif season significantly influences the quantity and quality of rain compared to the Rabi season. In the case of natural onions and cold onions stored in hessian cloth bags and nylon net bags, the physiological weight loss was 19.29 to 20.87% and 6.14 to 4.97%. After five months of storage, the total loss of ventilated bamboo structures was reduced to 39.23% compared to 53% of conventional storage structures [46]. The highest losses of onion bulbs were found to be 35.17 and 44.96% contained in the low-cost ventilated lower structure and suggested the lower ventilation structure [47, 48] respectively. As a result, maintaining humidity levels can reduce water loss to a level suitable for long-term storage of 65-70 percent [49].

4.2 Sprouting

One of the main reasons for reducing the storage life of onion bulbs is sprouting. Regular physiological changes in dormant bulbs mainly cause the development of reproductive stems. The storage environment does not contribute to the sprouting process but rather affects the rate of sprouting [42, 50]. Onions are living organisms that interact through various physiological processes. After maturation, the life of onion bulbs is divided into three stages: rest, rest, and regrowth. The plant, after harvest, is particularly resistant to sprouting and rooting growth because of the early maturation stage. The period depends on agronomy practices, harvest stages, and cultivation conditions (climates, cultivation practices, fertilizers, irrigation, etc.). If no other inhibitors exist, the bulbs are susceptible to development, such as sprouting (shooting) or rooting (growing roots) [51]. The percentage of bulb sprouts during storage increases with the longer storage time, and onion varieties are very different [44]. Wright, (1935) [52] studied the effects of storage temperature and humidity on the quality of onions and found that moisture had little influence on the growth of onions in storage but increased with temperature (between 0 and 10 °C). Abu-Goukh *et al.*, (2001) [44] reported that the low temperature or the lack of rest in the lamp may lead to a rise in the percentage of sprouts at the end of storage. The sprouting process occurs rapidly if storage continues during the winter and cool weather of the season [53, 54]. Tripathi *et al.* (2004) [55] found that low-cost ventilated structures produce low-cost bulbs. Adamicki, (2005) [56] studied the sprouts of onions at 18–20 °C. In the variety of onions of "Sochaczewska", the lowest percentage of sprouting was observed after five months of storage in a stored onion with air ventilation.

4.3 Rotting

The pathogens cause scales blackening and rotting of bulbs because of pathogens entering through improper curing, field damage, and thick neck. The most common symptoms in tropical conditions are fusarium bulb and neck rot. Ryall and Lipton, (1972) [42] reported most types of decay that are caused by bacteria and molds include soft rot (*Erwinia carotovora*), black mould (*Aspergillus niger*), and fusarium rot (botrytis spp). Bacteria and mold can target specific areas of lamps. In the first stages of infection, infected tissues are soaked with water and brown at the advanced stages. Tripathi and Lawande (2007) and Tripathi *et al.*, (2008) [48, 57] investigated the rotting of onion bulbs stored in cold and post-cold storage in organic conditions and environmental conditions with sprout suppression and packing materials [49, 58]. The onion was kept for four months without noticeable deterioration of the bulbs. Four months post storage, the rottenness was higher than at ambient temperature. The onion decay rate was 4.44% in cold storage and 16.04% in ambient storage. Under environmental storage conditions, leno bags had a higher rate of rotting than hessian cloth bags [58].

4.4 Root growth and other disorders

Root development is mostly caused by high relative humidity and poor ventilation. When onions are exposed to direct sunlight, the bulbs turn green. Roots formed in a few days under humid and high-temperature conditions, according to Kaufman *et al.*, (1953) [59]. It is mainly found in white onions. Unpleasant tastes, smells, while the internal, fleshy parts remain green [41]. Another limiting factor in long-term storage is to shoot growth. Shoot growth is influenced by storage temperature, with high temperatures inhibiting shoot formation while wounding bulbs during or after harvest promotes shoot growth [18, 19]. The curing time and bulb size greatly influence root growth when in storage, indicating a nine-day cure for bulbs between 3 and 6 cm in size is optimal. Field or artificial curing is useful because it helps decrease rooting, which allows bulbs to maintain their output for a more extended period. Previous research has shown that root elongation is linked to early sprouting. It has been stated that as the fact that researchers discovered that growth-promoting molecules (cytokinins) are created and transported to bulb sizes, leading to increased cell division and sprout development [19].

4.5 Effects of storage on quality

The physical appearance of the dry bulb's quality is more directly connected to its colour, texture, skin integrity, absence of infection, lack of sprouting, and root growth. There are no established market indications for evaluating quality prior to sale, but the chemical structure and nutritional value must be properly studied [51]. Long-term storage circumstances, such as low humidity and high temperatures, and vice versa, can considerably impact dried bulbs' chemical composition and physical appearance [14]. As a result, maintaining quality before and after harvest is critical, as is avoiding water losses, sprouting and roots, and undesired chemical composition and nutrient changes.

5. Conclusion

In conclusion, this study article delves into various onion storage systems, encompassing the materials used and the dimensions maintained for effective preservation. Furthermore, it elucidates the major influence of various storage formats on the overall quality of preserved onions. It is evident that addressing these storage challenges is crucial, and one effective approach to overcome them is by adopting improved post-harvest innovations and advanced storage structures. By embracing such innovations, farmers and traders can reap considerable financial benefits while simultaneously prolonging the storage life of onions. Implementing improved storage practices is vital for reducing post-harvest losses and ensuring that more harvested onions reach consumers in optimal condition. For this reason, it is imperative to emphasize and invest in scientific research focused on studying and enhancing the efficiency of storage structures for onions. A systematic approach to this research can yield valuable insights and innovative solutions, ultimately leading to extending onion storage life and reducing the losses incurred during post-harvest handling. In conclusion, pursuing scientific knowledge and advancements in onion storage will play a pivotal role in revolutionizing the supply chain and benefitting all stakeholders, from farmers to consumers. As we strive to optimize onion storage and minimize losses, the collaborative efforts of researchers, agricultural experts, and industry players are essential in creating a more sustainable and efficient onion storage system.

6. Acknowledgments

The author acknowledges that Mahatma Phule Krishi Vidyapeeth, Rahuri, and Chhatrapati Shahu Maharaj Institute of Research and Human Development (SARTHI) in Pune, Maharashtra, India, have provided financial assistance for these research projects.

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