

Breathing-Controlled Onion Storage: A Comprehensive Review of Storage Physiology, Ventilation and Aeration Design, Sensing and Automation, Empirical Evidence, and Deployment Challenges

Gade Raj Baburao, Prof. Abhishek Popat Bangar, Prof. Bhosale S. B., Dr. A. A. Khatri

Department of Computer Engineering, Jaihind College of Engineering, Kuran, Maharashtra, India

Abstract — Onions lose 30–40% of their weight and quality in storage, and up to 70–80% in poor structures, because bulbs keep respiring while heat and moisture build up around them. Controlling how a store exchanges air with its bulbs, termed here breathing-controlled storage, is widely proposed as a low-cost remedy for small farms. This paper presents a focused narrative review that synthesises five studies: a six-month field trial of an improved fan-aerated NHRDF store in Maharashtra, a four-week trial of a fan-aerated bin in Bangladesh, a broad review of postharvest treatment, storage and quality evaluation, an IoT design with UV-C disinfection, and a humidity-controlled window design. The review examines three connected themes: the physiology that sets the loss window, the strength of the empirical evidence, and the conditions that matter for deployment. In the field trial, total loss was 14.52% in the aerated store against 33.40% in a conventional ventilated store and 38.45% in a farmer's store. The bench trial reported a peak of 97.5% marketable bulbs against 91.6% outside the bin, although room air was almost identical in both places. Neither automation design reports data from stored onions. The trials are short or single-site, and none measures airflow or bulb respiration directly. The review contributes a comparative table, a conceptual architecture for a sensor-aided aerated store, and a prioritised agenda of research gaps.

Keywords— Onion storage, postharvest loss, respiration, forced ventilation, aeration, humidity control, IoT, small farmers.

I. INTRODUCTION

Onion is semi-perishable: it leaves the field at 85–87% moisture and is cured down to 7–10% for long storage [3]. Rabi onion is harvested in April–May, prices fall until July, and bulbs held for five to six months can earn three to four times more [1]. Storage losses of 30–40% are common and can reach 70–80% in poor structures [1]. One estimate puts 22% of India's annual output, about 233 lakh t, lost during storage [1].

Bulbs do not stop breathing after harvest. Respiration burns sugars and gives off heat, carbon dioxide and water, so more respiration means more weight loss [1]. Most small farms store onions in structures with fixed openings and no monitoring, so they cannot respond when heat or humidity builds [5]. Any improvement has to be affordable, work on small lots and run on a limited power supply.

We use **breathing-controlled storage** for a store whose air exchange is deliberately regulated to carry away respiratory heat and moisture without drying or chilling the bulbs. This differs from controlled-atmosphere storage, which changes oxygen and carbon dioxide levels themselves [3]. Reviewers also warn that attractive designs run ahead of field evidence, so evidence strength is a central concern here.

This paper reviews five studies: a field trial of an improved NHRDF store [1], an IoT design with UV-C disinfection [2], a broad postharvest review [3], a trial of a fan-aerated bin [4] and a smart-ventilation design [5]. Three questions guide the review. RQ1: Which physiological factors and design elements underpin breathing-controlled storage? RQ2: How strong is the evidence that aeration and automation reduce loss? RQ3: What does the evidence imply for small-farm deployment? The paper ends with a comparative table, a conceptual architecture and a list of research gaps.

II. REVIEW METHODOLOGY

This is a narrative review of a purposively chosen set of five papers supplied for the study, not a systematic database search, so no claim of exhaustive coverage is made. The papers are an article in Vegetable Science [1], an arXiv preprint [2], a review in Future Postharvest and Food [3], an article in Archives of Agriculture and Environmental Science [4] and an article in the International Journal of Creative Research Thoughts [5].

For each paper the aim, design, scale, main findings and stated limitations were extracted and compared. All figures quoted are those reported by the original authors. Studies that these papers

cite are described only as the citing paper describes them and are marked "as cited in"; they were not independently re-read. The five papers differ in kind: two report storage experiments [1], [4], one is a review [3], and two are designs without stored-onion data [2], [5]. Conclusions about sensor-driven automation are therefore inferences, and are labelled as such.

III. THEORETICAL FOUNDATIONS

1. Respiration and dormancy

Dormancy sets how long bulbs keep, and temperature and humidity decide whether it holds. Above 30 °C dormancy breaks and bulbs sprout and rot, while 0–4 °C can hold dormancy for up to 12 months [1].

High temperature with high humidity cuts water loss but raises sprouting and rot, so sufficient air movement is needed to balance the two [1].

2. Loss triggers

Each loss mode has its own trigger, which is why one set-point cannot serve all three [2], [3].

Loss mode	Driving condition	Typical loss (%)
Physiological weight loss	Above 32 °C and RH below 60%	20–25
Rotting	Above 32 °C and RH above 70%	10–12
Sprouting	0–2 °C and RH above 70%	8–10

Source: Table 4 of [3]. Recommended targets are 25–30 °C with 60–65% RH, or 0–5 °C with 65–70% RH [3].

3. Pathogens and curing

Pathogens add a second clock. Black mould (*Aspergillus niger*) thrives above about 75% RH [2], and about 26 pathogens are linked to storage rots [3]. Curing before storage matters too: field or forced-air curing at 25–35 °C and 65–80% RH dries the neck and outer scales and lowers later rot [3].

4. Aeration versus controlled atmosphere

Aeration moves air through the bed to remove heat and moisture. Controlled-atmosphere storage instead lowers oxygen and raises carbon dioxide; one trial at 1% O₂ and 5% CO₂ at 2 ± 1 °C stored onions for eight months (as cited in [3]). It costs more than refrigeration [3], so aeration remains the practical option for small farms.

IV. STORE DESIGN ELEMENTS AND CONTROL PRINCIPLES

1. Common elements

The reviewed sources use a small set of elements: a raised mesh or slatted floor, bottom and top vents, exhaust fans, roofing chosen for heat, insulated walls, sensors and a controller [1]–[5]. Roofing matters: thatch gave 9.4% loss against 22% under iron sheet (as cited in [3]).

2. Elements in the NHRDF improved store

The improved store at Sinnar, Maharashtra, holds 25 t on a 30 × 14 ft mesh floor (20 × 20 mm) raised 6 inches above the ground [1]. Bulbs sit 4 ft deep. Four exhaust fans blow air down through the bed, eight 6-inch wall vents let air in and out, and two mercury lamps are fitted for temperature control, although the paper does not explain how they act [1]. The fans run all day.

3. Elements in the aerated bin

The bin in [4] is a cylinder 3 ft across and 5 ft tall made from mild-steel rod and steel net. Two net chambers sit 1 ft above the base and 2 ft apart, and an exhaust fan at the top pulls air up from below [4].

4. Sensing and control elements

Element	Kumar and Singh [2]	Karthika et al. [5]
Controller	ESP32 (simulated on an Arduino Uno)	NodeMCU or Arduino
Sensing	DHT22 for temperature and RH; MQ-135 for ammonia and sulfur gases	DHT sensor, plus a separate humidity sensor
Actuation	Two fans, UV-C lamp (207–222 nm), dehumidifier, evaporative pads, buzzer	Exhaust fan, servo or pneumatic window, insulated walls
Thresholds	Fan 1 above 30 °C, fan 2 above 35 °C (code); text adds 75% RH	"Predefined", values not given
Remote link	MQTT dashboard	ESP8266 to ThingSpeak
Evidence	Tinkercad simulation only	None; conceptual

5. Cautions

Several cautions recur. Ventilation delays sprouting only for a time, and sprouting reached 41% after 26 weeks in one study (as cited in [3]). Bottom-ventilated stores can sprout more because bulbs meet cooler air, and deeper beds with higher airflow raise the pressure drop and weaken aeration (as cited in [3]).

Two cautions are the reviewer's own inferences. First, opening a window when indoor humidity is high helps only if outside air is drier. At Sinnar the ambient daytime RH averaged 89.52% over May–October, against 76.93% held inside the aerated store [1], and neither [2] nor [5] includes an outdoor sensor. Second, UV-C acts on exposed surfaces, so bulbs shadowed inside a deep bed may receive little dose; [2] reports no test on onions. The MQ-135 is also a broad-spectrum air-quality sensor and would need calibration against onion rot.

V. EVIDENCE OF EFFECTIVENESS

1. Passive structures

Traditional stores are sheds, heaps or temporary structures with fixed openings [3], [5]. Added air paths help, but only so far: the best passive design in [3] still loses nearly a quarter of the crop.

Structure	Weight loss (%)	Rot (%)	Total loss (%)
Top and bottom ventilated, mud-plastered walls	15.92	7.52	23.82
Bottom ventilated, single row, thatched roof	17.44	10.88	28.66
Bottom ventilated, single row	20.06	13.43	33.88
Modified bottom ventilated, chain-linked sides	22.73	14.19	37.30
Modified bottom ventilated, double row	19.43	17.94	37.69
Traditional single row	20.63	17.12	38.10
Traditional double row	22.18	22.72	46.11

Source: Table 6 of [3]. Totals also include a small scale loss of 0.31–0.39%.

2. Field trial of the NHRDF improved store

Variety NHRDF Red 3 was stored in April for six months in 2017–18 and 2018–19, beside a conventional ventilated store and a farmer's store, 25 t each [1]. The improved store did not remove temperature swings but damped them (six-month means) [1]:

Measure	Improved store	Conventional store (ambient)
Temperature, day / night (°C)	28.86 / 26.64	30.19 / 20.99
Relative humidity, day / night (%)	76.93 / 79.29	89.52 / 76.89

The day–night temperature gap was 2.2 °C against 9.2 °C, and daytime humidity was about 12.6 points lower [1]. Outcomes (means of two seasons):

Store	Good bulbs (%)	Good bulbs (t)	Sprouting (%)	Rot (%)	Weight loss (%)	Total loss (%)
NHRDF improved	85.50	21.37	0.00	0.69	13.83	14.52
NHRDF conventional	66.60	16.65	2.50	10.10	20.80	33.40
Farmer's store	61.60	15.39	3.50	12.30	22.65	38.45

Source: Table 5 of [1].

3. Bench trial of a fan-aerated bin

Forty kg of onion went inside the bin and 10 kg stayed outside in the same windproof room, from 12 October to 8 November 2022, with loggers recording 24 readings a day [4].

Week	Marketable (%), in / out	Moisture loss (%), in / out	Deterioration (%), in / out	Sprouting (%), in / out
1	95.75 / 87.40	0.635 / 0.90	6.125 / 11.70	1.65 / 2.50
2	96.75 / 86.80	1.931 / 7.01	1.23 / 6.185	0.673 / 4.123
3	97.54 / 91.63	2.126 / 7.70	0.337 / 0.669	0.285 / 0.223

Week	Marketable (%), in / out	Moisture loss (%), in / out	Deterior- ation (%), in / out	Sproutin- g (%), in / out
4	95.41 / 86.39	3.95 / 11.907	0.632 / 1.701	0.344 / 0.6

Source: [4]. By week four moisture loss inside was about one third of that outside. Yet mean air temperature ran from 28.44 to 26.57 °C inside and 28.46 to 26.65 °C outside, and humidity from 82.64 to 80.31% inside and 81.23 to 79.53% outside [4]. The room air was almost the same, so the benefit probably comes from airflow through the bed, which the authors did not measure.

4. Wider forced-ventilation evidence

The review in [3] collects supporting results, all as cited in [3]:

- Forced against natural or traditional ventilation: weight loss of 10.24%, sprouting of 0.34% against 0.63%, 31.48% less black mould, and soft rot of 3.43% against 10.79%.
- Forced against traditional storage: deterioration of 0.813% against 2.802%, and moisture accumulation of 12.01% against 14.65%.
- Fully ventilated stores in Ethiopia over 90 days: sprouting 1.03%, rot 1.81% and mould 2.73%.
- Fan operation at 25–33 °C and 55–70% RH kept 71–90% of bulbs marketable.

5. Quality of the evidence

Only [1] runs six months, and it replicates across two seasons rather than across stores. Paper [4] covers four weeks with no stated replicates. Neither logged airflow, bed temperature at depth or carbon dioxide, so the cause of the gain is inferred. In [1] the paper describes constant conditions, yet monthly daytime mean temperatures ranged from 26.98 to 31.88 °C, and the role of the mercury lamps is unexplained. Both field stores also ran at about 76–83% RH, above the 60–65% target in [3], which suggests that continuous airflow matters beyond the humidity set-point.

VI. DEPLOYMENT: ECONOMICS AND SMALL-FARM CONSIDERATIONS

1. Cost and return

The improved store cost Rs 2,97,780 against Rs 2,29,394 for the conventional one, a difference of Rs 68,386, and its figure includes Rs 11,280 of power for six months [1]. After six months the stored lot was worth a mean Rs 5,87,985, against Rs 4,53,850 (conventional) and Rs 4,20,425 (farmer's) [1]. In 2017–18 the extra revenue over the conventional store was Rs 69,760, barely covering the extra cost; in 2018–19 it was Rs 1,98,510 [1]. Returns thus depend heavily on how far prices rise during storage.

2. Scale, energy and flexibility

The improved design can be built for as little as 5 t, whereas cold storage is not feasible at that size [1]. Its frames can be removed in the lean period so the floor serves other farm uses [1]. Power was about Rs 450 per tonne over six months, but behaviour during outages is untested. Solar power is suggested in [2] and [5] without data.

3. Claims that need care

Paper [2] estimates INR 60,000–70,000 for its system without saying whether a building is included, and [1] spent Rs 2,50,000 on the room alone. Its conclusion also says the system was "designed and implemented" while its limitations admit simulation only, and it states that the ESP32 outputs at most 5 V, whereas its GPIO pins work at 3.3 V. Paper [5] gives no thresholds, test data or cost figures.

4. Transferability

Trials covered May–October in Maharashtra [1] and October–November in Bangladesh [4]. No dry-season, cold-climate or multi-variety data appear, and [4] does not name the variety, so transfer to other regions remains untested.

VII. COMPARATIVE ANALYSIS

Table 1 summarises the five reviewed studies. Findings are not directly comparable because designs, scales and outcome measures differ.

Table 1. Comparison of the five reviewed studies

Study	Objective and design / sample	Main findings and limitations
Bhasker et al. (2020) [1]	Aim: compare an improved fan-aerated store with conventional and farmer stores. Design: field trial, 25 t per store, 6 months, two seasons, variety NHRDF Red 3.	Findings: total loss 14.52% against 33.40% and 38.45%; higher net return. Limits: one site and variety; lamp role unexplained; no airflow data.

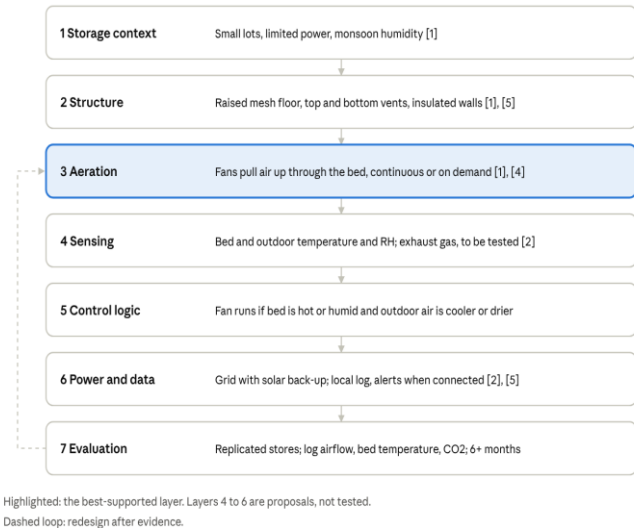
Study	Objective and design / sample	Main findings and limitations
Kumar and Singh (2026) [2]	Aim: design a low-cost IoT store with UV-C. Design: Tinkercad simulation and literature; no onions stored.	Findings: projected 15–20% spoilage, not measured. Limits: preprint; simulation only; cost basis unclear.
Kiran et al. (2024) [3]	Aim: review postharvest treatment, storage and quality evaluation. Design: narrative review.	Findings: best passive store loses 23.82%; forced ventilation cuts rot and weight loss. Limits: mixed methods; secondary data.
Muhit et al. (2024) [4]	Aim: build and test an aerated bin. Design: 40 kg inside, 10 kg outside, 4 weeks.	Findings: peak marketable 97.5% against 91.6%; moisture loss about one third by week 4. Limits: short, small, no stated replicates; room air identical.
Karthika et al. (2026) [5]	Aim: design a humidity-controlled window system. Design: concept; no onions stored.	Findings: none reported. Limits: no thresholds, data or cost figures.

The sources agree that forced aeration lowers rot and weight loss [1], [3], [4], and that passive designs hit a ceiling near 24% loss [3]. The strongest results come from the simplest control, continuous fans, while sensor-driven control remains unproven [2], [5].

VIII. PROPOSED CONCEPTUAL ARCHITECTURE

Figure 1 gathers the design implications of the reviewed studies into a layered architecture for a sensor-aided aerated onion store. It is a conceptual proposal derived from the literature and has not been tested experimentally.

Aeration is the tested core; sensing and control are proposed add-ons



layered architecture · 7 layers, 1 feedback loop

Fig. 1. Proposed conceptual architecture for a sensor-aided aerated onion store (conceptual, not experimentally validated) Layer 1 captures the context: small lots, limited power and humid seasons [1]. Layer 2 is the structure: a raised mesh floor, top and bottom vents and insulated walls [1], [5]. Layer 3 is the best-supported element, fans that pull air up through the bed, run continuously [1] or on demand [4]. Layer 4 senses bed and outdoor temperature and humidity; exhaust gas sensing is proposed in [2] but needs calibration against onion rot. Layer 5 is the authors' inference: run the fans only when the bed is hot or humid and outdoor air is cooler or drier, a rule that neither [2] nor [5] applies. Layer 6 supplies power and data, with solar back-up suggested in [2] and [5] and remote alerts via ThingSpeak or MQTT [2], [5]. Layer 7 closes the loop with replicated stores of six months or more that log airflow, bed temperature and carbon dioxide, with results fed back into layers 3 to 5.

IX. RESEARCH GAPS AND FUTURE DIRECTIONS

Gaps supported by the reviewed evidence. (i) Few long trials: only [1] runs six months, and it replicates across seasons rather than stores. (ii) Small, short bench work: [4] covers four weeks with 40 kg inside the bin. (iii) The breathing is not measured: neither [1] nor [4] logged airflow, bed temperature at depth or carbon dioxide. (iv) Automation lacks data: [2] and [5] report no stored-onion results. (v) Energy and reliability are barely costed, and outage behaviour is untested [1]. (vi) Narrow conditions: one monsoon-season site in India [1], one autumn trial in Bangladesh [4], and little on variety or dry-season climate. (vii) Sensor logic ignores outside air, an inference from the data in [1].

Directions requiring investigation. Priorities include a replicated three-way trial comparing passive, continuous-fan and sensor-controlled stores, with at least three stores per treatment for six months or more on the same onion lots; logging bed temperature at several depths, airflow, and carbon dioxide and humidity in the exhaust air; control that runs fans only when outdoor air is cooler or drier than the bed, compared on energy per tonne; calibration of gas sensors against the onset of rot, rather than the broad MQ-135 used in [2]; measurement of UV-C and ozone dose at depth against rot incidence; and full costing of capital, power per tonne and outage behaviour, including solar-backed fans.

X. CONCLUSION

Across the five reviewed studies, controlling how an onion store breathes is the most reliable way to cut storage loss. Continuous aeration lowered total loss from 33–38% to 14.5% in a six-month field trial [1], and a fan-aerated bin kept more bulbs marketable and lost less moisture over four weeks [4]. Passive designs, even well ventilated, still lost nearly a quarter of the crop [3].

Sensor-driven control is a sound idea, but the two designs reviewed [2], [5] have no stored-onion data, and their logic ignores the state of the outside air. For small farms this points to simple, fan-based aeration on a raised mesh floor, with sensing added only where it is tested. A replicated, season-long trial that measures airflow, outdoor conditions and bulb respiration together is needed before automated stores can be recommended as a proven remedy for storage loss.

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