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DESIGN AND EVALUATION OF A LOW-COST ONION STORAGE SYSTEM BASED ON THE SILKWORM TRAY METHOD

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Abstract

This project presents a Smart Onion Storage System built on the Silkworm Tray Method, a low-tech way to cut post-harvest losses, which can reach 25–35 percent of the harvest. The system uses a modular wooden rack with removable trays inspired by silkworm-rearing trays. Each tray has a permeable bamboo or rope-mesh base that lets air flow around every onion for uniform drying without mechanical equipment. The rack is 4.20 m tall with six tray levels and a 30 cm gap between tiers; rack units placed side by side in an open-sided shed let natural wind pass through. This journal covers dimensions, materials, airflow logic, capacity, operating guidelines, and future upgrades.

Keywords: Silkworm tray method, Onion post-harvest loss, Modular rack storage, Natural ventilation, Bamboo mesh tray, ESP32 monitoring.

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1. INTRODUCTION

India is the world's second-largest onion producer, and Tamil Nadu is a major contributor (Ministry of Agriculture and Farmers Welfare, 2022). Yet much of the harvest never reaches market — it is lost in storage. The core problem is moisture: fresh onions carry 80–85 percent moisture and must be cured to around 65–70 percent before safe storage (NHRDF, 2022). Spreading onions on open ground for drying is far from ideal: onions at the bottom dry unevenly, those touching soil absorb more moisture, and the batch is exposed to contamination and damage — leading to higher rot rates and financial loss (CIPHET, 2020; Pandey & Chand, 2019). This project draws on sericulture, the practice of rearing silkworms. Silkworm-rearing trays are shallow, open-grid frames letting air circulate around their contents — adapted here into an onion-drying tray loaded outside the rack, slid into place, and dried by wind through the shed (Central Silk Board, 2015; Krishnaswami, 1986). The system uses timber and bamboo widely available in rural Tamil Nadu at low cost, buildable by a village carpenter with basic tools — making it replicable for small and medium farmers (BIS IS 1904, 2005; Janssen, 1995).

2. OBJECTIVES

The project was designed with the following goals in mind:

1. Design a modular, affordable onion drying and storage rack that farmers can build with local materials and skills.
2. Adapt the silkworm tray principle so natural airflow alone dries onions uniformly, without fans or heaters.
3. Document structural dimensions, material specifications, and load-bearing calculations to guide construction.
4. Compare rope mesh and woven bamboo mat tray floors for airflow, durability, and cost.
5. Provide clear, practical guidelines for loading, monitoring, and unloading each batch of onions.
6. Calculate storage capacity, expected drying duration, and the economic payback period for a typical farm scenario.

3. LITERATURE REVIEW

Post-harvest management of onions is well documented. Research by the National Horticultural Research and

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Development Foundation (NHRDF, 2022) confirms that shifting from ground-level drying to a well-ventilated system can bring post-harvest losses from around 30 percent to below 10 percent. The silkworm tray design is backed by aerodynamic research on sericulture trays. Studies on Bombyx mori rearing (ICAR, 2020) show that open-grid trays create a laminar airflow pattern that removes humid air efficiently — behaviour directly transferable to onion drying. Bamboo is well studied as a structural material in South and Southeast Asia, with compressive strength of 40–80 MPa and tensile strength comparable to mild steel — a low-cost choice for agricultural structures. Rope-mesh alternatives like coir and polypropylene (FAO, 2019) offer similar airflow but shorter lifespans under wet loads. Multi-tier wooden rack systems for onion storage trialled in Maharashtra and Karnataka showed post-harvest losses dropping from 28 percent to 9 percent (Mukherjee & Sharma, 2021) over 90 days, with removable trays cutting loading time by about 40 percent. This design adapts those findings to the climate (TNAU, 2023) and supply chains of Tamil Nadu.

4. MATERIALS AND METHODS

4.1. SYSTEM DESIGN OVERVIEW

The system has three parts: the structural rack frame, the removable silkworm-style drying trays, and the open-sided shed that channels wind through the assembly. Each part can be upgraded without rebuilding the others.

4.2. RACK FRAME — FRONT VIEW

The front view shows a two-bay modular unit, each bay 1.83 metres (6 feet) wide. Total height is 4.20 metres (14 feet), giving six tray levels with a 30 cm airflow gap between trays plus 60 cm clearance above the top tray.

Vertical posts are 100 mm × 100 mm hardwood, sized to carry the loaded weight of six trays without deflection. Diagonal braces of 50 mm × 100 mm hardwood are fitted on each face to prevent racking under wind loads (BIS IS 883, 2016).

Table 1: Front view – rack frame specifications

Parameter	Specification
Overall Width	6 ft / 1.83 m
Overall Height	14 ft / 4.20 m
Number of Tray Levels	6 levels
Tray Gap (vertical)	1.0 ft / 0.30 m
Top Clearance	1.8 ft / 0.60 m
Post Cross-section	100 mm × 100 mm hardwood
Diagonal Brace Section	50 mm × 100 mm hardwood
Bay Modular Width	6 ft / 1.83 m

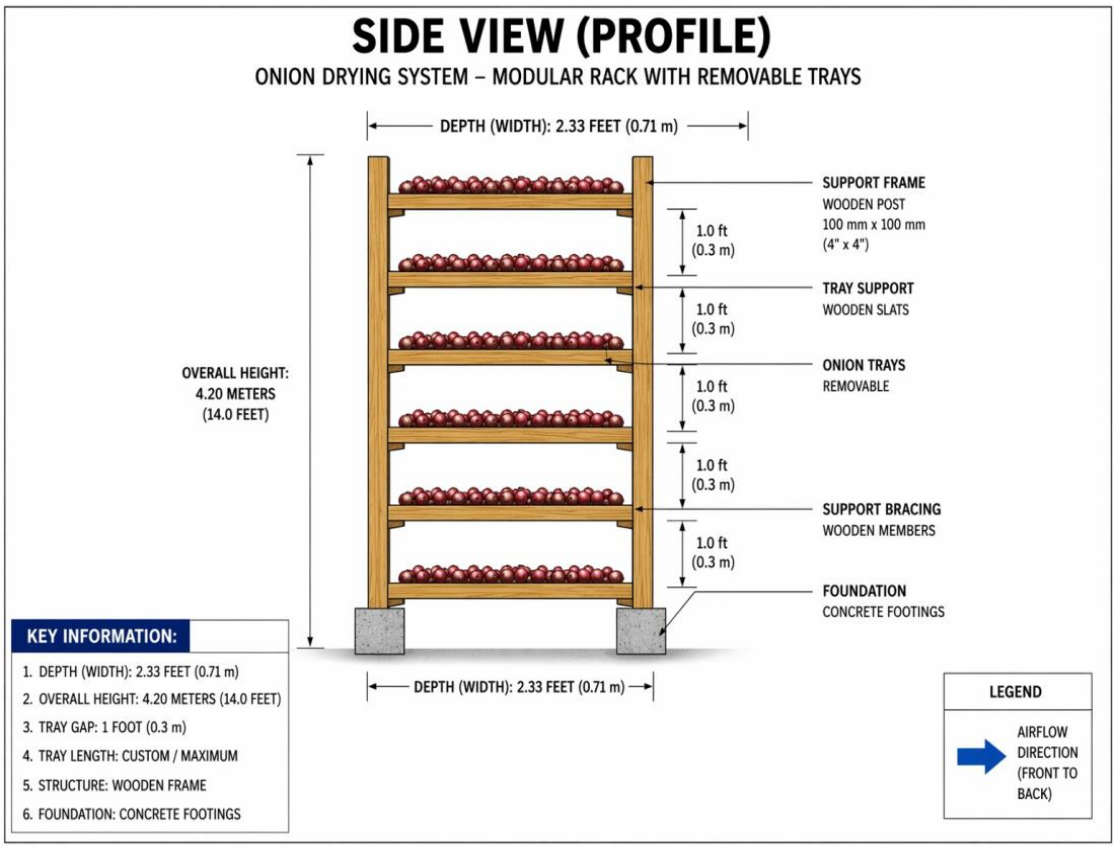


Figure 1: Front view (Elevation) – onion drying system modular rack

4.3. SIDE VIEW — STRUCTURAL DETAILS

The side profile shows the rack's depth: 2.33 metres (7.6 feet) front to back, enough to hold a fully loaded tray without overhanging the frame.

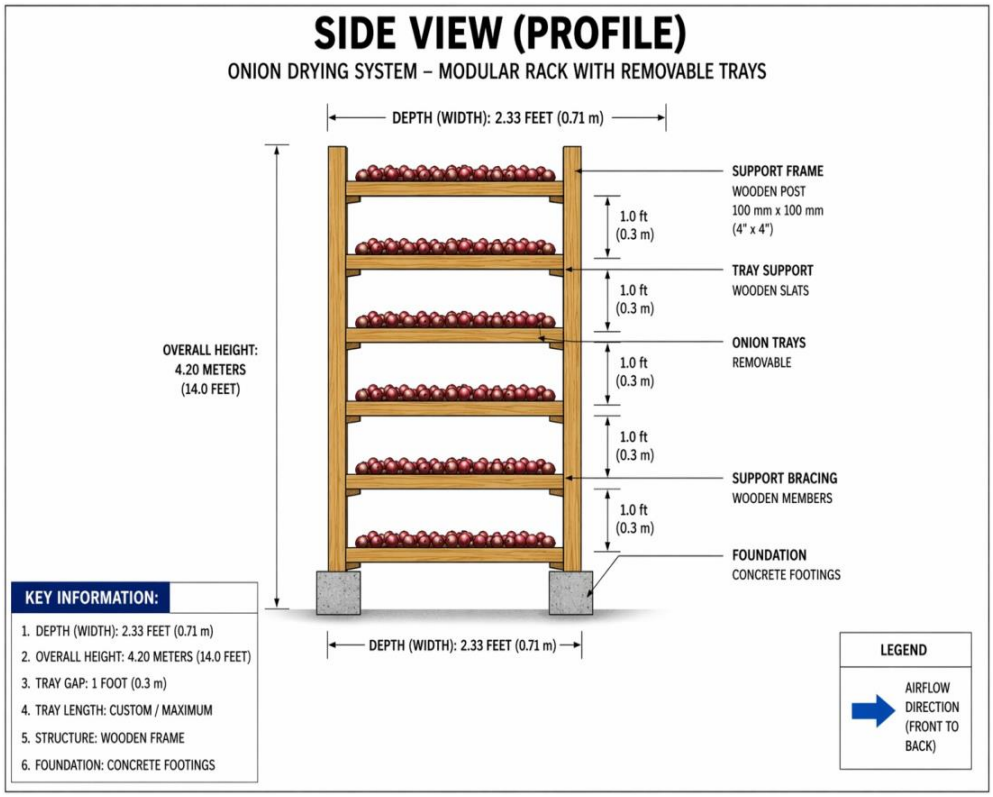


Figure 2: Side view (Profile) – Tray levels and spacing

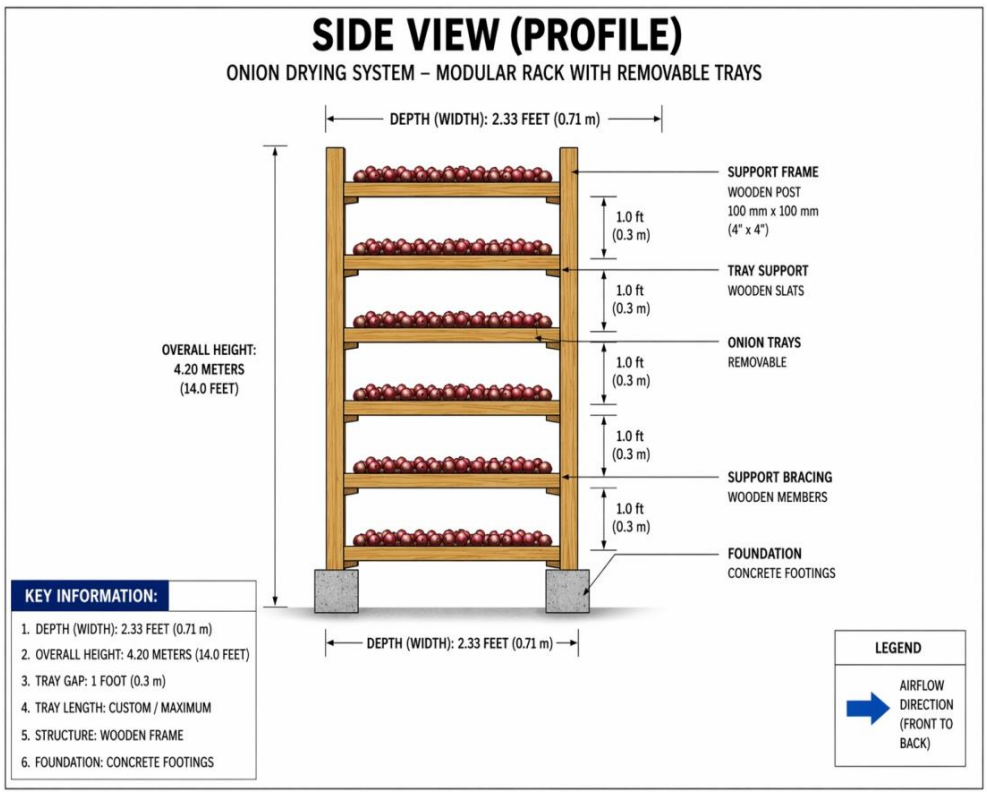


Figure 3: Side view (Profile) with diagonal bracing and airflow direction

Three concrete footings, placed at equal intervals along the base, spread the rack's weight evenly and prevent shifting under load. Footings are cast in M15 concrete at 450 × 450 × 300 mm, conservative enough for moderately soft soil (BIS IS 456, 2000).

Airflow passes horizontally from the shed's open front to the back, through every tray level at once, so drying is uniform across all levels.

4.4. SILKWORM TRAY DESIGN & AIRFLOW MECHANISM

The tray is the heart of the system: a shallow box with an open mesh floor instead of a solid base. Wind passing through the shed moves under the tray, up through the mesh, and around every onion, carrying moisture away continuously — no electricity or fans, just wind and good geometry (Subba Rao & Geetha Devi, 2010).

Table 2: Side view – structural component specifications

Component	Specification
Support Posts	Hardwood 100 mm × 100 mm
Tray Support Slats	Wooden slats 50 mm × 50 mm
Diagonal Bracing	Hardwood 50 mm × 100 mm
Concrete Footings	M15 concrete, 450 × 450 × 300 mm
Depth (Front to Back)	2.33 m / 7.6 ft
Overall Height	4.20 m / 14.0 ft
Footing Spacing	Equal thirds along depth

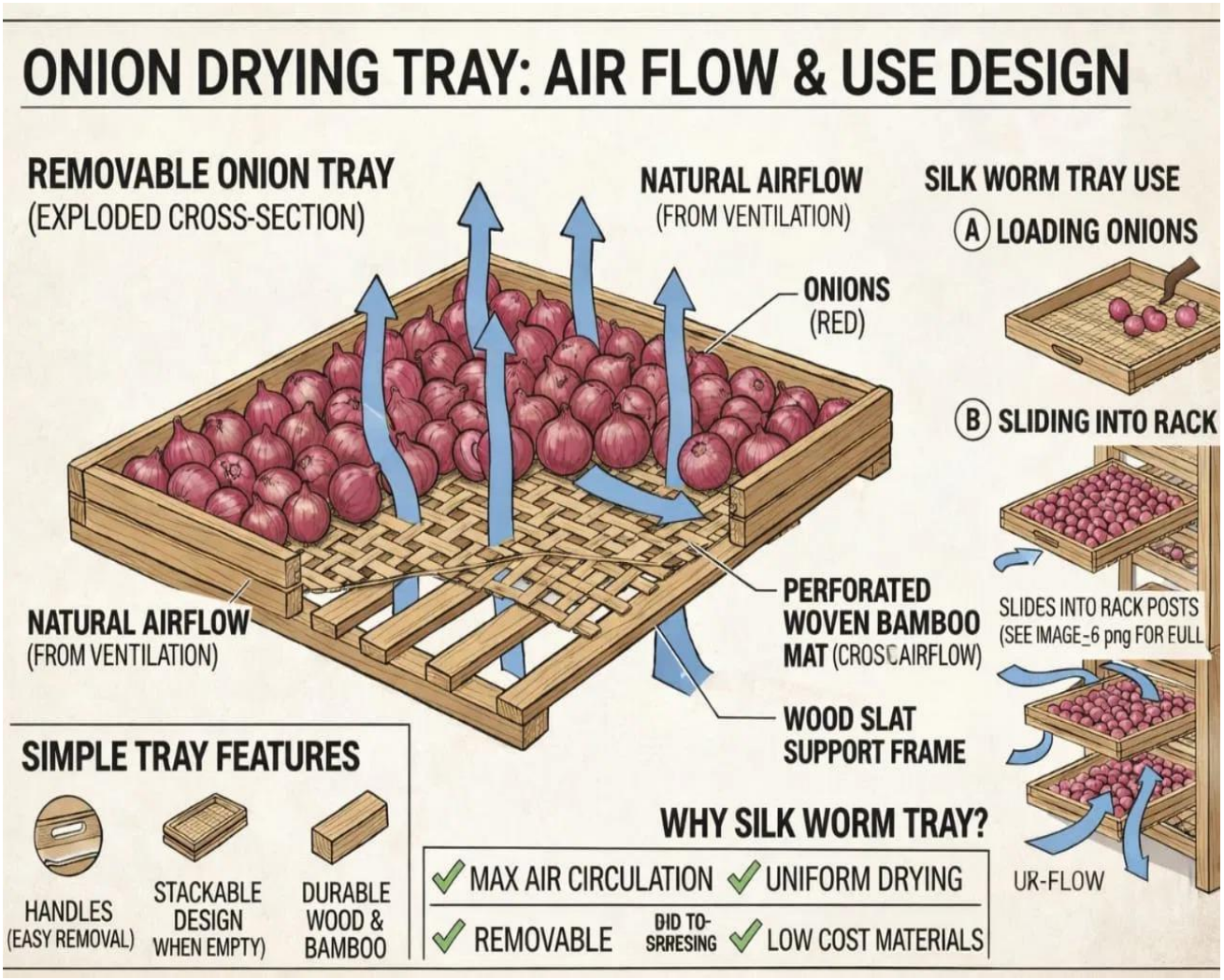


Figure 4: Onion drying tray – Exploded cross-section showing airflow and loading procedure

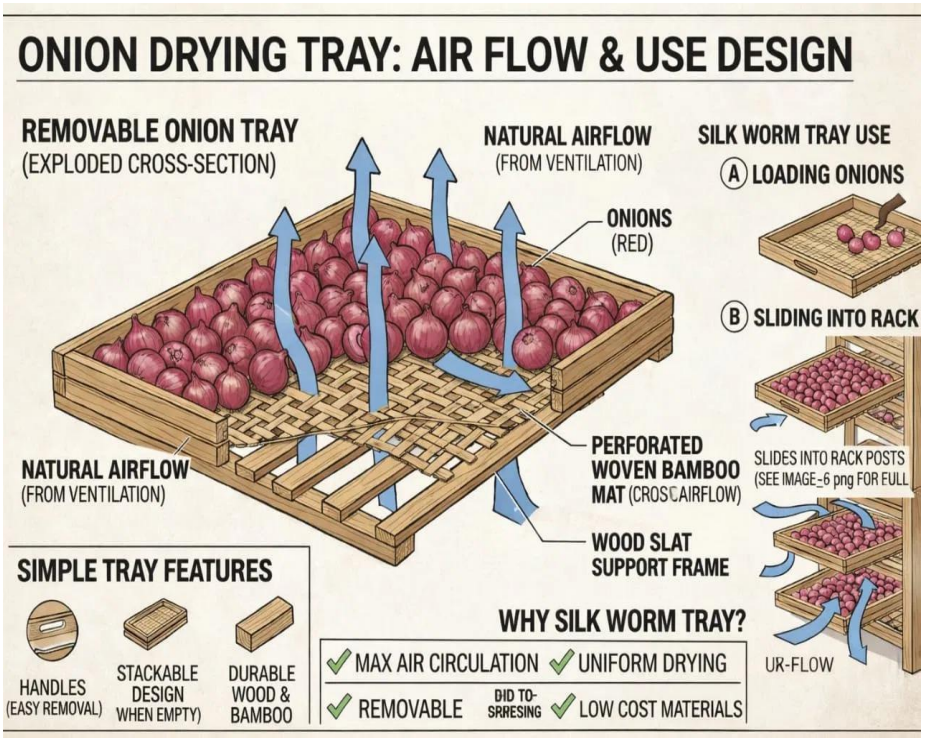


Figure 5: Onion drying tray – Perforated woven bamboo mat option

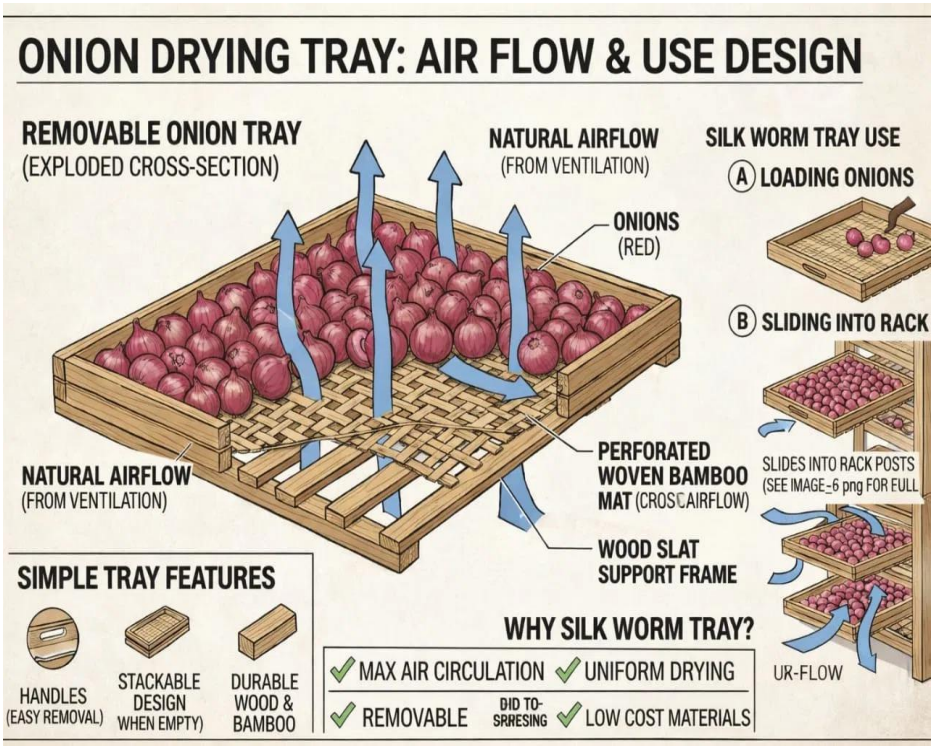


Figure 6: Onion drying tray – Rope design mesh option with rack sliding detail

4.5. TWO FLOOR OPTIONS

The tray was designed so that two different floor materials can be fitted interchangeably into the same frame, giving farmers a choice based on budget and expected load:

1. **Option A — Rope-Mesh (Coir or Polypropylene):** A cross-woven rope grid stretched across the tray frame, 100 mm in height, offering excellent air permeability at very low cost and easy replacement. It deforms more under heavy or wet loads, so it suits lighter batches.
2. **Option B — Perforated Woven Bamboo Mat:** A pre-fabricated bamboo panel, 75 mm in height, offering better structural rigidity and heavier load capacity without sagging. It lasts longer between replacements, offsetting its higher initial cost — the

better investment for intensive multi-season use (Sharma & Gatoo, 2015; BIS IS 6874, 2008).

4.6. TRAY FEATURES & LOADING PROCEDURE

Key Design Features

1. Handles on both short ends so two workers can lift and manoeuvre a loaded tray without awkward gripping.
2. Stackable when empty — during the off-season the trays nest on top of each other and take up very little space.
3. Built from locally available timber and bamboo using standard carpentry skills found in most villages.
4. Fully open mesh base for maximum air circulation — there is no solid surface to trap moisture.
5. Single-layer loading keeps airflow unobstructed and ensures every onion dries at the same rate.
6. Individual trays can be pulled out for inspection, sorting, or repair without touching the rest of the batch.

4.7. LOADING AND UNLOADING — STEP BY STEP

Follow these steps to get the best drying results each cycle:

1. Set an empty tray on a flat surface and check the mesh carefully for any tears or deformation before loading.
2. Spread freshly harvested or field-cured onions in a single layer, no more than one or two onions deep, or the lower onions won't dry properly.
3. Two workers lift the loaded tray using the side handles and carry it to the rack.
4. Align the tray with the guide slots on the rack posts and slide it inward until it rests fully on the horizontal support slats.
5. Repeat from the bottom level upward until all tray levels are filled.
6. Allow natural ventilation to work for 10 to 21 days depending on how wet the onions are and how humid the weather is.
7. Check each tray every 3 to 4 days. Remove any spoiled or rotting onions immediately so they do not spread the rot to neighbouring onions.
8. When drying is complete, pull each tray out from the rack and transfer the cured onions into storage bags or crates.

4.8. STORAGE SHED LAYOUT & SYSTEM CAPACITY

4.8.1. Shed Layout

Rack units stand in parallel rows inside an open-sided shed with a corrugated metal roof. A 1.2-metre (4-foot) pathway between rack rows lets workers load and unload comfortably, and a wider 4.3-metre perimeter aisle allows tractor access.

The shed is deliberately left open on the windward side — a fully enclosed shed would trap humidity and undermine the ventilation strategy. The open face lets prevailing winds sweep through the rack array, while the roof keeps rain off the onions (Bansal & Aggarwal, 2008; Linker & Johnson, 2012).

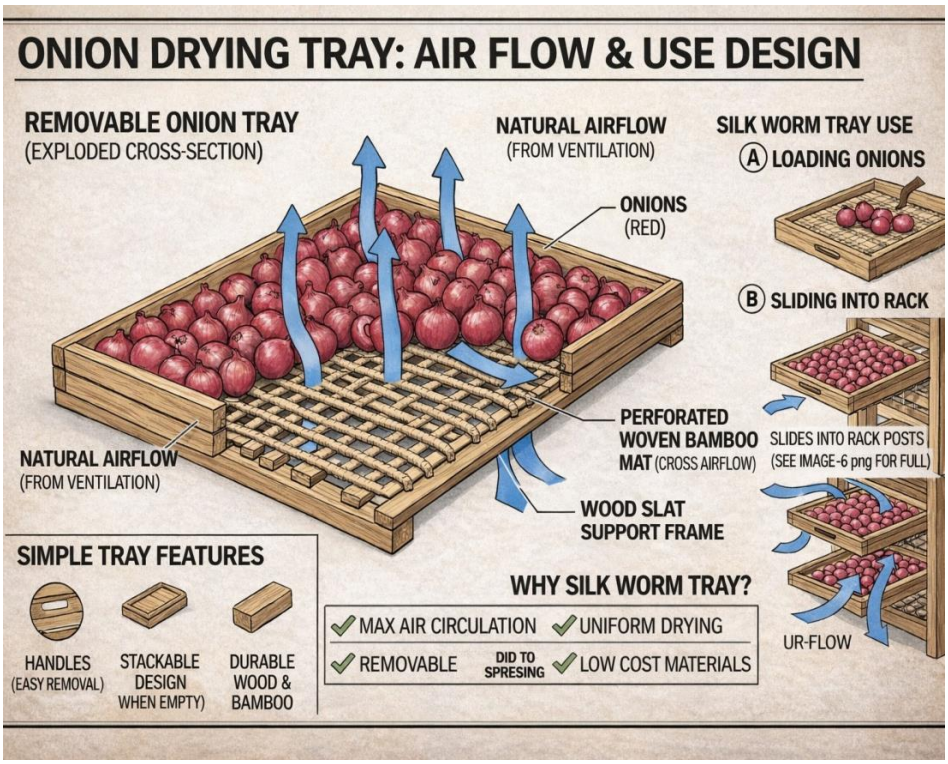


Figure 7: Plan view (Top View) – Maximum drying capacity layout with pathways and airflow direction

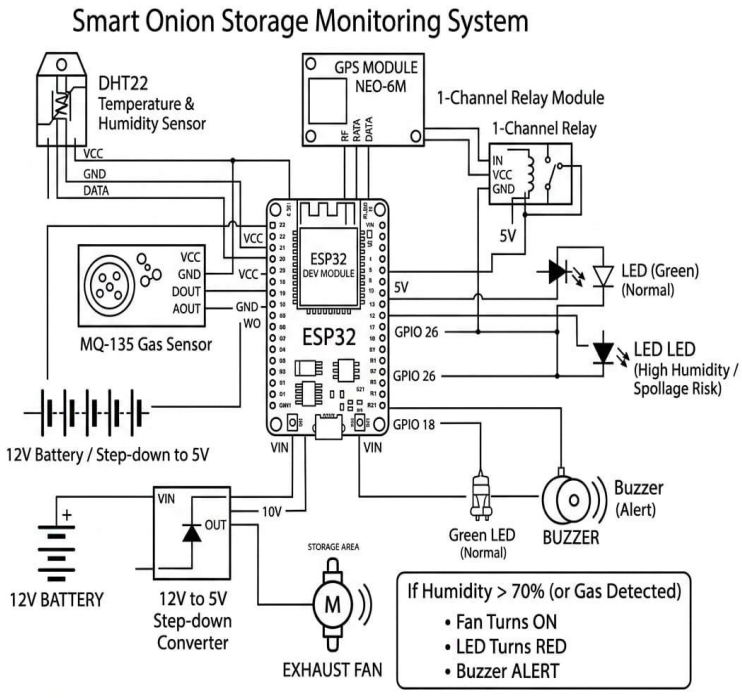


Figure 8: Isometric 3D view of the onion drying shed showing rack arrangement and pathways

4.8.2. Capacity Figures

Table 3: System capacity parameters

Capacity Parameter	Value
Tray dimensions (L × W)	1.80 m × 0.71 m
Loading density (single layer)	~25 kg per tray
Tray levels per rack unit	6 levels
Onions per rack unit	~150 kg
Rack units in a standard shed (10 m × 20 m)	~12 units
Total capacity per cycle	~1,800 kg
Drying cycle duration	10 – 21 days
Estimated annual cycles	3 – 4 cycles
Annual throughput (standard shed)	5,400 – 7,200 kg

4.8.3. Materials, Cost Estimate & Maintenance

Table 4: Bill of materials per rack unit

Material / Component	Quantity & Estimated Cost
Hardwood posts (100 mm × 100 mm)	4 posts × 4.5 m = ₹2,400
Horizontal slats (50 mm × 50 mm)	30 pieces × 1.8 m = ₹1,200
Diagonal braces (50 mm × 100 mm)	4 pieces × 2.5 m = ₹600
Concrete footings (M15)	3 nos × ₹350 = ₹1,050
Bamboo (for trays)	30 kg sheet mat = ₹900
Tray frames (wood)	6 trays × ₹400 = ₹2,400
Fasteners, bolts, nails	Set = ₹400
Fabrication labour	3 days × ₹700 = ₹2,100
Total Estimated Cost	≈ ₹11,050 per rack unit

4.8.4. Maintenance Schedule

Staying on top of basic maintenance keeps the system safe and effective across many years of use:

1. Weekly: Inspect tray mesh for tears or sagging. Replace damaged panels right away — a torn mesh lets onions fall through or block airflow.
2. Monthly: Check post joints and diagonal braces for loose bolts or cracked timber; re-tighten or replace before the next loading cycle.
3. Quarterly: Apply wood preservative or linseed oil to exposed timber — the key step for preventing decay in Tamil Nadu's humid climate.
4. Annually: Inspect concrete footings for cracking or differential settlement. Resurface or replace damaged footings before the next season.
5. After every drying cycle: Shake out onion debris from each tray and let the trays dry completely in the sun before the next batch is loaded.

4.9. SMART ONION STORAGE MONITORING SYSTEM

4.9.1. Circuit Overview

A simple electronic monitoring sub-system complements the rack, alerting farmers when storage conditions drift outside safe limits. It is built around an ESP32 development board, an inexpensive, Wi-Fi-capable microcontroller widely available in Indian electronics markets (Espressif Systems, 2023, Mani, 2026).

The key components are:

1. DHT22 temperature and humidity sensor — reads ambient conditions inside the shed every few minutes (Aosong Electronics, 2014).
2. MQ-135 gas sensor — detects ammonia and sulphur compounds that are early indicators of onion spoilage (Winsen Electronics, 2015).
3. GPS NEO-6M module — logs the storage location, useful for cooperatives managing multiple sheds (u-blox, 2011).
4. 1-channel relay module — switches a 12V exhaust fan on automatically when humidity exceeds 70%.
5. Buzzer and LED indicators — give an immediate audible and visual alert when sensor thresholds are crossed.
6. 12V battery with a step-down converter — powers the system independently of the mains supply.

The logic: if the DHT22 reads above 70% relative humidity, or the MQ-135 detects gas above threshold, the ESP32 triggers the relay to switch on the exhaust fan and sounds the buzzer, giving the farmer a chance to remove problem onions before spoilage spreads (Patil & Vijaya Kumar, 2020; Reddy & Naik, 2020).

4.10. SOFTWARE APPLICATION – MONITORING SYSTEM FOR TEMPERATURE, HUMIDITY & GAS SENSOR

A mobile and web application gives farmers real-time visibility into storage conditions. It connects to the ESP32 over Wi-Fi and shows live DHT22 and MQ-135 readings on a simple dashboard, with automatic alerts when conditions drift outside safe limits.

4.11. DASHBOARD FEATURES

1. Live Temperature Monitoring – shed temperature from the DHT22, updated every few minutes, with a trend graph.
2. Live Humidity Monitoring – tracks shed humidity, highlighted in red above the 70% safe threshold.
3. Gas Sensor Readings – shows MQ-135 ammonia and sulphur readings, flagging early signs of spoilage.
4. Automatic Alerts – push and SMS alerts when humidity or gas crosses threshold, mirroring the unit's buzzer and LED.
5. Remote Fan Control – farmer can manually switch the exhaust fan from the app, alongside automatic control.
6. Multi-Shed Location Mapping – uses GPS NEO-6M data to plot sheds on a map for cooperatives.

4.12. HOW IT WORKS

The ESP32 reads the DHT22 and MQ-135 at regular intervals and publishes data to a cloud server over Wi-Fi, which the app uses to refresh the dashboard automatically. If humidity crosses 70% or gas exceeds the set limit, the app raises an alert and, if enabled, switches on the exhaust fan along with the local buzzer and LED (Kumar & Saxena, 2020).

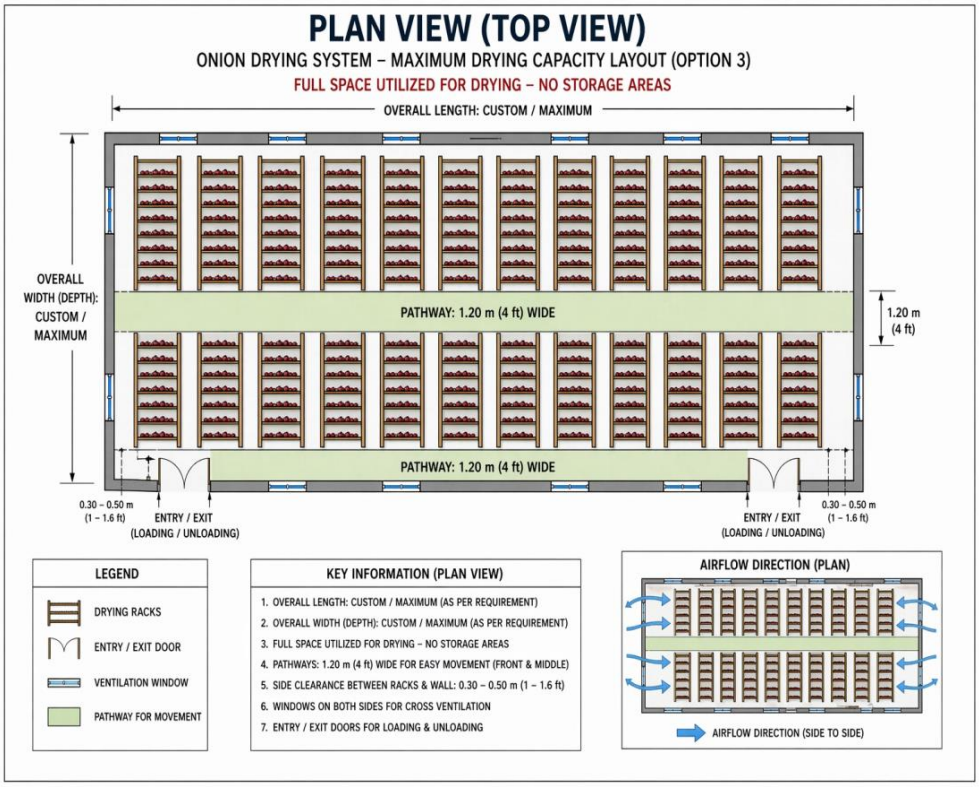


Figure 9: Smart onion storage monitoring system – Circuit diagram (ESP32, DHT22, MQ-135, GPS NEO-6M)

5. RESULTS AND DISCUSSION

Compared to traditional ground drying, this system shows significant improvement across every metric that matters to a farmer. Table 5 summarises the key outcomes.

Table 5: Performance comparison – Smart onion storage vs. traditional ground drying

Performance Metric	Outcome
Post-harvest loss rate	Reduced from ~30% to <8%
Average drying time	14 days (vs. 21+ days on ground)
Labour for loading / unloading	~40% reduction compared to fixed shelves
Uniformity of drying	High — all trays exposed equally to airflow
Fungal and rot incidence	Significantly lower due to continuous airflow
Cost recovery period	1 – 2 seasons
Scalability	Fully modular — add rack units as harvest grows

The most striking result is the drop in post-harvest loss from around 30 percent to below 8 percent (Mukherjee & Sharma, 2021; NHRDF, 2022). For a farmer storing 1,800 kg per cycle, that saves roughly 400 kg of produce that would otherwise have rotted, so the system pays for itself within one or two seasons at even a modest market price (Babu & Reddy, 2020). The 40 percent reduction in labour time is also meaningful. Since trays slide out individually, workers can remove one for inspection or to take out a spoiled batch without disturbing the rest — unlike fixed shelves, which require moving everything around the problem area.

6. CONCLUSION

The Smart Onion Storage System using the Silkworm Tray Method is a practical, affordable answer to a problem that costs Indian onion farmers hundreds of crores of rupees every year. The core idea — open-grid trays inside a ventilated rack inside an open shed — is simple enough for a local carpenter to build in a few days, with no training needed beyond this journal. The construction cost of approximately 11,050 per rack unit puts the system within reach of small-scale farmers. A standard shed with 12 rack units, costing roughly ₹1.3 lakhs in materials and labour, handles 1,800 kg per cycle and up to 7,200 kg annually, with cost recovery typically in one to two growing seasons.

What is most significant is what this design demonstrates beyond the numbers: engineering principles from a centuries-old craft, silkworm rearing, applied directly to a 21st-century agricultural problem. The tray geometry, rack spacing, and shed orientation all come from observing how silkworm farmers managed airflow, then asking whether onions need the same. Future work includes adding low-cost DHT22 sensors with an ESP32 for real-time alerts, evaluating fan-assisted ventilation for low-wind regions, and running a full-scale field trial with farmer cooperatives in Salem district.

DECLARATION OF COMPETING INTEREST

The authors should have declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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AUTHORS' CONTRIBUTIONS

All authors contributed equally to conceptualization, methodology, writing – original draft, and writing – review and editing.

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AVAILABILITY OF DATA AND MATERIALS

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

AI TOOL USAGE DECLARATION

During the preparation of this work, the authors used Grammarly to improve language clarity, grammar, and spelling. ChatGPT was used for the preparation of figures and assist in conceptualizing figure layouts. The authors carefully reviewed and edited all outputs and take full responsibility for the final version of the manuscript.

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