IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, November 2026
Impact Factor: 8.2

# A Survey of IoT-Driven Smart Agricultural Storage Systems for Fruits and Vegetables Preservation

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**Abstract:** *Post-harvest preservation of fruits and vegetables is a major challenge because quality changes rapidly when temperature, relative humidity, ventilation and ripening gases are not managed appropriately. Conventional storage often relies on periodic manual inspection, which can miss short-term environmental changes and delay corrective action. This survey reviews IoT-enabled monitoring and intelligent storage approaches for fresh produce, with emphasis on low-cost embedded systems suitable for small farms, shops and local storage facilities. The reviewed literature covers wireless monitoring of ambient parameters, cloud-connected cold-storage notification, machine-learning-based freshness classification, and fruit-specific temperature and humidity monitoring. Their sensing strategies, communication methods, control capabilities and validation limitations are compared. The review identifies gaps in crop-specific thresholds, sensor calibration, automatic control, power reliability, connectivity resilience and long-duration field validation. Based on these findings, a proposed ENTC project architecture is outlined using an ESP32, temperature-humidity sensing, a gas sensor, a display, a cloud dashboard and relay-driven ventilation or cooling. The paper presents a practical evaluation plan; it does not claim experimental results for the proposed prototype.*

**Keywords:** Internet of Things (IoT), smart agriculture, post-harvest preservation, fruit storage, vegetable storage, ESP32, temperature, humidity, gas sensing, cold chain, spoilage monitoring.

## I. INTRODUCTION

Fresh fruits and vegetables remain biologically active after harvest. Respiration, water loss, microbial growth, mechanical injury and ethylene-mediated ripening can reduce quality during handling, transport and storage. The rate and type of deterioration differ by commodity; therefore, one universal temperature or humidity setting is not appropriate for every crop. The Food and Agriculture Organization notes that successful storage depends on coordinated handling, temperature regulation, humidity, air circulation, stacking and inspection [1].

Internet of Things (IoT) technology can connect sensors, a microcontroller, communication networks and a dashboard so that storage conditions are observed continuously ratherthan only during manual checks. An embedded controller can compare readings with crop-specific limits, activate a fan or cooling device, and send an alert when a threshold is exceeded. Cloud logging can also help users identify recurring conditions associated with quality loss.

Scope and method. This survey synthesizes selected research articles and technical literature on IoT monitoring of fresh produce and perishable-food storage [2]–[5]. It compares reported system features and evidence without treating results from different crops or experimental settings as directly equivalent. The proposed design is a project-level synthesis, not a claim that a new prototype has already been tested.

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DOI: 10.48175/IJARSCT-40556

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## II.BACKGROUND

### A.Storage parameters affecting produce

Temperature affects respiration and microbial activity, while relative humidity influences water loss and condensation risk. Ventilation can remove accumulated heat and some gases, but excessive airflow may increase moisture loss. Carbon dioxide, volatile organic compounds (VOCs) and ethylene may provide additional information about respiration or ripening, but low-cost gas sensors are often cross-sensitive and should not be interpreted as laboratory-grade measurements without calibration. Light exposure, vibration and door-opening events may also matter for particular storage settings.

### B.IoT architecture

A typical system contains (i) sensors, (ii) an embedded controller such as ESP32, (iii) a communication link such as Wi-Fi/MQTT/HTTP, (iv) a dashboard or database, and

(v) local actuators and alarms. Local threshold logic should continue operating if the internet or cloud service is unavailable. Crop-specific setpoints must be selected from credible post-harvest guidance and validated for the actual produce and storage design.

### C.Monitoring versus closed-loop control

Monitoring systems report environmental conditions but leave corrective action to a person. Closed-loop systems use sensor readings to control a fan, damper, humidifier or cooling unit. Automatic control can reduce response delay, but poorly selected thresholds, sensor drift or relay failure may make conditions worse. A safe design therefore needs hysteresis, minimum actuator on/off times, fault detection, manual override and clear alarms.

## III.MOTIVATION AND PROBLEM STATEMENT

Small and medium-scale growers and vendors may not have access to expensive commercial cold-chain infrastructure or continuous technical supervision. Manual checks provide limited time resolution, while simple temperature-only monitors cannot identify every cause of deterioration. A low-cost IoT-driven storage unit is therefore worth investigating, provided that it is treated as an aid to appropriate post-harvest handling rather than a substitute for hygiene, grading, packaging or commodity-specific storage practice.

The project problem is to develop a prototype that records temperature and relative humidity, optionally monitors a gas-related indicator, alerts a user when readings leave a configured range, and controls selected storage equipment through a safe local controller. The design should be economical, understandable to farmers and testable using measurable criteria.

## IV. REVIEW OF RELATED WORK

### A.IoT-based cold-storage monitoring and notification

Afreen and Bajwa presented an IoT-based real-time intelligent monitoring and notification system for cold storage [2]. The work is relevant because it frames environmental monitoring as a continuous process and connects sensor observations to timely notifications. Notification systems can improve visibility and response time; however, an alert by itself does not guarantee that the storage environment will be corrected. Deployment also depends on sensor placement, communication reliability and the user's ability to respond.

### B.IntelliStore: IoT and machine learning

Singha et al. proposed IntelliStore, combining IoT monitoring of temperature, humidity and CO□ with pest-related sensing using a PIR sensor and microphone [3]. The authors report a dataset covering ten fruit and vegetable types and compare SVM, decision tree, AdaBoost and gradient boosting models; SVM achieved the highest reported accuracy of 88%. The work illustrates how multiple signals and data-driven classification may support freshness monitoring. Model accuracy, however, depends on dataset size, label quality, crop coverage and validation conditions; the reported result should not be assumed to transfer unchanged to a new storage room.

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**C.IoT monitoring of mango cooling**

Westari et al. described a mango cooling monitoring system using an ESP32 and DHT22 temperature-humidity sensor, with readingssent toan IoTplatform for remote observation [4]. The study reports real-time monitoring and low measurement error in its tests. This fruit-specific implementation is relevant to a low-cost ENTC prototype because it demonstrates a practical microcontroller-and-sensor arrangement. The available article summary does not establish that the system automatically controls all storage conditions or proves a quantified shelf-life extension.

**D.IoT and machine learning for banana ripeness**

A 2025 study in e-Prime proposed an IoT and machine-learning platform for banana ripeness evaluation and spoilage detection [5]. Its framework combines temperature, humidity and gas-emission measurements with an ESP32 and a cloud platform, then compares machine-learning methods for ripeness classification. This approach extends simple threshold monitoring toward quality estimation. For student projects, gas-sensor calibration, reproducible ripeness labels and testing on unseen fruit batches are essential before claiming reliable spoilage prediction.

**E.Summary of the literature**

Across the selected works, IoT sensing is useful for continuous visibility and remote notification; multi-sensor systems provide richer context than temperature alone; and machine learning may help interpret patterns that are not captured by fixed thresholds. Yet results differ in crop, storage environment, sensor set and evaluation method. These differences make a controlled, commodity-specific prototype evaluation necessary.

## V. COMPARATIVE ANALYSIS

| Study / approach | Main parameters or method | Strengths | Limitations / open issues |
|---|---|---|---|
| Afreen & Bajwa [2] | IoT monitoring and cold-storage notifications | Continuous monitoring; alerts can support timely action | Alerting alone does not guarantee automatic correction; deployment depends on connectivity and sensor quality |
| IntelliStore, Singha et al. [3] | Temperature, humidity, CO□, PIR/microphone; ML classifiers | Multi-sensor observations; reports 88% highest accuracy with SVM | Dataset and labels may limit generalization; sensing and model maintenance add complexity |
| Westari et al. [4] | ESP32 + DHT22 for mango cooling monitoring; IoT platform | Simple low-cost architecture; remote monitoring | Evidence summarized mainly concerns monitoring; broader control and shelf-life claims need validation |
| Banana ripeness platform [5] | ESP32, temperature, humidity, gas emissions and ML | Combines environmental sensing with ripeness/spoilage estimation | Gas-sensor selectivity, calibration and unseen-batch testing are important |
| Proposed ENTC prototype | ESP32, temperature/RH, gas indicator, dashboard, | Low-cost; local alarms and control can work even | Requires safe thresholds, calibration, actuator |
| Study / approach | Main parameters or method | Strengths | Limitations / open issues |
| | local relay control | when cloud is offline | interlocks and real produce trials |

Table I. Qualitative comparison of selected literature and the proposed student prototype.

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## VI. PROPOSED IoT-DRIVEN SMART STORAGE SYSTEM

### A. Proposed architecture

The proposed system uses an ESP32 as the main controller. A temperature-humidity sensor (preferably DHT22 or a more accurate calibrated sensor) measures the storage environment. A gas sensor may be included as an exploratory indicator of changing air composition; it must not be described as a selective ethylene detector unless the selected sensor and calibration method support that claim. The ESP32 filters readings, applies configured limits, updates a local display and sends data to a cloud dashboard when Wi-Fi is available. A relay module switches a fan or a suitable cooling-control interface. The high-current cooling load must use a properly rated driver and power supply; it must not be powered directly from an ESP32 GPIO pin.

### B. Hardware requirements

The prototype requires the following hardware to sense storage conditions, process readings, provide local control and enable remote monitoring:

- **ESP32 / NodeMCU ESP32 development board:** Main controller; reads sensor values, runs threshold logic and connects to the IoT dashboard through built-in Wi-Fi. Operates at 3.3 V logic.
- **Temperature and humidity sensor (DHT11 or DHT22):** Measures the storage chamber's temperature and relative humidity. The synopsis block diagram shows DHT11, while its component specification lists DHT22; finalize one sensor model before assembly.
- **Gas / air-quality sensor (MQ-4 or MQ-135):** Provides a gas-related indicator for abnormal conditions. The synopsis diagram and working description mention MQ-4, while the component list also mentions MQ-135. These sensors are not interchangeable for every gas; select according to the intended measurement and calibrate it.
- **Relay module and fan:** A suitably rated relay/driver switches the AC fan or a compatible exhaust/cooling fan when configured thresholds are exceeded. Match relay ratings to the load and provide safe isolation and electrical protection.
- **Power supply and voltage regulator:** Provides the required supply rails for the controller and sensors, with separate suitable power for the fan/actuator. The synopsis lists a 12 V DC supply with 5 V/3.3 V regulation; verify all module ratings.
- **Storage chamber / insulated box:** Holds the fruits and vegetables and provides a defined space in which temperature, humidity and gas-related conditions can be monitored.
- **Local display (16×2 LCD or OLED):** Displays sensor readings and operating status near the storage unit; it is optional if the phone dashboard is sufficient.
- **Buzzer / alert indicator:** Gives a local warning when readings cross configured limits; optional if alerts are delivered through the dashboard or phone.
- **Additional temperature sensor (DS18B20):** Optional second sensor for an additional or more accurate temperature measurement, as listed in the synopsis component specifications.
- **Humidifier/dehumidifier and ventilation hardware:** Optional actuators for humidity control and improved airflow; use only if the project includes closed-loop humidity control and the chosen components are safely rated.
- **Wi-Fi/cloud and mobile device:** ESP32 Wi-Fi sends data to a cloud platform such as ThingSpeak or Blynk; a phone or computer displays readings, trends and alerts. These provide the communication and monitoring interface rather than being chamber sensors.
- **LDR sensor:** Optional sensor listed in the synopsis for detecting light or possible door-opening conditions; include it only if this function is implemented.

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Data path: Produce storage chamber → temperature/RH and optional gas sensors → ESP32 → local threshold and fault logic
→ display/buzzer and relay output → Wi-Fi/cloud dashboard and historical data log.

**Block diagram :**

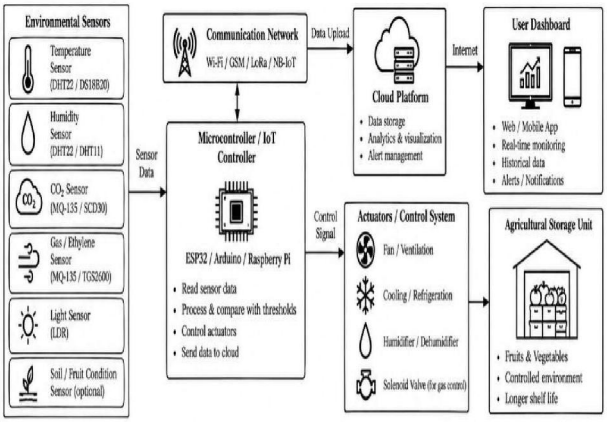



Fig. 1. Block diagram of an IoT-driven smart agricultural storage system for fruits and vegetables preservation.

**C. Main hardware components**

| Component | Purpose | Design consideration |
|---|---|---|
| ESP32 development board | Reads sensors, executes logic and connects to Wi-Fi | Use watchdog/timeouts; keep core safety logic local |
| DHT22 / calibrated temperature-RH sensor | Measures chamber temperature and relative humidity | Place away from direct airflow, wet surfaces and actuator heat; calibrate against a reference |
| Gas sensor (optional) | Provides a relative gas/VOC indicator | Cross-sensitivity and warm-up matter; do not infer exact ethylene concentration without validation |
| OLED/LCD and buzzer | Local status, readings and alarm | Must remain useful without cloud access |
| Relay/driver + fan or cooling interface | Controls ventilation or cooling equipment | Rate for load voltage/current; use isolation and electrical protection |
| Wi-Fi dashboard / database | Remote live view, trends and notifications | Use authenticated access; handle network outage and data gaps |
| Regulated power supply | Powers controller, sensors and actuators | Separate noisy/high-current loads from logic supply where appropriate |

Table II. Suggested prototype components and their roles.

**D. Operating algorithm**

1) Start the controller and check sensor availability. 2) Read temperature and humidity at a fixed interval and average or filter noisy samples. 3) Compare the values with crop-specific upper and lower limits selected for the chosen fruit or vegetable. 4) If a limit is exceeded for a configured duration, activate the relevant actuator and raise an alarm.

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5) Apply hysteresis and minimum run/off times to prevent relay chatter. 6) Publish readings and event status when the network is available. 7) If a sensor fails or readings become implausible, stop unsafe automatic action, indicate a fault and request manual inspection. 8) Log the time, sensor readings, actuator state and alarms for later analysis.

**Flow chart :**

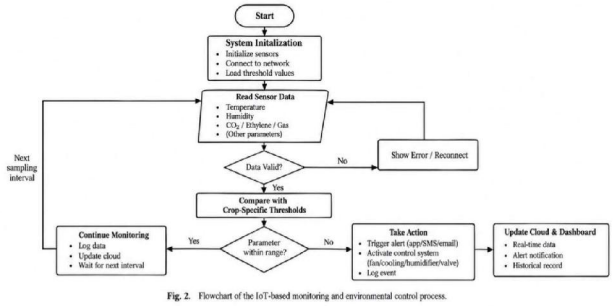



Fig. 2. Flowchart of the IoT-based monitoring and environmental control process.

**E. Control and safety considerations**

Different produce has different storage requirements, including sensitivity to chilling injury and humidity. Setpoints should therefore be configurable by commodity and supported by post-harvest references. The prototype should not assume that lower temperature is always better. The controller should use an independent thermal cut-out where appropriate, a manual override, safe default output states, relay protection and clear fault indication. Any compressor or mains-powered equipment must be interfaced through appropriately rated hardware and supervised by a qualified person.

## VII. RESEARCH GAPS

The review suggests five practical gaps: (1) many prototypes monitor conditions but provide limited closed-loop control; (2) thresholds are not always tailored to the crop and maturity stage; (3) low-cost gas sensors may be treated as direct spoilage detectors despite cross-sensitivity;

(4) evaluation often focuses on sensor readings or model accuracy rather than measurable produce quality and energy use; and (5) performance during internet loss, sensor failure and long-duration operation is not consistently reported. There is also a need to assess affordability, maintenance and usability in real small-scale storage settings.

## VIII. PROPOSED EVALUATION PLAN

The prototype should be evaluated only after assembly and calibration. Recommended tests are: (i) compare temperature and humidity readings against a reference instrument at several conditions; (ii) record sensor response time and data packet loss; (iii) test alert and actuator response at each configured threshold; (iv) disconnect Wi-Fi and verify that local monitoring and control continue; (v) simulate sensor disconnection and confirm fault handling;

(vi) measure energy consumption and actuator duty cycle; and (vii) compare produce stored in the prototype with a control batch under documented, comparable conditions.

| Metric | Suggested method | Reporting |
|---|---|---|
| Temperature / RH error | Compare against calibrated reference readings | Mean absolute error and range tested |
| Alert/control latency | Time from sustained threshold crossing to alert or actuator state change | Mean, maximum and number of trials |
| Connectivity robustness | Wi-Fi off/on test and dashboard data-gap check | Recovery time and missing records |
| System uptime | Continuous operation over a defined test period | Uptime percentage and reset/fault log |
| Preservation outcome | Record mass loss, visible defects, firmness or colour using a consistent protocol | Daily observations; avoid claiming causation without controls |

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| | | |
|---|---|---|
| Energy use | Measure controller and actuator energy separately if possible | Wh/day and actuator duty cycle |

Table III. Proposed evaluation metrics. These are planned tests, not completed results.

## IX. FUTURE SCOPE

Future development may include crop-specific profiles, calibrated CO□ or ethylene sensing, low-power wireless nodes, solar backup, SMS/app alerts, predictive analytics and integration with supply-chain traceability. A larger dataset from different maturity stages and storage conditions could support a machine-learning model, but model training should follow reliable ground-truth labelling and testing on separate fruit batches. A field trial with farmers or local vendors would help evaluate usability, maintenance burden and economic feasibility.

## X. CONCLUSION

This survey reviewed IoT-based storage monitoring, notification and machine-learning approaches for fruits and vegetables. The literature indicates that continuous temperature-humidity monitoring and remote alerts are practical starting points, while multi-sensor analysis may provide additional information about freshness. The key challenges are crop-specific environmental requirements, gas-sensor reliability, safe automatic control and evidence from long-duration real-produce trials. The proposed ESP32-based system combines local sensing, threshold logic, dashboard logging and optional actuator control in a low-cost architecture suitable for a BE ENTC project. Its actual effectiveness must be established through calibration, fault testing and controlled preservation trials; no shelf-life improvement is claimed until such measurements are completed.

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