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Design and Fabrication of a Portable Solar-Powered Smart Grain Dryer

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ABSTRACT—

Post-harvest drying of grains such as paddy, maize, wheat, and pulses is essential for preventing spoilage during storage, yet small farmers in many rural areas still depend on open-sun drying, which is slow, weather-dependent, and exposes the grain to dust, insects, birds, and rain. This paper presents the design and fabrication methodology of a portable, low-cost, solar-powered smart grain dryer for small-scale use. The dryer consists of an insulated metal drying chamber with perforated grain trays, a nichrome heating element housed in a separate protected heating chamber, and a DC blower that circulates hot air through a duct and manifold. A solar panel, charge controller, and rechargeable battery supply the electrical load, making the unit suitable for off-grid locations. An Arduino Uno microcontroller reads a temperature and humidity sensor and displays real-time readings on an LCD so that the drying environment can be observed. The paper describes the working principle, mechanical and electronic design, the design relations used to size the heater, blower, panel, and battery, the fabrication sequence, and the test procedure and performance indices for evaluating the prototype.

***Keywords*—**solar dryer, grain drying, hybrid dryer, nichrome heater, Arduino Uno, forced convection, post-harvest loss.

1. INTRODUCTION

Cereals and pulses form a major part of the daily food supply and an important source of income for farmers. After harvest, grain usually contains more moisture than is safe for storage. If the moisture is not reduced soon afterwards, the grain becomes vulnerable to fungal growth, insect infestation, self-heating, discolouration, and loss of germination capacity. Drying is therefore one of the most important post-harvest operations.

In many rural areas grain is still spread on open ground or mats and dried in direct sunlight. The method is inexpensive but depends entirely on the weather: rain, high humidity, and cloudy days delay drying, and the grain is exposed to dust, birds, rodents, and livestock. Mechanical dryers that use electricity or fuel provide better control, but their purchase and running costs are usually too high for small and marginal farmers, and most are not easy to move. Solar energy is clean and freely available, but on its own it is intermittent.

This work proposes a portable solar-powered smart grain dryer combining a photovoltaic (PV) charged battery supply, an electrically heated protected chamber, forced hot-air circulation through perforated trays, and low-cost temperature and humidity monitoring. The objectives are to (i) design a compact insulated drying chamber and a separate heating chamber, (ii) select a blower and air-distribution manifold for uniform airflow, (iii) size the solar panel and battery for the electrical load, (iv) monitor drying conditions with an Arduino Uno.

2. LITERATURE REVIEW

Open-sun drying needs no equipment but is slow and exposes the product to contamination and loss. Mechanical dryers give better control through a fan and a fuel or electric heat source, but at higher cost. Solar dryers are widely studied as a low-running-cost alternative and are generally classified as direct, indirect, mixed-mode, and hybrid types [4], [7]. Hybrid dryers add an auxiliary source, such as electrical heating, so that drying can continue when sunlight is weak. Dryers may also be classified by air movement: natural-convection (passive) dryers rely on buoyancy, whereas forced-convection (active) dryers use a fan, which gives better control and more uniform drying at the expense of electrical power [5]–[7].

Low-cost microcontrollers such as the Arduino Uno can read digital temperature and humidity sensors and show the values on a display. Recently reported Arduino-based rice dryers combine temperature sensing, a heater, and an air blower [1], [3], and a finite-element study has examined heat, mass, and airflow in a PV-assisted hybrid paddy dryer [2]. More recent work has reported IoT-based monitoring of paddy drying [8], IoT-integrated solar drying [9], Arduino-controlled dual-energy dryers [10], and microcontroller-controlled electrical dryers [11]. Table 1 summarises the related studies.

Research gap. Open-sun drying is weather-dependent, mechanical dryers are costly and difficult to move, and sun-only solar dryers are affected by weather and time of day. Many small dryers also do not show the drying conditions to the user. There is therefore a need for an affordable, portable,

battery-supported unit that keeps the heating element separate from the grain, distributes hot air through perforated trays, and displays temperature and humidity.

3. SYSTEM DESIGN AND METHODOLOGY

3.1 Proposed System

The proposed dryer is a portable forced-convection grain dryer with an electrical heating element powered from a solar-charged battery. Its major sections are the solar power supply, the heating section, the air-circulation section, the drying section, and the monitoring section. Fig. 1 shows the block diagram of the system, in which solid arrows denote electrical power and signals and dashed arrows denote airflow and sensing.

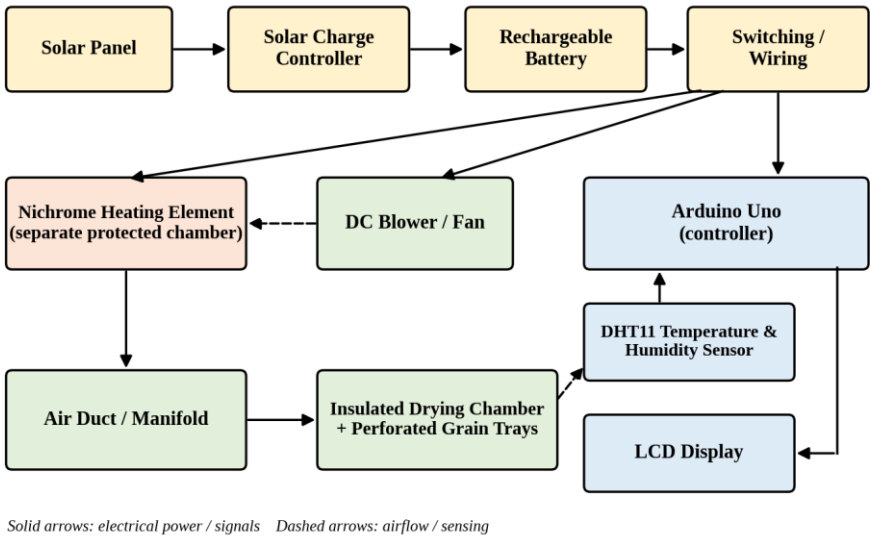


Fig. 1: Block diagram of the proposed solar-powered smart grain dryer

3.2 Working Principle

Sunlight falling on the solar panel is converted to DC electrical energy, which the charge controller regulates and delivers to the battery. When the heater is switched on, current flows through the nichrome element and heats it. Nichrome is used because of its high electrical resistivity and its ability to withstand high temperature. The element sits in a separate heating chamber so that it never touches the grain. The DC blower draws ambient air into this chamber, where the air takes heat from the element by convection, and the heated air flows through the duct and manifold into the drying chamber.

Inside the drying chamber the grain is spread in a thin layer on perforated trays, so the hot air passes through and around it. Heating lowers the relative humidity of the air and increases its capacity to absorb moisture. Heat is transferred from the air to the grain, moisture moves from inside the kernel to the surface and evaporates, and the moist air leaves through the vent at the top of the chamber. The Arduino Uno shows the measured temperature and humidity on the LCD, so the operator can switch the heater or blower on or off manually according to the observed conditions.

3.3 Mechanical Design

The structure consists of a frame, an insulated metal drying chamber, a separate heating chamber, a duct and manifold, and perforated trays (Fig. 2). The drying chamber is made of metal sheet and insulated on its sides, top, and bottom. Racks hold the trays one above the other with space between them for air movement. Hot air enters at the bottom through a manifold (plenum) that spreads the flow so that it rises evenly through the trays, avoiding short paths along which air bypasses part of the grain. A door allows loading, and a vent at the top releases moist air. The heating chamber is built from heat-resistant material with the element on insulating supports. The tray perforations must be smaller than the smallest grain, and the frame is kept compact and light enough to be moved by one or two persons.

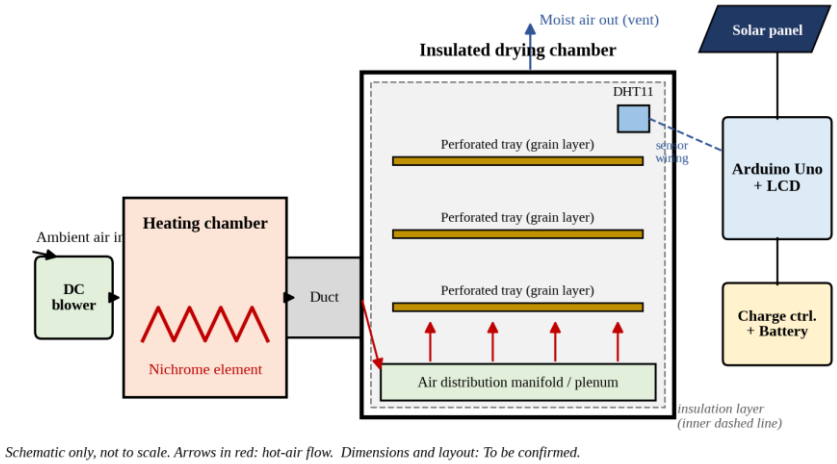


Fig. 2: Schematic arrangement of the proposed dryer (not to scale)

3.4 Solar Power and Monitoring System

The energy flow is: sunlight → solar panel → charge controller → battery → heater, blower, and Arduino Uno circuit. The ratings of the panel, controller, and battery depend on the heater and blower power and the desired operating time (Section 4.4). The electronic section is based on an Arduino Uno programmed using the Arduino IDE. A DHT11 temperature and humidity sensor is placed in the drying chamber and its readings are shown on the LCD at regular intervals. The DHT11 has a limited temperature range and moderate accuracy, so its datasheet range must be compared with the maximum air temperature at the sensor location; if that temperature may be exceeded, the sensor should be placed at a cooler location or replaced by a wider-range sensor. In the present scope the heater and blower are switched manually. A fuse in the battery line and properly insulated joints provide electrical protection, and the heater circuit is kept separate from the low-power electronics.

3.5 Fabrication Sequence

Fabrication proceeds in this order: frame; insulated drying chamber with door, vent, and tray rails; heating chamber with the nichrome element on insulating supports; ducts, manifold, and blower with sealed joints; perforated trays; solar panel, controller, and battery wiring; electronic assembly and Arduino programming; and finally testing of each section and of the complete system.

4. DESIGN RELATIONS

4.1 Heat Transfer Principles

Heat loss by conduction through a flat chamber wall of area A, thickness L, and thermal conductivity k, with a temperature difference ΔT across it, is given by Eq. (1). Convective heat transfer from the element to the air and from the air to the grain is given by Eq. (2), where h is the convective heat transfer coefficient, T_s the surface temperature, and T_∞ the air temperature. A blower gives forced convection, which has a higher h than natural convection; this is why forced circulation heats the grain faster.

$$Q = (k \times A \times \Delta T) / L \quad (1)$$

$$Q = h \times A \times (T_s - T_\infty) \quad (2)$$

The heat needed to raise the temperature of an air mass flow rate m_a by ΔT is given by Eq. (3), where c_p is the specific heat of air (about 1.005 kJ/kg·K).

$$Q = m_a \times c_p \times \Delta T \quad (3)$$

4.2 Moisture Removal and Heat Requirement

For a batch of initial mass m_i dried from an initial moisture content M_i to a final moisture content M_f (wet basis, per cent), the mass of water to be removed is given by Eq. (4), and the minimum heat required to evaporate it by Eq. (5), where h_{fg} is the latent heat of vaporisation (about 2260 kJ/kg).

$$m_w = m_i \times (M_i - M_f) / (100 - M_f) \quad (4)$$

$$Q_{evap} = m_w \times h_{fg} \quad (5)$$

The actual requirement is higher, because energy is also needed to heat the grain and the air, bound water needs more energy than free water, and heat is lost through the walls and with the exhaust air. As an illustration of the method only (assumed values, not project data or test results), a 10 kg batch dried from 22 % to 14 % (w.b.) gives $m_w = 10 \times 8/86 \approx 0.93$ kg and $Q_{evap} \approx 0.93 \times 2260 \approx 2102$ kJ ≈ 0.58 kWh.

4.3 Heating Element and Airflow

For a DC supply voltage V and element resistance R, the heater power is given by Eq. (6). The resistance of a wire of resistivity ρ, length L, and cross-sectional area A is given by Eq. (7), so the wire length needed for a required power follows from Eq. (8). The resistivity of nichrome (Ni-Cr 80/20) is typically about $1.1 \times 10^{-6}\ \Omega\cdot$m, and the value for the purchased wire should be taken from the supplier data.

$$P = V^2 / R \quad (6)$$

$$R = \rho \times L / A \quad (7)$$

$$L = V^2 \times A / (P \times \rho) \quad (8)$$

The required air mass flow rate follows from Eq. (3) as $m_a = Q/(c_p \Delta T)$, and the volume flow rate is this value divided by the air density (about 1.2 kg/m³ at ambient conditions). Because grain resists airflow, the blower must be selected for adequate flow and pressure against the heating chamber, ducts, manifold, and grain layer, not for flow in free air alone.

4.4 Solar Panel and Battery Sizing

The electrical energy for a drying period of t hours is given by Eq. (9). The battery capacity for a battery voltage V_b, depth of discharge DoD, and system efficiency η is estimated by Eq. (10), and the panel rating for a given number of equivalent peak sun hours (PSH) by Eq. (11).

$$E_{load} = (P_{heater} + P_{blower} + P_{control}) \times t \quad (9)$$

$$C = E_{load} / (V_b \times \mathrm{DoD} \times \eta) \quad (10)$$

$$P_{panel} = E_{load} / (\mathrm{PSH} \times \eta) \quad (11)$$

Electrical heating is a heavy load: a heater of several hundred watts running for an hour needs a battery and panel much larger than those required for the blower and electronics alone. The heater power, operating time, battery, and panel must therefore be chosen together so that the system stays within the ₹10,000 budget and remains portable.

5. TESTING AND PERFORMANCE EVALUATION

Performance is to be judged only from measured quantities. Tests proceed in stages: electrical checks including battery charging through the controller; a check of the Arduino and LCD readings against a reference thermometer or hygrometer; a blower and airflow check for leakage; a no-load heating test recording chamber temperature and humidity against time and the temperature uniformity between trays; a loaded drying test with grain mass recorded at regular intervals; and, optionally, a comparison with open-sun drying of the same grain. The parameters and instruments are listed in Table 2.

Table 2: Parameters to be measured and measuring method

No.	Parameter	Measuring method / instrument
1	Drying chamber temperature	DHT11 sensor; reference thermometer
2	Relative humidity in the chamber	DHT11 sensor; reference hygrometer
3	Ambient temperature and humidity	Thermometer / hygrometer
4	Battery voltage	Multimeter
5	Mass of grain with time	Weighing balance
6	Initial and final moisture content	Moisture meter or oven method

The performance indices are calculated from the measured data. The wet-basis moisture content is $M = (m_{wet} - m_{dry})/m_{wet} \times 100$ %, where m_{dry} is obtained by the oven method or a calibrated moisture meter. The drying rate is given by Eq. (12), and the thermal efficiency of drying by Eq. (13), in which the electrical energy supplied is obtained from the measured voltage, current, and time. Uniformity is assessed by comparing the final moisture content of grain from different trays.

$$R_d = \Delta m_w / \Delta t \quad (12)$$

$$\eta_d = [m_w \times h_{fg} / E_{supplied}] \times 100\ \% \quad (13)$$

6. EXPECTED BEHAVIOUR AND DISCUSSION

From the principles of heat transfer and drying, the following qualitative behaviour is expected; it is not test results and must be confirmed or corrected by measurement. Heating lowers the relative humidity of the air and increases its ability to absorb moisture. Forced circulation gives a higher heat transfer coefficient than natural convection and helps carry moisture out of the chamber, while insulation reduces heat loss. A thin grain layer on perforated trays should dry more evenly than a thick layer. Grain near the hot-air entry may dry faster than grain farther away unless the manifold distributes the air evenly, which is to be checked by comparing trays. The drying rate is expected to be high initially and to fall as the grain moisture decreases.

The drying temperature cannot be raised without limit, since excessive temperature can crack kernels, reduce milling quality, affect germination, and discolour the grain; the permissible temperature depends on the grain and its end use and must be taken from established recommendations. This is why temperature and humidity monitoring is useful. Other limitations are the small drying capacity and the heavy electrical load of resistive heating. Safety measures include never switching on the heater unless the blower is running, keeping grain away from the heating chamber, and letting the heating chamber cool with the blower running before shutdown.

7. CONCLUSION AND FUTURE SCOPE

A portable solar-powered smart grain dryer has been designed for small-scale agricultural use. It combines a PV-charged battery supply, a nichrome heating element in a separate protected chamber, a DC blower with duct and manifold, an insulated drying chamber with perforated trays, and Arduino Uno based temperature and humidity monitoring, with a target cost below ₹10,000. The paper presents the working principle, design relations for heating, airflow, and solar sizing, the fabrication sequence, and a test procedure with performance indices for drying time, moisture reduction, and drying efficiency.

Future work includes automatic heater cut-off using a relay and a tested program, wider-range and multi-level sensors, a solar air collector to reduce the electrical load, thermal storage for periods of weak sunlight, grain moisture sensing to identify the end of drying, improved insulation and manifold design, remote monitoring through wireless data transmission, and testing with different grains and batch sizes.

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REFERENCES

[1] E. J. Ilustre et al., “Automated rice grain dryer with sun-tracking solar panel using Arduino Uno,” Int. J. Res. Stud. Educ. Technol., vol. 8, no. 2, pp. 75–83, 2024, doi: 10.5861/ijrset.2024.8013.

[2] A. Jha and P. P. Tripathy, “Performance evaluation and finite element modeling of heat, mass, and fluid flow inside a hybrid solar dryer during drying of paddy grains,” Front. Food Sci. Technol., vol. 4, art. 1411956, 2024, doi: 10.3389/frfst.2024.1411956.

[3] A. P. Nebrida, “Smart integration in agriculture: an Arduino-driven rice grain dryer for optimal post-harvest management,” J. Electr. Syst. Inf. Technol., vol. 11, art. 46, 2024, doi: 10.1186/s43067-024-00170-0.

[4] Rahman et al., “Solar drying for domestic and industrial applications: a comprehensive review of innovations and efficiency enhancements,” Glob. Challenges, 2025, doi: 10.1002/gch2.202400301.

[5] Roy et al., “A comprehensive review on solar dryers for perishable agro-products: aspects of technological advancements, techno-economic performance, and environmental impacts,” Compr. Rev. Food Sci. Food Saf., 2025, doi: 10.1111/1541-4337.70186.

[6] R. K. Saini et al., “A review of agricultural solar dryers for the years 2016–2023,” Int. J. Ambient Energy, vol. 45, no. 1, art. 2352056, 2024.

[7] K. Venkateswarlu and S. K. Reddy, “Recent trends on energy-efficient solar dryers for food and agricultural products drying: a review,” Waste Disposal Sustain. Energy, vol. 6, no. 3, pp. 335–353, 2024, doi: 10.1007/s42768-024-00193-3.

[8] A. Hiendro, Syaifurrahman, F. T. P. Wigyarianto, and F. Husin, “Real-time paddy grain drying and monitoring system using long range-internet of things,” Int. J. Electr. Comput. Eng., vol. 15, no. 1, pp. 448–454, Feb. 2025, doi: 10.11591/ijece.v15i1.pp448-454.

[9] M. T. Le, X. T. Ngo, T. Nguyen, and T. S. Nguyen, “Design and development of an IoT-integrated solar water-heated drying system for macadamia nuts,” Agric. Eng. Int.: CIGR J., vol. 27, no. 3, pp. 122–135, Sep. 2025.

[10] N. R. Nwakuba et al., “Development of a smart dual-energy crop dryer with heat recovery integration: zero-load thermal dynamics test validation,” Niger. J. Technol. Dev., vol. 22, no. 5, pp. 100–109, Dec. 2025, doi: 10.63746/njtd.v22i5.3818.

[11] S. M. Jalil, A. Dabet, S. Akmal, S. Meliala, and Muhammad, “Dehydration of Moringa leaves using microcontroller and IoT controlled electrical dryer,” Int. J. Power Electron. Drive Syst., vol. 16, no. 4, pp. 2688–2698, Dec. 2025, doi: 10.11591/ijpeds.v16.i4.pp2688-2698.