



# Research on the Design and Fabrication of a Household-Scale Roasting System for Leafy Agricultural Products

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**Abstract:** The pre-processing and value-added production of leafy agricultural commodities—particularly green tea and medicinal herbs—constitute a pivotal component of Vietnam’s agricultural value chain and rural household economy. Nevertheless, ensuring consistent product quality remains a persistent challenge, largely due to dependence on manual roasting practices or rudimentary equipment lacking precise thermal regulation. This study presents the research, design, and simulation of a compact roasting system for leafy agricultural products, employing a rotary drum mechanism with a processing capacity of 3–5 kg per batch. The central objective is to optimize both the mechanical configuration and the control architecture in order to maximally preserve color, aroma, and thermolabile bioactive compounds. The proposed system incorporates a horizontally aligned cylindrical drum fabricated from food-grade stainless steel (Inox 304), ensuring compliance with food safety standards and superior resistance to high-temperature chemical corrosion. Within the drum, a set of four symmetrically configured agitator blades facilitates homogeneous mixing and multi-point heat transfer. A notable contribution of this work lies in the utilization of SolidWorks software to construct a detailed 3D model and perform kinematic simulations, enabling the prediction of thermal energy distribution within the drum prior to physical prototyping. The system is further integrated with a PLC-based intelligent control unit and a variable frequency drive (VFD), allowing precise regulation of drying temperature within an acceptable tolerance range, thereby enhancing moisture removal efficiency and ensuring operational stability. Experimental validation demonstrates that the system operates reliably, producing outputs with a final moisture content below 13.5%, in compliance with QCVN 01-54:2011/BNNPTNT standards. Additionally, the system reduces labor intensity by approximately 40% and achieves significant energy savings compared to conventional direct-heating methods. This research provides an advanced mechanical solution that contributes to the modernization of post-harvest processing technologies for smallholder farmers, in alignment with sustainable agricultural development strategies.

## Research Paper

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## 1. INTRODUCTION

Agriculture constitutes a cornerstone of Vietnam’s economic framework, particularly in relation to leafy and grain-based commodities. Nonetheless, a critical bottleneck persists in post-harvest processing, which is indispensable for product preservation and value enhancement. On a global scale, agricultural processing technologies have undergone a pronounced shift toward automation and state-of-the-art drying methodologies. Numerous industrial processes now necessitate low-temperature or even sub-ambient drying conditions to safeguard product integrity. Within cold-drying technologies, the deployment of heat pumps—

functioning as dehumidification or refrigeration systems—often synergistically integrated with desiccant materials, represents a pivotal technological enabler. By operating at reduced temperatures, these systems effectively mitigate discoloration and thermally induced degradation, while preserving nutritional constituents and intrinsic product characteristics to a near-optimal degree.

In contemporary large-scale manufacturing environments, prevalent equipment configurations include heat pump drying systems, freeze-drying (lyophilization) units, and, notably, rotary drum dryers.

Advanced platforms such as DSL-v2 incorporate sophisticated control architectures featuring computerized interfaces, touchscreen HMIs, and variable frequency drives (VFDs), enabling real-time monitoring and adaptive regulation of cooling capacity based on refrigerant evaporation temperatures, thereby delivering substantial energy efficiency gains. For sectors such as pharmaceuticals, food processing, and agricultural production under Vietnamese climatic conditions, these systems offer the added advantage of pre-dehumidifying inlet air prior to its introduction into the drying chamber. This enhances the thermodynamic driving force of the drying process and significantly reduces operational duration. For example, the adoption of cold-drying technology at Hai Ha Confectionery Company has resulted in approximately 58% reduction in electricity consumption compared to conventional dehumidification-based methods, while maintaining stringent product quality standards.

Within the field of agricultural engineering, rotary drum dryers have been extensively investigated and widely implemented due to their capacity for uniform material agitation and enhanced interfacial contact with the drying medium. A substantial body of research has focused on integrating rotary drum systems with clean and energy-efficient heat sources. Notably, studies have examined heat pump-assisted drying processes for various horticultural products, including bulb onions, scallions, bok choy, and aromatic herbs. Experimental investigations into carrot drying using a rotary drum heat pump system indicate that, under operating conditions of 40°C, an air velocity of 2.5 m/s, and a rotational speed of 15 rpm, the system achieves superior moisture extraction efficiency while preserving product coloration more effectively than conventional drying techniques.

For cereal grains, such as N97 glutinous rice seeds, the application of rotary drum drying integrated with heat pump technology at a drying temperature of 37°C, an airflow velocity of 6.6 m/s, and a rotational speed of 2.5 rpm has demonstrated stable and reproducible performance. After 19 hours of operation, the final moisture content reached 13.2%, with a germination rate of 89.3%, underscoring the efficacy of the approach.

Despite these technological advancements, post-harvest processing at the household level in Vietnam remains constrained by significant limitations. The majority of small-scale operations continue to rely on manual roasting techniques or rudimentary equipment, resulting in inadequate control over critical process parameters such as temperature and ambient humidity. The absence of rigorously engineered drying systems often leads to adverse outcomes, including discoloration and nutrient depletion caused by excessive or non-uniform thermal exposure. Consequently, there is a compelling need to develop a dedicated roasting system

for leafy agricultural products tailored to household-scale applications (approximately 8–12 kg per batch), incorporating intelligent control capabilities.

From a mechanical engineering standpoint, the design of such a system necessitates high precision in drivetrain analysis and adherence to fundamental machine design principles. The apparatus must feature a structurally robust rotary drum, typically fabricated from high-strength steels or materials such as CT3, contingent upon the specific properties of the processed material. The drying chamber is generally configured as a horizontally oriented cylindrical drum equipped with internal agitation blades to ensure homogeneous mixing. The drive system must be meticulously engineered with respect to motor power and rotational speed to deliver adequate torque for the intended material load. Furthermore, the integration of advanced control components—including programmable logic controllers (PLCs), human-machine interfaces (HMIs), variable frequency drives (VFDs), and temperature and humidity sensors—is essential to achieve a high degree of automation and process reliability.

In parallel with heat pump technologies, solar-assisted drying solutions leveraging natural convection have also been explored for agricultural products such as garlic, offering the potential for reduced energy consumption. However, for thermally sensitive leafy materials, achieving consistent product quality necessitates precise regulation of input drying parameters (temperature, airflow velocity, and humidity) and output variables (final moisture content and drying duration), typically optimized through design of experiments (DOE) methodologies. Key operating ranges, such as dew point temperatures from -15°C to 25°C and drying air temperatures between 35°C and 45°C, are commonly adopted in modern cold-drying systems.

Accordingly, the research, design, and fabrication of a household-scale rotary drum roasting system for leafy agricultural products represent a pragmatic and impactful direction. Such a system must not only fulfill throughput requirements but also adhere to stringent technical criteria regarding safety, durability, and energy efficiency. By leveraging established findings in rotary drum and cold-drying technologies, the proposed solution aims to address quality-related challenges faced by small-scale producers, thereby contributing to the modernization of post-harvest agricultural practices. Moreover, the application of advanced simulation tools and precision engineering methodologies enables pre-fabrication optimization of structural and operational parameters, minimizing developmental risks and enhancing overall system performance and functional value.

## 2. Rotary Drum Roasting System Model

### 2.1. Structural Configuration

#### Roasting Drum:

The roasting drum is designed as a horizontally oriented cylindrical chamber, fabricated from stainless steel with an internal cast-iron lining to enhance thermal retention and durability. The drum has a diameter of 350 mm and a length of 458 mm. Internally, four symmetrically arranged agitation blades are installed, each with a height of 35 mm. The blade height is carefully engineered to ensure sufficient lifting and tumbling of the material mass without excessively obstructing airflow circulation, which plays a crucial role in convective heat transfer.

These blades significantly contribute to heat transfer from the drum wall—heated via electrical resistance elements—to the agricultural material through direct conduction. Beyond their mechanical mixing function, the blades also act as auxiliary heat dissipation fins, thereby enhancing overall thermal efficiency. The drum is driven by an electric motor coupled with a reduction gearbox, rated at 1.5 kW, operating at a rotational speed of approximately 2.5 rpm.

#### Heating System:

The required thermal energy ( $Q$ ) is determined based on the mass of the raw material, its initial moisture content, and the desired final moisture level ( $Y \leq 13.5\%$ ). The system employs a PID-based control strategy integrated with temperature sensors (such as thermocouples or resistance temperature detectors—RTDs) to maintain a stable drying temperature within the range of 30–45°C for low-temperature drying modes, or at higher levels for thermal roasting operations.

#### Control System:

The control architecture is designed to achieve a high degree of automation and operational reliability. Core components include a programmable logic controller (PLC), such as the Omron CP1L, a Yaskawa variable frequency drive (VFD) for regulating motor speed, and a human-machine interface (HMI) for real-time monitoring of key process parameters, including temperature, humidity, drying airflow velocity, and material agitation speed. The integration of a VFD not only enables energy-efficient operation but also provides soft-start capability, thereby minimizing mechanical stress and enhancing motor longevity under load conditions.

The conceptual model of the leafy agricultural product roasting system is illustrated in Figure 1.

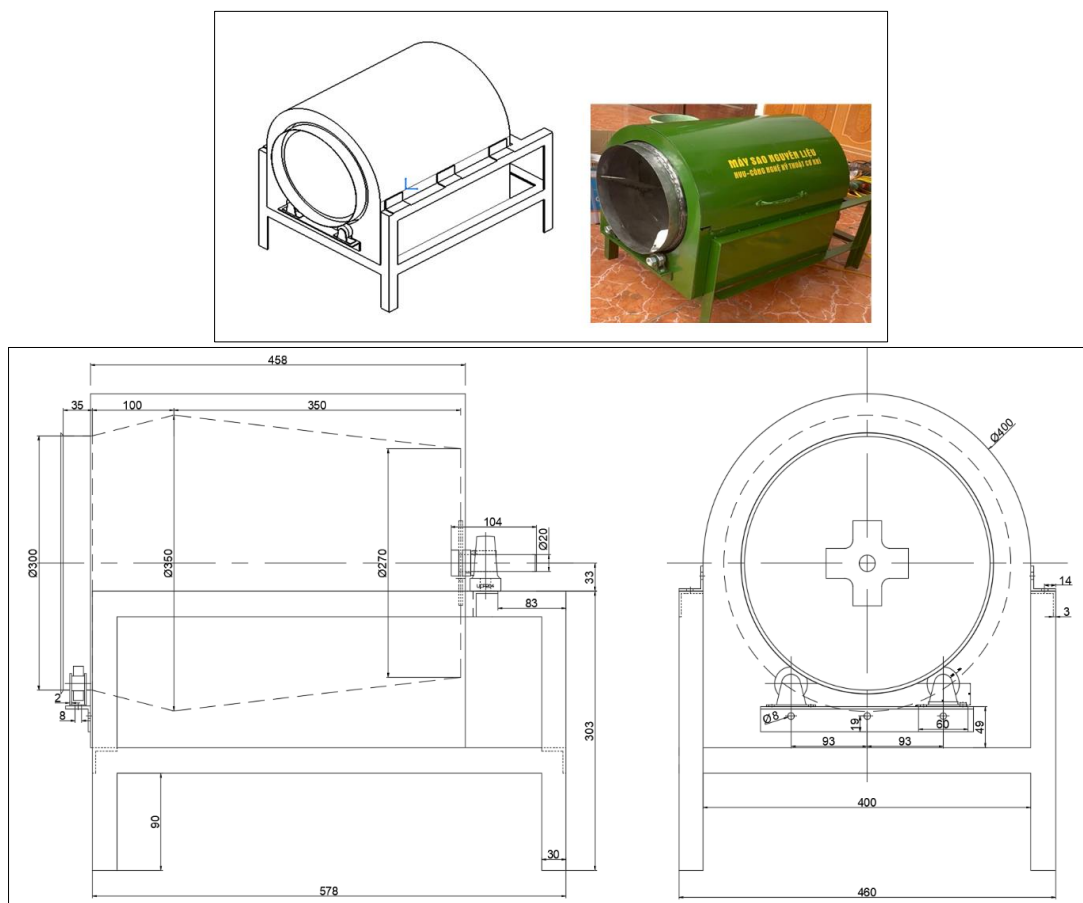


Figure 1: Schematic model of the rotary drum roasting system for processing leafy agricultural products

## 2.2. Operating Principle

The roasting system for leafy agricultural products operates on the synchronized integration of rotary mechanical motion and forced convective heat–mass transfer. The process is governed by a sequence of tightly coupled energy transformations and physical interactions, ensuring both processing efficiency and product quality.

Leafy agricultural materials are introduced into the drying drum through a strategically positioned feed inlet, designed for rapid loading into a chamber with a capacity optimized for household-scale applications. Once the material is loaded and the inlet is securely sealed, the control system is activated to initiate the geared motor. Through a belt transmission mechanism, torque is conveyed to the drum, inducing rotational motion within a variable speed range of approximately 2.5 to 30 rpm, depending on the predefined drying or roasting regime.

Within the rotating drum, the material is continuously lifted by the internal agitation blades and subsequently cascades downward toward the drum's center, forming a loosely dispersed particle curtain. This dynamic motion significantly enhances the effective contact surface area between the leafy material and the drying medium. Concurrently, the drying agent—heated air generated by the thermal system—is introduced into the chamber via an air distribution duct. Thermal energy carried by the hot air stream penetrates the material matrix, supplying the latent heat required for moisture evaporation and thereby intensifying the mass transfer driving force for moisture removal from the cellular structure of the leaves.

Throughout the roasting process, the control unit continuously monitors and regulates key operational parameters, including temperature, drying air velocity, and material agitation speed, based on real-time feedback from temperature sensors (e.g., resistance temperature detectors). The evaporated moisture is extracted by a forced exhaust system and discharged through an outlet duct, maintaining a stable drying environment within the chamber.

Upon reaching the predetermined processing duration or the target moisture content, the heating system is automatically deactivated. For product discharge, the drum is programmed to rotate intermittently and reverse direction, facilitating the

complete and efficient removal of processed material through the discharge outlet.

## 3. RESEARCH METHODOLOGY

### 3.1. Experimental Procedure

Leafy agricultural materials (such as green tea leaves or medicinal herbs) were subjected to preliminary preprocessing, including the removal of impurities, aged foliage, and non-uniform components, to ensure experimental consistency and objectivity. The mass of raw material for each experimental batch was fixed at approximately 2.5 kg, corresponding to the effective working capacity of the designed rotary drum system. Prior to loading, the initial moisture content of the material was accurately determined using dedicated moisture analysis instruments, such as the PM600 moisture analyzer or the TK-25G moisture meter.

The central control system was then activated to stabilize the preset operating parameters, including drying temperature and airflow velocity. Once the roasting chamber reached steady-state thermal conditions, the prepared material was introduced into the drum via the feed inlet. Throughout the roasting process, resistance temperature detectors (RTDs) and thermocouples continuously transmitted real-time data to the control unit, ensuring minimal temperature deviation from the setpoint.

Material samples were periodically collected at hourly intervals to monitor the evolution of moisture content and to conduct direct sensory evaluations. Upon completion of the process, the final product was discharged through the outlet port. This was achieved by programming the drum to rotate intermittently and reverse direction, thereby ensuring complete and efficient material release.

### 3.2. Experimental Design

To optimize the operational parameters of the system, the study employed a Design of Experiments (DOE) approach based on the second-order orthogonal matrix model of Box–Wilson. The principal input variables considered include drying temperature, airflow velocity, and air humidity. The corresponding response variables (objective functions) to be optimized comprise drying time, final moisture content of the material, and product quality indicators, such as sensory attributes or the retention ratio of bioactive compounds.

**Table 1: Input Parameters and Response Variables**

Symbol	Parameter (Influencing Factor)	Unit	Variation Range / Objective
Z1	Drying temperature	°C	30÷40
Z2	Drying air velocity	m/s	3,5÷8,5
Z3	Air relative humidity	%	30÷50
Y1	Drying time	h	To be minimized
Y2	Final material moisture content	%	≤13,5%
Y3	Sensory quality	%	Maximization of bioactive retention

All experimental data were processed using specialized statistical software (SPSS 17.0) to establish regression models describing the relationships among the influencing variables. Each experiment was replicated a minimum of three times to ensure data reliability and reproducibility.

The experimental results indicate that increasing the drying temperature and airflow velocity significantly reduces the drying time. However, these parameters must be carefully controlled to prevent localized overheating, which may adversely affect product quality.

## 4. RESULTS AND DISCUSSION

### 4.1 Analysis of Experimental Design and Optimization Results

Following the experimental runs conducted according to the Box–Wilson response surface methodology matrix, the results indicate that drying time is strongly dependent on key technological parameters, including drying chamber temperature, airflow velocity, and ambient air humidity. Based on statistical processing using SPSS software, a regression model describing the variation of drying time was established. The results reveal an inverse relationship between both drying temperature and airflow velocity with drying time, whereas air humidity exhibits a direct proportional relationship with drying duration.

Through iterative experimental evaluation, the optimal operating conditions were determined as follows:

- Drying air temperature ( $Z_1$ ): 37°C
- Air velocity ( $Z_2$ ): 6.6 m/s
- Drum rotational speed: 2.5 rpm

At these optimal settings, the final product achieved an average moisture content of 13.2%, fully complying with the quality requirements specified in QCVN 01-54:2011/BNNPTNT. The experimental findings confirm that the rotary drum roasting system integrated with an intelligent control architecture operates stably, achieves high moisture removal efficiency, and effectively preserves the intrinsic characteristics of leafy agricultural products, making it highly suitable for household-scale applications.

Thanks to low-temperature process control, the final product retains its natural green coloration, with no evidence of thermal degradation or nutrient loss. For seeds and medicinal plant materials, germination rates or bioactive compound retention reached approximately 89.3% in comparable experiments, demonstrating clear superiority over conventional thermal drying methods.

### 4.2 Evaluation of System Performance

The household-scale rotary drum roasting device demonstrates smooth, stable, and reliable operation. The integration of an intelligent control

system enables automated monitoring and adjustment of process parameters, thereby significantly reducing energy consumption.

Compared to traditional manual processing methods, the system minimizes human intervention, eliminates subjective errors arising from sensory-based judgment, and improves operator safety by reducing exposure to smoke and particulate emissions commonly associated with conventional biomass-fired roasting systems.

The experimental results confirm that the rotary drum roasting system combined with a heat pump or low-temperature thermal system represents an optimal solution for high-quality small-scale agricultural processing.

## 5. CONCLUSION

This study successfully completed the full development cycle, from theoretical calculations and simulation-based design to experimental fabrication of a household-scale rotary drum roasting system for leafy agricultural products. The application of advanced design tools such as SolidWorks and ANSYS enabled optimization of the agitation mechanism and heat distribution system, ensuring both mechanical robustness and thermal performance prior to physical implementation.

Experimental results based on the Box–Wilson design methodology identified the optimal operating parameters as 37°C drying temperature, 6.6 m/s airflow velocity, and 2.5 rpm drum rotational speed.

Under these conditions, the system operates stably and achieves superior dewatering performance. The final processed agricultural products (including green tea, medicinal herbs, and seeds) reached an average moisture content of 13.2%, fully satisfying the stringent quality standards of QCVN 01-54:2011/BNNPTNT. Importantly, the low-temperature control capability allows near-complete preservation of natural coloration and heat-sensitive bioactive compounds, effectively overcoming the localized scorching issues commonly observed in traditional manual roasting systems.

From an economic and social perspective, the device reduces labor demand by more than 40% while achieving significant energy savings through intelligent control and optimized thermal insulation. The use of stainless steel (Inox 304) enhances equipment durability and ensures compliance with food safety standards for household production.

Overall, this system represents a highly applicable engineering solution that contributes to the advancement of high-tech agricultural production and the modernization of post-harvest processing

technologies at the local level. Future development may focus on integrating real-time moisture sensing systems to enable fully automated control, thereby further enhancing product quality and elevating the value of Vietnamese agricultural commodities.

## REFERENCES

- Nguyễn Xuân Thùy, “*Study on the process and equipment for hygienic vegetable drying using a heat pump*” Final scientific report, 2003.
- Võ Mạnh Duy, Lê Chí Hiệp, “*Study on carrot drying using a rotary drum heat pump dryer*”, Journal of Science, Can Tho University, 2011.
- Nguyễn Trọng Các, Đinh Văn Nhượng, “*Research on seed rice drying using a rotary drum heat pump dryer*”, Journal of Science and Technology, University of Da Nang, 2017.
- Nguyễn Tấn Dũng et al., *Cold Drying Systems*, Ho Chi Minh City University of Technology and Education, 2016.
- Đinh Vương Hùng, Phạm Xuân Phương, Nguyễn Xuân Trung, “*Study on garlic drying using a hybrid solar natural convection drying system*”, Hue University Journal of Science, Vol. 71, No. 2, 2012, pp. 153–162.
- Trần Văn Phú, *Drying System Calculation and Design*, Education Publishing House, 2001.
- Phạm Anh Tuấn et al., “*Optimization of garlic drying process using rotary drum heat pump dryer*”, Journal of Science and Technology, Vol. 47, No. 3, 2009, pp. 47–56.
- Nguyễn Cảnh, *Design of Experiments*, Vietnam National University Ho Chi Minh City Publishing House, 1993.
- Hoàng Ngọc Đồng, Lê Minh Trí, “*Experimental model development of a heat pump drying system*”, Journal of Science and Technology, University of Da Nang, No. 4(27), 2008.
- Trịnh Chất, Lê Văn Uyển, *Design and Calculation of Mechanical Transmission Systems* (2 volumes), Science and Technology Publishing House, 2019.
- Nguyễn Hữu Lộc, *Machine Design Fundamentals*, Vietnam National University Ho Chi Minh City Publishing House, 2004.