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Development of An Improved Rotary Paddy Dryer

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Abstract: This article analyzes the structural solutions, energy efficiency, and technological capabilities of existing dryers used for agricultural products, in particular for drying grain and paddy rice. Conventional drying methods are considered the main problem due to their high energy consumption, contamination of the product with exhaust gases, and negative impact on grain quality. Based on this, an energy-saving and environmentally safe combined rotary dryer design is proposed.

In the design process of the dryer, special attention is paid to the efficient use of solar energy, removal of the initial moisture content of the grain by means of a pneumatic dryer, and improvement of grain mixing inside the drum.

Keywords: Paddy rice, agriculture, drying process, rotary grain dryer, solar energy.

Introduction: In recent years, the rapid growth of the world's population has become one of the major socio economic challenges on a global scale. In parallel with the increase in population, the demand for food resources has been steadily rising. As a consequence, there is a growing need to enhance the efficiency of agricultural production and to adopt advanced innovative approaches.

According to statistical data provided by international agricultural organizations, the global volume of paddy rice production in 2024–2025 amounted to 541.3 million tons. The steady increase in paddy production necessitates the improvement of technologies for storage and processing of agricultural products. In particular, special attention is being paid to the development of highly efficient and energy saving combined dryers designed for high quality drying of harvested grain products, including paddy rice.

A large number of scientific studies worldwide are devoted to the rapid, high quality, and economically efficient drying of agricultural crops, especially grain and seeds, including paddy rice, through the development of new types of drying equipment, optimization of their operating parameters, and improvement of drying technologies [2–3]. Improper organization of the paddy drying process, non compliance with drying regimes, and violation of technological requirements lead to a sharp deterioration in rice quality, an increase in the rate of grain breakage and cracking, as well as a decrease in the yield of the final product [4–6]. The drying process is usually carried out in specially designed drying units, where controlling heat and mass transfer processes with due consideration of the biological and physico mechanical properties of the grain is of particular importance. Proper organization of the drying process with regard to the biological characteristics of the grain significantly extends its storage period, preserves consumer and technological quality indicators, and helps reduce storage and processing costs.

The number of scientific studies devoted to the classification of grain drying methods, their division into various categories, and the scientific analysis of the main drying parameters (temperature, moisture content, air velocity, etc.) is increasing year by year. In practice, the most widely used drying methods are convective, contact, and radiation types, and in recent years energy saving drying systems based on their combinations have also been proposed. Each drying method and their combinations have specific advantages and limitations, which directly affect the structural design of dryers, energy efficiency, drying intensity, and product quality indicators [7].

LITERATURE REVIEW

In developing new designs of paddy drying equipment, it is very important to understand their classification, since each dryer employs one or more specific drying methods. Each method has its own advantages and disadvantages, which in turn determine the benefits or limitations of the corresponding equipment. Modern grain dryers, according to the way heat is supplied to the grain being dried, are mainly divided into the following types.

Convective drying is a method in which moisture migrates from the interior of the material particles to the surrounding environment and is removed from the material surface by a drying agent. The movement of moisture inside the product occurs under the influence of a temperature gradient and is associated with the direction of the heat flux, where the effect of thermo moisture conductivity becomes apparent.

Contact drying is a method based on evaporation of moisture due to direct heat transfer between the grain mass and a heated surface, while the heating medium (air or gas) does not interact directly with the grain, but transfers heat indirectly through a heated wall, plate, drum, or other heat transferring element. Because the heat flux in contact drying is relatively high, the drying process is more intensive and its energy consumption can be lower compared with convective drying.

Radiation drying is a method in which grain spread over a certain area under natural conditions is dried by solar radiation and the action of a natural drying agent, with the evaporated moisture discharged into the atmosphere. The thinner the layer of grain spread out, the more efficient the drying process becomes.

Sublimation drying is a highly efficient process based on removing ice phase water from the product by transforming it directly from the solid state to the gaseous (vapor) state without passing through the liquid phase. In this method, the product is first deeply frozen and then kept under low pressure (vacuum) conditions, as a result of which the ice sublimates directly, allowing the structure and nutritional composition of the product to be preserved to the greatest possible extent.

Infrared drying is a method based on heating raw material by infrared radiation and rapidly evaporating moisture within it. In this method, heat mainly penetrates into the inner layers of the product due to radiation, resulting in a high drying rate and good preservation of the natural color, taste, and biologically active compounds of the product.

Taking into account the advantages and disadvantages of the above mentioned drying methods, and based on an analysis of theoretical and experimental studies on grain drying equipment, we propose an energy efficient combined rotary dryer design. The purpose of developing this grain dryer is to enhance the drying process for paddy rice by modifying the dryer structure, thereby increasing energy efficiency, drying quality, intensity, and overall throughput.

METHODS

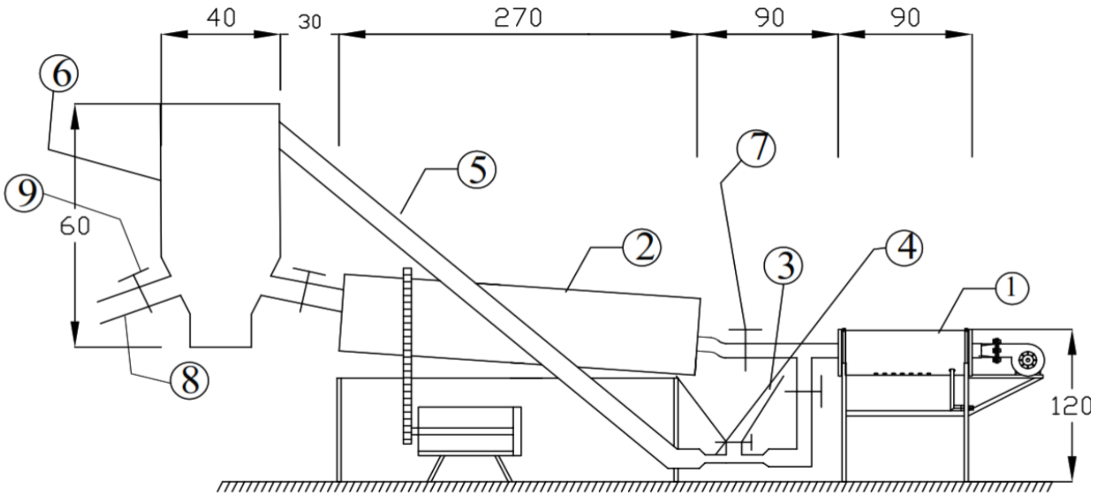
Rotary drum drying is a very complex process due to simultaneous mass and heat transfer, and also a complex movement of particles inside the drum.

Structure and characteristics of the proposed dryer

Below, several drying units are briefly analyzed and a structural variant developed by the authors is proposed.

Biogas-fired rotary drum dryer. In this design, a continuous rotary drum dryer for paddy rice equipped with a thermal unit was developed and tested for grain drying. The dryer is intended for use under farm conditions and represents a 150 kg-capacity prototype. The main advantage of this unit is that its thermal energy is supplied from hybrid sources – conventional LPG and renewable biogas – which improves energy efficiency and environmental sustainability. The drying system consists of three main sections: a thermal unit, a rotary drum drying chamber, and a feeding and separation system (Fig. 1). The thermal unit includes an insulated cylindrical chamber, a gas burner, and an air injector, which together provide a stable temperature field. Using temperature sensors and solenoid valves, automatic switching between LPG and biogas is achieved, ensuring a continuous and reliable drying process.

The rotary drum is installed horizontally with an inclination of 8°, and the efficient mixing and uniform drying of paddy grains are ensured by curved paddles (lifters) arranged spirally along the inner surface of the drum. The rotational speed of the drum is controlled in the range of 5–15 rpm via a gearbox. Hot air is supplied into the drum through a perforated pipe, which promotes uniform distribution of temperature and moisture within the grain mass.



Part No.	Part name	No off	Part No.	Part name	No off
1	Thermal unit	1	6	cyclone	1
2	Rotary drum dryer	1	7	Valves	2
3	In let hopper	1	8	out let	1
4	Vencury system	1	9	slide gate	3
5	Raising pipe				

Figure 1. Detailed drawing of developed rotary dryer.

The dryer consists of a thermal unit, a Venturi lifting device, a cyclone, and a rotary drum dryer, and the process is organized in four stages based on the theory of fluidized beds: initial high temperature drying in the Venturi, "settling" and further moisture removal in the cyclone, main drying inside the drum, and final drying as the product moves towards the discharge hopper. Experimental studies carried out at hot air velocities of 5–12 m/s, feed rates of 50–100 kg per batch, and drum speeds of 5–15 rpm revealed significant changes in drying degree, heat utilization coefficient, overall dryer efficiency, and specific energy consumption per kilogram of product. The main drawbacks of this solar dryer are as follows: the complexity of the dryer design requires skilled technical personnel for proper adjustment and operation; dependence on gaseous fuel as the primary heat source remains; and although biogas can potentially be used, its continuous and reliable production is not always guaranteed, which may adversely affect the continuity of the drying process.

A combined radio-frequency paddy drying system. This drying system is based on a hybrid technology that integrates hot air and radio frequency (RF) heating for large scale industrial drying of paddy rice (Fig. 2). In this approach, paddy is first dried in a continuous flow hot air dryer at stepwise temperature levels, typically reduced from 80 °C down to 50 °C depending on the moisture content, and then continuously conveyed through an RF chamber, where additional heating in the range of 38–50 °C is applied to the grain kernels by means of deeply penetrating dielectric heating.

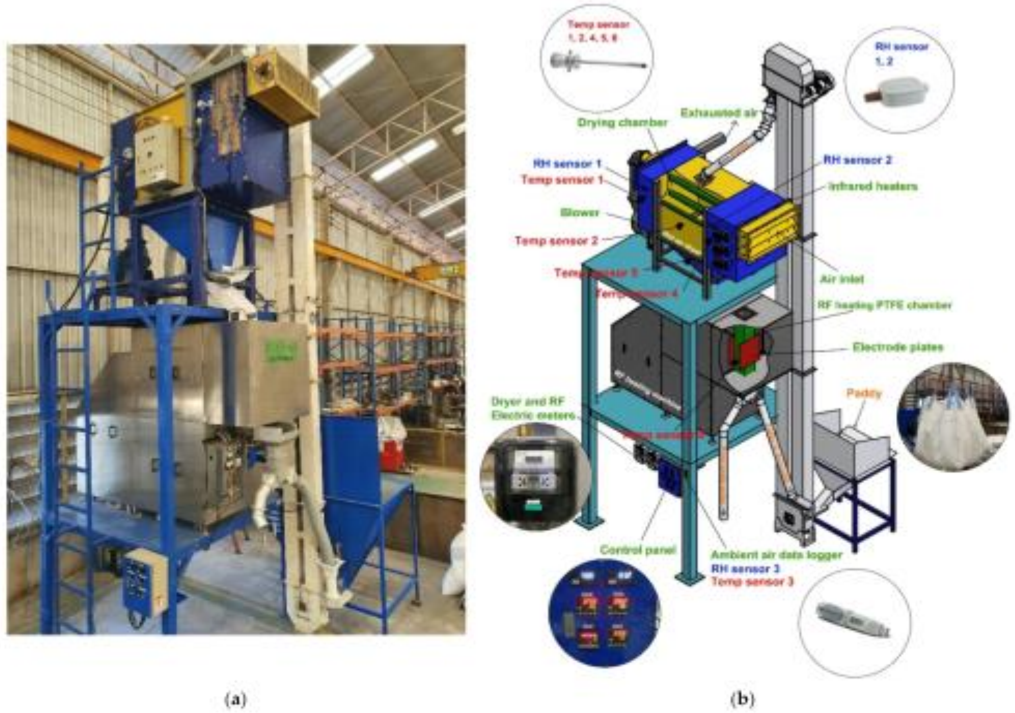


Figure 2. The industrial-scale continuous-flow hot-air dryer with RF heating machine: (a) prototypemachine (b) schematic diagram.

Such a combination improves the distribution of heat from the inside to the outside of the kernels, accelerates the migration of moisture from the kernel interior to the outer surface, and shortens the overall drying time, while at the same time reducing grain fissuring and breakage and thus helping to maintain the overall quality of milled rice. In experiments carried out with this dryer, a randomized complete block design was employed to test different RF temperatures and hot air regimes, and the optimal operating conditions were determined based on the milling and cooking quality of milled rice and its organoleptic properties. The main drawbacks of this combined RF paddy drying system are the complexity of the construction, which makes adjustment and maintenance difficult, and the need for continuous monitoring of voltage and grain temperature in the RF system, which in turn requires sophisticated automatic control and skilled operators.

A perforated drum combined solar energy dryer. The solar drum dryer considered in this study consists of a two-section drum (a stationary outer cylinder and a rotating inner perforated drum) and a porous-plate solar collector. The air heated by the collector is supplied to the inner drum using a centrifugal fan (Fig. 3).

The geometric dimensions of the collector and the thermophysical properties of the glazed cover were selected to minimize heat losses and to ensure a uniform distribution of airflow velocity across the absorber surface. Experimental studies conducted at drum rotational speeds ranging from 0.21 to 0.84 rpm, drum inclination angles of 1–2°, and corresponding airflow velocities demonstrated the existence of optimal operating conditions. Under these conditions, paddy can be dried to approximately 10% moisture content, the residence time of the material inside the drum can be effectively controlled, and the proportion of cracked grains can be reduced [14].

These results confirm that, with appropriate selection of drum geometry and operating parameters, solar drum dryers represent a promising technological solution for reducing energy consumption, lowering labor costs, and improving the final rice quality [12].

However, the proposed perforated drum combined solar-energy dryer has several limitations. The drying process slows down or stops under cloudy or rainy conditions, as well as during nighttime operation. In addition, the maximum loading capacity of the investigated dryer is about 10 kg, which requires more time and multiple units for drying large volumes of harvest.

Furthermore, due to the presence of a dual-drum system, a perforated inner drum, a solar collector, and a fan system, the overall design and manufacturing of the device are relatively complex.

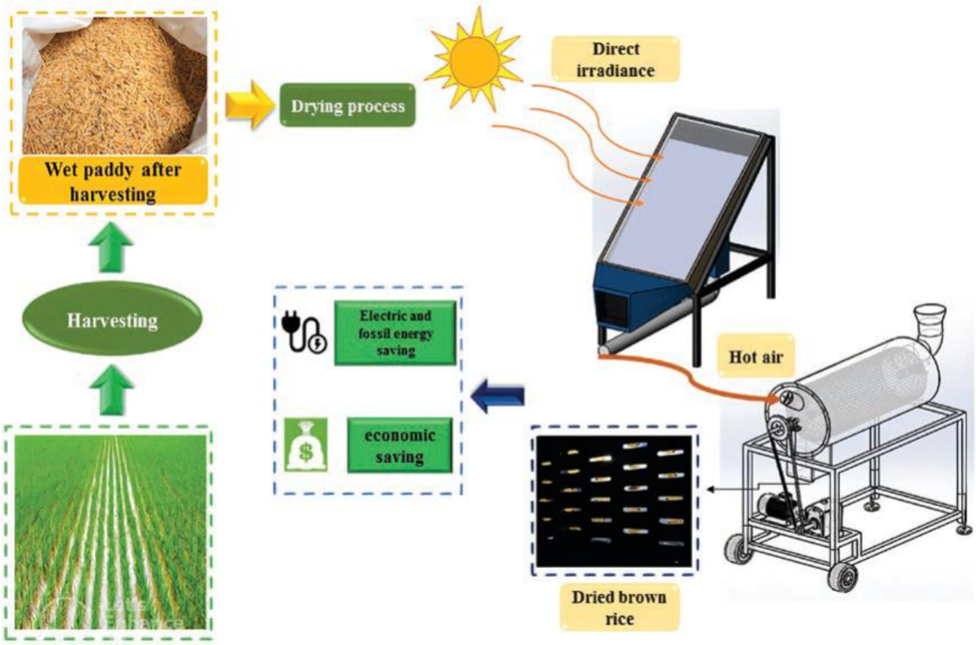


Figure 3. Combined perforated drum solar dryer.

Building on the advantages of the above mentioned dryers while addressing their shortcomings, an improved energy efficient rotary dryer for paddy rice was developed. In this design, rotary drum and pneumatic dryers are combined, with structural modifications introduced to increase capacity and drying intensity, additional use of solar thermal energy, and implementation as a laboratory scale experimental setup for the drying process (Fig. 4).

The proposed dryer consists of an outer rotating drum and a pneumatic dryer feeding the drum; the drum inclination angle is 3–5°, its length is 1200 mm, diameter 400 mm, the maximum dryer capacity is 17 kg of grain, and the hourly throughput is 60–90 kg/h. The drum rotational speed is designed to be controllable, while the thermal energy required for drying is supplied via a solar absorber plate.

It was found that the drum diameter is the main geometrical parameter affecting particle motion, and that the ratio between particle diameter and drum diameter varies with the drum diameter. The results also showed that, in order to reach a given final moisture content, a longer drum is recommended so that the slope and rotational speed of the inner drum can be increased accordingly.

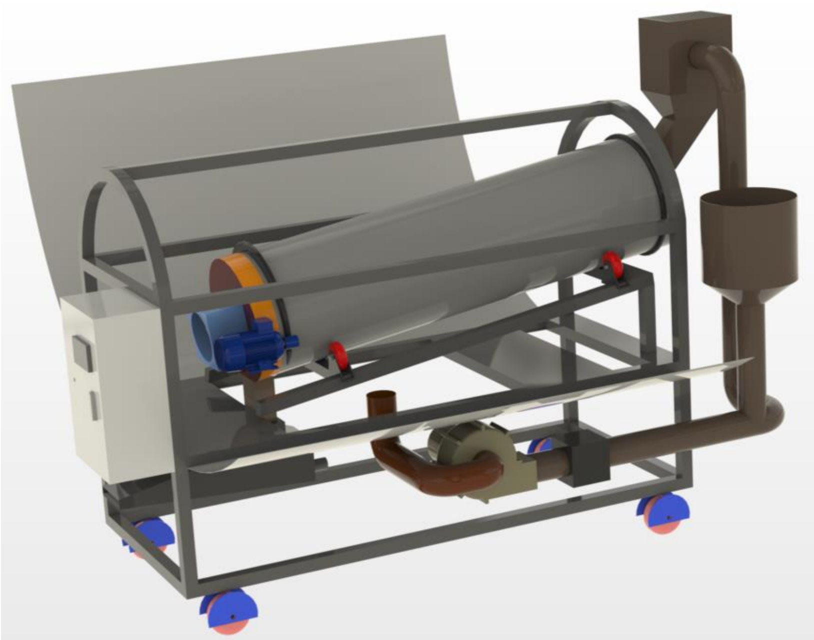


Figure 4. Improved drum-type rice (paddy) drying device.

In the proposed dryer, the grain is dried in three successive stages. In the first stage, preliminary drying is carried out in a pneumatic dryer, where the particles are entrained by a stream of hot air and remain in a suspended state, which provides intensive removal of surface moisture and a short residence time. In the second stage, the main drying process takes place in a rotary drum dryer, in which the grain layer is repeatedly lifted and cascaded by internal flights, ensuring good mixing and a high rate of heat and mass transfer along the length of the drum. In the final stage, drying and cooling are completed in a fluidized bed unit, where the product is fluidized by an upward flow of air, resulting in uniform temperature and moisture distribution and preventing thermal damage to the kernels.

The rotary drum, its drive motor and the electric air heater are completely installed inside the solar collector, which reduces heat losses to the environment and allows more efficient utilization of the collected solar thermal energy. The electric heater is positioned near the grain outlet end of the drum so that the highest air temperature is provided at the point of lowest product moisture content, thereby reducing the risk of overheating wet grain at the inlet. Inside the drum, the flights are rigidly fixed to the inner shell and rotate together with it, lifting and showering the material through the heated air stream and thus increasing the effective contact surface area between air and particles. A parabolic trough type reflector, mounted in a cut out configuration in front of the solar collector, directs the incident solar radiation onto the absorber surface while avoiding shading of the collector aperture, which leads to higher air heating efficiency under field conditions.

DISCUSSION

The analyses show that, under optimal technological conditions, the drying rate increases, the specific energy consumption decreases, and the physico chemical and technological quality indicators of the grain are improved. These results confirm that the proposed drying regime provides a better balance between heat and mass transfer, so that moisture removal is intensified while thermal damage to the kernels is minimized.

Compared with conventional drying methods, the proposed combined dryer is more economical due to the partial substitution of fossil fuel based heat with solar thermal energy and the more efficient utilization of the supplied air, which together lead to lower specific energy consumption and operating costs. In addition, the three stage configuration (pneumatic pre drying, rotary drum main drying and fluidized bed final drying and cooling) enables better control of the drying kinetics, resulting in more uniform moisture distribution and improved physical integrity of the grains.

The experimental observations also indicate that the use of the pneumatic pre dryer to remove surface moisture reduces the load on the rotary drum and shortens the required residence time in the main drying zone. As a consequence, the exposure of the grain to elevated temperatures is reduced, which is beneficial for preserving germination capacity and technological properties such as milling and cooking quality.

Thus, the improved rotary paddy dryer makes it possible to significantly increase the drying rate and throughput, enhance drying quality and utilize solar thermal energy more efficiently, thereby further improving the overall energy efficiency of the system. These findings suggest that the developed dryer represents a promising technological solution for application under agricultural conditions, especially in regions with high solar irradiation and limited access to conventional energy sources.

CONCLUSION

In this study, an aerodynamic three stage solar dryer for grain was conceptually designed and analyzed based on mathematical modelling and engineering calculations. The proposed configuration combines pneumatic pre drying, rotary drum main drying and fluidized bed final drying, and integrates the rotary drum, air heater and drive system inside a solar collector with a parabolic trough reflector to enhance solar energy utilization.

The calculation results indicate that, under optimal technological conditions, the drying rate can be increased, the specific energy consumption reduced and the physico chemical quality of the dried grain improved compared with conventional dryers. These findings suggest that the proposed combined dryer has the potential to be an energy efficient technological solution for agricultural grain drying; however, experimental validation on a laboratory or pilot scale prototype is required in future work to confirm the predicted performance under real operating conditions.

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