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Analysis of Quality Differences between Natural Sun-drying and Mechanical Drying of Rice under Farmer Conditions

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Abstract After the rice is harvested, reducing its moisture content has always been a problem that farmers cannot avoid. The common methods are spreading it out to dry in the sun or using a dryer. Both methods have their own drawbacks: when the weather is good, sun-drying saves electricity and money, but in case of rain or overcast days, the risk of moisture return and mold increases, and the quality is not very stable. In contrast, mechanical drying is faster and more uniform in removing moisture, resulting in a higher proportion of whole grains, less broken grains, and better stickiness and elasticity of the cooked rice. However, excessive high temperatures should not be pursued as it may increase the fatty acid value and affect the taste. From a cost perspective, although mechanical drying is more efficient, it consumes more energy, and may not be cost-effective for small-scale farmers. In practice, it is necessary to consider one's own conditions, avoid overly high temperatures, and frequently turn the rice when sun-drying to ensure both efficiency and quality.
Keywords Rice drying; Natural sun-drying; Mechanical drying; Quality evaluation; Sensory quality

1 Introduction

When it comes to food crops, rice has always held a significant position in China. However, after the rice is harvested, it is not just a matter of storing it in the barn. If the moisture content is not reduced, there will be many problems later on (Zhou et al., 2019). In the past, in many places, the rice was spread out in the fields to dry slowly, relying on the sun and wind to remove the moisture. This method was simple and required little investment. But in recent years, with the increase in agricultural machinery and the more centralized circulation of grain, mechanical drying has gradually become popular (Li et al., 2021). When comparing the two methods, their effects are not the same, and their impacts on the quality of rice are also different. Many farmers are hesitant in actual production as to whether to continue sun-drying or use a dryer.

Many studies have pointed out that mechanical drying has an advantage in efficiency, and the dehydration process is relatively uniform (Zhang et al., 2018). The whole grain rate is often higher, and the occurrence of mold and cracked grains is less. On the contrary, sun-drying has low investment and simple operation, but it is easily affected by weather changes, with uneven moisture content and unstable quality. Some people compare sun-drying, air-drying and mechanical drying together, and the results generally favor mechanical drying (Liu et al., 2022). However, most of these studies focus on only one or two indicators, and pay insufficient attention to the physical condition, physicochemical changes and eating quality of rice, so the overall evaluation is still insufficient.

This study focused on two common practices of farmers - sun drying and mechanical drying, and the conditions were designed to be as close to actual production as possible. Besides observing the intuitive indicators such as moisture content, whole polished rice rate, and broken rice rate, the study also measured the physical and chemical changes such as starch, protein, and fatty acids, and compared the texture of the cooked rice. By comparing from multiple aspects, it was not only to distinguish the superiority but also to clarify under what conditions it would be more appropriate. At the same time, the cost and ease of use were also taken into consideration. The hope is to provide farmers with more references when choosing the drying method, minimize post-harvest losses, and stabilize the quality of the rice.

2 Overview of Drying Methods for Rice under Two Farmer Conditions

2.1 Operation process and typical characteristics of natural drying

In many farmers, the drying of rice still relies on the old method - natural drying (Hwang et al., 2016). When the weather is good, spread the threshed rice on the open ground, not too thick, and flip it a few times during the day, slowly drying off the moisture with the sun. This study simulated this habit by spreading about 500 kg of rice with a thickness of about 0.04 m, flipping it at regular intervals, and covering it when needed. Drying requires almost no energy and has low investment, but the problem is also very obvious. Once it rains or at night, dew is prone to regain moisture, and if it is laid thick, it is not breathable. In addition, dust and debris are mixed in, which inevitably affects the quality (Figure 1) (Müller et al., 2022). Overall, this method saves money and effort, but has a long cycle, low efficiency, and poor stability.

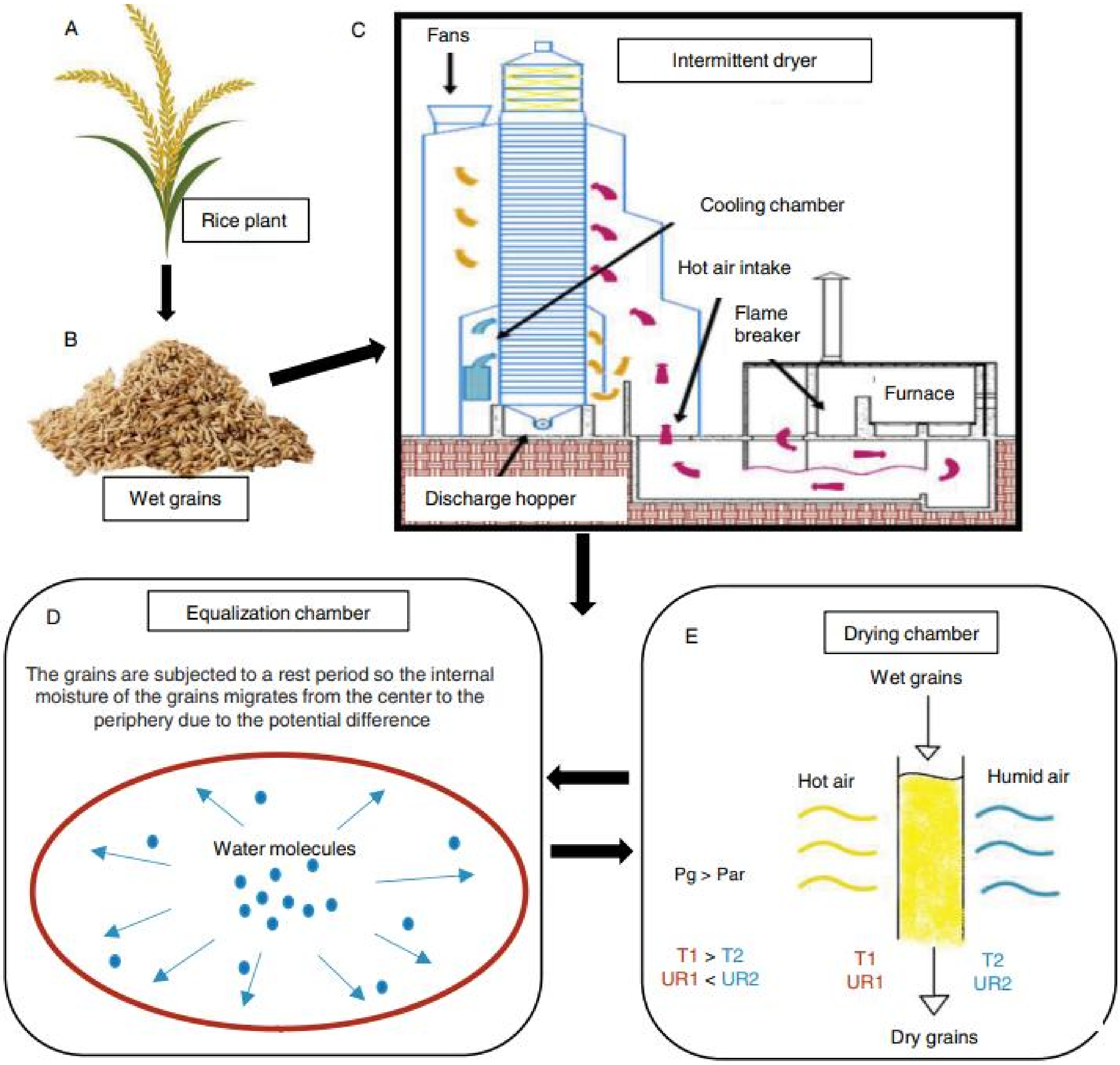

Figure 1 Drying process in rice grains (Adopted from Müller et al., 2022)

Image caption: A, Start drying in rice plant. B, Need to immediately subject the rice grains to drying. C, Intermittent dryer. The intermittent dryer consists of two chambers, one for drying and the other for equalization. D, Procedure in the equalization chamber. E, Procedure in the drying chamber. Pg, Grain vapor pressure; Par, Air vapor pressure; T1, Exhaust air temperature; T2, Inlet air temperature; UR1, Exhaust air relative humidity; UR2, Inlet air relative humidity (Adopted from Müller et al., 2022)

2.2 Types and operating modes of mechanical drying

The method of mechanical drying involves using hot air to gradually remove the moisture from the rice grains (Chen et al., 2017). Commonly used equipment for farmers includes flat-bed type and tower type. There are options using coal, gas, or electricity. Small-scale grain producers mostly use intermittent operation, processing one batch at a time; larger grain processing centers tend to adopt continuous operation, with a larger processing capacity. This study selected a circulating flat-bed dryer. The temperature is controlled at around 45 ℃, and the drying stops when the moisture content drops to 14.5%. This method does not depend on weather conditions, dries quickly, and saves manpower. However, the investment in equipment and energy consumption is considerable. If the temperature is not controlled properly, it may also affect the quality of the rice (Wang et al., 2020).

2.3 Realistic constraints for farmers' choice of different drying methods

In actual production, farmers do not first consider which method is "more advanced", but rather they first assess whether they can afford it (Peng et al., 2018). Once the funds and conditions are laid out, the choice usually becomes clear. Drying in the sun costs almost nothing, so small-scale farmers are more likely to use it, but this method is highly dependent on the weather. The thickness of the drying layer and the number of times it is turned must be closely monitored. In the event of continuous rain or nighttime temperature drops, moisture absorption and mold growth are prone to occur. Mechanical drying saves time and effort and is not affected by the weather. However, the equipment, energy consumption and maintenance are real costs.

Larger-scale growers or cooperatives usually choose to build drying centers or purchase services to handle moisture quickly; while small-scale farmers still prefer to dry in the sun or leave the crops in the shed to dry (Zhao et al., 2020). Additionally, due to different subsidy policies and service conditions, the judgment also changes accordingly. In the end, it is a balancing act between the amount of money spent, the speed of work and the quality of the product.

3 Effects of Drying Methods on the Physical Quality of Rice

3.1 Characteristics of moisture content changes and comparison of stability

In the end, drying is judged by how quickly and steadily the moisture content decreases (Yang et al., 2019). By comparing, it can be found that during mechanical drying, the moisture content decreases relatively evenly, with a smooth curve change, and the external environment has little impact on it. Natural drying is not as "obedient", as the temperature, humidity, and sunlight change, the moisture content also fluctuates accordingly.

For two samples with moisture contents of 24.4% and 18.7%, the mechanical drying side basically shows a steady decrease; while the drying group experienced rehumidification during nighttime cooling or rainfall, and the data fluctuated significantly (Phanphanich and Mani, 2017). When hot air is continuously supplied, the drying rhythm is relatively controllable, but for natural drying, it needs to rely on frequent turning over and timely rain protection to compensate for the interference caused by the weather; otherwise, the efficiency and stability cannot be guaranteed.

3.2 Analysis of the differences between whole-grain rice rate and broken rice rate

When evaluating the drying effect, the whole-grain rice rate is often the most intuitive (Siebenmorgen et al., 2014). After controlling the final moisture content at the same level in the experiment, the differences between the two methods became apparent. For example, for rice with an initial moisture content of 32.6%, the whole-grain rice rate after mechanical drying could reach 85.6%, while that after sun-drying was only 72.2%, and the broken rice was significantly more. The same is true for the burst-waist phenomenon.

Under high moisture conditions, the burst-waist rate after sun-drying was close to 11%, while that after mechanical drying was only about 5%; at a moisture content of 24.4%, the burst-waist rate after sun-drying was still around 3%, while that after mechanical drying was less than 1% (Figure 2) (Liao et al., 2020). This difference is mostly related to whether the drying process is stable. The temperature in mechanical drying is controlled, and the stress change is small; while sun-drying is repeatedly exposed to moisture and then dried, cracks are more likely to form, ultimately affecting the quality and yield of the rice.

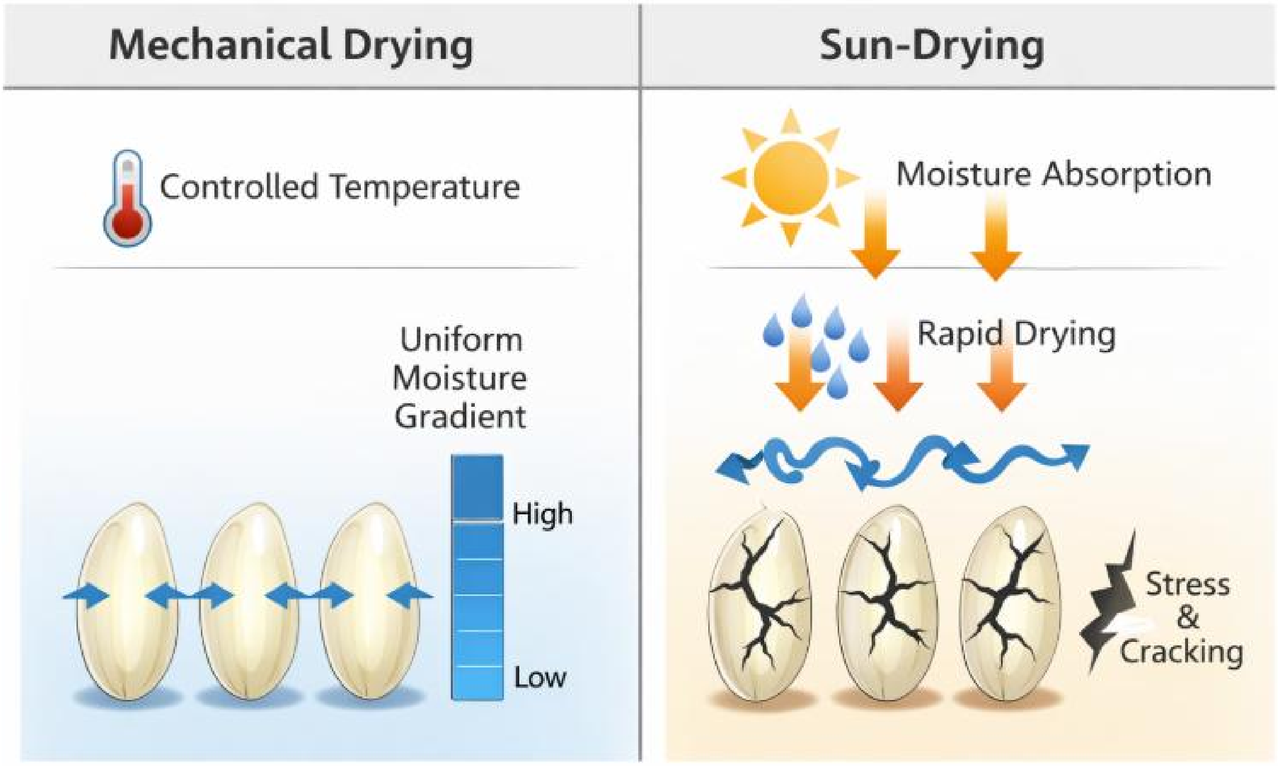

Figure 2 Schematic illustration of the drying mechanisms affecting rice grain integrity. Mechanical drying maintains stable conditions, while sun-drying induces repeated moisture fluctuations that lead to internal stress and cracking (Adopted from Liao et al., 2020)

3.3 Granular integrity and appearance quality changes

It's not just about whether the grains are broken or not; the appearance is also crucial (Zhang et al., 2018). Compared with other methods, the rice after mechanical drying has a whiter color, the grains look fuller, and there are fewer yellow grains and defective grains. For example, for a sample with an initial moisture content of 24.4%, the yellow grain rate after mechanical drying is only 0.05%, while it can reach 0.45% under sun-drying conditions. Problems such as immature grains and moldy grains are also relatively rare after mechanical processing.

Sun-drying is prone to being overly dry on one side and then getting damp again, causing the grain surface to wrinkle, develop mold spots, and even get dust and impurities attached, thus affecting the appearance grade (Liu et al., 2021). This is actually related to the previous situation of a higher burst waist rate. Overall, mechanical drying is more likely to maintain the uniformity and integrity of the grains, while the unevenness and contamination brought about during sun-drying will also be reflected in the appearance.

4 Effects of Drying Methods on the Physicochemical Quality of Rice

4.1 Changes in starch structure and gelatinization properties

Many people believe that the texture of rice is merely a matter of variety. In fact, the temperature during the drying process is equally crucial (Zhou et al., 2017). If the temperature is set too high, the internal structure of the starch is prone to be disrupted, resulting in an increase in amylopectin and a different final cooking state. This is particularly evident when drying at high temperatures. However, in this test, as long as the temperature is properly controlled, mechanical drying performed quite well.

For example, for a sample with a moisture content of 24.4%, the initial gelatinization temperature after drying was lower, the peak viscosity was the highest, and the gelatinization temperature was approximately 67.4°C. The rice cooked with this sample expanded more easily and was more moist and smooth. On the other hand, for the samples dried by sun exposure, the gelatinization temperature moved upward and the viscosity decreased, resulting in a poorer performance (Li et al., 2020). Overall, mechanical drying with controllable temperature is more likely to stabilize the starch state while removing moisture, and the taste is naturally not compromised.

4.2 Response differences of protein and lipid-related indicators

During drying, the nutritional components are not completely unchanged (Zhang et al., 2019). The total protein content seems to remain relatively stable, which is consistent in both the experiments and previous data. However, when the temperature is higher, the fatty acid value often increases. The reason is not complicated; high temperature makes lipolytic enzymes more active, and some fats are decomposed into free fatty acids. With a larger quantity, the rice grains are more prone to deterioration and may even produce substances with an unpleasant smell. In this study, the samples dried at high temperature and stored showed significantly higher fatty acid values than the low-temperature treatment group, and the degree of oil oxidation was also more severe.

Although the protein content difference was not obvious, its structure may have changed. From this, it can be seen that temperature control cannot be ignored. Lowering the temperature is more conducive to maintaining quality, while excessively high temperature will instead affect the taste (Liu et al., 2021).

4.3 The mechanism of the effects of drying temperature and rate on physicochemical properties

Many people think that drying means removing water. In fact, once the temperature and speed increase, changes have already occurred inside the grains (Zhou et al., 2017). It's not just about losing water on the surface; under high temperatures, starch granules will be disrupted, short-chain molecules will increase, and the gelatinization temperature and viscosity curve will shift accordingly. Sometimes the problem doesn't stop there; proteins will also denature under high temperatures and combine with starch.

Once this structure is formed, the starch's ability to absorb water and expand is limited, and the gelatinization performance naturally weakens. After long-term high-temperature treatment, the phenomenon of decreased viscosity and retrogradation value is also common (Li et al., 2020). If drying is only focused on speed, these changes are easily overlooked. Therefore, methods such as staged heating and slow cooling are actually more conducive to balancing efficiency and taste.

5 Effects of Drying Methods on Eating Quality and Sensory Characteristics

5.1 Differences in texture and taste of rice

Many people only realize the impact of the drying method when they taste the rice (Li et al., 2020). Comparing the data would be more intuitive. The mechanically dried samples performed better in terms of viscosity and stability. Taking rice with a moisture content of 24.4% as an example, the peak viscosity and disintegration value after drying were both higher. The cooked rice was sticky but not greasy, and had elasticity. The values of the samples dried in the sun were significantly lower, and the taste was thus more loose (Zhang et al., 2018).

The sensory scoring was actually not off track. The rice dried mechanically and those left in the shed were more recognized in terms of appearance and flavor. The sun-dried group often ranked lower. Overall, mechanical drying is more likely to retain the glutinous aroma and elasticity, while during the sun-drying process, the rice becomes harder and its stickiness decreases more frequently.

5.2 Preservation of aroma and flavour changes characteristics

Often, the rice aroma is subtly altered during the drying process (Figure 3) (Tan et al., 2025). The aroma of rice is inherently fragile and can easily deteriorate over time and in an uncontrolled environment. In experiments, it can be observed that mechanical drying with stable temperature control is more likely to preserve the original aroma; while prolonged sun-drying not only leads to a loss of aroma but may also introduce off-flavors.

In sensory scoring, the sun-dried group had the lowest flavor score, which is related to exposure to dust, pollutants, and excessive water loss (Pang et al., 2021). In contrast, samples treated with mechanical drying and proper storage in sheds had cleaner and more natural aromas, and received higher overall evaluations. From this perspective of smell, mechanical drying truly has an advantage.

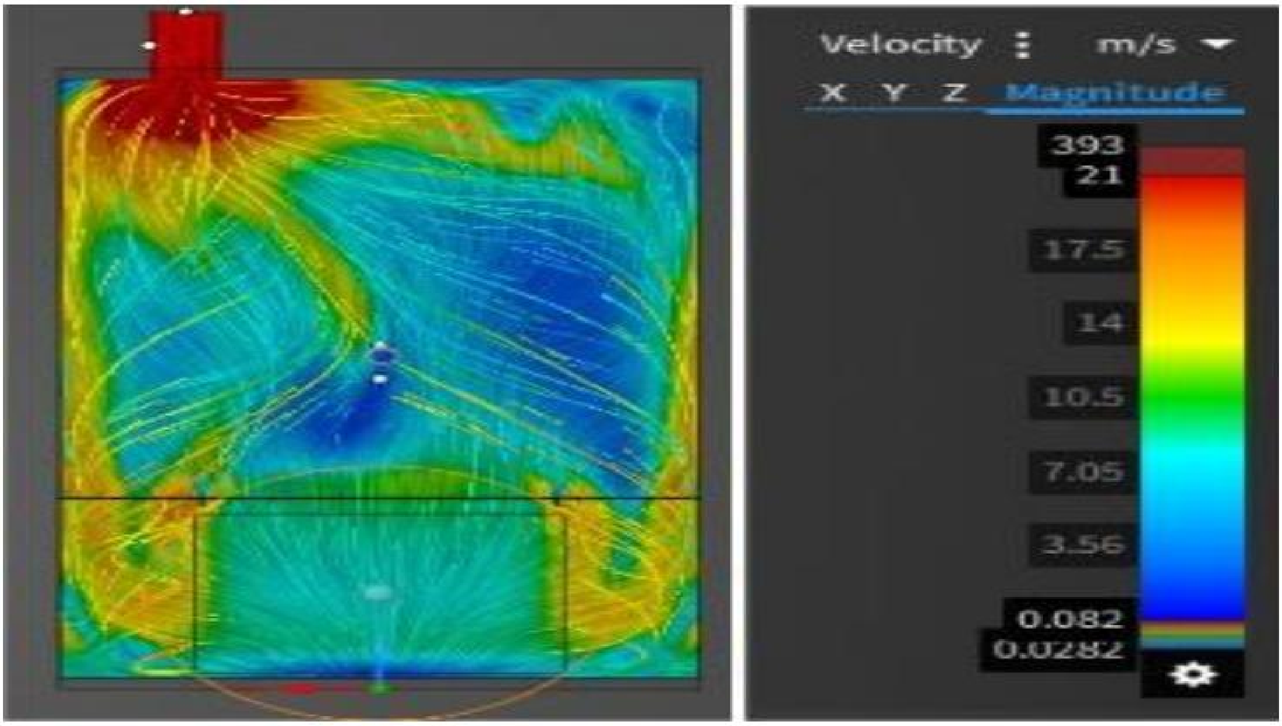

Figure 3 Simulation of airflow inside the drying chamber (Adopted from Tan et al., 2025)

5.3 Comprehensive comparison of sensory evaluation results

Just looking at the data might not be enough to get a clear picture. But when the test results and tasting experiences are compared together, it becomes very clear (Li et al., 2020). The samples that were mechanically dried had a clear advantage in terms of elasticity, taste, and flavor, and their overall performance was relatively stable, not much different from the ideal state of leaving the plants in the shed until harvest. On the other hand, the sun-drying group had lower scores in terms of appearance, aroma, and taste, and the difference could be felt clearly when eating (Pang et al., 2021).

Of course, leaving the plants in the shed until harvest has good quality, but it comes with high risks and the yield may not be guaranteed. In contrast, harvesting at an appropriate moisture level and then using mechanical drying to stabilize the quality is often more realistic and easier to balance efficiency and quality.

6 Analysis of Economic and Applicability of Drying Methods

6.1 Comparison of energy consumption and cost input

If we only consider electricity and fuel consumption, drying by sun exposure requires almost no energy (Sarker et al., 2019). This is why many farmers have been using this method. All they need to do is spread and turn the grain manually. Mechanical drying is different. Electricity and fuel costs are unavoidable expenses. However, the situation is changing. After equipment is updated, the energy consumption is not as high as expected. For example, after replacing fuel with heat pumps, the overall consumption can be reduced, and some money can be saved in a year (Zhou et al., 2021).

The initial investment is indeed larger, but methods like waste heat recovery gradually lower the unit energy consumption. Small-scale farmers are more concerned about spending less money. Drying grain by the sun has almost zero energy consumption. While for large-scale drying centers, they usually calculate the equipment investment, operating costs and efficiency together. It's not easy to determine whether it's cost-effective or not, as it depends on the overall configuration.

6.2 Analysis of drying efficiency and production risks

When it comes to speed, many farmers actually have a clear idea in their minds (Sarker et al., 2019). No matter how skilled they are in the process of drying, they still have to take into account the weather conditions.

Sometimes it can be quick, but when it rains, they can only wait. When the rice piles up, problems such as moisture absorption and temperature rise occur, and the risks of mold and germination also increase. The mechanical drying method takes a different approach.

Once the equipment is turned on, it can operate continuously day and night. With multiple machines connected, it's not uncommon to process hundreds of tons of rice in a day (Zhou et al., 2021). The cycle is naturally shortened. Temperature control and ventilation keep the uncertainty of the weather outside, but one must not be careless either. Equipment failures or temperature out-of-control can also affect the quality. Overall, the efficiency advantage lies with the mechanical drying method, but this is only true if it is operated properly.

6.3 Selection of appropriate drying methods for different-sized farmers

The drying methods for farmers of different scales do not necessarily have to be the same (Peng et al., 2018). Small-scale farmers with limited funds often prefer open-air drying on the ground, but they need to be more meticulous in management, controlling the thickness of the drying layer, frequently turning it over, and withdrawing it in advance in case of rain. Larger-scale growers or cooperatives are more suitable for building or using professional drying equipment, for centralized processing and unified control.

They can stabilize the quality by using measures such as pre-heating and slow cooling. The government and cooperatives can also establish public drying platforms and provide technical guidance, so that small-scale farmers no longer rely solely on natural drying but gradually adopt semi-mechanized methods to reduce losses (Figure 4) (Zhao et al., 2020). In the end, the choice depends on one's own conditions. The scale should be appropriate, the method should be suitable, and cost and quality can be balanced.

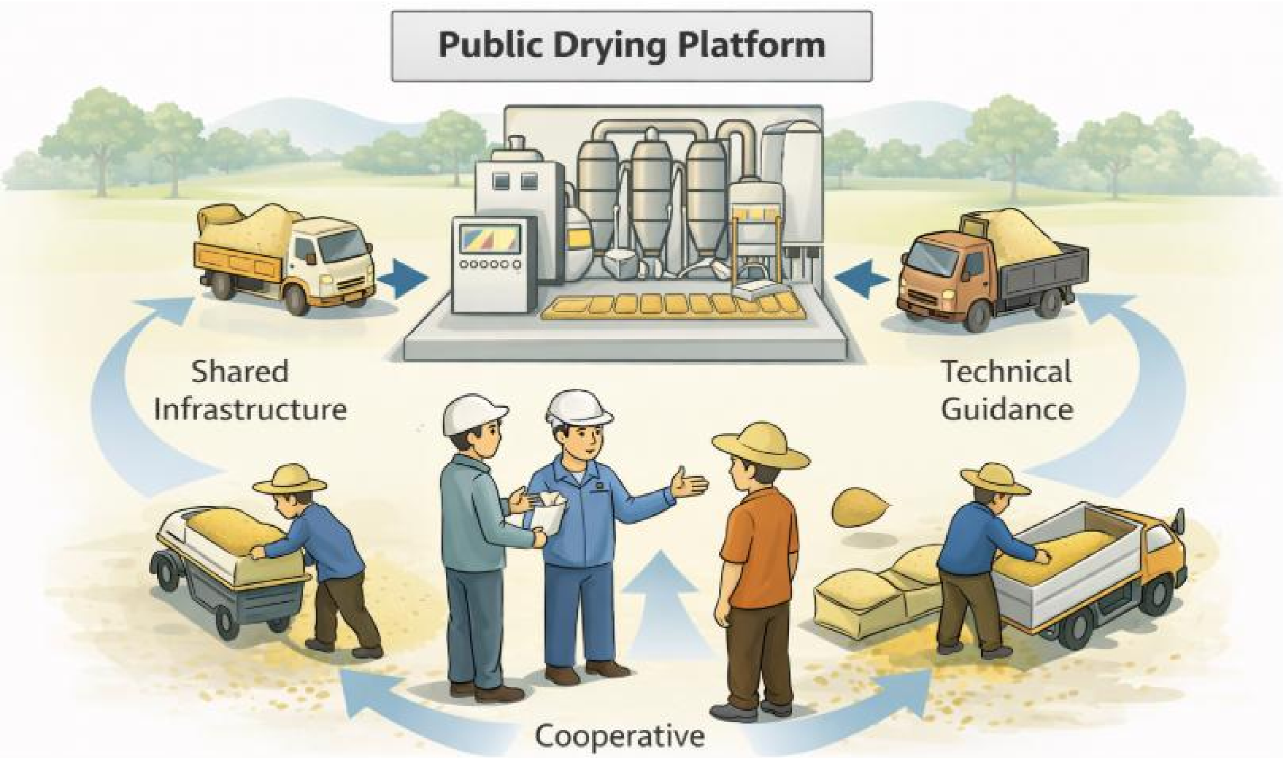

Figure 4 Schematic illustration of public drying platforms and cooperative support systems that facilitate access to drying technology for small-scale farmers, reducing reliance on traditional sun-drying methods (Adopted from Zhao et al., 2020)

7 Case Study: Comparison of Natural Drying and Mechanical Drying under Typical Farmer Conditions

To better illustrate the differences, this study created a hypothetical scenario of a southern rice-growing area and conducted simulations based on common practices (Liao et al., 2020). The local climate was humid and hot. Farmer A chose traditional drying, spreading the rice on the cement floor of the courtyard, about 0.05 meters thick, and turning it twice a day; Farmer B sent the rice to the cooperative and used 45°C low-temperature hot air to dry it. Both methods dried the rice to a moisture content of 14% before comparison.

The results were clear: the whole-grain rice yield of the drying method was only 78%, with a broken rice rate of 12%, and the rice was relatively hard; while the mechanical drying method increased the whole-grain rice yield to 88%, the broken rice rate dropped to 5%, and the taste was more elastic and glutinous (Wang et al., 2020). In terms of efficiency, the processing time for one ton of rice by group B was only one-fiftieth of that of group A. The grain temperature was more uniform, and moldiness was also less. This case demonstrates that in high-temperature and high-humidity conditions, mechanical drying has an advantage.

8 Conclusions and Recommendations

Based on the common practices of farmers, namely sun-drying and mechanical drying, this paper compared the changes in rice quality. From the results, it can be seen that mechanical drying is faster and more uniform in reducing moisture content. When the moisture content is approximately 24%, the whole polished rice yield can exceed 92%, and the broken rice rate is close to 1%. At the same time, problems such as yellow grains and burst kernels have significantly decreased, and the appearance has become more stable. However, higher temperature is not always better. Although high temperature speeds up the process, it is prone to increase the fatty acid value and disrupt the internal structure. In the taste test, the mechanical-dried rice has better viscosity and elasticity, and the aroma is retained more fully. Overall, using mechanical drying under an appropriate moisture content is more likely to achieve a balance between efficiency and quality, and has more advantages over simple sun-drying.

Based on the previous results, there are several key points to pay special attention to in the operation. The harvesting time of the rice should not be too early or too late. Due to different initial moisture contents, the subsequent drying parameters also need to be adjusted. The critical temperature is not fixed. When using mechanical drying, it is advisable to adopt a segmented temperature increase or intermittent ventilation method. Don't raise the temperature too quickly at once; when the moisture content drops below 20%, the heat risk should be controlled at 45-50°C and maintained for 20-30 hours, which will result in relatively more stable efficiency and quality. If you choose to dry in the sun, the layer should be thin and uniform, and it should be frequently turned over. Cover in time when encountering moisture, and try to avoid rainy days. You can also stagger the batches with neighboring farmers. If conditions permit, small-scale drying equipment or renting socialized services can also be chosen. Combined with the agricultural machinery subsidy policy, the cost pressure can be significantly reduced.

It should be noted that the analysis in this article is mainly based on hypothetical scenarios and experimental results. More on-site verification is still lacking, and the conclusions may vary under different rice varieties and climatic conditions. Future research can expand the scope and conduct field trials in different regions to see if the impact of changes in drying parameters on quality is consistent. At the same time, energy consumption and environmental protection issues during the drying process should also be paid attention to, such as energy-saving technologies like heat pumps and solar-assisted systems. In addition, the stability of storage after drying, as well as the changes in quality during processing and circulation, also need to be further tracked to provide a more complete reference for production practice.

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Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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