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The Best Method for Rough Rice Drying Based on Operational Energy and Head Rice Yield Quality

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Abstract Drying is an energy intensive operation in cereal grains production chain. Selection of appropriate method of drying and operation management has influence on quality of the final product as well as the operational energy for drying. Rice as a strategic products cultivated in some area other than the north of Iran. This crop needs to be dried after harvesting. In this study two local varieties of rough rice (long and moderate grain) were dried by several thin layer dryer included indirect active solar dryer, mixed-mode active solar dryer and continuous dryer, at three temperature levels of 35, 45, and 55^{OC}. Also, rough rice was dried by sundry method as the traditional and common used method (control treatment). Energy consumption for different parts of aforementioned dryers was measured and determined. Total consumed energy for drying per amount of Head Rice Yield (HRY) was calculated. Results indicated that drying temperature had significant effect on HRY, total energy consumption, and the ratio of total energy consumption per amount of HRY. It was observed that continuous dryer was more efficient according to low ratio of energy consumption to amount of HRY.

Key words: Drying, energy, rice milling, rough rice

INTRODUCTION

Rice is one of the main food sources in the world`s people diet. According to the FAO reports, nearly 161 million hectares were under cultivation of rice with the total yield of 679 million tons in the world in year 2009, and ranked at third place after maize and wheat (Anonymous, 2011). It is undergone several processes from harvesting till supplying to the market in the form of white rice. The final quality of white rice is influenced by these processes. Drying as one of the main and of necessity processes has critical effect on the quality of final product. It was reported that for optimum head rice recovery in rice milling process, the moisture content of paddy should be within 10 to 13 percent (w.b.) (Teter, 1987).

For some local paddy varieties of Fars province, Iran, moisture content is recommended within 8 to 10 percent (w.b.) (Shaker and Alizadeh, 2002; Sadeghi and Nassiri, 2010).The most losses of paddy during different post-harvest processes referred to the improper drying (Brooker et. al., 1992). Thermal and moisture content gradients while drying produce stresses within paddy kernels. When these stresses excess its allowable limit, produces some crakes in kernels and reduces head rice recovery (Yang et.al. 2002; Siebenmorgen and Qin, 2005; Zhang et al., 2005; Prachayawarakorn et al., 2005).

Drying is also important activity from economics point of view, because it is energy intensive process (Brooker et.al., 1992). On the other hand, the price of a rice bulk containing the fissured kernels is reduced to one tenth of high quality rice, depending on the amount of cracked kernels (Courtois et.al. 2001).Therefore; the aim of the rice production industry is to produce whole kernel rice with low energy input and at the minimum possible time (Sarker et.al., 1996). The main objective of the present study was to compare the head rice recovery of two local paddy varieties (medium and long length kernels) when paddy has been dried by different drying methods. Assessing the energy productivity was another objective of the study.

MATERIALS and METHODS

Samples

Two local paddy varieties Lenjan (medium-grain) and Fajr (long-grain) were collected from Fars Province, Iran. The initial moisture content for aforementioned varieties was around 18 and 17% (w.b.), respectively. The samples were sealed in plastic bags and stored in a refrigerator at 4^{O}C. Samples were removed from the refrigerator 12 hours before the drying experiments to warm up at room temperature (20^{O}C). Moisture content was determined before and after each drying treatment by gravimetric method in an air-oven at 105^{O}C for 24 hours (AOAC, 1985).

Physical characteristics (length, width, thickness, slenderness, and the weight of 1000 kernels) of rough rice and head rice of both varieties were measured using a micrometer with accuracy of ±0.01 mm. the measurements were performed for hundred kernels, and the mean values were reported.

Drying systems

The final moisture content of 10.5±0.5 (w.b.) was desired for all samples. So, the rough rice varieties were dried by different ways and under certain conditions.

Continuous drying system with hot air

Drying was done using a continuous inclined laboratory dryer. Paddy was confined between two screen sheets with 20 mm distance. The heated air was passed through the paddy in transverse direction with 0.28 kg/m^{2}s flow rate. The air was heated up to three levels 35, 45 and 55^{O}C. The temperature was controlled by PT-100 sensor based thermostat. About 1600 g paddy fed into the dryer from upper hopper. The movement rate of paddy in dryer was controlled by a multi-vane rotary gate at the bottom of the dryer (Figure 1). Discharged materials refilled in hopper manually.

In each trial at first, 5, 15, 25 and 40 minutes from beginning, and after that, each 20 minutes, the moisture content was measured by a portable moisture meter (±0.1 accuracy).

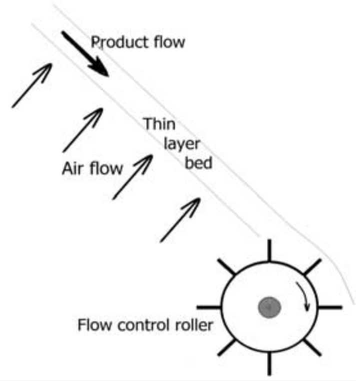

Figure 1. Schematic diagram of the continuous dryer

Indirect active solar drying system

Dryer was equipped by a 1500×550 mm flat solar collector. Collector was sloped about 45 degree (Duffie and beckman, 1991). Solar collector was covered by a black fiber sheet, so that three different temperature levels (35, 45 and 55^{O}C) were obtained. A 357 watt electrical heater was also used to help the solar collector for establishing the constant drying temperature at necessary times. The volumetric air flow rate was the same as previous dryer (0.28 kg/m^2 s). About 850 g paddy in 20 mm thickness spread over the dryer tray and inserted into the dryer. For determining the moisture content alternatively, the tray was weighed with a digital balance (±1 g accuracy) at the periods same as previous tests (Figure 2).

Mixed-mode active solar drying system

The procedure was the same as indirect active solar dryer, except that the sun rays were also radiated directly to the filled sample tray (Fig. 2).

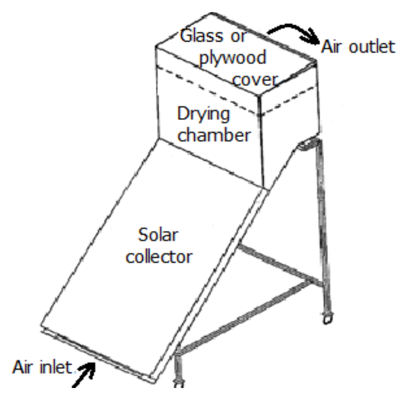

Figure 2. Schematic diagram of the solar dryer

Sun drying

This is a common method in paddy cultivation region of Fars province. Therefore, 3200 g paddy was spread in 325×225×80 mm wooden boxes and exposed to the sun radiation. Samples were aerated manually for uniform drying by 2 hours.

Tests attribute measurement

In all above drying methods the amount of consumed energy was measured accordingly. The required energy for electric motor and blower set, heaters and any electrical consumers were measured by electricity counters. The solar energy was computed by considering the amount of average solar radiation (using shade meter) and surface area of the collectors.

Dried paddy samples were sealed in plastic bags and stored 24 hours at ambient temperature. The 50 g sub-samples were selected from each treatment and shelled using a laboratory scale rubber roller husker (model THU-35A, Satake, Japan). Brown rice was milled for 30 s in the Kett polisher (Kett electric laboratory, Tokyo, Japan) to remove the barn. Head rice yield (HRY) was calculated as the ratio of the mass of whole white rice kernels obtained to the total mass of rough rice. The term "head rice" denotes white kernels 3/4 or more of the original kernel length (Aquerreta et al., 2007; Yadav and Jindal, 2008). This ratio was determined manually in samples of 10 g of white rice. Analysis of variance and multiple range post test of Duncan were applied on all obtained data.

RESULTS and DISCUSSION

Some physical characteristics of the paddy and their brown rice kernels have been showed in tables 1 and 2. As it is obvious, Fajr variety had more length and larger slenderness (length to width) ratio as compared to Lenjan.

Table 1. Some physical characteristics of Fajr and Lenjan (paddy)

Variety	Length (mm)	Width (mm)	Thickness (mm)	Weight of 1000 kernels (g)
Fajr	10.6±0.6	2.1±0.1	2±0.1	21.6±1.2
Lenjan	8.3±0.6	2.6±0.2	1.9±0.1	19.8±1.2

Table 2. Some physical characteristics of Fajr and Lenjan (brown rice)

Variety	Length (mm)	Width (mm)	Thickness (mm)	Length to width ratio
Fajr	7.3±0.2	1.9±0.1	1.8±0.1	3.8±0.2
Lenjan	6.0±0.4	2.3±0.2	1.7±0.1	2.7±0.3

Head rice yield

The amount of HRY was obtained after whitening. Analysis of variance on HRY values showed that the main effect of variety, drying air temperature and drying method was significant ($p<0.1$). Comparison between means by Duncan post hoc test depicted that Lenjan had more HRY than Fajr variety. It might be due to higher value of slenderness ratio (Figure 3). Longer kernels of Fajr did not tolerate the created forces while dehusking and whitening. Same results was observed in Mathews and Spadaro (1976), and clement and Seguy (1994) reports. The HRY losses were increased by increasing in drying air temperature from 35 to 55^{O}C.

At higher temperatures due to created thermal stresses during drying, cracks were developed in kernels (Courtois et al., 2001; Iguaz et al., 2006; Kermani et al., 2006), and thereby HRY was reduced as shown in Figure 4.

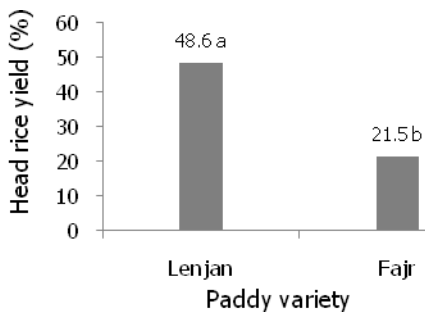

Figure 3. Percentage of head rice yield for different paddy varieties

Continuous dryer at higher temperature improved the amount of HRY as compared to indirect and mixed-type solar dryers. It was found that HRY was not influenced by direct solar radiation in mixed-type solar dryer (Figure 5).

The most HRY was obtained when paddy was dried at 35^{O}C in all drying methods. It means that drying method had no effect on cracks development at lower drying temperature (Figure 6). However, an interaction between the drying temperature and drying method was observed. Non-uniform and rapid drying process of dryers produced more broken. If fast rate drying is desired, continuous dryer is more suitable. It is due to this fact that drying air contacts with grains in better manner when they are moved. In the other hand, there is a short tempering period between discharging from dryer and reloading. Hence, this period decreases thermal stresses in kernels.

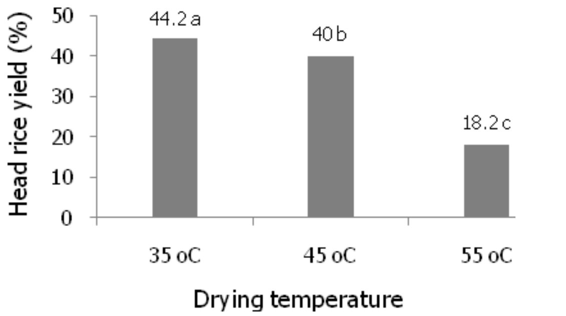

Figure 4. Percentage of head rice yield at different drying temperatures

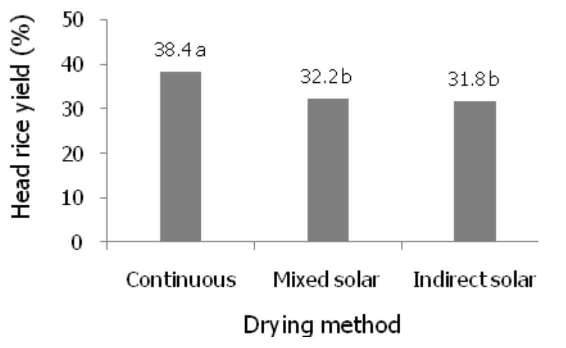

Figure 5. Percentage of head rice yield in different drying methods

Energy use efficiency

The amount of total energy use per kilogram of vaporized water was calculated as an index of energy use efficiency (Figure 7). The ratio was from 9.1 to 57.5 MJ/kg of vaporized water. The minimum and maximum values were obtained for continuous dryer at 35^{O}C and indirect solar dryer at 45^{O}C, respectively. Low ratio at 35^{O}C referred to minimum energy consumption to heat up the ambient air temperature (on average 28^{OC}) in one hand, and adequate time for moisture emission inside the kernel in the other hand. At 55^{OC} the phenomenon was quite different.

High temperature produced more water vapor pressure inside the kernels and pushed out the moisture. Though, more energy was applied for drying but the amount of removed water was also more. Therefore, the ratio decreased with respect to corresponding values at 45 ^{O}C. It should be noted that drying at 55^{O}C produced more fissured kernels because of thermal stresses. Weerachet et al. (2010) reported that this ratio was 3.9 to 4.4 MJ/kg of vaporized water. The difference might refer to the method of drying in the present study in thin layer form. It is evidence that most of heated air has been vented out from dryer without effective use and recovery. The ratio of total energy use per kilogram of dry matter of head rice was also calculated. The lowest was for continuous drying at 35^{O}C and the highest was for mixed-type solar dryer at 55^{O}C (Figure 8).

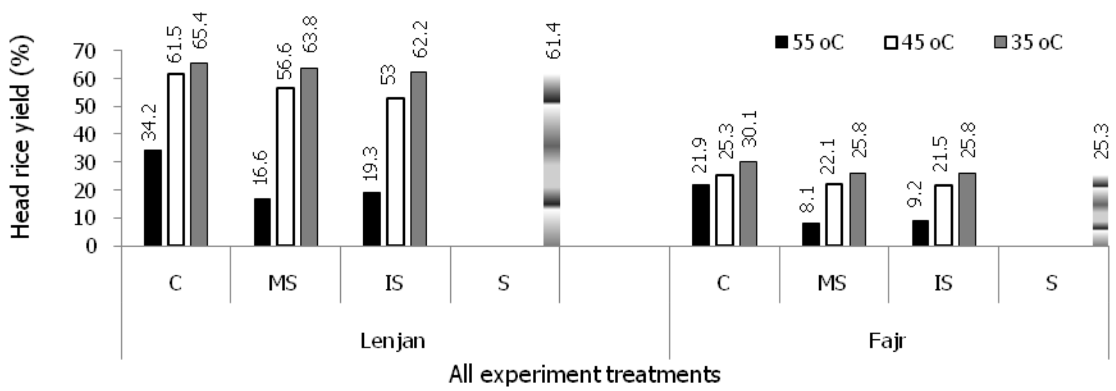

Figure 6. Percentage of head rice yield in all experiment treatments (C=continuous; MS=Mixed solar; IS=Indirect solar, S=Sun drying)

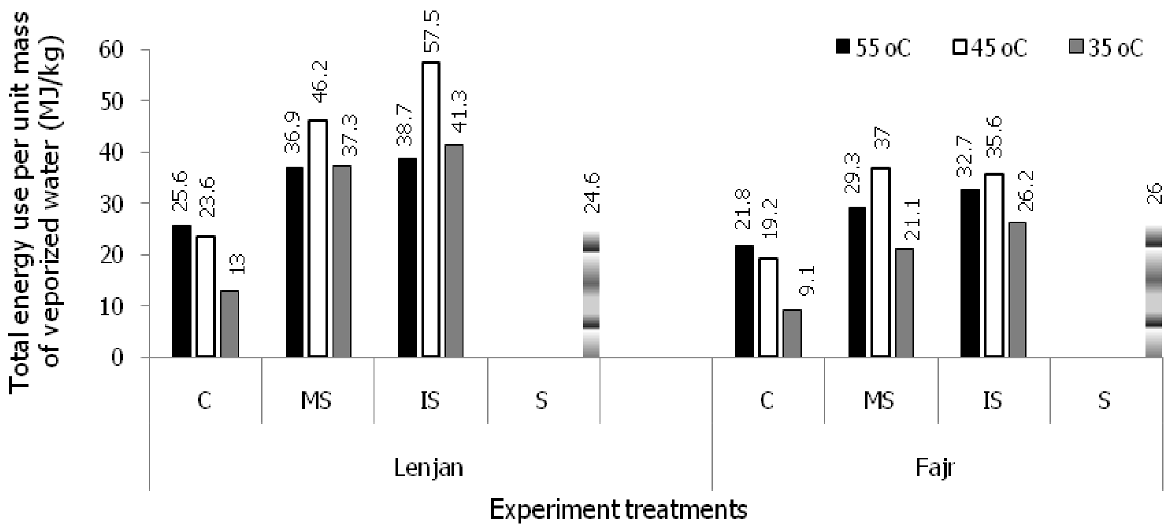

Figure 7. Total energy use per unit mass of vaporized water in all experiment treatments (C=continuous; MS=Mixed solar; IS=Indirect solar, S=Sun drying)

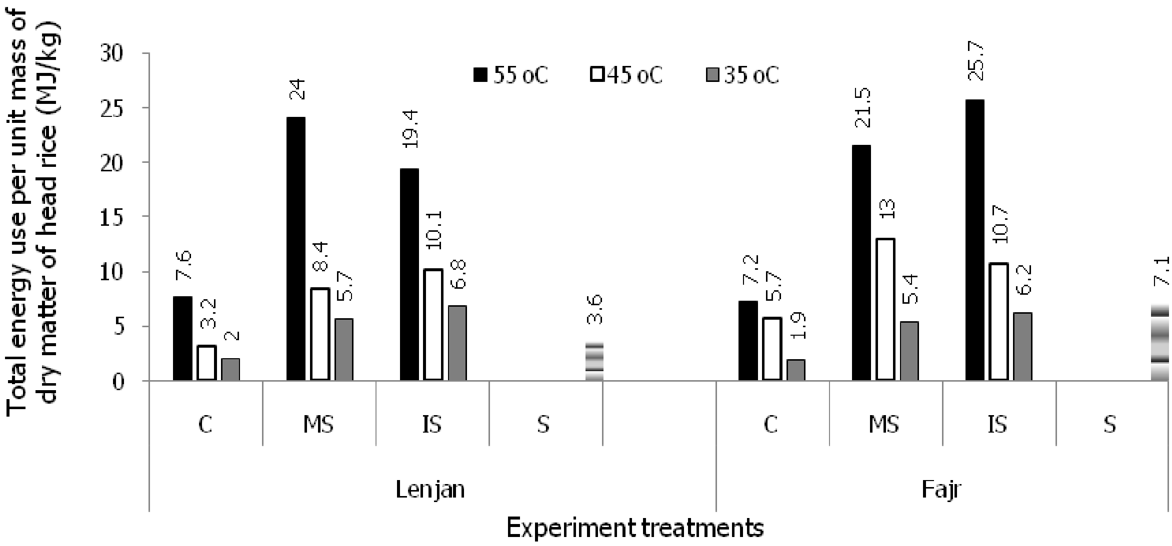

Figure 8. Total energy use per unit mass of dry matter of head rice in all experiment treatments (C=continuous; MS=Mixed solar; IS=Indirect solar, S=Sun drying)

It is important to know that on average nearly 67% of energy use by solar dryers was prepared by sun radiation. Consequently, the ratio of electrical energy use per kilogram of dry matter of the head rice was calculated as tabulated in Table 3. It is clear that continuous drying method was the best method because of low energy consumption and uniform drying. A part of more use of electrical energy for solar dryers might refer to the size of dryers that was larger than continuous one. On the other hand, drying duration was also taken in to the account (Table 3). It seems that paddy has stayed longer time in continuous dryer than other dryers, but by considering the required rest times for discharging and refilling the dryer, it can be concluded that this dryer acted more efficient than others.

Table 3. Ratio of electrical energy use to unit mass of dry matter of head rice yield for different drying methods

Paddy Variety	Drying Method	Drying Temperature (°C)	El. Energy/ dry matter of HRY (MJ/kg)	Drying Time (Min)
Lenjan	Continuous	35	6.2	368
		45	3.2	262
		55	1.9	150
	Mixed Solar	35	6.7	306
		45	2.1	141
		55	1.6	70
	Indirect Solar	35	6.2	339
		45	2.7	179
		55	2.1	76
	Sun	-	0	669
Fajr	Continuous	35	8.1	247
		45	6.2	173
		55	2.5	123
	Mixed Solar	35	11.0	175
		45	3.9	115
		55	2.2	56
	Indirect Solar	35	10.7	227
		45	1.8	111
		55	3.7	56
	Sun	-	0	709

CONCLUSION

The study showed that:

1- Shorter length grain Lenjan had more HRY than longer one.
2- HRY was improved when paddy was dried by continuous dryer.
3- There was no significant difference between HRY for indirect and mixed-type solar dryer.
4- There was an inverse relationship between drying air temperature and HRY.
5- The highest ratio of energy use per kilogram of dry mass of white rice was obtained at 55^{OC}. A significant difference between this ratio at 55^{OC} and other drying temperatures (45 and 35^{OC}) was observed.
6- About 67% of required energy was prepared by solar radiation for solar dryers.

Considering all above, combination of solar collectors and continuous dryer can be recommended for drying paddy for maximum HRY, minimum electrical energy consumption, and therefore minimum ratio of energy use per kilogram of dry mater.

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