Air temperature and final grain moisture effects on drying time and milling quality in two types of fluidized bed dryer

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Abstract: Drying process is one of the important stages in paddy milling process and plays a key role in the product quality. In this modified the effects of air temperature (40 ℃, 50 ℃ and 60 ℃) and final paddy grain moisture content (8-9%, 9-10% and 10-11% d.b.) were examined on the drying time and milling properties in fluidized bed dryer with two heating sources (infrared radiation and heater types). The experimental design was randomized complete design with factorial layout in which three levels of final paddy grain moisture content, three levels of air temperature and two types of dryers with three replications in each treatment. The results indicated that the lowest cracked grain (8.01%) was related to the air temperature of 40 ℃ and the moisture content of 10%-11%; whereas the highest cracked grain percent (14.67%) was registered at the air temperature of 60 ℃ and the moisture content of 8%-9%. The milling recovery decreased as the air temperature and final paddy grain moisture content increased. At each final paddy grain moisture content, the drying time decreased and broken rice increased significantly ($P<0.01$) as the air temperature increased from 40 ℃ to 60 ℃, however the broken rice and drying time in infrared fluidized bed dryer was significantly ($P<0.01$) lower than those of the heater type one. The drying time in the infrared fluidized bed dryer was reduced by 67.7%, 70.0% and 75.4% compared to heater type fluidized bed dryer at the air temperatures of 40 ℃, 50 ℃ and 60 ℃, respectively.

Keywords: paddy drying, milling recovery, fluidized bed dryer, infrared radiation.

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1 Introduction

Rice is one of the important plants from crop category and basic food of most people in the world. Rice provides much of the food energy for about half of the world population that most of them live in Asia. Due to the growth of high population in Asia, where about 90% of the world rice is produced and consumed, annual production of rice should be about 1.7% increase until the future need of consumers to satisfy (Mohadesi et al., 2013). Due to population growth and restrictions in increase of the rice cultivation area, the main purpose of the rice processing industry is to improve milling. To achieve this goal, it is necessary that the paddy to be dried immediately after harvest to prevent of biological and microbial deterioration (Nasrnia et al., 2012).

It is typically dried using heated air, which is a slow process because only relatively low air temperatures can be used to avoid reducing rice milling quality. The heated warm air the outer layer of the paddy kernel and causes the moisture to evaporate from the kernel surface into the

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drying air. As the moisture is removed from the outer layers of the grain, a moisture gradient is established within the kernel. Sometimes, this gradient causes stresses in the grain, causing the rice kernel to fissure after drying (Ban, 1971; Kunze, 1979).

Infrared drying method, which is the most efficient form of electromagnetic radiation for heat transfer, has been gaining interest in the agro-industry because of its high thermal efficiency, fast heating response time, and direct absorbability by the material. This drying technology has appeared as one of the potential alternatives to the traditional heating methods for obtaining high-quality dried food, because of several intrinsic advantages, such as simplicity of the required equipment, easy adaptation of the infrared radiation heating with conductive, convective, and microwave heating, and significant energy conservation (Laohavanich and Wongpichet, 2008). The penetration could provide more uniform heating in individual rice kernels and may reduce the moisture gradient during heating and drying. In addition, since infrared radiation does not heat the medium, the temperature of a rice kernel would not be limited by the wet bulb temperature of the surrounding air and would become high in a short time (Pan et al., 2011).

Many published studies were primarily interested in infrared drying of agricultural materials using a conventional electric emitter (Afzal et al., 1999; Afzal and Abe, 1997; Kumar et al., 2006). Research on paddy drying by using the infrared radiation emitter, in which heat was generated from natural gas, was carried out (Amaratunga et al., 2005).

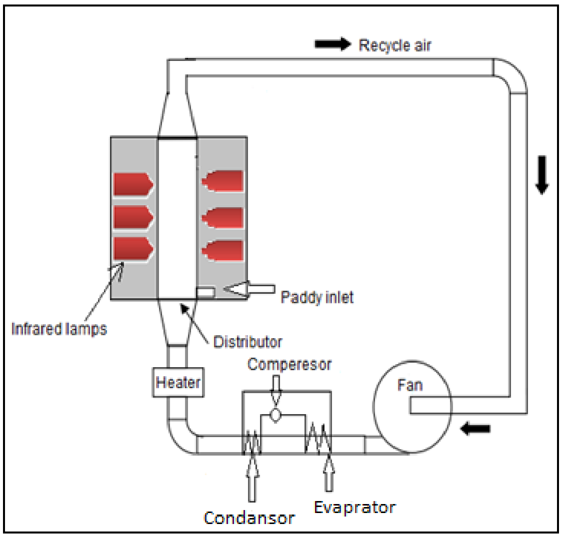
Studies of drying material with infrared radiation showed that by increasing the intensity of infrared radiation the drying time is reduced (Dosite et al., 1989; Hashimoto et al., 1991). Long-term exposure biological substances are versus infrared radiation causing cracking in them (Jones, 1992). Also, it has been reported that infrared radiation changes physical, mechanical, chemical and functional properties of barley seeds (Fasina et al., 1996). Afzal and Abe reported that the infrared radiation method compared with warm air caused faster drying of barley seeds; however it reduce the quality of dried seeds when increasing the intensity of infrared radiation (Afzal et al., 1999). In order to achieve optimum drying conditions for reducing drying time and to minimize grain losses during milling process, it is important to compare drying efficiency and its effects on milling parameters of the two infrared radiation and hot air fluidized bed dryers. Therefore, the objective of this study was the effects investigation of air temperature and final paddy grain moisture on drying time and milling characteristics in fluidized bed dryer with two heating sources; infrared radiation and heater.

2 Material and method

2.1 Drying apparatus

In this research a fluidized bed dryer was used for drying rough rice samples with two thermal sources: infrared radiation and heater as shown in Figure 1. The apparatus was fabricated in the Department of Agricultural Machinery Engineering, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran. It was consisted of a 3 hp radial flow centrifugal type blower fan, auxiliary chamber, heater chamber, fluidized and infrared lamps chambers and temperature control units. Fluidization dryer chamber was a plexiglas cylinder with 200 mm in diameter and 600 mm in height. In order to facilitate fluidization process, an auxiliary chamber with a diameter of three times of cylinder was set up above it. In order to control the air temperature, three temperature sensors (ELREHA, GMBH, Germany) were installed at inlet, middle and bottom of the drying unit. In the heater-type fluidized bed dryer, an electric heater of 1650 W was used for heating the air. In the infrared radiation method, infrared lamps with radiation intensity of 0.031, 0.042, 0.053 Wcm^{-3} was used to obtain the corresponding air temperature of 40 ℃, 50 ℃, 60 ℃.

In order to achieve a constant humidity in the system, an air dehumidifier (SAMWON, SU-503B, Japan) was used.



(a)

(b)

Figure 1 (a) fluidized bed dryer, (b) fluidizing chamber

2.2 Experimental method

A common high-yielding rice variety in northern region of Iran, namely Shiroudi was selected for this experiment. The paddy samples were provided by the Rice research institute of Iran (RRII), Rasht, Iran. The initial moisture content was determined based on the American Society of Agricultural Engineers Standard (ASAE, 2000) and it was found to be 15% (d.b.). Before loading the samples, the dryer was turned on for two hours to establish a steady-state condition at the system. At each test run, 200 g paddy was fed into the dryer. During the drying process, the samples were weighted by using a digital scale (Satorius, Germany) with an accuracy of ±0.1%. The paddy samples were dried to the three final paddy grain moisture content levels of 8-9%, 9-10% and 10-11% at three air temperatures of 40℃, 50℃ and 60℃ with three replications.

In order to determine the milling parameters of the dried samples, three samples of 150 g were randomly chosen from the dried paddy samples lot. A laboratory husker (Satake Engineering Co., Ltd., Japan) was used to husk the paddy samples. Then, the output of the husker which was brown rice was fed to the whitener machine for bran removal. A laboratory friction type rice whitener (McGill Miller, USA) was used for whitening process. A rotary indent separator (Satake, TRG 058, Japan) was used for separating head and broken kernels. A kernel having equal to or more than 75% of complete grain was considered as whole kernel (Farouk and Islam, 1995). The milling recovery and broken rice percent were determined as in Equations 1 and 2:

$$\text{Milling recovery} = \frac{\text{Weight of total milled rice}}{\text{Weight of dried paddy}} \times 100 \quad (1)$$

$$\text{Broken rice percent} = \frac{\text{Weight of broken white rice}}{\text{Weight of total milled rice}} \times 100 \quad (2)$$

In order to measure cracked grains, a crack tester (Mahsa, Iran) was used. The apparatus have a fluorescent lamp that is installed below a mesh plate. To calculate the crack percent before drying operation, three samples of 50 grains were randomly selected and their husks were picked up manually. Then the hulled grains (the brown rice) were placed on the crack tester and the numbers of cracked grains were counted. Also, after each drying treatment, the cracked grains were determined for each sample and the crack rate before drying operation was subtracted from that. The data was analyzed in factorial layout based on randomized complete block design in three replications in which three levels of final paddy grain moisture content, three levels of air temperature and two types of dryers were the independent variables and the rice milling properties and drying time as the dependent parameters. Treatment effects were analyzed using analysis of variance by SAS (9.1, 2004) statistical software. When the analysis of variance was significant (P<0.05), treatment means were compared by the LSD, and charts were drawn through Microsoft Office Excel 2010.

3 Results and discussion

The analyses of variance of treatments effect on the rice milling properties (Shirudi variety) were given in Table 1. The results indicated that the effect of final paddy grain moisture content was significant (P<0.01) on the cracked percent, drying time and milling recovery. The effect of air temperature was significant (P<0.01) on the cracked and broken grains percent as well as on the milling recovery (P<0.05). Also, the cracked grain percent, broken rice and drying time were significantly (P<0.01) affected by the dryer type. Interactive effect of air temperature and final paddy grain moisture content was significant (P<0.05) on the cracked grains and the drying time (P<0.01). Interaction effect of air temperature and dryer type was significant on the drying time (P<0.01).

Table 1 Analysis of variance of the treatments effect on the rice milling properties and drying time

Mean square						
Source of variation	Df	Cracked grains, %	Broken grains,%	Milling recovery, %	Degree of whiteness, %	Drying time min
Final paddy grain moisture content	2	15.407**	9.853^{ns}	2.85**	1.24^{ns}	337410.9**
Air temperature	2	70.296**	146.560**	1.34*	1.55^{ns}	1483053.1**
Dryer type	1	21.407**	63.57**	1.67^{ns}	1.94^{ns}	2331682.2**
Moisture content ×air temperature	4	6.851*	7.143^{ns}	0.324^{ns}	1.27^{ns}	30211.3**
Moisture content×dryer type	2	4.74^{ns}	5.264^{ns}	0.237^{ns}	0.43^{ns}	35293.1**
Air temperature ×dryer type	2	0.962^{ns}	9.905^{ns}	0.38^{ns}	0.049^{ns}	369722.6**
Moisture content ×air temperature×dryer type	4	3.962^{ns}	2.107^{ns}	0.135^{ns}	1.173^{ns}	2418.8**
Error	34	1.982	4.118	0.230	0.92	379.76
C.V.	-	13.823	6.33	3.34	3.57	5.046

** significant at 1% level, * significant at 5% level, ^{ns} not significant difference

The means comparison of interactive effects of final paddy grain moisture content and air temperature on the cracked grins percent were given in Table 2. The results indicated that at the three final paddy grain moisture content levels, increasing the air temperature from 40 ℃ to 50 ℃, there was no significant effect on the cracked grain percent, while with increasing the air temperature from 50 ℃ to 60 ℃ the cracked percent significantly increased. The minimum cracked grains (8.07%) was related to the final paddy grain moisture content of 10%-11% and air temperature of 40 ℃; whereas the maximum cracked grain (14.67%) was belonged to the final paddy grain moisture content of 8%-9% and air temperature of 60 ℃. This could be attributed to that at low air temperature, the thermal stresses imposed on paddy during drying is lower than that of the higher temperature. However, at the air temperature 50 ℃ and 60 ℃, the surface layer of the paddy grains dries quickly and an internal severe vapor pressure creates large tensions, thereby increasing the cracking (Mohajeran et al., 2006).

Table 2 Means comparison of interaction effects of air temperature and final paddy grain moisture content on the cracked grains percent

Moisture	Air temperature
d.b., %	℃

	40	50	60
8-9	9.07^{Ab}	10.07^{Ab}	14.67^{Aa}
9-10	8.34^{Ab}	9.07^{Ab}	11.01^{Aa}
10-11	8.07^{Ab}	10.34^{Aa}	11.34^{Aa}

Small letter at each row and capital letter at each column represents the means comparison (P<0.05) at different air temperature and paddy moisture, respectively.

According to Figure 2, with increasing the air temperature from 40 ℃ to 60 ℃ the broken rice percent increased from 29.47% to 35.11%. As shown in Figure 3, heater-type fluidized bed dryer had higher broken rice percent (33.22%) than the infrared fluidized bed dryer (30.89%). Similar results have been reported by other researchers (Pan et al., 2011).

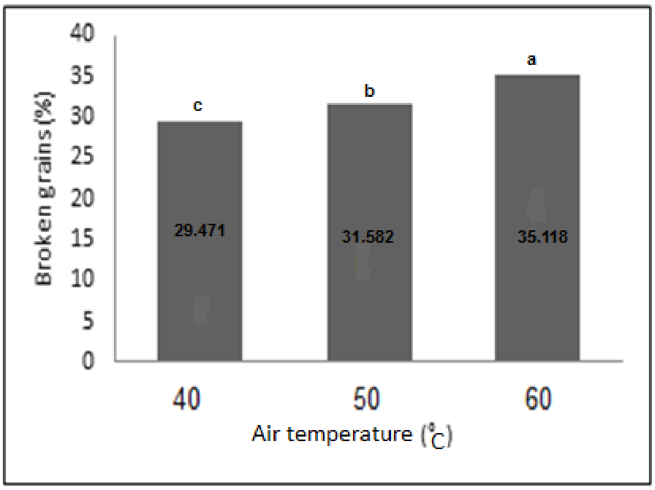


Figure 2 Broken grains percent at the different air temperatures (P<0.05)

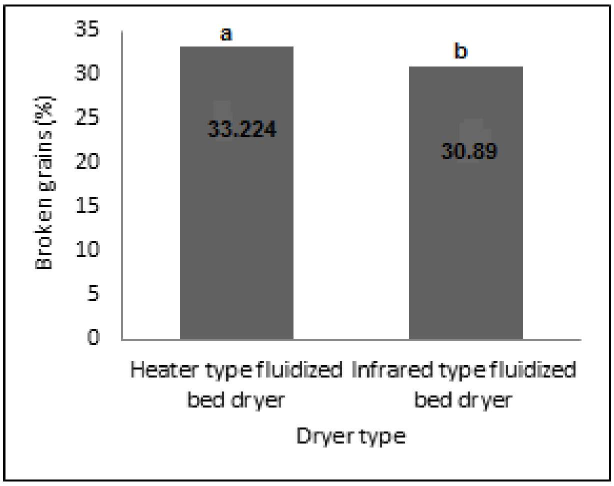


Figure 3 Broken grains percent in different dryers

According to Figure 4, with increasing the paddy moisture from 8%-9% to 10%-11% the milling recovery decreased from 72.96% to 72.20%. Also in Figure 5, the milling recovery decreased from 72.84% to 72.35%, as the air temperature increased from 40 ℃ to 60 ℃. This may be due to that in a specified milling apparatus and degree of milling, lower bran removal occurred during the whitening process at low and air temperature which resulted in higher milling recovery (Web and Calderwood, 1977).

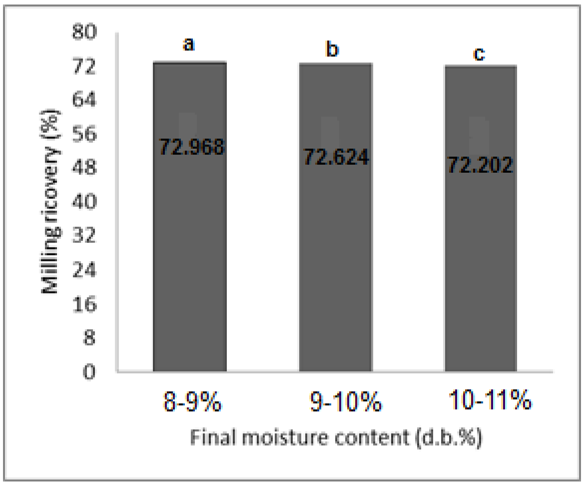


Figure 4 Milling recoveries at different final paddy grain moisture contents

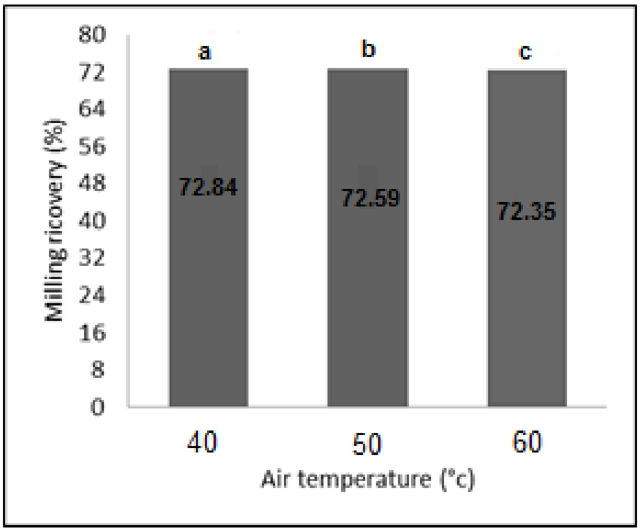


Figure 5 Milling recoveries at different air temperatures (P<0.05)

According to Figure 6, although there was no significant difference in drying time at all of moisture contents levels, however there was a decreasing trend in drying time with increasing final paddy grain moisture content. The effect of air temperature on the drying time was significant (P<0.01), so that the drying time decreased with increasing air temperature. At the moisture contents 8%-9%, 9%-10% and 10%-11%, the drying time decreased from 929.2 to 220.8 min, 669.2 to 126.33 min and 473.8 to 79.17 min as the air temperature increased from 40 ℃ to 60 ℃, respectively. As observed, at each level of final paddy grain moisture content, the drying time decreased as the air temperature increased. This may be due to the increased thermal gradient inside the grain and as a result of increased intensity of moisture evaporation (Sun, 1995). Also, the drying time decreased with increasing final paddy grain moisture content. Therefore, drying time varied inversely with air temperature and final paddy grain moisture content. Similar results have been reported by other researchers (Doymaz, 2004; Khoshtaqaza et al., 2007).

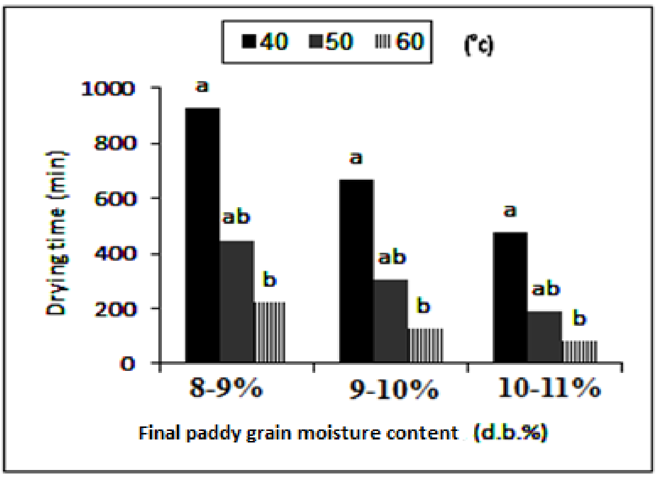


Figure 6 Drying time at different final paddy grain moisture contents and air temperatures (P<0.05)

As shown in Figure 7, at all the three moisture content levels, there was no significant difference in drying time in the two types of dryers. However, at each final paddy grain moisture content level, the drying time in the infrared fluidized bed dryer was significantly lower than that of the heater-type fluidized. Similar results have been reported by Laohavanich and Wongpichet (2008). Their results showed that the final paddy grain moisture content decreased exponentially with time. The final paddy grain moisture content of the paddy at considered time rapidly decreased during the first five minutes of the drying process, and then decreased slowly with further drying time.

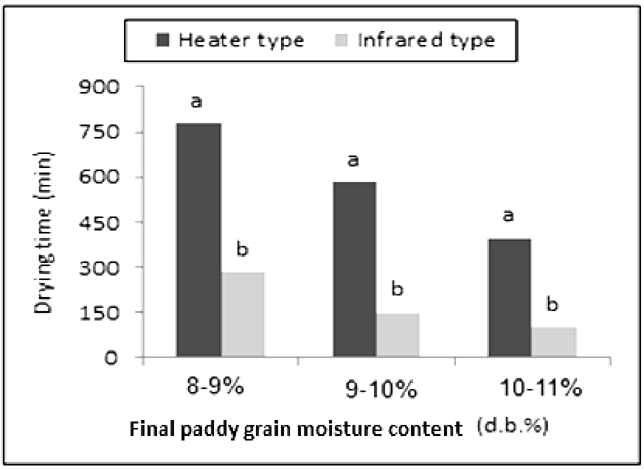


Figure **7** Effect of final paddy grain moisture content on drying time in two drying methods (P<0.05)

The means comparisons of interactive effect of air temperature and dryer type on the drying time were represented in Figure 8. It can be seen that at each air temperature level, the drying time in heater-type fluidized bed dryer was significantly (P<0.01) higher than that of the infrared type one. The highest drying time was measured at the air temperature of 40 ℃ and the lowest value was obtained at the air temperature of 60 ℃. The drying time in infrared radiation at three equivalent radiations of 0.031, 0.042 and 0.053 w.cm^{-3} were obtained 336.67, 143.33 and 56.11 min, respectively which were lower than the corresponding values (1044.78, 485.56 and 228.11min) in heater-type fluidized bed dryer at three air temperatures 40 ℃, 50 ℃ and 60 ℃, respectively. The results have been confirmed by Mohajeran et al., (2006).

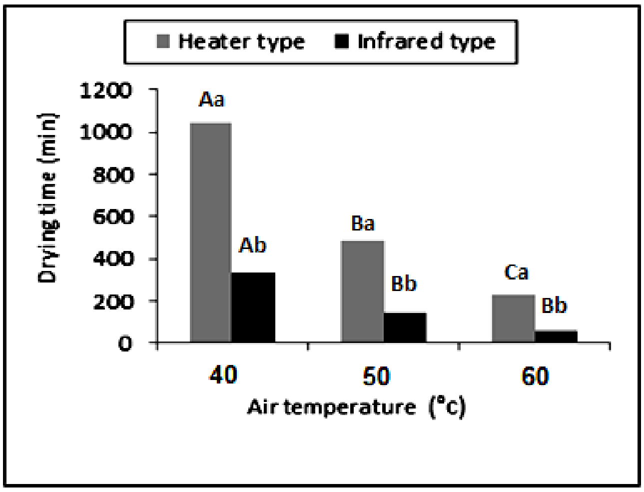


Figure 8 Drying time at different air temperatures to two drying methods (P<0.05)

4 Conclusions

1. In terms of the broken rice percent and milling recovery, the optimal air temperature and final paddy moisture content were 40 ℃ and 8%-9%, respectively.

2. The paddy drying time decreased from 336.67 to 56.11 min and from 1044.78 min to 228.11 min, as the air temperature increased from 40 ℃ to 60 ℃ in the two infrared and heater-type fluidized bed dryers, respectively.

3. At each final paddy grain moisture and air temperature level, the broken rice in infrared drying method was lower than that of the heater-type one.

4. The milling recovery decreased with increasing the air temperature.

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