Egypt. J. Agric. Res. , 78 (2), 2000

ACCELERATED PARTIAL DRYING AND STERILIZATION OF HIGH MOISTURE ROUGH RICE

EL-SAHRIGI [1], A.F., A. MATOUK[2], H.EL.ABD ALLA,[3] M.M. EL-KHOLY[4]

1 Prof. of Agric. Eng., Fac., of Agric. Ain-Shams Univ., and former Director of Agric. Eng. Res. Inst. (AEnRI).
2 Prof. of Agric., Eng., Fac. of Agric., Mansoura Univ.
3 Assoc. Prof., of Agric., Mech., Fac. of Agric., Mansoura Univ.
4 Agric. Eng. Res. Institute (AEnRI) Dokki, Giza.

(Manuscript received 7 April, 1999)

Abstract

A study was carried out to evaluate the effectiveness of high temperature-short time conduction heating for accelerated partial drying and sterilization of high moisture rough rice (Giza 176). Experimental rotary heating unit was specifically designed and constructed at the workshop of Agric. Mech. Dept. Fac. of Agric. Mansoura Univ., to provide heating surface temperatures of 75, 100, 125 and 150°C, exposure time of 2,3,6,8,10 and 12 mins., cylinder rotational speed of 5, 10 and 15 r.p.m., and grain feed rate of 1.5, 2.5 and 3.5 kg/pitch. Rapid moisture removal from rough rice existed during high temperature, short time conduction heating process. The moisture removal rate was found to be dependent upon heating surface temperature, exposure time, and grain feed rate. High temperature short time conduction heating also distinctly reduced fungal activity in rough rice.

Quality evaluation tests of milled rice showed an increase in head rice yield accompanied by a reduction in milled rice whiteness. Heat treatment of rough rice corresponding to a fungal mortality level of 75-80% led to a maximum head rice yield and acceptable level of reduction in whiteness of milled rice. Mathematical models were developed to predict the moisture content and other quality changes of grain during conduction heating process. These models may be used in any further studies aiming to develop a full-scale conduction heating rotary dryer.

INTRODUCTION

Rice is presently among the most important cereal crops in the world with one fourth of the population totally depending on it as a major staple food. In Egypt, it is not only a staple food but also a major source of livelihood. Rice support more human beings per feddan than any other grains. Therefore, increased production through direct increase in yield and minimization of losses will directly contribute to the better well being of most people (RRTC, 1998).

Rough rice is usually harvested at relatively high moisture levels (21 to 24% w.b.) to minimize field losses such as grain shattering, insects, birds and rodent attack. However at these moisture levels; rough rice may suffer substantial losses both in quality and quantity due to specific physical, physico-chemical, and biological factors or a combination of them (*Fukazawa*, 1997). Methods of conditioning and holding high moisture rough rice prior to final drying include the use of chemical preservatives, airtight storage and the aeration of wet grain *El-Kholy* (1991). These methods have been used only with limited success. On the other hand, heat sterilization and accelerated drying of high moisture rough rice as a method of grain conditioning has been tried through a limited number of studies.

There are evidence in literature that heating of high moisture fresh paddy using high temperature short time techniques, as a method of conditioning could be beneficial in terms of rapid drying, improved milling quality and possible destruction of microorganisms.

Chancellor (1968) studied the characteristics of conduction heat drying in comparison with those of other drying methods. The results showed that, the heated air drying process is dependent upon the loss of moisture from the grain by diffusion to produce the temperature differences necessary for the transport of heat energy into the grain from the surrounding air. Individual kernels in conducted-heat drying process are supplied directly with heat energy independent on diffusion. *Mittal and lappp* (1984) reported that in conventional dryers, air is used as the heat transfer medium because it can be easily handled and does by itself contaminate the grain . The low heat transfer coefficients of air coupled with the resistance to moisture diffusion out of the kernel result in extended drying times and relatively low thermal efficiency. Conduction drying was found to be faster than conventional air drying, and natural convection was sufficient to carry away the evaporated moisture.

Jindal and Reyes (1987) studied the heat sterilization and accelerated drying of high moisture rough rice as a means of preserving its physical quality. The grain was directly rolled over the heated surface of a rotary dryer. The results showed that, high-temperature short-time conduction heating of freshly harvested paddy could effectively inactivate the fungi and extend the safe storage period. Also, heat treatments resulted in rapid moisture removal, and improvement in head rice yield.

Younis *et al.* (1993) stated that, at present, few dryers using hot air as heat and moisture transfer medium are reported in Pakistan. But air-drying has been described as an inefficient process. Conducted heat energy is transferred directly from the heated surface to the surface of grain with higher thermal efficiency in comparison with forced convection air drying process.

Iqbal *et al.* (1996), extensively investigated the accelerated drying of grain in solid media and quality change of the dried grains. They stated that, accelerated drying of grain proved to be a more effective drying method in terms of reduction of drying time and it can be also considered as energy saving method. This study aims to evaluate the use of high temperature short time conduction heating technique for partial drying and sterilization of high moisture rough rice as a conditioning method prior to final drying. In addition, the effect of heat treatment on the grain physical quality and milling potential were also investigated immediately after the process.

MATERIALS AND METHODS

The experimental work included laboratory tests for studying the effect of high temperature-short time heat treatments on the drying and sterilization of high moisture rough rice using a one pitch experimental heating unit. The unit consists of a rotary cylinder (0.6m diameter and 0.2 m long) inclosed into a fixed insulated cylinder (0.8 m diameter and 0.3 m long). One side of the rotary cylinder was covered with a steel sheet connected to a driving system consisting of 0.15 m diameter steel flange fixed into the side cover of the rotary cylinder and welded to a steel bar riding into a heavy duty ball bearing. A 0.5 kW controlable low speed electric motor was used for power supply. The other side of the rotary cylinder was used for feeding rice samples. The grain was discharged through a perforated removable sector of the cylinder bottom. For heating and temperature control of the rotary cylinder surface ,a 2.0 kW electric resistance heaters were placed in between the rotary cylinder and the insulated exterior cylinder to supply the required heat. The surface temperature of the rotary cylinder could be raised up to 75-150 °C and maintained within ±5 °C using a precise thermostat. Figure (1) shows a schematic diagram for the one pitch conduction-heating unit.

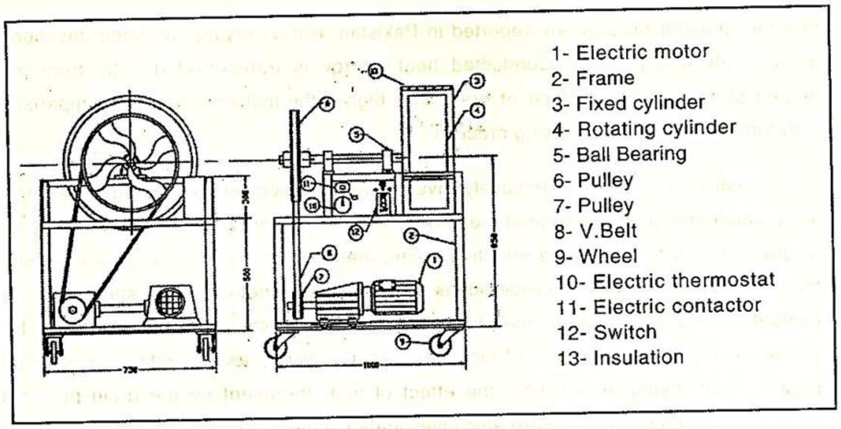

Figure (1) Overall feature of the one pitch conduction-heating unit

Test conditions

The following experimental treatments were considered for the experimental work using one pitch-heating unit:

Experimental treatments	Levels of treatments
Initial grain moisture content	21, and 24 ±1% w.b.
Heating surface temperature	75, 100, 125, and 150°C
Exposure time	2,4,6,8,10 and 12 mins.
Grain feed rate.	1.5,2.5, and 3.5 kg/pitch
Cylinder rotational spped	5,10 and 15 r.p.m.

Test procedure and measurements:

Immediately after harvest, the average moisture content of rough rice was measured and found to be in the range of 24 ±1% w.b. using the (*AOAC*) procedure (1990). Rice samples were stored temporarily in a freezing room adjusted to a temperature of (-5 ^{O}C) in order to suppress fungal growth and minimize quality change. Before each experiment, rough rice samples were taken out from the freezing room and left at the ambient temperature until the initial temperature of the grains approached an equal level for all samples. After heating the grains to the required heating level, they were cooled to room temperature in wooden buckets covered with a perforated aluminum foil to allow the escape of vapoer during the cooling process. Subsequently the grains were dried to about 14% w.b. moisture content by spreading on nylon mats and prepared for quality evaluation tests. The following measurements were conducted during drying by conduction heating:

1- Grain moisture content determination:

The moisture content of the heat treated rough rice samples was measured by the standard air oven method using 25 g sample placed in air oven at 130 °C for 16 h. according to *AOAC* (1990).

2- Grain bulk temperature measurements:

The remote-type infra red spot thermometer (model HT-11) was used for measuring the inner surface temperature of the rotating cylinder. The grain bulk temperature was also measured at the discharge point of the rotated cylinder.

Tests to Evaluate Grain Quality

A. Germination test:

The effect of different time-temperature combinations on the viability of the heat-treated grain was examined. Rough rice samples were sterilized using 2% sodium solution and rinsed three times using distilled water. Germination tests were replicated three times by growing 100 rice kernels in petri dishes containing moistened filter for a week to assure that rough rice kernels develop both roots and shoots.

B. Fungal Colony Count:

The spread plate method recommended by Flannigan (1977) was used to determine the change in fungal colony counts in paddy samples.

C. Milling test:

The partially dried and sterilized rough rice samples were left under shade until reaching a final moisture content of about 14% w.b., prior to milling test. The milling quality of rough rice samples were evaluated in terms of total milling yield and percentage of broken rice. For each test 125 g of air dried rough rice samples were passed through a Satake rubber roll husker (*model THU 35 A*) with clearance adjusted to give about 90% brown rice in one pass. The resulting brown rice was poured into the polishing chamber of the Satake rice polisher (model *SKD-DBKK*) which was operated automatically for one minute in each test. For separating head rice from the broken, a laboratory grader (model TRG-05) was utilized. Total milled rice recovery and broken percentage of milled rice were measured for each treatment. The following equations were used for calculating total milling yield and percent broken kernels.

$$\text{Miling yield (\%)} = \frac{\text{weight of milled rice}}{\text{weight of rough rice}} \times 100 \text{------} (1)$$

$$\text{Broken kernels (\%)} = \frac{\text{weight of broken kernels}}{\text{weight milled rice}} \times 100 \text{------} (2)$$

D. Whiteness degree of milled rice

The whiteness degree of milled rice samples was measured using a *Kett* whiteness meter (*model* C-300).

RESULTS AND DISUSSION

1. Moisture removal during accelerated drying of high moisture rough rice:

Figure (2) shows a typical plot giving the reduction in grain moisture contents as related to exposure time during conduction heating of high moisture rough rice at 1.5 kg/pitch grain feed rate. Other similar plots are available for FR=2.5,3.5 kg/pitch. Rapid moisture removal from rough rice was obvious in all experiments particularly at high heating surface temperatures; low grain feed rate and long exposure duration.

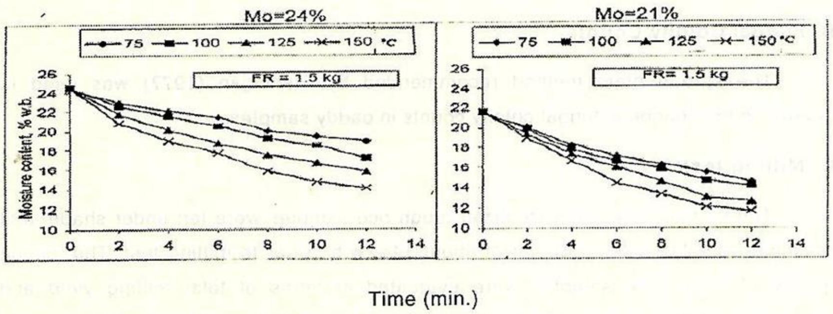

Figure 2. A typical plot of reduction in grain moisture content at different surface heating temperatures as related to exposure time for grain feed rate of 1.5 kg/pitch.

A simple logarithmic model (*Jindal and Reyes* 1987) was examined to describe the drying behaviour of rough rice conduction heating process.There is no information available about the equilibrium moisture of rough rice in a temperature range of 75 to 150 °C when the air relative humidity is very low. However, the rough rice samples will be bone dried after prolonged heating under such conditions. Therefore, the moisture ratio was approximated simply by dropping the equilibrium moisture content term and thus the ratio of instantaneous moisture content of rough rice to its initial moisture content was used to represent grain moisture ratio. Accordingly, the equation representing the simple logarithmic model was modified to the following form:

$MR = A\ EXP\ (-kt)$ ------------------------------ (3)

where :

MR = moisture ratio, (M)/ (Mo), dimensionless

Mo = grain initial moisture content,% (w.b.)

A = empirical constant, dimensionless

K = drying constant (l/min)

t = drying time, min.

The results of examination showd that, the simple logarithmic model satisfactorily described the drying behavior as indicated by the high values of coefficients of determination shown in Table (1). The dependence of the drying constant (k) of equation (3) on the experimental parameters was further studied using the step-wise multiple regression analysis. It was found that, the drying constant (k) was dependent strongly upon the cylinder surface temperature (Ts). The regression equation of the best fit was:

$K = 0.0426 + 3.12\ Ts$ ------------------------------ (4)

$(R^2 = 0.96; SEE = 0.0035)$

Another best fit empirical equation was also used to examine the relationship between the grain moisture ratio (MR) and grain feed rate (FR), cylinder surface temperature (Ts), and exposure time (t) using multiple regression analysis, which revealed that, the grain moisture ratio was affected by all these parameters and the combined correlation coefficient was 0.95. The regression equation for the best fit was:

$M/Mo = 1.0305 + 0.0455\ Fr - 0.0017\ Ts - 0.0224\ t$ ---- (5)

$(R^2 = 0.95\ ;\ SEE = 0.0308)$

The observed and the predicted grain moisture ratio using equation (5) showed a standard error of (0.0308) indicating that, equation (5) could also satisfactorily describe the change in moisture of high moisture rough rice during conduction heating.

6. Tests to evaluate grain quality:

A. Grain germination

The laboratory tests for determining the effect of heat treatment on grain germination using the one pitch experimental heating unit showed that, the heat treatments at a temperature range of 100-150°C resulted in a drastic reduction in grain germinability. The reduction in grain germination percentage was dependent upon

Table 1. Regression coefficient of Eq. (3) representing drying behavior of high moisture roug rich using the one-pitch experimental unit.

Grain initial M.C. (%w.b.)	Grain feed rate (kg/pitch)	Heating surface temperature (C)	Drying correlation coefficients		
			A	k	R^2
24	1.5	75	0.9583	0.0186	0.97
		100	0.9684	0.0270	0.98
		125	0.9290	0.0317	0.99
		150	0.9119	0.0409	0.98
	2.5	75	0.9683	0.0175	0.98
		100	0.9624	0.0209	0.99
		125	0.9510	0.0294	0.97
		150	0.9395	0.0341	0.99
	3.5	75	0.9705	0.0144	0.98
		100	0.9587	0.0168	0.98
		125	0.9562	0.0247	0.99
		150	0.355	0.0256	0.97
21	1.5	75	0.9540	0.0298	0.99
		100	0.9587	0.0345	0.97
		125	0.9562	0.0431	0.97
		150	0.9378	0.0499	0.96
	2.5	75	0.9316	0.0153	0.97
		100	0.9663	0.0215	0.97
		125	0.9853	0.0340	0.97
		150	0.9556	0.0384	0.99
	3.5	75	0.0011	0.0160	0.97
		100	0.9873	0.0186	0.97
		125	0.9815	0.00248	0.99
		150	0.9717	0.0313	0.99

grain initial moisture content, cylinder surface temperature and exposure time. This result was obviously achieved for all samples heated over 6 minutes in which no germination at all was observed as shown in Table (2).

B. Fungi inactivation during conduction heating process

Figure (3) illustrates the change in fungal mortality level as related to exposure time for different grain initial moisture content and feed rates. It was obviously showed, that, the high temperature conduction heating reduced the fungal load in high moisture rough rice in an effective manner. Also, higher heating surface temperature resulted in shorter exposure time for reducing the fungal load to a specific level. Heating at 150^{o}C for about 6 minutes was enough to attain fungal mortality level of 70-80% without significant effect on grain final quality. Considering the relationship between the fungal mortality level (Fml) and the grain feed rate (Fr), cylinder surface temperature (Ts) and exposure time (t), step-wise multiple regression analysis was employed. The results showed a highly significant linear relationship (R^2 = 0.98) between these parameters. The multiple regression equation for best fit was:

$$Fml=-30.7164-0.0455\ Fr + 0.5758\ Ts + 3.2445\ t \ldots\ldots\ldots\ldots\ldots\ (6)$$

(R^2 = 0.98; SEE = 3.98)

The above mentioned results, showed the beneficial effects of heat treatments in terms of reducing fungal activity and partial drying of high moisture rough rice thus

Table 2. Germination percentage of heat-treated grains as related to exposure time

Initial M.c. % (w.b.)	Initial M.c. % (w.b.)	Germination percentage, % heating surface temperature 75	100	125	150 ^{o}C
24	0	97	97	97	97
24	2	86	73	56	15
24	4	79	24	5	0
24	6	64	2	0	0
24	8	94	1	0	0
24	10	43	0	0	0
24	12	5	0	0	0
21	0	98	98	98	98
21	2	84	49	33	11
21	4	73	15	5	3
21	6	61	5	1	0
21	8	11	0	0	0
21	10	9	0	0	0
21	12	1	0	0	0

could contribute directly to a safe holding period of newly harvested rough rice.

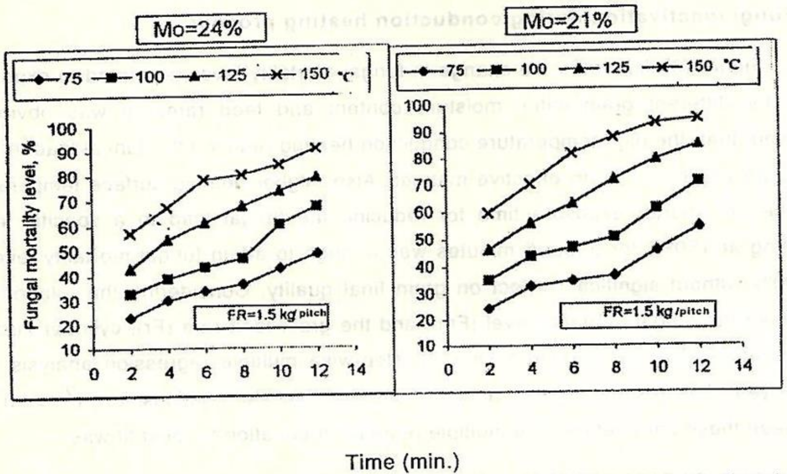

Figure 3. Typical changes in fungal mortality level as related to exposure time for different grain initial moisture contents of 21 and 24% and feed rate of 1.5 kg/pitch.

C. Effect of heat treatment on grain broken percentage

The effects of various heat treatments on grain broken percentage are summarized in Table (3) for different grain initial moisture contents and feed rates. Heat-treated rough rice samples showed a reduction in broken percentage initially and a subsequent increase depending upon the cylinder heating surface temperature, exposure duration and grain feed rate. Similar observations have been confirmed in the past during the high temperature conduction heating of high moisture rough rice by (*Jindal and Reyes*, 1987). When comparing the broken percentage obtained from the grain having 24% initial moisture content with the grain having 21%. The grain samples of 24% initial moisture content produced lower broken percentage especially at higher levels of heating surface temperature and longer exposure duration. The reduction in broken percentage of the heat-treated grain could be attributed to the gelatinization of starch granules and cementing of fissures present in kernels. At heating surface temperature of 150^{o}C and expousure time of 4-6 mins, the calculated reduction in grain broken percentage was approached about 30-45% in comparison with the naturally dried grains.

Table (3): Change in grain broken precentage during conduction heating using the one-pitch experimental unit.

Grain feed rate Kg/pitch		1.5		2.5		2.5	
Cylinder surface temp (°C)	Exposure time (min)	No (% w.b)		No (% w.b)		No (% w.b)	
		24	21	24	21	24	21
75	0	2.72	2.83	2.72	2.83	2.72	2.83
	2	2.15	2.28	2.57	2.53	2.61	2.79
	4	1.97	2.36	2.45	2.39	2.49	2.65
	6	1.84	2.19	2.43	2.31	2.45	2.51
	8	1.84	2.39	2.39	2.45	2.41	2.60
	10	1.95	6.62	2.18	3.81	2.23	2.90
	12	2.12	25.12	2.29	4.44	2.39	3.19
100	2	1.98	2.39	2.44	2.49	2.59	2.68
	4	1.81	2.53	2.16	2.41	2.18	2.49
	6	1.73	3.88	1.98	2.38	2.00	2.45
	8	1.85	19.77	1.76	3.29	1.83	2.75
	10	1.89	28.21	1.85	3.84	1.76	3.73
	12	3.55	19.70	2.56	5.73	2.43	4.01
125	2	1.84	2.98	2.07	2.60	2.15	2.46
	4	1.76	3.25	1.67	2.69	1.79	2.33
	6	1.69	61.21	1.61	3.71	1.74	2.26
	8	2.08	29.93	1.81	5.24	1.70	2.47
	10	6.58	41.30	2.39	6.47	2.11	4.51
	12	13.54	45.48	8.95	10.63	4.68	8.82
150	2	1.79	3.98	1.90	2.65	2.11	2.38
	4	1.64	6.51	1.57	3.24	1.73	2.17
	6	2.18	26.51	1.52	5.97	1.67	2.34
	8	7.18	38.57	2.43	8.23	1.92	3.97
	10	17.13	43.83	3.64	22.73	3.38	17.92
	12	33.8	49.26	12.16	38.94	10.83	32.46

D. Effect of heat treatments on milled Rice whitenes

Heat-treated rough rice samples yielded milled rice slightly yellowish in apperance in compaeison with the unheated control samples. This change in color could be attributed to the non-enzymatic browning and/or the diffusion of coloring pigments of the rice hull and bran to the endosperm caused by exposure of the grain to high levels of temperature. In general, the change in grain color was less sever for milled rice produced from rough rice samples having lower initial moisture content and as well as from samples exposed to lower heating surface temperature and shorter exposure time as shown in figure (4).

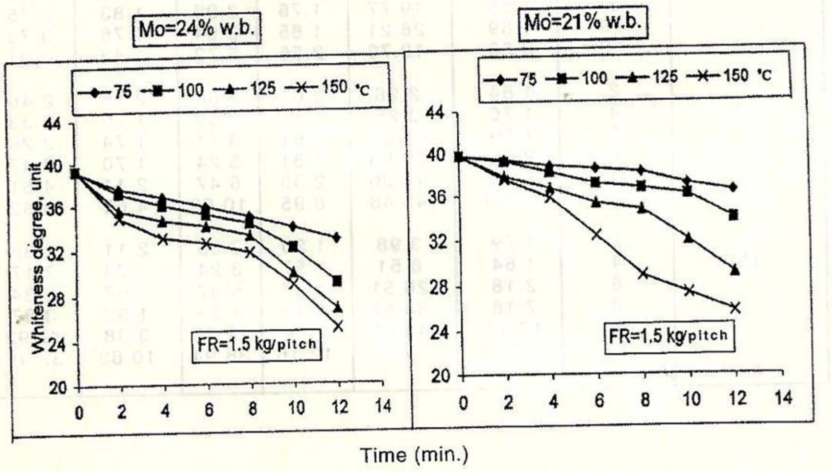

Figure 4. Typical plot of grain whiteness degree as related to exposure time for different grain initial moisture contents of 21 and 24% and feed rate of 1.5 kg/ pitch.

CONCLUSIONS

1- High-temperature short time conduction heating of freshly harvested rough rice could rapidly reduce the grain moisture content specially at higher heating surface temperature, longer exposure duration and lower grain feed rate.

2- A generalized procedure developed in this study (equation 5) can be used for predicting the moisture removal from high moisture rough rice during high temperature conduction heating in terms of mean bulk grain temperature .

3- Heat treatment of high moisture rough rice reduced the fungal growth rate and hence the spoilage in freshly harvested rough rice leading to its safe storage.

4- The broken percentage of the heat treated high moisture rough rice was reduced first and then increased rapidly with prolonged heating time depending on heating surface temperature, grain initial moisture content and grain feed rate.

5- The whiteness degree of milled rice obtained from the heat treated rough rice was slightly reduced due to non-enzymatic browning and/or the diffusion of coloring pigments of the rice hull and bran to the endosperm.

REFERENCES

1. AOAC. 1990. Official Methods of Analysis. (15 th. Ed), Association of Official Analytical Chemists. Washiungton, DC.

2. Chancellor, W.J. 1968. Characteristics of conducted heat drying and their comparison with those of other drying methods. Trans. Of the ASAE. 11 (6) 863-866.

3. El-Kholy, M.M. 1991. Temporary storage of high moisture paddy under different aeration system. Unpublished M.Sc Thesis. Asian Institute of Technology Bangkok, No. AE-91-2.

4. Flannigan, B. 1977. Enumeration of fungi and assay for ability to degrade structural and components of grain. In Biodeterioration investigation techniques (ed. H. Walters) London, Applied Science Publishers, pp. 185-199.

5. Fukazawa, H. 1997. Generation of cracked grains and its related factors. Technical Report, Rice Mechanization Project, Japan-Egypt Cooperation, Meet El-Dyba. Kafr El-Sheikh, Egypt.

6. Iqbal, M., M. younis, M.S. Sabir and S.A. Qumar. 1996. Design nd development of a continuous-flow rotary grain dryer. AMA. 27 (2): 41-45.

7. Jindal, V.K. and V. G. Reyes, Jr. 1987. Conduction heating of rough rice for accelerated drying. Paper No. 87-6043, American Society of Agricultural Engineers (ASAE) Summer Meeting, Baltimore, June 28-July 1, ASAE, St. Joseph, MI.

8. Mittal, G.S. and H.M. Lapp. 1984. Grain drying with solid heat transfer media. AMA. 15 (3): 45-50.

9. Yonis, M., M. S. Sabir, G.S. Sheikh, A. Shafi and M. Iqbal. 1993. Design and development of a grain dryer using sand as heat medium. AMA. 24 (1): 28-30.

المراجع العربية :

مركز البحوث والتدريب فى الأرز RRTC (١٩٩٨) ، التوصيات الفنية لمحصول الأرز - برنامج الأرز - مركز البحوث الزراعية - وزارة الزراعة .

التجفيف الجزئي السريع والتعقيم لمحصول الأرز ذو المحتوي الرطوبي المرتفع

أحمد فريد السهريجي[١]، أحمد محمود معتوق[٢]،
حسني الشبراوي[٣]، محمد الخولي[٤]

[١] *أستاذ الهندسة الزراعية – كلية الزراعة – جامعة عين شمس، ومدير معهد بحوث الهندسة الزراعية سابقا.*
[٢] *أستاذ الهندسة الزراعية – كلية الزراعة – جامعة المنصورة.*
[٣] *أستاذ مساعد الميكنة الزراعية – كلية الزراعة – جامعة المنصورة.*
[٤] *باحث – معهد بحوث الهندسة الزراعية – الدقى – جيزة.*

أجري هذا البحث بهدف دراسة وتقييم إستخدام درجات الحرارة المرتفعة لفترات زمنية قصيرة في التجفيف الجزئي والتعقيم لمحصول الأرز ذو المحتوي الرطوبي المرتفع حيث تم تصنيع نموذج تجريبى لمجفف دوراني يعمل بخاصية التوصيل الحراري المباشر كصورة أساسية لعملية الانتقال الحراري من سطح اسطوانة التجفيف إلي الحبوب بغرض إجراء التجارب المعملية عليه حيث يعطي النموذج التجريبي مدي من درجات الحرارة تمثل في ٧٥ ، ١٠٠ ، ١٢٥ ، ١٥٠ °م سرعة دوران من ٥ – ١٥ لفة / دقيقة، معدل تغذية للحبوب ١,٥ ، ٢,٥ ، ٣,٥ كجم/ بالإضافة إلي تغيير زمن بقاء الحبوب داخل الوحدة التجريبية لفترات زمنية تراوحت بين ٢، ٤، ٦، ٨، ١٠، ١٢ دقيقة. وقد تم استخدام الوحدة التجريبية السابقة في إجراء التجارب المعملية للحصول علي أفضل العوامل المؤثرة في كفاءة عملية التجفيف الجزئي والتعقيم للحبوب حيث أظهرت النتائج المتحصل عليها إنخفاض المحتوي الرطوبي للحبوب بصورة سريعة تزيد بزيادة درجة حرارة سطح إسطوانه التجفيف وكذلك زمن التجفيف ، بينما تنخفض بزيادة معدل تغذية الحبوب. تم أيضا قتل نسبة عالية من الفطريات التي تنمو علي سطح الحبة حيث وصلت تلك النسبة إلي حوالي ٧٠ – ٨٥٪ عند استخدام درجة حرارة ١٥٠ °م لمدة تراوحت بين ٤ – ٦ دقائق حسب المحتوي الرطوبي الابتدائي للحبوب. أدت عملية التجفيف السريع والتعقيم باستخدام النظام المقترح إلي خفض نسبة الكسر في الحبوب إلي حوالي ٣٠ – ٤٥٪ بالمقارنة بالحبوب المجففة بالطريقة التقليدية. تم إستنتاج مجموعة من المعادلات التجريبية والمعادلات العامة يمكن إستخدامها في دراسات مستقبلية تهدف إلي تصميم وتصنيع مجفف دوراني كامل.