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STORAGE OF CONDITIONED HIGH MOISTURE PADDY UNDER DIFFERENT STORAGE SYSTEMS

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Abstract

The effect of conditioning process (accelerated drying and sterilization) on safe storage of high moisture rough rice was studied. The optimum time-temperature combination of 150^{o}C and 6 mins and a feed rate of 2.5 kg/pitch was selected for conditioning high moisture rough rice (24±1% w.b.) using a full-scale conduction heating rotary dryer (El-Sahrigi *et al.*, 1999). The obtained final grain moisture content and the fungal mortality level after the conditioning process were 18.23 (% w.b.) and 79.8% respectively. The conditioned grain was stored for 8 months under different storage conditions of aerated silos, non-aerated silos and sack storage method and compared with the grains dried in the open to a similar level of final moisture content. The results showed that, storage of the conditioned high moisture rough rice resulted in a grain moisture reduction up to a final level of 14% w.b. after 13 and 115 days for the aerated silos and burlap sacks storage methods respectively. However, the grain moisture content was approached about 16.8% at the end of storage period for the grain stored in non aerated silos. The drying effect of grain during storage process was greatly contributed to keep the grain without deterioration during long term storage in both aerated silos and burlap sacks. Under all storage conditions, heat-treated and sterilized grain exhibited lower broken and discolored kernels in comparison with the naturally dried grains stored under similar storage condition. The percentage of broken and discolored kernels was the lowest for grains stored in aerated silos followed by sack storage method and non-aerated silos respectively.

INTRODUCTION

Rice is presently the most important grain 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. 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)*. These losses include reduction in germinability, discoloration of whole or part of the grains, reduced milling yields, unfavorable changes in cooking and eating quality, and potential health hazards from mycotoxines *(Jindal and Reyes 1987)*. Recently, in Egypt rice harvesting has been mechanized by the use of combine harvesters, which enable large quantities of high moisture grains to be harvested in short time. The almost universal use of the combine harvester, coupled with increased yield, has made it difficult for milling companies to dry all the grain in few weeks during and shortly after harvest. On the other hand the delay in processing the high moisture grain results in rapid qualitative deterioration and high quantitative losses *(El-Kholy, 1991)*. A real solution to this problem will consist of either avoiding drying delays or extending the safe storage period of high moisture paddy by conditioning the grain for delaying or stopping its rapid deterioration during this period.

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. 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, as a method of conditioning could be beneficial in terms of rapid drying, improved milling quality and possible destruction of microorganisms. A side from drying grains to safe moisture level, heat sterilization of high moisture rough rice could prove to be an innovative approach to extend its safe storage period. The inactivation of microorganism by the application of heat is common in food processing industry but it has not been applied to preserve the quality of high moisture grains. *(Christensen and Kaufmann, 1974)*.

Gustafson and Morey (1978) found that a combination of high temperature, low temperature drying system resulted in significant effect in keeping the grain quality without deterioration as measured by fine material, test weigh, breakage susceptibility, germination and mold development when compared to a conventional high-temperature drying system.

Abd El-Aziz (1981) proposed a concept to overcome the problem of harvesting large quantities of high moisture paddy in a short period of time using combine harvesters. In this concept the grains will be partially dried to 18%, thoroughly cleaned and stored temporally for about a month before final drying to 14%. Such a concept has the capability of spreading out the peak drying demand.

Tumambing (1986) conducted an experimental work on two-stage or combination drying of high moisture paddy in the humid tropics. The results of the experiment showed that two-stage drying is a highly feasible drying strategy in terms of technical efficiency, cost effectiveness and product quality.

Matouk (1981) reported that, the practice of holding wet grain through by using aeration become more wide spread, corn at 18 to 22 percent moisture has been held from harvest to the next spring.

El-Kholy (1991) studied the effectiveness of aeration methods during storage of high moisture paddy on reducing the initial moisture content and maintaining the quality of the stored grains. He concluded that, aeration process reduced moisture content and temperature of the stored grains to a level prevented spoilage.

This study aims to asses and evaluate storage of the conditioned high moisture rough rice (partially dried and sterilized) under different storage conditions of aerated silos, non-aerated silos and burlap sacks. In addition, the effect of heat treatment used for the conditioning process on safe storage period and the changes in grain physical quality and milling potential were also investigated.

MATERIAL AND METHODS

Rough rice used for the experimental work was a short grain variety (Giza 176) which was harvested from the experimental farm of the Rice Mechanization Center (R.M.C) at Meet El-Dyba, Kafr El-Sheikh Governorate during 1997 rice harvesting season. The experimental work included storage of the conditioned grain (partially dried and sterilized) under different storage conditions of aerated silos, non-aerated silos, and burlap sacks. In addition, laboratory tests were conducted for evaluating the quality changes of the stored grain.

Test procedure and equipment

High moisture rough rice with initial moisture content of 24.53 % was partially dried and sterilized using a full-scale conduction heating rotary dryer *(El-Sahrigi et al., 2000)* at a time-temperature combinations of 150^{O}C for 6 mins and a feed rate of 2.5 kg/pitch. The obtained grain final moisture content was about 18.23% w.b. and the corresponded fungal mortality level was about 79.8%. For evaluating the above grain conditioning method, a similar amount of freshly harvested rough rice was naturally dried in the open up to a nearly similar level of grain final moisture content. Both types of grain were stored under different storage conditions of aerated silos, non-aerated silos and burlap sacks for a period of 8 months.

Structure of storage silos

Four identical cylindrical silos were designed and constructed at the workshop of the department of Agric. Mech., Fac. of Agric. Mansoura Univ. The experimental silos were installed at the research station of Rice Mechanization Center, Meet El-Dyba, Kafr El-Sheikh governorate. Each silo having a gross dimensions of 0.75 m diameter and a 1.5 m height with a false bottom forming a plenum chamber of about 0.3 m height. Two silos were connected to a 0.25 kW centrifugal fans by means of 0.05 m (2 in) diameter and 2m long P.V.C. pipe, each pipe provided with a control valve for air flow rate adjustment. The centrifugal fans were automatically operated using a differential thermostat adjusted to operate the fan when the temperature of the stored grain bulks is higher than the temperature of the ambient air by $5^{o}C$. Each fan also connected to an electric counter for recording the operating hours and electricity consumption. For comparison, another two similar silos were left without aeration, one of them was filled with heat-treated and sterilized grain and the other was filled with naturally dried grain. Figure 1 shows the structure of the experimental storage silos.

Sack storage tests

Two ballets of grains stored in sacks were used as a representative of sack storage method used in the traditional milling companies. The sacks were placed on wooden platforms and covered by sheets of convas to protect them from rain. One ballet of sacks was filled with a partially dried and sterilized grain and the other ballet was filled with grains dried in the open to a similar level of moisture content.

For dryaeration purpose of the conditioned grain (partially dried and sterilized grain), air flow rate used for bulk storage in the aerated silos was adjusted to 0.04 m^3/h. kg. of grains as recommended by *El-Kholy (1991)*. This rate of air flow was continued until the grain moisture content reached about 14% w.b., after that the air flow rate was reduced to 0.02 m^3/h per kg of grains as used in the commercial milling companies during long term storage. As the storage experiments proceeded, samples of grain were taken every two weeks for determining the changes in grain quality. The following measurements were taken during the storage period:

Test conditions:

A-Storage methods:

1- Aerated silos.

2- Non-aerated silos.

3- Burlap sacks.

B-Grain condition:

1- Heat treated grain

2- Naturally dried grain

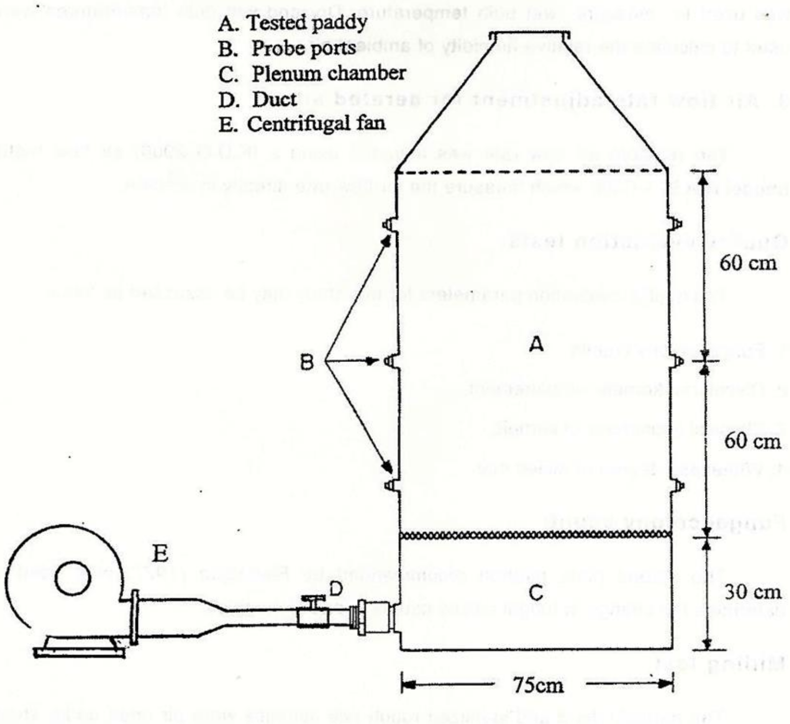

Fig. 1. Structural feature of the aerated silo.

1. Grain moisture content

Samples from different layers of the storage silos and sacks ballets were taken every two weeks for moisture content determination using the oven drying method *(AOAC 1990)*.

2. Grain bulk and air temperature measurements during storage process

The universal digital measuring system (model Kaye Dig. 14) connected to 48 channels scanning box with thermocouples was used to measure the grain bulk temperatures at different points of each storage method. Thermocouples were placed at top, middle, and bottom zones of each bin and ballets. One thermocouple was used to measure dry bulb temperature, another thermocouple covered with wet cotton cloth was used to measure wet bulb temperature. Dry and wet bulb temperatures were used to calculate the relative humidity of ambient air.

3. Air flow rate adjustment for aerated silos

The required air flow rate was adjusted using a (K.D.G 2000) air flow meter (model R.A.B. 14728) which measure the air flow rate directly in m^3/min.

Quality evaluation tests:

The quality evaluation parameters for this study may be assessed as follow:

1. Fungal colony counts.
2. Discolored kernels measurement.
3. Physical soundness of kernels.
4. Whiteness degree of milled rice.

Fungal colony count:

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

Milling test

The partially dried and sterilized rough rice samples were air dried under shade up to a final moisture content level 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 was passed through a *Satake* rubber roll husker (model *THU 35A*) 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.

$$\text{Milling yield (\%)} = \frac{\text{weight of milled rice}}{\text{weight of rough rice}} \times 100 \quad \text{......................... (1)}$$

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

Discolored kernels measurement

A total of 125 g of rough rice sample was dehusked and milled using a "*satake*" laboratory husker and polisher. The resulted white rice was weighed, and the discolored kernels in milled rice was separated manually by visual inspection and then expressed later as percentage by weight using the following equation:

$$\text{discolored kernels, \%} = \frac{\text{weight of discolored kernels}}{\text{total weight of sample}} \times 100 \quad \text{............. (3)}$$

Whiteness degree of milled rice

The whiteness degree of milled rice samples was measured using a *Kett* whiteness meter *(model C-300)*. The meter was calibrated using the calibration Figures for white rice. The white rice samples was filled into the measuring Figures and inserted into the meter tube for a three mins. The whiteness degree of the tested sample was displayed digitally into the meter screen as units.

RESULTS AND DISCUSSION

1. Moisture-time history during storage of high moisture rough rice under different storage conditions

Figure 2 illustrates the change in grain moisture content as related to storage time at different layers of the storage silos during bulk storage of the conditioned and the naturally dried grains. The figure shows that, moisture content of the conditioned and the naturally dried grain stored in the aerated silos could be reduced to a final moisture content of about 14% after 9 days of storage. It also indicates that, a drying zone was established immediately at the bottom layer of both silos and moved to the middle and top layers based on the changes of grain moisture content and air relative humidity at each layer.

Beyond this period, the average moisture content of both the conditioned and the naturally dried grain stored in the aerated silos was remained fluctuated between 13.5 and 15% w.b. up to the end of storage period as presented in Figure 3.

In case of the non-aerated silos, the average moisture content of the heat-treated grain decreased at a very slow rate up to final moisture content of 16.7% at the end of storage period. However, the moisture content of the naturally dried grain was increased up to about 21.3% and started to decrease after 28 days up to a final moisture content of 17.4% at the end of storage period. The observed increase in grain moisture content of the non-aerated silo filled with naturally dried grain could be attributed to the water vapor produced as a result of grain and fungi respiration during this period. The above mentioned results reflected the effect of grain sterilization in reducing fungal activity and respiration rate of the stored grain. In fact, the change in moisture content of the grain stored in the non-aerated silos does not necessarily follow a certain pattern, but depends strongly upon the grain condition and the surrounding ambient temperature.

The moisture content of the naturally dried grain stored in burlap sacks was slightly higher in comparison with that of the conditioned grain. This slight difference in moisture content between the conditioned and the naturally dried grain may be attributed to the difference in grain respiration and fungal growth rate. In general, grain moisture content was reduced to about 16% after 50 days of storage and 14% after 115 days of storage for both types of grain. The reduction in moisture content of the grain stored in the burlap sacks may be attributed to the natural aeration occurred as a result of sacks orientation perpendicular to the wind direction as used in the commercial milling company.

2. Effect of storage conditions on grain bulk temperature:

The change in grain bulk temperature as related to storage time for different grain and storage conditions is illustrated in figure 4. This figure shows that, the bulk temperature for the heat-treated and the naturally dried grain stored in aerated silos was relatively reduced during the first few days of storage. The reduction in grain temperature during this period could be attributed to the evaporative cooling resulted

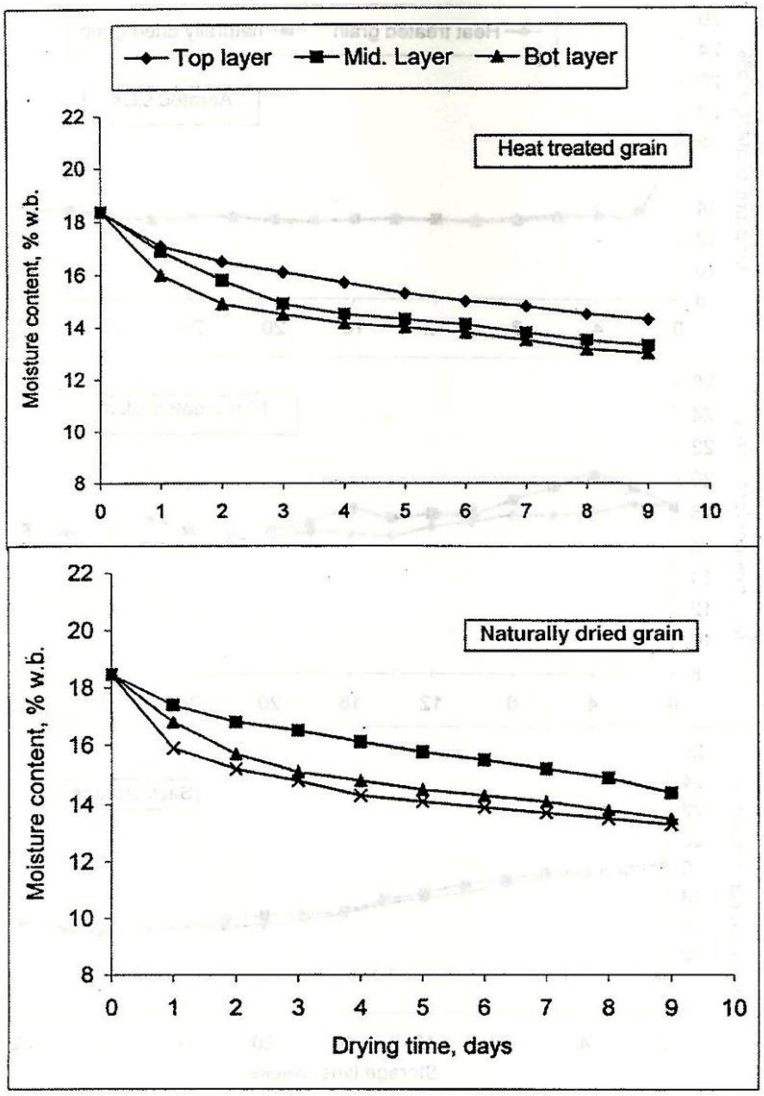

Fig. 2. Grain moisture reduction in the aerated silos during in-storage drying of the partially dried grains.

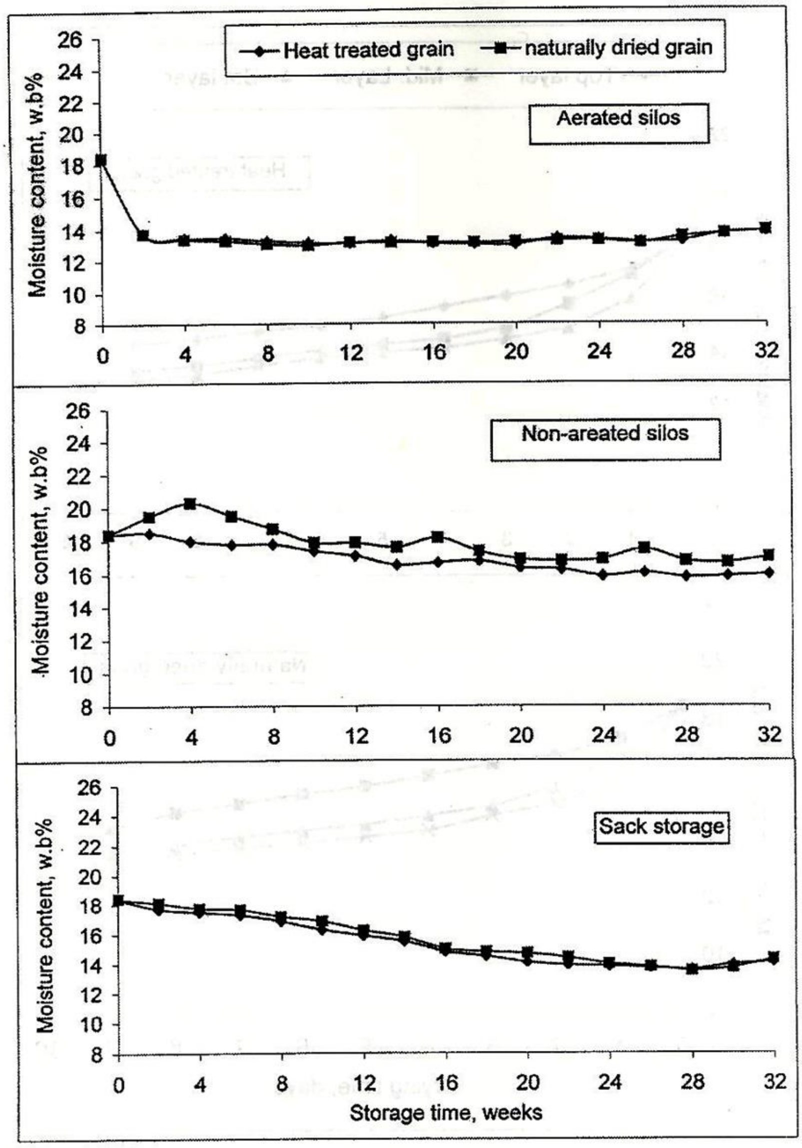

Fig. 3. Change in grain moisture content during long-term storage under different storage methods.

from moisture loss during this period. After that, the grain temperature was remained nearly similar or slightly lower than the ambient temperature throughout the storage period. This proved that, the temperature control system used for aeration process was working efficiently and could prevent any additional heat to be accumulated in the grain bulk during the storage period. However, the fan operation times for the silo filled with the naturally dried grains was longer than that of the silo filled with the heat-treated grain. This means that, the grain bulk temperature of the naturally dried grains was increased more times during the storage period. The recorded fans operation time for the aerated silo filled with heat-treated grain was 1320 h. in comparison with 1570 h. for the aerated silo filled with naturally dried grain. The corresponded electricity consumption for the centrifugal fans used for the aeration process were 251 and 329 kW respectively, this means that, the silo filled with heat-treated grain had reduced the electricity consumption by 23.71%.

When comparing grain bulk temperature of aerated silos with that of non-aerated silos, the effect of aeration process on reducing grain bulk temperature was very pronounced. Non aerated silos exhibited higher temperature levels in comparison with the aerated silos for both types of grain. The observed difference in grain bulk temperature between the conditioned and the naturally dried grains stored under similar storage conditions could be attributed to the differences in respiration and fungal growth rate of both types of grain. The bulk temperature of the heat-treated grain, which stored in burlap sacks, was also lower than that of the naturally dried grain during the first period of storage. After that, the ambient air temperature and relative humidity for both types of grain affected the grain bulk temperature. Figures 5 and 6 illustrate the maximum and minimum ambient air temperatures and air relative humidity during storage period.

3. Effect of storage conditions on fungal growth rate and discoloration of milled rice

The change in fungal load ratio as related to storage time for different grain and storage conditions is illustrated in figure 7. Fungal load ratio [fungal count at any time during storage period/fungal count just before start of storage period] of the heat-treated grains was lower than that of the naturally dried grains under all storage conditions. The fungal load ratio was 26.41 and 87.54% at the beginning of storage period for the heat treated and the naturally dried grains respectively. However, due to the drying and cooling effect of the aeration process, fungal load ratio was reduced up to 6.4% and 16% respectively at the end of storage period.

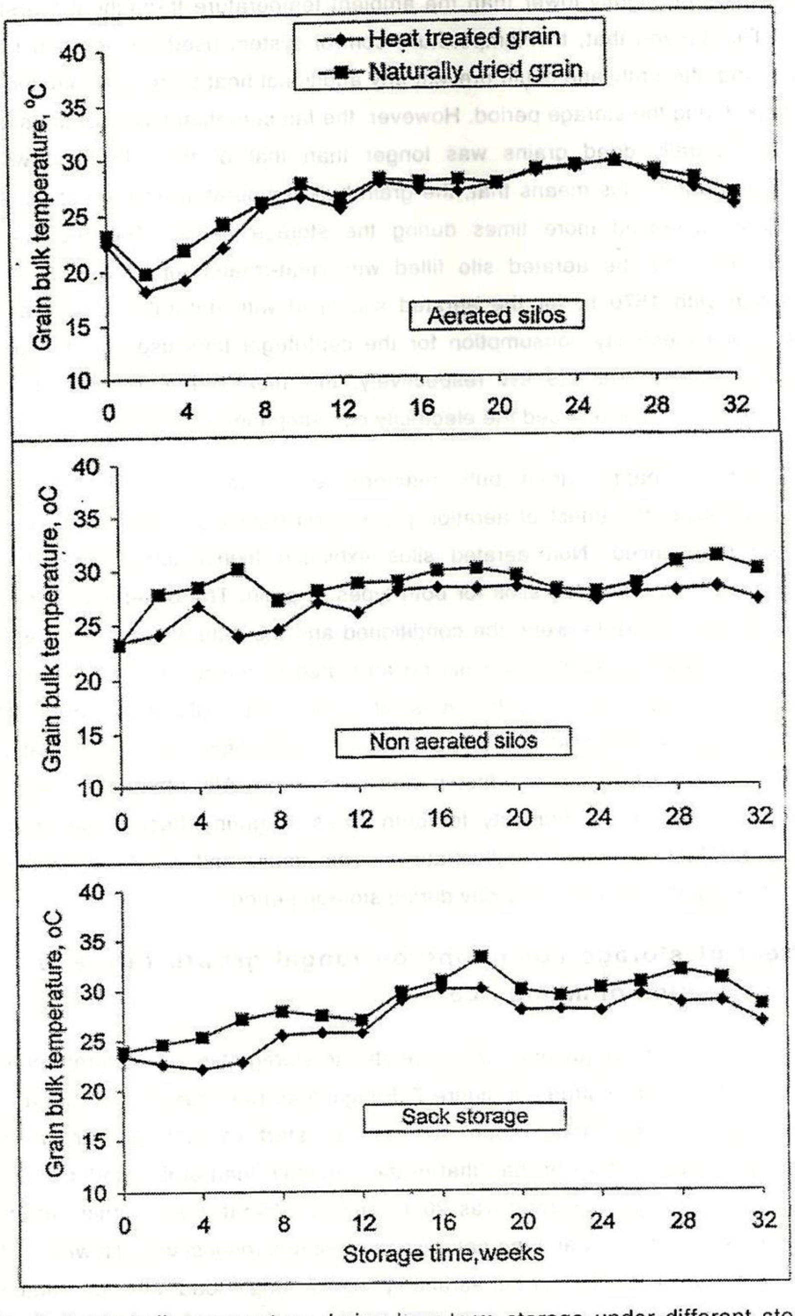

Fig. 4. Grain bulk temperature during long-term storage under different storage method.

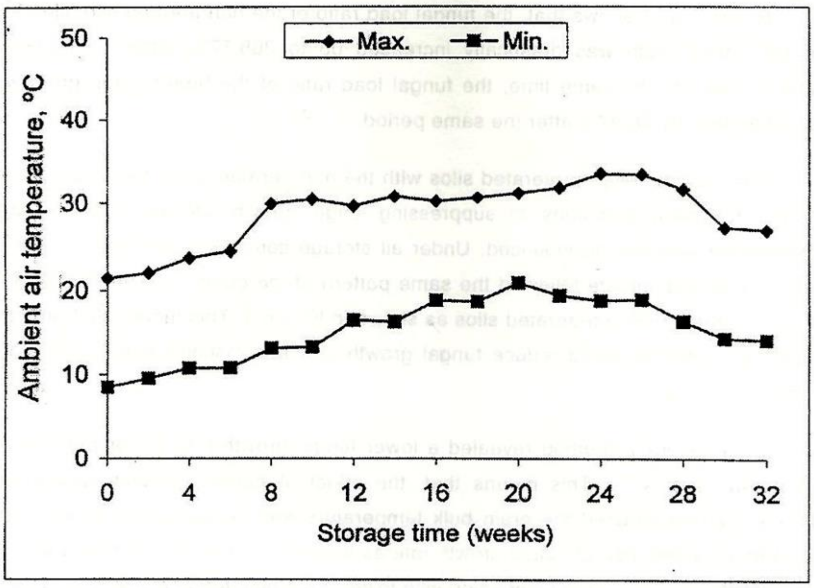

Fig. 5. Ambient air temperature during storage period.

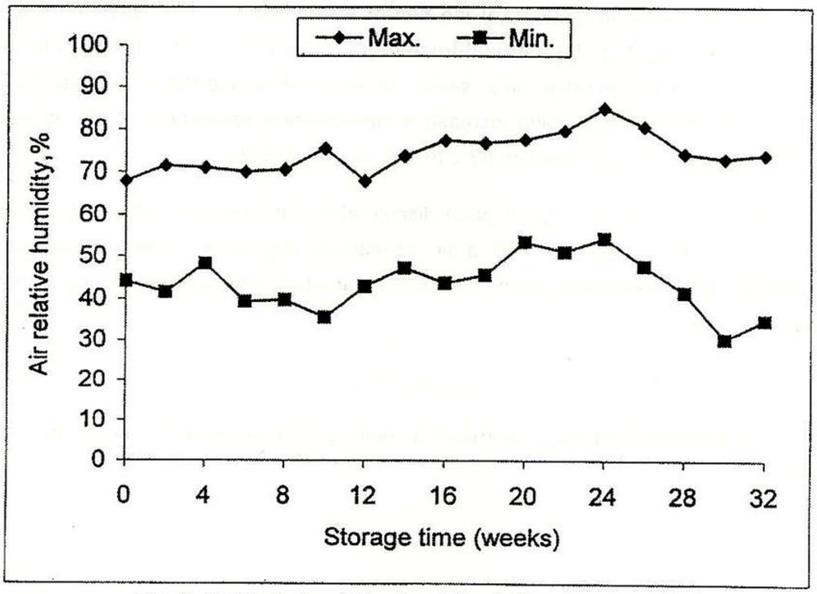

Fig. 6. Ambient air relative humidity during storage period.

Figure 7 also shows that, the fungal load ratio of the non-aerated silo filled with naturally dried grain was drastically increased up to 208.57%, after 14 weeks of storage time. On the same time, the fungal load ratio of the heat-treated grain was increased only by 56.97% after the same period.

When comparing the aerated silos with the non-aerated silos, the effect of both storage and grain conditions on suppressing fungal growth rate and reducing grain discoloration was very pronounced. Under all storage conditions, the change in grain discoloration percentage followed the same pattern of the change in fungal load ratio for both aerated and non-aerated silos as shown in Figure 8. This means that, the heat sterilization process could reduce fungal growth rate and discoloration of the stored grains.

Sacks storage method revealed a lower fungal growth rate in comparison with the non-aerated silos. This means that, the effect of natural aeration during sack storage method reduced the grain bulk temperature and moisture content to a level prevented the increase of fungal growth rate as observed in the non-aerated silos. The lower fungal growth rate accompanied with lower grain bulk temperature and moisture content reflected in a lower percentage of discolored kernels. However, when comparing the sack storage method with the aerated silos, fungal load ratio and the percentage of discolored grain were slightly higher at the sack storage method for both types of grains. In general, at the end of storage period, the increase in grain discoloration percentage for the heat-treated grain was 0.83, 2.20 and 4.53% for the storage conditions of aerated silos, sacks storage method and the non-aerated silos respectively. The corresponding increase in discoloration percentage of the naturally dried grain was 1.42, 2.52, and 25.53% as shown in Figure 9.

To estimate the change in grain discoloration ratio (Gd) as related to storage time (t) for different storage and grain conditions, regression analysis revealed a significant linear relationship between these parameters. The regression equation for the best fit was:

$$Gd = A + Bt \qquad (4)$$

The values of regression correlation coefficients in equation (4) are summarized in Table 1.

Table 1. Regression and correlation coefficients of equation (4) for different storage conditions.

Storage condition	Type of grain					
	Heat treated grain			Naturally dried grain		
	A	B	R^2	A	B	R^2
Aerated silos	1.0765	0.0996	0.97	1.6173	0.1206	0.85
Non-aerated silos	5.0883	0.5465	0089	19.449	2.449	0.96
Sacks storage	1.306	0.2378	0.89	1.8855	0.2331	0.97

4. Effect of storage conditions on broken percentage of milled rice

Heat-treated rough rice grains showed a marked reduction in the proportion of broken kernels in comparison with the naturally dried grains stored under similar storage conditions. Figure (10) illustrates the change in grain broken percentage as related to storage time for the heat-treated and the naturally dried grain. The figure shows that, the broken percentage of rough rice stored in the aerated silos was the lowest followed by sacks storage method and non-aerated silos. On the other hand, at similar storage conditions, the heat-treated grains showed lower broken percentage in comparison with the naturally dried grains.

The observed lower broken percentage of the heat treated grain at the beginning of storage period could be attributed to the initial improvement in milling quality of the heat treated grain as a result of heat treatment as explained by *(El-Sahrigi et al., 1999)*. Following this period, the increase rate in grain broken percentage was dependent upon the increase of damaged kernels resulted from fungal activity. At the end of storage period, heat-treated rough rice samples showed an increase in broken percentage of milled rice by about 1.22, 2.80 and 5.66% for storage conditions of aerated silos, sack storage and non aerated silos respectively. The corresponding increase in broken percentage of the naturally dried grain stored under similar storage conditions were 2.11, 3.01 and 19.48% respectively.

For estimating the change in broken ratio (Br) of milled rice as related to storage time (t), regression analysis was applied. It indicated a significant linear relationship (P = 0.05) between these parameters for all storage conditions. The regression equation obtained was:

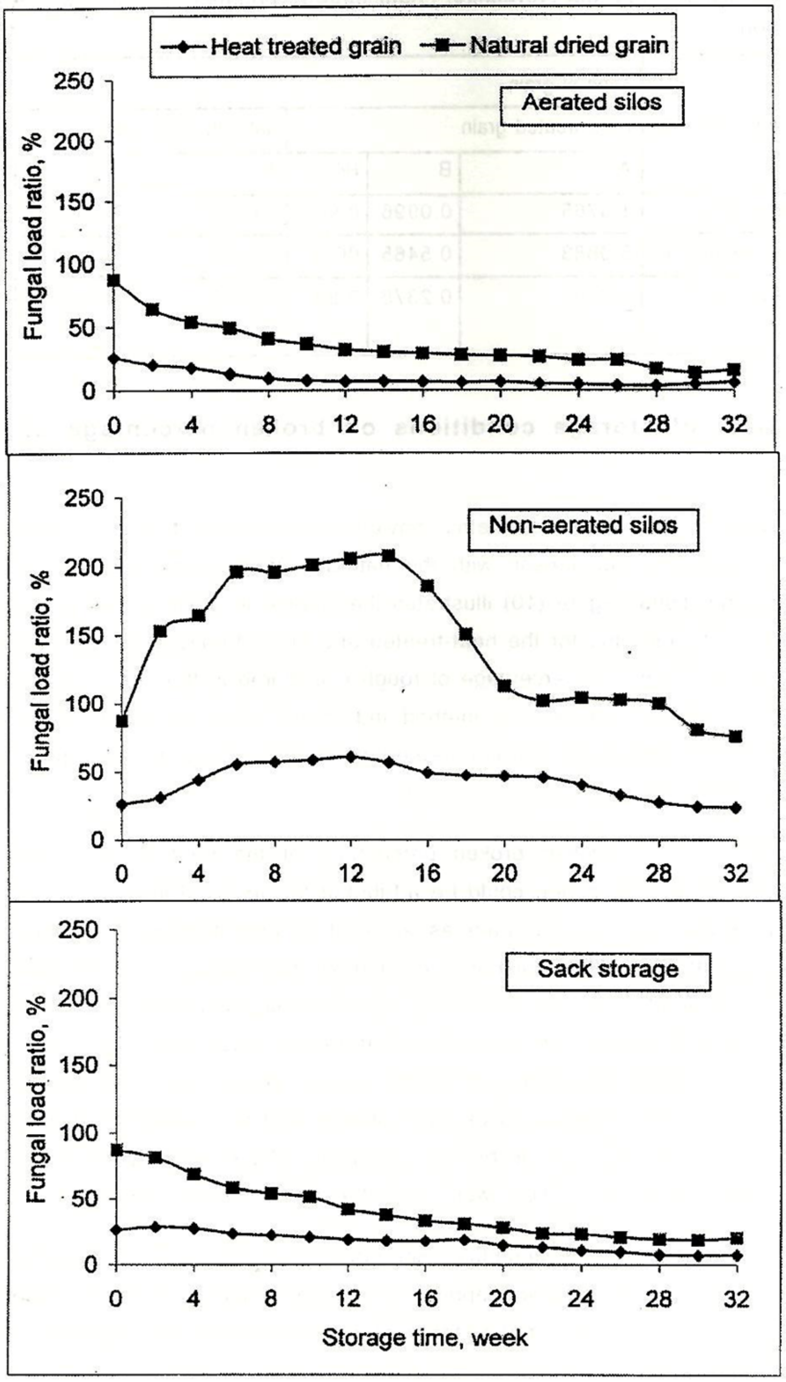

Fig. 7. Fungal load ratio as related to storage time for different storage methods.

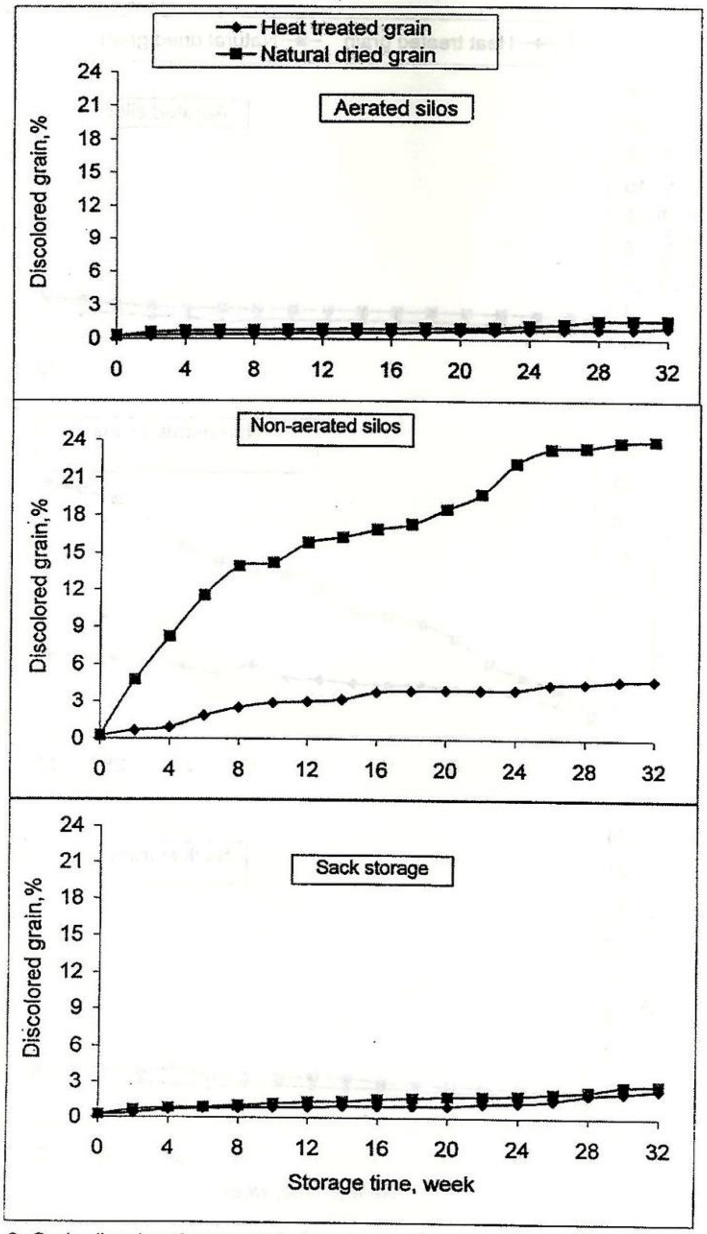

Fig. 8. Grain discoloration as related to storage time for different storage methods.

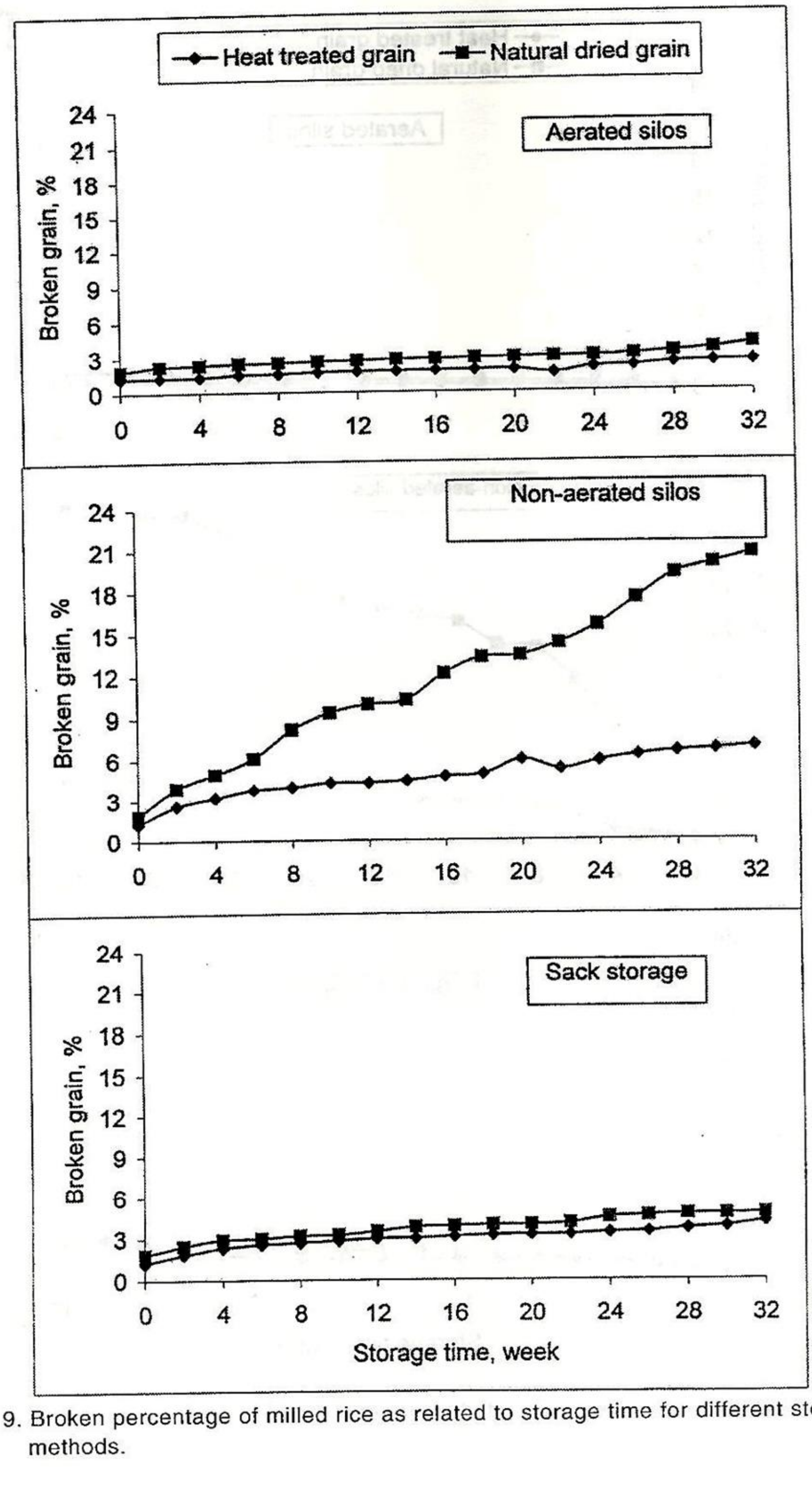

Fig. 9. Broken percentage of milled rice as related to storage time for different storage methods.

$Br = A + Bt$ .... (5)

The values of regression and correlation coefficients in equation (5) are summarized in Table (2).

Table 2. Regression coefficients of equation (5) relating grain broken ratio with storage time.

Storage condition	Type of grain					
	Heat treated grain			Naturally dried grain		
	A	B	R^2	A	B	R^2
Aerated silos	0.9958	0.0284	0.95	1.1318	0.0239	0.90
Non-aerated silos	2.1195	0.1081	0.96	1.5795	0.3052	0.99
Sacks storage	1.4115	0.0534	0.94	1.3485	0.0416	0.97

In general, the drying effect of grain during storage process and the changes in fungal load ratio was greatly contributed to maintain the grain without deterioration during long term storage.

CONCLUSION

1. Storage of the conditioned grain (partially dried and sterilized) resulted in moisture reduction to a final level of 14% w.b. in both of aerated silos and burlap sacks storage methods. However, the required period to approach this moisture level was varied and dependent upon both grain and storage conditions.

2. The drying effect of grain during storage process was greatly contributed to keep the grain without deterioration during long term storage in both aerated silos and burlap sacks.

3. The limiting factor affects the safe storage period of high moisture rough rice and thus its market grade was the percentage of broken and discolored kernels. This percentage was affected by both grain and storage conditions. Under all storage conditions, heat-treated and sterilized grain exhibited lower broken and discolored kernels in comparison with the naturally dried grain. The percentage of the broken and discolored kernels was the lowest for grains stored in aerated silos followed by sack storage method and non-aerated silos respectively.

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تم دراسة تأثير عملية التكييف (التجفيف الجزئي السريع والتعقيم) لحبوب الأرز ذو المحتوي الرطوبي المرتفع (٢٤ ٪ ± ١ علي الأساس الرطب) علي فترة التخزين الآمن للحبوب. وتمت عملية التكييف للحبوب باستخدام المجفف الدوراني الذي يعمل بخاصية التوصيل الحراري المباشر (السهريجي وآخرون ١٩٩٩) حيث تم ضبط درجة حرارة المجفف عند ١٥٠ ° م وكانت مدة بقاء الحبوب داخل اسطوانة التجفيف حوالي ٦ دقائق مما أدي إلي خفض المحتوي الرطوبي للحبوب إلي حوالي (١٨٪ ± ١ علي الأساس الرطب) ونسبة قتل الفطريات وصلت إلي حوالي ٧٩.٨ ٪ . تم تخزين الحبوب المكيفة بالطريقة السابقة داخل نظم مختلفة للتخزين لمدة ثمانية أشهر ومقارنتها بحبوب مجففة بالطريقة الطبيعية إلي نفس المحتوي الرطوبي. أظهرت النتائج المتحصل عليها انخفاض المحتوي الرطوبي للحبوب المخزنة داخل صوامع مزودة بنظام التهوية الميكانيكية إلي حوالي (١٤٪ علي الأساس الرطب) وذلك بعد حوالي ١٣ يوم من التهوية المستمرة وانخفض المحتوي الرطوبي للحبوب المخزنة في أجولة إلي نفس المستوي بعد حوالي ١١٥ يوم، بينما استمر المحتوي الرطوبي للحبوب المخزنة داخل صوامع غير مهواة أعلي من المستوي الأمثل للتخزين حتي نهاية المدة.

أدت عملية تكيف الحبوب بالإضافة إلي استمرار عملية التجفيف داخل صوامع التخزين إلي زيادة فترة التخزين الآمن للحبوب بالإضافة إلي حفظ جودة الحبوب حتي نهاية مدة التخزين بالمقارنة بالحبوب المجففة بالطريقة الطبيعية تحت جميع ظروف التخزين المستخدمة فكانت طريقة التخزين في صوامع مزودة بنظام التهوية الميكانيكية هي أفضل طرق التخزين تلي ذلك طريقة التخزين في أجولة موجهة في الاتجاه العمودي للرياح بينما لم تكن طريقة التخزين في صوامع غير مهواة ملائمة لعملية التخزين لكلا من الحبوب المكيفة والحبوب المجففة بالطريقة الطبيعية.