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Pyseth Meas, *Massey University*
Anthony H. J. Paterson, *Massey University*
Donald J. Cleland, *Massey University*
John E. Bronlund, *Massey University*
A. John Mawson, *London South Bank University*
Allan Hardacre, *Massey University*
Joseph F. Rickman, *International Rice Research Institute*

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Effects of Different Solar Drying Methods on Drying Time and Rice Grain Quality

Pyseth Meas, Anthony H. J. Paterson, Donald J. Cleland, John E. Bronlund, A. John Mawson, Allan Hardacre, and Joseph F. Rickman

Abstract

Paddy rice was sun dried in Cambodia in 2004 using a range of methods practiced by local rice farmers. For each treatment in the experiment, a grain sample at about 22% moisture (typical harvest moisture content) was sun dried between 8 a.m. and 4 p.m. During experiments, the grain moisture content was measured at regular intervals. The grain varieties used, bed depths, stirring of the grain, bulk tempering after drying and the drying pads had significant effects on the drying time. Drying was faster when bed depth was reduced, regularly stirred but not shaded or covered and when the drying was carried out on a porous pad. Damage to the dried grain was reduced when the bed was thin, stirred and shaded and when the drying was slow on pads with less air circulation.

KEYWORDS: rice, drying, solar, head rice yield, drying time

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1. Introduction

Sun drying of rice after harvest is still the most common practice in Cambodia and many other developing countries, as solar radiation is convenient, simple, and very economical. Therefore, understanding the different parameters that can be controlled by growers on drying performance and on the final quality of the dried rice grain quality is very important, as it can optimize the drying process and maximize the quality and hence value of the grain.

Contrary to other cereals, rice is preferably consumed as cooked whole grains (Kamst et al., 2002). Thus, maximizing the head rice yield (HRY), which is usually expressed as a weight percentage of whole and broken white rice kernels that are larger than 3/4 of the kernel of the paddy, is a priority for growers. Arora et al. (1973), Cnossen et al. (2001), Cnossen et al. (2003), Muthukumarappan et al. (1992), Siebenmorgen et al. (1992), Siebenmorgen (1994), Steffe and Singh (1980), Webb et al. (1986) and Zhang et al. (2003) all show that the typical value of broken rice is about one third to one half of that of whole rice. Head rice yield depends not only on variety and crop management but also on the management of post-harvest operations and in particular, the conditions used to dry the rice (Abud-Archila et al., 2000, Brooker et al., 1992; Izadifar and Mowla, 2003; Siebenmorgen, 1994).

The drying of grains is influenced by a number of processes which can broadly be split between the heating of the grain and mass transfer processes such as the removal of moisture by the movement of air or water vapour and diffusion processes. Diffusion is the main process occurring to transfer heat and moisture within the rice grains. As a rule of thumb, diffusion processes are about an order of magnitude slower than heat transfer.

When rice is sun dried the grain is spread in a thin layer on flat ground and exposed to the sun, wind and other atmospheric conditions. In this system, heat and mass transfer occur simultaneously; solar radiation heats the exposed surface of the grain bed and part of this energy is transferred from the surface to the base of the bed by conduction from grain to grain and by convection of air within the bed to raise the temperature of grain deeper within the bed. As the bed heats, the water vapour deficit between the air within the bed and the rice grains increases and the grain begins to dry. Clearly, air deeper in the bed will be cooler and more saturated with water vapour than air near the surface of the bed and for this reason shallow beds and frequent stirring are likely to increase the rate of drying. Some of the heat absorbed by the grain bed can also be lost by conduction to the ground below the grain bed (Garg and Kumar, 1999).

The drying rate in the system depends on several factors. High incident solar radiation levels or solar intensity will increase the temperature at the bed surface and hence the rate of energy transfer into the bed. Reductions in the relative humidity (RH) of the air at the bed surface will, also increase the rate of drying by increasing the vapour pressure deficit increasing the rate of drying of the rice in the bed. Increasing wind velocity decreases the thickness of the boundary layer at the surface of the bed and will increase the rate of mass transfer of moisture from the bed to the surrounding air (Mulet et al., 1993).

The objectives of this research were to investigate some farmer controlled variables that can affect the rate of sun drying of head rice from 22% to 14% grain moisture content in Cambodia during 2004 using a range of methods practiced by local rice farmers.

2. Materials and methods

Two rice varieties (Phka Knhey and CAR11) that are commonly grown in the region were used in this study. All of the rice sown was purchased from seed growers to ensure that the varieties were true to type. The crop was manually harvested when the grain moisture content (MC) was around 22%. The grain was immediately removed from the rice heads using the traditional threshing method of trampling with human feet and was cleaned by hand winnowing using traditional methods. Since the freshly harvested grain available for this work was at a lower moisture content than the 22% MC required for the drying experiments it was re-wetted and slowly dried to the required moisture content using the method described by Fan et al. (2000b), Morita and Singh (1979) and Siebenmorgen and Jindal (1986). After mixing thoroughly, the grain samples were sealed in airtight bags with low moisture permeability, before storage at $5^{o}C$. The bags were turned and shaken periodically to establish uniform moisture distribution within the grain mass.

The required amount of grain was removed from cold storage one day prior to each of the drying experiments and kept in sealed containers while equilibrating to room temperature and to prevent condensation occurring during equilibration (Chen and Wu, 2001; Jindal and Siebenmorgen, 1987; Shei and Chen, 2002; Steffe and Singh, 1980; Sun et al., 2002; Wongwises and Thongprasert, 2000).

The sun drying experiments were conducted between 8 am to 4 pm from December 18 to 25, 2004 in Cambodia. The different drying treatments imposed were based on traditional methods used by Cambodian farmers. The experiment was designed as a full factorial with four main factors, these were; drying pad type (4 levels), rice variety (2 levels), bed depth (2 levels), and mixing. The four drying pad treatments of using a tarpaulin, nylon net, nylon net on husk layer of about 7 cm and mat made of sugar palm leaves beneath the grain bed was blocked within the overall design. The grain bed depths were either 2 or 3 cm and

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the grain was either left unmixed or mixed hourly by hand raking. During drying the grain was either shaded from the sun or left unshaded between 11 am to 2 pm.

For each treatment 5kg of rice was used and for this reason the area of each treatment varied depending on bed depth.

During the drying process the moisture content of the grain was measured hourly using a Wile 55 digital moisture meter. The meter was calibrated against grain samples for which the moisture content had been measured by oven drying at 130°C for 24 h in accordance with the ASAE methods (2001 and 2004). This method is widely used (Cnossen et al., 2003; Jindal and Siebenmorgen, 1987; Manski et al., 2002; Perdon, 1999; Perdon et al., 2000; Sarwa and Kunze, 1989; Sun et al., 2002).

Most of the beds established during this work reached the targeted moisture content of 14% (wwb) within one day but some required a little longer and were repackaged in sealed plastic bags overnight before drying was completed the following day. When the target MC was reached, the grain was immediately collected and packed into sealed plastic bags and stored at ambient conditions until testing was completed.

A milling test was performed following the principles described by Abud-Archila et al. (2000), Bautista et al. (2000), Bhashyam et al. (1975), Patindol et al. (2003), Perdon (1999), Reid et al. (1998), Steffe and Singh (1980), Wongpornchai et al. (2004), Zhang et al. (2003) and Zhang et al. (2005). After a thorough re-clean by a small cleaner, two replicate samples were milled about two weeks after the drying experiment.

A small mechanical seed cleaner or mill consisting of a rubber-roller husker, a friction polisher and an indented cylinder separator was used to assess head rice yield (HRY) as a proportion of the weight of the paddy rice sample. The machine was designed and produced in Thailand and has been used widely by Thai and Cambodian rice millers to test the milling quality of paddy rice. The machine first dehulls the seed before weighing and grading in the indented cylinder section to separate kernels longer than ¾ of the whole kernels, from the broken kernels. The head rice yield (HRY) was determined as:

$$HRY_{MILL} = \frac{W_{3/4}}{W_{pi}} \times 100 \qquad (1)$$

Where,

$W_{3/4}$: Weight (g) of white rice longer than ¾ of whole kernels

W_{pi} : Initial weight (g) of paddy sample, g

A mechanical impact tester (MI) that was designed and constructed by Plant and Food Research Ltd. (New Zealand), based on the principle of the Stein breakage tester, was used to determine the ability of the grain to withstand a period of mechanical impacts. Similar methods have been used for testing maize grain by many researchers (Fortes and Okos, 1980; Hardacre et al., 1997; Meas, 1999; Miller et al., 1981; Thompson and Foster, 1963; Weller et al., 1990). A 50 g sample of brown rice was placed in the breakage tester and impacted for 1 minute. The processed material was then graded using an indented cylinder separator (LA-T, Westrup, Slagelge, Denmark). After grading, the HRY from the impact test was determined as:

$$HRY_{MI} = \frac{W_{3/4}}{W_{bMI}} \frac{W_{bd}}{W_{pi}} \times 100 \tag{2}$$

Where,
W_{bd} : Weight (g) of brown rice obtained from dehusking the paddy rice
W_{bMI}: Weight(g) of the brown rice sample assigned for MI test

This test therefore represents the proportion of whole brown rice grains longer than ¾ of whole kernels that remained after the MI test as a proportion of the yield of brown rice produced from dehusking the paddy rice. This, in effect, is the yield of white rice that is produced from brown rice after polishing and a standardised handling test.

All the data obtained from the experiments were subjected to an analysis of variance using SAS for Windows, v. 8.02 (SAS Institute, Cary, NC) and Minitab (release 14) to detect significant differences among the applied treatments on the drying performance and the quality of the dried grain. Differences were considered significant for $p<0.05$.

3. Results and discussion

3.1 Effect on the drying time

The analysis revealed that there was no significant interaction effect between the various factors on the drying time, indicating that the factors acted independently.

For the main effects, drying times for the two rice varieties were significantly different ($p<0.05$). On average, to reach the target MC of 14%, Pka Knhey variety took 15 h and 34 min which was about one and a half hours longer than CAR11 variety (Table 1). The reason for this is not known, however it may have been due to either harder endosperm or larger grain with a lower surface to volume ratio.

When the depth of the grain bed was reduced from 3 to 2 cm the drying time was significantly reduced ($p<0.01$) by 4.3 hours or about 25% which is in proportion to the 30% reduction in bed depth (Table 1). Mixing the grain in the bed hourly to bring cooler grain with a high moisture content to the surface also significantly ($p<0.001$) reduced the drying time and the grain reached the target MC three hours faster than when it was not stirred (Table 1).

Table 1: Effect of variety, depth, stirring, covering and pad on the drying time, h

Factor	Variety	Drying time (h)	P (significance)
Variety	Pka Knhey	15.57[a]	<0.05
	CAR11	13.93[b]	
Bed depth	2 cm	12.60[a]	<0.01
	3 cm	16.90[b]	
Stirring method	No stirring	16.28[a]	<0.01
	Stirring	13.22[b]	
Shading	No shading	11.40[a]	<0.01
	Shaded	18.10[b]	
Drying pad	Tarpaulin on soil	15.50[a]	<0.01
	Net on soil	15.31[a]	
	Mat on soil	14.13[b]	
	Net on husk	11.08[c]	

Note: Means obtained from each individual variable with the same letter are not significantly different at critical p indicated.

Reducing incident solar radiation by shading the grain bed retarded the drying significantly ($p <0.01$). On average the shaded treatments took about 6.7 h longer to dry than the unshaded treatments (Table 1).

There were significant differences ($p = 0.0001$) in drying time found for the grain dried on different pads (Table 1). Drying on a tarpaulin and on nylon net, both spread directly on the soil, took about 3.5 hours longer than grain dried on the husk layer. This can be explained by the air flow through the husk layer helping to remove moisture from the bed.

3.2 Effect on head rice yield

The head rice yield (HRY) obtained by milling the paddy rice showed significant differences for most of the main effects analysed. None of the second or third order interaction effects were significant at $p<0.05$.

The yield of head rice from the paddy rice (HRY) was similar for the two rice varieties at about 40% (Table 2). However, the MI test shows that the CAR11 variety had kernels that were significantly ($p<0.001$) less prone to breaking during the MI test where the yield of unbroken rice grains was about 4% greater ($p < 0.001$) than that of PkaKnhey variety (Table 2). The kernels of the two varieties had very different dimensions and only one indented cylinder was used in the grading process.

Table 2 shows that the HRY_{MILL} of the grain dried with the two bed depths were not significantly different and that neither the stirring treatment nor the covering treatment significantly affected HRY_{MILL}**.** Small increases in the HRY_{MI} proportions were recorded for the stirring treatment that kept grain in the bed mixed and for the shaded treatment that slowed the rate of drying. Similarly, the drying pad treatments that increased the rate of drying also reduced the HRY_{MILL} and the HRY_{MI}. This is due to stresses built up in the grain due to faster drying that increase the susceptibility of the grain to mechanical damage and associated milling losses. As reported by other authors for maize (Hardacre, Pomeratnz, Stenvert) the drying of glassy grain types such as maize and rice must be carefully controlled with respect to rate of drying, the temperature used and the rate of cooling to reduce the build-up of stresses in the grains and subsequent fracture during storage and handling.

Table 2: Effect of variety, depth, stirring, covering and pad on the HRY

		Variable	
Main effect	Treatment	**HRY_{MILL}, %**	**HRY_{MI}, %**
Variety	Pka Knhey	40.5^a	35.7^a
	CAR11	40.9^a	39.8^b
Bed depth	2 cm	40.8^a	37.6^a
	3 cm	40.5^a	37.9^a
Stirring method	No stirring	41.0^a	37.0^a
	Stirring	40.4^a	38.5^b
Covering method	No covering	39.4^a	36.2^a
	Cover and Shade	41.9^b	39.3^b
Drying pad	Tarpaulin on soil	41.4^a	38.5^a
	Net on soil	41^{ab}	38.8^a
	Mat on soil	40.7^b	37.3^b
	Net on husk	39.6^c	36.4^c

Note: Means for individual variable and quality test with the same letter are not significantly different. (at 1, 5, 1, and 1% levels for variety, bed depth, stirring and covering, respectively. For the pad, the means are significantly different at 1 and 10% for the MI and milling HRYs, respectively).

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4. Conclusions

The drying of rice grain using "on farm" grain handling systems in Cambodia is constrained by two contradictory factors. The first is the need to dry as quickly and as evenly as possible and the second is to preserve the quality of the grain by reducing stresses in the grain that lead to breakage of the grain during handling after dying. Although the yield of head rice for the two rice varieties were similar using the HRY_{MILL} test the Pka Knhey variety clearly withstood handling, estimated from the HRY_{MI} test, better than the CAR 11 variety.

Treatments that reduced the rate of drying or interrupted drying by repositioning grain in the bed (mixing) tended to increase HRY_{MILL} and HRY_{MI}

These results show that uniform slower drying is critical to producing higher HRY. The likely mechanism can be assigned to reduced moisture gradients being induced in the grains and within the bed which in turn eliminates rewetting of the grain which has been attributed to being the cause of cracking of grain kernels.

From the data analysed in this work it can be concluded that the best balance between drying rice grain quickly while maintaining grain of high quality is to dry using a thin bed while stirring the grain bed regularly to enable fast and uniform drying without over drying some grains and under drying others. The key in managing this process is to prevent the rapid drying to a low moisture content of grain near the top of the bed and the very slow drying of grain near the bottom of the bed. For the unstirred system this would mean that to obtain grain at a safe storage moisture content for all the grain in the bed, grain at the top of the bed would have to be at a very low moisture content and therefore highly susceptible to handling damage and eventually poor economic value.

While taking advantage of the faster drying by using an uncovered bed and a pad below the grain that allows some air and moisture movement below the grain bed greater care will have to be taken to manage the drying rate of the grain by using shading when solar radiation is maximal to reduce the drying rate so preventing susceptibility to grain damage.

Since the two rice varieties dried at different rates and showed different resistances to damage under similar drying conditions, variety selection based on simple quality indices after drying is worth considering.

5. References

1. Abud-Archila, M., Courtois F., Bonazzi C. and Bimbenet J. J. (2000). Processing Quality of Rough Rice during Drying - Modelling of Head Rice Yield versus Moisture Gradients and Kernel Temperature. *Journal of Food Engineering*, 45(3): 161-169.

2. Arora V. K., Henderson S. M. and Burkhardt T. H. (1973). Rice drying cracking versus thermal and mechanical properties. *Transactions of the ASAE.* 16(20): 320-327.

3. ASAE. (2001). Moisture Relationships of Plant-Based Agricultural Products: *ASAE. Standard* D245.5 DEC01.

4. ASAE. (2004). Moisture Relationships of Plant-Based Agricultural Products: *ASAE. Standard* D245.5 DEC01.

5. Bautista C. R., Siebenmorgen J. T. and Millsap C. S. (2000). Performance Evaluation of Three Laboratory Rice Mills. *Proceedings of the AACC 2000 Annual meeting* held in November 5 - 9, 2000, in Kansas City, Missouri, USA.

6. Bhashyam M. K., Srinvas T. and Desikachar H. S. R. (1975). Controlled Sun Drying of Freshly Harvested Paddy for Improved Milling Quality. *Journal of Food Science and Technology.* 12: 124-126.

7. Brooker B. D., Bakker-Arkema, W. F. and Hall W. C. (1992). *Drying and Storage of Grains and Oilseeds.* Van Nostrand Reinhold. New York, USA.

8. Chen C. H. and Wu P. C. (2001). Thin-Layer Drying Model for Rough Rice with High Moisture Content. *Journal of Agricultural Engineering Research.* 80(1): 45-52.

9. Cnossen A. G., Siebenmorgan T. J., Yang W. and Bautista R. C. (2001). An Application of Glass Transition Temperature to Explain Rice Kernel Fissure Occurrence during the Drying Process. *Drying Technology*. 19(8): 1661-1682.

10. Cnossen A. G. Jimenez, M. J. and Siebenmorgen T. J. (2003). Rice Fissuring Response to High Drying and Tempering Temperatures. *Journal of Food Engineering*. 59: 61-69.

11. Fan J., Siebenmorgen T. J. and Yang W. (2000b). A Study of Head Rice Yield Reduction of Long- and Medium-Grain Rice Varieties in Relation to Various Harvest and Drying Conditions. *Transactions of the ASAE.* 43(6): 1709-1714.

12. Fortes M. and Okos M. R. (1980). Changes in Physical Properties of Corn during Drying. *Transactions of the American Society of Agricultural Engineers:* 23, 1004-1008.

13. Garg H. P. and Kumar R. (2000). Thermal Modelling and Performance Prediction of Drying Processes under Open-Sun-Drying. http://www.kenes.com/Ises. Abstracts/ Htm/0458.htm.

14. Hardacre K.A, Brenton-Rule R. and Clark M.S. (1997). The Analysis of Maize Grain Quality in New Zealand and Calibration of Testing Methods. *Report No. 367* prepared for the Maize Grain Quality Committee, New Zealand Manufacturers Association. New Zealand Institute for Crop and Food Research Ltd., Christchurch, New Zealand.
15. Izadifar M. and Mowla D. (2003). Simulation of a Cross-Flow Continuous Fluidized Bed Dryer for Paddy Rice. *Journal of Food Engineering.* 58(4): 325-329.
16. Jindal V. K. and Siebenmorgen T. J. (1987). Effects of Oven Drying Temperature and Drying Time on Rough Rice Moisture Content Determination. *Transactions of the ASAE.* 30(4): 1185-1192.
17. Kamst G. F., Bonazzi C., Vasseur J. and Bimbenet J. J. (2002). Effect of Deformation Rate and Moisture Content on the Mechanical Properties of Rice Grains. *Transactions of the ASAE*. 45(1): 145-151.
18. Manski J. M., Siebenmorgen T. J. and Matsler A. L. (2002). Effects of Storing High Moisture Content Rough Rice on Subsequent Drying Characteristics and Milling Quality. Paper no. 026012 written for presentation at the *2002 ASAE Annual International Meeting / CIGR XVth World Congress* July 28 – July 31 at Hyatt Regency Chicago, Illinois, USA.
19. Meas P. (1999), Performance Evaluation of a Prototype Flat-Bed Grain Dryer. A thesis presented in partial fulfilment of the requirements for the degree of Master of applied science in postharvest technology. *Massey University*, New Zealand.
20. Miller B. S., Hughes J. W., Rousser R. and Pomeranz Y. (1981). Measuring the Breakage Susceptibility of Shelled Corn. *Cereal Foods World,* February 26(2): 75 - 80.
21. Morita T. and Singh P. R. (1979). Physical and Thermal Properties of Short-Grain Rough Rice. *Transactions of the ASAE.* 22: 630-636.
22. Mulet A., Berna A., Rossello C. and Canellas J. (1993). Analysis of Open Sun Drying Experiments. *Drying technology*. 11: 1385-1400.
23. Muthukumarappan K., Jindal V. K. and Gunasekaran S. (1992). Volumetric Changes in Rice Kernels during Desorption and Adsorption. *Transactions of the ASAE.* 35(1): 235-241.
24. Patindol J., Wang Y. J., Siebenmorgen T. and Jane J. F. (2003). Properties of Flours and Starches as Affected by Rough Rice Drying Regime. *Cereal Chemistry.* 80(1): 30-34.
25. Perdon A. A. (1999). Amorphous State Transition in Rice During the Drying Process. A dissertation submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy. *University of Arkansas*, USA.

26. Perdon A., Siebenmorgen T. J. and Mauromoustakos A. (2000). Glassy State Transition and Rice Drying - Development of a Brown Rice State Diagram. *Cereal Chemistry.* 77(6): 708-713.
27. Reid J. D., Siebenmorgen T. J. and Mauromoustakos A. (1998). Factors Affecting the Slope of Head Rice Yield vs. Degree of Milling. *Cereal Chemistry*. 75(5): 738-741.
28. Sarwar G. and Kunze O. R. (1989). Relative Humidity Increases that Causes Stress Cracks in Corn. *Transactions of the ASAE.* 32(5): 1737-1743.
29. Shei H. J. and Chen Y. L. (2002). Computer Simulation on Intermittent Drying of Rough Rice. *Drying Technology.* 20(3): 615-636.
30. Siebenmorgen J. T. (1994). Role of Moisture Content in Affecting Head Rice Yield. In: *Rice Science Technology.* Edited by Marshall E.W. and Wadsworth, I. J. Marcel Dekker, Inc. New York, USA. 342-379.
31. Siebenmorgen T. J. and Jindal V. K. (1986). Effects of Moisture Adsorption on the Head Rice Yields of Long-Grain Rough Rice. *Transactions of the ASAE.* 29(6): 1767-1771.
32. Siebenmorgen T. J., Counce P. A., Lu R. and Kocher M. F. (1992). Correlation of Head Rice Yield with Individual Kernel Moisture Content Distribution at Harvest. *Transactions of the ASAE.* 35(6): 1879-1884.
33. Steffe. F. J. and Singh P. R. (1980). Theoretical and Practical Aspects of Rough Rice Tempering. *Transactions of the ASAE.* 775-782.
34. Sun Z. H., Yang W. D., Siebenmorgen T., Stelwagen A. and Cnossen A. (2002). Thermomechanical Transitions of Rice Kernels. *Cereal Chemistry*. 79(3): 349-353.
35. Thompson R. A. and Foster G. H. (1963). Stress Cracks and Breakage in Artificially Dried Corn. *United States Department of Agriculture. Marketing Res. Report No.* 631. 24.
36. Webb D. B., Pomeranz Y., Afework S., Lai F. S. and Bollich C. N. (1986). Rice Grain Hardness and its Relation to Some Milling, Cooking, and processing characteristics. *Cereal Chemistry.* 63(1): 27-30.
37. Weller C. L., Paulsen M. R. and Steinberg M. P. (1990). Stress Cracking and Breakage Susceptibility as Affected by Moisture Content at Harvest for Four Yellow Dent Corn Hybrids. *Transactions of the American Society of Agricultural Engineers* 33(3): 863-869.
38. Wongpornchai S., Dumri K., Jongkaewwattana S. and Siri B. (2004). Effects of Drying Methods and Storage Time on the Aroma and Milling Quality of Rice (Oryza Sativa l.) Cv. Khao Dawk Mali 105. *Food Chemistry.* 87(3): 407-414.
39. Wongwises S. and Thongprasert M. (2000). Thin Layer and Deep Bed Drying of Long Grain Rough Rice. *Drying Technology.* 18(7): 1583-1599.

DOI: 10.2202/1556-3758.2378

40. Zhang Q., Yang W., Howard L. and Earp C. F. (2003). Tracing Fissure Information by Scanning Electron Microscopy Characterization of Naturally Fissured Surfaces of Rice Kernels. *Transaction of the ASAE.* 46(6): 1583-1588.

41. Zhang Q., Yang W. and Sun Z. (2005). Mechanical Properties of Sound and Fissured Rice Kernels and their Implications for Rice Breakage. *Journal of Food Engineering,* 68(1): 65-72