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Drying of post-harvest rough rice with silica gel: A preliminary investigation

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ABSTRACT

Rice drying operations can encounter problems of over drying and losses in head rice yield (HRY) through the formation of fissures. Typical rice drying methods also utilize large volumes of expensive fossil fuels to dry the kernels. Drying of rice with a solid desiccant such as silica gel has several potential advantages that avoid some of these problems. Two cultivars of long-grain rough rice, 'Cheniere' and 'Wells' with harvest moisture contents of 17.8% and 22.0%, respectively, were dried over a 48-h period with various ratios of rough rice-to-silica gel. It was found that an intimate mixture of 3:1 rough rice to silica gel was sufficient to dry these rice lots to 12.5% and 14.3% within 12 h, respectively. Head rice yields of desiccant-dried rice showed no considerable differences from the control. Rough-rice drying curves for all rough rice-to-silica gel mixtures followed exponential relationships.

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INTRODUCTION

The drying of rough rice, like many other crops, is one of the most energy consuming activities in agricultural production. Once harvested, rice must be immediately dried to a moisture content (MC) near 12.5% (w.b.) to prevent damage by microorganisms and respiration (all moisture contents are expressed on a wet basis). The use of ambient air is typically too slow a process; so heated air is typically used to effectively dry rough rice. Unfortunately, the most common form of energy used in these systems is fossil fuel, an increasingly expensive source of energy. It is also widely accepted that under some situations, drying of rice at elevated temperatures can cause fissured kernels and thus lower milling yields. Moreover, increased harvesting and transportation capabilities of rice producers are placing increased pressure on commercial drying and storage facilities to receive and dry rice on a timely basis. A possible means of alleviating the pressure placed upon commercial driers is to pursue on-farm drying methods that are effective and practical in drying rough rice.

Silica gel is a commercially available desiccant that has long been used in many industrial applications as a dehydrating agent. It is an inert granular solid that is ideal for air-drying. Comprised of amorphous silicon dioxide, this desiccant's large surface area acts to readily ad-sorb water molecules. Silica gel can adsorb up to 40% of its weight in moisture at 100% relative humidity (RH). It remains dry and free-flowing when water-saturated. Silica gel is resistant to attrition and is regenerated by heating to an elevated temperature.

Although previously not applied to rice, this desiccant has shown promise in drying corn, soybean, and other crops. Danziger et al. (1972) have reported that a 3:1 mixture of corn to silica gel effectively dried corn from 24.9% to 14.6% within 24 h. Moreover, research by Wright and Warnock (1983) on the effects of vapor pressure difference between rough rice kernels and drying air have indicated that at low drying air temperatures (52 and 57°C), representative of those experienced with desiccant drying, vapor pressure does not significantly affect milling yields.

The capability to more effectively and efficiently dry rough rice on-farm during the rice harvest season could dramatically improve the rice industry's ability to dry rice at an increasingly rapid pace. The objective of this study was to first evaluate the drying potential of an intimate mixture of rough rice and silica gel by observing the latter's drying capabilities and characteristics. Second, this study sought to distinguish if desiccant drying has any deleterious effects on the milling yield of rough rice.

MATERIALS AND METHODS

Long-grain rice cultivars 'Cheniere' and 'Wells' were harvested at MCs 17.8% and 22.0%, respectively, from the University of Arkansas Rice Research and Extension Center Stuttgart, Ark. in 2005. Immediately after harvest, the rice was cleaned and stored in plastic bags at 4°C.

Silica gel (Type A; 1-3 mm beads, AGM Container Controls, Tucson, Ariz.) was provided to the University of Arkansas Rice Processing Program. This bead size was chosen due to the ease of separation from rough rice when intimately mixed. Additionally, the bead size provides a large surface area-to-volume ratio compared with a larger bead size. Silica gel was activated by drying at 135°C for 24 h in a forced-air oven.

Preliminary experiment

Preliminary experiments were conducted to evaluate the drying capabilities and characteristics of silica gel when intimately mixed with rough rice. Mason jars (Quart, Golden Harvest) were used to seal mixtures of rough rice and silica gel. Based on literature findings with other crops, mixture ratios of 9:1, 3:1, and 1:1 rough rice to silica gel were evaluated for 'Cheniere' and mixtures of 9:1 and 3:1 were evaluated for 'Wells.' For each cultivar and ratio a single trial was conducted by placing 100 g of rice and the respective mass of desiccant into each of 10 jars. Once filled and sealed, the jars were held in a room at 22?C for 48 h. At regular intervals during the 48-h drying trials, separate jars were randomly selected and opened. The jar contents were separated using a no. 7 U.S. standard sieve. Fifteen-gram rough rice samples in duplicate from the separated rice were immediately taken for MC determination. Moisture content was determined by drying rough rice in tins with a convection oven at 130?C for 24 h.

For both cultivars, the 3:1 rough rice-to-silica gel ratio best exhibited the ability to dry rough rice to near typical dried MCs of 12.5% and was applied in all further experimentation.

Further experimentation

Further experimentation was conducted to explore drying kinetics and to evaluate the effect of drying rough rice with silica gel on milling yields. The drying procedure previously mentioned was used.

A larger amount of rice, 430 g, and desiccant, 142 g, were used to produce the 3:1 rough rice-to-silica gel mixture. Sensors (HOBO, Onset Computer Corporation, Bourne, Mass.) equipped with temperature and RH probes were placed in each jar to measure the inter-kernel air temperature and RH throughout the drying trial. For each jar selected at the given intervals

MEET THE STUDENT-AUTHOR

Stephen J. O'Brien

I graduated from Fayetteville High School in 2001 and enrolled at Trinity University in San Antonio, Texas. Trinity is a nationally competitive private university that prides itself as being one of the few schools in the south with 'ivy league' standards. However, after my sophomore year, I transferred to the University of Arkansas because of its research-oriented focus. While finishing my undergraduate degree in biochemistry, I have been working with Dr. Ya-Jane Wang, a professor in Food Science, on an independent study project. My work on that project, concerning "The Effects of Chemical Composition and Granule Organization on Enzymatic Hydrolysis of Starches", has allowed me to be selected as an Undergraduate Research Paper Competition finalist competing at the Institute of Food Technologist's (IFT) annual meeting and food exposition. Meanwhile, I've also have been working with Dr. Terry Siebenmorgen, a professor in Food Science, on this research project to gain a better understanding of the engineering principles involved in food processing. I also competed in the Ozark Food Processors Association's Food and Beverage Innovations Competition and was awarded 1st place for a unique soluble fiber-enriched beverage. Upon graduating in 2006, I plan to enroll in graduate school and further my study in field of Food Science at the University of Arkansas.

throughout a drying trial, rice moisture content was measured as before and the remaining rice was placed into a chamber maintained at 21°C and 55% RH to gently equilibrate to 12.5% MC. Those samples that were dried below 11% MC were not included in this equilibration procedure or the subsequent milling analysis. These over-dried samples were removed from further analysis due to the general acceptance that abnormally low MC can cause inconsistent milling characteristics and skew the true head rice yield (HRY). The 'Cheniere' desiccant drying trial was replicated. The drying of the 'Wells' was not replicated due to rice unavailability.

After the rice was equilibrated to 12.5% MC, milling tests were conducted in order to measure HRYs. Replicate 150 g rough rice samples were dehulled using a laboratory huller (THU-35A, Satake Engineering Co., Tokyo, Japan). Brown rice was then milled for 30 s in a lab mill (McGill no. 2, Brookshire, Texas). The mass of the head rice was determined using an image analyzer (Graincheck 2312, Foss North America, Minneapolis, Minn.) and HRY was calculated as the mass fraction of complete kernels of rough rice remaining as head rice kernels. The head rice was then separated from brokens by hand and measured for whiteness using a whiteness meter (C-300, Kett Electronic Laboratory, Tokyo, Japan) as an indication of degree of milling.

To serve as a control, replicate samples of each cultivar were sealed in jars without desiccant for the 48-h duration of each trial and then gently dried in the EMC chamber from the HMC to 12.5% MC, resulting in minimal breakage and consequently a high HRY. The HRYs of the samples having been desiccant-dried were then compared against the HRY of the control samples.

RESULTS AND DISCUSSION

Preliminary Experiment

Results from the preliminary experiment indicated that all rough-rice drying curves exhibited a typical exponential drying relationship (Fig. 1). The most extensive drying occurred within the first 24 h. Slightly different asymptotes were observed for the cultivars when dried with the same rough rice-to-silica gel ratios. The cultivar with the lower harvest moisture content

(HMC), 'Cheniere', was dried to a lower MC than 'Wells' using the 9:1 and 3:1 ratios. For example, using the 3:1 rough rice-to-silica gel ratio, 'Cheniere' was dried from 17.8% to 9.6% MC in the 48-h drying cycle while 'Wells' was dried from 22.0% to 11.3% MC. This trend is speculated to be due to the desiccant's drying capacity. Again, rough-rice drying operations target the final MC of their rough rice at approximately 12.5%. For both cultivars, the 3:1 rough rice-to-silica gel ratio best exhibited a drying "capacity" to lower rice MC near this value within 48 h.

Further experimentation

Results from further experimentation using a larger volume of rough rice and the 3:1 rough rice-to-silica gel ratio can be seen in Fig. 2. The drying trends, particularly the asymptotic MC values reached in the previous experiment and this further analysis, were in close agreement despite the differing amounts of rice and silica gel used. Further observations of drying rough rice with silica gel (Fig. 2) confirm that most of the drying occurred within the first 24 h. 'Cheniere' rough rice was lowered to 12.5% MC in approximately 12 h whereas 'Wells' rough rice MC was lowered to 14.3% MC in approximately the same drying duration. These results support work done by Danziger, et al. (1972) and demonstrate that silica gel can quickly dry high-MC rough rice.

The silica gel first acted by dramatically decreasing the RH of the inter-kernel air within the first 2 h of drying. Then beyond 2 h, the RH of the inter-kernel air rebounded. This demonstrates that a MC gradient had been quickly established between the high-MC rough rice and the dry inter-kernel air. As the rough rice moisture is drawn to the surrounding inter-kernel air, it is taken up by the desiccant and additional moisture from the kernel interior is transferred to the air. Once the desiccant begins to reach its saturation, a slight increase in the inter-kernel air RH is observed. By 18 h into drying, the MC gradient between the inter-kernel air and the kernel had effectively diminished. Again, different asymptotes were observed for the two cultivars. For the cultivar with the lower HMC, Cheniere, the inter-kernel RH stabilized near 30% and a kernel MC of 9.6% after the 48-h drying period. This observed value corresponds to a theoretical equilibrium moisture content of 9.0% predicted by the Chung-Pfost equation (ASAE Standards, 2005) using 30% RH and 22°C. Similarly, Wells' inter-kernel RH stabilized near 40% and a kernel MC of 11.3% MC. This observed value also corresponds to a theoretical equilibrium MC of 10.0% predicted by the Chung-Pfost equation using 40% RH and 22°C.

Desiccant-dried HRYs were comprised of 10 samples each while the controls were done in duplicate. No desiccant-dried sample had a HRY below that of the control (Table 1). The average HRYs for desiccant-dried samples were similar to those of the controls. Average whiteness values were included to verify that sample sets were equitably milled and HRYs could be compared. 'Wells' HRYs were not different and can be compared since whiteness values are close. A slightly higher whiteness value for the 'Cheniere' control sample indicates that the rough rice had been milled to a greater degree. This greater degree of milling would correspond to a decrease in HRY as more bran would have been removed from the kernel. Given the expected slightly lower HRY of the 'Cheniere' control samples due to greater inherent whiteness, the HRYs of the 'Cheniere' desiccant-dried samples were similar to the control HRYs.

These data support the findings (Wright and Warnock (1983)) that at low drying-air temperatures, vapor pressure caused by a MC gradient between the rice kernels and drying air does not significantly affect milling yields. This study warrants further research, including the quantification of silica gel carried over after rice polishing.

ACKNOWLEDGEMENTS

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Table 1 – Head rice yields (HRYs) and whiteness of desiccant-dried Cheniere and Wells rough rice.

Cultivar	Average HRY	Whiteness
Cheniere (desiccant dried)	65.2 ± 0.34	43.8 ± 0.57
Cheniere (control)	64.4 ± 0.18	45.1 ± 0.71
Wells (desiccant dried)	61.5 ± 0.42	38.1 ± 0.50
Wells (control)	61.1 ± 0.08	38.2 ± 0.71

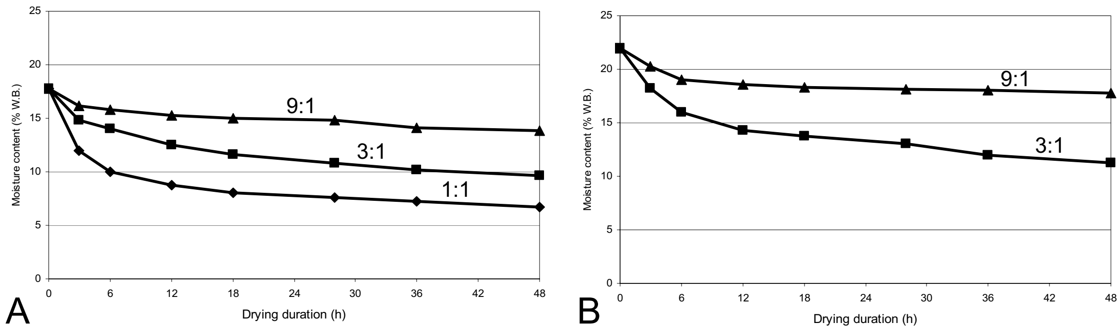

Fig. 1. Preliminary experimentation using 100-g samples of A) 'Cheniere' and B) 'Wells' rough rice to evaluate drying kinetics for the indicated rough rice to silica gel ratios (w/w).

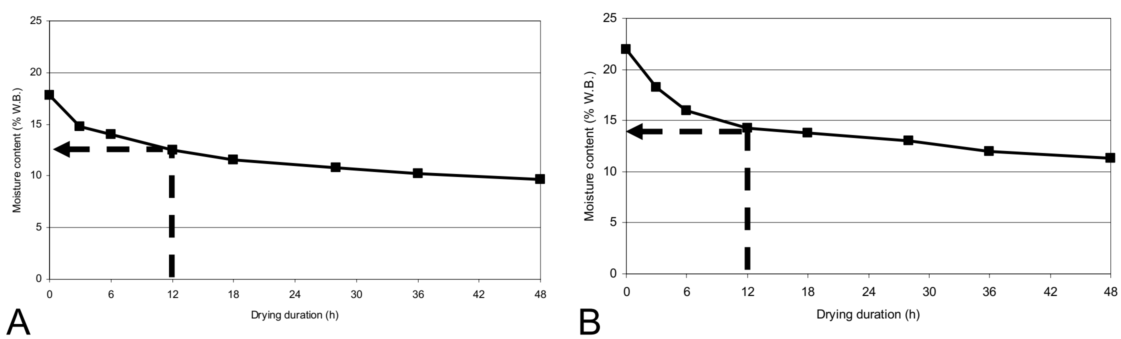

Fig. 2. Moisture contents of 430 -g samples of A) 'Cheniere' and B) 'Wells' rough rice during silica gel drying using a 3:1 rough rice to silica gel ratio.