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Incorporating glass transition concepts to explain rice milling-quality reductions during the drying process

Derek A. Schluterman and Terry J. Siebenmorgen†*

ABSTRACT

Previous research has indicated that while drying rough rice using air temperatures above the glass transition temperature (Tg), head rice yield (HRY) reductions are incurred if a state transition occurs when severe intra-kernel moisture content (MC) gradients are present. State transitions can occur by extended drying using high-temperature air or by cooling kernels below Tg before sufficient tempering has occurred. The objectives of this experiment were to determine the maximum MC removal per initial drying pass and the associated tempering durations required to prevent HRY reduction. Two long-grain cultivars, 'Francis' and 'Wells', at two harvest moisture contents (HMC) were used. Samples were dried with air conditions of either 60°C/17% RH or 50°C/28% RH for various durations to create a range of intra-kernel MC gradients and were subsequently tempered in sealed bags for durations ranging from 0 to 160 min. After tempering, samples were cooled to cause a state transition, and then slowly dried to 12.2% MC. Samples were then milled to determine HRY. Control samples were dried at 21°C/60% RH. Results showed that the amount of moisture that could be removed in the initial drying pass was directly related to the HMC and the drying air condition. The tempering duration required to prevent HRY reductions increased with the amount of MC removed from the kernel in a drying pass. The HRY reduction patterns concur with a hypothesis that explains fissure formation during the drying process based on the Tg of rice kernels.

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INTRODUCTION

In the United States, rough rice is typically harvested at moisture contents (MCs) ranging from 14% to 24%, and subsequently dried to approximately 12% for safe long-term storage. High-temperature drying creates temperature and MC gradients within kernels, which induces tensile stresses at the kernel surface and compressive stresses at the kernel interior (Sharma and Kunze, 1982). These stresses can lead to fissure formation within the kernel and subsequently reduce quality due to reduction in head rice yield (HRY). In order to reduce these stresses, tempering is typically practiced, during which kernels are held in a non-drying condition in order to allow MC gradients within kernels to subside. Intermittent drying/tempering cycles are often used to avoid fissure formation and HRY reductions.

Rice drying and tempering have been studied extensively (Chen, 1997; Chen et al., 1997; Cnossen and Siebenmorgen, 2000; Cnossen et al., 1999; Kunze, 1979: Mossman, 1986) toward the goal of drying rice more quickly while maintaining high HRY. When drying rough rice, the glass transition temperature (Tg), the temperature at which a state transition occurs causing the rice to change from a 'glassy' to a 'rubbery' state, plays a significant role in the rate at which moisture can be removed from the kernel (Cnossen and Siebenmorgen, 2002) and in the occurrence of fissure formation (Cnossen and Siebenmorgen, 2000). Cnossen and Siebenmorgen (2002) found that the drying rate was greater if the rice kernel temperature was above Tg.

Figure 1 shows the inverse relationship between Tg and the MC of rice. If the rice kernel temperature is below Tg, the starch exists in a 'glassy' state with a high viscosity and modulus of elasticity, but low specific heat, specific volume, and expansion coefficient. If the kernel temperature is above Tg, the starch exists in a 'rubbery' state with a much higher specific heat, specific volume, and expansion coefficient (Perdon et al., 2000). Cnossen and Siebenmorgen (2000) presented a hypothesis incor-

MEET THE STUDENT-AUTHOR

I graduated from Subiaco Academy in Subiaco, Ark., in 2000. I then enrolled at the University of Arkansas where I majored in Biological Engineering and worked part time for Dr. Terry Siebenmorgen with the University of Arkansas Rice Processing Program within the Food Science Department. I will graduate in May 2005 with a B.S. in Biological Engineering and have recently accepted a position as program assistant and lab manager for the Rice Processing Program.

I am a member of the American Society of Agricultural Engineers (ASAE). I was part of a four-person team who submitted a design project in the AGCO National Student Design Competition in the summer of 2004 as part of the ASAE annual meeting. We received an award for second place for our project entitled: The Design of a System for the Rapid Pasteurization of Carcasses Contaminated with High-Risk Pathogens. This project was sponsored by the Arkansas Livestock and Poultry Commission and involved designing and testing a pilot-scale pasteurization system and the design of a commercial-scale, portable system that could be used throughout the United States.

My primary research area in the Rice Processing Program focuses on drying rough rice to achieve the highest quality rice possible. This includes evaluating both infrared and fluidized bed driers as possible new and more efficient ways to dry rough rice. I am also evaluating the use of infrared energy as a means of controlling insects in stored rice as an alternative to fumigation. Another project that I am working on, with a group of researchers and farmers, is the validation of a computer model used for predicting performance in on-farm bin drying of grains.

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porating the Tg concept to explain rice kernel fissuring during drying and tempering. To explain this hypothesis, Fig. 2 shows hypothetical temperature and MC gradients created within a rice kernel during drying. When drying using air temperatures above Tg, rice transitions from the 'glassy' to the 'rubbery' state. This transition dramatically changes kernel material properties. During this high-temperature drying, the outer layer of the kernel will dry much more quickly than the center of the kernel, causing an MC gradient within the kernel. This can cause the surface and the center to be at different material states (Fig. 3). Extended drying causes a sufficient volume of the kernel surface to transition to the 'glassy' state, thereby creating an imbalance in the expansion rate that initiates fissure formation.

During tempering and/or cooling, depending on the temperature to which the kernel is exposed, the outer kernel layer may transition to the 'glassy' state, while the center remains in the 'rubbery' state, causing portions of the kernel to experience different magnitudes of material properties (Cnossen and Siebenmorgen, 2000). Figure 4 shows this process, which can also lead to fissure formation. During tempering, if the kernels are cooled below the Tg temperature before the MC gradient is allowed to subside, fissures will occur due to the surface and center conforming to different properties; this is shown with situation 'B' in Fig. 4. Once the MC gradient subsides, the rice kernels can be exposed to temperatures below the Tg temperature without incurring fissures.

Most commercial rice dryers try to safely remove the maximum amount of MC in as short a period as possible without incurring HRY reductions. Given the Tg hypothesis, the objectives of this experiment were to determine the maximum MC removal per initial drying pass and the associated tempering durations required to prevent HRY reduction using air temperatures that produce kernel states both above and below the Tg. This information is intended to help optimize performance of commercial rice driers.

MATERIALS AND METHODS

In the fall of 2003, two long-grain rice cultivars, Francis (with HMC of 19.5 and 17.4%) and Wells (with HMC of 21.6 and 16.1%), were obtained from the University of Arkansas Rice Research and Extension Center near Stuttgart, Ark. Immediately after harvest, the rice was transported to the University of Arkansas Rice Processing Laboratories and was cleaned with a dockage tester (Model XT4, Carter Day Co., Minneapolis, Minn.) and stored at 4°C for six weeks until drying tests were conducted.

Rice samples were dried using a temperature and relative humidity (RH) control unit (Climate Lab AA: 300 CFM, Parameter Generation & Control, Inc., Black Mountain, N.C.). The air conditions were monitored using a hygrometer (Hygro-M2, General Eastern, Woburn, Mass.). Air from the temperature and RH control unit was supplied to a laboratory drying chamber, which included 16 trays (25 cm x 14 cm x 6.5 cm) with perforated bottoms. The 16 trays were arranged as two eight-tray sets, which served as two repetitions. Approximately 110 g of rough rice was added to each tray to form a layer of two to three kernels deep. Three different drying air conditions were tested:

Condition H (high temperature)	60°C, 17.0% RH	Equilibrium MC 5.5%
Condition L (low temperature)	50°C, 28% RH	EMC7.2%
Condition C (control)	21°C, 60% RH	EMC 12.2%

Extended drying using the control conditions has been shown to produce no reductions in HRY (Fan et al., 2000). For each drying air condition, samples were dried for various durations to produce a range of MC gradients within the kernels. The different magnitudes of the MC gradients formed during drying would indicate the maximal amounts of MC that could be removed before fissures were formed due to differential stresses formed within the kernels when crossing the Tg line, as depicted in Fig. 3. After each drying duration, samples from the two repetitions were tempered, which consisted of placing samples in an oven set at either 50°C or 60°C in sealed bags for various durations ranging from 0 to 160 min in increments of 30 to 40 min depending on the drying duration; the longer increments, 40 min, were used for the extended drying durations. After tempering, the samples were placed into a conditioning chamber maintained at 21°C and 60% RH to cool and continue to dry to 12.2% MC. The purpose of tempering the samples for different increments was to determine the shortest duration needed to allow the MC gradient that was created during drying to subside. If the tempering duration was too short resulting in the kernel cooling below Tg before the gradient subsided, fissures would result. This transition is illustrated with Situation 'B' in Fig. 4. After each drying duration, the MC was determined in triplicate using an oven method, which comprised drying 15 g of rough rice for 24 h in a convection oven set at 130°C (Jindal and Siebenmorgen, 1987).

To determine the effect of the drying and tempering treatments on milling quality, 150 g samples of rough rice were dehulled using a laboratory huller (THU, Satake, Tokyo, Japan), and the resultant brown rice was milled in a laboratory mill (McGill #2, RAPSCO, Brookshire, Texas). During milling, a 1.5 kg weight was placed on the lever arm of the mill, 15 cm from the centerline of the mill chamber. The samples were milled for 30 s. The amount of head rice, milled kernels that are at least three-fourths of the original kernel length (USDA 1997), in each milled rice sample was determined with an image analysis system (Graincheck 2312 Analyzer, Foss Tecator, Höganäs, Sweden). Head rice yield was then calculated as the mass percentage of rough rice that remained as head rice.

For the control, five 200 g samples of rice from each of the four cultivars/HMC lots were gently dried in the conditioning chamber described above from the HMC to 12.2% MC, resulting in minimal breakage and therefore the highest possible HRY. The five HRYs from each variety/HMC lot were averaged to represent the control HRY of each lot. The HRYs of the different drying/tempering treatments were compared to the respective control HRYs to determine the amount of HRY reduction caused by drying and/or tempering.

RESULTS AND DISCUSSION

Figure 5 shows the HRY data of 'Wells' (HMC of 21.6%) versus tempering duration for various drying durations ranging from 10 to 55 min using drying air at 60°C/17% RH. When drying for 10, 20, and 31 min and tempering for at least 90 min, no HRY reductions were measured compared to the control HRY. Thus, as much as 6.4 percentage points of MC (PPMC) were removed without appreciable damage, given sufficient tempering before cooling. However, when drying for 43 min and removing 7.7 PPMC, a reduction of 5 percentage points of head rice yield (PPHRY) resulted compared to the control HRY, even after extended tempering durations. A reduction of 18 PPHRY resulted after drying for 55 min, removing 8.8 PPMC, and tempering for over 2 h. Therefore, the maximum amount of MC that could be safely removed in a single pass with air at 60°C/17% RH from 'Wells' at 21.6% HMC was 6.4 PP. It is speculated that beyond this amount of MC removal, MC gradients and resultant transitioning of sufficient portions of the kernel surface to the 'glassy' state created stresses within the kernel during extended drying that were too great to overcome during tempering, resulting in permanent HRY reductions.

A Tg diagram is shown in Fig. 6 for 'Wells' (HMC 21.6%) dried using air at 60°C/17% RH for the various durations indicated in Fig. 5. The points in fig. 6 indicate the rice temperature (60°C), the corresponding PPMC removed for each drying duration, and the associated HRY reductions (after tempering for 90 min), in relation to the Tg line. As indicated above, drying for 10, 20, and 31 min, removing 3.1, 4.7, and 6.4 PPMC, respectively, and tempering for at least 90 min resulted in no HRY reductions compared to the control HRY. For these drying durations, the average MC after drying caused most of the kernel to be in the rubbery state, which would also indicate that a significant portion of the kernel surface had not transitioned from the 'rubbery' to the 'glassy' state (Fig.6). However, drying for 43 min and removing 7.7 PPMC resulted in HRY reductions compared to the control HRY, even after extended tempering durations. For this situation, the average kernel MC and temperature after drying positioned the kernel material state very near the Tg line, which would indicate that a large portion of the kernel periphery had transitioned into the 'glassy' region while the kernel center remained in the 'rubbery' region (Fig. 6). As reported by Cnossen and Siebenmorgen (2000), this condition results in kernel fissuring and reduced HRYs. Proportionately greater HRY reductions occurred (17.1 PP) as greater MC gradients were produced, caused by removing 8.8 PPMC (Fig. 6).

The HRY data for 'Francis' (HMC of 17.4%) at various tempering durations and drying durations ranging from 23 to 88 min using drying air at 50°C/28% RH are shown in Fig. 7. Even drying for 88 min, removing 5.6 PPMC at this condition, and tempering for at least 120 min resulted in little to no HRY reduction compared to the control HRY. Therefore the amount of MC removal required to reach a safe storage level of less than 12% MC was removed in a single pass given the required tempering duration of 120 min. This can be explained because the low HMC of 17.4% and mild drying condition placed the kernel state near the Tg line at the start of drying. This resulted in insufficient MC gradients when the kernel transitioned from the 'rubbery' to the 'glassy' state, which occurred during drying, resulting in high HRYs compared to the control HRY with sufficient tempering.

A Tg diagram is shown in Fig. 8 along with the drying and tempering data of Fig. 7 for Francis. The points in Fig. 8 indicate the rice temperature (50°C), the corresponding PPMC removed for each drying duration, and the associated HRY reductions (after tempering for 120 min), in relation to the Tg line. Because of the low HMC and the mild drying condition placing the kernel state near the Tg line at the start of drying, the amount of MC removed had little effect on HRYs, given sufficient tempering before cooling. Drying up to 68 min and removing 4.5 PPMC resulted in no HRY reductions; less than 1 PPHRY reduction was measured for 88 min of drying compared to the control HRY. Thus, drying low-HMC rice with air conditions starting at the transition line resulted in little to no HRY reduction. This is due to the fact that while MC gradients were created inside kernels, the kernel had not initially transitioned into the 'rubbery' state so as to create the fissure formation scenario described above.

Figures 6 and 8 illustrate that the HMC has a large role in affecting fissure formation according to the Tg hypothesis. To summarize this role, the HRY reductions for 'Wells' with HMCs of 21.6 and 16.1% and for 'Francis' with HMCs of 19.5 and 17.4% versus MC removed using air at 60°C/17% RH are illustrated (Fig. 9); the data represent samples that were tempered for 90 min at 60°C immediately after drying and before cooling and subsequent drying. As a clarification of how Fig. 9 was developed, the HRY reductions and the PPMC removed for 'Wells' (HMC 21.6%) in Fig. 9 were obtained from Fig. 6. HRY reduction began after 2.3, 4.2, 4.8, and 6.4 PPMC were removed for 'Wells' (16.1% HMC), 'Francis' (17.4% HMC), 'Francis' (19.5% HMC), and 'Wells' (21.6% HMC), respectively. During drying with high HMC rice, even though a severe MC gradient formed within the kernel, fissuring did not occur until a sufficient amount of the kernel surface transitioned into the 'glassy' state. Thus, as the MC at which drying began increased, more moisture could be removed per drying pass without incurring HRY reductions given sufficient tempering immediately after drying. Thus for this air condition, or any given drying air condition, the amount of MC that could be removed without HRY reduction was directly related to the HMC of the rice.

The following conclusions were drawn from this study:

• Drying with air temperatures below the Tg of rice, with sufficient tempering, produced little to no HRY reduction, due to the lack of an MC gradient within the kernel during the state transition. This is because the center and surface of the kernel remains in the 'glassy' region as opposed to drying above Tg, where the center and surface of the kernel could be in different regions resulting in an MC gradient and a difference in material properties, which could lead to fissure formations and HRY reductions without sufficient tempering.

• Tempering rice for at least 90 min at the drying air temperature immediately after high-temperature drying was sufficient to cause intra-kernel MC gradients to subside and thus prevent HRY reduction upon cooling and further drying.

• The amount of MC that could be removed in the initial pass with sufficient tempering was directly related to the HMC. This is illustrated by Figs. 5 through 9 and concurs with the Tg hypothesis developed by Cnossen and Siebenmorgen (2000).

• These results confirm the importance of monitoring both the rice and drying conditions in order to obtain the greatest HRY possible.

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LITERATURE CITED

Ban, T. 1971. Rice cracking in high rate drying. Japanese Agric. Res. Quar. 6: 113-116.

Chen, Y. 1997. A thin layer equation for intermittent drying of rough rice. ASAE Paper No. 976071. St. Joseph, Mich.: ASAE.

Chen, H., T.J. Siebenmorgen, and B.P. Marks. 1997. Relating drying rate constant to head rice yield reduction of long-grain rice. Trans. ASAS 40: 1133-1139.

Cnossen, A.G., T.J. Siebenmorgen, J.D. Reid, and A.A. Perdon.1999. Incorporating the glass transition temperature concept in rice drying and tempering to optimize moisture removal and milling quality. ASAE Paper No. 99-6022. St. Joseph, Mich.: ASAE.

Cnossen, A.G., M.J. Jimenez, and T.J. Siebenmorgen. 2003. Rice fissuring response to high drying and tempering temperatures. J. of Food Eng. 59:61-69.

Cnossen, A.G., and T.J. Siebenmorgen. 2000. The glass transition temperature concept in rice drying and tempering: Effect on milling quality. Trans. ASAE. 43:1661-1667.

Cnossen, A.G., and T.J. Siebenmorgen. 2002. The glass transition temperature concept in rice drying and tempering: Effect on drying rate. Trans. ASAE. 45:759-766.

Fan, J., T.J. Siebenmorgen, and W. Yang. 2000. A study of head rice yield reduction of longand medium grain rice varieties in relation to various harvest and drying conditions. Trans. ASAE. 43: 1709-1714.

Jindal, M.K. and Siebenmorgen, T.J. 1987. Effects of oven drying temperature and drying time on rough rice moisture content determination. Trans. ASAE 30:1185-1192.

Kunze, O.R. 1979. Fissuring of the rice grain after heated air drying. Trans. ASAE. 22:1197-1202, 1207.

Mossman, A.P. 1986. A review of basic concepts in rice-drying research. CRC Critical Rev. in Food Sci. and Nutri. 25: 49-71.

Perdon, A., T.J. Siebenmorgen, and A. Mauromoustakos. 2000. Glassy state transition and rice drying: development of a brown rice state diagram. Cereal Chem. 77: 708-713.

Sharma, A.D., and O.R. Kunze. 1982. Post-drying fissure development in rough rice. Trans. ASAE. 25:465-468, 474.

Siebenmorgen, T.J., W. Yang, and Z. Sun. 2004. Glass transition temperature of rice kernels determined by dynamic mechanical thermal analysis. Trans. ASAE. 47:835-839.

USDA. 1997. Inspection handbook for the sampling, inspection, grading, and certification of rice. HB 918-11, section 5.41. USDA Agricultural Marketing Service: Washington, D.C.

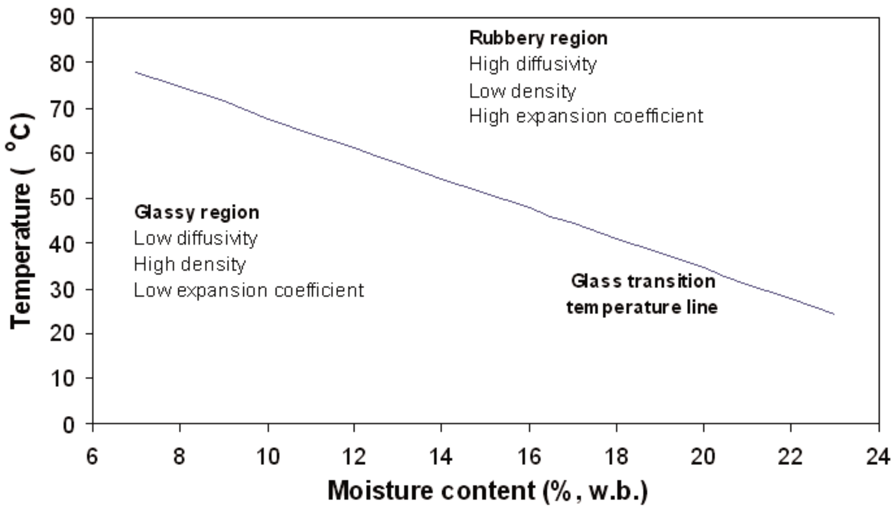

Fig. 1. Glass transition temperature relationship for brown rice, indicating the glassy and rubbery regions, as well as the general property trends associated with each region (Siebenmorgen et al., 2004).

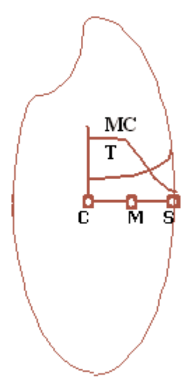

Fig. 2. Hypothetical temperature (T) and moisture content (MC) distribution within a rice kernel during the drying process. Points (C), (M), and (S) correspond to the center, mid-point, and surface locations of the rice kernel, respectively.

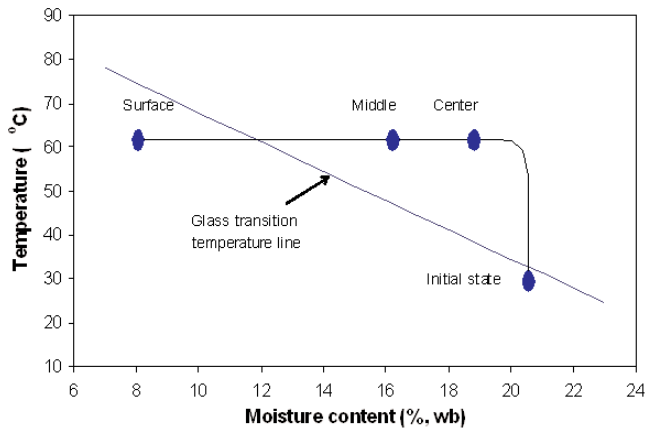

Fig. 3. Hypothetical temperature and moisture content gradients within a rice kernel at the locations depicted in Fig. 2, after extended high-temperature drying.

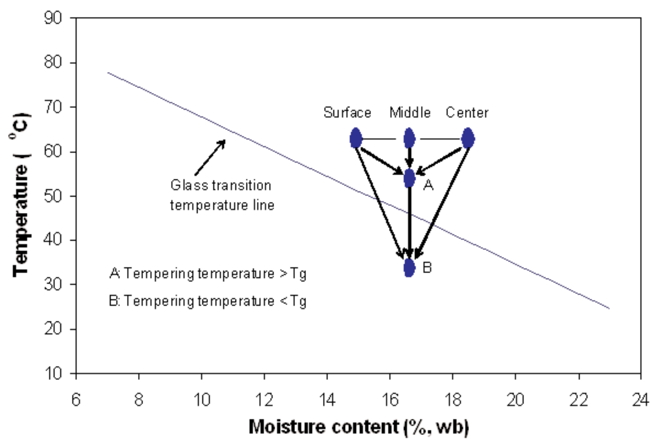

Fig. 4. Hypothetical tempering situations above and below the glass transition temperature (Tg) for a rice kernel that had been dried using air temperatures above Tg. Surface, middle, and center correspond to the kernel locations depicted in Fig. 2.

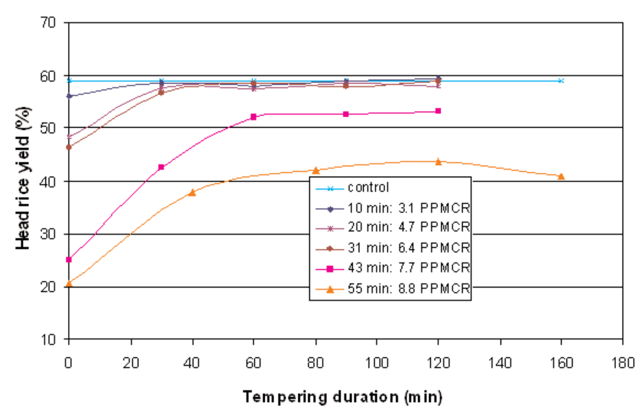

Fig. 5. Head rice yield versus tempering duration for cultivar Wells, with a harvest moisture content of 21.6%. Samples were dried using air at 60°C/17% RH for 10, 20, 31, 43, and 55 min, removing 3.1, 4.7, 6.4, 7.7, and 8.8 percentage points of moisture content (PPMCR), respectively, tempered at 60°C, and then cooled to 21°C. Each data point represents the average of two replicate sample HRYs.

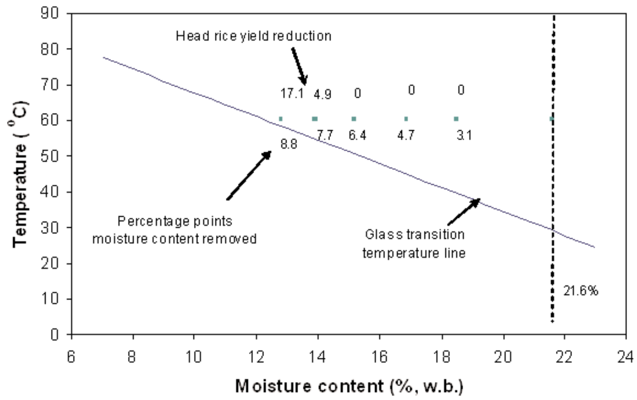

Fig. 6. Head rice yield reductions corresponding to the indicated percentage points moisture content removed plotted onto a Tg diagram of temperature versus moisture content. Samples of cultivar Wells with a harvest moisture content of 21.6% were dried using air at 60°C/17% RH. All samples were tempered for 90 min at 60°C immediately after drying and before cooling and subsequent drying. Each data point represents the average of two replicate sample HRYs.

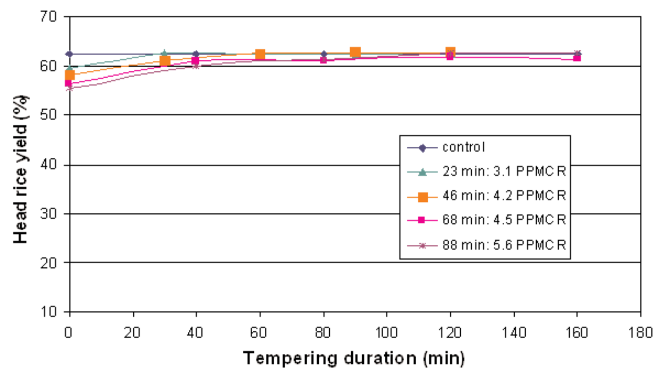

Fig. 7. Head rice yield versus tempering duration for cultivar Francis, with a harvest moisture content of 17.4%. Samples were dried using air at 50°C/28% RH for 23, 46, 68, and 88 min, removing 3.1, 4.2, 4.5, and 5.6 percentage points of moisture content (PPMCR), respectively, tempered at 50°C, and then cooled to 21°C. Each data point represents the average of two replicate sample HRYs.

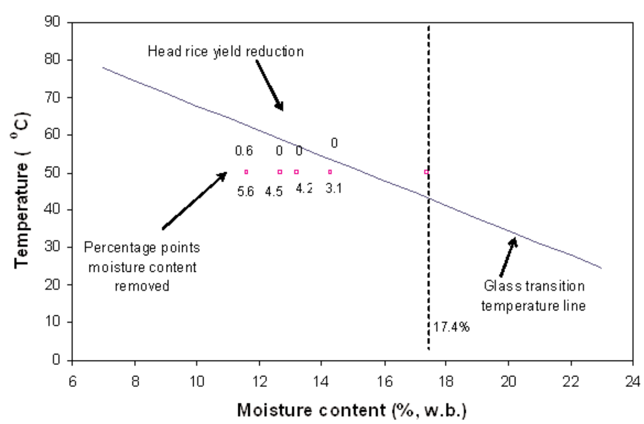

Fig. 8. Head rice yield reductions corresponding to the indicated percentage points moisture content removed plotted onto a Tg diagram of temperature versus moisture content. Samples of cultivar Francis with a harvest moisture content of 17.4% were dried using drying air at 50°C/28% RH. All samples were tempered for 90 min at 50°C immediately after drying and before cooling and subsequent drying. Each data point represents the average of two replicate sample HRYs.

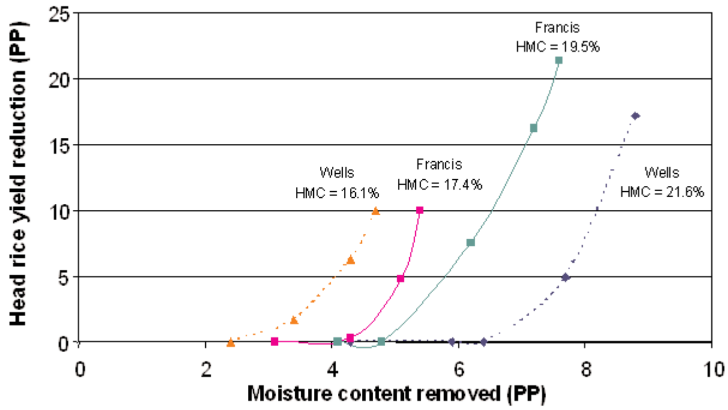

Fig. 9. Head rice yield reduction versus percentage points moisture content removed for cultivars Wells and Francis at the indicated harvest moisture contents (HMCs) using drying air at 60°C/17% RH. Each data point represents the average of two replicate sample HRYs. All samples were tempered for 90 min at 60°C immediately after drying and before cooling and subsequent drying.