The Effects of Damaged Kernel Caused by Combine Harvester Settings on Milled Rice Free Fatty Acid Levels

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ABSTRACT: Milled rice surface oil and free fatty acid (FFA) contents determine rice acceptability to the brewing industry. Both could subsequently contribute to beer off-flavors and thus compromise milled rice brewing quality. Controlling milled rice FFA by harvesting practices could be important in maintaining brewing quality as some rough rice is damaged by hull removal and/or bran disruption during harvesting. To determine the effect of harvester speed on kernel damage, the long-grain rice variety Cocodrie was harvested at 3 different combine harvester settings and the percent of damaged kernel (w/w) was measured. Combine harvester cylinder speed had a significant effect on rough rice kernel damage. The percentages of damaged kernels for 550, 850, and 1000 rpm cylinder speeds were 1.2%, 4.0%, and 9.0%, respectively. The FFA level of milled rice with varying amount of damaged kernels was investigated over 6 mo of storage. The faster harvester cylinder speeds resulted with time in significantly greater FFA levels in "as-harvested" rice. The FFA content of 1000 rpm as-harvested rice almost reached the 0.1% (w/w) level. The greater the amount of damaged kernel, the greater was the milled rice FFA level, and it was significantly greater than milled rice with no damaged kernels during accelerated storage. The as-harvested rice with 1000 rpm had the highest FFA level, followed by 850 and 500 rpm.

Keywords: free fatty acid, milled rice, combine harvester settings, damaged kernel, off-flavor, brewery

Introduction

Milled rice free fatty acid (FFA) and surface oil contents continue to be vital quality factors that determine rice acceptability to the brewing industry. Beer brewers are major rice users in the United States. Milled rice surface lipids are lipase-hydrolyzed to yield FFAs (Tanako 1989; Ohta and others 1990) and may further oxidize to form off-flavors (Yasumatsu and others 1966; Aibra and others 1986; Tanako 1993). Oxidation of FFAs and subsequent off-flavor development occurs more rapidly than oxidation of esterified bran oil (Mistry and Min 1987). The brewing industry is particularly concerned about FFAs and oxidation off-flavor development, as it adversely affects beer quality. The FFA level is important because FFAs rapidly oxidize to produce off-flavors in beer (Grosch 1987; Chrastil 1994; Lam and Proctor 2003b; Monsoor and Proctor 2004). The amount of milled rice FFAs is used as a quality indicator for rice by the brewing industry. A milled rice FFA level of 0.1% is sufficient for the brewing industry to reject an entire rice batch (Marlin 2000). Therefore, understanding where and how FFAs develop is of economic interest to rice growers and processors.

Previous studies have shown that milled rice storage, transport temperature, and humidity are key factors influencing FFA levels (Lam and others 2001; Monsoor and Proctor 2002). Lam and others (2001) found a significant increase in milled rice FFA levels within 48 h of storage at 37 °C and 70% relative humidity (RH) immediately after milling. Monsoor and Proctor (2003) found that commercially milled broken rice had significantly greater amount of surface lipids and FFA than whole kernels. Monsoor and others (2004) found that the surface lipids and FFAs of broken or damaged kernels, generated through abrasive milling after various drying treatments were significantly greater than those of whole kernels generated through the same milling and drying treatments. They also found that broken rice produced significantly greater off-flavors relative to whole kernels when stored at 37 °C and 70% RH for 30 d (Monsoor and Proctor 2004). It appears that damaged kernel has a significant effect on the lipid and flavor quality of milled rice when it is used as a brewing adjunct.

Rice is usually harvested as rough rice (unhulled rice) and is typically dried to about 12% to 13% moisture content prior to storage or milling. Prior to milling, rough rice is dehulled to form brown rice. Milling removes bran from brown rice to produce white rice or milled rice. Rice quality is partially determined by weather conditions during production but could also be controlled by pre- and postharvest practices. These include rough rice harvesting, drying, and milling. The field rice moisture content, in large part, determines the harvester "settings" (cylinder speed), and these settings could later impact milled rice surface FFA quality. Rough rice damage results from abrasion due to the combine harvester cylinder speed. Harvesting and handling conditions may well be important factors in determining rough rice damage and subsequent milled rice surface FFA development and reduction in rice brewing quality. Therefore, controlling milled rice FFA by harvesting practices could be important in maintaining brewing quality as some rough rice is damaged by hull removal and or bran disruption during harvesting. Understanding these relationships will have an economic impact on the rice industry and in promoting rice quality and sales. However, the effect of combine harvester cylinder speed on kernel damage and subsequent milled rice surface FFA formation during storage has not been studied. The

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objectives of this research were to determine the effects of combine harvester cylinder speed on rough rice kernel damage and to determine the effects of rough rice damaged kernel and subsequent storage on milled rice FFA levels.

Materials and Methods

Harvest and drying

The long-grain rice variety *Cocodrie* was harvested at 16% moisture content at the Pine Tree Experiment Station, Colt, Arkansas, in September 2003. A harvester (John Deere, Deere and Co, Moline, Ill.) with rasp at 1.8 mph ground speed was used to harvest the rice samples. A 60-kg batch of harvested rice from each of 3 combine harvester cylinder speeds (550, 850, and 1000 rpm) was obtained. The corresponding linear speeds for this 3 cylinder speeds were 18.74, 28.97, and 34.08 m/s, respectively. Proper harvester condition should be based on conditions in a given field and the threshing characteristics of the particular crop variety. For this experiment, the concave clearance and the lower blower fan speed of the harvester were kept constant and only the cylinder speed was changed. This was done to subject the rough rice samples to a range of abrasive harvesting conditions. The threshing losses were measured as 2% to 3% for these cylinder speeds. Rough rice samples obtained through the 3 harvester settings were stored in plastic sacks immediately after harvest and transported to the Food Science Dept. at the Univ. of Arkansas, Fayetteville, for drying. Each batch was spread out on a concrete floor, indoors for 4 d at approximately 27 °C and 60% RH to produce 12% rough rice equilibrium moisture content.

Determination of damaged kernels at each cylinder speed

Triplicate 1-kg samples of "as-harvested" rice (rough rice samples before removing the damaged rice kernels) were taken from each 60-kg batch to determine the percentage of damaged kernels, namely the kernels that had the hull removed with or without bran damage. "Sound" rice (rice containing no damaged kernels) and the damaged kernels were separated. The weight of the damaged kernels was determined and expressed as a percent of the total weight of the sample on a wet basis. The percent of damaged kernels for each cylinder speed was calculated as the mean of 3 replicate samples.

Rough rice room temperature storage study

Rough rice samples of as-harvested and sound rice from 550, 850, and 1000 rpm cylinder speeds were stored at room temperature (22 °C) in plastic sacks. The RH of the room was recorded as 55% ± 10% for the storage period. The plastic sacks containing the rice samples were tightly closed so that the changes in relative humidity should not affect the sample moisture content. Samples were obtained at monthly intervals from 0 mo (control) to 6 mo. Rough rice samples were milled and the lipid quality of the milled rice samples was measured.

Rice dehulling and milling

From each rough rice sample, 150 g rough rice subsamples were hulled in a Satake rice sheller (Satake Engineering Co. Ltd., Tokyo, Japan). The thickness of the unpolished (brown) rice was 1.69 ± 0.02 mm. The resultant brown rice was then milled for 30 s using a McGill Nr 2 mill (Rapsco, Brookshire, Tex., U.S.A.) with a 1500-g mass positioned on the mill lever arm 15 cm from the centerline of the milling chamber. An aspirator (Seedboro Equipment Co. Chicago, Ill., U.S.A.) was used to remove the loose bran from the milled rice.

Head rice yield and degree of milling

The head rice (milled kernels of rice having length that is 75% or more of the original brown rice kernel length) within the milled rice fraction was separated using a double tray shaker table (Grainman Shaker Table, Grain Machinery Manufacturing Corp., Miami, FL, U.S.A.) with both trays having indented holes to separate the broken kernels from the head rice. The hole sizes of the trays were 4.76 mm. The head rice yield (HRY) was calculated by expressing the milled rice (head rice) mass as a percentage of the original 150 g rough rice mass. The degree of milling of head rice was determined using a Satake degree of milling meter (Model mm1-B, Satake Engineering Co.). The milling meter displays degree of milling as a value from 0 (for brown rice) to 199 (for pure white rice). Each determination was the mean of 3 replications.

Surface lipid and FFA content of the milled rice

Surface lipids of the milled head rice samples were extracted with 8 mL isopropanol by vortexing 10 g rice sample and measured (Lam and Proctor 2001), and FFA content of the extracts was determined colorimetrically (Lam and Proctor 2001). Three measurements of surface lipid and FFA contents were carried out for milled rice samples.

Milled rice accelerated storage study

A 300-g sample from as-harvested and sound rough rice from each harvesting cylinder speed was collected at 0 mo and 6 mo of storage at room temperature. These rough rice samples were milled, placed on perforated trays, and stored in a humidity chamber (Hotpack, SP Industries Inc., Philadelphia, Pa., U.S.A.) at 37 °C and 70% RH for 8 d. This condition was chosen to provide the optimum temperature and relative humidity for rice bran lipases. Samples were collected on days 0, 2, 4, 6, and 8 to monitor FFA development at accelerated storage. The surface lipid and FFA contents of the milled rice samples were determined by the method described in the earlier section (surface lipid and FFA contents of the milled rice).

Statistical analysis

The percent of damaged kernels, HRY, and degree of milling, as well as surface FFA level from long-term-storage and accelerated-storage studies were analyzed statistically. Tukey HSD at the 5% significance level was used to compare means for combinations of treatments and time. Statistical computing was done with JMP 5 software package (SAS Inst. Inc., Cary, N.C., U.S.A.).

Results and Discussion

Determination of damaged kernels at each cylinder speed

Table 1 shows the percent of damaged kernels produced by combine harvester settings. Combine harvester cylinder speed had a significant effect on rough rice kernels damaged. The percent of damaged kernels for 550, 850, and 1000 rpm cylinder speed were 1.2%, 4.0%, and 9.0%, respectively. Increasing combine harvester cylinder speed increased the percent of damaged rice kernels. This rough rice damage resulting from faster combine harvester settings was probably caused by the greater abrasive force generated by the harvester at greater speeds. Therefore, knowledge of the effect of preprocessing factors, such as harvester cylinder speed, would be valuable in maintaining rough rice quality.

HRY and degree of milling

The HRY and the degree of milling from different combine harvester settings of *Cocodrie* rice are presented in Table 2. There was no significant difference between HRYs from sound rice and as-

Table1—Percentages of damaged kernels caused by combine harvester cylinder speed settings on *Cocodrie* rice using a 9500 John Deere harvester[a]

Cylinder speed (rpm)	Damaged kernels, % (w/w) ± SD[b]
550	1.2 ± 0.02a
850	4.0 ± 0.12b
1000	9.0 ± 0.12c

[a]Values not sharing a common letter are different at the 5% level of significance by Tukey's HSD. Each determination was the mean of 3 replications.
[b]Damaged kernels are defined as kernels that had the hull removed with or without bran disruption.

Table 2—Percentages of head rice yields and the degree of milling from different combine harvester cylinder speed settings on *Cocodrie* rice[a]

Rice[b]	Cylinder speed (rpm)	Head rice yield (%)[c]	Degree of milling[d]
Sound	550	67.2 ± 0.19a	107.0 ± 3.00ab
As-harvested	550	67.1 ± 0.32a	103.0 ± 1.00b
Sound	850	66.5 ± 0.20ab	111.3 ± 2.89ab
As-harvested	850	65.7 ± 0.32ac	103.7 ± 3.51ab
Sound	1000	65.2 ± 0.18c	113.7 ± 1.53a
As-harvested	1000	63.9 ± 1.30d	105.0 ± 1.73ab

[a]Values in the same column not sharing a common letter are different at the 5% level of significance by Tukey's HSD.
[b]Sound rice, harvested rice with harvest damage kernels removed; As-harvested rice, rough rice as obtained from the harvester.
[c]Each determination was the mean of 3 replications and expressed with ± SD.
[d]The head rice yield is expressed as weight % on wet basis.

harvested rice at 550 or 850 rpm harvester cylinder speeds. However, at 1000 rpm there was significantly less HRY from as-harvested rice relative to sound rice. This difference was probably due to the greater amount of damaged kernels at 1000 rpm cylinder speed. The differences in degree of milling for sound rice compared with as-harvested rice were not significant for all combine harvester speeds. It appeared that the combine harvester cylinder speed settings (550, 850, and 1000 rpm) do not have any significant effect on the bran removal rate of long-grain Cocodrie rice.

Milled rice surface FFA level of rough rice stored at 22 °C

Figure 1 shows the changes in milled rice surface FFA content of *Cocodrie* stored at 22 °C for 6 mo. At the beginning of the study, the FFA levels were similar for all the treatment groups. At month 1, the FFA content of all treatments had increased relative to their initial values. The as-harvested rice had a higher FFA development rate than sound rice for all combine harvester speeds. However, there were very little differences in FFA development in the sound rice samples. The differences in FFA content between as-harvested rice and sound rice became greater as storage proceeded. Faster combine cylinder speeds resulted in significantly greater FFA levels in as-harvested rice with time. The FFA content of 1000 rpm as-harvested rice almost reached the 0.1% (w/w) level, which has been regarded as a critical quality value. The greater FFA development at faster cylinder speeds reflects the larger number of damaged rough rice kernels that were producing FFAs during storage. However, there was no difference in FFA development in sound rice, indicating that damage during harvesting promotes FFA development.

The fastest change in FFA levels in the as-harvested rice occurred in the 1st 2 mo of the study. This was probably caused by bran disruption and subsequent bran lipases and bran oil interaction (Morrison 1978). At month 2, FFA levels for rough rice of all combine harvester speeds subsequently stabilized with no net increase until month 4. This stabilization on FFA levels was probably caused by feedback inhibition of rice bran lipases (Garcia and others 1991; Lam and others 2001; Monsoor and Proctor 2003). The largest increase in FFA development occurred after month 4 with as-harvested rice having the largest increase in FFA content. This increase in FFA levels was probably due to hydrolysis of lipids caused by microbial contamination of stored rice (Phillips and others 1989; Lam and Proctor 2003a). This finding agrees with that of Lam and Proctor (2003a) who found that the change in FFA levels occurred in 3 stages when milled rice was stored at 37 °C and 70% RH. In the 1st stage, the FFA level increased rapidly, then FFA levels stabilized with no net increase in FFAs, and in the 3rd and final stage, there was the largest overall increase in FFA level.

Surface FFA level of milled rice subject to accelerated storage conditions

Milled rice surface FFA development at 37 °C and 70% RH for 8 d for the rough rice samples immediately after drying is presented in Figure 2. This investigation was done to find whether high-temperature accelerated storage could predict the behavior of surface lipids over a longer period. The FFA levels for all milled rice samples increased

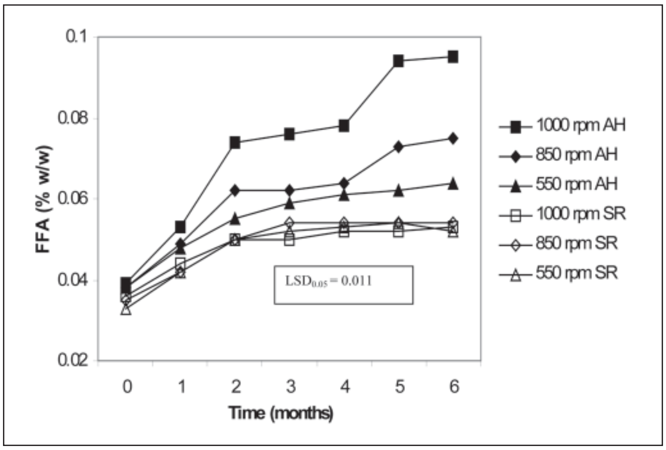

Figure 1—Milled rice FFA levels obtained from rough rice stored at room temperature for 6 months. (SR = Sound rice; AH = As harvested rice)

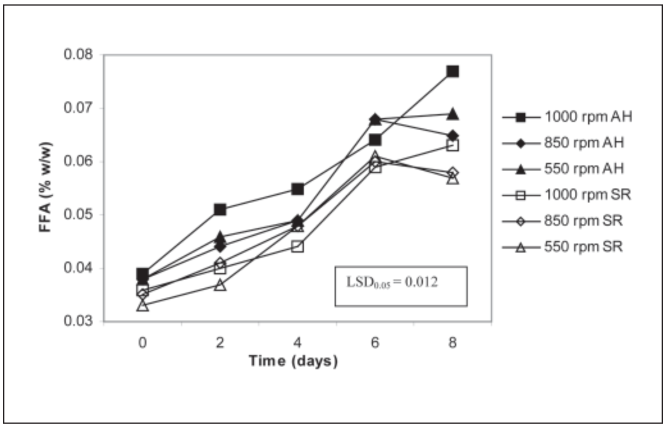

Figure 2—Milled rice surface FFA development obtained from rough rice immediately milled after drying and stored for 8 d at 37 °C and 70% RH. (SR = Sound rice; AH = As-harvested rice).

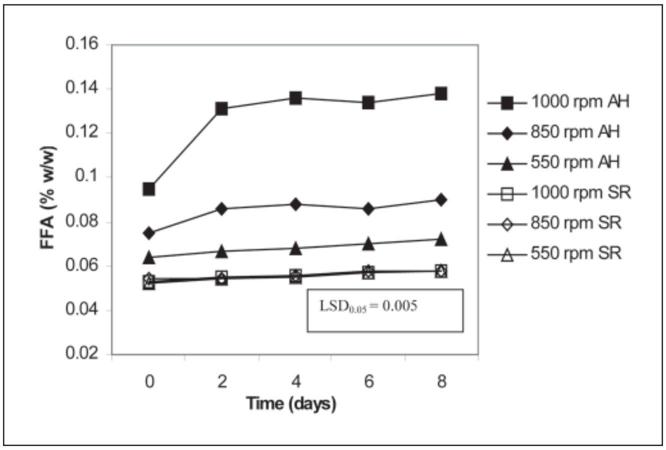

Figure 3—Milled rice surface FFA development during 37 °C and 70% RH for 8 d obtained from rough rice stored at room temperature for 6 mo after drying. (SR = Sound rice; AH = As-harvested rice).

during accelerated storage. The as-harvested rice had significantly greater FFA levels than sound rice throughout the storage period. This was probably due to the presence of damaged kernels in as-harvested rice, because rice lipids break down rapidly into FFA during storage after bran disruption (Morrison 1978). Although, the differences between sound rice and as-harvested rice were not as pronounced as in Figure 1, the presence of damaged kernels coincide with increased FFA development and could be used as a predictor of potential for FFA formation during long-term storage.

Figure 3 shows the milled rice surface FFA development at 37 °C and 70% RH for 8 d for the rough rice samples stored at room temperature for 6 mo. All the sound rice had similar FFA levels, and there were no statistically significant differences over time. This plateau of FFA development was probably due to the equilibrium between FFA formation and breakdown or to the feedback inhibition of rice bran lipases. This pattern of FFA development in sound rice is also shown in the rough rice storage study (Figure 1). FFAs are very susceptible and break down faster than the esterified bran oil to form hydroperoxides and other oxidation products. All the as-harvested rice had significantly greater FFA levels than the sound rice samples. The as-harvested rice with 1000 rpm had the greater FFA level followed by 850 rpm and 550 rpm treatments. Differences were probably due to the number and degree of damaged kernels at the higher cylinder speeds, resulting in greater rice bran damaged, with greater surface lipids-lipase contact, and enhanced lipid hydrolysis.

Conclusions

The amount of damaged rice positively correlated with the cyl inder speed of the combine harvester setting. The FFA development of rough rice depended on the amount of damaged kernels. This probably explains why rough rice with greater percentages of harvest-damaged kernels was associated with more FFAs and off-flavor development. The presence of damaged kernels in the rice batch also reduced the degree of milling values. This indicated that the bran removal rate for damaged kernels was slower, compared with sound rice and, thus, affected milling efficiency. Combine harvester speed setting had a significant effect on brewing rice quality by increasing FFA levels through harvest-damaged kernels. Most harvester manuals describe the appropriate cylinder speed settings for various crops, but the farmers should adjust these settings based on the harvest conditions and the characteristics of the crop variety. Long-grain rice varieties are easier to thresh than short- and medium-grain varieties so require lower cylinder speed, smaller concave clearance, and lower blower fan speed. The low combine harvester cylinder speed would produce lower number of damaged kernel but also would compromise the time of harvesting. A combine harvester cylinder speed may be chosen to obtain rough rice with minimum amount of damaged rice depending on the food application and required harvesting time. Removing damaged kernels on harvesting would also promote rice-brewing quality.

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