# Effect of Moisture Content and Temperature on Respiration Rate of Rice[1]

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## ABSTRACT

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One cause of yellowing or stackburn of rice may be elevated respiration rates caused by storage at either high moisture content (MC) or temperature. The effect of MC and temperature on the respiration rate of *Oryza sativa* L. 'Bengal' and 'Cypress' rice harvested in the fall of 1998 was investigated. For respiration rate measurement of rough rice at different temperatures, rice samples at high, medium, and low MC were sealed in quart jars and equilibrated to temperatures of 20–80°C. The respiration rate was quantified by measuring the rate of $CO_2$ accumulation in the free air space. To determine the effect of MC on respiration rate, rough rice was tested at 12–25% MC. Respiration was greatly affected by MC and temperature. The response of respiration to temperature was dependent on MC and varied between rice cultivars. Respiration rates increased as MC increased from ≈15 to 25%. Maximum respiration was at 50°C when MC was high (20–25%). At 15% MC, respiration increased from 20 to 70°C, while respiration of 12% MC rice, although very low, appeared to increase up to 80°C. A model was developed from this data to predict the respiration rate of rice over the MC range tested.

Postharvest discoloration of rice, commonly referred to as yellowing or stackburn, can be a significant problem to the rice industry. Delayed or improper drying can cause heat burns or heat discoloration, yielding yellow rice kernels (Sahay and Gangopadhyay 1985). Associated with yellowing are adverse changes in quality, appearance, flavor, and yield (Singaravadivel and Raj 1983, Phillips et al 1988). Other problems include weakened kernels, resulting in breakage and economic loss (Misra and Vir 1991).

There are many theories as to what causes yellowing. Some of these include the effects of fungi or mold (Schroeder 1963), high respiration rates (Schroeder 1963), and elevated water activity, temperature, and $CO_2$ content (Bason et al 1990). It has also been proposed that several of these factors interactively produce yellowing (Bason et al 1990). In most studies, mold growth and heating occurred simultaneously in rice with higher moisture contents (MC) (Gilman and Barron 1930, Milner 1951, Phillips et al 1988). This increased temperature could be created by factors such as mold growth, seed respiration, and insect growth (Gilman and Barron 1930, Schroeder 1963).

Respiration is a metabolic process associated with the kernels of grain as well as the microbes present (Brooker et al 1974). Heat, water, and $CO_2$ are produced from the oxidation of sugars as:

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O + 677.2\ \text{cal} \qquad (1)$$

The respiration of the rice kernel is difficult to separate from the respiration of molds and other microflora so it is often measured as one respiration value (Hoseney 1994).

The objective of this research was to determine the effects of temperature and MC on respiration of rice cultivars Cypress (long-grain) and Bengal (medium-grain), and use the data to develop a model for predicting the respiration rate of rice. The respiration rate measured in these experiments included both kernel and microbe respiration because not only are they difficult to separate, but the combined rate also represents the rate that would be experienced in commercial practice. By conducting these experiments, a better understanding of the conditions affecting respiration rates was sought as a basis for controlling yellowing in rice.

## MATERIALS AND METHODS

### Respiration Rate Measurement

For all respiration experiments, rough rice samples were sealed in glass quart jars. A septum was placed in the lid for taking free air space (headspace) samples and to prevent air from leaking in or out of the jar during sampling. Headspace samples (1 mL) were taken through the septum with a 1-mL disposable syringe. Samples were analyzed in the Food Science Department at the University of Arkansas, Fayetteville, AR, with a gas partitioner (model 29, Fisher-Hamilton, Pittsburgh, PA) equipped with an integrator (SP4290, Spectra-Physics, San Jose, CA). Two columns separated the gas sample. Column 1 was a 1.83-m × 0.64-cm (i.d.) Di-2-ethylhexylsebacate column on a 60–80 mesh Columnpak (liquid phase known as DEHS). Column 2 was 1.98-m × 0.48-cm (i.d.) on a 40–60 mesh molecular sieve. The carrier gas was helium, and a thermal conductivity detector was used to analyze the separated gases. The gas partitioner was standardized with 0.5% $CO_2$, and the area of this curve was used for calculating the $\%CO_2$ of samples. The $CO_2$ content was used to determine the respiration rate, calculated as:

$$\%CO_2 = \text{Area of sample } CO_2 \text{ curve } (0.5)/\text{Area of standard } CO_2 \text{ curve} \qquad (2)$$

where 0.5 was the $\%CO_2$ in the calibration sample. The respiration rate was then calculated as:

$$\begin{aligned} &\Delta\%\ CO_2/100 \times [\text{volume of headspace (mL)/sample mass (kg)} \times \text{time (hr)}] \\ &\quad \times [(2.04\ \text{mg/mL} \times 273)/\ 273 + \text{temp } (^\circ\text{C})] = \text{mg of } CO_2/\text{kg-hr} \end{aligned} \qquad (3)$$

where $\Delta\%\ CO_2$ was the difference between the initial $CO_2$ level, measured after 1.5 hr of preheating and the $CO_2$ level of the sample after the final heating. The volume of the headspace included all free air space in the jar; rough rice sample mass was 300 g; time was the duration in the oven; 2.04 mg/mL was the correction factor for the density of $CO_2$ in Fayetteville, AR; and 273 was the conversion for temperature from centigrade to the Kelvin scale. Free air space was determined by pouring water over the rough rice sample in the jar and measuring the amount of water needed to fill the total void space in the jar.

### Sampling Time and Size

To determine the best headspace sampling time for rough rice samples and the appropriate sample size for the quart jars, either 300 or 400 g of Cypress rough rice for high MC (25.5%) and low MC (13.3%) rice from Stuttgart, AR, was placed into duplicate jars. Immediately after the jars were sealed, an initial headspace sample was taken as a baseline measurement. The jars were then held at room temperature (23°C) and headspace samples were taken after 1, 2, 4, 6, and 24 hr and analyzed with the gas partitioner. From these measurements, it was determined that 300 g was an

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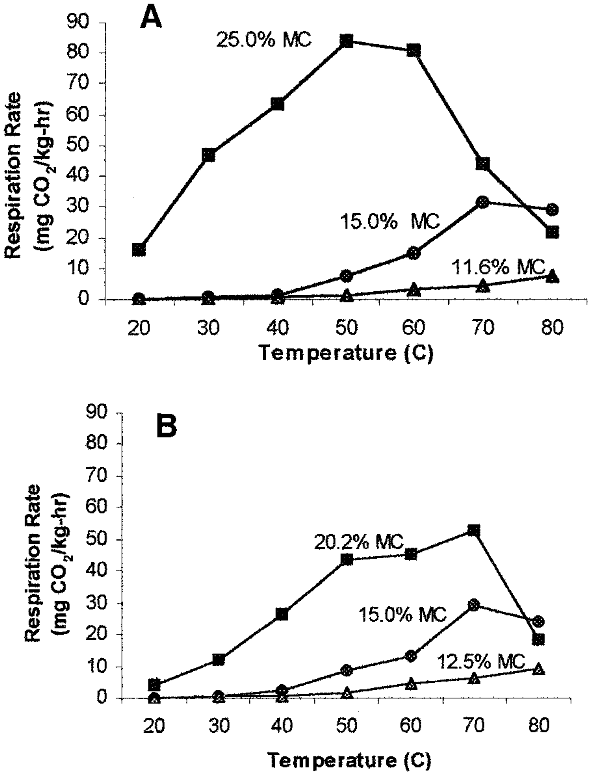

**Fig 1.** Respiration rates for rice cultivars Bengal (**A**) and Cypress (**B**) at different temperatures and moisture contents (MC). Each data point is the mean of the measurement on three separate replicates.

adequate sample size for further experiments. Sampling time was selected as 4 hr for high MC rice and 24 hr for low MC rice because this was the time when a measurable change in $CO_2$ was first detected for each MC level.

### Temperature Effects on Respiration

To determine how temperature affects the respiration rate of rough rice, freshly harvested Bengal and Cypress rice from Stuttgart, AR, and Keiser, AR, from the 1998 harvest was used. Multiple ovens were set at 20–80°C in 10°C increments. Three quart jars, each containing a 300-g subsample of rice from a given MC lot, were placed in each oven. The jars of rice were preheated in the ovens for 1.5 hr for the rice to equilibrate to the oven temperature. After preheating, initial headspace samples were taken. High and medium MC rice was sampled after 4 hr at each of the seven temperatures, while low MC rice was sampled after 24 hr. Different sampling durations were necessary to account for the slower respiration rates at lower MC levels as determined in the sampling time and size experiment. The procedure was repeated for high, medium, and low MC rice for Cypress (20.2, 15.0, and 12.5% MC) and Bengal (25.0, 15.0, and 11.6% MC). Thus, there were 126 experimental units (seven temperature levels × two cultivars × three rice MC levels × three replicate jars).

### MC Effects on Respiration

The effect of conditioned MC level, as well as the maturity of the rice as indicated by the harvest MC level, were tested to determine the effect of MC on respiration rates of rough rice. Multiple harvest MC lots from both Stuttgart and Keiser were used: 24.5, 19.9, and 18.5% for Bengal; and 23.0 and 20.2% for Cypress. Rice from each harvest MC lot was dried on screen trays in a controlled environment chamber (43°C, 38.2% rh) to ≈12.5% MC with subsamples taken every 3–4 percentage points during the drying process. Respiration rate was measured on subsamples of each harvest lot at the initial harvest MC and on the dried subsamples of each harvest

**TABLE I**
**Parameter Estimates and Standard Errors of Equation $Y_i = \alpha e^{\beta\,(MC_i)} + e_i$ Fit to Respiration Rate Data of Rice Cultivars Bengal and Cypress**

| | Bengal | | Cypress | | Both Cultivars | |
|---|---|---|---|---|---|---|
| Variable | Parameter Estimate | Approximate Standard Error | Parameter Estimate | Approximate Standard Error | Parameter Estimate | Approximate Standard Error |
| α | 0.028 | 0.0080 | 0.026 | 0.0085 | 0.025 | 0.0052 |
| β | 0.304 | 0.0124 | 0.303 | 0.0150 | 0.308 | 0.0092 |

lot. Headspace sampling and treatment were the same as described for the experiments determining the effects of temperature, except the oven temperature was maintained at 30°C for all samples.

### Respiration Rate Prediction Model Development

Nonlinear models are usually chosen because they are more realistic or because the functional form of the model allows the response to be better characterized, perhaps with fewer parameters. In many cases, the rate of change in the mean of a response variable $Y$ at some value of the independent variable $X$ is expected to be proportional to its value or some function of its value. Such information can then be used to develop a response model. Models developed in this manner often involve exponentials of some form. If we assume that the respiration rate of rice is proportional to the average respiration rate of rice at a specific MC, the derivative of the mean of $Y$ ($E(Y)$) with respect to MC is:

$$\delta E(Y)/\delta \mathrm{MC} = \beta E(Y) \tag{4}$$

Integrating this differential equation and imposing the condition that the respiration rate of rice at MC = 0 was $\alpha$ when $\beta$ is positive, then the exponential growth model is:

$$E(Y) = \alpha e^{\beta\,(\mathrm{MC})} \tag{5}$$

If additive errors are assumed, then we could express our respiration rate data according to the nonlinear model:

$$Y_i = \alpha e^{\beta\,(\mathrm{MC}_i)} + e_i \tag{6}$$

where $Y_i$ represents a single respiration rate observation for a given sample MC, location, and cultivar from our data, and ($\alpha$, $\beta$) are unknown parameters to be estimated from the data.

## RESULTS AND DISCUSSION

### Temperature Effects on Respiration

Substantial differences were found in the respiration rate of rice at different MC levels when held at various temperatures (Fig. 1). The respiration rate trend for the high and medium MC levels for both cultivars increased up to a certain temperature and then declined. The high MC rice had the highest respiration rate for both Bengal and Cypress, but the two cultivars peaked at different temperatures. The difference in peak respiration temperatures for the two cultivars at high MC level may be due to the difference in MC values because MC obviously has a great effect on the rice respiration rate.

The medium MC rice respiration rate peaked at ≈70°C for both cultivars, and the low MC rice, which had a slower respiration rate, remained fairly constant at low temperatures, then increased slightly at higher temperatures. The temperatures where the greatest respiration rates occurred in the high and medium MC rice were similar to temperatures where yellowing occurs, as shown by other experiments (data not shown). While MC and temperature both greatly influenced respiration rate, there was not a large cultivar effect. Cypress and Bengal showed similar trends and magnitudes in respiration rate across the range of temperatures tested.

### MC Effects on Respiration Rate

Because rice harvested from Stuttgart and Keiser showed similar trends, the respiration rate data for the MC experiments from both

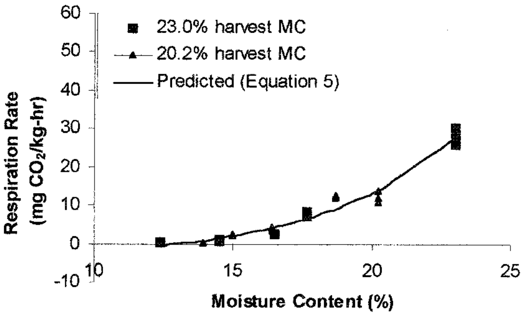

**Fig. 2.** Respiration rates of rice cultivar Cypress harvested at different moisture contents (MC). Data were collected from three replicates for each treatment at the harvest MC and at subsequent MC as the rice dried. All measurements were made at 30°C.

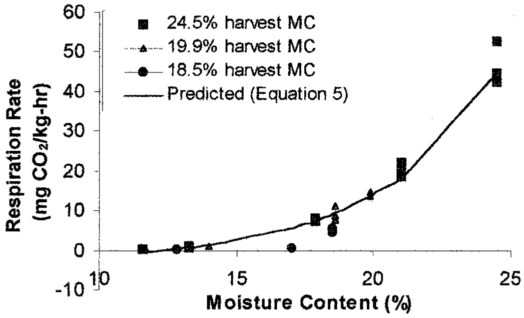

**Fig 3.** Respiration rates of rice cultivar Bengal harvested at different moisture contents (MC). Data were collected from three replicates for each treatment at the harvest MC and at subsequent MC as the rice dried. All measurements were made at 30°C.

locations were pooled for each cultivar. There was negligible difference in the respiration rate of the rice harvested at different MC for both cultivars (Figs. 2 and 3), indicating that there was not a cultivar effect in these experiments. These figures also show that the respiration rate increased exponentially as MC increased, with dramatic increases as MC rose to >15%. This shows that MC has a major effect on the respiration rate of rice regardless of the cultivar. To reduce the respiration rate of rice and resultant heat production, the MC of rough rice should be kept at <15%.

## Application of Respiration Rate Prediction Model

We first attempted to fit Equation 6 to the respiration rate data shown in Figs. 2 and 3. Bailey (1940) predicted the respiration rate of rough rice with a similar model. JMP (version 3.2, SAS Institute, Inc., Cary, NC) nonlinear fitting platform was used to obtain estimates of the parameters $\alpha$ and $\beta$ for each cultivar through iteration in an attempt to minimize the least square criterion. The parameter estimates of $\alpha$ and $\beta$ and their approximate standard errors (Table I) and 95% confidence intervals show that we could use the same model for both cultivars.

Respiration rate curves similar to those shown in Figs. 2 and 3 were reported for rough rice by Bailey (1940) (Fig. 4). Bailey's curves, however, only included MC ≤17%. Within the MC range used by Bailey, the respiration rates of Bengal and Cypress rice were practically identical to those reported by Bailey. Results in Fig. 4 further indicate that there was not a significant cultivar effect because the respiration data for both cultivars were similar.

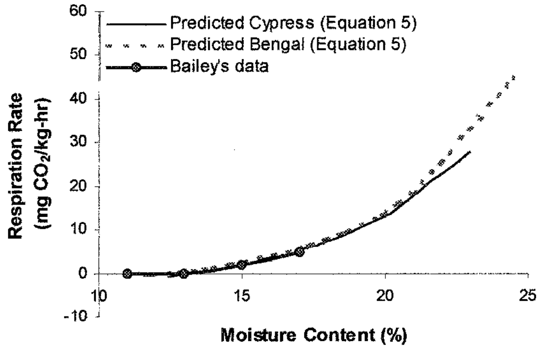

**Fig. 4.** Predicted respiration rate curves as reported by Bailey (1940) and for rice cultivars Cypress and Bengal generated from experiments where conditioned moisture content (MC) was varied and temperature was maintained at 30°C.

## SUMMARY

Data collected in this study provide information on the respiration rate of rough rice as affected by temperature and MC. Experiments in which rough rice was exposed to a range of temperatures at given MC levels showed that the respiration rate increased up to a certain temperature and then declined. The temperature at which maximum respiration rate was reached was MC dependent: at 20% MC the temperature corresponding to the maximum respiration rate was 50–70°C, while at 15% MC this temperature was 70°C. MC and temperature both affected the respiration rate of both cultivars. There was not, however, a significant cultivar difference in the respiration rate at a particular temperature.

Experiments designed to quantify the respiration rate specifically due to MC showed that there was a low but increasing respiration rate at ≤15%, after which an exponential increase in the respiration rate of both cultivars occurred. This suggests that MC should be kept at <15% to minimize the respiration rate of rough rice, as well as associated temperature increases. While MC had a dramatic effect on the respiration rate of the rice, there was negligible effect of different harvest MC or cultivars. Predicted respiration rates corresponded to the previous data reported by Bailey (1940) and extended the respiration rate prediction to ≈24% MC. This information will now be compared to research quantifying the degree of yellowing in rice due to temperature to determine whether there is a relationship between conditions under which increased respiration rates and increased yellowing occur. By quantifying the respiration rate and its relationship to yellowing, rice quality degradation due to yellowing may be easier to control.

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