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COMPREHENSIVE RESEARCH ON RICE
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PROJECT TITLE:

Study of Rice for Improved Quality and Processing Efficiency

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OBJECTIVES AND EXPERIMENTS CONDUCTED, BY LOCATION, TO ACCOMPLISH OBJECTIVES:

We have gained substantial knowledge in improving drying efficiency and quality of rough rice in past several years. Particularly, last year we investigated sorption characteristics of M202 and M206 rice varieties to explain the difference in their head rice yields. At high humidities (>80% RH) M206 variety absorbed moisture slower than M202 variety, which could be among the possible reasons for higher fissure resistance of M206. Chemical composition and distribution of nutrients within rice kernels is known to affect sorption behavior of materials. Therefore, understanding the underlying mechanisms in their sorption behavior is crucial in the prediction of fissuring potential of different varieties in the future.

In our previous studies, we have examined mathematical modeling of moisture sorption and drying processes of different forms of rice, namely white rice, brown rice and rough rice. These models can be used to determine impact of different shapes, sizes or ambient conditions, in other words different grain varieties, such as short, medium or long, on moisture content of rice kernels during any drying or sorption process. In the current study, we investigated impact of changing thickness of bran and husk on drying and high relative humidity desorption profiles of medium grain rough rice. These models could be used by breeders to examine the effect of different physical and chemical properties of rice grains on moisture absorption or desorption rate, which could predict the fissuring resistance of the kernel.

During magnetic resonance imaging (MRI) experiments, we found that during drying, moisture removal rate was greater in regions close to kernel embryo (or germ) than the other regions. To confirm this finding, we evaluated sorption isotherms of different rice regions. These findings have the potential to detect the pathways of moisture uptake or removal within the kernel that could significantly aid in increasing the accuracy of the mathematical models, therefore giving a deeper insight of the ongoing real-world phenomena.

Using X-ray imaging methods, we detected existence of a gap between brown rice kernel and husk. We found that dry rice kernels had larger gaps than the wet ones and the size of the gap is the highest on the top and the bottom regions of the kernel. Based on theoretical principles of moisture movement, such air-gap can affect sorption and drying process significantly. Therefore, we quantified the size of the air-gap at different relative humidity environments. Knowledge of the size of the air-gap could help in increasing the accuracy of the mathematical models.

To achieve the above-mentioned goals, we have selected following specific objectives:

1. Compare distribution of carbohydrates, proteins and lipids in M202 and M206 rice varieties.
2. Determine impact of husk and bran thicknesses on drying and sorption characteristics.
3. Compare sorption characteristics of different regions of M206 variety.
4. Investigate structure of rice kernel using X-Ray Imaging and quantify the gap between husk and brown rice.
SUMMARY OF 2010 RESEARCH (major accomplishments), BY OBJECTIVE:

Distribution of carbohydrates, proteins and lipids in M202 and M206 rice varieties

Amount of different nutrients in rough rice kernels of both rice varieties were determined (Anresco Laboratories, San Francisco). No significant differences among nutrients of these two rice varieties were found (Table 1), which could be due to closeness in pedigree of these two varieties. It is also seen from Figure 1 that the distributions of protein and carbohydrate in both varieties are very similar. Similarly, lipid distribution was also found to be alike in the kernels of these varieties. The closeness in chemical composition of these two varieties might lead to similar physical, chemical and hygroscopic properties.

Table 1. Comparison of nutrients (%, dry basis) between rough rice of M202 and M206 rice varieties

<table>
<thead>
<tr>
<th>Rice Variety</th>
<th>Carbohydrate</th>
<th>Protein</th>
<th>Fat</th>
<th>Ash</th>
<th>Calories</th>
</tr>
</thead>
<tbody>
<tr>
<td>M202</td>
<td>85.49</td>
<td>5.75</td>
<td>2.86</td>
<td>5.90</td>
<td>390.57</td>
</tr>
<tr>
<td>M206</td>
<td>85.50</td>
<td>5.79</td>
<td>2.87</td>
<td>5.83</td>
<td>390.42</td>
</tr>
</tbody>
</table>

Figure 1. Distribution of protein (blue color on the edges) and carbohydrates (lavender color) in brown rice kernels of (A) M202 and (B) M206 varieties

Impact of husk and bran thicknesses on drying and sorption characteristics

In the last few years, we have gained significant expertise and developed a three dimensional mathematical model for whole rice grains for absorption and desorption processes. Detailed descriptions of these models can be found in our previous annual reports. However, the effect of the thickness of bran and husk, which could significantly affect the rate of moisture absorption and desorption, was not investigated. In this study, we examined the effect of husk and bran thickness on moisture content during both a high relative humidity desorption process at 25°C and a heated air drying process at 45°C.

Generally, during air drying of rice the relative humidity of the air is very low. Therefore, in the current report we have chosen to different terms although conceptually they indicate moisture loss from the rice. The term drying was referred to the regular drying operation where relative humidity of the air is very low (<10%) and the temperature is well above the ambient temperature and the term desorption was
referred to the moisture loss of rice when moved from a high relative humidity to a lower relative humidity environment at ambient temperature.

In the modeling of the desorption process, we have used moisture diffusivity values those were obtained during moisture loss of equilibrated rough rice when the RH is changed from 98% to 80% at 25°C. By increasing and decreasing actual bran and husk thickness of M206 rice variety by 50%, three levels of bran and husk thickness was obtained, respectively. The mathematical model was run considering each level of these thicknesses which are designated in this report as low, normal and high. Moisture loss of rice is expressed in terms of dimensionless moisture ratio (MR, %), which is defined as:

$$MR = 100 \times \frac{M_o - M}{M_o - M_e} \%$$

where, M is moisture content (% dry basis) of rice at a particular time, M_o (% dry basis) is initial moisture content and M_e (% dry basis) is equilibrium moisture content of rice at a particular temperature and relative humidity.

During desorption at 25°C, which is relatively a slow process, differences in desorption profiles can be clearly observed after 300 minutes (Figure 2A). Even after 20 hours, MR of rice with low and high level of bran, differed by only 5%. Heated air drying profiles of rice with different thicknesses of bran were similar (Figure 2B). Since heated air (45°C) drying is typically conducted for 20-30 minutes, impact of bran thickness on drying could be considered insignificant. Such observations could be explained on the basis of low proportion (< 5% by mass) of bran present in rough rice.

During moisture desorption (Figure 3A) the difference in MR of rice with low and high husk thickness was 11%. During heated air drying (Figure 3B), within the first 30 and 100 minutes, MR of rice with low and high level of husk, differed by 3% and 9%, respectively. Therefore, it can be concluded that the effect of husk thickness on moisture loss at different temperatures is greater than the effect of bran thickness. This could be due to higher weight proportion of husk in the rice kernel.

Figure 2. Effect of bran thickness during (A) moisture desorption at 25°C and (B) heated air (45°C) drying of rough rice kernels at 45°C on moisture change.
Sorption characteristics of rice components

During the harvest season, the relative humidity in Sacramento valley could change from 90% early in the morning to 10% in the afternoon. Therefore, the rice kernels absorb moisture when the relative humidity is high and then desorb it when the relative humidity decreases. It is known that significant fissuring in rice kernels could occur when rice undergoes through these absorption/desorption cycles, which lowers the economic value of the crop. The study of sorption isotherms characterizes how much moisture a rice kernel could carry at different relative humidity environments and therefore elucidates the degree of absorption and desorption when the relative humidity of the environment changes.

In our previous reports, we investigated the sorption isotherms of both M202 and M206 varieties and found that the sorption characteristics of husk, rough, brown and white rice were very similar for the two medium grain varieties. In our current study, by studying the different parts of the kernel of the M206 variety we are dissecting the sorption isotherm characteristics.

A Dynamic Vapor Sorption (DVS Advantage-1, Surface Measurement Systems, PA, USA) was used to obtain sorption isotherm characteristics of different regions of M206 variety. DVS equipment uses compressed nitrogen as the carrier gas and works in the temperature range of 5 to 60°C with 0.1°C sensitivity and in the relative humidity (RH) range of 0-98% with 1% sensitivity.

Unbroken brown rice kernels of M206 rice variety were cut into three parts using a sharp blade (Figure 4). During cutting, it was tried to ensure that part #1 (portion including embryo) and part #3 were of similar in size and shape. Among the three parts, part #2 was the largest. Cut rice kernels were stored at 4°C before the experiments. For each experiment, at least three pieces of the same region were placed into the pan of the equipment. The relative humidity was changed from 0% to 98% or from 98% to 0% with 20% RH increase or decrease for every step and the temperature was kept constant at 25°C (between 80% and 98% the step size is 18%). Detailed procedure of these sorption experiments are described in our previous year's report.

Figure 3. Effect of husk thickness during (A) moisture desorption at 25°C and (B) heated air drying of rough rice kernels at 45°C on moisture change.
Sorption isotherms for different parts of M206 variety are presented in Figure 5. For each part of the rice, hysteresis was observed. Hysteresis is generally observed in most hygroscopic products. A product is called hygroscopic if it is able to bind water when the vapor pressure is lowered. The degree of hysteresis was more significant for part #2 and #3, than part #1. It was also observed that, absorption isotherms exhibited lower moisture content than the desorption isotherms at a given relative humidity, possibly due to the hygroscopic nature of rice kernels.

Figure 5. Sorption isotherm of different parts of M206

It is clearly seen from Figure 5 and Figure 6 that at relative humidities (RH) equal or lower than 80% and equal or greater than 20% the moisture absorption and desorption rate of all part of the rice kernel are very close. However, when relative humidity is higher than 80%, region containing embryo i.e. part #1, absorbs moisture faster than the other parts of the rice (Figure 6F). This observation confirms our MRI experimental finding that moisture removal is the fastest in the embryo region during initial stages of drying. Therefore, it can be concluded that moisture movement within the rice kernel is not uniform.
Figure 6. Sorption characteristic of (A) desorption at 0%, (B) desorption at 20%, (C) absorption at 40%, (D) absorption at 60% (E) absorption at 80% (F) absorption at 97.9% relative humidity
Structure of rice kernel using X-Ray Imaging and the gap between husk and brown rice

In our previous report we illustrated the structure of a rice kernel by taking its scanning electron microscopy (SEM) image. The SEM images revealed that there was a gap between husk and the brown rice. The existence of the gap was also confirmed by X-ray imaging of wet and dry kernels of M202 and M206 kernels. In our current research we investigated how the gap varied when rice was equilibrated to different RH conditions. Rice kernels were equilibrated at 0, 10, 33, 54, 76, 85 and 100% relative humidity conditions using different saturated salt solutions.

For X-ray imaging, equilibrated rice kernels and a solid square object of known dimensions were placed on an eight inch diameter ring-tray lined with a Rubbermaid brand transparent contact sheet. The tray was then placed on an X-ray film holder enclosing a 35 cm by 43 cm Kodak industrex CX sheet of ISO 9002 x-ray film. The rice samples were then X-rayed for two minutes at 17 kV in a Hewlett Packard faxitron series X-ray cabinet (model #43804N) equipped with a beryllium window (0.25mm) X-ray tube. The X-ray film was then developed using a Kodak X-OMAT 2000 Processor. The developed film was then scanned at a resolution of 1200 dpi using a Microtek Scan Maker 9800XL scanner. The scanned images, shown in Figure 7, were analyzed using GIMP 2.6.7 software. In order to get actual size of length and width the dimensions of the square object placed on ring tray was measured after developing the X-ray films using a caliper.

![Figure 7](image_url)

Figure 7. Selected kernels from X-ray image of rough rice of M206 variety
Using the selection tool of GIMP, the brown rice and rough rice were selected as shown in Figure 8 and pixel count was found for each rice kernel, which was averaged and expressed in pixel/mm. The gap between brown rice and husk was measured in pixels and was then converted to mm. For each relative humidity level at least 10 kernels were analyzed and the average values are reported.

![Figure 8](image1.png)

Figure 8. Selection of a) brown rice and (b) rough rice kernels using GIMP imaging software’s selection tool

It is seen from Figure 9A-C that with an increase in RH, rough rice and brown rice expands and the gap between rough and brown rice decreases. Figure 9A shows that the area of rough rice does not change significantly with RH. On the contrary, brown rice expands significantly at relative humidities higher than 30%, therefore, the gap between rough rice and brown rice decreases significantly. This is in accordance with our previous finding that the gap was smaller in dry rough rice kernels than the wet grains.
Figure 9. Area of (a) rough rice, (b) brown rice, and (c) gap between brown and rough rice found by using GIMP imaging software.
CONCISE GENERAL SUMMARY OF CURRENT YEAR’S RESEARCH

We have gained substantial knowledge in improving drying efficiency and quality of rough rice in the past several years. This year, we continued to focus on examining the physical, chemical and hygroscopic differences between the M202 and M206 varieties that might elaborate the differences in their fissure resistance. Furthermore, we gained deeper understanding of the structures of these two varieties and how they respond to different environmental conditions.

It is well known that the M206 rice variety has higher head rice yield than the M202 variety. To determine the underlying root cause of the differences in their fissure resistance, distribution of carbohydrates, proteins and lipids of these two varieties were measured using scanning electron microscopy (SEM). SEM images revealed that the distribution of these above-mentioned nutrients were very similar in both varieties. This result was further confirmed by analytical tests in which, chemical compositions of the rough rice kernels of these two varieties were found identical. Based upon our previous and current research, it can be concluded that rice kernels of these two varieties are very similar in physical, chemical and hygroscopic properties of brown rice. The differences in their fissuring could be due to the differences in their maturing in field and slightly faster moisture sorption of the M202 variety.

Using mathematical models, we have gained the capability to predict changes in moisture content during adsorption and desorption at different relative humidities as well as during drying processes. Such models can further be used to determine impact of varying shape, size or ambient conditions on moisture content of rice kernels. In this study, we investigated impact of changing thickness of bran and husk on moisture profiles during desorption and drying. Increasing or decreasing bran thickness by 50% caused insignificant impact on moisture profiles during both processes. However, changing husk thickness by 50% resulted in larger variations in moisture profiles. The context of these mathematical models could be extended to compare drying, sorption or fissure characteristics of different rice varieties having different shapes and sizes and could be used by rice breeders and in the dryer design process of a new variety.

Moisture movement during drying and desorption processes was not uniform from all regions of rice kernel. Using magnetic resonance imaging (MRI), we found that during drying, moisture removal rate is larger in regions near kernel embryo (or germ) than the other regions. In our current study, we cut brown rice kernel into three parts and conducted sorption tests with each of these parts. It was found that portion containing embryo, absorbed moisture faster than the other portions which is in accord with our MRI findings.

SEM and X-ray imaging methods have shown the existence of a gap between brown rice kernel and husk. Based on theory of moisture movement, the size of the gap can affect moisture losses or gains significantly. Therefore, to gain deeper understanding of moisture transfer between environment and rice kernel, this year, quantification of the size of the air-gap at different relative humidity conditions was achieved by image processing techniques. It was found that with increase in RH, brown rice kernels expand at a larger rate than rough rice kernels, which decreases the size of the gap.

In this year's research we made important progresses in understanding rice structure, pathways of moisture movement and mathematical modeling of drying processes at different temperatures and relative humidities. This knowledge could assist in predicting fissure resistance of different varieties and aid in designing a drying operation and understanding the response of kernels when exposed to different relative humidity environments.
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