

# Post Production

## Economics

### Economic Considerations

The section on economics highlights the economic considerations associated with farming in general and in a shift in technology in particular.

#### Introduction

- It is almost impossible to predict what the change in yield will be associated with any shift in management.
- Our strategy is to define the cost of the shift in terms of kg of grain.
- This allows an easily understood assessment of the risk involved in the technology shift.

Use the **Economic Calculator** to estimate the relative costs of practices in terms of the amount of harvested grain needed to pay for the different practices.

The discussion below shows a manual example of how costs are estimated in the **Economic Calculator**.

#### Calculating the economics of change - The information needed is:

- Cost of old practice (A)
- Cost of new practice (B)
- Farm grain price (C)

*How much grain (kg) is required to break even with the new practice?*

- =  $(B-A)/C$
- Example for a shift in fertilizer rates
  - **Cost of old practice (A)**
    - Old practice = 50 kg N/ha as Urea
    - Amount of Urea required =  $50 \text{ kg N}/(0.46 \text{ N/kg Urea}) = 109 \text{ kg Urea/ha}$  (Approximately)
    - Unit cost of Urea (US\$) = 0.20/kg
    - Cost of old practice =  $109 \text{ kg Urea/ha} * 0.20 \text{ \$/kg} = \text{US\$}21.80/\text{ha}$

#### Cost of new practice (B)

New practice = 75 kg N/ha as Urea; plus 20 kg P<sub>2</sub>O<sub>5</sub> and 20 kg K<sub>2</sub>O per ha

- Amount of complete fertilizer (14:14:14:) required to apply 20:20:20 (N:P<sub>2</sub>O<sub>5</sub>:K<sub>2</sub>O) per ha =  $20 \text{ (kg nutrient/ha)}/0.14 \text{ (kg nutrient/kg product)} = 143 \text{ kg product/ha}$  (i.e., complete fertilizer)
- Unit cost of complete fertilizer = 0.17 \$/kg
- Cost of complete fertilizer =  $143 \text{ kg/ha} * 0.17 \text{ \$/kg} = \text{\$}24.3/\text{ha}$
- Additional N required as Urea =  $75 \text{ kg total N/ha required} - 20 \text{ kg N/ha supplied as complete fertilizer} = 55 \text{ kg N/ha required as Urea}$
- Amount of Urea required =  $55 \text{ (kg N/ha)}/0.46 \text{ (kg N/kg Urea)} = 120 \text{ kg Urea/ha}$
- Unit cost of Urea (US\$) = 0.20\$/kg
- Cost of Urea =  $120 \text{ kg Urea/ha} * 0.20 \text{ \$/kg Urea} = \text{US\$}24/\text{ha}$

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- Total cost of new practice/ha (B)
- Total cost = Cost of complete fertilizer + cost of Urea = \$24.3/ha + \$24/ha = \$48.3/ha
- **Difference in cost of practices = New cost-old cost = \$48.3 /ha - \$21.8/ha = \$26.5/ha**

*How much grain is required to cover the costs of the new practice?*

- Farm grain price (C) = US\$0.24/kg
- Cost difference (B - A) = \$48.3/ha - \$21.8/ha = \$26.5/ha
- Grain equivalent = 26.5 (\$/ha)/0.24 (\$/kg grain) = 110 kg grain/ha

Thus to cover the costs of the change in practice, the farmer must harvest at least an extra 110 kg Grain/ha.

## Examples of Farm Costs

Comparative annual revenues and costs of rice production among RTDP farms, US \$ hectare<sup>-1</sup>, 1999.

|                              | Central Luzon, Philippines                | Central Plain, Thailand | Mekong Delta, Vietnam | West Java, Indonesia | Tamil Nadu, India | Red River Delta, Vietnam |
|------------------------------|---|-------------------------|-----------------------|----------------------|-------------------|--------------------------|
|                              | (US \$ hectare <sup>-1</sup> )            |                         |                       |                      |                   |                          |
| Gross Revenue                | 2083                                      | 1302                    | 1160                  | 1490                 | 1375              | 1834                     |
| Labor                        | 501                                       | 207                     | 435                   | 472                  | 490               | 764                      |
| Hired                        | 415                                       | 95                      | 60                    | 328                  | 430               | 30                       |
| Family (imputed)             | 86  | 112                     | 375                   | 144                  | 60                | 735                      |
| Fertilizer                   | 139                                       | 125                     | 95                    | 73                   | 90                | 145                      |
| Machine rental and fuel cost | 109                                       | 147                     | 40                    | 44                   | 70                | 3                        |
| Pesticides                   | 47  | 91                      | 44                    | 65                   | 7                 | 45                       |
| Seeds                        | 63  | 61                      | 56                    | 9                    | 30                | 33                       |
| Other costs                  | 29  | 4                       | 12                    | 7                    | 11                | 78                       |
| Total costs per hectare      | 888                                       | 636                     | 683                   | 670                  | 698               | 1068                     |
| Total costs per ton of paddy | 96  | 59                      | 74                    | 69                   | 62                | 86                       |
|                              | (costs as % of gross revenue per hectare) |                         |                       |                      |                   |                          |
| Labor                        | 24  | 16                      | 38                    | 32                   | 36                | 42                       |
| Fertilizer                   | 7   | 6                       | 5                     | 3                    | 4                 | 7                        |

|                                |    |    |    | Post Production                |    |    |
|--------------------------------|----|----|----|--------------------------------|----|----|
| Machine rental and fuel cost   | 5  | 7  | 2  | 2                              | 3  | 0  |
| Pesticides                     | 2  | 4  | 2  | 3                              | 0  | 2  |
| Seeds                          | 3  | 3  | 3  | 0                              | 1  | 2  |
| Other costs                    | 1  | 0  | 1  | 0                              | 1  | 4  |
| All costs excl. land and mgmt. | 43 | 49 | 59 | 45                             | 51 | 58 |
|                                |    |    |    | (% of total costs per hectare) |    |    |
| Labor                          | 56 | 33 | 64 | 70                             | 70 | 72 |
| Fertilizer                     | 16 | 20 | 14 | 11                             | 13 | 14 |
| Machine rental and fuel cost   | 12 | 23 | 6  | 7                              | 10 | 0  |
| Pesticides                     | 5  | 14 | 6  | 10                             | 1  | 4  |
| Seeds                          | 7  | 10 | 8  | 1                              | 4  | 3  |
| Other costs                    | 3  | 1  | 2  | 1                              | 2  | 7  |

Note that all data are on an annual basis, not a per crop basis. For all sites, data are based on two crops of rice per year.

Source: Moya PF, Dawe D, Pabale D, Tiongco M, Chien NV, Devarajan S, Djatiharti A, Lai NX, Niyomvit G, Wardana P (2001).

“The Economics of Intensively Irrigated Rice in Asia,” in Increasing the productivity of intensive rice systems through specific nutrient management.

Dobermann A, Witt C, Dawe D (editors). International Rice Research Institute (IRRI), Makati City, Philippines. IRRI Publishers, Inc, Enfield, USA.

## Principles of Post Production

The section on post-production highlights the importance of managing grain moisture at the various stages of post-production management. It provides general guidelines for all post-production operations including harvest, grain cleaning and drying, storage, and milling as well as a section on rice by-product uses.

Post-production includes all operations starting from harvesting: cutting, stacking, hauling, threshing, cleaning, drying, storage, milling, and grading. Rice quality The key to post-production is correct timing of operations to manage grain moisture content (**MC**). Target MC for key post-production operations are shown in the Table:

| Operation | Desired Moisture | Primary Cause of |
|-----------|------------------|------------------|
|-----------|------------------|------------------|

|              | <b>Content (%)</b>   | <b>Losses</b>  |
|--------------|--|--|
| Harvesting** | 20-25<br>(California: Short and medium grain (23%) and Long grain (18%) - these MCs are a little lower than for the Tropics.)  | Shattering if grain is too dry   |
| Threshing    | 20-25<br>for mechanical threshing (varies slightly with variety: e.g., California: Short and medium grain (23%) and Long grain (18%) - these MCs are a little lower than for the Tropics.)<br><20 % for hand threshing | Incomplete threshing, grain damage and cracking/breakage                             |
| Drying       | Final moisture content is 14% or lower   | Spoilage, fungal damage, discoloration, smell  |
| Storing      | <14% for grain storage<br><13% for seed storage<br><9% for long term seed preservation   | Fungal, insect & rat damage, smell   |
| Milling      | 14%  | Grain cracking and breakage<br>Overmilling - (i.,e., remove more kernel than needed) |

\* the Moisture contents stated in the table are for tropical, humid climates typical for most rice-growing countries in Asia.

\*\* For fully mechanized harvesting, optimal moisture contents are often a trade-off between grain quality and costs for mechanical drying . Because wetter rice is more expensive to dry, growers frequently harvest rice at a moisture content lower than what is best for quality. For most varieties, the trade-off MC is 22% +/- 1%. The exception are long grain varieties which are harvested at lower MC (20% or less) as they contain less moisture than medium or short grains.

### Calculating moisture content

Moisture content can be on a wet (MC wet) or dry (MC dry) basis:

- MC wet = Weight of moisture in wet grain \* 100/(weight of wet grain)
- MC dry = Weight of moisture in wet grain \* 100/(weight of dry grain)

### Moisture Content

### Calculating Moisture Content

Moisture Content (MC) of grain (i.e., the amount of moisture in the grain) is usually determined on wet basis:

- $MC \text{ wet} = \text{Weight of moisture in wet grain} * 100 / (\text{weight of wet grain})$ , or:
- $MC \text{ wet} = (\text{Weight of wet grain} - \text{Weight of dry grain}) * 100 / (\text{weight of wet grain})$

During drying, paddy grain loses weight due to the loss of moisture:

- $\text{Final weight of grain} = \text{Initial weight} * (100 - MC \text{ initial } \%) / (100 - MC \text{ final } \%)$

Example: 1000 kg of paddy is harvested at 25% MC, and dried down to 14% MC  
 final weight of grain =  $1000 * (100 - 25) / (100 - 14) = 872$  kg of paddy at 14 % MC

## Measuring Moisture Content

Moisture content of grain can be measured by using a drying oven, or by using a commercial moisture meter

### Measuring MC with a drying oven:

1. Pre-heat the oven to 130°C (Note: Temperatures above 40°C will kill grain samples)
2. Weigh three paddy samples of 10 grams each and place them inside the oven
3. Remove the samples after approximately 16 hours, and obtain the final weight of each sample
4. Compute the MC for each sample :
5.  $MC = (10 - \text{Final weight of dried sample in grams}) * 100 / (10)$
6. Compute the average MC of three samples

### Measuring MC by using a commercial moisture meter:

There are many different types of grain moisture meters (click here to see photo). Make sure your meter is suitable for paddy grain. Consult the manual to find out the correct procedure for measurement.

The following is the procedure for the Kett Rice Tester.

**NOTE:** IRRI does not endorse any particular brand or type of moisture meter.

1. Turn on the moisture meter and make sure that button indicating "paddy" is on.
2. Fill the tray of the moisture tester with paddy to the required level.
3. Turn the knob until the moisture reading is displayed.
4. Take measurements of 3 to 5 samples and compute the average MC

**NOTE:** Most moisture meters have to be calibrated using MC calculated using an oven.

## Factors Affecting Grain Quality

### Variety

Different varieties have different physical and chemical characteristics that affect grain quality and yields. The dimension, shape, weight, volume and density of grains determine the physical characteristics of rice and in turn influence head rice yield.

Varieties that:

- Have short and medium type grains, which are more rounded, thicker and harder than long grains produce higher head yield.
- Are earlier maturing tend to produce less head rice than late maturing varieties.
- Fill uniformity have higher grain density and less chalkiness
- Flower unevenly also ripen unevenly. Non synchronous varieties can have a variation of up to 10% in moisture content and take 5 days longer for the grain to mature at the bottom of the panicle, when compared to the grain in the top of the panicle.

## Crop Management

### Crop Management

The management of the crop will influence the time and uniformity of crop maturity. Basic requirements of good crop management include good:

- Crop establishment
- Water management, and
- Nutrient management

The following table summarizes the general effects of crop management on rice quality:

| Production factor                      | Possible effect on quality   | Recommendation                      |
|--|--|-------------------------------------|
| <b>Land preparation &amp; Leveling</b> | <p>If a field is not level, then crops, especially under direct seeded conditions, will generally emerge differentially. Delaying maturity can result in a wider spread of grain moisture at harvest and damaged grain if the crop is mechanically threshed.</p> <p>Uniform water depth throughout the season will contribute to uniform ripening across the field and consequently more consistent moisture content in the grain between locations. Cut areas may mature sooner than fill areas of a field. Large differences in grain moisture content</p> | Prepare fields as level as possible |

|  |  |  |
|--|--|--|
|  | in rice contribute to fissuring and accelerate spoilage.   |  |
| <b>Crop establishment and replanting</b> | Replanting will delay maturity resulting in a wider range of moisture contents at harvest (See above).   | Limit replanting by ensuring good land preparation & leveling                    |
| <b>Variety</b>                           | Genetics plays a dominant role in grain quality - especially for length, shape, chalkiness and amylose content.  |  |
| <b>Seeding date</b>                      | Seeding date can affect conditions during maturation. High temperatures after flowering can lower the amylose content, increase chalkiness and increase gelatinization temperature. Grain length is little affected by environment.  | Avoid planting to have the rice maturing during periods of high temperature.     |
| <b>Seeding rate</b>                      | Higher seeding rates will lead to higher plant population, more competition for limited resources, and possibly more lodging and smaller grain size. Lower seeding rates will result in increased tillering with possibly more variation in maturing within the panicle, and higher weed populations.                                  | Select right seeding rate  |
| <b>Nutrient management</b>               | <p>Uneven crop nutrition can lead to variation in tillering and tiller maturity across a field resulting in a range of grain moisture content at harvest. Nutrition can affect head rice and amylose content.</p> <p>Delayed nutrition may lead to delayed growth and crop maturing, which increases the probability that the crop</p> | <p>Ensure uniformity of nutrition across the field.</p> <p>Timely nutrition.</p> |

|  |   |  |
|--|---|--|
|  | is affected by adverse weather during harvesting season (typhoon, rain, etc.)   |  |
| <b>Water management</b>  | <p>Kernel weight is very stable, although variation up to 10% can be found. A 10% volume difference equates to around 3% variation in grain radius. Under stress, rice tends to abort excess grains and fill fewer grains instead.</p> <p>Too early drainage prior to harvest may lead to incomplete grain filling and more misshapen kernels. Too late drainage prior to harvest may lead to inability to harvest rice at right moisture content (due to field inaccessibility).</p>   | <p>Keep fields level.</p> <p>Drain field at the right time.</p>  |
| <b>Pest control</b><br><b>Insects</b><br><b>Weeds</b><br><b>Diseases</b><br><b>Rats</b><br><b>Snails</b><br><b>Birds</b> | <p>Insects such as stink and rice bugs that attack the grain during soft or hard dough stages can result in deformed or spotty grains. The spotty grains come from infection by bacteria transmitted during feeding.</p> <p>Late applications of pesticides may result in unacceptable pesticide residues in the grain. Heavy weed infestations can reduce grain quality by out-competing the rice for resources (nutrients, sunlight), or by contaminating the rice with weed seeds with high moisture content. The latter can lead to a differential transfer of moisture within the grain mass that promotes</p> | <p>Good land leveling, tillage, water management, and timely weed control. Timely harvesting, threshing, and drying to neutralize fungi brought in from the field.</p> |



|  |  |                                |
|--|--|--------------------------------|
|  | <p>fissuring.</p> <p>Stemborers cause whiteheads and thus add unfilled grain (i.e., material other than grain) to the harvested material, but don't have much other effects.</p> <p>Rice crop in the field is contaminated with numerous fungi. Under high moisture and high temperature conditions some fungi (e.g. smut) may develop before harvest. Most fungi in the field require a grain moisture content of more than 22% to develop. After the rice is harvested and dried down, these fungi die and a different group of fungi (storage fungi) will develop. A high incidence of smutted kernels will drastically reduce grain quality.</p> |                                |
| <b>Grain moisture content at harvest</b> | <p>Grain formation starts from the tip of the spikelets from the top of the panicle. Thus, any given panicle will have grain having a range of moisture contents. Re-adsorption of moisture after grain MC drops to 15% or less will result in fissuring.</p>  | <p>Dry grain and keep dry.</p> |

### Crop Establishment

Establishing the correct number of plants is essential to maximize water and nutrient use. A target population that results in 4-500 panicles per m<sup>-2</sup> is desirable. This means establishing at least 70-100 seedling m<sup>-2</sup> when transplanting, or broadcasting 80-120 kg seed ha<sup>-1</sup> when direct seeding.

Low populations may result in:

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- increased tillering, which creates more variation in panicle maturity,
- increased weed populations, and
- reduces the yield potential of the variety.

High plant populations may reduce yield and quality by:

- competing for water and nutrients,
- mutual shading,
- lodging and
- reduced grain size.

## **Water Management**

To be able to manage water, the fields must be level and the bunds or levees well maintained. Uniform water depth across the field will contribute to more uniform crop, higher grain yields, uniform maturity and thus more consistent moisture content in the grain sample. Reducing the variation in moisture content at harvested reduces grain fissuring (cracking) and also reduces the chance of spoilage through yellowing and of odors.

Good water management helps reduce weed competition, which not only increases yields but also improves grain quality by reducing dockage levels and reducing moisture differentials between weed seeds and grain. Wet spots in the grain due to uneven drying or weed seeds can lead to off odors and discoloration of the grain.

## **Nutrient Management**

Supplying the correct level and type of nutrients for the variety and growing conditions is essential. The prudent application of nitrogen is essential to get an even maturing crop with full grain size and high protein levels. Excessive and uneven application of N can stimulate late tiller production, which results in heads on the main culm ripening a number of days faster than the tillers. This results in more immature and green heads in the sample as well as higher moisture content that increasing the chance of fissuring and spoilage. Conversely insufficient nitrogen can lead to reduced grain size and protein content.

## **Harvesting**

### **Introduction to Harvesting**

Harvesting can be done manually, or mechanically with the use of machines. Below are a number of guidelines that will ensure that grain quality is preserved during harvest operations, and that losses are kept to a minimum.

- **Timeliness: Harvest and thresh at the right moisture content**
- **Avoid rewetting of harvested kernels**
- **Avoid delays in threshing**
- **Use proper thresher machine settings**

- **Clean grain thoroughly after threshing**

### **Timeliness: When to Harvest**

Harvest and thresh at the right moisture content. Grain moisture content at harvest is crucial in preserving grain quality and reducing grain loss. **Crops should be cut at 20-25% moisture content or when 80-85% of the grains are straw colored and the grains in the lower part of the panicle are in the hard dough stage** - in the tropics, this is typically about 30 days after flowering. Correct timing of harvesting, reduces mechanical damage to the grain, as well as being a tradeoff between grain loss, optimum head rice and germination potential. Below 20% or above 25% grain can be damaged (cracked) during mechanical threshing or grain is lost due to shattering.

Grains should be firm but not brittle when squeezed between the teeth. If the crop is too dry, fissures will form in dry kernels and when these are rewetted, they break during milling. If the crop is harvested too early, there will be many immature grains that will reduce milling yield and head rice recovery. The immature rice kernels are very slender and chalky and this results in excessive amount of bran and broken grains.





Correct timing of harvesting is crucial in preventing quality deterioration. Harvest the crop when 85 % of the kernels are straw-colored.

## Avoid Rewetting

**Avoid rewetting of harvested kernels:** When kernels are rewetted they can form fissures that break during threshing and milling - lowering head rice recovery. To avoid rewetting and reduce grain breakage, thresh and dry the grain as soon as possible after cutting.



Fissures in rice as seen through a red light filter. Fissured grain will break during milling and therefore fissures reduce the market value of rice considerably. Common causes of fissuring are rapid moisture loss of the grain during drying, and exposure of dry grain to moist air. Harvest and dry your paddy in time to prevent fissure formation. Do not mix wet grain with dry grain.

## Avoid Delays in Threshing

Immediate threshing reduces the exposure of crop to insects, birds and rodents, disease, and molds. Crop that is piled over a period of time generates heat that serves as an ideal medium for growth of molds, disease and pests. Discoloration increases dramatically when the crop is stacked for 3-4 days. Germination and spoilage can also occur. While piling can lead to problems, field drying prior to

threshing can lead to a rapid reduction in moisture content to below 20% (i.e. too dry for mechanical harvest), and can lead to high shattering losses.



Postponing threshing by piling the harvested crop along the field for more than day will result in heat buildup in the grain. This will result in grain discoloration and lower quality of milled rice. If you rely on a contractor for threshing, avoid delays in threshing by choosing a harvesting date depending on the availability of the contractor.

### Proper Machine Settings

The drum tip speed of the threshing drum should be about 12-16 m/sec, equivalent to around 600 rpm for most threshers (with a 20 - 25 cm radius drum). Higher speeds result in higher grain damage. Lower speeds increase the amount of non-threshed grain and result in grain loss. **Clearance between threshing teeth and the concave** should be about 25 mm: smaller clearance increases grain damage.





### **Proper Machine Settings for Combine Harvesting**

Use proper machine setting for combine harvesting. Combines require settings unique to the crop, variety and maturity. Most harvester manuals give initial settings for the crop, but the operators should adjust these based on conditions in a given field and the threshing characteristics of the particular variety. Medium or short-grain varieties are more difficult to thresh than long grain varieties. More difficult to thresh varieties require higher cylinder drum speed, smaller concave clearance, and lower blower fan speed.





The picture shows heavily damaged paddy indicated by partially and fully husked grain, and grain breakage. Mechanical damage to paddy grain can be a problem in harvesters, threshing machines or grain dryers when they are not adjusted or operated properly.

## Clean Grain

**Clean grain thoroughly after threshing:** Remove all materials other than grain, including straw, chaff, immature grains, and unfilled grains. Foreign materials will affect grain quality during storage and milling, and reduce milling recovery. If the crop is machine threshed, adjusting the blower to the correct speed (~800 rpm) will provide good initial cleaning. For more information on grain cleaning see the next section

## Grain Cleaning

### Introduction to Grain Cleaning

Grain cleaning after harvest is important as it removes unwanted materials from the grain. Clean grain has a higher value than grain that is contaminated with straws, chaff, weed seeds, soil, rubbish, and other non-grain materials. Grain cleaning will improve the storability of grain, reduce dockage (i.e., price penalties) at the time of milling, and improve milling output and quality. Seed cleaning will reduce damage by disease, and improve yields (Link to **clean seed**). Following are some general guidelines for cleaning grain and seed.



Harvested paddy grain typically contains quantities of straw, chaff, unfilled grains, immature grains and other impurities. Clean grain is easier to dry, has better storability, and will produce better quality of milled rice. Clean the grain prior to storage and milling to attain high milled rice quality.

## **Winnowing**

Lighter materials such as unfilled grains, chaff, weed seeds, and straw can be removed from the grain by using a blower, air fan, or by wind. Recover only the heavier seeds.

The simple traditional cleaning method is winnowing, which uses wind or a fan to remove the light elements from the grain. Mechanical winnowers that incorporate a fan and several superimposed reciprocating sieves or screens are now used in many countries. These can be manually powered or motorized and have capacities from 100 kg to 2-3 tons per hour. Where combine harvesters are used, there is a trend towards using large capacity centralized seed cleaners. These are normally equipped with a series of vibrating sieves and are capable of 10-30 tons per hour.





Winnowing is an important technique for cleaning grain at the farm level. If there is not enough wind, simple electric air fans can be used to separate lighter materials from the grain.

### **Screening/Sifting**

Smaller materials such as weed seeds, soil particles and stones can be removed by sieving the grain through a smaller sized screen (a screen of 1.4 mm or less sieve opening is typically used).



Sifting can be done either by mechanical grain cleaners, or by hand with simple sieves as shown in the picture.

## **Seed Cleaning**

Malformed, discolored, germinated, broken or moldy grains in seed lots can severely impact seed quality, viability and vigor. Visually inspect the seed prior to storage and consider removing these grains from the seed lot.

## **Seed Grading**

For commercial seed processing, seed grains should have uniform size and weight. A variety of commercial equipment can be used to achieve uniformity in seed size and shape. These include gravity tables, rotary screens, indented cylinders, and length graders.

### **Photos of Seed Graders:**

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## Seed Purity

Maintain seed purity by preventing mixing with other varieties, and contamination with other species.

## Grain Drying

### Introduction to Grain Drying

Drying will reduce grain moisture content down to a safe level for storage. Drying is therefore the most critical operation after harvesting. Paddy should be dried to 14% MC as soon as possible after threshing. (See **grain storage** for an indication of grain moisture contents and safe storage periods.) Drying provides preliminary control against insect infestation, and reduces losses from natural respiration. Proper drying procedures ensure paddy with good milling quality (i.e., high head rice, and high milling recovery).

Drying involves two stages - drying of "surface" moisture which brings grain moisture content down to around 18% MC and then drying to remove "internal" moisture. The following are general guidelines for drying of paddy.

### Effects of Delayed Drying

**Do not delay drying of wet paddy.** Delays in drying of wet paddy cause quality deterioration and physical loss with discoloration occurring increasing dramatically within 2-3 days after threshing. Paddy with high moisture content (>20% MC) must be dried as soon as possible down to 18% ("skin dry") then to 14% MC to preserve milling, cooking, smell, and eating qualities.



A general yellowing of the rice grain is a result of heat buildup in the paddy grain before drying. Discolored grain drastically reduces the market value of rice. Although discoloration is a complex biochemical process, it can be easily avoided by timely drying of paddy after harvest.

### Sun Drying

The target for drying grain for storage and milling is 14% MC. If not done properly, sun drying can result in over-drying or paddy with variable MC. The guidelines for proper sun drying are:

- Turn or stir the grain at least once per hour to achieve uniform MC - variation in MC within the grain causes rewetting and subsequent grain cracking of drier grain;
- Keep the thickness of the grain bed between 5 and 10 cm;
- On hot days, the grain temperature can rise above 50-60°C, thus cover the grain during mid-day to prevent over-heating;

- Cover the grain immediately if it starts raining. Rewetting of grain causes fissured grains and high grain breakage during milling
- Prevent contamination of grain with other materials, and keep animals off the grain
- Sun drying is presently the most common practices of drying in Asia. Typically it produces poor quality grain, but is very economical.



Sundrying is still the most common grain drying method used in Asia. Although the energy from the sun is for free, it is not an automatic process. Frequent stirring and turning of the grain (as shown) will reduce overheating and overdrying of grain, and improve uniformity of drying.

## Machine Drying

The target for drying grain for storage and milling is 14% MC. For production of premium rice quality or quality seed, artificial drying with heated air dryers ("machine drying") is recommended. Machine drying will lead to more uniform drying of grain and higher milling yield and head rice recovery.

- The most common smaller dryers have a capacity of 1-3 tons per day with drying times of 6-12 hours. For drying of paddy in tropical areas an air temperature of 40-45 °C is normally used with a heater capable of raising the air temperature 10-15° C. An air velocity 0.15-0.25m/s is required and typical power requirements are 1.5-2.5 kW /ton of paddy. The efficiency of these dryers is also improved by stirring the grain.
- Before loading the dryer, clean the grain by removing fines and green, immature grains. Fines reduce the air flow through rice, causing increased drying time and can cause wet spots.
- In the dryer, do not mix dry rice with wet rice. The drying air gains moisture as it passes through the dryer and may cause the dry rice to fissure.





Medium-sized grain dryers such as this recirculating batch dryer are now a common sight throughout Asia. In general, mechanically dried grain will produce better quality of rice. Grain recirculation allows for uniformly dried grain, and automatic drying air temperature control will reduce overheating or overdrying.

## Drying for Seed Production

The temperature of the drying air should not exceed 43°C. Drying air temperature affects seed viability. Some literature suggests you should use lower temperatures during first stage of drying of seed (if grain is very wet), so 40°C is often seen as optimum. Exposing paddy to 60°C for one hour can reduce seed germination rate from 95% to 30%. Two hours at 60°C will reduce germination rate to 5%.

Dry seed below 13%. For successful storage of seed in sealed bags, pots, or containers, paddy should be dried down to 10-12% MC to provide long term seed viability and minimize insect damage. Seed can be safely stored in sealed containers. The lower the MC of seed at the beginning of storage, the longer the seed remains viable. (See **grain storage**).

## Drying for Grain Production

Avoid over-drying (< 14% MC). If grain MC is lower than its **Equilibrium Moisture Content**, grain will reabsorb moisture from the atmosphere and crack. This results in lower head rice recovery and reduced milling recovery.

**For very wet paddy, consider pre-drying with ambient air.** Aeration reduces drying costs and maintains the eating quality of rice. High temperature drying of high moisture paddy causes deterioration of taste and decreases in germination. In general, aeration is possible if the Relative Humidity of the air is lower than 70%. See **Equilibrium Moisture Content**.



Broken rice (left) has about half the market value of Head rice (right). Proper drying procedures can minimize breakage in rice. Avoid overdrying (drying below 14% MC) and rewetting of dry rice to maximize head rice recovery.

## Drying Rates and Temperatures

- The drying rate is dependent on type of dryer, air flow rate, etc. If the grain is suspended in air or somehow in motion (as in the recirculating dryer), it can be higher than fixed-bed dryers. For most batch dryers, drying rates are in the 0.75 to 1 % moisture decline per hour, on average for the entire drying process. Typical drying rates are around 1% moisture/hour at 65°C and 0.5-0.75 % moisture per hour at 43°C. The higher temperature can be used to dry grain down to 18 % MC (to remove "surface moisture") and then the lower temperature can be used to remove internal moisture from within the grain. In general drying rates for first stage are higher than second stage because during first stage moisture is readily removed as it sits in the "skin". Second stage drying involves removal of "internal" moisture.
- For seed, drying air temperature should never exceed 43°C, regardless of the MC to avoid overheating of the grain which kills the germ.
- Using two stage drying means that you need to be able to carefully estimate MC during the drying process. If you can't or the MC is variable, it is better to



stay with 43°C. It is also recommended to include a tempering period before changing from higher to lower temperature drying.

- Do not leave wet rice in the dryer for extended periods. Undried rice may begin to heat, which causes the kernel to turn yellow.

## Grain Storage

### Conditions for Safe Storage

Safe storage of paddy grain for longer periods is possible if three conditions are met:

1. grain is dried down to 14% MC or less;
2. grain is protected from insects and rodents;
3. grain is protected from rewetting by rain or the surrounding air;

The longer the grain needs to be stored, the lower the required grain MC. Seed stored at MC's higher than 14 % will experience growth of molds and rapid loss of viability. The following table shows the MC required for different storage periods.

| Storage period   | Required MC for safe storage | Potential problems                     |
|------------------|------------------------------|--|
| 2 to 3 weeks     | 14 - 18%                     | Molds, discoloration, respiration loss |
| 8 to 12 months   | 13% or less                  | Insect damage                          |
| more than 1 year | 9% or less                   | Loss of viability                      |

## Grain Storage

The key to good storage is hygiene and grain moisture contents. The target moisture for storage is less than 14%. The following table shows the storage possibilities and problems associated with different grain moisture contents.

| Grain moisture content (%) | Safe storage | Possible problems |
|----------------------------|--------------|-------------------|
| >40                        |              | Germination       |
| 18                         | 2 weeks      |                   |
| 12-14                      | 1 year       |                   |
| >8                         |              | Insect damage     |
| 8-10                       | > 1 year     |                   |

### Calculating moisture content

Moisture content can be on a wet (MC wet) or dry (MC dry) basis:

- $MC\ wet = \frac{\text{Weight of moisture in wet grain}}{\text{weight of wet grain}} * 100$
- $MC\ dry = \frac{\text{Weight of moisture in wet grain}}{\text{weight of dry grain}} * 100$

Gain moisture depends upon the temperature and the relative humidity of the air. The following table shows this relationship. Shaded cells show desirable environmental conditions for storage:

| RH (%) | Temperature (celcius) |      |      |      |      |      |      |
|--------|-----------------------|------|------|------|------|------|------|
|        | 22                    | 24   | 28   | 32   | 36   | 40   | 44   |
| 50     | 11.2                  | 10.9 | 10.7 | 10.5 | 10.2 | 10.0 | 9.9  |
| 55     | 11.7                  | 11.5 | 11.2 | 11.0 | 10.8 | 10.6 | 10.4 |
| 60     | 12.3                  | 12.0 | 11.8 | 11.6 | 11.4 | 11.2 | 11.0 |
| 65     | 12.7                  | 12.6 | 12.4 | 12.2 | 12.0 | 11.8 | 11.6 |
| 70     | 13.5                  | 13.3 | 13.1 | 12.8 | 12.6 | 12.5 | 12.3 |
| 75     | 14.3                  | 14.0 | 13.8 | 13.6 | 13.4 | 13.2 | 13.0 |
| 77     | 14.6                  | 14.3 | 14.1 | 13.9 | 13.7 | 13.5 | 13.4 |
| 79     | 14.9                  | 14.7 | 14.5 | 14.3 | 14.1 | 13.9 | 13.7 |
| 81     | 15.3                  | 15.1 | 14.9 | 14.6 | 14.5 | 14.3 | 14.1 |
| 83     | 15.7                  | 15.7 | 15.3 | 15.1 | 14.9 | 14.7 | 14.5 |
| 85     | 16.1                  | 15.9 | 15.7 | 15.5 | 15.3 | 15.1 | 15.0 |
| 87     | 16.6                  | 16.4 | 16.2 | 16.0 | 15.8 | 15.6 | 15.5 |
| 89     | 17.2                  | 17.0 | 16.8 | 16.6 | 16.4 | 16.2 | 16.1 |
| 91     | 17.9                  | 17.7 | 17.5 | 17.3 | 17.1 | 16.9 | 16.7 |

### Hygiene for storage

- Keep storage areas clean
- When storage rooms are emptied, clean and before using again, consider spraying walls and crevices, including the wooden pallets, with the recommended insecticide to disinfest insect breeding places.
- Place sticky traps in the drying and storage areas for rats. (Keep a cat)
- Storage rooms should be physically rodent and bird proof, if possible.
- If necessary, treat storage sacks with insecticide to prevent insect infestation. This however is a dangerous practice if there is a chance that the seeds will be milled for consumption, and therefore is not recommended.
- Inspect the stored seeds once a week for signs of insect infestation. Should there be infestation, under the direction of a trained pest control technician, the storage room or the seed stock may be enclosed hermetically with tarpaulin and fumigants. Phostoxin is used by the grain milling industry. This will kill all insects, larvae, and rodents in the enclosure.
- For long term seed storage, store the seeds in bags in storerooms with controlled temperature and relative humidity. The recommended storage environment for rice seeds are <20C and 40%RH. In this conditions both fungi and insects will be inhibited.

### Equilibrium Moisture Content of Paddy

In storage, the moisture content of rice depends on the temperature and the relative humidity of the air surrounding the grain. The final grain moisture content resulting from storage is called the Equilibrium Moisture Content (EMC). The following table shows the EMC of paddy under different storage conditions. **The underlined & colored areas** represent the desirable environmental conditions for storage of paddy in the tropics.

| RH (%) | Temperature (celcius) |      |      |      |      |      |      |
|--------|-----------------------|------|------|------|------|------|------|
|        | 22°                   | 24°  | 28°  | 32°  | 36°  | 40°  | 44°  |
| 50     | 11.2                  | 10.9 | 10.7 | 10.5 | 10.2 | 10.0 | 9.9  |
| 55     | 11.7                  | 11.5 | 11.2 | 11.0 | 10.8 | 10.6 | 10.4 |
| 60     | 12.3                  | 12.0 | 11.8 | 11.6 | 11.4 | 11.2 | 11.0 |
| 65     | 12.7                  | 12.6 | 12.4 | 12.2 | 12.0 | 11.8 | 11.6 |
| 70     | 13.5                  | 13.3 | 13.1 | 12.8 | 12.6 | 12.5 | 12.3 |
| 75     | 14.3                  | 14.0 | 13.8 | 13.6 | 13.4 | 13.2 | 13.0 |
| 77     | 14.6                  | 14.3 | 14.1 | 13.9 | 13.7 | 13.5 | 13.4 |
| 79     | 14.9                  | 14.7 | 14.5 | 14.3 | 14.1 | 13.9 | 13.7 |
| 81     | 15.3                  | 15.1 | 14.9 | 14.6 | 14.5 | 14.3 | 14.1 |
| 83     | 15.7                  | 15.7 | 15.3 | 15.1 | 14.9 | 14.7 | 14.5 |
| 85     | 16.1                  | 15.9 | 15.7 | 15.5 | 15.3 | 15.1 | 15.0 |
| 87     | 16.6                  | 16.4 | 16.2 | 16.0 | 15.8 | 15.6 | 15.5 |
| 89     | 17.2                  | 17.0 | 16.8 | 16.6 | 16.4 | 16.2 | 16.1 |
| 91     | 17.9                  | 17.7 | 17.5 | 17.3 | 17.1 | 16.9 | 16.7 |

**Example:** at 81% Relative Humidity and 32°C, paddy will attain 14.6 % Moisture Content.

## Estimating Relative Humidity

For a crude but simple method to estimate Relative Humidity:

1. Measure the ambient air temperature with a mercury thermometer (Celcius)
2. Wrap the tip of the thermometer in a piece of cloth that is soaked in water
3. Measure the air temperature with the wetly wrapped thermometer while holding it in the wake of the wind or airfan.
4. The difference between the first ("dry") and second ("wet") temperature is a measure of the Relative Humidity:
  - 0 - 1°C difference: Relative Humidity is more than 90%
  - 2 - 3°C difference: Relative Humidity is between 80 and 90%
  - 4°C or more: Relative Humidity is 70% or lower

## Hygiene in Storage

Hygiene in the grain store or storage depot is important in securing grain and seed quality over time. Following are some guidelines for hygiene in the grain store:

- Keep storage areas clean;
- Clean storage rooms after they are emptied, and consider spraying walls, crevices, and wooden pallets against insects before using them again
- Place rat traps in drying and storage areas, and keep a cat to deter or control rats and mice;
- Inspect storage room regularly to keep it rat and bird proof
- Inspect the stored seeds once a week for signs of insect infestation. Only if necessary and under the direction of a trained pest control technician, the storage room or the seed stock may be enclosed hermetically with tarpaulin and treated with fumigants

## Pests in Grain Storage

Insects in stored rice can be classified into **four** groups according to their feeding habits namely internal feeders, external feeders and scavengers.

**1. Internal Feeders** - These are insects whose larvae feed entirely within the kernels of the grain. These includes rice weevil, angoumois grain moth and lesser grain borer.

- **Rice Weevil** (*Sitophilus oryzae* (Linnaeus))
- **Angoumois Grain Moth** (*Sitatroga cerealella* (Olivier))
- **Lesser Grain Borer** (*Rhyzopertha dominica* (Fabricus))

**2. External Feeders** - External feeders are insects that feed from the outside of the grain even though they may chew through the outer coat and devour the inside.

- **Cigarette or Tobacco Beetle** (*Lasioderma serricorne* (Fabricius)): Feeds on books, flax tow, cottonseed meal, rice, ginger, pepper, dried fish, crude drugs, seeds, pyrethrum powder, and dried plants.
- **Flat Grain Beetle** (*Cryptolestes pusillus* (Schonherr)): The female places her eggs loosely in the grain mass. The larvae and adults are able to penetrate the seed coat of the undamaged grain.

**3. Scavengers** - Scavengers feed on the grain only after the seed coat has been broken either mechanically or by some other insect.

- **Saw-toothed Grain Beetle** (*Oryzaephilus surinamensis* (Linnaeus))

## 4. Rodents in Storage

(source: Gwinner et al, Manual on the Prevention of Post-harvest Grain losses, GTZ, Eschborn, 1996)

## Storage Options

Besides temperature and relative humidity, the type of bag or container used is crucial for successful storage:

- **Traditional storage:** Typically grain is traditionally stored in 40-50 kg sacks made of jute or woven plastic. The grain MC in these bags will fluctuate as moisture in the air can freely transfer through the bag. A combination of high temperature and high relative humidity will lead to insect infestation in these bags, even if the grain was properly dried before storage. Bags are usually stacked under a roof or in a shed and will likely need periodic fumigation to control insects. Some farmers use granaries, which are made from timber or mud/cement or large woven baskets and these also suffer from insect and rodent damage.



Farmers often store seed and grain in claypots or woven plastic bags that are also used for fertilizer. Grain stored under these conditions is often exposed to moisture fluctuation, insects and rodents. Alternatives are available to improve storage conditions and reduce grain or seed quality deterioration.

- **Sealed storage:** For longer term storage of grain and seed, sealed or hermetic storage is an alternative. In such storage, carbon dioxide builds up and oxygen is reduced. The seed remains viable but insects can not survive. Thus, ensuring complete sealing is important. If grain is dried to 14% and stored in a sealed storage it reduces the risk of insect and rodent damage and the grain should not absorb moisture from the atmosphere or be damaged by rain. For storage up to one year, grain needs to be dried down to 13% MC or to 9% MC for storage longer than 1 year.



Recycled oil drums and PVC containers can be used as low-cost sealed storage devices for paddy seed and grain. Plastic containers like the ones shown can be commonly found throughout Asia and can hold from 25kg up to 250 kg of grain. Care should be taken to dry the grain to 13% MC before sealing, and to seal off the covers carefully to create a sealed environment inside the container.

Sealed storage containers come in all shapes and sizes. They may range from a small plastic container to a sealed 200-liter drum to the more complex and costly sealed plastic commercial storage units. Most large commercial steel and concrete silos being used in western countries can be sealed for fumigation.



Hermetic storage of grain has recently proved successful in keeping paddy seed viable for periods longer than 12 months. In the hermetically sealed storage environment, insects create an oxygen-deficient atmosphere that reduces insect infestation drastically and to an acceptable level. Hermetic storage is a good option for storage of grain and seed in particular where

cold storage is not available or too expensive.

- For storage of **small seed lots**, a variety of plastic bags or packages can be used. Different types of plastic have different resistance against transmission of water vapor. Glass jars, hard pvc, or bags containing aluminum liners will provide best protection against moisture re-entry. Polypropylene or polyethylene bags are the next best choice. Use of paper bags or flexible pvc bags for long term storage of seed is discouraged.
- **Importance of temperature:** No bags or container can protect seed from the detrimental effects of high temperatures. For each 5°C increase in temperature, seed storage life will be reduced by half.

## Grain Milling

### Grain Milling

Milling is the final step in postproduction of paddy. There are three requirements for producing good quality milled rice:

- the starting quality of the paddy is good and at the right moisture content (14%),
- the rice mill is well maintained, and
- the mill is operated by a skilled operator.

If any of these requirements are not met, milling will result in poor quality rice. For instance, milling of poor quality paddy will always result in poor quality milled rice, even if a state-of-the-art mill is used or the miller is experienced. Similarly, the use of good quality paddy by a well skilled operator may result in poor quality rice if the mill is not maintained regularly.

The best quality milled rice will be attained from a mill that has:

- Pre cleaning of the paddy,
- Rubber rollers to remove the husk,
- Effective separation of paddy from brown rice after husking
- Two separate whiteners and one polisher, and
- Grader for the polished white rice.

### Main Milling Practices

- **Mill rice at the right moisture content:** 14% MC. If MC is too low, high grain breakage will occur resulting in low head rice recovery. Broken grain has only half the market value of head rice (head rice = 75-100% of whole kernel).
- **Pre-clean paddy before husking:** Use of paddy without impurities will ensure a cleaner and higher quality end product. The more impurities and unfilled grains are present in the paddy, the lower the milling recovery of the rice mill.

A simple pre-cleaner often used in rice mills contains an oscillating double screen bed with an aspirator. The first screen (7 mm opening or larger) is a scalper that lets through the grain but retains straw. The second screen (1.4



## TropRice

mm opening) retains the grains but lets through broken grains and small stones or weed seeds. The air aspirator sucks out dust and the light empty grains. Air dampers on the blower have to be adjusted to prevent the good grain from being sucked out. The capacity of the paddy pre-cleaner should be based on the capacity of the rice mill. Example: a typical pre-cleaner for a 3 ton/hr rice mill will need to have 5 ton/hr cleaning capacity.

- **Use rubber roll technology for husking:** Engleberg-type or "steel" hullers are no longer acceptable in the commercial rice milling sector, as they lead to low milling recovery and high grain breakage.



The Engleberg-type mill is an adaptation of the "Engleberg" coffee huller from the United States. It is still the mainstay technology for milling parboiled paddy in Bangladesh, and in many African countries. The "iron hullers", or "single pass mills" which all refer to the same mill are notorious for breaking the paddy grain. Because of the high breakage, the total milled rice recovery is 53-55%, and head rice recovery is in the order of 30% of the milled rice. The fine brokens are mixed with the bran and the ground rice hull. This by-product is used for animal feed. In many rural areas, Engleberg mills are used for custom milling the rice requirements of households. The bran produced is left to the miller as the milling fee. The poor performance of the Engleberg mill has led governments to discourage its use and has limited further proliferation.





An example of a rubber roll mill is the compact 2-stage rice mill which has 0.5 to 1 ton per hour paddy input. A typical compact rice mill consists of a 6-inch diameter x 6-inch wide rubber roller husker, and a friction whitener. The friction whitener has a very similar design configuration as the Engleberg except that it has no husking knife. The milling performance of the compact rice mill is superior to the single pass Engleberg huller. Milling recoveries are normally above 60%.



Paddy should be at 14% Moisture content and continuously fed to the rubber rolls. Grain flow rate through the husker is controlled by the feed adjusting valve which is controlled manually or automatically. A clearance of 0.8 to 1.0 mm between the roll surfaces should be maintained to prevent damage to the rolls. This is roughly half the thickness of the paddy grain. The clearance should be adjusted to obtain a husking efficiency of 90 to 95%. The rated husking life of the rubber rolls can vary from 40 to 100 tons, and should be indicated by the manufacturer. Interchanging the left and right roll at mid life will enhance rubber roll life as the rolls will wear out more evenly.

- Separate all paddy from the brown rice before whitening:** Paddy separation after husking will lead to better quality milled rice, and reduce overall wear and tear on the rice mill. The performance of the rubber roll husker can be expressed by the husking efficiency, which is the % of husked rice in total grain flow. In a properly adjusted rubber roll husker, husking efficiencies can be as high as 95%, however husking efficiencies are often around 80% (i.e. there will be 20% paddy in the output). Besides machine adjustments, uniformity of grain thickness will affect the husking efficiency. If a mixture of varieties is fed into the husker, or paddy grain that did not mature uniformly in the field, husking efficiencies will be lower.



A very simple separator with no moving parts is the screen separator, which can be seen in smaller commercial mills located near rural markets. Brown rice/paddy will move through a number of screens that are set at 31-35° angle. The rough rice moves down the top screen, a mixture of rough rice and brown rice moves down the middle screen and finishing screen, and brown rice will accumulate underneath the finishing screen. Suggested screen sizes are represented in the following table.

| Screen Name | Screen size:<br>lateral Mesh-number<br>(opening in mm) | Screen size:<br>longitudinal Mesh-<br>number (opening in<br>mm) |
|-------------|--|---|
| Top screen  | # 5.5 – # 6.0  | # 7.5 – # 8.0   |

|                  |                |               |
|------------------|----------------|---------------|
| Middle screen    | # 6.0 - # 7.0  | # 7.5 - # 8.0 |
| Finishing screen | # 7.0 - # 7.25 | # 7.5 - # 8.0 |

- **Consider two-stage whitening:** Having at least two stages in the whitening process (and a separate polisher) will reduce overheating of the grain and will allow the operator to set individual machine settings for each step. This will ensure higher milling and head rice recovery.



Installing a 1.4 mm round screen on the outlet of a horizontal friction whitener (as shown), will reduce the amount of small brokens, chips, and germs from the milled rice. The material that falls through the screen can be used to make rice flour.

- **Install a screen sifter** to remove small brokens and chips from the polished rice. Most screens or sieves with a sieve opening not greater than 1.4 mm will be effective in removing small brokens. Rice with a large number of small brokens (or brewer's rice) has a lower market value. The small brokens can be utilized to produce rice flour.
- **Monitor and replace spare parts regularly** to keep milled rice quality high at all times. Turning or replacing rubber rolls, refacing stones, and replacing worn screens regularly will keep milled rice quality high at all times.
- **Do not mix varieties prior to milling:** Different varieties of paddy have different milling characteristics that require individual mill settings. Mixing varieties will generally lead to lower quality of milled rice.

## Defining and Measuring Grain Quality

### Introduction to Grain Quality

Quality is not always easy to define as it depends on the consumer and the intended end use for the grain. All end users want the best quality that they can afford. The quality of grain is usually the best when it reaches physiological maturity and everything that is done after that point can only cause a decline in quality.

Grain quality is not solely a varietal characteristic but also depends on the crop production environment, harvesting, processing and handling systems. Therefore, maintaining good grain quality is the concern of all disciplines such as breeding, agronomy, entomology, chemistry and engineering.

## **Defining Quality**

### **Defining Quality for Paddy or Rough Rice**

#### **Moisture Content**

Paddy is at its optimum milling potential at moisture content of 14%. Moisture content has a marked influence on all aspects of paddy and rice quality and it is essential that paddy be milled at the proper moisture content to obtain the highest head rice yield. Grains with high moisture content are too soft to withstand hulling pressure without undue breakage and may be pulverized. Grain that is too dry becomes brittle and has greater breakage.

Moisture content and temperature during the drying process is also critical as it determines whether fissures and/or full cracks are introduced into the grain structure.

#### **Degree of Purity**

Purity is related to the presence of dockage in the grain. Dockage refers to material other than paddy and includes chaff, stones, weed seeds, soil, rice straw, stalks, etc. These impurities generally come from the field or from the drying floor.

Unclean paddy increases the time taken to clean and process the grain. Foreign matter in the grain reduces milling recoveries and the quality of rice and increases the wear and tear on milling machinery.

#### **Varietal Purity**

A mixture of varieties causes difficulties at milling and usually result in reduced capacity, excessive breakage, lower milled rice recovery and reduced rice. Different sizes and shaped grains makes it more difficult to adjustments the hullers and polishers to produce whole grains. This results in low initial de-hulling efficiencies, a higher percentage of re-circulated paddy, non-uniform whitening, and lower grade of milled rice.

#### **Grain Dimensions**

Grain size and shape (length-width ratio) is a very stable varietal property. Long slender grains normally have greater breakage than short, bold grains and consequently have a lower mill rice recovery. The grain dimensions will also dictate

to some degree the type of milling equipment needed. As an example, the Japanese designed milling equipment may be better suited to short-bold grains.

### Length classification (after hulling)

| Classification | Length (mm) | Relation to other factors         |
|----------------|-------------|-----------------------------------|
| Extra long     | >7.5        | Tends to be fluffy (high amylose) |
| Long           | 6.61-7.50   |                                   |
| Medium         | 5.51-6.60   |                                   |
| Short          | < 5.51      | tends to be sticky (low amylose)  |

### Grain shape (ratio of length to width on brown rice)

| Classification | Ratio   |
|----------------|---------|
| Slender        | > 3.0   |
| Medium         | 2.1-3.0 |
| Bold           | 1.1-2.0 |
| Round          | <1.1    |

### Cracked Grains

Overexposure of mature paddy to fluctuating temperature and moisture conditions leads to development of fissures and cracks in individual kernel. Cracks in the kernel are the most important factor contributing to rice breakage during milling. This results in reduces milled rice recovery and head rice yields.

### Immature Grains

The amount of immature paddy grains in a sample has a major affect on head rice yield and quality. The immature rice kernels are very slender and chalky and this results in excessive production of bran, broken grains and brewer's rice. The optimal stage to harvest grain is at about 20-24% grain moisture or about 30 days after flowering. If the harvest is too late, many grains are lost through shattering or dry out and are cracked during threshing, which causes grain breakage during milling.

### Discolored/Fermented Grains and Damaged Grains

#### Damaged grains

Paddy deteriorates through biochemical change in the grain, the development of off-odors and changes in physical appearance. These types of damage are caused from water, insects, and heat exposure.

**Yellowing** is caused by over-exposure of paddy to wet environmental conditions before it is dried. This results in a combination of microbiological and chemical activity that overheats the grain similar to a milled form of parboiling. These

fermented grains frequently possess partly gelatinized starch cells and generally resist the pressures applied during grain milling. While the presence of fermented grain does not affect milling yields it does downgrade the quality of the milled rice because of the unattractive appearance.

The presence of black spots around the germ end of the brown rice kernel is caused by the microorganisms (fungi) and is increased by unfavorable weather conditions. In the process of milling, these black spots are only partly removed which consequently increases the presence of damaged grains.

## **Defining Quality for Milled Rice**

### **Physical Characteristics**

#### *Milling Degree*

The degree of milling or percent brown rice removed as bran affects the level of recovery and influences consumer acceptance. Apart from the amount of white rice recovered, milling degree influences the color and also the cooking behavior of rice. Unmilled brown rice absorbs water poorly and does not cook well. The water absorption rate improves progressively up to about 25% milling degree after which, there is very little effect.

The flow (frictional property) and packing (bulk density) behaviors of rice are also depend on milling. Likewise, the nutrient content of rice is also strongly influenced since most micro-nutrient located largely in the peripheral layers of brown rice are removed with high milling degree.

#### *Head Rice Recovery*

The head rice percentage is the volume or weight of head grain or whole kernel in the rice lot. Head rice normally includes broken kernels that are 75-80% of the whole kernel. High head rice yield is one of the most important criteria for measuring milled rice quality. Broken grain has normally only half of the value of head rice. To a large extent, the characteristics of the paddy determine the potential head rice yield although the milling process is responsible for some losses and damage to the grain.

#### *Whiteness*

This characteristic is a combination of varietal physical characteristics and the degree of milling. In milling, the whitening and polishing greatly affect the whiteness of the grain. During whitening, the silver skin and the bran layer of the brown rice is removed. Polishing is undertaken after whitening to improve the appearance of the white rice. During polishing some of the bran particles stick to the surface of the rice which polishes and gives a shinier appearance.

#### *Chalkiness*

Grain appearance is largely determined by the endosperm opacity and this is commonly classified as the amount of chalkiness. Opaqueness has an overall chalky texture caused by interruption of final filling of the grain. Though chalkiness



disappears upon cooking and has no direct effect on cooking and eating qualities, excessive chalkiness downgrades the quality and reduces milling recovery.

### Quality standards for milled rice in Philippines (National Food Authority)

| Grade Specifications               | Grade   |         |         |         |
|------------------------------------|---------|---------|---------|---------|
|                                    | Premium | Grade 1 | Grade 2 | Grade 3 |
| Head rice (min %)                  | 95.00   | 80.00   | 65.00   | 50.00   |
| Brokens (max %)                    | 4.90    | 19.75   | 34.50   | 49.00   |
| <b>Defectives</b>                  |         |         |         |         |
| Damaged grains (max %)             | 0       | 0.25    | 0.50    | 2.00    |
| Discolored grains (max %)          | .50     | 2.00    | 4.00    | 8.00    |
| Chalky and immature grains (max %) | 2.00    | 5.00    | 10.00   | 15.00   |
| Red grains (max %)                 | 0       | .20     | .50     | 2.00    |
| Red streaked grains (max%)         | 1.00    | 3.00    | 5.00    | 10.00   |
| Foreign matter (max 5)             | 0       | .10     | .20     | .50     |
| Paddy (max no./kg)                 | 1       | 8       | 10      | 15      |
| Moisture content (max %)           | 14.00   | 14.00   | 14.00   | 14.00   |

### Chemical Characteristics

#### *Gelatinization Temperature*

The time required for cooking is determined by gelatinization temperature. Environmental conditions, such as temperature during ripening, influence gelatinization temperature. A high ambient temperature during development results in starch with a higher temperature.

Gelatinization temperature is estimated by the extent of alkali spreading and clearing of milled rice soaked in 1.7% KOH at room temperature or at 39 degrees C for 23 hours (Little et al, 1958). The degree of spreading is measured using a seven-point scale as follows:

1. grain not affected
2. grain swollen,
3. grain swollen, collar incomplete and narrow,

TropRice

4. grain swollen, collar complete and wide,
5. grain split or segmented, collar complete and wide,
6. grain dispersed, merging with collar; and
7. grain completely dispersed and intermingled.

Alkali spreading value corresponds to gelatinization temperature as follows:

- 1-2 high (74.5-80°C),
- 3, high intermediate,
- 4-5, intermediate (70-74°C), and
- 6-7, low (<70°C).

There is normally a distinct preference for rice with intermediate gelatinization temperature.

### *Amylose Content*

Starch makes up about 90% of the dry matter content of milled rice. Starch is a polymer of glucose and amylose is a linear polymer of glucose. The amylose content of starches usually ranges from 15 to 35%. High amylose content rice shows high volume expansion (not necessarily elongation) and high degree of flakiness. The grains cooked dry, are less tender, and become hard upon cooling. In contrast, low-amylose rice cooks moist and sticky. Intermediate amylose rice are preferred in most rice-growing areas of the world, except where low-amylose japonicas are grown.

Based on amylose content, milled rice is classified as

- waxy (1-2% amylose),
- non-waxy (>2% amylose),
- very low (2-9% amylose),
- intermediate (20-25% amylose) and
- high (25-33% amylose).

The colorimetric iodine assay indexes the amylose content of milled rice.

### *Gel Consistency*

Gel consistency measures the tendency of the cooked rice to harden on cooling. Gel consistency is determined by heating a small quantity of rice in a dilute alkali. This test differentiates the consistency of cold 5.0% milled rice paste. Within the same amylose group, varieties with a softer gel consistency are preferred, and the cooked rice has a higher degree of tenderness.

Harder gel consistency is associated with harder cooked rice and this feature is particularly evident in high-amylose rice. Hard cooked rice also tend to be less sticky.

## **Measuring Quality**

### **Physical Properties of Paddy**

#### **Moisture Content of Paddy**

Two methods can be used to measure moisture content:



- The primary or direct method ( Air oven method)
- The secondary method (Electronic moisture tester)

### Air oven method

1. Set the oven at 130°C.
2. Weigh three 100 g paddy samples and place the samples inside the oven.
3. Measure the final weight of the samples after the 16 hours.
4. Compute for the moisture content wet basis (MCWB) using the equation:

$$MCWB = \frac{\text{Initial Weight} - \text{Final Weight}}{\text{Initial Weight}} \times 100$$

5. Compute the average MC.

### Moisture Tester

1. Read the operators instruction
2. Turn on the moisture meter and ensure that the machine is set for paddy or rough rice.
3. Fill the tray/bowl of the moisture tester with paddy samples.
4. Turn/press the knob until the moisture reading is displayed.
5. Test at least three samples.

### Crack Detector

Using the Paddy Crack Detector, count the number of cracked grains in a 100 grain sample then compute the % cracked grains using the equation:

$$\% \text{ Cracked grains} = \frac{\text{No. of cracked grains}}{100 \text{ grains}} \times 100$$

### Grain Dimensions

Using the Vernier caliper or photographic enlarger, collect 20 paddy samples at random from each replicate and measure the dimensions to obtain the average length and width of the paddy grains. To obtain the paddy shape, the following equation will be used:

$$\text{Length to width ratio (L/W)} = \frac{\text{Average paddy length, mm}}{\text{Average paddy width, mm}}$$

Paddy will be classified based on International Organization for Standardization (ISO) for paddy.

### Production practices - effects

- Variety - Length and shape are highly heritable. Grain length and shape are related to head rice yield as long grain varieties tend to break more than short to medium grain during milling.
- Length is little affected by environment, so management has little effect.

### Immature Grains

1. Select a 25 gm grain sample

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2. Select, segregate and weigh the immature grains in sample. Calculate the percentage immature grains in the sample using the formula:

$$\% \text{ Immature grains} = \frac{\text{Wt of immature grains}}{\text{Total weight of samples}} \times 100$$

### **Dockage**

Remove light foreign matter, stones, weed and seeds from a 100gm sample. Obtain the total weight then compute the dockage percentage as follows:

$$\% \text{ Dockage} = \frac{\text{Wt of dockage}}{\text{Total wt of sample}} \times 100$$

### **1000 Seed Weight**

Count and weigh 1,000 grains (paddy).

## **Physical Properties of Milled Rice**

### **Milling Degree**

Milling degree is computed based on the amount of bran removed from the brown rice. To obtain the weight of brown rice, dehull the paddy samples using the Laboratory Huller.

Estimate the percent milling degree using the following equation:

$$\% \text{ Milling degree} = \frac{\text{Wt of milled rice}}{\text{Wt of brown rice}} \times 100$$

### **Milling Recovery**

Using the Abrasive Whitener, mill the dehulled samples. Compute milling recovery by dividing the weight of milled rice recovered by the weight of the paddy sample.

$$\% \text{ Milling recovery} = \frac{\text{Wt milled rice}}{\text{Wt of sample used}} \times 100$$

### **Dockage**

Select, segregate and weigh the foreign matter. Record the number of unhulled grains collected from the sample. Determine the percentage of dockage of milled rice using the equation:

$$\% \text{ Dockage}(mr) = \frac{\text{Wt. of dockage}}{\text{Total wt of milled rice}} \times 100$$

### **Broken Grain**

Using the Grain Grader, separate the broken grain from the whole grains. Compute the percentage of the milling recovery components using the following equations:

$$\% \text{ Broken} = \frac{\text{Wt of broken grains}}{\text{Wt of paddy samples}} \times 100 \quad \% \text{ Head rice} = \frac{\text{Wt of whole grains}}{\text{Wt of paddy samples}} \times 100$$

### Chalkiness

A visual rating of the chalky proportion of the grain is used to measure chalkiness based on the standard Evaluation System SES scale presented below:

| Scale | % area of chalkiness |
|-------|----------------------|
| 1     | less than 10         |
| 5     | 10-20                |
| 9     | more than 20         |

Select, segregate and weigh the chalky grains (SES Scale 9). Determine the % chalky grain using the equation:

$$\% \text{ Chalky grain} = \frac{\text{Wt of chalky grains}}{\text{Wt of milled rice}} \times 100$$

### Production practices - effects

- Chalkiness is highly affected by genetics and also by environment - especially high temperature just after flowering. Thus planting date may influence chalkiness.
- The effects of fertility and water management are unknown.

### Whiteness

1. Measure the grain whiteness using the Whiteness Meter.
2. Separate and weigh yellow-fermented grains. Calculate the percentage of yellow/fermented grains using the formula:

$$\% \text{ Yellow grains} = \frac{\text{Wt yellow grains}}{\text{Wt total milled rice}} \times 100$$

### Production practices - effects

Discoloration accelerates rapidly when grain is stacked or stored at high MCs.

### Grain Shape

Follow the procedure of determining grain shape of paddy. Based on the length to width ratio, the shape of the milled rice will be determined. The ISO Classification is as follows:

$$L/W \text{ ratio} = \frac{\text{Avg. length of rice}}{\text{Avg. width of rice}} \times 100$$

| Scale | Shape   | L/W ratio   |
|-------|---------|-------------|
| 1     | Slender | Over 3.0    |
| 3     | Medium  | 2.1 – 3.0   |
| 5     | Bold    | 1.1 – 2.0   |
| 9     | Round   | 1.0 or less |

### 1000 Grain Weight

Count and weigh 1,000 whole grains.

## Chemical Characteristics of Milled Rice

### Amylose Content

Twenty grains are selected and ground in the UDY Cyclone Mill. Amylose content is analyzed using the simplified iodine colorimetric procedure. Samples are categorized into low, intermediate and high based on the following grouping:

| Category     | %Amylose Content |
|--------------|------------------|
| Low          | 10-20            |
| Intermediate | 20-25            |
| High         | 25-30            |

### Amylose content and typical characteristics

| Term                 | Amylose content(%) | Characteristics when cooked  | Types of products made                    | Country where preferred                            |
|----------------------|--------------------|--|---|--|
| Waxy (or glutinous)  | 0-2                | Absorb little water and therefore have little volume expansion                                       | Rice cakes, desserts, sweets, puffed rice | Staple in RainFed lowlands Laos, N and NE Thailand |
| Low amylose          | 8-20               | On cooking tend to be moist, sticky and glossy. Split if overcooked. Most japonicas have low amylose | Fermented rice cakes                      |  |
| Intermediate amylose | 21-25              | Cook fluffy, remain soft.  | Fermented rice cakes                      | Indonesia, Philippines, Thailand and Vietnam       |
| High Amylose         | > 25               | Cook dry and   | Noodles                                   | Staple - Sri                                       |

|                               |  |                        |
|-------------------------------|--|------------------------|
| (See <b>gel consistency</b> ) | fluffy, become hard when cool. Resist disintegration during boiling. | Lanka, Pakistan, India |
|-------------------------------|--|------------------------|

### Production practices - effects

Amylose content can vary as much as 6% depending upon environmental conditions - High temperatures during ripening lower amylose content, so planting date can be important.

### Gelatinization Temperature

Gelatinization temperature is measured using alkali-spreading value. The alkali digestibility test is employed. Grains are soaked in 1.7% KOH and incubated in a 30°C oven for 23 hours. Measurement ranges based on the following:

| Category     | Temp ranges (°C) | Alkali Spread |
|--------------|------------------|---------------|
| Low          | 55-69            | 6-7           |
| Intermediate | 70-74            | 4-5           |
| High         | 75-79            | 2-3           |

Gelatinization temperature is the temperature at which the rice absorbs water and starch granules swell irreversibly.

| Classification | Gelatinization temperature (GT) | Observations and Implications   |
|----------------|---------------------------------|---|
| Low            | < 70°C                          | Most Japonica varieties have low GT.  |
| Intermediate   | 70-74°C                         | Most tropical Indica varieties have intermediate or low GT.   |
| High           | >74°C                           | If very high, then rices become excessively soft and disintegrate when overcooked. Require more cooking and water than rices with lower GT. |

### Production practices - effects

Variety - GT is highly heritable although it can vary by as much as 10oC within a variety depending upon environmental effects. High temperature after flowering raises GT; low air temperature lowers it.

### Gel Consistency

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Two to 10 grains are selected and ground separately in the Wig-L Bug. Gel consistency is measured by the cold gel in a test tube, being held horizontally, for one hour.

Measurement ranges and category are as follows:

| Category | Consistency, mm |
|----------|-----------------|
| Soft     | 61-100          |
| Medium   | 41-60           |
| Hard     | 26-40           |

The gel consistency test differentiates rices with high amylose content into three types:

| Type       | Gel consistency |
|------------|-----------------|
| Very flaky | Hard            |
| Flaky      | Medium          |
| Soft       | Soft            |

Gel consistency is genetically determined.

## Standards

### ISO Standards

#### International Standards

This International Standard lays down the minimum specifications for rice (*Oryza sativa* L.) of the following types: husked rice, husked parboiled rice, milled rice and milled parboiled rice, suitable for human consumption, directly or after reconditioning, and which is the subject of international trade.

#### Normative References

The following standards contain provisions, which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards listed below. Members of IEC and ISO maintain registers of currently valid International Standards.

- ISO 712: 1985, Cereals and cereal products – Determination of moisture content (Routine reference method).
- ISO 950: 1979, Cereals – Sampling (as grain).

#### Definitions

For the purposes of this International Standard, the following definitions apply.

1. paddy: paddy rice: rough rice: Rice retaining its husk after threshing.
2. husked rice: cargo rice: Paddy from which the husk only has been removed. The processes of husking and handling, particularly of parboiled rice, may result in some loss of bran.
3. milled rice: Rice obtained after milling which involves removing all or part of the bran and germ from the husked rice.

*It could further be classified into the following degrees of milling.*

- undermilled rice: Rice obtained by milling husked rice but not to the degree necessary to meet the requirements of well-milled rice.
  - well-milled rice: Rice obtained by milling husked rice in such a way that some of the germ, and all the external layers and most of the internal layers of the bran have been removed.
  - extra-well-milled rice: Rice obtained by milling husked rice in such a way that almost all the germ, and all the external layers and the largest part of the internal layers of the bran, and some of the endosperm, have been removed.
4. parboiled rice: Rice, the starch of which has been fully gelatinized by soaking paddy or husked rice in water followed by a heat treatment and a drying process.
  5. glutinous rice: waxy rice: Special varieties of rice (*Oryza sativa* L. *glutinosa*) the kernels of which have a white and opaque appearance. The starch of glutinous rice consists almost entirely of amylopectin. It has a tendency to stick together after cooking.
  6. size of kernels, broken kernels and chips
    - 6.1 whole kernel: Kernel without any broken part.
    - 6.2 head rice: Kernel, the length of which is greater than or equal to three quarters of the average length of the corresponding whole kernel.
    - 6.3 large broken kernel: Fragment of kernel, the length of which is less than three-quarters but greater than one-half of the average length of the corresponding whole kernel.
    - 6.4 medium broken kernel: Fragment of kernel, the length of which is less than or equal to one-half but greater than one-quarter of the average length of the corresponding whole kernel.
    - 6.5 small broken kernel: Fragment of kernel, the length of which is less than or equal to one-quarter of the average length of the corresponding whole kernel but which does not pass through a metal sieve with round perforations 1.4 mm in diameter.
    - 6.6 chip: Fragment of kernel which passes through a metal sieve with round perforations 1.4 mm in diameter.
  7. extraneous matter: Organic and inorganic components other than kernels of rice, whole or broken
  8. heat-damaged kernels: Kernels, whole or broken, that have changed their normal color as a result of heating. This category includes whole or broken kernels that are yellow due to alteration. Parboiled rice in a batch of non-parboiled rice is also included in this category.
  9. damaged kernels: Kernels, whole or broken, showing obvious deterioration due to moisture, pests, disease or other causes, but excluding heat-damaged kernels (3.8).
  10. immature kernels: Kernels, whole or broken, which are unripe and/or underdeveloped.



11. chalky kernels: Kernels, whole or broken, except for glutinous rice, of which at least three-quarters of the surface has an opaque and floury appearance.
12. red kernels: Kernels, whole or broken, having a red coloration covering more than one-quarter of their surface, but excluding heat-damaged kernels (3.8).
13. red-streaked kernels: Kernels, whole or broken, with red streaks, the lengths of which are greater than or equal to one-half of that of the whole kernel, but where the surface covered by these red streaks is less than one-quarter of the total surface.
14. pecks: Kernels, whole or broken, of parboiled rice of which more than one-quarter of the surface is dark brown or black in color.
15. other kinds of rice
  - 15.1 Paddy in husked rice, in husked parboiled rice, in milled rice and in milled parboiled rice.
  - 15.2 Husked rice in husked parboiled rice, in milled rice and in milled parboiled rice.
  - 15.3 Milled rice in husked parboiled rice and in milled parboiled rice.
  - 15.4 Glutinous in non-glutinous rice.

## Specification

1. General, organoleptic and health characteristics
  - Kernels of rice, whether or not parboiled, husked or milled, and whether or not whole or broken, shall be sound, clean and free from foreign odors or odor which indicates deterioration.
  - The levels of additives and pesticide residues and other contaminants shall not exceed the maximum limits permitted by the national regulations of the country of destination or, in their absence, by the joint FAO/WHO Commission of Codes Alimentarius.
  - The presence of living insects, which are visible to the naked eye, is not permitted.
2. Physical and chemical characteristics
  - The moisture content, determined in accordance with ISO 712, shall be not greater than 15% (m/m)  
NOTE: Lower moisture contents may be required for certain destinations depending on the climate, duration of transport and storage. For further details, see ISO 6322, parts 1, 2 and 3.
  - The maximum contents of extraneous matter, defective kernels and other kinds of rice in husked and milled rice, whether or not parboiled, and determined in accordance with the method described in annex A, shall be not greater than the values specified in table 1.
  - All commercial contracts should be clearly the total percentage of broken kernels permitted, classified according to the agreed categories, and the relative proportions of each category, and the total percentage of extraneous matter and of defective kernels, determined in accordance with the method described in Annex A.
  - The proportion of chips shall not exceed 0.1%.

## ISO 7301 standards for rice

| Defect  | Reference to the definition | Husked rice (%) | Milled rice (non-glutinous) (%) | Husked parboiled rice (%) | Milled parboiled rice (%) |
|---|-----------------------------|-----------------|---------------------------------|---------------------------|---------------------------|
| Extraneous matter<br><i>organic</i><br><i>inorganic</i> | 7                           | 1.5<br>0.5      | 0.5<br>0.5                      | 1.5<br>0.5                | 0.5<br>0.5                |
| Paddy   | 1                           | 2.5             | 0.3                             | 2.5                       | 0.3                       |
| Husked rice   | 2                           | -               | 1.0                             | -                         | 1.0                       |
| Milled rice   | 3                           | -               | -                               | 2.0                       | 2.0                       |
| Heat-damaged kernels                                    | 8                           | 4.0             | 3.0                             | 8.0                       | 6.0                       |
| Damaged kernels   | 9                           | 4.0             | 3.0                             | 4.0                       | 3.0                       |
| Immature kernels  | 10                          | 12.0            | 2.0                             | 12.0                      | 2.0                       |
| Chalky kernels  | 11                          | 11.0            | 11.0                            | -                         | -                         |
| Red kernels   | 12.0                        | 12.0            | 4.0                             | 12.0                      | 4.0                       |
| Red-streaked kernels                                    | 13.0                        | -               | 8.0                             | 0                         | 8.0                       |
| Glutinous rice  | 5.0                         | 1.0             | 1.0                             | 1.0                       | 1.0                       |
| Pecks   | 14.0                        | -               | -                               | 4.0                       | 2.0                       |

1.

## Philippine Standards

### Philippine Standards

Type topic text here.

## References for Rice Quality

- Mackill, D.J., Coffman, W.R., and Garrity, D.P. 1996. Rainfed Lowland rice improvement. International Rice Research Institute, P.O., Box 933, Manila, Philippines. 242 p.

## **Rice Byproduct Utilization**

### **Why Use Rice Byproducts?**

With an increase in crop yields and cropping intensity, the management of rice by-products is becoming a problem as well as an opportunity. In traditional rice cropping systems, rice straw was either removed from the fields at harvest time and stored as stock feed, or burnt in the fields. Similarly rice husks were either returned to the field after milling or burnt. Concerns over air quality, in particular the release of particulate matter into the air during burning, have brought about efforts to restrict burning in many countries. When by-products are not burnt, changes in residue management at field level or off-farm uses must be found to overcome the problem.

There are many good reasons for using rice byproducts:

- they contain energy
- they are a renewable resource
- their utilization can reduce waste problems and related environmental pollution
- they are carbon neutral i.e. no net emission of CO<sub>2</sub> in the atmosphere

Of the many possible uses for rice byproducts, the ones presently most likely to be economic include:

- Rice straw as an in-field means of maintaining soil organic matter levels,
- Rice straw as a low grade animal feed in areas with no other feed options,
- Rice straw as a mulch in high value crops,
- Rice hulls as a fuel source, and
- Bran as a source of oil
- Brewer's rice and small brokens as a source of flour.

## **Rice Byproducts Properties**

### **Rice Straw Properties**

Rice straw is generated in the field during harvesting.

- The quantity of straw can vary from 2 tons/ha to more than 8 tons/ha, and will depend on the variety of rice, productivity (high rice yield will result in high straw yield), and harvesting method (cutting closer to the ground will result in more straw). Total straw available in the field is proportional to grain yield. The straw to grain ratio typically varies from 0.8:1 to 1.2:1
- The length of straw varies by variety and harvesting method, and ranges from 30-120 cm
- At harvest, the moisture content of straw is usually more than 60% on a wet basis (i.e. more than half is water), however in dry weather straw can quickly dry down to its equilibrium moisture content of around 10-12%.
- The bulk density of dry rice straw is around 75 kg/m<sup>3</sup> for loose straw, and 100 to 180 kg/m<sup>3</sup> in packed or baled form. In comparison, the bulk density of paddy grain is 500-650 kg/m<sup>3</sup> depending on moisture content. In packed or baled form, straw bales take up at least three times the amount of space as wood logs for the same amount of weight.

- In packed form, rice straw has low thermal conductivity, i.e. it is a good insulator. Packed or baled rice straw also has good fire-resistant characteristics.
- Rice straw has a high ash content (up to 22%) and low protein content. As a result, rice straw does not decompose as readily as other straw from other grain crops such as wheat or barley.
- Rice straw is more resistant to bacterial decomposition than other materials and therefore more suitable to serve as building material
- The calorific value (measure of how much energy is contained in the material) of rice straw is 14-16 MJ/kg on a 14% moisture content basis. In comparison, most dry woods contain 18-20 MJ/kg, and coal contains 25-30 MJ/kg. The higher the ash content of the straw, the lower the calorific value.
- The main carbohydrate components of rice straw are hemicellulose, cellulose and lignin.
- Rice straw contains moderate levels of potassium and chlorine, which reduces the melting temperature of straw ash to approximately 750 to 900°C meaning increased "Slag" (molten glass) deposits when straw is used as a fuel.

### **Rice Hull or Husk Properties**

Rice hulls are generated during the first stage of rice milling, when rough rice or paddy rice is husked i.e. husk is separated from the rest of the grain.

- In general, 100 kg of paddy rice will generate 20 kg of hulls. Short grain varieties produce slightly more hull than medium or long grain varieties.
- Moisture content of rice hull is around 10%; the equilibrium moisture content is lower than that of paddy or rough rice.
- Bulk density of rice hulls is 100 to 150 kg/m<sup>3</sup>. If rice hulls are ground, bulk density increases to 200 to 250 kg/m<sup>3</sup>.
- Rice hull contains 16 to 22% ash, and 90-96% of the ash is composed of silica. Therefore, rice hull ash can be considered a slightly impure form of silica.
- The ash composition and structure give rice hulls an abrasive character. Metal surfaces in frequent contact with rice hulls will wear out and eventually puncture.
- The calorific value of rice hull is 14-16 MJ/kg on a 10% moisture content basis. In comparison, most dry woods contain 18-20 MJ/kg, and coal contains 25-30 MJ/kg. The higher the ash content of rice hulls, the lower the calorific value.
- The main carbohydrate components of rice hulls are cellulose and lignin.
- Rice hulls contains only minor levels of potassium and chlorine, and therefore ash melting temperatures of rice hull are much higher than those of rice straw. Thus, you have less problems of "slag" (molten glass) deposits when hull rather than straw is used as a fuel.

### **Rice Bran Properties**

Rice bran is generated during the rice milling process. From a nutritional point of view, it is the most valuable byproduct. Rice bran consists of the outer layers (pericarp, aleurone, germ, and part of the endosperm) of the rice kernel that are removed during whitening and polishing of husked rice. When paddy is hand-

pounded or milled in a one-pass Engleberg steel huller, rice bran is not produced separately but mixed with rice hulls.

- Out of 100 kg paddy rice, 5 to 8 kg of bran can be typically produced.
- Moisture content of rice bran is in the 10 to 15 % range, on wet weight basis
- Rice bran is a mixture of substances, including protein, fat, ash, and crude fiber. In many cases, bran contains tiny fractions of rice hull, which increases the ash content of bran.
- Bran composition is largely dependent on the milling process. In modern rice mills, several different kinds of bran are produced: coarse bran (from the first whitening step), fine bran (from second whitening step) and polish (from the polishing step). Polish consists of part of the endosperm and is often referred to as meal.
- Rice bran has a high nutritive value. Besides proteins, rice bran is an excellent source of vitamins B and E. Bran also contains small amounts of anti-oxydants, which are considered to low cholesterol in humans.
- Rice bran contains 10-23% bran oil. The oily nature makes bran an excellent binder for animal feeds. Bran oil, once stabilized and extracted, is a high quality vegetable oil for cooking or eating.
- Rice Bran has a wide particle size distribution, with majority of particles in the 0.1 to 0.5 mm range. The particle size distribution is strongly affected by the milling conditions.

## Rice Flour Properties

Rice is consumed largely as a whole grain. During the processing of rice, some breakage occurs and smaller pieces of the broken rice kernels are used for grinding into rice flour, or for beer brewing.

- Rice flour contains primarily starch, and variable amounts of protein (~6%), fat (~2%), and ash (~1%). The actual composition depends on the rice variety from which the flour originated.
- The main difference between rice flour and wheat flour is the absence of gluten in rice flour. Gluten is the main structure-forming protein in bread. Gluten affects the texture of bread i.e. its "softness" or "hardness". In general, short- and medium-grain rice flour can produce soft-textured breads, but long-grain rice flour yields sandy, dry bread crumbs.
- Flour properties are further evaluated by a so-called amylograph pasting curve which displays the viscosity of rice flour paste as it is heated and subsequently cooled (a paste is made by mixing 10 to 20% of rice flour in water). This technique is used to characterize rice varieties that give different texture results in breads made from rice flour. For instance, IR8 has a low gelatinization temperature (see also rice quality module) which is favorable for baking, but a high final viscosity which adversely affects bread texture. As a result, bread made from IR8 has a dry, crumbly texture within 24hr after baking. The flour properties of rice flour are closely related to the amylose content of the rice (see rice quality module)

Source: Rice Processing and utilization, Bohr S. Lu, Encyclopedia of Agricultural Science Vol 3, Academic Press, 1994.

## Rice Byproduct Uses

### Rice Byproduct Uses

Traditional uses of rice byproducts includes straw and hull for energy, animal feed, and building materials. The byproducts of the one-pass Engleberg rice mill (a mixture of ground rice hulls and bran) are often used as feed for chickens or other small animals. Various factors will dictate whether byproducts are used or not. In India, straw and hull are widely used for feed, cooking fuel, and roofing material. Here population pressure, rural poverty, and limited access to fuel wood results in the extensive use of rice byproducts. In Bangladesh, rice hull briquettes are now commonly used as cooking fuel. Use of the briquettes is encouraged by increasing prices of conventional cooking fuels, the wide availability of rice hull, and low cost technology for converting hulls into briquettes.

In order to evaluate the feasibility of a technology or system in any given situation, the following issues should be addressed:

- the quantity and quality of byproduct needed for successful utilization;
- the efficiency of the process i.e. how much energy or product can be produced out of a unit of byproduct;
- the marketability of the product such as the price of alternative fuels or products, fluctuation of prices, etc;
- the amount of capital necessary for acquiring and installing the technology;
- operating costs of the technology such as fuel, labor, and electricity costs;
- other issues not directly affecting the cost (i.e., referred to as externalities), such as environmental impact (smoke, noise, etc.) of the technology.

### Rice Straw Uses

#### In-Field Straw Management

##### *Stubble Incorporation*

Straw decays most readily in the presence of moisture and oxygen. Straw decays fastest when it is incorporated into a soil that has a moisture content at about 60% of the water holding capacity and temperatures above 25°C. In these aerobic (with oxygen) conditions, microbes decompose straw into organic matter, minerals and carbon dioxide.

Straw also breaks down in anaerobic (without oxygen) conditions. This process is much slower and results in the production of methane, hydrogen sulfide and organic acids. Different microbes are at work under anaerobic and aerobic conditions. Chopping the straw into smaller pieces and incorporating it into the soil enhances the process of decomposition. If the material is left on the surface, it needs to be evenly spread and chopped into small pieces (1-10cm length) to enhance the flow of tillage implements and reduce equipment blockages. When fields are double cropped or there is insufficient moisture or time for straw to decay naturally, the straw must be chopped and evenly spread on the surface.

### *Stubble Mulching*

Rice straw can be used as mulch for rice or for other crops. Mulch reduces evaporation from the soil, increases water infiltration and protects the soil against erosion (the latter being especially important on sloping land). Relatively more residue is required to reduce evaporation than to reduce erosion. While the rates depend on soil type and slope, typical amounts of residue required to reduce both water and wind erosion range from 1-2.5 t/ha. By contrast rates of >8 t/ha straw residue can be required before significant reductions in evaporation occur, and then the benefits may only be short term (e.g., 1 month).

### *Stubble Composting*

Field composting is increasingly used in some areas to recycle rice straw nutrients back to the field. While rice straw composition of major nutrients is rather poor, the amounts of K can be significant (see table). For example, for every 1 t of straw (dry weight) returned to the field, there will be between 5-8 kg N, 0.5-1 kg P, 13-20 kg K, 5-1 kg S, 0.3-1.7 kg Ca and 1.5-1.6 kg Mg added to the soil. It is clear that straw can be a significant source of K. Thus a t/ha crop may produce of the order of 4 t straw meaning: 20-32 kg N, 2-4 kg P, 52-80 kg K, 2-4 kg S, 1.2-6.8 kg Ca and 6-7.2 kg Mg are added back to the soil.

**Table: typical rice straw composition of major nutrients:**

|         | <b>N</b> | <b>P</b> | <b>K</b> | <b>S</b> | <b>Ca</b> | <b>Mg</b> |
|---------|----------|----------|----------|----------|-----------|-----------|
| Straw % | 0.5-0.8  | 0.05-0.1 | 1.3-2.0  | 0.05-0.1 | 0.03-0.17 | 0.15-0.16 |

### *Open Field Burning*

In many cases, open field burning of rice straw is the most cost-effective method farmers have for straw management. While straw burning is still practiced in many countries, it is increasingly becoming unacceptable because of environmental and health concerns. When stubble is burnt, air is polluted through emissions of particulate matter, carbon monoxide, methane, hydrogen, hydrogen chloride, poly aromatic hydrocarbons, nitrogen oxides and biogenic silica fibres. Prolonged exposure to some of these pollutants can be hazardous to humans.

### *Straw Collection Systems*

Field-collection systems for rice straw include swathing, raking, baling, roadsiding, truck loading, and road transport. Since straw collection costs are inversely proportional to the straw yield (i.e., the more straw collected from a field, the lower the collection costs per ton of straw) it is recommended to cut the straw as low to the ground as possible prior to baling. Common bales for rice straw include small rectangular bales, large rectangular bales ("Hesston" bales), or round bales. The type of bale is often dictated by the end-users: small rectangular bales for straw-bale houses, large rectangular bales for energy production, and round bales for use as animal feed. The advantage of large bales is a higher bale density (i.e. lower



transportation costs and less space needed for storage), however larger bales require use of heavier machinery that can bog down in harvested rice fields.

## Off-Field Straw Use

### *Animal Feed*

Rice straw has a low nutritive value as feed, owing to its low protein, high ash, and high silica content. It is often used as an animal feed by in-field grazing during the fallow period, or as livestock feed when the harvested crop has been threshed at a centralized location. Rice straw for animal consumption should be stacked or baled at low moisture levels (10-12%) and kept under shelter to avoid the infestation of straw with mold-developed toxins.

Supplements such as molasses and urea are added to the straw to increase the digestibility of rice straw. Typical rates are 5 kg of molasses/urea per 100 kg of dry matter.

There are some commercial initiatives to enhance the feed quality of rice straw by adding nitrogen and removing ash/silica, the status of commercialization is unknown. The high silica content of straw can cause excessive wearing of animal teeth.

### *Fuel*

#### Combustion

Rice straw can be used as a fuel source for combustion in furnaces and boilers for driving steam turbines to generate process steam and electricity. The efficiency of energy conversion for most conventional combustion systems is about 20 to 25%. As each kilogram of straw or husk contains 14MJ of energy, 1.2 kg of straw has the potential to produce 1 kW-hr of electric power. The efficiency further depends on parasitic load of the plant (i.e. how much energy is used by the powerplant itself), and straw moisture content.

Straw contains potassium, sodium and chlorine, which may cause problems of slagging, fouling, and corrosion in boilers and furnaces. This occurs because even moderate levels of potassium (2-3%) reduce the melting point of silica from above 1700°C down to 800 -1000°C. As most furnaces normally operate in this temperature range, fouling and slagging occur. Fouling and slagging will lead to build-up of glassy deposits in the boiler, requiring frequent shutdowns for maintenance. Chlorine corrodes metallic surfaces such as heat exchangers which lead to high maintenance costs. Potassium, sodium and chlorine can be leached from the straw at extra cost. It takes at least 4 hours of leaching with water or 100 mm of rainfall with water to reduce the potassium levels to an acceptable level. Besides fouling and corrosion problems, use of rice straw as fuel on a large scale faces the problems of the costs of collecting, transporting and storage. Baling and gathering costs range from \$15-30/ ton, and costs are dependent on straw yield and type of the collection system.

In Denmark and the United Kingdom, small powerplants (10 to 30 MW electricity) have been established that use straw from other cereal crops such as wheat and barley - which do not have the same high levels of potassium, sodium or chlorine. In these countries, governmental support through subsidies, tax incentives or mandates

have created advantageous circumstances for the commercial development of straw-to-energy conversion. In colder climates, straw can be used in farm-level combustion systems for heating of buildings. There are more than 1000 biomass fired power plants in USA, however rice straw has been excluded as fuel because of higher maintenance costs.

#### Gasification

Thermo-chemical gasification involves burning biomass without sufficient air for full combustion, but with enough air to convert the solid biomass into a gaseous fuel. The gas (often referred to as producer gas) can be used in internal combustion engines to replace diesel or gasoline, as fuel for heating, or cooking. It should be noted that the gas should be handled in an appropriate manner given its high carbon monoxide content.

Rice straw can be used to generate "producer" gas by heating the material to 400-500°C in a gasifier reactor. "Producer" gas consists of a mixture of gases including methane, hydrogen and carbon monoxide. The by-product of gasification is char which is produced in the gasifier and must be periodically removed. Most gasification systems have energy efficiencies of about 30%. Problems may occur if the gas mixture is not sufficiently cleaned or scrubbed to remove the tar. Tar forms when hydrocarbons contained in the gas condense and this causes mechanical problems through gumming up the engine heads and valves. Tar must also be disposed in a safe manner.

The gas output of these systems range from 100-300 kg/m<sup>2</sup>/hr and most gasifiers are connected directly to an engine. A 75 kW diesel engine requires approximately 20 l diesel per hour. This would be equivalent to burning 80 kg of rice straw/husk or 60 kg of wood per hour. Recent developments in gasification and gas clean-up technology have shown that gas produced from biomass can be competitive with generators that are coupled to diesel engines. In China, there are some implementations of pipeline distribution of thermal gas for household cooking.

#### Biogas

Small-scale biogas digesters have been widely deployed in China, India, Nepal, and other Asian countries. Most of the biomass from human and animal waste, landfill waste, and crop residues can be converted into biogas. The exception is the biomass component lignin (a major component of wood, but only a minor component of rice byproducts) which can not be converted to biogas. Anaerobic digestion is a microbial decomposition process that is relatively slow, however the main advantage is it does not require a lot of maintenance.

Fermentation by anaerobic bacteria is used to produce biogas which contains methane, carbon dioxide, water and small concentrations of hydrogen sulfide. Production of biogas is also referred to as bio-gasification or bio-methanation and is used in municipal waste water treatment or animal manure processing. For anaerobic digesters to function properly, the feedstock (i.e. fuel source) should have a carbon to nitrogen ratio of approximately 30:1. Rice straw has a carbon to nitrogen ratio of 80 -100:1. Therefore to attain the correct ratio a source of nitrogen such as manure must be added. Typical energy efficiencies are around 25%. Depending on the source of manure between 2.5-20kg of material must be digested to produce 22-24 MJ/m<sup>3</sup>. Chicken and pig manure are superior to cattle manure for gas production. The hydrogen sulfide contained in biogas is highly corrosive in combustion engines and must be removed by scrubbers for long term use.

A significant advantage of anaerobic digestion is its byproduct: sludge. Sludge is a valuable fertilizer in particular when it is dried.

#### Liquid Fuel

Ethanol is produced by fermentation of sugars and is the predominant liquid fuel derived by biochemical means from biomass. Ethanol is normally used as a blending agent with gasoline from 10-12% in conventional gasoline engines, or as primary fuel in modified internal combustion engines. Currently most of the fuel ethanol in the world is produced from corn (USA) or sugar cane (Brazil).

About 60% of rice straw is composed of hemi-cellulose and cellulose, which can be converted into ethanol, provided that straw is pretreated through acid or enzymatic hydrolysis. One ton of rice straw is capable of producing 300 l of ethanol. The equivalent weight of corn would produce 400 l. Ethanol contains 29.9 MJ/kg (21 MJ/l) while gasoline contains 44MJ/kg (34 MJ/l). Corn grain or sugar cane are the preferred materials for ethanol production, as hydrolysis is not required. In recent years, commercial energy companies have stepped up research and development efforts into ethanol production from ligno-cellulosic biomass including straw, however no plants have yet been installed beyond the pilot stage. Currently two plants have been proposed to produce ethanol from rice straw in California. As with most renewable energy options, incentives should be in place so ethanol from biomass can compete with regular liquid fuels.

#### *Fiber/Construction Material*

Straw can be used as wall materials in the construction of houses or for manufacturing particleboard. The advantage of using straw is its excellent insulation characteristics, which can reduce costs for space heating. As a 300 m<sup>2</sup> house requires 5-600 bales or 1.2 tons of compacted rice straw to construct the outside walls, straw as construction material represents a very small market.

Straw has also been used to produce particleboard for use in house construction and furniture manufacturing. Artisans have found the material hard to work and the high silicon levels causes excessive wear and tear on equipment. There are several straw board manufacturing plants in the United States, but none of them uses rice straw. Although commercial initiatives for rice straw-derived particleboard are on-going, straw board has not yet been able to compete with board made from wood waste. Important constraints are the need for energy-intensive grinding of straw into smaller particles, and large amount of space needed for storage (given the low bulk density of straw, even in baled form).

#### *Rice Straw for Fiber/Paper*

Straw can be an important source of raw materials for the production of paper. Cereal straw, in particular wheat straw, is a major source of pulp for paper production in China and other Asian countries. The high silica content of rice straw (9-14%) however prohibits the economic use of rice straw for this purpose. The silica will cause problems in the recovery of chemicals used in the pulping process. For rice straw, there is currently no commercially available solution for this problem. Other problems with the use of straw for pulp are the higher water retention capacity of straw, the lower yield per ton of raw material compared to wood (straw yields 45% of pulp whereas wood yields 55% pulp), and the low bulk density of straw.

### *Rice Straw for Erosion Control/Soil Amendment*

Rice straw is being used in bales or waffle pods for erosion control, reclamation areas and re-establishment of denuded areas following civil works such as road construction. This use is limited by the transportation costs of the straw, and the small volumes used in the erosion control methods. In California, highway contractors are required to use rice straw materials for erosion control purposes.

## **Rice Hull or Husk Uses**

### **Availability of Rice Hulls**

The availability of rice hulls varies from country to country and from location to location. Rice hull availability depends on the type and size of the rice mills, and their locations. Larger rice mills that are located in or close to urban areas will have more disposal problems with hulls compared to smaller village-type rice mills located in rural areas. In addition, some rice mills operate only a few months out of the year, whereas others operate throughout the year. Finally, restrictions on open-pile burning affect the availability of hulls as well.

In most rice mills rice hulls are separated from husked rice through aspiration, as rice hulls are lighter in weight than husked rice. In some rice mills, hulls are ground prior to piling or storage. Grinding makes it easier to transport hulls in suspended air, reduces space needed for storage, and reduces transportation costs.

### **Rice hull as Animal feed**

Rice hull has traditionally been used as an ingredient in ruminant and poultry feeds. Currently, commercial feeds may contain up to 5% to 10% of ground rice hulls. Feeding ground rice hulls directly as roughage to cattle, hogs, and horses is a common practice in many countries, although rice hulls have low digestibility and nutritive value. Of all cereal by-products, the rice hull has the lowest percentage of total digestible nutrients (less than 10%). Like rice straw, adding a source of nitrogen can enhance rice hulls as a feed source. Rice-mill feed is a mixture of rice hulls and other rice milling byproducts and is an acceptable component of animal feeds. The feed value of rice-mill feed is higher because of the presence of rice bran and polish in the feed. The byproduct of the Engleberg-type rice mill is an example of such a feed as it consists of a blend of ground rice hull, bran and polish. Constraints for rice hull use as feed are low digestibility, its peculiar size, low bulk density, high ash/silica content, and abrasive characteristics.

### **Rice hull as fertilizer**

Rice yields can be improved over and above yields obtained with regular use of fertilizer by addition of rice husk ash. Rice hull can also serve as a moisture retention helper or as a weed growth inhibitor in a soil. When rice hull is burned, the remaining ash can serve as a mix for fertilizer as was done traditionally in China, and is currently practiced in Bangladesh, Vietnam and other countries where rice hull is used as a domestic fuel. Finely ground rice hulls are also used as component in commercial mixed fertilizers. The rice hull prevents caking of other fertilizer components. In Japan, farmers have been using carbonized (partially burnt) rice hulls as soil conditioner for a long time. To what extent the current restrictions on pile burning have limited this use, is unknown.

Worms can play a key role in rice hull decomposition, as rice hulls can be difficult to compost, with their low **C:N ratio**, their high **cellulose** and **lignin** content, and their waxy surface cover that impedes microbial attack, due to its low capacity to absorb water. Using composts made by mixing rice hulls with manure contributes micronutrients and improves soil structure (more water and air retention).

References: <http://www.agroecology.org/cases/ricehullcompost.htm>;

### **Fuel: Rice hull combustion**

Rice husks are a much more economic material for direct combustion compared to rice straw. Husks do not contain the same levels of potassium or chlorine, therefore they do not require leaching before use. Husks are generated at a central location at the rice mill and can be easily transported. Husks also produce higher purity ash that can be used in iron furnaces and cement. Approximately 30% of the husk ends up as ash which presently has a retail value of \$200 per ton. In the USA, the cost of installing an electrical power plant, which uses rice husks, is approximately \$1 million per MW of electric power capacity. Such a power plant will require 1.5-2.0 tons of husk for each MW hour of electricity produced. Production costs are 2-3 cents per kWhr and the power plant will consume about 10% of the power produced for its own needs. In California, rice hull is used as a fuel for electricity generation in medium sized (25 - 50 MWe) combustion facilities.

In the modern rice milling industry, rice hulls are used as fuel source for grain drying and parboiling. In Thailand, rice is dried in high-temperature fluidized bed dryers, and drying heat is provided by cyclonic rice hull furnaces. In Arkansas, about 30% of rice produced is parboiled, and heat for process steam and rotary grain dryers is produced from rice hulls. In Bangladesh, rice hulls are the preferred fuel for parboiling, and rice hulls are widely used for grain drying in the larger rice mills in Northern India.

At the domestic level, rice hull can be briquetted to improve combustion characteristics and ease of handling. Extruder technology for rice hulls that originated in Korea and is now common in rural Bangladesh.

### **Fuel: Rice hull gasification**

The gasification of rice hulls to produce a combustible gas can have several objectives: direct combustion in boilers or furnaces, combustion in Internal Combustion (IC) engines, or production of cooking gas. Gas produced in gasifiers (commonly referred to as "producer gas") for use in boilers and furnaces is a technically and economically proven technology, and provides a more efficient type of energy conversion than direct combustion of rice hull. Technologies for combustion in IC engines were developed in a number of countries (China, Italy, Thailand, India, U.S.A.), and this is technically feasible for both diesel and gasoline-fueled engines. Large Italian rice mills have traditionally gasified their rice husks and used the gas to drive power units for milling. However, considering the volume of production of rice hull in the world and the wide use of IC engines, use of this technology is not widespread. A limited number of small-scale rice hull gasifiers (5 - 20 kW) are in use in Northern-India for generation of electricity and irrigation water pumping.

### **Industrial use of Rice hull and Rice hull ash**

Given the high silica content of rice hull ash, rice hull ash is used as industrial commodity in the steel industry. It is used as an insulator during steel

manufacturing, to prevent rapid cooling of steel and ensure uniform solidification. Prices for rice hull ash on the world market are approximately \$200 per ton of ash (equivalent to \$ 40 per ton of rice hulls, or \$ 8 per ton of rough rice). Using rice hull ash in the cement industry is currently considered as well. Other reported industrial uses of rice hull include use of rice hulls in ceramic bricks, refractory, furfural, abrasives, and sodium silicate.

## **Rice Bran Uses**

### **Prospective Uses of Rice Byproducts**

The conventional use of rice bran is as ingredient for animal feeds, in particular ruminants and poultry. In recent years however, advances in stabilization techniques have been made which has led to new uses for bran and its derivatives, most notably bran oil for cooking and waxes for cosmetic products. In the developing countries, rice bran is underutilized due to a lack of suitable stabilization techniques.

### **Rice Bran Stabilization**

The key to successful use of rice bran is stabilization. Upon milling, bran will be exposed to enzymes from the outer layers of the rice kernel, resulting in hydrolysis of bran oil, a major component of the bran. This in turn will lead to rancidity of the bran which will give it an acid taste, hence rendering it unsuitable for consumption by humans. Techniques for bran stabilization include cold storage, chemical stabilization, irradiation, and heat stabilization (either through direct heat or microwave). Heat stabilization is the most common method and has additional advantages of simultaneously killing bacteria, molds, and insect eggs.

### **Rice Oil Production**

Edible rice oil is a liquid that is derived through stabilization and extraction of bran oil. Rice oil is used as a household salad oil and cooking due to its plain, good taste, as well as favorable oxidation characteristics. It is also used commercially in the production of mayonnaise and dressings. Due to its heat stability, it is widely used in Japan as oil for frying potato chips and other snacks. The byproduct of stabilization is called dark oil, which is used as an additive in production of commercial feeds.

After stabilization of bran, bran undergoes an intricate industrial extraction process that includes pre-treatment (sifting of impurities), steaming, solvent extraction, de-acidification, and de-waxing.

### **Cosmetic Products from Rice Bran**

Traditionally, Rice bran was used to prepare vitamin-B concentrates. The development of synthetic vitamins has greatly reduced use of bran for this purpose. Currently, many cosmetic products are available that are to some extent based on rice bran extracts. The development of these products is largely driven by the demand for non-artificial, "nature-based" products. Commercial cosmetics that use rice bran include face waxes, soaps and oils.

## Rice Flour Uses

- Flour made from broken grain is used in a variety of food products including breakfast cereals, and snack foods. Rice flour is also used in composite flours for baking i.e. blends of up to 20% of rice flour into wheat flours.
- Baby cereal: Precooked rice cereal is frequently prescribed as the infant's first solid food. Precooked rice cereal is produced by preparing and cooking a slurry, and subsequently drying the slurry in drum drier. Extrusion-cooking is also used. Ingredients added during the manufacturing of baby cereal include sugar, iodized salt, sodium and iron phosphates as well as amino acids. Rice cereal will become rancid if packaged in a hermetically sealed container. The package material most suitable for keeping rice cereal is one that allows for transmission of moisture vapor and gas, such as paperboard cartons.
- Thickening agent: Rice flour from waxy/glutinous rice is used as thickening agent for sauces, puddings and oriental snack foods.

## Terminology in Grain Quality

**Brown rice or husked rice** - is the least processed form of rice. It has the outer hull removed, but still retains the bran layers that give it that characteristic tan color and nut-like flavor. The outer layer of the bran gives this rice a chewier texture than white rice.

**Chalkiness** - if part of the milled rice kernel is opaque rather than translucent, it is often characterized as chalky. Chalkiness disappears upon cooking and has no effect on taste or aroma, however it downgrades milled rice. Cause of chalkiness is interruption during the final stages of grain filling.

**Head rice** - milled rice with length greater or equal to three quarters of the average length of the whole kernel

**Head rice recovery** - weight percentage of head rice (excluding brokens) obtained from a sample of paddy. Can be specified on paddy (ISO standard) or on milled rice basis

**Large brokens** - milled rice with length less than three quarters but more than one quarter of the average length of the whole kernel  
the husked rice

**Milling degree** - a measure of the amount of bran removed from the brown rice

**Milling recovery** - weight percentage of milled rice (including brokens) obtained from a sample of paddy.

**Milled rice** - rice after milling which includes removing all or part of the bran and germ from

Modern rice milling process consists of:

- pre-cleaning - removing all impurities and unfilled grains from the paddy
- husking - removing the husk from the paddy



- husk aspiration - separating the husk from the brown rice/unhusked paddy
- paddy separation - separating the unhusked paddy from the brown rice
- destoning - separating small stones from the brown rice
- whitening - removing all or part of the branlayer and germ from the brown rice
- polishing - improving the appearance of milled rice by removing remaining bran particles and by polishing the exterior of the milled kernel
- sifting - separating small impurities or chips from the milled rice
- length grading - separating small or large brokens from the head rice
- blending - mix head rice with predetermined amount of large or small brokens, as required by the customer
- weighing and bagging - preparing milled rice for transport to the customer

**Parboiled rice** - rough rice which has been subjected to a steam or hot water treatment prior to milling. Parboiling increases the percentage of head rice and the vitamin content of milled rice. This procedure gelatinizes the starch in the grain, and results in firmer more separate grains. It also takes longer to cook.

**Red rice** - an annual grass, adapted to an aquatic habitat, that reproduces by seed. The leaves have short, stiff hairs on their upper and lower leaf surfaces. The plants tiller profusely, becoming brushier than white rice plants. Panicles are loose and open and droop slightly. The grain shatters easily when ripe. The many types include those with short, medium, or long grains; those with straw-colored, red, or black hulls; and those with short or long awns on the spikelet.

**Rough rice** - similar term for paddy, or rice retaining its husk after threshing

**Small brokens or "brewers rice"** - milled rice with length less than one quarter of the average length of the whole kernel.

**Total milled rice (polished rice)** - bulk of the starch endosperm consisting of head rice, second heads, screenings, and brewers' rice.

**Whiteness** - a measure of the color of milled rice. A result of milling degree, varietal characteristics and postharvest handling (see also yellowing).

**Whole kernel** - milled rice grain without any broken parts

**Yellowing/discoloration** - yellowing is caused by over-exposure of paddy to wet environmental conditions after harvest, and sometimes referred to as fermented grains. Yellowed grain

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