Quality assurance of paddy & rice with GRANIFRIGOR™ cooling conservation.

by Ralph E. Kolb & Dr. Claus M. Braunbeck

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The origin of rice is believed to lie in the Himalayas. Starting in China, rice cultivation then spread into other Asian countries. The North Africans brought rice to Europe around 100 BC. Rice came to Central and South America with Columbus in 1493.

Botanically, rice belongs to the Gramineae (or Poaceae) and the genus Oryza sativa. Around 8,000 different varieties of rice have been identified, of which many are actively cultivated. In rice milling, three basic types are distinguished:
- Long-grain rice
- Medium-grain rice
- Short-grain rice

Rice requires heat and ample water for growth. The temperature should be, depending on the variety, between 20 and 35 °C and one kilogram of rice requires, for growth, about 3,000 to 10,000 l of water.

Paddy storage

Paddy grows during the harvest season in a short period of time in large quantities and is stored immediately after drying. Depending on the climate conditions and available water supply, multiple harvests per year are possible. During the storage time, it is important to maintain the quality of the rice. There are basic requirements on the storage process. In general, storage for paddy must be easily accessible, dry and protected from the weather. In addition, it must prevent access by rodents, birds, cats and dogs. The materials used for storage of the paddy must be suitable. In the following the two most important types of storage are described from a perspective of maintaining quality by grain cooling conservation.

Silo system

A paddy silo has the advantage that it is well closed off (Figure 1). This keeps birds, rodents, cats and dogs out. However, a common silo is not airtight. Filling and emptying follows clear specifications and can be automated well. Modern silo systems are usually made from galvanized sheet steel; larger systems, on the other hand, are typically made from reinforced concrete.

Warehouse storage

When a suitable building structure already exists, warehouse storage is often chosen and integrated into the structure (Figure 2). The main advantage of warehouse storage is that it can also be temporarily used for other applications. Use as a machine hall is not permissible for hygienic reasons. The most significant problem for warehouse storage is discharging the paddy bulk. Removal is typically performed with shovel excavators. This can damage the air distribution. Ideally, the paddy is filled from above, e.g. with stationary and movable conveyor belts. The filling process can be automated well.

Air supply to storage

The variation of the air distribution has to be dimensioned according to the diameter and height of the silo. For a silo system with multiple silos, the intake nozzles of the individual silos are often connected to a central air line. For each silo, an extra shut-off device is necessary. Flaps or gate valves are typically used. Fittings such as bends must be designed so that they facilitate flow. 90° bends (elbows) should be avoided where possible. Branches and bends should be designed in 30° or 45° parts. The diameter of the main line must be sufficiently dimensioned. The air speed in the channel should be low enough so that pressure loss is not too large. Water traps in which condensation could accumulate should be avoided. The main line should not be too long to keep energy loss low. Cool air flows in the line, which means that an insulated main channel is advantageous. For air distribution, cooling beams are used for silos with conical hopper outlet. Often perforated underground channels are laid in the silo floor; here it should be ensured that there is sufficient outflow area.

For warehouse storage that is loaded and unloaded with shovel excavators, there is the problem of the trafficability. Underground channels or half-shells as above ground channels are used for air distribution (Figure 3). Recently, telescopic tubes have also been used, which are retracted out of the storage area before the grain is removed. The use of drainage hoses is not recommended.

Storage exhaust ventilation

Similar to air distribution, the importance of exhaust ventilation of the storage area is often underestimated. Air removal is just as important as air distribution. A sufficient number, a good distribution and a suitable size of vents must be provided. The dry, cold air that is fed into the storage facility absorbs energy and humidity from the paddy. The air must then be removed via ventilation.
In warehouse storage facilities, typical probe thermometers are used to measure the temperature, in silo systems, temperature sensor lines on steel cables are used. Ideally, the storage temperature is measured and documented continuously.

A single measurement point is not representative for a grain bulk. For this reason, a number of measurement sensors must be used or measurements must be taken at a number of locations in succession. The temperature measurement is an important aspect of monitoring the status of the stored goods. If the temperature is too high at a location, action must be taken.

The cooling conservation process

The fan of the GRANIFRIGOR™ – grain cooling devices draws in cold ambient air (Figure 4). The air heats up in the fan due to friction. The increase in temperature depends on the counterpressure of the grain bulk, the delivered air flow and the efficiency of the fan. This air is then cooled by an air conditioner: the evaporator, to the desired temperature and is thereby dehumidified. Dehumidification takes place in general except when the air is extremely dry. During the dehumidification process, water (condensation) is created. The relative humidity of the air increases even though the water content is lower. As the cold air can hold less water than warm air, this chilled air then goes to the HYGROTHERM™. The HYGROTHERM™ unit heats up the cold, moist air. This lowers the relative humidity and the air becomes dry (3). Since the HYGROTHERM™ heating unit uses energy from the chilled air, it involves no further energy costs. The dry, cold air is fed through a hose in the ventilation system of the storage facility and is forced through the bulk. This process can be employed in a warehouse or in a silo. The outgoing air is led outside via exhaust vents, extracting absorbed heat and moisture from the grain bulk.

At lower outside temperatures, modern grain cooling devices switch automatically to ventilation mode. If the ambient temperature rises again, the compressor is automatically switched back on. This improves the profitability of the process.

The many advantages of conservation cooling come at a cost. Apart from investing in the cooling device, extra electric power is needed as drive energy. Energy consumption depends on the outside temperature, the humidity of the outside air, the paddy’s moisture content and the paddy temperature (Table 1). Drying effect through cooling

A cooling process creates a drying effect that must be taken into account as well. The drying effect for paddy for one cooling cycle is approximately 0.75% in average. Wherein it depends on the paddy temperature and moisture content and the temperature and relative humidity of the supplied cooling air. Since the supplied cooling air warms up at the grain bulk and warmer air can absorb more moisture, the process conditions are continuously changing. If the relative humidity of the supplied cooling air is significantly below the equilibrium moisture content of the paddy, the drying effect will be higher. The device of HYGROTHERM™ after-heating for adjusting the relative humidity of the cooling air is therefore crucial. The after-heating should not be set too high to avoid unnecessary energy use. Typically, after-heating of 3 to 7 K is used. For higher moisture contents of paddy, the drying effect is greater (4).
In cellular respiration, oxygen is absorbed and carbohydrates are then converted into carbon dioxide, water, and heat. The result is a loss of substance. Per kilogramme of respired grain dry substance, approximately 16.48 MJ of heat, 0.58 kg of water, and 1.54 kg of carbon dioxide are released. The energy heats up the grain mass and the water wets the grain, promoting the growth of fungus.

Fig. 6 shows the grain heat generation dependent on the grain’s temperature and moisture content in practice, which can be used to determine the substance loss of the stored grain.

Hygroscopicity
Hygroscopicity is the ability of a substance to adjust to the moisture content of the surrounding air by absorbing or releasing water. Water vapour absorption is called adsorption, water vapour release is called desorption [7]. The sorption isotherm shows the hygroscopicity of the substance [8]. The sorption isotherm shows the equilibrium state. Above the sorption isotherm, desorption occurs, below it adsorption. The sorption isotherm is temperature dependent. The sorption isotherm is typically shown for 20 °C.

The sorption isotherms of paddy at varying grain temperatures are shown in Fig. 7. At 14.5% moisture content and 20 °C, the water activity of the grain \( a_w \) is approximately 0.64. This corresponds to an equilibrium moisture content of 64% relative humidity. If air that has a relative humidity above 64% comes into contact with the paddy, it would wet the paddy. This would inevitably lead to spoilage of the stored grain.

Coated grain can be stored with a higher moisture content.

Heat generation 
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The following equations ([5]) describe the heat generation during grain storage modified according to Jouin [6].

\[
\begin{align*}
\text{Heat generation (MJ/t, day)} & = \frac{1000 \times 1122.81 \times 16.48}{1000} \\
& = 1543.86 \\
& = 578.95 \\
& = 16.48 \\
& = 5,637.64 \text{ KJ/mass unit} \\
\end{align*}
\]

Water activity value \( a_w \)
The water activity is a measure of the free, unbound water as a fraction of the total water content in the grain crop ([9]).

Described theoretically, the \( a_w \) value is the ratio of water vapour pressure of a grain to the saturation pressure of water \( \text{Pv}/P_w \). One of the components of paddy is water. This can be loosely associated or more strongly bound. A higher water activity \((>0.64)\) favours fungal growth, a value above 0.8 will even promote bacterial growth.

Natural air flow in the grain crop storage facility without cooling
Inside the silo, in particular for cold outside conditions, there is a significant amount of natural circulation. In the outer silo area, the air moves downward because cold air is heavier than warm air; at the core the air rises ([10]). This thus transports moisture to the upper area of the grain mass. Due to the cellular respiration, the uncooled rice has become warmer. The moisture condenses out of the rising warm, humid air under the cold silo roof, forming drops that “rain down” onto the grain. The result is the so-called “green meadow”.

It is not uncommon for the grain mass to spoil up to a meter below the surface. This often results in an extremely important additional problem. When removing the grain from the silo, clumping can cause the discharge equipment to become clogged. Extreme caution is therefore needed. Once a side slider is opened, the static stability of the silo can be damaged. Cooling can provide a remedy, as there is a low amount of circulation in the interior of the storage area when the grain is cooled.

Heat conduction
Grain is a bad conductor of heat. The heat conductivity of paddy with a moisture content between 10 and 20% is 0.12 W/Km. As a comparison, steel (for instance a silo wall) has a conductivity of approximately 45.3 W/Km. Harvest heat and the heat generated by cellular respiration are poorly dissipated to the outside. This problem is exacerbated by the fact that the air cushions between the grains provide additional insulation. The cavities in a grain mass make up approximately 40% of the volume. In addition, the grains touch one another at just a single point, meaning there is a small area provided for heat conduction (Figure 8). For this reason, a warm rice pile remains warm for a long period of time and a cool pile remains cool for a long period as well. Once the paddy is cooled, recooling is only necessary after many months even under tropical conditions.

The cavity in a grain mass and the air cushions between the grains provide additional insulation. The cavities in a grain mass make up approximately 40% of the volume. In addition, the grains touch one another at just a single point, meaning there is a small area provided for heat conduction (Figure 8). For this reason, a warm rice pile remains warm for a long period of time and a cool pile remains cool for a long period as well. Once the paddy is cooled, recooling is only necessary after many months even under tropical conditions.

The cavities in a grain mass make up approximately 40% of the volume.
Temperature and moisture content

The objective is to maintain the quality of the paddy in the storage facility. To do so, proper conditions must be achieved. The key parameters are temperature and moisture content of the stored paddy. To prevent microbes from causing damage, paddy should be stored, for instance, at a value for $a_w$ of 0.64 [11]. To also protect the grain from insects, it should also be cooled below 15 °C.

For paddy moisture content of 14.5% and more and a low counterpressure (warehouse storage), cooling of the paddy close to the cooling air temperature of the GRANIFRIGOR™ outlet is possible. For dry paddy, the grain temperatures are approximately 2 to 8 K above the supplied cooled air which could be achieved during the usual cooling performance. This is due to the evaporation of moisture from grain with a higher moisture content, which causes an additional cooling effect.

Animals in the storage facility

According to the FAO, the following causes are responsible for spoilage:
- 80% due to insects
- 10% due to rodents and birds
- 10% due to fungi

Insects and mites

In a rice storage facility, various types of insects may be encountered. One thing they all have in common is that they are more or less active depending on the temperature. In tropical humid countries, the rice weevil and red flour beetle are especially active.

Insects and mites multiply explosively under favourable conditions. An insect can generate several thousand offspring in one year. The feeding locations stimulate respiration in the rice and hot spots develop. In addition, there is the metabolic activity of the pests themselves, which further promotes heat and humidity. This in turn creates more favourable conditions for mould and, at very high levels of humidity, even bacterial growth. Most insects are nocturnal and prefer warm spaces with dust deposits. If insects find optimal temperature and humidity conditions, losses will occur due to feeding and excrement.

Fig. 9 shows some species of the most common insects in humid tropical areas and their optimal life and development conditions. Losses through insects can effectively cease by cooling the harvested crop to temperatures under 15 °C, as these insects become inactive.

Animals in the storage facility

According to the Food and Agriculture Organization of the United Nations (FAO) worldwide approximately 15% of the harvested crops spoil [12]. This means roughly 270 million tons of grain spoil each year, mainly during storage.

Fungi mycotoxins

Microorganisms such as fungi and bacteria adhere to the surface of the grain kernel [13]. On the field, a hygrophilous primary flora dominates that requires a water activity > 0.9. In the storage facility, osmophilic secondary flora is then generated, which multiplies at water activities > 0.7.

The development of fungi depends on the temperature, humidity and the grain’s moisture content (Figure 10). By drying and cooling paddy, this development is prevented in the storage facility.

With the harvest, fungi that developed in the fields are transported into the paddy storage facility. Additional fungi are also generated in the storage facility. Mycotoxins can be formed from the fungi. Mycotoxins have a toxic effect on humans and animals. Most mycotoxins are heat-stable and very resistant.

During processing they are typically not broken down chemically or otherwise rendered harmless. For this reason, the formation of toxins must be prevented by targeting harmful fungi [15].

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Adantages of GRANIFRIGOR™ – grain cooling conservation

The advantages of grain cooling for paddy and rice processing can be inferred in part by what has been said already. These advantages are directly targeted at the avoidance of storage and post-harvest losses. Both the quantity and the quality are preserved and additional advantages result for certain rice processing procedures. These are summarised in the following text to provide a clear picture on the purpose and benefits of cooling conservation of paddy and rice.

Securing the quantity of rice

Primarily, respiration of the rice during storage represents a gradual loss, determined by the storage temperature and moisture content of paddy. A calculation example is used to demonstrate this fact, using typical values for storage conditions in the tropics and subtropics (Example 1).

Comments on the example calculation:

No one would leave paddy at a temperature of 30 °C for storage. Rather, a silo operator would try to lower the temperature in the grain by recirculating the grain or ventilation with outside air. A potential humidification would be accepted. To now calculate the dry mass loss over the storage duration, the loss over time must be determined over time in multiple steps, in which the corresponding individual values are calculated. For the calculation of the actual total storage loss, multiple steps using the above formula are used. The results are then added.

From the example we can see that the loss of paddy can be considerable, which has a negative effect on the economic success of the operating company. By using a GRANIFRIGOR™ – grain cooling device, losses can be significantly limited as the respiration activity is reduced at lower storage temperatures, making the mass losses negligible.

In addition to respiration, additional mass loss in the paddy can occur due to insects, fungi and bacteria. According to the FAO estimates, insects are the most important hazard, causing up to 80% of the post-harvest losses (12). Evaluating the damaged paddy, it quickly becomes clear just how significant the damage can be. If from 1,000 paddy grains just 10 are damaged by insects, the loss per ton of paddy is 4.3 kg of dry substance or for a moisture content of 14%, 6.25 kg of paddy (18).

Example 2 illustrates the hazard of mass loss due to insects. It can be seen that even a small amount of damage to the paddy due to insects causes a high level of economic damage and that, by using GRANIFRIGOR™ – grain cooling devices, this mass loss can be avoided.

For completeness, bacteria, fungi and other microorganisms should be mentioned. They also contribute to mass loss, although their effect on paddy quality is of greater importance. For this reason, quantification of the losses due to direct attack is negligible, as due to changes in quality, the paddy is crucially affected and losses will be much greater, up to complete loss. Nevertheless, the use of cooling conservation brings the activity of bacteria, fungi and other microbes to a standstill so that losses can be limited.

Example 3 illustrates the potential:

{Table}

Example 3:

Increase in proportion of whole grain

<table>
<thead>
<tr>
<th></th>
<th>Given:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price of head rice</td>
<td>450 EUR/t</td>
</tr>
<tr>
<td></td>
<td>Price of broken rice</td>
<td>290 EUR/t</td>
</tr>
<tr>
<td></td>
<td>Storage quantity</td>
<td>10,000 t</td>
</tr>
<tr>
<td>Result:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Additional head rice proportion 5%</td>
<td>60,000</td>
</tr>
<tr>
<td></td>
<td>Additional head rice proportion 15%</td>
<td>16,000</td>
</tr>
</tbody>
</table>

Example 2:

Loss due to insects

Given:

|          | Paddy moisture content | 14% |
| Paddy price         | 300 EUR/t |
| Storage quantity    | 10,000 t |

Formula:

\[
\text{Substance loss} (t) = \frac{\text{heat generation (MJ/t day) \times storage duration (day) \times storage mass (t)}}{15,000 (MJ)}
\]

Result:

<table>
<thead>
<tr>
<th>Substrate loss (t)</th>
<th>Mass loss [%]</th>
<th>Loss (EUR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>uncooled at 30 °C</td>
<td>128</td>
<td>1.28</td>
</tr>
<tr>
<td>uncooled at 25 °C</td>
<td>64</td>
<td>0.64</td>
</tr>
<tr>
<td>cooled at 10 °C</td>
<td>minimal (x 1)</td>
<td>–</td>
</tr>
</tbody>
</table>

*  After drying or direct from field in summer.
** See Fig. 6.
*** Grain moisture content and husk taken into account

Maintaining rice quality

Rice is typically consumed directly without processing. If you disregard the milling process that makes rice edible and which has only a minor influence on decisive quality factors such as taste without high processing losses or expense. For this reason, a particular focus is placed on maintaining the quality of the paddy after the harvest. In addition to the consumption of rice, the use as seed must not be forgotten, which is no less important, as it ensures the yield and the next harvest.

The various quality criteria for paddy and rice are given in country-specific standards for trade. Addressing aspects of these is beyond the scope of this paper, and thus only a selected number will be discussed here, for which the cooling conservation is particularly positive.

A subjective parameter of rice quality is taste, which is evaluated differently from region to region. The issue is not the basic taste of the different rice varieties, but rather the purity of this specific quality factor. It should be noted again how important this parameter is due to the direct consumption of rice. With GRANIFRIGOR™ – grain cooling conservation, the specific taste is maintained as it was after the harvest. Primarily, this is achieved by reducing unfavourable storage conditions that have an adverse effect on taste. This includes grain respiration, which leads to spontaneous heating and release of water, thus providing favourable conditions for additional negative factors, such as insects and microbes. These can significantly affect taste, so that it can become musty, leading to a significant devaluation of the rice quality.

Damaged and discoloured rice grains are listed in the evaluation systems for rice quality. Damaged grains are not just the result of the use of post-harvest technology but also the result of insect infestation. Eating by the insects and drilling holes to deposit eggs are the typical types of damage to the rice grains, which lead to a devaluation of the rice quality. Due to a lower temperate range in the storage facility, which slows down and reduces the activity of the insects, the quality risk of damaged grains is minimised and the harvest quality is ensured. In addition, the yellow discolouration of rice is reduced (17) or avoided (18) by storage at low temperatures, allowing higher quality standards to be achieved.

As previously described, the cooling process also leads to a reduction of moisture or a drying effect. Due to the duration of the cooling conservation, the drying occurs slowly. Thus the moisture compensation in the paddy kernel between the dry zone at the outer surface and the core occurs gently so that only minimal stress occurs and the grains do not crack. The rice grain remains whole during the milling processing, which greatly reduces the proportion of broken grains. This allows the whole grain proportion to be increased by up to 20%. This means a potential increase in quality, which results in significantly higher sales.
Another important quality criterion of rice is the microbial purity, which is somewhat less important due to the type of rice preparation, but which is becoming ever more important due to the rise in living standards. Not only the burden of fungi and bacteria is relevant, but also the excreta from insects and fungal toxins. It thus becomes apparent that cooling conservation can make a significant contribution toward achieving an improved hygienic standard of rice.

Primarily, rice is seen as a food, a basic requirement for ensuring the availability of rice is cultivation and thus the use as a seed. The germination capacity is crucial for securing the yield, even when rice mostly is grown using transplanting. With the GRANIFRIGOR™ – grain cooling conservation, the germination capacity of seeds can be ensured over longer periods at a sufficiently high level (Figure 11).

Combination of cooling conservation and drying

Paddy is harvested with a moisture content that makes drying absolutely necessary to achieve storage life. Therefore, the drying capacity at harvest time is a process bottleneck, which can be significant depending on the harvest moisture content. This cannot be avoided if the rice quality is to be preserved. By using cooling conservation, this bottleneck can be bypassed without any loss. The increase of drying capacity has been widely described with performance increases of 30-40% [20]. Paddy is dried down to a moisture content of 16 – 18% and then cooled. Thereby the time and energy consuming drying process down to low moisture levels ≤ 14% is postponed for the time being. With GRANIFRIGOR™ – grain cooling, the paddy is not just made ready for storage, it is also dried by an additional 0.5 – 2% [4]. The subsequent drying to the final moisture content is thus shortened or even becomes unnecessary. This leads to savings in management.

costs and time, in addition to the previously described advantages with respect to rice quality, yellow discoloration and head rice yield. Various process combinations of drying and cooling are possible, as shown in the figure (Figure 12).

Use of the GRANIFRIGOR™ – grain cooling conservation in combination with parboiling

Cooling conservation has a number of advantages for parboiling. For one, the paddy can be stored at a higher moisture level after the harvest. Thus remoistening the paddy before parboiling is accelerated as the paddy can be used not at 12 – 14%, but rather 16% for parboiling. This means a time saving, which leads to higher production capacity of the parboiling system. The accelerated process provides further advantages, such as a greater degree of whiteness of the rice and thus a higher commercial quality [22]. In addition, the drying process after the parboiling is accelerated by cooling conservation, as previously described. An additional advantage is that the cooling device for cooling the paddy can be used for tempering after parboiling, which reduces the process time of parboiling, thus saving silo volume for tempering or allowing pre-drying to be performed. The cooled air reduces not only the temperature, but due to its higher drying capacity the lower temperature and the low water content, it can remove more moisture form the paddy. Here the evaporative cooling of the water is additionally used for cooling the paddy.

Efficient milling processing using cooling conservation

The previously described advantages of cooling conservation of rice lead to more efficient processing of paddy and rice in the mill (Figure 13). Above all, the factors that increase quality make faster processing possible. Due to the gentle drying process during cooling, fine stress cracks in the rice grain are not formed, which would have otherwise have inevitably led to broken grains. It is thus possible to make the settings of the processing machine more efficient and increase the throughput without increasing the proportion of broken rice (Figure 14). In addition, it is expected that the rice will not need to be polished as aggressively, as the quality losses due to poor storage have been eliminated. This is increased even more, as the yellow discoloration of the rice no longer occurs due to the GRANIFRIGOR™ – grain cooling conservation. It can easily be recognised that an increase in throughput of up to 5% is possible without a decrease in quality. In addition, a reduction of the polishing depth means more rice remains to be sold, increasing revenue.
The use of fumigation can only be justified with sufficient protection of human health and the environment. Here the paddy cannot be processed for 3 to 30 days. A requirement is a gas-tight storage facility, as otherwise regular re-gassing is unavoidable, incurring significant costs. In addition, arising resistance to several fungi must be assumed, which necessitates updating and changing the fumigant, creating additional cost pressure. The use for organic rice is not permitted, creating additional cost pressure. The potential for process improvement with the use of GRANIFRIGOR™—grain cooling conservation becomes clear and it becomes necessary for forward-looking paddy storage facilities and rice mills to secure and expand their market position.

### Example 4:

**Economic losses due to moving rice per move**

<table>
<thead>
<tr>
<th>Given:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Price of head rice</td>
<td>480 EUR</td>
</tr>
<tr>
<td>Price of broken rice</td>
<td>290 EUR</td>
</tr>
<tr>
<td>Storage quantity</td>
<td>10,000 t</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Results:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gridding loss 0.06%</td>
<td>6</td>
</tr>
<tr>
<td>Additional broken rice proportion 3%</td>
<td>48,000</td>
</tr>
<tr>
<td>Total loss per move</td>
<td>50,700</td>
</tr>
</tbody>
</table>

### Summary

Cooling of paddy, brown rice and white rice with a GRANIFRIGOR™ is a worldwide proven, natural process for quality assurance of grains of all kinds. In warm and humid climates, there is virtually no alternative to its application. Due to continued climate warming and increasing rice demands, cooling conservation is gaining in importance. Good storage maintenance and care, as well as good air distribution and ventilation in the storage facility are necessary. To operate the cooling device optimally, the settings for chilled air and the subsequent after-heating for adjusting the relative cooling air humidity must be set properly. The temperature of the paddy and rice is checked regularly to monitor the process. In particular for paddy and rice, cooling conservation offers a number of benefits which result in reduction of loss and cost increasing the revenue and thus the market strength of paddy granaries and rice millers.

In conclusion, a GRANIFRIGOR™ grain cooler presents many advantages that must be considered in terms of economic efficiency:

- **Risk-free long-term storage without quality loss**
- **Conservation of harvest freshness for outstanding taste of rice**
- **Minimizing respiration losses**
- **Protection from insects and their damage to paddy and rice**
- **Avoiding expensive and uneconomical chemical treatment like fumigation**
- **Protection of organic paddy and rice**
- **Protection from fungi and their mycotoxins**
- **Reduction of drying costs and energy consumption**
- **No yellow discoloration because of overdrying and low storage quality**
- **Higher head rice recovery because of less fissures and cracks**
- **Higher milling performance and efficiency**
- **Faster parboiling with brighter whiteness of rice**
- **Simplification of storage management**
- **Independent operation of weather conditions**
- **No aeration damage by rewetting of paddy**
- **No breakage nor grinding losses of rice by circulation**
- **Conservation of germinating quality for fast grow and high yield**
- **Increase of revenue and improving of market position**
- **Short amortization period**

### References

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23. Josephine: M. (1999), Quality changes, starch gelatinisation, and implications during grain storage handling. R.I. Thesis, Kansas State University Manhattan, Kansas, USA.
Models GRANIFRIGOR™ - Grain cooling units

FrigorTec (formerly product division of Axima and Sulzer Escher Wyss) – The specialist for refrigerators and heat pumps:

Grain cooling
GRANIFRIGOR™

Crane air conditioning
CRANEFRIGOR™

Standard cooling
STANDARDFRIGOR

Special solutions
SHELTERFRIGOR

Insect heat treatment
DEBUGGER

Hay dryer
AGRIFRIGOR™

SERVICE – Our service keeps the units maintained and ensures the spare parts supply - worldwide.