



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

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



1 Silo system

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

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 galvanised 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 moveable 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



2 Warehouse storage with central air distribution for GRANIFRIGOR™ - grain cooling

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.

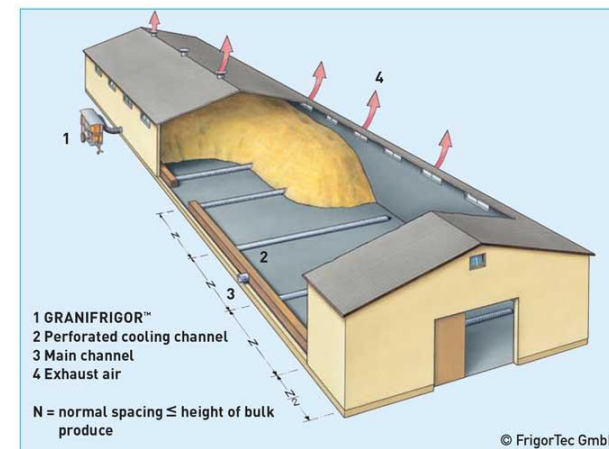
Water traps in which condensation could accumulate should be avoided. The main line should not be too long to

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



3 The principle of air distribution in a warehouse storage facility

openings. The vents must be installed circumferentially. Of course, exhaust vents must be equipped with weather protection for rain and a bird screen.

Fans are also used for effective exhaust ventilation of the storage space. Exhaust fans should transport roughly 1.5 to 2 times the volume flow of the maximum possible air flow that is transported in the storage area. The exhaust fans do not need to generate extra pressure and thus can be relatively inexpensive. They only need to transport the air volume over the pile in the so-called head room to the outside. For storage facilities that are not too long, the exhaust fans can be installed in the gable. For large warehouses, the exhaust fans are placed on the roof along the ridge.

Storage handling

Grain crops should be cleaned and examined before being stored. Shrivelled grains and chaff typically have a greater Fusarium burden. In foreign particles and dusts, there are microbes and moulds, which can lead to the formation of hot spots. The storage facility must be well cleaned and dry before bringing in the harvest [1]. Air distribution must also be included in these preventative measures. All channels must be dry and free of dust and dirt. Old paddy stocks and new harvests should be stored separately [2]. All extraneous seeds and impurities have to be avoided.

When filling, cones have to be prevented. Therefore the paddy should be either automatically well distributed or manually levelled. Storages with large surface areas have to be equipped with levelling equipment (baffle plates, spreaders, etc.) to achieve good distribution with a low level of segregation.

Measurement technology

In general, measurement equipment should be used in a grain storage facility to monitor the bulk temperature.

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.

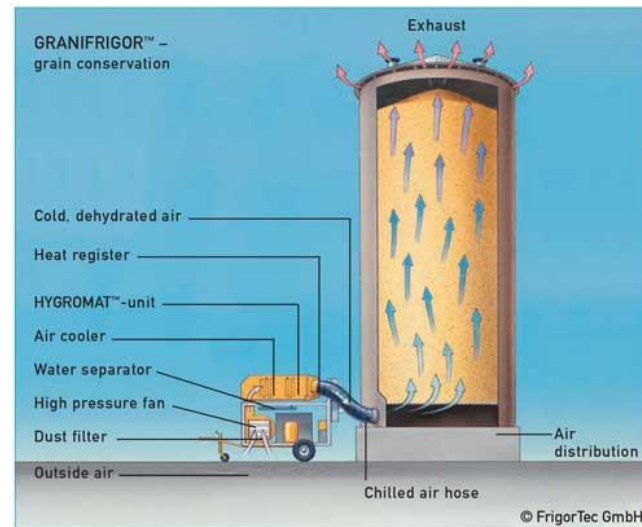
A single measurement point is not representative for a grain bulk. For this reason, a number of measurement sensors must be used or measurements must be taken at a number of locations in succession. The temperature measurement is an important aspect of monitoring the status of the stored goods. If the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

The cooling conservation process

The fan of the GRANIFRIGOR™ – grain cooling device draws in the 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.



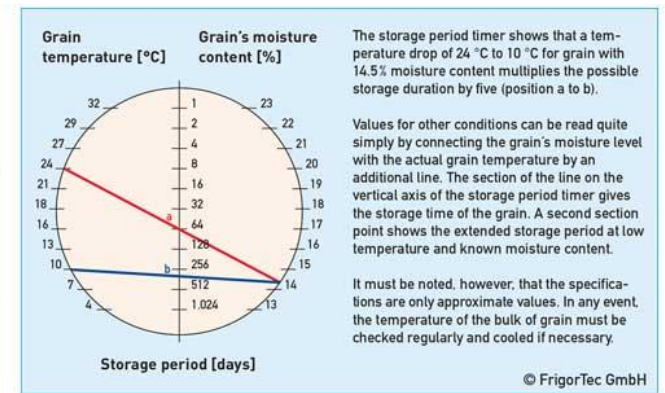
4 Process principle of the GRANIFRIGOR™ – grain cooling conservation

This improves the profitability of the process.

GRANIFRIGOR™ systems operate independently of the weather conditions. The device can also be used during rain or fog as well as under humid tropical conditions.

After the start of cooling, the harvested crop becomes cold in the lower area. At the top, the temperature rises initially. The air absorbs the energy and humidity from the grain before it leaves the storage area at the top, saturated with humidity and heat. Once cold air escapes from the top, the paddy has been "cooled all the way through". Under no circumstances may the cooling process be stopped too early. This could cause major problems in the upper area of the grain bulk. Cooling can be stopped when the paddy temperature 20 cm below the surface of the grain bulk has reached a temperature 2 to 4 K above the temperature of the chilled air supply to the harvest crop. A slight temperature difference between the bottom and the top layer may remain due to the air resistance of the bulk. A cooling cycle may only be interrupted temporarily to prioritise an endangered lot. Once the interrupted cooling cycle is resumed, the cooling is continued at the same set temperature values. Any interruption should only last for short period of time. After the cooling cycle is completed, all openings and connections are closed. This protects against the formation of condensation due to the introduction of warmer air and against animals.

The storage period timer in Figure 5 shows that a temperature drop from 24 °C to 10 °C for paddy with 14.5% moisture content multiplies the possible storage duration by five (position a to b). Values for other conditions can be read quite simply by connecting the grain's moisture level with the actual grain temperature by an additional line. The section of the line on the vertical axis of the storage period timer



5 Storage period timer for grain

Cooling [K]	20 (e.g. from 35 °C to 15 °C)
Region	Asia
Climate zone	Tropics
Energy consumption in [kWh/t]	6-12

Table 1: Empirical values for energy consumption for one cooling process of paddy in the tropics

gives the possible storage time of the grain. A second section point shows the extended storage period at lowered temperature and known moisture content.

It must be noted, however, that the specifications are only approximate values. The temperature of the bulk of grain must be checked regularly and cooled if necessary. If the temperature is too high, re-cooling is necessary.

Energy consumption for cooling conservation

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 set 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]. For moisture contents > 19%, the paddy should be dried in a dryer before the cooling cycle.

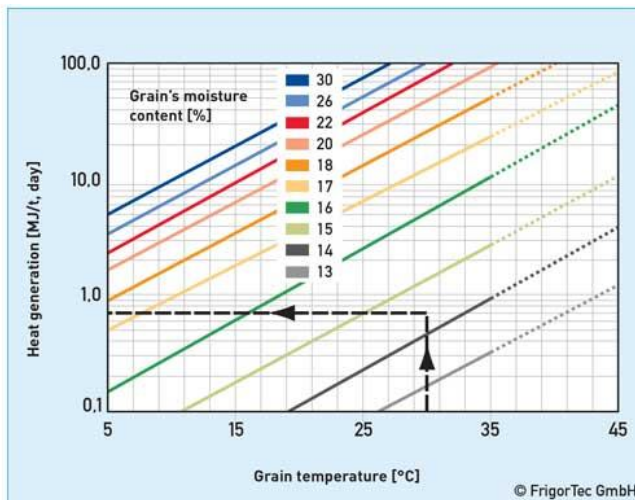
Cooling during rain and fog

The GRANIFRIGOR™ can be used during rain and fog without any limitations. Due to the after-heating of the chilled air after the evaporator, the relative air humidity is lowered. During rain and/or fog, the water condensation will be higher. More water will flow out of the condensation hose.

Influence of the cooling conservation on the storage stability of paddy

Respiration

Paddy continues to live after being cut and the threshing process. Paddy and rice are highly hygroscopic; they absorb and release humidity. Losses in freshly harvested paddy are primarily caused by the cellular respiration and its consequent spontaneous heating. This process is dependent on the paddy's moisture content and temperature. As the temperature and moisture increase, its respiration becomes more intensive. The consequences of spontaneous heating are loss of substance and promoting the development of insects and mildew. In humid tropical regions, the risk of spoilage through hot and humid climate conditions is particularly high. In temperate climate zones, it is well-known that during the cooler seasons there is appreciably less substance loss in grain storage than during the summer months. With the GRANIFRIGOR™ cooling conservation, the winter climate conditions are brought to the post-harvest period of the paddy.



6 Heat generation during grain storage modified according to Jouin [6]

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, this 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 substances [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 crop.

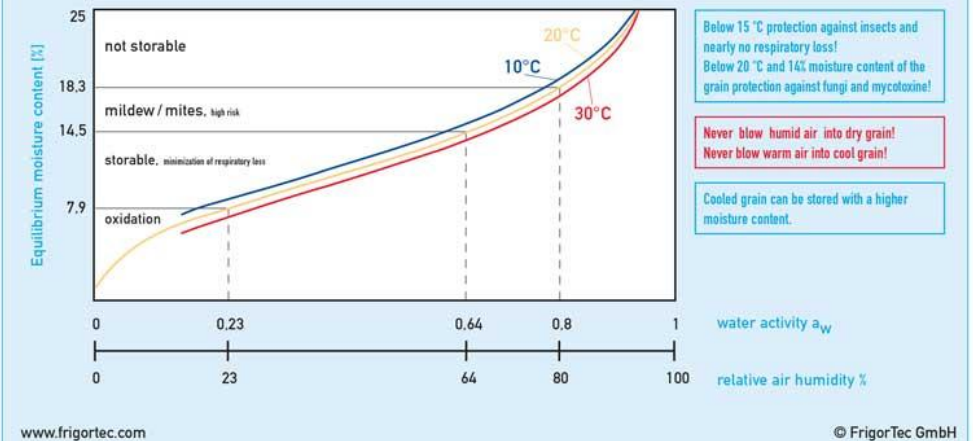
So: **Never introduce moist air into dry grain! Never introduce warm air into cooler grain!**

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

Sorption isotherms of paddy

The sorption isotherm shows the equilibrium moisture content between grain and air. At the state of equilibrium no moisture changes from the grain into the air and vice versa (no water adsorption / no water emission).



7 Sorption isotherms of paddy

grain crop to the saturation pressure of water (P_G/P_W). One of the components of paddy is water. It 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

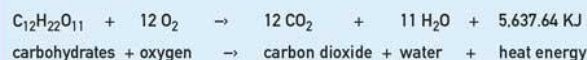
Grain is a bad conductor of heat. The heat conductivity of paddy with a moisture content between 10 and 20% is 0.09 to 0.12 W/Km. As a comparison, steel (for instance a silo wall) has a conductivity of approximately 45.3 W/Km. Harvest heat and the heat generated by cellular respiration are poorly dissipated 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.



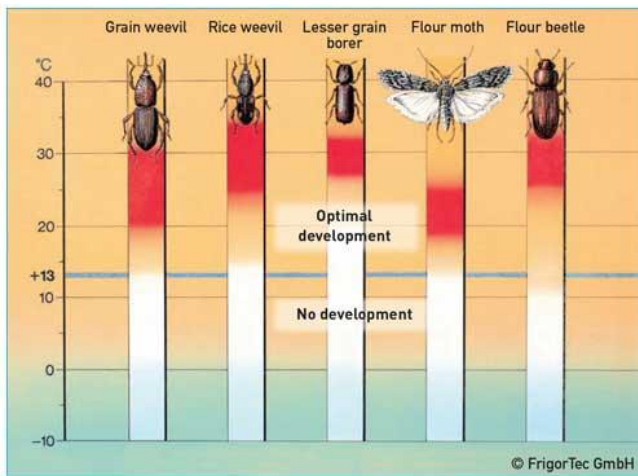
8 Porosity and grain's contacts in a paddy bulk

The grain respiration molecular formula of the chemical process [5]:



For 1 kg grain, the mass balances are:

$$1,000 \text{ g} + 1,122.81 \text{ g} = 1,543.86 \text{ g} + 578.95 \text{ g} + 16.48 \text{ MJ heat}$$



9 Development of relevant insect dependent on temperature

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.

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.

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 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

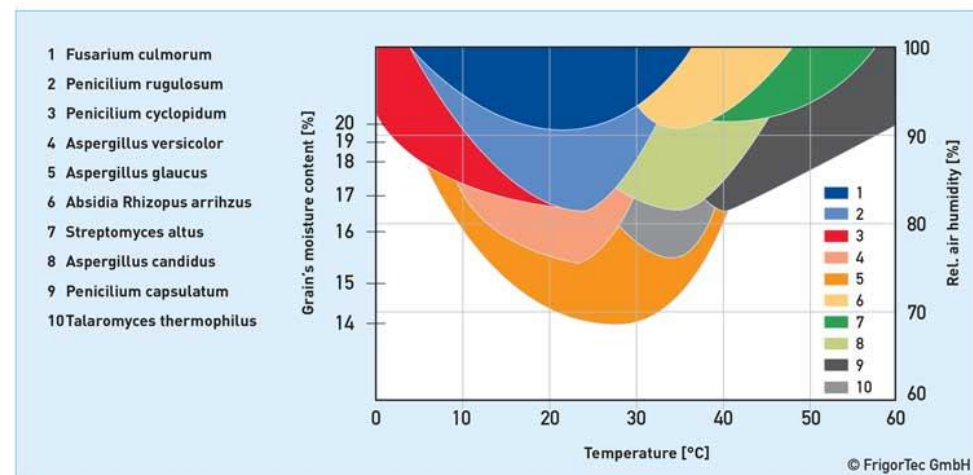
Microorganisms such as fungi and bacteria adhere to the surface of the grain kernel [13]. On the field, a hygrophilous primary flora dominates that requires a water activity > 0.9. In the storage facility, osmophilic secondary flora is then generated, which multiplies at water activities > 0.7.

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].



10 Development of various microorganisms as a function of relative humidity, temperature and grain's moisture content [14]

Advantages 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 recirculation of 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

Example 1:

Respiration losses – dry substances loss			
Given:			
	Paddy moisture content	14.5%	
	Paddy temperature	30 °C *	
	Paddy price	300 EUR/t	
	Storage period	8 months	
	Storage quantity	10,000 t	
Formula:			
$\text{Substance loss (t)} = \frac{\text{heat generation [MJ/t, day]}^{**} \times \text{storage duration [day]} \times \text{storage mass [t]}}{15,000 \text{ [MJ/t]}}$			
Result			
		Substance loss [t]	Mass loss [%]
uncooled at	30 °C **	128	1.28
uncooled at	25 °C	64	0.64
cooled at	10 °C	minimal (≤ 1)	–

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

Example 2:

Loss due to insects			
Given:			
	Paddy moisture content	14%	
	Paddy price	300 EUR/t	
	Storage quantity	10,000 t	
Formula:			
$\text{Damaged grain [\%]} = \frac{\text{Number of damaged grains [n]} \times 100 \text{ [t]}}{1,000}$			
$\text{Dry mass loss [t]} = 0.5 \times \text{damaged grains [\%]} \times \text{storage quantity [t]} \times (1 - \text{paddy moisture content})$			
Result			
	Dry mass loss [t]	Paddy loss [%]	Loss [EUR]
10% damaged grain	430	6.25	187,500
5% damaged grain	215	3.125	93,750
1% damaged grain	43	0.625	18,750
Cooled grain	0	–	–

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 [16].

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.

Finally, it can be said that using cooling conservation of grains, physiological mass losses as well as losses caused by insects and microbes can be limited and the value achieved through storage can be maintained and guaranteed.

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 all 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 temperature 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. Example 3 illustrates the potential.

Example 3:

Increase in proportion of whole grain	
Given:	
Price of head rice	450 EUR/t
Price of broken rice	290 EUR/t
Storage quantity	10,000 t
Result:	
	Profit [EUR]
Additional head rice proportion 5%	80,000
Additional head rice proportion 3%	48,000
Additional head rice proportion 1%	16,000

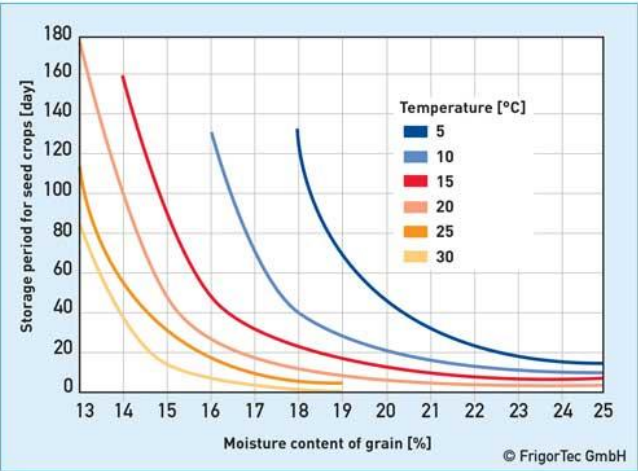


Another important quality criterion of rice is the microbial purity, which is somewhat less important due to the type of rice preparation, but which is becoming ever more important due to the rise in living standards. Not only the burden of fungi and bacteria is relevant, but also the excreta from insects and fungal toxins. It thus becomes apparent that cooling conservation can make a significant contribution toward achieving an improved hygienic standard of rice.

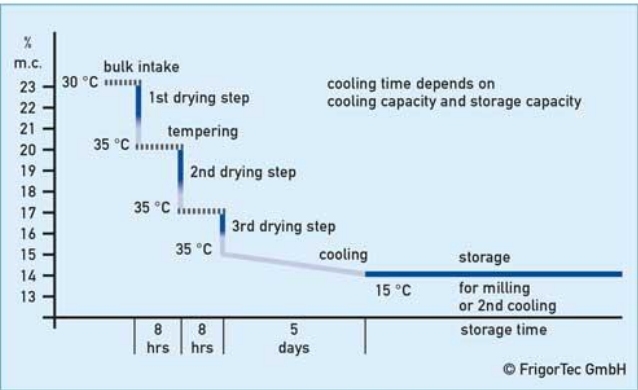
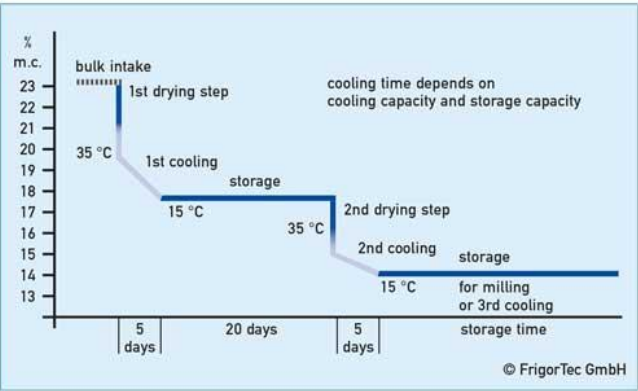
Primarily, rice is seen as a food; a basic requirement for ensuring the availability of rice is cultivation and thus the use as a seed. The germination capacity is crucial for securing the yield, even when rice mostly is grown using transplanting. With the GRANIFRIGOR™ – grain cooling conservation, the 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,



11 Permissible storage period for seed crops according to Avena [19]



12 Process combinations of paddy drying with GRANIFRIGOR™ – grain cooling conservation [21]

costs and time, in addition to the previously described advantages with respect to rice quality, yellow discolouration 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



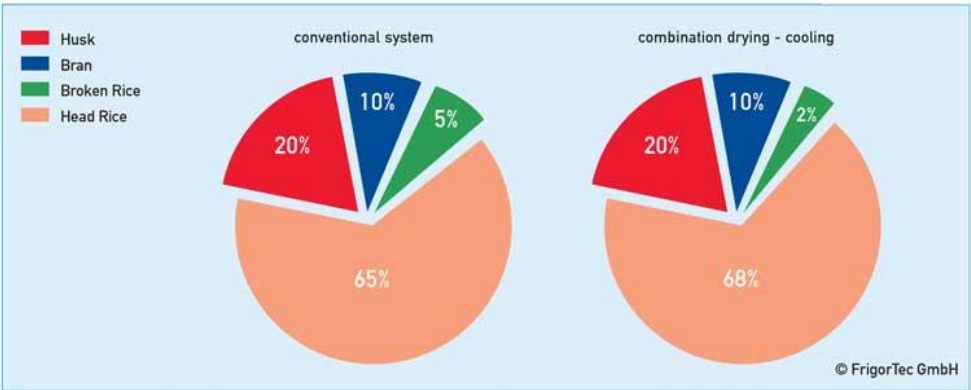
13 White rice silo with GRANIFRIGOR™ cooling unit in a rice mill

temperature, but due to its higher drying capacity, the lower temperature and the low water content, it can remove more moisture from 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 discolouration 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.



14 Comparison of head rice yield between conventional rice drying and in combination with GRANIFRIGOR™ – grain cooling conservation [20]

Simplification of storage by using GRANIFRIGOR™ – grain cooling conservation

Storage management is responsible for maintaining the quality of the paddy before processing. It must also be ensured that losses are kept to a minimum. Common techniques include aerating, fumigation and moving the grain to avoid heat and insect damage. When aerating the paddy, the temperature and the relative humidity of the ambient air must be observed to avoid or minimise damage to the paddy. In tropical conditions where the grain is cultivated, this is difficult to achieve. It can clearly be seen that cooling conservation, which is independent of the weather, represents an easier option and does not lead to a degradation of the storage quality.

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 fumigants must be assumed, which necessitates updating and changing the fumigant, creating additional cost pressure. The use for organic rice is not permitted, making clear the importance of residue in foodstuffs and the associated health risks. GRANIFRIGOR™ – grain cooling conservation is easy and safe, with low operating costs and lasting effect over a long period without any residue issues, that fumigation becomes an obsolete and unnecessary technology. Moving paddy is sometimes used to deal with hot spots. This requires investment in equipment for additional storage capacity and transport equipment, incurring costs for work and energy. The management must also be able to react quickly and effectively. While this technique can be used for paddy, it cannot with rice, as otherwise

Example 4:

Economic losses due to moving rice per move		
Given:		
Price of head rice	450 EUR/t	
Price of broken rice	290 EUR/t	
Storage quantity	10,000 t	
Result:		
	Rice loss [t]	Loss [EUR]
Grinding loss 0.06%	6	2,700
Additional broken rice proportion 3%		48,000
Total loss per move		50,700

the grinding losses due to conveyor equipment of up to 0.06% can occur [23] or an additional broken grain proportion of up to 3% per move may be generated [24]. The economic consequences can be illustrated using Example 4.

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.

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 continuing climate warming and increasing hygiene 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 unecological 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

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Models GRANIFRIGOR™ – Grain cooling units



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