one side of the aeration ducts and exhausted out the fans after horizontally passing through the grain bulk. With nearly five years of application, it has been demonstrated that the storage technologies in this new ventilation system, such as aeration, grain cooling, fumigation and controlled atmosphere treatment can be done effectively, ande grain moisture loss during ventilation can be reduced by 0.3-0.5 percentage points. Alos, the efficiency of loading and unloading grains can be increased by 100% as compared to the vertical ventilation system because on-floor ducts do not need to be removed during the unloading process.

Therefore, application of the granary transverse aeration system will obtain better economic and operational benefits as summarized in Tab. 1.

Tab. 1 Evaluation of vertical and transverse ventilation system.

No.	Evaluation index	Vertical ventilation	Transverse ventilation	Remark
1	Ventilation uniformity	80-85%	90-95%	Increase of 10%
2	Percent of moisture loss during ventilation	0.7-1.0%	0.2-0.3%	Reduced by 3-5 times
3	Capacity of grain load/unload/hour	50 t/hour	＞100 t/hour	Increase of 100%
4	The load/unload cost of per ton	5.0 ¥/t	3.0 ¥/t	Reduced by 40%
5	Labor cost	high	low	Reduced by 50%
6	Depreciation expense	high	low	Reduced by 20%
7	Labor intensity	high	moderate	
8	Mechanization level	low	high	

Until now, the transverse ventilation system has been applied in more than twenty provinces throughout China, and the quantity of stored gain has reached 3 million tons of warehouses storage capacity that is equipped with the new transverse system.

Technical and Economic Evaluation of Ambient and Chilled Aeration Strategies to Maintain the Quality of Paddy Rice During Storage in a Tropical Climate

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Abstract

Warm and moist conditions of some tropical climate regions make it difficult to use ambient aeration to cool stored grain, which contributes to pest problems and increases dependence on chemical control as part of grain management strategies. Grain chilling is a non-chemical alternative to cool grain stored under high risk climatic conditions. The objective of this research was to use computer simulation to evaluate the technical and economic viability of using grain chilling compared to four ambient aeration strategies developed for paddy rice stored under the tropical climatic conditions of the North Pacific coast of Costa Rica. The minimum grain temperature achieved through ambient aeration at the end of the six-month simulated storage period was 30.8°C, using an aeration strategy based on a grain-ambient temperature differential greater than 10°C. Grain chilling lowered the average grain temperature from 35°C to below 15°C in 117 hours and the maximum average temperature it registered after six months of storage was 15.5°C. The economic evaluation of the ambient aeration and chilling strategies determined that the operational costs of grain chilling were 1.83 US $/t lower than ambient aeration plus chemical control of pests. However, the initial cost of the grain chiller made the net present cost (NPC) of the grain chilling strategy 0.22 US $/t higher than the cost of ambient aeration plus chemical control over a 10-year analysis. Several potential financial options were analyzed to make the grain chiller economically feasible for a rice miller in Costa Rica.

Keywords: Paddy rice, ambient aeration, grain chilling, economic feasibility.

Introduction

The conditions of high temperature and relative humidity (RH) during most of the year in most tropical climatic regions limit the cooling capacity of ambient grain aeration. This is why in this climate ambient aeration is used mainly to maintain the grain temperature and moisture content (MC) in equilibrium with the average ambient conditions, which avoids the development of hot spots and prevents condensation on walls and roofs (Lawrence and Maier, 2011; Noyes and Navarro, 2002).

A limited number of research studies have come up with strategies that give viable options for aeration in tropical climates. One of these studies was presented by Sinicio and Muir (1998), in which they determined that using a difference of 6°C between the average grain and ambient temperature, at an airflow between 0.08 and 0.16 m^3/min/t, provided the best storage conditions for wheat during eight month storage (only 0.1% shrink loss) under Brazilian conditions.

Aeration during night time or early morning hours has also been considered a technically viable option for tropical climates since lower temperatures during these hours have reasonable cooling effect on stored grain (Monroy and Valencia, 1978; Recio, 1999). However, the risk of rewetting grain is a restriction for using lower temperatures in this latitude, but according to Noyes and Navarro (2002), the RH is usually lower in the plenum due to the heat of compression produced by the aeration fans. According to Noyes and Maier (2002), for every ~248 Pa (1 in. of water column) of static pressure (SP) that is generated in the aeration system, the temperature of the air passing through the aeration fan can increase by ~0.5°C (1°F). According to Zeledon and Barboza (2000) (unpublished), the RH inside the plenum can be between 6 and 18 percentage points drier than the ambient air.

Grain chilling is an alternative to ambient aeration that allows cooling of grain under 20°C in weather conditions where otherwise it would not be possible. This helps limit or stop completely insect population growth (Fields, 1992). This technology has proven to be effective for cooling grain to below 17.5°C in relatively short periods of time (80-300 hours) in silos between 500 and 5000 metric tons (t), located in tropical regions of Argentina, Brazil and Israel (Calderon, 1972; Lazzari et al., 2010; Roskopf and Bartosik, 2009).

The high purchase price of grain chillers and the lack of economic studies that complement the technical studies has limited the implementation of this technology more widely in some tropical regions. One of the only studies that has made an effort to evaluate the true value of this kind of investment in the long term was developed by Rulon et al. (1999), in which they analized the economic feasibility of a grain chilling prototype developed by Purdue University using the Net Present Cost (NPC) methodology that analyzes the net cost of an investement through its life cycle. This study demonstrated that the grain chilling technology was highly competitive compared to the cost of using ambient aeration plus chemical control.

The obejctive of this resesearch study was to use computer simulation to evaluate the technical and economic feasibility of using grain chilling compared to four ambient aeration strategies developed for paddy rice stored under the tropical climatic conditions of the North Pacific coast of Costa Rica.

Materials and Methods

Ambient aeration and grain chilling computer simulation model

The ambient aeration and grain chilling strategies were analyzed using a finite element computer simulation model adapted from Lawrence and Maier (2011) and based on the storage conditions of paddy rice in the North Pacific region of Costa Rica, also called Guanacaste. For the development of the computer model, five years of weather data (2010-2014) during the storage period of paddy rice in this region (November to May of next year) were collected. The initial conditions of the paddy rice were determined at 13% MC and 35°C, assuming it would go into storage directly from the dryer, and the physical properties such as bulk density, porosity, and thermal properties which were retrieved from ASABE standards D241.4 and D243.4.

The storage structure used in the computer model was a corrugated steel silo of 1500 t (diameter-to-height ratio of 1.0), which is commonly used for long term storage in this region. The aeration system of these silos consisted of one 20 HP centrifugal fan and a perforated false floor. Using these specifications, the airflow rate of the ambient aeration fan was determined to be 0.22 m^3/min/t (~0.2 cfm/bu) and the static pressure (SP) produced by the aeration system was determined to be 2070 Pa (~8.3 inches of water column) (Dickinson and Morey, 2013). This SP would cause an increase of the aeration air of approximately 5°C according to Noyes and Maier (2002) which was accounted for in the ambient aeration simulations.

Based on the analysis of the climatic conditions of the region and the structural conditions of the storage structure, the following ambient aeration strategies were proposed:

Run ambient aeration fan when ambient temperature is less than or equal to 24°C and ERH in the plenum is less than 70%.
Run ambient aeration fan from 6:00 a.m. to 8:00 a.m. and from 5:00 p.m. to 7:00 p.m.
Run ambient aeration fan from 5:00 a.m. to 9:00 a.m. and from 5:00 p.m. to 9:00 p.m.
Run ambient aeration fan whenever ambient temperature is 10°C lower than grain temperature in the top section of the grain mass.
The grain chilling strategy was programmed to start the grain chiller as soon as the paddy rice entered the silo and continue the cycle until the top section of the grain mass reached 15°C. The input data for the development of this strategy was collected from field trials developed on wheat storage in Kansas, U.S.A., during the summer of 2015 and 2016 (Morales-Quiros, 2017). The grain chiller used for these trials has a rated capacity to cool 100 to 170 t of grain per 24 hours of continous operation on silos of up to 1800 t, according to the manufacturer (Coolseed, 2016).

Net Present Cost economic model

The cost of the ambient aeration strategy with the best results from the previous section, based on fan run hours, MC, and final grain temperature, was compared with the cost of the grain chilling strategy using the NPC methodology developed by Rulon et al. (1999). The NPC economic model calculated the net cost of the investment over its life cycle (10 years for the grain chilling equipment), using factors like annual interest rate, tax rate, rate of return on equity and percent of business financed by debt. This information was collected from financial entities in Costa Rica.

The NPC of the ambient aeration strategy was calculated based on the power requirement of the aeration fan, maintenance labor, sampling labor and shrink loss. Due to the fact that it is not possible to control pests only with ambient aeration in this region, the cost of this strategy included fumigation cost, insecticide application, personnel safety equipment cost, application labor, among others. This information was collected from agrochemical companies and local rice milling industries.

The NPC of the grain chilling strategy was calculated based on factors like purchase price of the grain chiller (US $74700, according to the manufacturer), power requirement, installation and maintenance labor, sampling labor and shrink loss. Additionally, financial options for making the grain chilling technology feasible for the Costa Rican rice miller were also analyzed. Some of these alternatives were a leasing option, improving the capacity of the grain chiller, and premium sale price of paddy rice treated with the grain chilling technology. This information was compiled from previous field experience, financial entities and local rice milling companies.

The NPC calculations were based on a hypothetical rice milling company with six silos of 1500 t of paddy rice each, which is the average for the region, stored for six months.

Results and Discussion

Ambient aeration and grain chilling strategies

The results of the computer model demonstrated that it is possible to use low temperature, high RH air to aerate paddy rice since the temperature increase of approximately 5°C in the plenum will reduce the RH by approximately 20percentage points. This means that it is possible to use ambient air of up to 90% RH because in the plenum the RH will decrease to 70%. Similar observations were made by Zeledon and Barboza (2000).

The first ambient aeration strategy (Ambient temp. ≤24°C, plenum RH <70%) only reduced the average of the 5-year average temperatures of the grain mass by two degrees (35°C to 33°C), without noticeable MC variation.

The second and third ambient aeration strategies (2 and 4 early morning and night time fan run hours, respectively) showed adverse results because the temperature of the grain mass essentially remained unchanged but the average of the 5-year average MC was reduced dramatically due to the lack of restrictions for the conditions of ambient air that could be used in these strategies. The number of fan run hours were also excessive in these strategies (729 and 1458 hours, respectively). For this reason, the period of aeration was limited to between November and January of the storage period, which are the months with the lowest minimum temperature of the year. This helped to reduce the average of the 5-year average of rice temperature to approximately 33°C, without noticeable MC variation. This modification also reduced the fan run hours to 312 and 624 hours, respectively.

The fourth strategy (grain-ambient temp. difference ≥10°C) was the one that reduced the average of the 5-year average paddy rice temperature the most by the end of the six-month storage period, down to 30.8°C. This strategy increased the average of the 5-year average MC by 0.1% and required the least amount of fan run hours (214 ±43 hours) among all ambient aeration strategies analyzed (Fig. 1).

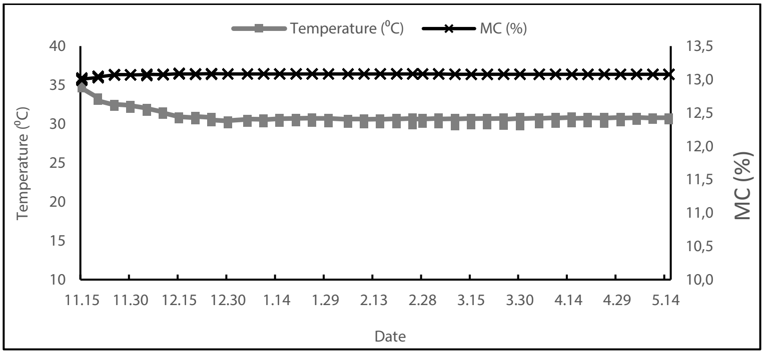

Fig. 4 Five-year average of the average grain temperature and moisture content (MC) profile of paddy rice stored from Nov. 15th to May 15th in Guanacaste, Costa Rica and aerated using Strategy 4.

The computer simulation of the grain chilling strategy showed that the average of the 5-year average grain temperature was reduced from 35°C to below 15°C in 117 hours of active chilling, and remained below 15.5°C for the six months of storage. Nevertheless, the average of teh 5-year average paddy rice MC increased by 0.2 percentage points with this strategy (Fig. 2).

Preserving paddy rice at low temperature demonstrated to be effective at controlling *R. dominica* and *Sitophilus* spp. for 60 days of storage in Brazil (Lazzari et al., 2006).

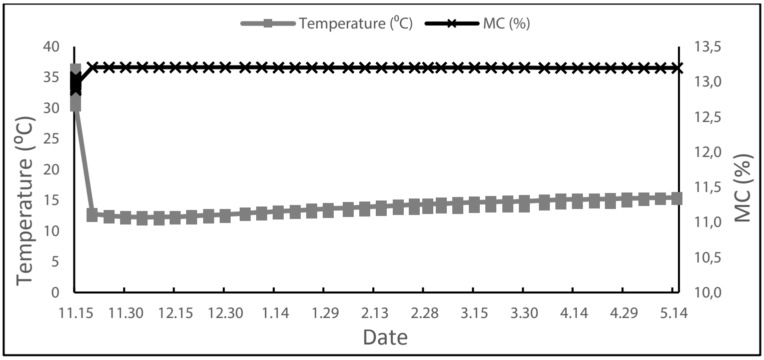

Fig. 5 Five-year average of average grain temperature and moisture content (MC) profile of paddy rice stored from Nov. 15th to May 15th in Guanacaste, Costa Rica and aerated using the grain chilling strategy.

NPC economic analysis

Since the fourth ambient aeration strategy was the one that required the least amount of fan run hours, and thus resulted in highest energy savings, and was also the one that maintained the lowest grain temperature throughout the six months of storage among all ambient aeration strategies, it was chosen for the NPC economic analysis. Its feasibility was compared against the feasibility of the grain chilling strategy.

The NPC economic analysis showed that, although the operational costs of running the ambient aeration fan in the fourth ambient aeration strategy were low, the added cost of the chemical control of pests increased the annual operational costs of this strategy up to 2.36 US $/t. On the other hand, the annual operational cost of running the grain chiller was only 0.53 US $/t, given that preserving the paddy rice at temperatures below 20°C in a climatic region, where otherwise it would not be possible, replaces the need for chemical control. Similar observations were made by Rulon et al. (1999).

Although the grain chilling strategy predicted to reduce the annual operational costs of the Costa Rican rice milling company, the high initial investment of the grain chilling equipment (US $74700) increased the total NPC of this strategy. It resulted in an annual amortized NPC of 1.51 US $/t, while the annual amortized NPC of the fourth ambient aeration strategy plus chemical control was 1.29 US $/t (Fig. 3), i.e., 14.5% lower.

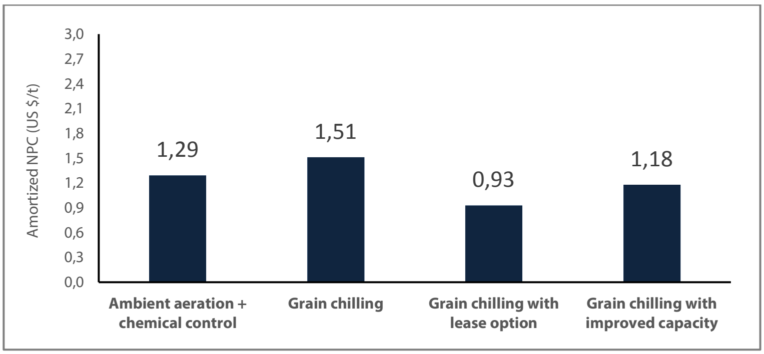

Fig. 6 Amortized Net Present Cost (NPC) of ambient aeration Strategy 4 and the grain chilling strategy with financial options for reducing the NPC.

In order to lower the NPC of the grain chilling strategy a leasing option was analyzed. It showed that leasing the grain chilling equipment for an annual rate lower than US $11,000 for a 10-year period (assumed useful life time of the equipment), would reduce the NPC of chilling from 1.51 to 0.93 US $/t (Fig. 3), or -38.4%. Although this option would increase the annual opertional cost of the grain chilling strategy from 0.53 US $/t to 1.77 US $/t due to the addition of the annual leasing payment, this cost would still be lower than the operational cost of the fourth ambient aeration strategy plus chemical control, i.e., 2.36 US $/t.

Another feasible option for financing the grain chiller, according to the NPC economic analysis, was to increase the capacity or number of tons treated with the grain chilling technology, which would dilute the cost per ton of the grain chilling strategy. This analysis showed that increasing the number of silos of 1500 t treated with the grain chilling technology from six to eight would reduce the amortized NPC from 1.51 US $/t to 1.18 US $/t, i.e., -21.9% (Fig. 3). This seems like an achievable quantity for the rice milling industry of Costa Rica since there is usually more than one harvest per year. The rice companies are receiving paddy rice basically all year, which would justify the purchase of the grain chiller given that it would be utilized throughout the year, lowering the NPC further.

A third financial option for the grain chilling strategy, according to the NPC economic model, would be to sell the rice treated with the grain chilling technology as a value-added product because it would be free of residues from postharvest pesticides. If it were possible to incease the sale price of this product by US $0.50 to US $1.00 per ton, this would reduce the amortized NPC of the grain chilling strategy below 1.29 US $/t (amortized NPC of the ambient aeration plus chemical control strategy).

Conclusions

The ambient aeration strategy based on a grain-ambient temperature differential of 10°C or higher showed the best results on final grain temperature, moisture content and fan run hours; nevertheless, it was not possible to reduce the average temperature of the paddy rice below 30.8°C by the end of the six-month storage under the tropical conditions of Guanacaste, Costa Rica. On the other hand, the grain chilling strategy reduced the average grain temperature below 15.5°C in less than five days, and paddy remained below this temperature for the rest of the six-month storage period. This would potentially reduce insect populations and eliminate the requirement for chemical control.

The grain chilling strategy reduced the annual operational costs of the Costa Rican rice milling company, according to the NPC economic analysis, but the high initial cost of the grain chilling equipment made the amortized NPC of this strategy higher than the amortized NPC of the ambient aeration strategy plus chemical control. The leasing option of the grain chilling equipment at a reasonable price, increasing the capacity (number of tons treated) of the grain chiller, or charging a premium sale price of the paddy rice treated with the grain chilling technology, are all feasible options for reducing the amortized NPC of the grain chiller.

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CHILLING TEMPERATURE AND LOW MOISTURE CONTENT TO KEEP SOYBEAN GRAIN QUALITY DURING STORAGE

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Abstract

Soybeans are used as food, feed, oil and fuel. Losses may happen at harvesting, transportation, and mainly during storage. Moisture content (MC %) and temperature (T °C) of the soybean grain mass during storage are the main factors affecting quality, quantity and value of the product by favoring the development of microorganisms and insects. Large grain chillers have been used to maintain soybean quality and reduce insect infestation during storage. To evaluate the effect of MC and temperature on the quality parameters of soybean seeds, samples were stored at 58±2% RH, with five different MCs, at 15 °C (chilling temperature) and 30 °C (average temperature inside silos in Brazil) for 180 days. The following was observed: reduction in the MC at higher temperature; the weight of soybeans was maintained at either temperature when the MC was at about 12%; MC above 14% reduced the weight value independent of storage temperature; at 15°C the weight of 1,000 seeds was maintained during storage; low MC and temperature kept germination and vigor of the seeds at high rates; low MC and temperature reduced electrical conductivity; there was no noticeable influence of the storage temperature, regardless of the MC of the beans, on the free fatty acid content. In general, quality attributes tend to be reduced during storage, being more remarkable at higher temperature and MC of the seeds. In conclusion, the temperature of 15ºC, which simulates grain cooling conditions, favors the maintenance of quality, quantity and value of soybean for long-term storage.