Journal of Stored Products Research 59 (2014) 76–81

Contents lists available at ScienceDirect

Journal of Stored Products Research

journal homepage: www.elsevier.com/locate/jspr

Effects of using eolic exhausters as a complement to conventional aeration on the quality of rice stored in metal silos

Wagner Schellin Vieira da Silva*, Nathan Levien Vanier, Valmor Ziegler,
Maurício de Oliveira, Alvaro Renato Guerra Dias, Moacir Cardoso Elias

Department of Agroindustrial Science and Technology, Universidade Federal de Pelotas, 96010-900 Pelotas, Brazil

ARTICLE INFO

Article history:
Accepted 27 May 2014
Available online

Keywords:
Oryza sativa L.
Milled rice
Exhauster
Aeration
Heat

ABSTRACT

The aim of this study was to evaluate the effects of utilizing an eolic exhauster on reducing the qualitative losses of rice stored in silos. Paddy rice was stored for a nine-month period, in triplicate, in metal silos with a 550-ton capacity that were or were not equipped with an exhauster system and were analyzed every three months. To evaluate the effects of complementary eolic aeration, the energy consumed for aeration and the physical properties of the grain, as well as the thermal and pasting properties of rice, were analyzed. Using the exhauster system in the rice storage silo reduced the loss of dry matter, the energy required for aeration maintenance over a 9-month period, grain hardening, the development of grain staining defects and the darkening of the grain, while preserving the conclusion temperature of gelatinization and the enthalpy, the final viscosity and the head rice yield and not affecting the onset temperature or the peak temperature of gelatinization. Increasing the duration of storage reduced the aeration maintenance requirement, changed the cooking time, the hardness of the grains, the conclusion temperature and the enthalpy, the peak viscosity and final viscosity, the head rice yield, the development of grain staining and the darkening of rice grains, but with less intensity when the rice was stored in silos that used an exhauster system, without affecting the onset and peak temperatures of gelatinization.

1. Introduction

Rice is a major source of energy for nearly two-thirds of the world population. In developing countries, besides being the basis of the food diet, rice is also an important vehicle for vitamins and minerals (Heinemann et al., 2005). Closely following maize, rice ranks second in grain production, with 722,559,584 tons of rice being produced in 2011 (FAO, 2013). The decrease in the quality of rice during storage can decrease consumer acceptance and may render the rice inappropriate for consumption.

The head rice yield (HRY) and the grain color are among the most important parameters for industrial rice production because these parameters are used to define rice quality for commercial transactions (Yadav and Jindal, 2008). In addition to the traditional dishes involving cooked rice, many rice-based products have been developed with the aim of improving the utilization of this nutritionally rich food. Among the newly developed rice-based foods are rice pasta, rice cookies and rice bread (Bassinello et al., 2011; Marti et al., 2013; Sivaramakrishnan et al., 2004).

In countries where the rice harvest is seasonal, the grains must be stored properly to be processed and supplied throughout the year. Studies have shown that inadequate paddy storage conditions, in addition to sanitary aspects, can affect the HRY and the cooking quality of milled rice (Chrastil, 1990; Hamaker et al., 1993) and can increase the kernel hardness (Dhaliwal et al., 1990). According to Sodhi et al. (2003), some of these changes are due to modifications of the cell wall structure and composition, starch–protein interactions and lipid oxidation. These changes occur most quickly during the first months of storage (Perez and Juliano, 1982).

The grain moisture and the bulk temperature are the most critical factors for good conservation of the grains during storage. The heat generated due to the active metabolism of the grain and the associated micro-organisms are controlled by ventilating chilled air or ambient air via an aeration process. Although these aeration techniques are suitable for maintaining a relatively uniform temperature throughout the grain bulk during storage, water condensation can occur on the surface of the grain bulk and in other parts of the silo, moistening and causing the deterioration of the rice grains (Dussadee et al., 2007). Furthermore, the annual

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* Corresponding author. Tel./fax: +55 53 32757258.
E-mail address: wagnersvsilva@yahoo.com (W.S.V. da Silva).

http://dx.doi.org/10.1016/j.jspr.2014.05.006
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operating period of the ventilation fan is very high, sometimes as much as 30–40% of the time when the environmental conditions are favorable for aeration (Maier et al., 1993). For these reasons, eolic exhausters may be used complementarily to increase the efficiency of aeration, contributing to cooling and maintaining the quality of the grains, without expending electrical energy.

Changes from a suspension to a solid, solid-to-gel transition and the destruction and hardening of the protein matrix of grains occur during storage, impacting the grain quality. One method for evaluating these parameters is differential scanning calorimetry (DSC), which has provided valuable information about those phenomena (Hsu et al., 2000). According to Zhou et al. (2010), the gelatinization of rice is affected by temperature and the storage time, as demonstrated in the gelatinization temperature and enthalpy. Attempts to explain the changes in functionality that are associated with storage have focused on the properties of rice components, such as starches, proteins and lipids, and interactions among them during storage (Chrastil, 1994).

The aim of this study was to evaluate the effects of utilizing eolic exhausters in silos on the energy consumption, head rice yield, percentage of stained grains and the whiteness and hardness of the grains, as well as the thermal and pasting properties of paddy rice during storage, with the goal of reducing the qualitative losses of stored rice.

2. Materials and methods

2.1. Materials

Rice (long grain with high amylose content, *Oryza sativa* L.) was cultivated under an irrigation system in the countryside of Turvo (28°55′34″S 49°40′45″W) in the State of Santa Catarina, Brazil. The rice grains were harvested when the moisture content was approximately 20% and were subjected to cleaning and drying processes until a moisture content of 12% w.b. (wet basis) was achieved by drying in metal dryer silos at 35 °C. The grains were then stored in the same metal dryer silos, which had the capacity to store 550 tons of rice grains and were 10 m high and 11 m in diameter, with strict monitoring to control pests and phosphine treatment to combat them, at the Realengo® Rice Industry. Three silos were equipped with 10 exhausters each, while other three silos were not equipped with exhausters. The exhausters that were utilized were classified as static type (CYA 60, Cycloar, Brazil), were triggered by wind or light breezes without the use of electric motors, and were 600 mm in diameter and 500 mm in height, with a flow rate of 4100 m^3 of air h^{-1} (at 10 km h^{-1} wind velocity). The aeration system was activated when the temperature of the bulk reached 5 °C above the outside ambient temperature. Every three months, during a nine-month period, rice samples were collected from six different positions in each silo, one from the middle and the other five positions from the sides, by using a 1.8 m-deep grain sampler. The different samples from the same bin were homogenized, placed in polyethylene bags and transported to the Laboratório de Pós-colheita, Industrialização e Qualidade de Grãos of the Universidade Federal de Pelotas.

The rice grains (100 g) were dehusked and polished using a Zaccaria rice machine (Type PAZ-1-DTA, Zaccaria, Brazil). After cleaning and grading, the brown rice samples were polished until 9% of the bran was removed. The degree of milling was determined using the following equation: DOM = [1 − (weight of the milled rice/weight of the rice with husk)] × 100. Broken grains were removed using the laboratory grader of the same Zaccaria rice machine (Type PAZ-1-DTA, Zaccaria, Brazil). The grains were ground to a 100-mesh sized powder using a laboratory mill (Perten 3100, Perten Instruments, Sweden).

2.2. Cooking time

The optimal cooking time for the milled rice was determined using the Ranghino test (Mohapatra and Bal, 2006). Approximately 100 mL of distilled water was boiled (98 ± 1 °C) in a 250-mL beaker, and 10 g of head rice samples was dropped into the water. The measurement of the cooking duration was started immediately. After 10 min and at every minute thereafter, 10 grains of rice were removed and pressed between two clean glass plates. The cooking time was recorded when at least 90% of the grains no longer had an opaque core or an uncooked center. The rice was then allowed to simmer for approximately 2 min longer to ensure that the cores of all the grains had been gelatinized.

2.3. Rice whiteness (L value)

The color of the grains was determined using a Minolta CR-310 chroma meter (Minolta, Japan) using the CR-A50 granular-materials attachment. The L^* value, which represents lightness, was determined. A white porcelain plate ($L^* = 99.41$, $a^* = -4.91$ and $b^* = +7.33$) was used for calibration.

2.4. Rice hardness

A textural profile analysis (TPA) of the cooked rice was performed using a texture analyzer (TA-XT2, Texture Technologies Corp., UK) with a 5-kg load cell using a two-cycle compression method (Park et al., 2001). The analyzer was linked to a computer that recorded the data via the XTRA Dimension software program (v. 8, Texture Technologies Corp., Scarsdale, NY). The rice samples were prepared by cooking samples of 10 g of rice in a 250-mL beaker with 200 mL of distilled water at 100 ± 1 °C until the white core disappeared. The cooked rice was completely drained of water using a strainer, and the surface moisture of the samples was removed by blotting. The cooked rice samples were maintained on the base so that testing could be conducted while the samples were still hot (Juliano et al., 1984). A two-cycle compression force versus time program was used to compress the samples to 90% of the original cooked grain thickness, after which the texture analyzer was returned to the original position before performing the second compression. A 20-mm diameter probe was used to compress 2-3 grains, with pre-test and post-test speeds of 1 mm min^{-1} and a test speed of 5.0 mm min^{-1}. Hardness was determined from the test curves. The textural analyses were replicated 10 times per sample.

2.5. Thermal properties

The gelatinization characteristics of the white rice were determined using differential scanning calorimetry (TA-60WS, Shimadzu, Kyoto, Japan). Ground samples (approximately 3.5 mg, d.b.) were weighed directly in an aluminum pan (Mettler, ME-27331), and distilled water was added to obtain a suspension of 70% water. The pan was hermetically sealed and allowed to equilibrate for 1 h before analysis. An empty pan was used as a reference. The sample pans were then heated from 10 to 140 °C at a rate of 10 °C min^{-1}. The temperature at the onset of gelatinization (T_o), the temperature at the peak (T_p), the temperature at the conclusion (T_c) and the gelatinization enthalpy (ΔH) were determined.

2.6. Pasting properties

The pasting properties of the white rice were determined using a Rapid Visco Analyser (RVA–4, Newport Scientific, Australia) using a Standard Analysis 1 profile. The viscosity was expressed in rapid visco units (RVUs). Ground rice (3.0 g, 14% wet basis) was weighed