Journal of Stored Products Research 78 (2018) 89–97

Contents lists available at ScienceDirect

Journal of Stored Products Research

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

Impacts of storage temperature and rice moisture content on color characteristics of rice from fields with different disease management practices

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ARTICLE INFO

Article history:
Received 12 June 2018
Accepted 6 July 2018

Keywords:
Long-grain rice
Discoloration
Mold growth
Rice chilling/cooling
Disease management

ABSTRACT

Rice downgrading due to discoloration in storage presents a significant loss to growers and processors. The objective of this study was to investigate impacts of storage temperature and rice moisture content (MC) on color characteristics of milled hybrid rice (cv. XL 745) from fields with differing production practices. Freshly-harvested rough rice from field plots treated with and without fungicide for rice disease control during production were procured and stored at four MC levels (12.5%, 16%, 19% and 21% wet basis), and at five temperatures (10 °C, 15 °C, 20 °C, 27 °C, 40 °C) for 16 weeks, with samples taken every 2 weeks. Kinetics of mold growth and rice color were determined. It was observed that at 12.5% MC, discoloration was abated across all studied temperatures and treatments until 6 weeks of storage and increased not in excess of 20% thereafter 16 weeks. As the storage MC increased to 16%, discoloration increased and became significantly notable at the highest temperature of 40 °C. By week 16, at 40 °C storage temperature, discoloration increased significantly to 87.9% and 73% for sample lots from fungicide and non-fungicide treated plots, respectively. At the highest MC (21%), increase in rice discoloration was notable as early as after 2 weeks, across all storage temperatures, and continued to increase, especially for the highest storage temperature of 40 °C, to as high as 99.1% and 96.47%, after 16 weeks, for sample lots from fungicide and non-fungicide treated plots, respectively. There was more expression of discoloration patterns on samples stored at the highest temperature of 40 °C compared to that at lower temperatures, for both categories of sample treatments and ranges of studied MCs. Although not yet widely used for rice, this study suggested that cooling technology for rice, may have potential to extend rice storability, especially by retarding discoloration in the first few weeks after harvest.

1. Introduction

The long-term goal of this study is to provide science-based knowledge to inform improved regional and national food security and safety, especially for rice, through the control of foodborne hazards and to further evaluate and develop economical and adoptable control strategies that are aimed at reducing incidences of foodborne hazard(s) related to rice and to boost rice growers' returns (Harein and Meronuck, 1995; Atungulu et al., 2015; Shafiekhani et al., 2016).

One of the main factors contributing to spoilage of rice in storage is microbial development. Therefore, proper pre-harvest and post-harvest management of the rice is crucial to maintain the grain quality and safety (Misra and Vir, 1991; Maier, 1994; Grolleaud, 2001; Smith and Dilday, 2003). This study especially targeted answering questions raised by rice growers and processors who use on-farm, in-bin storage systems. The primary questions raised by these growers and processors pertain to the safe storage temperature and moisture content (MC) of rice to maintain milling yields and overall quality of processed rice. Another question asked by the growers is whether economic input to rice disease management measures such as fungicide application during growth carries with it any benefits to post-harvest rice quality during storage on-farm.

The on-farm, in-bin rice storage systems use natural air for conditioning or drying rice; if not managed properly, the rice processed using the system is prone to promote the development and contamination of the grain with mold which may lead to severe

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https://doi.org/10.1016/j.jspr.2018.07.001

quality deterioration (Singaravadivel and Raj, 1983; Sahay and Gangopadhyay, 1985; Phillips et al., 1988). The on-farm, in-bin rice conditioning or drying system usually involves use of a fan (often more than one) to mechanically push ambient air through a rice column, from the bottom to the top of the bin. As the ambient air moves vertically through the rice column inside the bin, the ambient "air quality" or equilibrium moisture content (EMC), which defines the capability of air to hold moisture at set conditions of temperature and relative humidity, determines the extent to which grain of a given MC gains or loses the moisture. In cases where the grain is dried and then stored in the same bin, the duration required for the natural air in-bin drying, generally 2–4 weeks or even longer, is directly affected by local weather conditions, which sometime may not be conducive for complete drying, especially for upper layers of rice (Atungulu et al., 2014). When drying is incomplete, rice, especially that stored in the upper layers, remains at high MCs for prolonged durations leading to extensive microbial activity, dry matter loss, and hence reduction in overall rice quality - particularly rice kernel color. Rice downgrading due to discoloration presents a significant loss to growers and processors.

The Federal Grain Inspection Service (FGIS) of the United States Department of Agriculture Grain Inspection, Packers and Stockyards Administration assigns grades to rice based on the number of discolored or otherwise unacceptable kernels in a sample. U.S. No. 1 grade milled rice may contains, at maximum, only one "heat-damaged" kernel per 500-g sample (USDA, 2009). This low threshold can have a large impact on growers' and/or processors' profits if their rice exceeds the number of "heat-damaged" kernels permitted. To minimize the issues of rice discoloration, the trend among many rice growers in the U.S., in recent years, has been adoption of a recently-introduced technology for on-farm, in-bin rice drying, chilling and storage. The new technology allows controlling fan operation by the principle of EMC. Thus, fans used to blow air used to condition and/or drying the grain are operated only under set conditions to avoid over-drying or rewetting of the grains. The new technology comprises sensors to measure ambient air conditions, as well as cables to monitor grain MC and temperature throughout the grain bin mass, and the data can also be accessed anytime via the internet; this, just like other automated practices in agriculture (Shafiekhani et al., 2017), has revolutionized monitoring capabilities for the in-bin storage process. From an electronic monitor and fan control standpoint, this new technology appears very promising. However, the ultimate success hinges on effectively maintaining the quality of stored rice, especially those in the upper bin layers.

Kinetics of mold growth and rice quality deterioration, especially discoloration of kernels, have been reported for environmental condition and MCs regimes typical of on-farm conditioning of rice in bin storage systems in Arkansas (Atungulu et al., 2016; Siebenmorgen and Haydon, 2017). Surprisingly, even for some rice kernels with low MC at cool temperatures, some sort of discoloration was still detectable. Also variegated patterns of discoloration for kernels stored at the same temperature and MC conditions have been reported (Siebenmorgen and Haydon, 2017). The reason why some kernels were susceptible to discoloration has not be clarified (Schroeder, 1963); there are speculations that microbes might have a role in the discoloration of the kernel (Gilman and Barron, 1930; Baldacci and Corbetta, 1964; Phillips et al., 1988; Bason et al., 1990); this begs the question of whether some sort pre-harvest disease control measures such as fungicide treatment of rice might diminish microbial activity to some extent leading to better control of rice quality postharvest, in-bin storage.

The specific objective of this study was to determine links among mold growth and prevalence on rice, and the rice kernel discoloration during storage at various storage condition of temperature and rice MC; for rice lots from fields differing in disease management practices.

2. Materials and methods

2.1. Rice samples procurement and preparation

Hybrid long-grain rice cultivar CLXL745 was used in this experiment. The rice was grown in 2016 in two commercial rice fields located in Pocahontas, Arkansas. In one of the rice fields, the rice was treated with fungicide Quilt-Xcel at the rate of 17 Oz/acre sprayed during the late boot stage (Norman et al., 2010), henceforth reported as treated field/sample (or with fungicide treatment). The second rice field had no fungicide administered, henceforth reported as control field (or without fungicide treatment). The rice were harvested at 22% MC in wet basis (w.b.). Henceforth MC is in w. b. unless otherwise stated. Harvested rice from each plot (treated and control) were cleaned with a dockage tester (Model XT4, Carter-Day, Minneapolis, MN). Afterward, the cleaned rice (treated and control) was divided into four sub lots in which each of the sub lots were conditioned to MCs 12.5%, 16%, 19%, and 21%. The samples were gently dried in conditioned environment (26 °C, 56% relative humidity) to the desired MC. The MC of the samples was confirmed following the procedure by the American Society of Agricultural and Biological Engineers (ASABE) standard S352.2 which involves putting 15-g of the samples in an oven set at 130 °C for 24 h.

After conditioning and/or drying the rice to the desired MC levels, the samples were immediately placed in individual well labeled sealed quart-sized, glass containers and then transported to five separate temperature environments 10 °C, 15 °C, 20 °C, 27 °C and 40 °C. The chosen environments consisted of a combination of one incubator (BINDER Inc., Bohemia, NY) for samples stored at 40 °C, one conditioning chamber for 27 °C samples and three refrigerators for 10 °C, 15 °C and 20 °C samples. The samples were stored for a period of 16 weeks and collected every two weeks except after week 12, when the rice samples were stored for a continuous period of four weeks. Samples were also pulled out on the first day of storage (henceforth regarded as 0-week sample) for analysis.

2.2. Analysis of rice kernel discoloration pattern

2.2.1. Sample preparation for analyses

After the samples were removed from the storage, they were placed on a metal screen (thin layer) in the conditioning chamber (AA5582, Parameter Generation and Control, Inc., Black Mountain, NC) to gently dry to 12.5% MC. This was to ensure that all the samples MC were standardized for subsequent analysis. 150-g sub-samples from each dried sample were dehulled with an impeller husker (Model FC2K, Yamamoto, Yamagata, Japan), then milled with a laboratory mill (McGill No. 2, RAPSCO, Brookshire, TX). After milling, the sub-samples were aspirated to remove excess bran, and sorted into whole kernels and broken kernels. Whole kernels were regarded as rice kernels with at least ¾ of the length of a whole kernel. Subsequent analysis were performed on the milled whole kernels. All experiments were duplicated.

2.3. Color measurement

The color of the whole rice kernels was measured using an image analysis system (WinSEEDLE Pro, 2005a™, Regent Instruments Inc., Sainte-Foy, Quebec, Canada). The system comprises of acrylic tray sample holder (152 mm × 100 mm x 20 mm), scanning bed with blue background lid and software provided by the manufacturer installed on auxiliary desktop computer. The