Journal of Stored Products Research 69 (2016) 235–244

Contents lists available at ScienceDirect

Journal of Stored Products Research

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

Storage of hybrid rough rice – Consideration of microbial growth kinetics and prediction models

Griffiths G. Atungulu*, Supriya Thote, Shantae Wilson

Department of Food Science, University of Arkansas Division of Agriculture, 2650 N Young Avenue, Fayetteville, AR 72704, USA

ARTICLE INFO

Article history:
Received 30 August 2016
Accepted 19 September 2016

Keywords:
Hybrid rough rice
Storage
Microbial growth
Prediction models

ABSTRACT

The objective of this study was to determine kinetics of mold growth on popularly grown hybrid long-grain rough rice during storage at conditions that simulate delayed drying and prolonged storage. Three long-grain hybrid rice cultivars, XL753 (2014) and CL XL745 (2014, 2015) and XL760 (2015) conditioned to four different moisture contents (MCs) (12.5%, 16.0%, 19.0%, and 21.0% wet basis) were stored in rough rice form at temperatures ranging from 10 °C to 40 °C for a period of 16 weeks. The study was repeated using rice from two consecutive crop seasons, 2014 and 2015. For all cultivars, a direct relationship between mold counts and rice MC was observed – whereas more complex trends were observed for the effect of temperature and the duration of storage on mold growth. Kinetic models including Baranyi, Weibull, Gompertz, Richard and Buchanan were successfully modified and fitted using non-linear regression and used to predict the mold counts ($\log_{10}$ CFU/g) for varying conditions (correlations = 0.65–0.76). The study concluded that long-grain hybrid rough rice could be stored at low MC levels (≤17%) and moderate temperatures (≤27 °C) for up to 6 weeks without any change in the mold growth profile. However, storing rice at high MC (>17%) for more than 8 weeks, especially at higher (>27 °C) temperatures should be avoided due to the potential for high mold activity leading to loss of the grain quality.

1. Introduction

Optimal milling yield and quality of rice is maintained at rice harvest moisture contents (MCs) ranging between 19 and 21%, wet basis. At such high harvest MCs, the grain is prone to heating which arises from excessive respiration of the grain itself and associated microorganisms and pests; this leads to rapid deterioration of the grain quality (Harein and Meronuck, 1995; Atungulu et al., 2015). Typically, the rate of proliferation of microorganisms and pests in the grain storage ecosystem is dependent on the grain water activity, grain temperature, and storage duration (Lacey and Magan, 1991; Mutters and Thompson, 2009). Therefore, timely and proper drying of the grain to safe storage MC and temperature is very important to minimize quality reduction (Skyrme et al., 1998; Lee, 1999; Ranalli and Howell, 2002; Atungulu et al., 2015).

Normally, the rice harvesting "window" is relatively short. The harvest period is also characterized by warm and humid conditions that favor proliferation of microbes and pest within the grain storage ecosystem. Timely scheduling of postharvest operations by rice producers is vital to minimize the grain quality. In the recent past, annual rice yields per acre have been on the increase; this is largely due to efforts by breeding programs to increase productivity and meet food demand. Development in rice harvesting technology has also increased the speed at which rice can be harvested; and along with larger and faster grain carts, trucks, and trailers for transporting rice from combines to driers, a much greater rice delivery rate to driers is typical within the short rice harvesting "window". Unfortunately, the rice drying infrastructure has not grown at the same rate as that of delivery at commercial drying facilities. In such instances, temporary "wet holding" (delayed drying) of rice has become inevitable; this possess a lot of challenge, particularly for rice coming in at high initial loads of microorganism and pest.

The goal of this research was to provide useful information that could aid development of proper postharvest management practices for hybrid long grain (HLG) rice. Morphologically, HLG rice has a pubescent characteristic and is very morphologically distinct from conventional long-grain pureline and medium-grain rice. This study hypothesized that the pubescence on the rice may predispose

* Corresponding author.
E-mail address: atungulu@uark.edu (G.G. Atungulu).

http://dx.doi.org/10.1016/j.jspr.2016.09.003

it to harbor and support microbial and pest growth in a manner different from non-pubescent rice (Atungulu et al., 2015); this morphological distinctiveness necessitated, as a first step, an investigation of the interactions among storage microorganisms, storage pests and the grain within the storage ecosystem.

In the last decade, HLG rice has become very popular among United States rice growers. The primary reasons behind this surge in popularity include the potential for high rice yields, high resistance to disease, and short growing seasons (Nalley et al., 2014). A Significant amount of research effort has been dedicated to studying insect infestations and control for rough rice (RR) storage. Skyrme et al. (1998) and Ranalli and Howell (2002) characterized molds and APCs on rice during storage, but largely for long- and medium-grain varieties. By and large, the greatest challenge to rice safety during storage a rises from the potential of toxigenic mold contamination which under certain conditions may produce substances called mycotoxins. Some mycotoxins pose a significant public health risk and lead to huge economic losses.

Few studies, if any have focused on identifying and enumerating mold counts or determining aflatoxin growth kinetics for stored HLG rice (Jayas et al., 1994; Wawrzyniak et al., 2013; Atungulu et al., 2015). With the recent rise in the use of in-bin drying systems for HLG rice, there is increased need to generate relevant data to support development of models for predicting microbial kinetics during the rice drying and storage; this is particularly important to ensure that critical drying and storage regimes that ensure safety of rice are maintained. An immediate application of such information is in optimization of on-farm in bin drying of rice using recently-introduced “cabling and sensing technology”. The new technology uses the concept of equilibrium moisture content to monitor grain MC and temperature and achieve automated fan control during natural air in-bin drying and storage of the rice. The duration required for 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 (delayed), rice, especially that in the upper layers, remains at high MCs for prolonged durations leading to excessive rice respiration, microbial activity, dry matter loss, and hence reduction in overall rice quality. At present, the allowable duration rice can remain at high MC during on-farm, in-bin drying is under-researched and is vaguely determined, in part based on dry matter loss guidelines from corn-related research – typically recommended not to exceed 0.5% (Reed et al., 2007). What is not known is the extent to which using the dry matter loss guideline, which does not account for rice types, effectively prevents mold proliferation or production of mycotoxin on rice during natural air in-bin drying and storage. In the absence of such knowledge, on-farm rice drying and storage with natural air will likely remain susceptible to contamination with toxigenic fungi and their associated mycotoxins, many of which are carcinogenic to humans.

Based on literature survey, Buchanan three-phase linear, Gompertz, Richards, Weibull and Baranyi model for microbial growth have been used to successfully predict mold growth kinetics (López et al., 2004). New data describing microbial growth kinetics for HLG rice could be fitted to these existing models to determine suitability for predicting microbial growth kinetics over a wide range of storage conditions encountered in actual field scenarios. Such information will be vital in development of post-harvest processing and storage guidelines for safe storage of rice, especially for the HLG rice cultivars.

The specific objectives for this study were to determine (1) kinetics of mold growth on HLG rice at different MCs and storage temperatures; (2) mathematical models that best describe the kinetics of the mold growth; and (3) safe storage conditions for HLG rice by considering the activity of mold growth during storage.

2. Materials and methods

2.1. Samples

Freshly-harvested rice was procured from rice fields located in Arkansas. Two HLG rice cultivars, CL XL745 from Running Lake Farms near Pocahontas, AR and XL753 from Keiser, AR (University of Arkansas, Research Station) were harvested in 2014 (Year 1, Table 2) at approximately 22% MC wet basis (w.b.). All MCs for this study are expressed on a w.b. unless otherwise stated. For the year 2015 (Year 2, Table 2.), HLG cultivars, CL XL745 and XL760 were harvested from Running Lake Farms near Pocahontas, AR at approximately 22% MC w.b. The rice samples were then cleaned to remove chaff and foreign matter using a dockage tester (Model XT4, Carter-Day, Minneapolis, MN) and then conditioned to four initial MC levels (12.5%, 16%, 19% and 21%) by placing the rice on a tarp at room temperature. The MC was monitored periodically during this drying step by a moisture tester (AM 5200, Perten Instruments, Hägersten, Sweden). After conditioning the rice to the set MC levels, the rice samples were immediately stored in individual quart-sized, glass containers (mason jars) to prevent significant alterations of their initial MCs 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 three Parameter Generation and Control (PG&C, Black Mountain, NC)) units, including one PG&C unit maintaining the environment of a walk-in equilibrium moisture content (EMC) chamber, one walk-in refrigerator and, one incubator (BINDER Inc., Bohemia, NY). The jars were stored for a period of 16 weeks and sampled every two weeks except after week 12, when the rice samples were stored for a continuous period of four weeks. The same sampling protocol was followed during 2015. A total of 56 jars (4 MC × 2 cultivars × 7 storage durations) were placed in each of the environmental units, resulting in a total of 280 experimental units for each of the two years. The experimental design is illustrated by Table 1.

2.2. Temperature monitoring

The temperature of the chosen storage environments was monitored by placing two temperature sensors (HOBO™ Pro v2, Onset Computer Corp., Bourne, MA) in each of the five environmental units. These sensors recorded the temperature every 5 min throughout the storage period.

2.3. Moisture content measurement

To determine the rice sample MC, the HLG RR stored in jars was removed from the storage environments and placed at room temperature conditions where they were allowed to equilibrate for at least 24 h before removing samples for MC determination. The MC of each sample was measured in duplicate by placing a 15 g sample into a 130 °C convective oven (Shellblue, Sheldon Mfg., Inc., Cornelius, OR) for 24 h followed by cooling in a desiccator for at least half an hour (Jindal and Siebenmorgen, 1987). The measured MC values were within 1.5 percentage point of the set value. Table 2 provides the MC values obtained using the oven method.

2.4. Water activity measurement

The water activity for the 2015 cultivars (CL XL745 and XL760) was measured using a water activity meter (AquaLab Pre, Decagon Devices, Pullman, WA). The measurements were performed in duplicate. Fig. 1 provides the linear regression for the measured