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EFFECTS OF CONTROLLED ATMOSPHERES FOR INSECT CONTROL AND QUALITY PRESERVATION OF MILLED RICE USING THREE WAYS TO REDUCE OXYGEN

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ABSTRACT

Milled rice is a staple food for more than 60% of the world's population, especially in Asia. As a primary dietary source of human nutrition, milled rice plays an important role in meeting energy requirements and nutrient intakes. It is necessary for a country to store adequate milled rice to ensure the elementary living and the food safety. However milled rice is one of grain varieties which is the most difficult to storage and fresh-keeping. Aging, damage caused by pest and mould are main problems of milled rice during storage. Aiming at these main problems, the field experiment of milled rice under controlled atmospheres storage for stored grain insect control and quality preservation were undertaken in Guangdong Province, P. R. China. The purpose of this trial was to determine if three ways to reduce oxygen (O_2), including treatments of filling nitrogen (N_2), using deoxidizer and N_2+deoxidizer, could reduce and maintain the quantity of O_2 low enough and long enough to control stored grain insects and keep the quality of milled rice stored bag-stacks sealed in plastic enclosures. The results showed that all of three ways had reduced O_2 content inside the sheeted bag-stacks to lower than or about 2% since 1 week after treatment. Under controlled atmosphere for 3 months at the room temperature, tested stored grain insects, *Rhyzopertha dominica* (Fabricius), *Sitophilus oryzae* (Linnaeus), *Tribolium castaneum* (Herbst), were killed. The quality changes in senses indices, color changing, moisture content, acidity and tasting assessment value of milled rice treated were similar to those of untreated as a control, but milled rice treated made an increase to the cooking and eating qualities. It means the controlled atmospheres using three ways to reduce O_2 have effects on controlling stored grain insects and keeping rice quality. Among three ways, using deoxidizer is the lowest costs. The results will provide useful information for milled rice storage.

Key words: milled rice, controlled atmospheres, rice storage, quality preservation, *Rhyzopertha dominica* (Fabricius), *Sitophilus oryzae* (Linnaeus), *Tribolium castaneum* (Herbst)

INTRODUCTION

Rice (*Oryza sativa* L.) is a staple food for more than 60% of the world's population, especially in Asia. As a primary dietary source of human nutrition, milled rice plays an important role in meeting energy requirements and nutrient intakes (Park et al, 2012). In recent years, as the natural disasters and other emergencies occur frequently, it is more and more important for a country to store adequate milled rice to ensure the elementary living, emergency supplies of food and maintaining social stability. However, milled rice is one of grain varieties which is the most difficult to storage and fresh-keeping (Wang and Zhou, 2005). Due to having had its bran and hull layers removed by milling, and being directly exposed to the air, milled rice is more susceptible to insects and mould with changes in physicochemical and sensory-properties to speed up (Kim et al, 2000; Zhang et al, 2003). Aging, damage caused by pest and mould are important problems during storage of milled rice (Noomhorm et al, 1997). Over the years, grain reserves are mainly in raw grain, such as paddy and wheat, and there are relatively few studies on the theory, technology, equipment and facilities of milled rice storage. Therefore, safe storage of milled rice is now a challenge.

The conventional milled rice storage and fresh keeping technologies include storage at room temperature, storage at low temperature, controlled atmospheres storage and storage by chemical methods in and out of the country(Wu et al, 2008; Qu et al, 2009; Yang et al, 2010). With increasing concerns about health and environmental safety, consumers demand for chemical-free and insect contamination-free products is a general tendency. Controlled atmospheres storage used in milled rice is one of green grain storage technology devoting major efforts to developing (Gao and Xie, 2007; Zhu et al, 2010).This technology involves the alteration of the natural ratio of the atmospheric gases, oxygen (O_2), nitrogen (N_2) and carbon dioxide (CO_2), to render the atmosphere in stores unfavourable to pests (Annis, 1990; Banks and Fields, 1994; Adler et al, 2000; Conyers and Bell, 2007). It can inhibit the respiratory of insect pests and reduce the consumption of dry matter inside milled rice, thus effective control pests and to keep grain quality (Navarro, S.2009). The field experiments of milled rice under controlled atmospheres storage for stored grain insect control and quality preservation were undertaken in Guangdong Province, P. R. China. The purpose of this trial was to determine if three ways to reduce oxygen (O_2), including treatments of filling nitrogen (N_2), using deoxidizer and N_2+deoxidizer, could reduce and maintain the quantity of O_2 low enough and long enough to control stored grain insects and keep the quality of milled rice stored bag-stacks sealed in plastic enclosures.

MATERIALS AND METHODS

Bag-stacks preparation

The trials were undertaken at Xintang Grain Depot, Zengcheng City Grain Bureau, Guangdong Province, P. R. China in 2011. Bag-stacks stored milled rice was produced in location, belonging to long grain rice. The moisture content was 14%±1%.

Four bag-stacks of milled rice sealed in plastic enclosures were prepared for four kinds of treatment of controlled atmospheres, respectively for filling nitrogen (N_2), using deoxidizer, N_2+deoxidizer and blank-control. Each stack with 1 tone of 15kg bagged milled rice was sealed on six-sides with a new nylon composite film, which made from five-layers polyamide (PA) and polyethylene (PE) by co-extrusion. The covered film was 0.1mm thick. The size of each stack was about 1.4m^3 (L1.05∗W0.9∗H1.5m). 3 plastic tubes with 6mm internal diameter were inserted into the stack at various locations for filling N_2 gas into stack, releasing air from the stack and monitoring the O_2 concentration respectively. Each plastic tube had a switch.

Test insects

Three tested insect species of laboratory cultures were rice weevil (*S. oryzae*), lesser grain borer (*R. dominica*), and red flour beetle (*T. castaneum*). All insects were adults with age mixed, and were placed in the insect cages made of PVC pipe sections covered with screens at both ends. 30 adults of each specie with feed were placed in a insect cage as one replicate. There were 5 replicates for each insect species, with three species for each stack. The insect cages were inserted at various locations at a stack.

Gas-tightness

According to Van and Annis (1990) and the standard of "Technical regulations for controlled atmosphere storage of grain by purging carbon dioxide" (LS/T 1213-2008), set by The Chinese State Administration of Grain, application of vacuum revealed that a negative pressure was measured for gas-tightness. It requests that time to half pressure increase (negative 500 to negative 250 Pa) was more than 240s for controlled atmosphere storage.

Before treated, each stack sealing with a film sheeting was pressure tested using a micro-manometer model DP2000 made by Shanghai Guigu Instruments Co., Ltd. The film was checked for the leaks, and any leaks need to be heat sealed.

Controlled atmospheres application

N_2 was gaseous in a pressurized cylinder with purity (V/V)≥99.9%, manufactured by Guangzhou Yuegao gas industries Co., Ltd. The deoxidizer in food grade was manufactured by Guangzhou Pinnigao food additives Co., Ltd.

For filling N_2 stack, the plastic tube inserted into the bottom layer of the stack was connected with a N_2 cylinder, while the plastic tube on the top layer was connected with a vacuum air pump, and the monitoring plastic tube in the middle was connected with a gas analyzer model PA-Zr-O_2/CO_2-L made by Witt-gasetechnik GmbH & Co KG. First, to operate the vacuum air pump, let the pressure inside the stack to reach negative 500Pa. Then, gaseous N_2 from a cylinder installed a pressure reducing valves was introduced to the stack through the plastic tube at a constant rate, until O_2 concentration of 2% was reached and the pressure inside and outside the stack was balanceable.

For using deoxidizer stack, 1200g deoxidizer were place on the top of stack, the plastic tube inserted into the bottom of the stack was turned off the switch, the other two plastic tubes were connected with those as the same of filling N_2 stack. After operating the vacuum air pump and pumping gas to -500Pa, stop operating.

For using N_2+deoxidizer stack, 400g deoxidizer were place on the top of stack, three plastic tubes were connected with those of the same as filling N_2 stack. The operations were also like those of the filling N_2 stack, but the O_2 concentration just reached 5%.

For blank-control stack, no to fill N_2, no to use deoxidizer and no to pump gas, just to insert a monitoring plastic tube on the middle to measure the O_2 concentration.

Controlled atmospheres procedure

During the entire controlled atmospheres storage period, the temperatures of stored milled rice were recorded at a frequency of one hour with a data logger model RC-1+ made by Shanghai Jingchuang Electronics Co., Ltd, that can be inserted in the bag stacks in the central zone. The O_2 concentrations within the stacks were sampled daily and were monitored by a gas analyzer model PA-Zr-O2/CO2-L.

Post controlled atmospheres

At the end of 3 months of controlled atmospheres storage, milled rice quality and insect mortality were assessed for each stack. Samples of milled rice were collected from three different bag (top, middle and bottom) using a probe in each stack, and were placed in plastic bags with hermetic sealing and taken to the laboratory. The analyzed parameters were the senses indices, color changing, moisture content (m.c.), acidity, tasting assessment value, cooking and eating qualities and so on, using the Chinese national standards methods according to GB5492-2008, GB5517-85 and GB/T15682- 2008. Insect cages were taken to the laboratory to observe. When insect mortality was recorded in the blank control stack, the adjusted mortality for the treated stacks was computed using the Abbott's formula.

RESULTS AND DISCUSSION

Gas-tightness

Four stacks were pressure tested. Time to half pressure increase (negative 500 to negative 250 Pa) was above 300s for all stacks. It means all treatment stacks had good gas-tightness.

Grain temperature

During the trials the temperatures of the milled rice were normal. The grain temperatures in the stacks were between 24.8-32.5°C, average temperature was 28.9 °C.

O_2 concentration

The O_2 concentration curves during controlled atmospheres storage was shown in Fig.1. The results showed that all of three ways had reduced O_2 content inside the sheeted bag-stack to lower than or about 2% since 1 week after treatment. The O_2 concentrations in the stacks of filling N_2, using deoxidizer and N_2+deoxidizer, were respectively 2.35%, 1.84% and 1.52% at that time. Subsequently, the O_2 concentrations in treated stacks become calm. At the time of 7 weeks after treatment, the O_2 concentration was 0.90% for filling N_2 stack, 0.8% for using deoxidizer stack and 2.63% for using N_2+deoxidizer stack. Based on these results, the O_2 concentrations were maintained lower than or about 2% for at lease 7 weeks, and reached controlled atmosphere storage requirements.

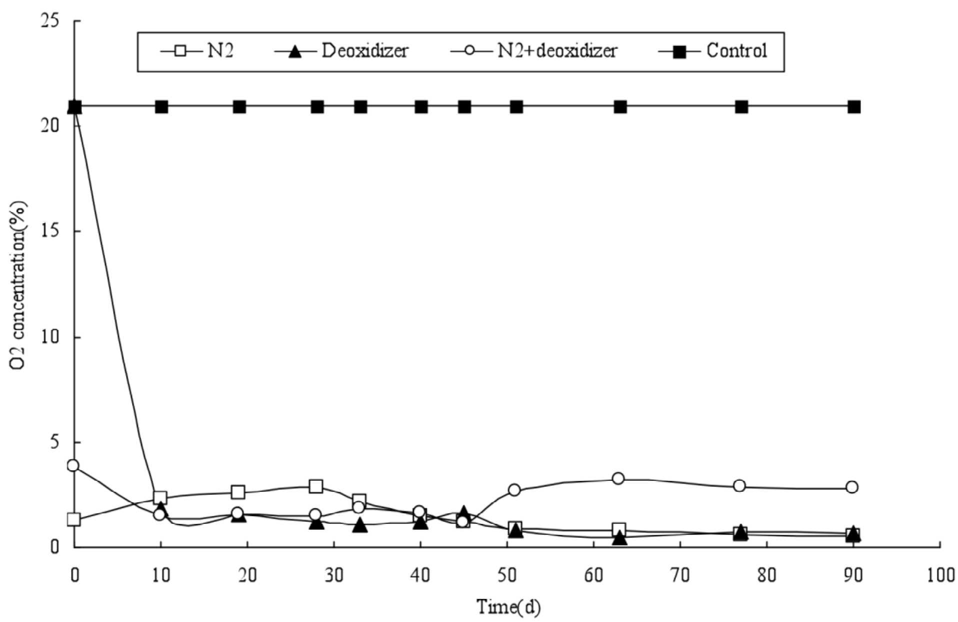

Fig.1- Concentrations of oxygen measured during controlled atmospheres of milled rice

Insect control

The population suppression results for three tested insect species were 100% (Table 1). Under three controlled atmosphere storage for 3 months at the room temperature, no live insects were found in any of the treated insect cages inspected in the laboratory. There were 86, 78 and 1373 live insects of *R. dominica*, *S. oryzae* and *T. castaneum* in insect cages of blank-control stack, respectively. The results showed that three ways to reduce O_2, including filling N_2, using deoxidizer and N_2+deoxidizer, could control stored grain insects well.

Table 1. Population suppression effect of controlled atmospheres using 3 ways to reduce O_2 on stored grain pests

Treatments	Number of live insects			The rate of suppression(%)		
	R. dominica	*S. oryzae*	*T. castaneum*	*R. dominica*	*S. oryzae*	*T. castaneum*
N_2	0±0 a	0±0 a	0±0 a	100	100	100
Deoxidizer	0±0 a	0±0 a	0±0 a	100	100	100
N_2+deoxidizer	0±0a	0±0a	0±0 a	100	100	100
Control	86±10 b	78±11b	1373±105			

* Means followed with same letters in the same insect species within the same column are not significantly different at 0.05 level by Duncan's multiple range test.

Quality of milled rice

Tables 2 and 3 showed the results of quality changes of milled rice under different controlled atmosphere storage for 3 months. In Table 2, the quality changes in appearance, yellow-colored rice, m.c., acidity and tasting assessment value of milled rice treated were similar to those of untreated as a control. In Table 3, milled rice treated made an increase total score to the cooking and eating qualities. It means the controlled atmospheres using three ways to reduce O_2 have effects on keeping rice quality under sheeted bag-stacks.

Table 2. Effects of controlled atmospheres for 3 months using 3 ways to reduce O_2 on milled rice quality

Treatments	Odour	Yellow-colored rice %	Moisture content %	Acidity ml/10g	Tasting assessment value
N_2	Normal	0.6	13.9	0.45	75
Deoxidizer	Normal	0.5	14.0	0.41	76
N_2+deoxidizer	Normal	0.4	13.7	0.41	76
Control	Normal	0.5	13.5	0.43	73

Cost-benefit analysis

Based on the results obtained, the controlled atmosphere using three ways to reduce oxygen had not significantly different effects on controlling stored grain insects and keeping rice quality, so the focus here were to compare their using costs. Costs should include labor cost, equipment cost, cost of chemicals (N_2 and deoxidizer) used and so on. Calculated according to amount used in the trails, cost of N_2 used to the filling N_2 stack was RMB 23.6 ¥/m^3, cost of deoxidizer used to the using deoxidizer stack was RMB 13.7 ¥/m^3 and cost of N_2 and deoxidizer used to the using N_2+deoxidizer stack was RMB 16.4 ¥/m^3. It means that among three ways, using deoxidizer is the lowest costs.

Table 3. Effects of controlled atmospheres for 3 months using 3 ways to reduce O_2 on cooking and eating quality of milled rice

Treatments	Odour	Appearance and structure			Palatability			Taste	Texture of cold cooked rice	Total score
		Color	Gloss	Rice integrity	Viscosity	Elasticity	Softness and hardness			
N_2	16.2	5.2	5.6	4	7	7.2	7.2	18.4	4	74.8
Deoxidizer	16	5.2	5.2	4	7.2	7.8	7.8	19.2	4	76.4
N_2+deoxidizer	15.8	5.4	5.4	4	7.4	7.6	7.6	19.2	4	76.4
Control	16	4.8	5.8	4.2	6.8	6.8	6.6	18	3.8	72.8
Score	20	7	8	5	10	10	10	25	5	100

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