International Journal of Latest Research in Agriculture and Veterinary Sciences (IJLRAVS)
www.ijlravs.com
Volume 01 Issue 01 ǁ July – September 2022 ǁ PP. 34-44

The Influence of Three Different Storage Methods on the Quality of Middle and Late Indica Rice

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Abstract: Middle and late indica rice was stored for a year using three typical storage methods（nitrogen controlled atmosphere, quasi-low temperature and conventional storage）to explore the influence of different storage methods on the commercial quality. The results showed that for any of the above storage methods, with the extension of time, the quality of both middle and late indica rice changed. The fatty acid value and crack rate grew, while the milled rice rate, head rice yield and taste score dropped with the extension of storage time. After one-year storage, the fatty acid value of conventional storage increased by 7.5mg KOH/100g on a dry weight basis, the fatty acid value of nitrogen controlled atmosphere storage increased by 1.6 mg KOH/100g on a dry weight basis and the fatty acid value of quasi-low temperature storage increased by 1.2 mg KOH/100g on a dry weight basis. The increase of the fatty acid value of conventional storage was the highest, 4.7 times that of nitrogen controlled atmosphere storage, 6.25 times that of quasi-low temperature storage. The milled rice rate and head rice yield of conventional storage dropped by 8% and 5.8% respectively, the milled rice rate and head rice yield of nitrogen controlled atmosphere storage dropped by 4.7% and 2.8% respectively and the milled rice rate and head rice yield of quasi-low temperature storage dropped by 2.7% and 2.2% respectively. The differences in the milled rice rate and head rice yield were significant. The drop of quasi-low temperature storage was the smallest, followed by nitrogen controlled atmosphere storage. The drop of conventional storage was the greatest. Thus, nitrogen controlled atmosphere storage and quasi-low temperature storage can slow down the aging of grains. On the other hand, quasi-low temperature storage can retain water to a certain degree, which is beneficial to the safe storage of middle and late indica rice.

Keywords: middle and late indica rice; conventional storage; nitrogen controlled atmosphere storage; quasi-low temperature storage; quality

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1. Introduction

In 2018, the total rice production in China was 212.13 million tonnes, up 1.7% over 2017. Middle and late indica rice accounts for about 50% of the total rice production. The average storage time is 16 months (Zhengyou Luo, et al., 2004). The main purpose of middle and late indica rice is food for residents. With the rapid development of economy in an all-round way, people produce and consume middle and late indica rice no just to fill their stomach. They raise higher demands for the quality of rice(Yunrong Zhang. et al., 2009). Therefore, it appears to be particularly important to study storage methods that can maintain the commercial quality of middle and late indica rice.

Airtight storage has a long history in China. In the Tang Dynasty, there were already large-sized underground airtight storage silos. Controlled atmosphere storage of grains evolved from airtight storage. Nitrogen controlled atmosphere storage means that high-concentration nitrogen is separated from air and filled into a silo that meet airtight requirements through a gas pipe, for the purpose of replacing oxygen in the heaps, maintaining high-concentration nitrogen for a long time, creating an ecological environment that is adverse to the growth and reproduction of pests and molds and reducing the respiratory metabolism of grains (Table 1). China Grain Reserves Group has made great efforts to promote the application of nitrogen controlled atmosphere storage. By the end of 2015, more than 180 nitrogen controlled atmosphere storage depots had been built and the capacity was over 13 million tonnes.

Low temperature can inhibit the growth and reproduction of pests and molds, restrict the change in the quality of stored grains and improve the stability of grain storage. Through long-term research and practice, people believe that 15 ℃ is an ideal temperature for low temperature grain storage, which can effectively restrict the vitality of organisms and delay changes in the quality of stored grains. When the grains are stored at a temperature not higher than 20 ℃, this temperature not only has some of the effect of low temperature storage, but also reduces the operating cost of low temperature storage, while improving the benefits of low temperature storage, so it is also called quasi-low temperature storage. In China, low temperature storage means that the average temperature of heaps is maintained at 15 ℃ and below throughout the year and the highest local grain temperature is not higher than 20 ℃. While quasi-low temperature storage means that the average temperature of heaps is maintained at 20℃ and below throughout the year and the highest local grain temperature is not higher than 25 ℃. At present, quasi-low temperature storage is mostly achieved by mechanical refrigeration. Common refrigeration equipment includes grain coolers and air conditioners, etc. The quasi-low temperature storage process involved in this paper includes silo-wide cooling and surface air/conditioning using shallow geothermal energy (Table 1).

Table 1 Storage Techniques, Equipment and Facilities and Their Characteristics

Storage Technique	Main Equipment And Facilities	Characteristics
Nitrogen Controlled Atmosphere	Nitrogen generator 	Nitrogen is separated by pressure swing adsorption on a carbon molecular sieve.

	Air bag 	Single films commonly used in controlled atmosphere storage are polyvinyl chloride, polyethylene, polypropylene and other plastic films with a thickness of 0.07-0.40mm.
Shallow Geothermal Energy A/C	Outdoor unit  Indoor unit 	When air circulates in the silo, the heat in the silo is exchanged to the refrigerant of the low temperature storage equipment. The low temperature storage equipment heats up the refrigerant and exchanges heat with the circulating water. Then the heat is transferred to the circulating water. When the circulating water is circulated to the underground, it exchanges heat with the surrounding floor and the circulating water is cooled.

Conventional storage means that under natural climate conditions, the grains are mainly stored using general techniques and conventional management measures, such as cleaning, natural ventilation and regular inspection of grain conditions, etc.

So far, as internationally-acknowledged green storage techniques, controlled atmosphere and quasi-low temperature storages are the main forms of scientific grain storage and effective measures to maintain quality and retain freshness. Among them, nitrogen controlled atmosphere storage has been widely promoted and applied in State Grain Reserves in southern China (Sufen Gao, 2009), while low-temperature storage just forms a certain scale for the storage of finished grains, due to its high airtight requirements for silos and high operating cost (Changqiong Xiang, et al., 2015). The storage of raw grains is mostly conducted by quasi-low temperature storage. In this paper, we track and explore the change rules of the commercial quality of middle and late indica rice with three different storage methods, nitrogen controlled atmosphere storage, quasi-low temperature storage and conventional storage, with a view to provide a scientific basis for the safe storage of middle and late indica rice.

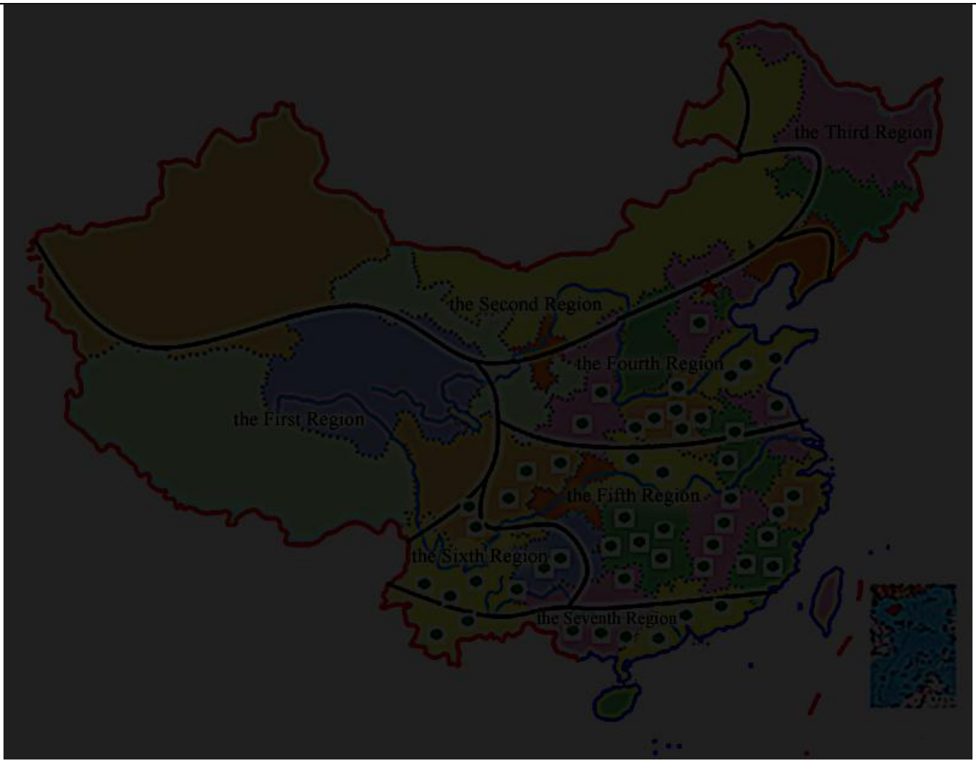

Figure. 1 The Distribution of Nitrogen Controlled Atmosphere Storage Silos Built by China Grain Reserves Group (2012)

2. Materials and Methods

2.1 Test Conditions

Conventional storage: to be stored under normal conditions without any other measures.

Nitrogen controlled atmosphere storage: more than 90% of grains were subject to nitrogen controlled atmosphere storage from April to November in 2018.

Quasi-low temperature storage: after the grains were put into storage, silo-wide cooling was given immediately to remove heat in the heaps. In summer, both silo-wide cooling and space A/C would be used. The silo temperature was kept below 20°C throughout the year.

2.2 Test samples

The grains put into storage were middle and late indica rice which was newly harvested in 2017 and sampled every 3 months according to GB/T 5491-1985.

2.3 Sampling method

The grain surface is divided into five points, each area does not exceed 50 m^2, each district has five points at the center and four corners. The number of districts is two or more, the two points on the boundary of the two districts are sharing points, and the points on the edge of grain mass is about 0.5m away. The grain mass is 6 m high, with 4 layers for each sampling point. The upper layer is 0.5 m below the grain surface, the middle layer is 2.0 m and 3.5 m below the grain surface, and the bottom layer is 0.5 m above the bottom. The amount of samplings per layer at each cutting point is no less than 100 g.

The test period was from November 2017 to December 2018 and the test cycle was 12 months.

2.3 Instruments

The testing instruments included a rice husker (JLG-II, Chengdu Reserves, China Grain Reserves) for testing, a rice mill (JNM-III, Chengdu Reserves, China Grain Reserves) for testing, a rice polisher (LTJM160, Shanghai Qingpu Oasis Testing Instrument Co., Ltd.), an electro-thermostatic blast drying oven (XMTD-8000, Chengdu Shengjie Technology Co., Ltd.) and an electronic balance.

2.4 Main indicators

Moisture, fatty acid value, husked rice yield, head rice yield, milled rice rate, crack rate and taste score.

Water moisture was determined according to GB 5497-85 "Inspection of grain and oilseeds methods for determination of moisture content"; yellow-colored rice and crack kernels were determined according to GB/T 5496-1985 "Inspection of grain and oilseeds methods for determination of yellow-colored rice and crack kernels "; Tasting score was based on GB/T 15682-2008 "Inspection of grain and oils method for sensory evaluation of paddy or rice cooking and eating quality"; Color and odor were based on GB/T 5492-2008 " Inspection of grain and oilseeds identification of colour,odour and taste of grain oilseeds". Fatty acid value was determined according to GB/T 20569-2006 “Guidelines for evaluation of paddy storage character”

The rice yield is the percentage of the weight of rice bran to the weight of paddy sample after removing bran layer (including pericarp and aleurone layer) and seed embryo after milling by rice mill, and then removing the bran through circular hole sieve with diameter of 1.0 mm. That is, the percentage of finished rice, broken rice, heterochromatic grains (removing the residue of rice husk and bran, white rice flour) to the consumption of raw grain

3. Results and Analysis

3.1 Changes in the moisture content

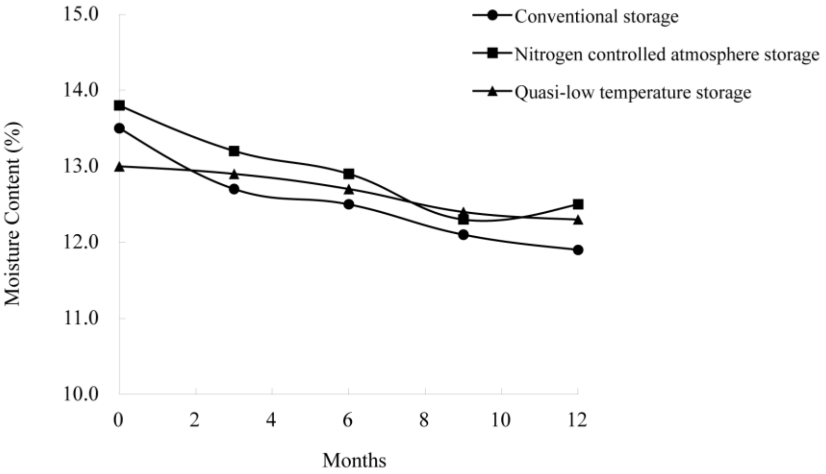

Figure. 2 Changes in the Moisture Content of Middle and Late Indica Rice during Storage

The moisture was determined using 105℃ constant weight method. The samples were dried at a temperature of 105±2℃ to constant weight (the actual rangeability can be ±0.005g). The difference between weights before and after drying was exactly the weight of moisture. The moisture loss not only affected taste, but also seriously affected the economic benefits of storage companies. How to retain water and increase efficiency has always been a research topic for storage companies. From **Fig. 2**, it can be seen that with the extension of storage time, for all of the three storage methods, the moisture in heaps presented a slow downward trend. After grains were put into storage, their respiration warmed up the heaps. Under this circumstance, either dissipating the hot air or cooling and ventilating with the natural dry cold air in winter would reduce the moisture content. In the quasi-low temperature silo, after the grains were put into storage, the grain temperature was controlled with shallow geothermal energy, which can effectively dissipate heat, while maintaining the original moisture. Only some of the moisture was lost during the ventilation in winter. Previous studies have shown that storage temperature can affect the moisture content of rice. When the temperature was low, there was little heat and moisture exchange and the moisture content fell slowly. When the temperature was high, the heat and moisture exchange accelerated and the moisture content fell sharply (Xuqiang Shu, 2004). Therefore, low temperature was an effective measure to reduce the moisture loss.

3.2 Changes in fatty acid value

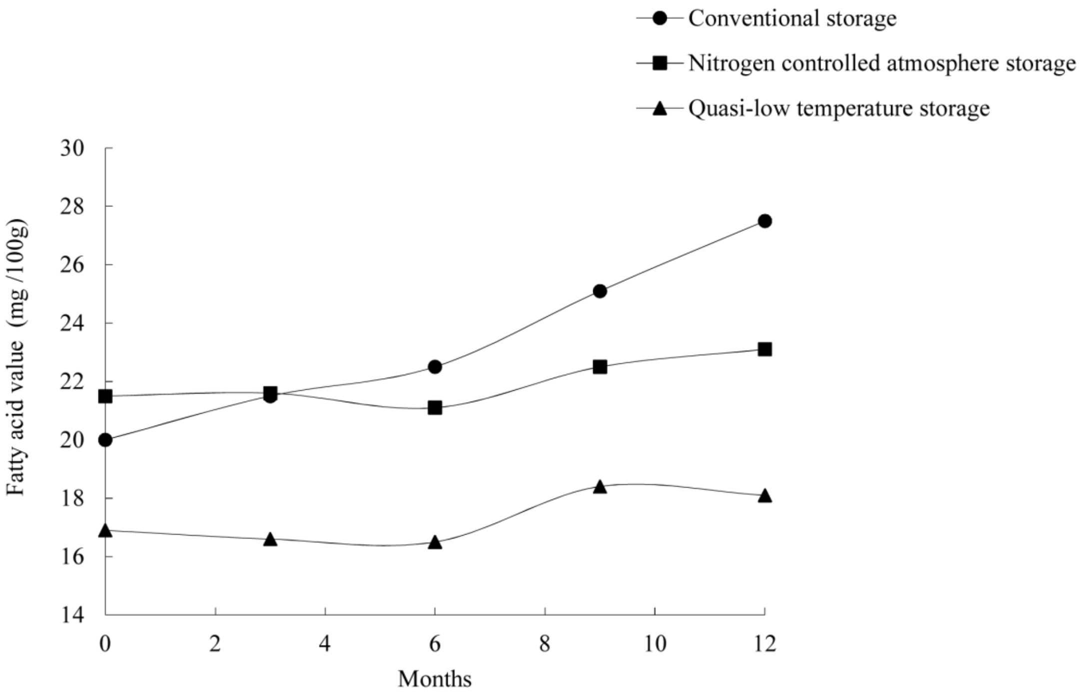

Figure. 3 Changes in the Fatty Acid Value of Middle and Late Indica Rice during Storage

During storage, the fat of grains was easy to hydrolyze and significantly brings down the content of free fatty acid, especially when the moisture content and temperature were high. Therefore, by measuring the fatty acid value, we can judge the changes in the quality of rice. According to the properties of fatty acid, that is, insoluble in water but soluble in organic solvents, the fatty acid in the samples was lixiviated using absolute ethyl alcohol and then titrated to an endpoint using a potassium hydroxide standard solution. The results were represented as the weight (in milligrams) of potassium hydroxide required to neutralize free fatty acid in 100g grains samples.

Lu Qianyu (1993) treated rice with normal hexane. After some of the lipid was removed, there was no obvious aging whether the grains were stored at 15 ℃ or 50 ℃, suggesting that the change of lipid was the most important factor for the reduced freshness of rice. Fatty acid value is able to reflect changes in the quality of rice in an objective and sensitive way. From **Fig. 3,** it can be seen that in the conventional storage silo, the fatty acid value of middle and late indica rice grew from 21.5 mg KOH/100g on a dry weight basis when put into storage to 27.5 mg KOH/100g on a dry weight basis after summer. In the quasi-low temperature storage silo, shallow geothermal energy was used for silo-wide cooling. The heap temperature was controlled below 20℃. The fatty acid value grew from 16.5 mg KOH/100g on a dry weight basis when put into storage to 18.1 mg KOH/100g on a dry weight basis after summer. This indicated that fatty acid value was susceptible to high temperature.

When the temperature was low, it changed slowly. When the temperature was high, it changed dramatically. Z. Zhou et al., (2003) examined changes in the fatty acid value of husked rice when it was stored at a temperature of 4℃ and 37 ℃ for 7 months and found that the fatty acid value of husked rice didn't change significantly at 4℃, but the fatty acid value of husked rice grew rapidly at 37℃, which suggested that temperature had a great impact on the fatty acid value. Low temperature can inhibit the rapid growth of fatty acid value. In the nitrogen controlled atmosphere storage silo, the fatty acid value grew from 21.5 mg KOH/100g on a dry weight basis when put into storage to 23.1 mg KOH/100g on a dry weight basis half a year later. This proved that nitrogen controlled atmosphere storage can slow down the growth of fatty acid value.

3.3 Changes in husked rice yield

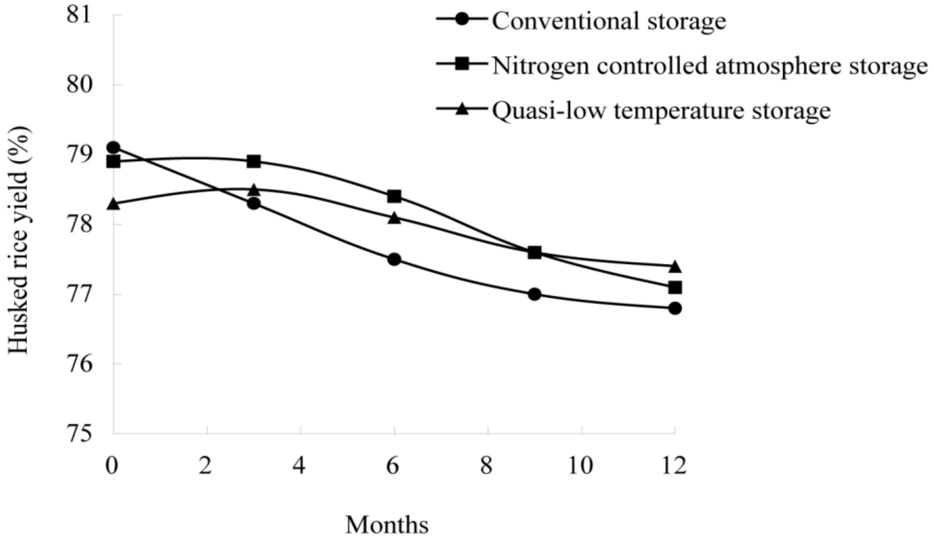

Figure. 4 Changes in the Husked rice yield of Middle and Late Indica Rice during Storage

The husked rice yield of rice refer to the percentage of husked rice (cleaned rice whose chaff had been removed) weight in the sample weight. Incomplete grains are calculated as half. The husked rice yield reflects the potential of milled rice rate. It can be seen from **Fig. 4** that after one-year storage, the husked rice yield of middle and late indica rice in the conventional storage silo, nitrogen controlled atmosphere storage silo and quasi-low temperature storage silo dropped by 2.3%, 1.7% and 0.9%, respectively. With the extension of storage time, the husked rice yield changed more slowly, which was in agreement was other literatures (Wenya Bi, 2017). On the other hand, some scholars pointed out that husked rice yield was a stable property mainly controlled by genes, so it didn’t have much to do with storage time(Tianzhen Li, 2005).

3.4 Changes in head rice yield and milled rice rate

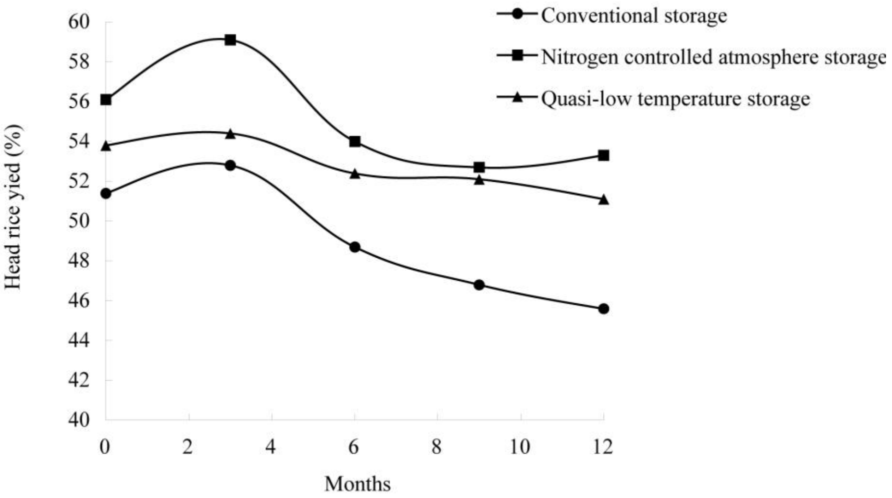

Figure. 5 Changes in the Head Rice Yield of Middle and Late Indica Rice during Storage

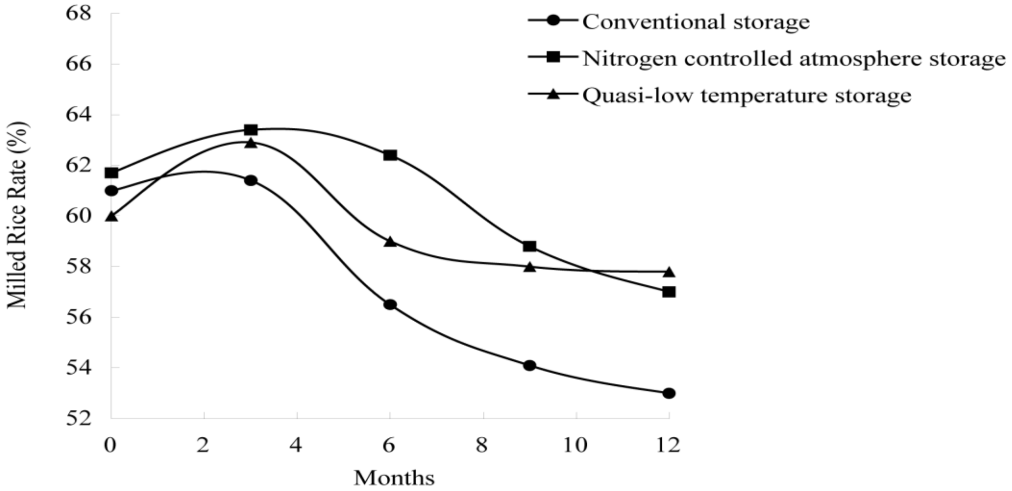

Figure. 6 Changes in the Milled Rice Rate of Middle and Late Indica Rice during Storage

Head rice yield referred to the percentage of head rice weight in the cleaned rice sample weight, after a certain amount of cleaned rice was husked, the husked rice was milled to rice with a specified degree of milling and the bran powder was removed. Head rice yield was one of the important measures for the quality of rice and milled rice rate directly reflected the ultimate commercial value of middle and late indica rice. To be specific, it was a percentage of head rice weight in the rice sample weight, after husked rice was milled with a rice mill, the bran (including the pericarp and aleurone) and the embryo was dislodged and then the bran powder was sifted out using a 1.0mm round hole sift, namely, the percentage of the sum of finished rice, broken grains and grains of different colors (the remainder after the husk, bran and white bran powder was removed) in raw grains.

As can be seen from **Fig. 5 and 6,** the head rice yield and milled rice rate of middle and late indica rice showed a trend of “rising then falling”. This was because after the grains were put into storage, the ambient temperature and relative humidity accelerated the physiological reaction speed of the rice itself, thereby increasing the head rice yield and milled rice rate. After winter, the head rice yield and milled rice rate dropped to varying degrees, probably attributable to the decrease of moisture, the longer the storage time was, the more moisture would be lost in the middle and late indica rice. Some trace elements and nutrients which relied on moisture would be lost, too. All biochemical indicators deteriorated. At this point, milling can cause broken grains and decrease the degree of milling easily. A comparison of three storage methods showed that the drop of the milled rice rate of quasi-low temperature storage was the smallest, followed by that of nitrogen controlled atmosphere. The drop of the milled rice rate of conventional storage was the greatest.

3.5 Changes in crack rate

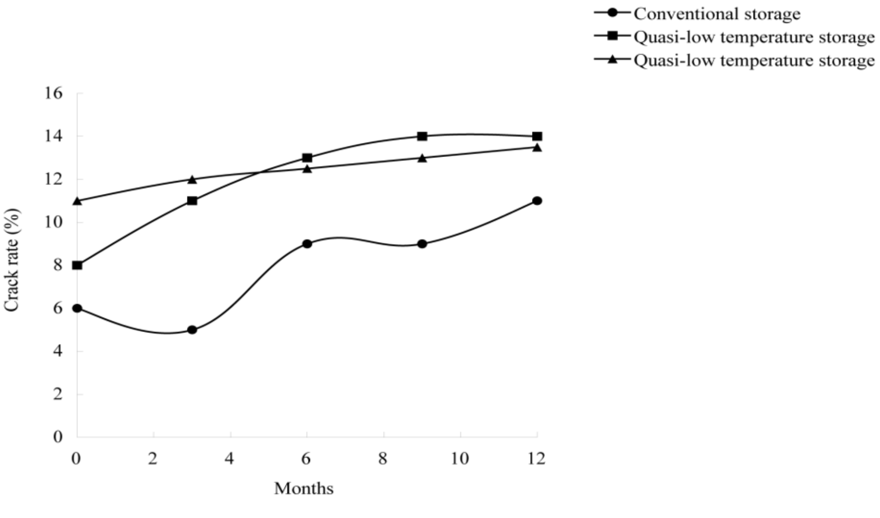

Figure. 7 Changes in the Crack Rate of Middle and Late Indica Rice during Storage

It is inevitable that some grains will be broken after middle and late indica rice is processed, partly because of the processing machinery itself, but more importantly, because there are existing cracks before processing. Cracked grains refer to husked grains whose surface has cracks. The cracks will not only increase the number of broken grains, but also affect the quality of finished products. For this reason, we took 100 complete husked grains indiscriminately, identified them using a magnifying glass and picked out the grains with cracks. The number of grains that had been picked out was the crack rate.

Cracks may occur in both the drying process and moisture absorption process of dry rice, but the main reason for cracks is the moisture absorption of grains (Guofeng Yang, 2004). According to relevant literatures, the crack rate before processing is basically the same as the broken grain rate after processing and they are positively correlated to each other (Qiuqiong Cheng, et al., 2000), suggesting that cracks are the main cause of broken grains. It can be seen from **Fig. 7** that with the extension of storage time, the crack rate of middle and late indica rice gradually increased, which was also consistent with the descending data of milled rice rate.

3.6 Changes in taste score

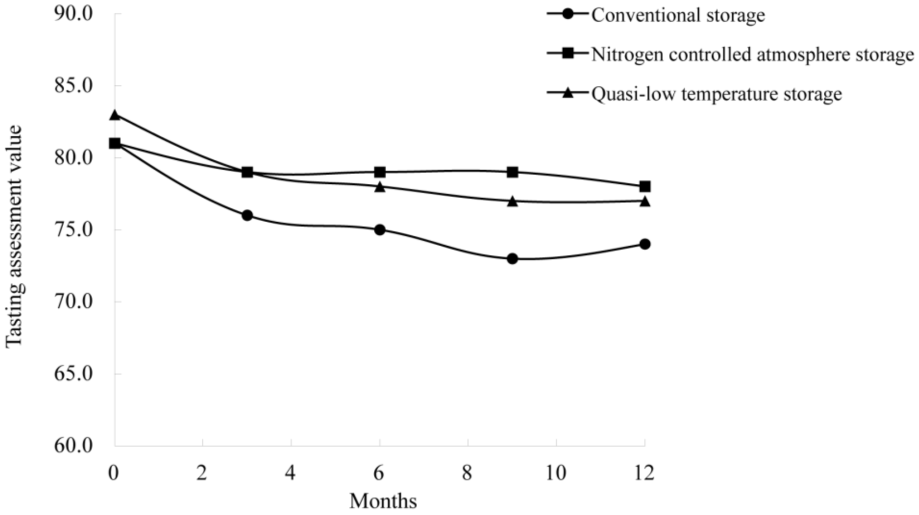

Figure. 8 Changes in the Taste Score of Middle and Late Indica Rice during Storage

The taste score is a very intuitive measure for the quality of food, which can reflect the quality of food in a truthful and direct way. After being husked and milled, the grains were made into samples with 3rd degree of milling. A certain amount of samples were taken and boiled into rice under specified conditions. The evaluators discriminated the smell, appearance, structure, palatability, taste and cold rice texture, etc. of the rice using their sensory organs. The evaluation result was expressed as the average of the total score given by all evaluators.

Color, smell and taste scores are very intuitive measures for the quality of middle and late indica rice, which can reflect the quality of middle and late indica rice in a truthful and direct way. During the one-year storage, the color and smell of middle and late indica rice remained normal. From **Fig. 8**, it can be seen that with the extension of storage time, the taste scores of three storage methods gradually dropped. Compared with the conventional storage silo, the taste scores of the nitrogen controlled atmosphere storage silo and the quasi-low temperature storage silo dropped more slowly. The nitrogen controlled atmosphere storage and the quasi-low temperature storage can slow down the aging of grains, which was beneficial to the safe storage of grains.

Discussion

Rice is a living organism. During storage, with the extension of time, the activity of enzyme will be reduced, the respiration will be weakened and the physicochemical properties will be changed. The rice become inactivated and aged and inevitably lead to the poor quality of processing and food. The aging of rice is the combined action of storage temperature, moisture, time and their interactions on multiple components in the grains(Xingjun Li, 2010). By studying the change rules of quality indicators of middle and late indica rice using three storage methods, nitrogen controlled atmosphere storage, quasi-low temperature storage and conventional storage, we found that with the extension of storage time, for all of the three storage methods, the fatty acid value and crack rate grew, the moisture content, head rice yield, milled rice rate and taste score fell slowly, while the husked rice yield didn't change significantly. All of the indicators of nitrogen controlled atmosphere storage and quasi-low temperature storage changed more slowly than those of conventional storage, suggesting that these two storages can better maintain the quality of middle and late indica rice.

The changes in fatty acid value reflected the deterioration of the quality of grains during storage. During storage, the fatty acid value of middle and late indica rice grew with the extension of storage time. After one-year storage, the fatty acid values of nitrogen controlled atmosphere storage, quasi-low temperature storage and conventional storage grew by 1.6, 1.2 and 7.5mg KOH/100g on a dry weight basis, respectively. This was because the conjugated fatty acid in the tri-acylglycerol and phospholipid in rice cells kept hydrolyzing under the influence of lipases and oxidases during storage, accompanied by changes in the acidity of cells. The fatty acid value of rice gradually increased with the increase of storage temperature (Jianxin Zzhou, et al., 2011). The higher temperature, the faster the fatty acid value grew (Fan Wu, 2012). At low temperatures, the fatty acid value changed slowly. In the nitrogen controlled atmosphere storage silo, the fatty acid value changed slightly because low oxygen would weaken the respiration of rice, but the slow hydrolysis of lipids would produce a small amount of free fatty acid.

Milled rice rate is a more intuitive and rapid measure than husked rice yield and head rice yield, etc. which can directly reflect the ultimate commercial value of middle and late indica rice and effectively reduce high husked rice yield, low milled rice rate and low quality as a result of the variety of rice. Therefore, when middle and late indica rice is delivered from storage, most processing plants consider the milled rice rate as the most important reference for the price of rice. Within the one-year storage, for all of the three storage methods, the husked rice yield of middle and late indica rice dropped by about 1%. In the quasi-low temperature storage silo, the milled rice rate and head rice yield dropped by 2.7% and 2.2% respectively. In the nitrogen controlled atmosphere silo, the milled rice rate and head rice yield dropped by 4.7% and 2.8% respectively. In the conventional storage silo, the milled rice rate and head rice yield dropped by 8% and 5.8% respectively. The differences in the milled rice rate and head rice yield were significant. The drop of quasi-low temperature storage was the smallest, followed by nitrogen controlled atmosphere storage. The drop of conventional storage was the greatest. On taste score, compared with the conventional storage silo, the taste scores of the nitrogen controlled atmosphere storage silo and the quasi-low temperature storage silo dropped more slowly. Thus it can be seen the nitrogen controlled atmosphere storage and the quasi-low temperature storage can reduce the aging speed of grains, which was beneficial to the safe storage of grains. In actual applications, many grain depots compare quality by pre-embedding samples and verify that a combination of quasi-low temperature and nitrogen controlled atmosphere can well maintain the quality of grains. The fatty acid value of these two storages grows more slowly than that of the conventional storage. The color and smell remain normal, the changes in the quality are delayed and water can be retained to a certain degree. Therefore, they have good economic benefits and social benefits.

Conclusion

The advantages of nitrogen controlled atmosphere storage and quasi-low temperature storage are fresh and nutritive. They can delay the increase of middle and late indica rice and fatty acid value (Jian Yang, et al., 2013) and effectively control the number of pests in stored food.

Acknowledgments

The authors would like to thank"Young Elite Scientists Sponsorship Program by CAST, YESS, 2018QNRC001". We thank 2015 grain public welfare industry for partial funding of this research. We thank Young Elite Scientists Sponsorship Program by CAST, YESS, 2018QNRC001".

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