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# Effects of three types of modified atmospheric packaging on the physicochemical properties of selected glutinous rice

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The effect of modified atmospheric packaging (MAP) on the physicochemical properties of selected glutinous (Thadokkham-8 and Thadokkham-11) rice was studied and compared with a non-glutinous rice (Doongara). The freshly harvested/milled grains were packed in four different MAP conditions viz. control, vacuum, $CO_2$ and $N_2$ for 12 months at room temperature ($23 \pm 1$ °C). Gas ($N_2$ or $CO_2$) was flushed in aluminum bags at the pressure of 300 kPa for 3 s and subsequently hermetically sealed. Vacuum packaging was done at −100 kPa. Results showed that ageing induced changes in the starch granules were less prominent in vacuum and/or MAP samples using $CO_2$ or $N_2$. Surface analysis showed that control storage significantly reduced the percentage of lipids and increased the percentage of proteins on the surface in all selected varieties. $N_2$ and $CO_2$ storage of TDK8 and DG slowed down the shift of properties of macromolecules and maintained the surface starch/proteins/lipids ratios during 6 months of storage. Moreover, the grains stored in vacuum maintained the lipids with lower proportion of proteins exposed to the surface after cooking. $N_2$ and $CO_2$ induced increase in pasting temperature but significant reduction in final viscosity when compared to control. The findings correlated well with thermal analysis. The *in situ* Thermal Mechanical Compression Test (TMCT) device cooking and texture analysis revealed that modified storage slightly slowed the ageing induced changes in the cooking quality and stickiness of glutinous rice. Among all storage conditions used vacuum was relatively the best to maintain the quality of the grain.

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## 1. Introduction

The significance of food storage especially for cereals such as rice and wheat has become important because of frequent natural disasters such as floods, drought and earthquakes to ensure food security (Tulyathan and Leeharatanaluk, 2007). Rice being the primary staple food of more than half of the world's population requires adequate storage with preservation of its eating quality to ensure an uninterrupted supply to end users all year round (Thongrattana, 2012). Storage of rough and milled rice undergoes a wide range of physicochemical changes on the characteristics of rice such as pasting properties (Ziegler et al., 2017), thermal properties (Faruq et al., 2015; Ziegler et al., 2017), and textural changes in the cooked rice over a time period (Nawaz et al., 2016b; Zhou et al., 2007b; Keawpeng and Venkatachalam, 2015; Jungtheerapanich et al., 2016).

Age-related effect on the cooking quality of rice has been obvious to the consumers. Ageing is very complex process and attributed to several changes (Zhou et al., 2015) in cell walls and proteins (Zhou et al., 2002; Sodhi et al., 2003), starch/protein interaction (Tananuwong and Malila, 2011), and oxidation of lipids resulting in breakdown of products (Park et al., 2012). Loss of stickiness is one of the most noticeable changes occurring in glutinous rice (Chen et al., 2015). Several factors are responsible for this physicochemical deterioration. Previous studies have demonstrated the strong association of ageing and endogenous enzymatic reactions on rice starch (Zhou et al., 2003a; Huang and Lai, 2014), proteins (Zhou et al., 2003a) and lipids (Zhou et al., 2003b). Huang and Lai (2014) reported the effects of endogenous amylase on the isolated starch fine structures of aged waxy rice varieties (TNW1 and TCSW1) and reported that the structural changes in the starch fine structures with a decreasing percentage of longer chains and an increasing percentage of shorter chains of amylopectin when rice was stored for a longer period (15 months) of time.

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Although, the studies on rice protein suggested that there was no significant difference in the gross protein contents of fresh and aged rice (Zhou et al., 2002), storage in ambient conditions could induce oxidation reaction of proteins resulting in the formation of intermolecular disulphide bonds (-S-S-) (Teo et al., 2000). The polymerisation of rice proteins due to intermolecular disulphide bond formation can increase the average molecular weight of rice storage proteins especially oryzenin (Zhou et al., 2007a). The formation of bigger protein bodies in stored rice can lead to increased final viscosity during rapid visco analysis and reduced stickiness of cooked waxy rice (Ohno and Ohisa, 2005; Zhou et al., 2007b). In addition to this, previous studies (Shin et al., 1986; Park et al., 2012) have reported that there was no significant change found in the fatty acids (both unsaturated and saturated) in the propanol-water extractable lipid (PWE-L) fraction between fresh and stored rice grains. However, unsaturated fatty acids fractions in the petroleum ether extractable lipid (PEE-L) of aged rice grains was significantly ($P < .05$) lower than that of fresh rice grains (Zhou et al., 2015). This suggests that the unsaturated fatty acids in PEE-L fraction are more unstable and could be more responsible for the oxidation than those in PWE-L fraction during storage (Tsuzuki et al., 2014). It is now quite well defined that the lipid peroxidation during storage can cause quality deterioration of rice grains, especially, lipoxygenase-3 (LOX-3), which is one of the key enzymes catalysing the reaction (Shin et al., 1985; Hildebrand, 1989; Suzuki and Matsukura, 1997). The above studies suggest that an efficient direction for improving the storage property of the rice grains can be achieved through proper storage environment.

To slow down ageing induced physicochemical changes in stored rice, storage at chilling temperatures (at or below 8 °C, targeting 5 °C) is usually reported as the best method (Pearce et al., 2001). However, cold storage is not cost effective due to initial capital investment for cooling system installation, high energy consumption during its operation, and also expensive equipment maintenance (Evans et al., 2014). In addition, the suggested method cannot be effectively applied in the developing nations facing energy shortage. Thus, modified atmospheric packaging of rice can be the best option to reduce ageing induced physicochemical changes at ambient temperature conditions and maintain the cooking quality.

In modified atmospheric packaging (MAP), extra nitrogen ($N_2$) or carbon dioxide ($CO_2$) is added to alter the ratio of oxygen ($O_2$), $N_2$, and $CO_2$ (Caleb et al., 2012). Altered ratio of $O_2$, $N_2$, and $CO_2$ in the micro-environment of food product can maintain the physical and cooking quality of aged food product by slowing down the physicochemical changes such as the speed of oxidation reactions (Caleb et al., 2013) and other physicochemical changes. The MAP of fresh fruits and vegetables is quite well-established technique mainly focusing on the prolonging shelf life by reducing the respiration rate and microbial growth (Oliveira et al., 2015; Shaarawi and Nagy, 2017). However, to the best of our knowledge MAP of rice has not been widely reported by researchers due to its least susceptibility towards microbial spoilage, having relatively longer shelf life and less importance given to the cooking quality of rice.

Good quality glutinous rice grains usually lose their shape during cooking and become very sticky. However, storage at ambient temperature induces physicochemical changes in glutinous rice resulting in significant reduction in the stickiness during cooking. As mentioned earlier, although ageing induced changes can be minimised by storing the rice at the refrigerated condition, this method is not feasible due to the cost factor and large volume of the grains. Therefore, the objective of the present study is to investigate the effect of altered atmospheric (vacuum, $N_2$, and $CO_2$) storage on the functional properties of selected glutinous rice varieties. For this, the milled rice grains of two glutinous rice varieties viz. Thadokkham-8 (TDK8) and Thadokkham-11 (TDK11) were selected and stored in four different modified atmospheric conditions for one year. For comparison, one non-glutinous rice variety (Doongara (DG)) was also milled and stored in the same condition. This modified storage is expected to maintain the functional quality of aged glutinous rice grains stored at ambient temperature by reducing the rate of physicochemical changes in rice, in particular, the loss of stickiness.

## 2. Material and methods

Two *Oryza sativa* indica cultivars of glutinous rice from Lao PDR viz. Thadokkham-8 (TDK8) and Thadokkham-11 (TDK11) having 3.77% and 3.72% apparent amylose contents (AAC), respectively and one *O. sativa* japonica non-glutinous rice from Australia (Doongara (DG), 19.71% (AAC)) were used in this study. The milled TDK8 with 9% degree of milling (harvested March/April 2015) was provided by the National Agriculture and Forestry Research Institute, Lao PDR, while TDK11 and DG (harvested March/April 2015) were provided by Rice Research Australia Pty Ltd, Mackay, QLD, Australia.

### 2.1. Paddy milling

TDK11 and DG paddies were milled to brown rice by using a rice husker (Satake, Japan). The brown rice of both cultivars was milled to white rice using an abrasive polisher (Satake, Japan). The DOM of both TDK11 and DG was maintained at 9% to be consistent with milled TDK8 provided by NAFRI, Lao PDR.

### 2.2. Modified atmospheric packaging

The milled rice kernels (250 g per bag) of TDK8, TDK11, and DG were packed in sealed aluminium bags (West's Packaging Services, Melbourne, VIC, Australia) using various modified atmospheric conditions viz. vacuum, $N_2$, $CO_2$ by using a table top vacuum chamber machine equipped with gas flushing system; Vacumatic 282 (Vacumatic Australia Pty Ltd, Pakenham, VIC, Australia). $N_2$ and $CO_2$ were flushed in aluminium bags at a pressure of 300 kPa for 3 s and subsequently hermetically sealed. Similarly, vacuum packaging was done at -100 kPa. Moreover, one control without any treatment was also kept in sealed aluminium bags for comparison. The control and MAP packets of rice grains of selected rice varieties were stored at room temperature ($23 \pm 1$ °C). The experimental design of the present study is presented in supplementary section Fig. S1.

### 2.3. Scanning electron microscopy of cross-section of rice kernels

The cross sections of milled rice kernels of fresh, 6 and 12 months aged TDK8, TDK11, and DG stored in various MAP were mounted onto SEM stubs by placing them on a double-sided carbon adhesive tape. Biological materials suffer from extensive charge build-up under the electron beam; hence they need to be coated with conductive material. Thus, samples were iridium-coated for 3 min (~15 nm thick). The samples were examined using a Philips XL30 Field Emission Scanning Electron Microscope operating at 8 kV accelerated voltage.

### 2.4. Surface chemical analysis

The surface chemical analysis of pure rice components (starch, proteins, and lipids), milled uncooked rice kernels, and freeze dried cooked rice kernels of fresh, 6 and 12 months aged TDK8, TDK11, and DG stored in various MAP were analysed by using a Kratos AXIS Ultra Kratos Analytical (Manchester, UK) spectrometer with a monochromatic Al X-ray source at 150 W. This method follows the

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