International Food Research Journal 22(6): 2180-2187 (2015)
Journal homepage: *http://www.ifrj.upm.edu.my*

Mini Review

Effect of aging on changes in rice physical qualities

[1*]Keawpeng, I. and [2]Venkatachalam, K.

[1]*Program of Food Science and Technology, Faculty of Agricultural Technology. Songkhla Rajabhat University, Muang, Songkhla 90000, Thailand*
[2]*Department of Food Technology, Faculty of Science and Industrial Technology, Prince of Songkla University (Surat Thani Campus), Muang, Surat Thani 84100, Thailand*

Article history

Received: 23 January 2015
Received in revised form: 25 April 2015
Accepted: 30 April 2015

Keywords

Rice
Aging
Storage
Quality changes
Physicochemical

Abstract

Rice ageing commences during preharvest and continues with the postharvest storage. It dramatically involves the changes in physical and physicochemical properties of the rice grain such as cooking, pasting, and thermal properties. The present report reviews and reveals the effect of rice ageing on the changes of rice physical properties. The studies discovered that, during ageing, cooked aged rice had a harder texture and much fluffier than fresh rice and also less in stickiness and adhesiveness. The viscosities such as final and setback viscosity of aged rice increased dramatically after the short to intermediate term of storage. These were affected by two major factors such as time and temperature of storage. During ageing, aged rice grain at higher temperature and longer time showed a significant increase hardness of cooked rice, peak temperature, and the conclusion temperature. However, the pasting and the breakdown viscosity of rice decreased with longer aging times.

© All Rights Reserved

Introduction

Rice (*Oryza Sativa* L.) is one of the leading food crops in the world and as well as the staple food for more than a half of the world's population, particularly in Asia (Wei *et al*., 2007). It is the primary source of dietary carbohydrates and plays a significant role in nutrient intake (Yang *et al*., 2006). It is considered as a semi-aquatic and annual grass plant. The two cultivated rice species such as *O. Sativa* L. and *O. glaberrima* Steud. can grow in a wide range of regimes such as wetland and dry land hill slopes. Rice is typically consumed as cooked and although a minor amount is used as an ingredient in the several processed foods. This pattern of usage resulted in the need of production and storage of rice in the varying periods. Stored rice is preferred in some markets and whereas, in the other markets fresh rice is preferable. Typically, rice during storage undergoes numerous changes in its physical properties and chemical composition, and these changes cause impact on rice cooking and eating quality (Sodhi *et al*., 2003; Patindol *et al*., 2005; Singh *et al*., 2006). Moreover, there is some report showed that aging generally results in a higher head rice yield on milling, higher volume expansion and water absorption upon cooking, and harder, less sticky cooked rice. The changes in cooked rice texture associated with aging are enhanced by high storage temperatures (Tsugita *et al*., 1983; Chrastil, 1990).

The changes in rice properties such as pasting, color, flavor and composition during storage are usually termed as aging. These changes are found to be greater in a non-waxy rice than waxy rice while aging (Zhou *et al*., 2002). Aging induced the physiochemical changes, and that can be noticed in the minimum of three month period in stored rice (Perez and Juliano, 1981). However, rice physical properties such as texture, pasting, and thermal properties are the key factors that affected mostly in aged rice. Normally, the texture of the cooked aged rice was harder and less sticky than the freshly harvested cooked rice (Indudhara *et al*., 1978; Chrastil, 1990; Noomhorm *et al*., 1997; Perdon *et al*., 1999; Sowbhagya and Bhattacharya, 2001; Zhou *et al*., 2002; Sodhi *et al*., 2003; Ohno and Ohisa, 2005; Patindol *et al*., 2005; Singh *et al*., 2006; Katekhong and Charoenrein, 2013a; Katekhong and Charoenrein, 2013b). Additionally, aged rice exhibits increased volume in expansion and water absorption during cooking. There are several studies reported the effect of aging on quality changes of cooked rice. Although, still there are lacking wide ranges of information on the changes of physical properties aged rice while

*Corresponding author.
Email: *ittipornk@gmail.com*
Tel: +66-74336933; Fax: +66-74324221

cooking. The present review is explored and analyzed the available information on the effect of aging on changes in rice physical qualities.

Rice storage

Rice is one of the few cereal crops that has been primarily consumed as the whole rather than as flour, and the values are highly correlated with the intact of its kernels. The rough rice is harvested once in a year and stored for a year in the temperate areas of the world. Whereas, in tropical regions, rough rice is frequently harvested in a year and due to the extreme environmental conditions, it usually stored for a short period (Champagne, 2004). Storage of rice is necessary to reduce problems during crop failure or poor yield in the following year. A proper storage of rough rice is the key factor in maintaining its qualities and the values. Physical and cooking properties such as head rice yield, pasting, volume expansion and water absorption of rice regularly changes during storage (Champagne, 2004). However, the exact mechanisms of these changes are mostly unknown. Although, several reports showed that the values of those properties are increased during rice storage between two and four months after harvest and after that, taper off or return to its original values during prolonged storage.

Aging

Aging of rice is one of the typical steps between harvest and consumption. During aging of rice, a number of physiochemical properties of the rice are subjected to change (Singh *et al*., 2006). Normally, during aging of freshly harvested rice, there is an increase of rice volume expansion and water absorption observed. The storage conditions are important in the aging process and they could impact on the number of changes in rice physical properties such as textural properties, pasting, color, flavor, composition and eating quality (Teo *et al.*, 2000; Zhou *et al*., 2003a). The textural properties are included; adhered to lips, hardness, cohesiveness, roughness, tooth pull, particle size, tooth pack and looseness of particles. Typically, rice physical properties mainly depend on its variety, storage conditions (exposure to light, temperature) and amylose content (Chrastil, 1990). They have attributed to changes in rice cell walls and proteins, the interaction between proteins, the breakdown products of lipid oxidation and starch–protein interactions (Sodhi *et al*., 2003). The mechanism of rice aging has influenced by the level of proteins and lipids in rice. Lipids formed free fatty acids and complexes with amylase, carbonyl compounds, and hydroperoxides, which can quicken protein oxidation and condensation plus the accumulation of volatile carbonyl compounds. Protein oxidation is the formation of di-sulfide linkages from sulfhydryl groups and together with an increase in the strength of Mitchell binding of starch. It inhibits swelling of starch granules and affects the texture of cooked rice. Moreover, the oxidation of ferulate esters of hemicellulose contributed to cross-linking and increased the strength of cell walls during storage of rice (Sodhi *et al*., 2003).

The effect of aging on cooking properties of rice

Cooking properties of rice are naturally related to the gelatinization of starch. During the cooking process, starch granules become swollen, release exudates of starch molecules, and the soluble amylose loses with residual cooking water (Nardi *et al.*, 1997). The reduction in extractable solids in aged rice could increase water insolubility of rice starch, proteins and thus, resulting in a slower cooking rate. The texture of the cooked rice grain had been shown to describe the ultimate acceptance of rice by consumers when it consumed as the whole grain (Sesmat and Meullenet, 2001). The relevant parameters for the evaluation of the texture of cooked rice grain include hardness, adhesiveness and cohesiveness. Although, the texture is multidimensional, hardness and stickiness are critical and being the most important and most commonly measured parameter (Meullenet *et al.*, 1998). Hardness is well-defined as the maximum force that occurs at any time during the first compression cycle. Stickiness is measured by taking the total work done on the sample during the second cycle and dividing it by the work done during the first cycle (Smewing, 1999). As rice has aged, the texture of the cooked rice grain became harder and less sticky than cooked fresh rice, and the aged rice showed increases in volume expansion and water absorption during the cooking process (Pushpamma and Reddy, 1979; Noomhorm *et al*., 1997). The changes in textural properties of aging rice have been associated with the protein content (Zhou *et al.*, 2003a), particularly the oxidation of proteins in the external layers of grains (Ohno and Ohisa, 2005). The recent reports of aging rice affected the texture of cooked rice during various conditions are summarized in Table 1.

Zhou *et al*., (2007) studied the effect of different storage temperatures such as at 4°C and 37°C on cooking properties of rice. They reported that at a high temperature (37°C) of rice storage obtained greater water uptake, reduced pH and turbidity of residual cooking liquid as compared to low temperature storage (4°C). The solid contents in the residual cooking water also decreased at 37°C as compared

Table 1. Changes of texture characteristics of rice during aging

Storage period (months)	Storage temperature (°C)	Rice Variety/ grain type	Texture characteristics				References
			Hardness	Stickiness	Cohesiveness	Adhesiveness	
4	15	88 zao 229 /paddy rice	↑	↓	-	-	Wang *et al.* (1998)
6	2	milled rice	↑	↓	-	-	Zhou *et al.* (2002)
	29		↑	↓	-	-	
6	15	Glutinous RD 6/ paddy rice	↑	-	↑	↓	Wiset *et al.* (2011)
	20		↑	-	↑	↓	
	30		↑	-	O	↓	
8	4	KDML105/ brown rice and germinated rice	↑	-	-	-	Parnsakhorn and Langkapin (2013)
	37		↑	-	-	-	
12	15	Hom Daeng/ milled rice	↑	-	-	-	Tananuwong and Malila (2011)

↑ = increased; ↓ = decreased; O = was not significantly changed; - = was not reported

to storage at 4°C ($p<0.001$). Also, the textural profile of the cooked rice grain had differed during this storage condition. Hardness increased ($p<0.01$), and adhesiveness reduced ($p<0.01$) during storage at 37°C compared to 4°C. The higher hardness and lower adhesiveness are likely to be associated with the lower hydration process of starch granules in aged rice grains stored at a higher temperature. Higher temperature storage led to an increase in cohesiveness as compared to low temperature storage. This increase may be related to an increase in resistance to the hydrothermal disruption of starch granules and the increase in insoluble materials (starch and proteins) as the samples that are very cohesive are perceived as tough and difficult to break up in the mouth. Wiset *et al*. (2011) studied the effects of the different storage, cold aeration, and ambient temperature on physicochemical properties of the glutinous rice cultivar (RD6). They reported that the textural properties such as hardness, cohesiveness and chewiness were increased during storage while adhesiveness was decreased. Furthermore, the paddy stored at ambient temperature and paddy stored in a gunny bag showed the greatest change in textural properties than stored at cold temperature. The sensory evaluation of cooked rice showed that paddy rice stored at ambient temperature and gunny bags had an abnormal aroma.

Tananuwong and Malila (2011) revealed that an increase in storage duration (12 months) at an ambient temperature of the raw organic hulled rice led to an increase in hardness after it cooked. During the cooking of the aged rice kernels, starch granules tend to absorb less water, granule swelling is more restricted and disruption of the crystalline structure of starch granules during cooking decreases. Further physical entanglements of starch polymers in starch granules may occur. Therefore, starch gels with greater stiffness may be formed. In addition, the longer the rice storage duration is stronger the network of oryzenin gel. The structural modifications of starch and protein gels may enhance the hardness of the cooked rice prepared from the aged samples. Parnsakhorn and Langkapin (2013) reported, the increased of hardness values observed in the cooked germinated brown rice while aging at various temperature (4 and 37°C). Although, aging process at higher temperature led to increasing the hardness values in cooked brown rice and also in geminated brown rice grains. Park *et al.* (2012) studied the changes in textural properties of aging rice during storage at different temperatures. High temperature led to decreases in adhesiveness of aging rice. Storage at higher temperatures increased the cohesiveness in comparison with storage at lower temperatures. This result was in agreement with the finding of Zhou *et al.* (2007), who demonstrated that increased cohesiveness could be linked to an increase in resistance to the hydrothermal disruption of starch granules and the increase in insoluble material content. Cohesive samples are perceived as tough and difficult to break up in the mouth.

The effect of aging on pasting properties of rice

One of the most sensitive indices of the aging process in rice is the change in pasting properties, which can be measured through thermo-viscometry (Perdon *et al*., 1999). Pasting properties of starch are generally determined by using Brabender visco-amylography, the rapid viscous analysis, or dynamic rheometry that provides useful information for understanding the textural change or retrogradation potency of the applied products. Pasting parameters of starch slurry during heating have been proposed to be related to the granule size (Okechukwu and

Table 2. Changes of pasting properties of rice during aging

Storage period (months)	Storage temperature (°C)	Rice Variety/ grain type	Pasting behaviors PV	BD	FV	SB	References
4	4	Japonica/ milled rice	↑	↓	-	↑	Park *et al.* (2012)
	20		↑	↓	-	↑	
	30		↑	↓	-	↑	
	40		↑	↓	-	↑	
10	20	KDML105/ paddy rice	↓	↓	↑	↑	Kanlayakrit and Maweang (2013)
	30		↓	↓	↑	↑	
	40		↓	↓	↑	↑	
12	25	KDML105/ milled rice	↓	↓	↑	↑	Katekhong and Charoenrein (2012a)
12	15	KDML105/ milled rice	↓	↓	↑	↑	Katekhong and Charoenrein (2012b)
12	15	Hom Daeng/ milled rice	↑	↓	-	↑	Tananuwong and Malila (2011)
16	4	Kyeema/ milled rice	↓	↓	O	O	Zhou *et al.* (2003a)
	37		↓	↓	↑	↑	
48	26	S701/ paddy rice	-	↓	-	↑	Sowbhagya and Battacharya (2001)

PV = peak viscosity; BD = break down; FV = final viscosity; SB = setback
↑ = increased; ↓ = decreased; O = was not significantly changed; - = was not reported

Rao, 1995), properties of swelling power/solubility (Evans and Lips, 1992), or properties of the swollen granules and soluble materials of starch (Doublier *et al*., 1987). The swelling of starch is mainly a property of amylopectin while amylose acts as a diluent. As the rice aged, cooked rice texture became fluffier and harder (Indudhara *et al*., 1978). The viscosity of rice pasting increases dramatically over short to intermediate-term the storage (months) of milled rice. However, it decreases during longer-term storage (years) (Sowbhagya and Bhattacharya, 2001). The effects of rice aging on pasting properties are summarized in Table 2. Zhou *et al.* (2003b) observed that longer storage (4°C and 37°C) period (16 months) of milled rice decreased the peak viscosity and breakdown of pasting curve and it could be due to the interaction between starch and non-starch components. Park *et al.* (2012) reported that peak viscosity greatly increased during storage (4 months) at higher temperature (40°C). The increase in peak viscosity has been attributed to the progressive decline in a-amylase activity in rice grains. The increase in viscosity with temperature may also be attributed to the removal of water from the amylose exuded by the granules as they swell. Tananuwong and Malila (2011) observed that an ambient temperature storage (12 months) of milled rice have increased in pasting temperature, peak viscosity and decreased in the break down level after 6 months of storage of aged rice at a high temperature. The changes in pasting properties of the aged milled rice was delayed with a low temperature storage. Wiset *et al*. (2003) determined pasting properties of the flours from stored paddy. They found that peak viscosity and the setback of the samples increased during 4 months of storage at 25°C. Sowbhagya and Bhattacharya (2001) studied, pasting properties of the flours from milled rice prepared from aged paddy during storage at 26°C, as storage duration increased from 3 to 36 months; breakdown decreased while setback increased. Katekhong and Charoenrein (2012a) reported that aged rice samples showed significant decreases in PV and BD. The changes in PV showed that the starch granules of aged rice were more resistant to swelling than those of fresh rice. The decrease in BD indicates that the capacity of the starch granules to rupture after cooking was reduced significantly with aging of the starch granules (Zhou *et al*., 2003b). These findings were in accord with Tulyathan and Leeharatanaluk (2007), who found that the PV and BD of KDML 105 (Khao Dawk Mali 105) decreased with longer aging times and reaching a plateau after 6 months of aging time. In addition, the final viscosity (FV) and setback viscosity (SBV) of the milled rice flour showed a significant increase with increasing aging. It is well documented that starch-lipid complex formation impacts on rice pasting behavior (Biliaderis and Tonogai, 1991; Kaur and Singh, 2000). This is traditionally attributed to the formation of a complex between amylose and lipids and thereby restricted granular swelling. Hence, any changes in endogenous lipids during storage might account for the observed changes in the pasting behavior of the aged rice.

The effect of aging on the freeze-thaw stability of rice gel

The ready-meal market has grown in both developed and developing countries. Many ready-to-eat meals, including starch-based frozen food

Table 3. Changes of thermal properties of rice during aging

Storage period (months)	Storage temperature (°C)	Rice Variety/ grain type	Thermal characteristics				References
			T_o	T_p	T_c	ΔH	
4	25	Makmurr 77/ rice flour	↑	↑	↑	↑	Toe *et al.* (2000)
	35		↑	↑	↑	↑	
12	15	KDML105/ milled rice	-	↑	-	↑	Katekhong and Charoenrein (2012b)
12	15	Hom Daeng/ milled rice	↑	↑	-	↑	Tananuwong and Malila (2011)
12	25	KDML105/ milled rice	-	↑	-	↑	Katekhong and Charoenrein (2012a)
12	4	Kyeema/ milled rice	O	↑	O	O	Zhou *et al.* (2010)
	37		↑	↑	↑	↑	
16	4	Bengal/ paddy rice	↑	↑	↑	O	Fan and Marks (1999)
	21		↑	↑	↑	↑	
	38		↑	↑	↑	↑	

T_0 = onset temperature; Tp = peak temperature; Tc = conclusion temperature; ΔH = enthalpy
↑ = increased; ↓ = decreased; O = was not significantly changed; - = was not reported

products, have been prepared and launched on the world market. During the freezing process of starch pastes or gels, phase separation can occur upon formation of ice crystals. Then, while thawing, a phenomenon known as syneresis occurs in which starch pastes and gels harden because the water can be easily expressed through the dense network (Karim *et al*., 2000). Repeated freezing and thawing cycles, encourage phase separation and ice growth. As the ice crystals become larger, the syneresis and sponge formation are occurring more readily (Eliasson and Kim, 1992). Starch-based frozen food products undergo textural changes that related to amylose and amylopectin retrogradation, and show the syneresis after thawing and also make such products unacceptable to consumers (Varavinit *et al*., 2000). The determination of the percentage of syneresis from the freeze-thawed flour gels are used to evaluate the ability of the starch to withstand the undesirable physical changes which occur during freezing and thawing (Charoenrein and Preechathammawong, 2010). Syneresis in freeze–thawed gels are due to an increase in molecular associations between starch chains, in particular the retrogradation of amylose (Morris, 1990) which results in the expulsion of water from the gel structure (Saartratra *et al*., 2005). Thus, the amount of water released due to syneresis is a useful indicator of the tendency of starch to retrograde (Karim *et al*., 2000). Katekhong and Charoenrein (2012a) observed that the rice gel from aging rice (KDML 105) for 12 months was reduced to freeze thaw stability. Rice gels are made from the aged rice were freeze-thawed for up to 5 cycles, and this led to an increase in syneresis values and hardness with the increasing of rice aging. Rice aging caused an increase in the enthalpy of melting of the amylose-lipid complex during frequent freeze-thawed cycles and increased in peak gelatinization temperature and gelatinization enthalpy with longer rice aging. The enthalpy of the amylose-lipid complex of rice flour made from aged rice was higher than rice flour gel from flesh rice during freeze thaw cycles (Zhou *et al*., 2002; Vandeputte *et al*., 2003; Zhou *et al*., 2003b). Thus, the enthalpy of the amylose-lipid complex of aged rice was higher than that of fresh rice. Rice flour gel from aged rice showed significantly higher hardness values than gel from fresh rice. The freeze-thaw gel from aged rice had a spongy structure, and it was thicker than rice gel made from raw rice. This could explain the harder texture noted in freeze-thaw gel with a longer aging duration (Katekhong and Charoenrein, 2012a).

The effect of aging on thermal properties of rice

Aging is one of the key factors to determine the rice qualities. It affects the quality and functionality of rice by altering their components and induce the interaction between the components such as protein, lipid, and starch. This can be influenced the thermal properties of aging rice. The increase in enthalpy can be attributed to the increased rigidity of the granules at the end of storage, which increases the energy required to disrupt the structure of the starch granules (Zhou *et al*., 2010). The studies on the effect of rice aging on thermal properties of rice are summarized in Table 3. Peak temperature and peak width appear to be the most notable impacts of storage of aging rice. Zhou *et al.* (2010) observed rice flour from aged rice grain at higher temperature storage showed a significant increase in peak temperature (T_p) as compared to low temperature storage. It also increased the conclusion temperature (T_c) of rice, which led to its thermogram peak becoming broaden relative to that with storage at a lower temperature. The increased in peak temperature and the conclusion temperature indicated that it took longer to disorder the structure of aged rice grain during the gelatinization process. This was related to the slow penetration of moisture into the starch granule during gelatinization. The structure of the aged rice grains formed during the high temperature storage would be associated with the reduction in starch granule swelling, disruption and leaching of starch components during the gelatinization process (Zhou *et al.*, 2007). Zhou *et al*. (2010) reported that enzyme treatment (amylase) produces significant differences in the thermal properties relative to the untreated samples. They explained that the observation was due to the surface of starch granules representing a primary barrier to processes such as hydration and disruption during gelatinization. Thus, the gelatinization may be influenced by the presence, orientation, and nature of surface lipids and proteins. The latter seems to be more responsible for the changes in the surface properties of starch granules during rice storage. As rice aged, it is proposed that the denaturation of protein bodies occurred during the aging process, and this denaturation would be associated with the exposure of hydrophobic groups of protein molecules, which leading to a decrease in the extractability of proteins for each fraction (Zhou *et al*., 2003a). The changes in the granule structure of protein bodies contribute to an increase in hydrophobicity that would affect hydration and swelling of starch granules. Another explanation for this is that the interactions between the starch granules and protein molecules provide the granule a rigidity or strength due to enhanced protein disulfide bridges and inter/intra protein molecular cross-linking in the stored rice samples (Zhou *et al*., 2010; Paraginski *et al*., 2014).

Conclusion

Aging of rice is coincided during harvested to until consumption. It affects the physical and chemical properties of rice, and moreover, physicochemical properties such as pasting properties and cooking properties. Cooked aged rice shows harder texture and is less sticky than cooked fresh rice. This is profound in rice stored at high temperature rather than at lower temperature. Aged rice at higher temperature and longer time had harder texture and much fluffier than fresh rice and also less in stickiness and adhesiveness. Aging of rice showed that viscograms for the BD of rice samples decreased over the time, and the peak seen in aged samples disappeared.

References

Biliaderis, C. G. and Tonogai, J. R. 1991. Influence of lipids on the thermal and mechanical properties of concentrated starch gels. Journal of Agricultural and Food Chemistry 39(5): 833-840.

Champagne, E. T. 2004. Rice: Chemistry and Technology. American Association of Cereal Chemists: Minnesota, U.S.A.

Charoenrein, S. and Preechathammawong, N. 2010. Undercooling associated with slow freezing and its influence on the microstructure and properties of rice starch gels. Journal of Food Engineering 100(2): 310-314.

Chrastil, J. 1990. Chemical and physicochemical changes of rice during storage at different temperatures. Journal of Cereal Science 11(1): 71-85.

Doublier, J. L., Llamas, G. and Le Meur. M. 1987. A rheological investigation of cereal starch pastes and gels. Effect of pasting procedures. Carbohydrate Polymers 7(4): 251-275.

Eliasson, A. C. and Kim, H. R. 1992. Changes in rheological properties of hydroxypropyl potato starch pastes during freeze-thaw treatments. 1. A rheological approach for evaluation of freeze-thaw stability. Journal of Texture Studies 23(3): 279-295.

Evans, I. D. and Lips, A. 1992. Viscoelasticity of gelatinized starch dispersions. Journal of Texture Study 23(1): 69-86.

Fan, J. and Marks, B. P. 1999. Effects of rough rice storage conditions on gelatinization and retrogradation properties of rice flours. Cereal Chemistry 76(6): 894-897.

Indudhara, S. Y. M., Sowbhagya, C. M. and Bhattacharya, K. R. 1978. Changes in the physicochemical properties of rice with aging. Journal of the Science of Food and Agriculture 29(7): 627-639.

Kanlayakrit, W. and Maweang, M. 2013. Postharvest of paddy and milled rice affected physicochemical properties using different storage conditions. International Food Research Journal 20(3): 1359-1366.

Karim, A. A., Norziah, M. H. and Seow, C. C. 2000. Methods for the study of starch retrogradation. Food Chemistry 71(1): 9-36.

Katekhong, W. and Charoenrein, S. 2012a. The effect of rice aging on the freeze–thaw stability of rice flour gels. Carbohydrate Polymers 89(3): 777-782.

Katekhong, W. and Charoenrein, S. 2012b. Effect of rice storage on pasting properties, swelling and granular morphology of rice flour. Asian Journal of Food and Agro-Industry 5(4): 315-321.

Kaur, K. and Singh, N. 2000. Amylose-lipid complex formation during cooking of rice flour. Food Chemistry 71(4): 511-517.

Meullenet, J. F. C., Gross, J., Marks, B. P. and Daniels, M. 1998. Sensory descriptive texture analyses of cooked rice and its correlation to instrumental parameters using an extrusion cell. Cereal Chemistry 75(5): 714-720.

Morris, V. J. 1990. Starch gelation and retrogradation. Trends in Food Science and Technology 1: 2-6.

Nardi, S., Dellungo, T. and Bellopede, M. 1997. Rice quality assessment - Comparison between a traditional method and the hot water soluble amylose determination to evaluate cooking loss. Italian Journal of Food Science 9(1): 57-64.

Noomhorm, A., Kongseree, N. and Apintanapong, N. 1997. Effect of aging on the quality of glutinous rice crackers. Cereal Chemistry 74(1): 12-15.

Ohno, T. and Ohisa, N. 2005. Studies on textural and chemical changes in aged rice grains. Food Science and Technology Research 11(4): 385-389.

Okechukwu, P. E. and Rao, M. A. 1995. Influence of granule size on viscosity of cornstarch suspension. Journal of Texture Study 26(5): 501-516.

Paraginski, R. T., Vanier, N. L., Moomand, K., Oliveira, M., Zavareze, E. R., Silva, R. M., Ferreira, C. D. and Elias, M. C. 2014. Characteristics of starch isolated from maize as a function of grain storage temperature. Carbohydrate Polymer 102: 88-94.

Parnsakhorn, S. and Langkapin, J. 2013. Changes in physicochemical characteristics of germinated brown rice and brown rice during storage at various temperatures. Agricultural Engineering International 15(2): 293-303.

Park, C. E., Kim, Y. S., Park, K. J. and Kim, B. K. 2012. Changes in physicochemical characteristics of rice during storage at different temperatures. Journal of Stored Products Research 48(1): 25–29.

Patindol, J., Wang, Y. J. and Jane, J. I. 2005. Structure-functionality changes in starch following rough rice storage. Starch/Stärke 57(5): 197-207.

Perdon, A. A., Siebenmorgen, T. J., Buescher, R. W. and Gbur, E. E. 1999. Starch retrogradation and texture of cooked milled rice during storage. Journal of Food Science and Nutrition 64(5): 828-832.

Perez, C. M. and Juliano, B. O. 1981. Texture changes and storage of rice. Journal of Texture Studies 12(3): 321-333.

Pushpamma, P. and Reddy, M. U. 1979. Physico-chemical changes in rice and jowar stored in different agro climatic regions of Andhra Pradesh. Bulletin of Grain Technology 17: 97-108.

Saartratra, S., Puttanlekb, C., Rungsardthong, V. and Uttapap, D. 2005. Paste and gel properties of low-substituted acetylated canna starches. Carbohydrate Polymers 61(2): 211-221.

Sesmat, A. and Meullenet, J. F. C. 2001. Prediction of rice sensory texture attributes from a single compression test, multivariate regression, and a stepwise model optimization method. Journal of Food Science 66(1): 124-131.

Singh, N., Kaur, L., Sandhu, K. S., Kaur, J. and Nishinari, K. 2006. Relationships between physicochemical, morphological, thermal, rheological properties of rice starches. Food Hydrocolloids 20(4): 532-542.

Smewing, J. 1999. Hydrocolloids. Gaithersburg, MD: Aspen Publishers.

Sodhi, N. S., Singh, N., Arora, M. and Singh, J. 2003. Changes in physico-chemical, thermal, cooking and textural properties of rice during aging. Journal of Food Processing and Preservation 27(5): 387-400.

Sowbhagya, C. M. and Bhattacharya, K. R. 2001. Changes in pasting behaviour of rice during aging. Journal of Cereal Science 34(2): 115-124.

Tananuwong, K. and Malila, Y. 2011. Changes in physicochemical properties of organic hulled rice during storage under different conditions. Food Chemistry 125(1): 179-185.

Teo, C. H., Abd, A., Cheah, P. B., Norziah, M. H. and Seow, C. C. 2000. On the roles of protein and starch in the aging of non-waxy rice flour. Food Chemistry 69(3): 229-236.

Tsugita, Y., Ohta, T. and Kato, H. 1983. Cooking flavour and texture of rice stored under different conditions. Agricultural and Biological Chemistry 47(6): 543-549.

Tulyathan, V. and Leeharatanaluk, B. 2007. Change in quality of rice (*Oryza sativa* L.) cv. Khao Dawk Mali 105 during storage. Journal of Food Biochemistry 31(3): 415-425.

Vandeputte, E. G., Vermeylen, R., Geeroms, J. and Delcour, J. A. 2003. Rice starch. I. Structural aspects provide insight into crystallinity characteristics and gelatinization behavior. Journal of Cereal Science 38(1): 61-68.

Varavinit, S., Anuntavuttikul, S. and Shobsngob, S. 2000. Influence of freezing and thawing techniques on stability sago and tapioca starch pastes. Starch/Stärke 52(6-7): 214-217.

Wang, J., Zhao, Y. and Bian, K. 1998. Relation of insoluble amylose to texture characteristics of stored-rice. The 7th International Working Conference on Stored-Product Protection, Beijing, China, Sichuan Publishing House of Science and Technology.

Wei, C., Kwon, O. Y., Lui, X., Kim, H. C., Yoo, W. K., Kim, H. M. and Kim, M. R. 2007. Protein profiles of major Korean rice cultivars. Journal of Food Science and Nutrition 12(2): 103-110.

Wiset, L., Laopreasert, P., Borompichaichartkul, C., Poomsa-ad, N. and Tulyathan, V. 2011. Effects of in-bin aeration storage on physical properties and quality of glutinous rice cultivar RD 6. Australian Journal of Crop Science 5(6): 635-640.

Yang, C. Z., Shu, X. L., Zhang, L. L., Wang, X. Y., Zhao, H. J., Ma, C. X. and Wu, D. X. 2006. Starch properties of mutant rice high in resistant starch. Journal of Agricultural and Food Chemistry 54(2): 523-528.

Zhou, Z., Robards, K., Helliwell, S. and Blanchard, C. 2007. Effect of storage temperature on cooking behaviour of rice. Food Chemistry 105(2): 491-497.

Zhou, Z., Robards, K., Helliwell, S. and Blanchard, C. 2002. Aging of stored rice: Changes in chemical and physical attributes. Journal of Cereal Science 35(1): 65-78.

Zhou, Z., Robards, K., Helliwell, S. and Blanchard, C. 2003a. Rice aging: Effect of changes in protein on starch behaviour. Starch/Stärke 55(3): 162-169.

Zhou, Z., Robards, K., Helliwell, S. and Blanchard, C. 2003b. Effect of aging on rice pasting properties. Food Research International 36(6): 625-634.

Zhou, Z., Robards, K., Helliwell, S. and Blanchard, C. 2010. Effect of storage temperature on rice thermal properties. Food Research International 43(3): 709-715.