Research Paper

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Assessment Study of the Effects of Heat Shock Treatment on Rice Quality during Storage—Milled Rice Case

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Abstract

Milled rice (cv. Koshihikari) was subjected to microwave radiation up to three temperature levels of 60, 70 and 80℃ and kept heat-treated for 0, 1 and 3 min, and then stored at 40℃ for 6 months. During storage, the control (non-treated rice) showed an accelerated aging and deterioration processes. There was an initial increase followed by a slight decrease of volume expansion. The water uptake ratio, soluble sugars, total starch and soluble amylose rapidly decreased after first 1 or 2 months and then leveled off or kept low values. An increase of titratable acidity, total amylose and insoluble amylose was also specified. The above changes also occurred in heat shock treated (HST) rice, but with certain extent of delay mainly for the first 1 or 2 months storage. Particularly, the 60 and 70℃ HSTs were effective in retarding aging and deterioration processes of stored rice. Extending the exposure duration pronounced such effects. The results showed that HST would benefit rice quality management during storage.

[Keywords] microwave irradiation, heat shock treatment, milled rice storage, rice quality, aging process, deterioration process

I Introduction

Rice is produced worldwide and is a primary staple food for more than half of the world's population. The rice harvest season is compressed into a relatively narrow time frame, but the grains are processed and consumed throughout the year. In addition, a considerable quantity of rice has to be stored in rotation for the next harvest season as a food security measure. Thus, the quality management of stored rice is important and necessary.

Previous researches have shown that the physicochemical properties of rice grains change during storage. This phenomenon is known as aging. As the rice ages, head rice yield increases, water absorption during cooking increases, and cooked rice texture becomes fluffier and harder (Villareal et al., 1976 ; Indudhara Swanmy et al., 1978 ; Tsugita et al., 1983 ; Chrastil, 1990a ; 1992). The progressive decrease in the amylase content (Desikachar, 1956), hardening of cell wall (Desikachar and Subrahmanyan, 1959), development of free fatty acids and their complexing with starch (Yasumatsu et al., 1964) have been also found out during aging of stored rice. To minimize those changes, low temperature and control atmosphere storage are usually the applied methods. However these techniques are expensive due to high initial cost of cooling systems or special packages as well as maintenance expenses so they cannot be suitably applied in developing countries. Therefore, the search for alternative techniques is desired.

It has been reported by other researchers that heat shock treatment (short time exposure at high temperature) effectively retarded ripening of agricultural products by delaying chlorophyll degradation and pigment formation (Sozzi et al., 1996 ; Tian et al., 1996), delay softening (Shalom et al., 1996 ; Lurie and Nussinovich, 1996), inhibition of ethylene synthesis (Biggs et al., 1988), and inhibition of cell wall degrading enzymes (Yoshida et al, 1984 ; Lurie and Nussinovich, 1996). Heat treatment is considered as an alternative technique for postharvest quality management of agricultural products (Nguyen et al., 2004). Rice is usually exposed to medium heat during drying to reduce moisture content before storage. However, the effect of heat shock treatment on aging and quality of stored rice is rarely reported in literatures.

In order to find an alternative technique for rice quality maintenance, this research is focused on the study of the effects of heat shock treatment on rice quality during storage.

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II Materials and methods

1. Materials

White milled rice (cv. Koshihikari produced in Gifu pref.) was obtained in July 2006. The rice was cleaned and stored in double vinyl bag at room temperature for 3 days for temperature and moisture uniformity.

2. Heat shock treatment source

High Frequency Generator (Type FDU-122DT, Fuji Elec. Ind. Co., Japan) fitted with a time controller was used as a heat shock treatment source. The unit is operated on 200 V, 60 Hz alternating current and emits radiation at a frequency of 2,450 MHz.

3. Heat shock treatments (HSTs)

Separated 100 g rice samples were placed in 200 ml Pyrex beaker (6 cm diameter), which was fitted inside another 300 ml Pyrex beaker containing 75 ml of water. The sets of samples and water were irradiated by rotation inside the Microwave Generator running on a power of 500 W for 2.7, 3.3 and 3.8 min as the temperatures reached 60, 70 and 80℃, respectively. The temperatures of the samples were measured at several places inside the rice mass and recorded as an average of three readings taken immediately after radiation treatments. Just after radiation, the samples were exposed for additionally 0, 1 and 3 min at such high temperatures by keeping them inside an induced hot water beaker. Then the rice was cooled by low humidity air using electric fan fluxing through silica gel for 30 s. After such treatments nine different HST rice samples obtained were 600HST, 601HST, 603HST, 700 HST, 701HST, 703HST, 800HST, 801HST and 803HST, in which the first two numbers refer to treated temperature and the third number is additional exposure time in minutes. Further the performance of physicochemical analysis, one kilogram rice of each HST sample was collected and stored in airtight K-coated nylon polyethylene film bags at 40℃ up to 6 months.

4. Physicochemical measurements

Physicochemical properties were measured immediately after HST and also after 1, 2, 4 and 6 months storage. The moisture content of rice grains was measured by drying duplicate samples for 24 h in an air-ventilated oven at 135℃, while the moisture content of rice flour was measured by drying duplicate samples for 1 h in the air-ventilated oven at 130℃ (AOAC, 1990). The volume expansion was determined by miniaturization of regular test by reading the change in volumes of glass tube containing 2 g rice grains and 4 ml water before and after cooking in an autoclave at 100℃ for 45 min (Indudhara Swamy, 1978). The water uptake ratio was determined by calculating the weight change of 2 g rice grains after cooking with 20 ml distilled water in a boiling water bath for 15 min (Singh et al., 2005). The titratable acidity was expressed as sodium hydroxide required for neutralizing the acids in a 100 g rice flour using phenolphthalein as an indicator (AOAC, 1990). The soluble sugars were estimated by the phenol-sulphuric acid method using glucose as the standard (Dubois, 1951). The total starch was determined by a colorimetric method using anthrone solution (Chrastil, 1990b). The total amylose and soluble amylose were determined by iodine-colorimetric methods (Sowbhagya et al., 1979 ; Shanthy et al., 1980) using petroleum ether as extractor and purified amylose obtained from Sigma Chemicals as the standard.

5. Data analysis

All determinations were carried out in triplicate and analyzed statistically by analysis of variance (ANOVA). The means were compared with the control by the least significant difference (LSD) test at a significance level of 0.05.

III Results and discussion

During storage a range of physicochemical changes affecting rice quality could occur. Therefore in this research any improvement or delay of those indexes was considered as a benefit for quality maintenance of rice.

1. Moisture contents (MCs)

Figure 1 shows the changes in MCs of control (non-HST rice) and HST rice at 60, 70 and 80℃, respectively. During storage the MCs of both control and HST rice decreased continuously. There was no significant difference in moisture change of 60 and 70℃ HST rice in relation to the control sample, while a distinct decrease in moisture content between the 80℃ HST rice and the control was observed.

2. Volume expansion

Figure 2 shows the changes in the volume expansion of both control and HST rice. During storage the volume expansion of control sample increased rapidly, reached maximum value of 57% after 2 months then decreased. Different changing patterns were observed in HST rice. The volume expansion of 60℃ HST rice increased more slowly than that of the control. The volume expansion of 600 HST rice reached maximum value after 4 months and maintained such high value after 6 months storage, while the volume expansion of 601 and 603 HST rice samples continued to increase. The volume expansion of 70℃ HST rice increased rapidly after 1 month then increased slowly up to 6 months storage. The volume expansion of 80℃ HST rice increased rapidly to reach a maximum value after 1 month and then began to decrease afterwards.

As an indirect estimate of the stickiness of cooked rice, the increase of volume expansion during storage has been documented (Indudhara Swamy et al., 1978). In our experiment, the volume expansion of control rice sample increased rapidly during the first 2 months

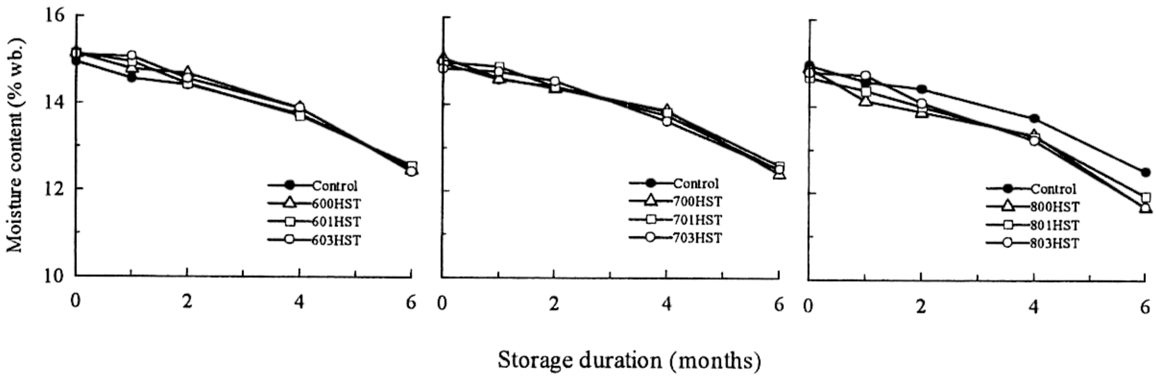

Fig. 1 Changes in the moisture content of heat shock treatment (HST) rice at 60, 70 and 80℃
The terms, 600HST, 601HST and 603HST express the HST conditions of microwave irradiation up to 60℃ and additional outside heat treatment for 0, 1 and 3 min, respectively. The same applies to the other HST conditions.

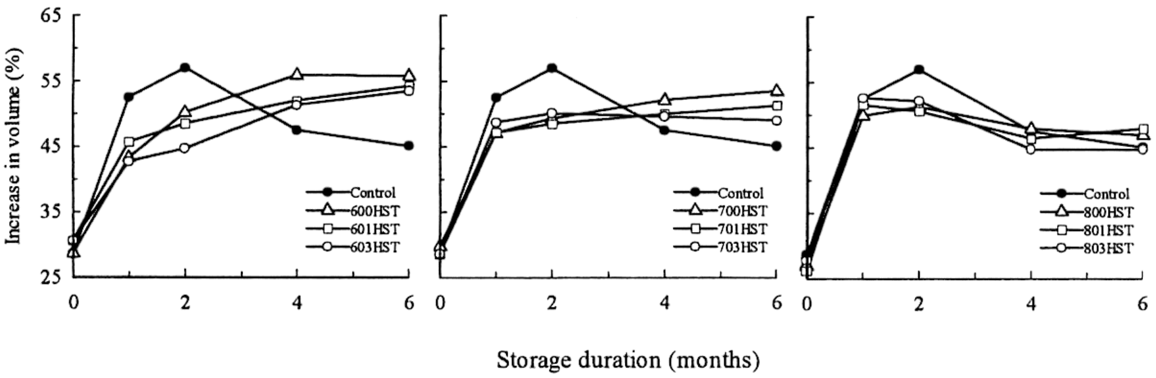

Fig. 2 Changes in the volume expansion of heat shock treatment (HST) rice at 60, 70 and 80℃

storage at 40℃ and decreased afterwards. We considered that the postharvest ripening process would be continued during storage and the rice granules became more stable leading to increase of volume expansion. However for further storage, a range of chemical changes such as lipid oxidation were severe enough to affect the stableness of rice granule resulting decrease of volume expansion. We proposed that aging process and deterioration process would be occurred during storage. The aging process is related to post-harvest ripening period showing increases of volume expansion and peak viscosity (data not shown). The deterioration process is related to significant chemical changes that slowdown the quality by inducing decrease of volume expansion and peak viscosity value (data not shown).

In our experiment the HST affected changing pattern of volume expansion differently. We considered that the levels of appiied heat shock temperature influenced the structural changes of rice granules as well as enzymatic activity differently. We found that HST at 60 and 70℃ effectively delayed increasing rate of volume expansion. Moreover, the delay in volume expansion was more pronounced in HST at 60 and 70℃ for longer exposure duration.

3. Water uptake ratio (WUR)

Figure 3 shows the changes in the water uptake ratio of control and HST rice. The WUR of control rice sample decreased rapidly after 1 month, until the lowest value of 3.6 times was attained and then increased slightly linear afterward. The HST rice attained low WUR value just after HST and decreased rapidly after 1-month storage, however their WUR values were higher than that of the control. The WUR of 60 and 70℃ HST decreased for the next 1 month, increased slightly for the next 2 months then decreased. On the other hand, the WUR of 80℃ HST increased slightly from the 1st to the 4th month storage before decreasing.

It was reported that the WUR of rice decreased during storage (Indudhara Swamy et al., 1978). As the rice ages, their structures become more compact and water is difficult to perform hydrate binding in cooking rice. In our experiment WUR decreased rapidly

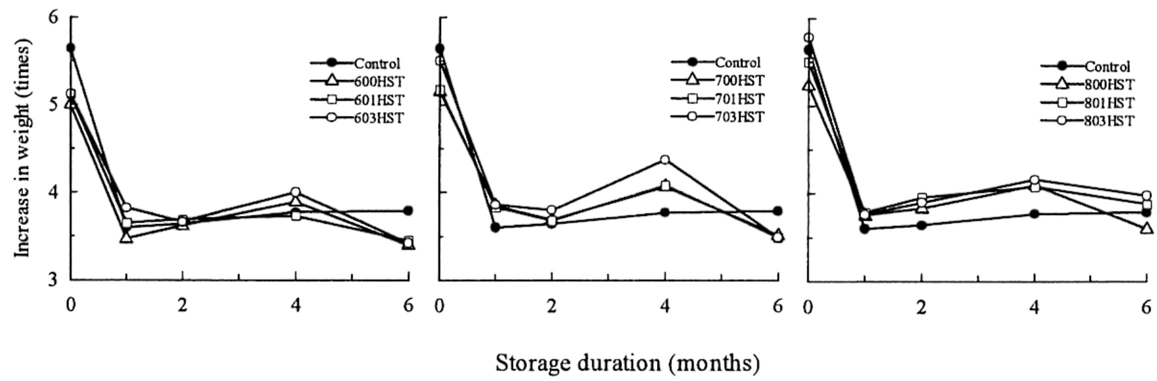

Fig. 3 Changes in the water uptake ratio (WUR) of heat shock treatment (HST) rice at 60, 70 and 80℃

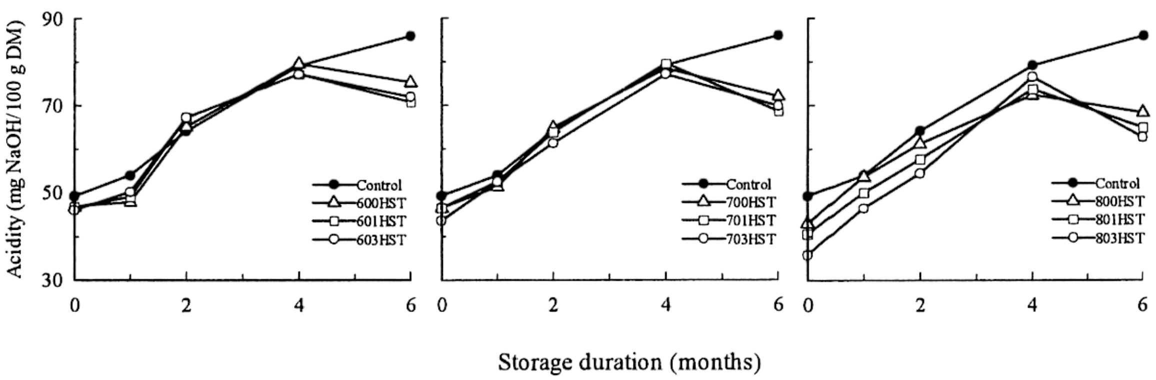

Fig. 4 Changes in the titratable acidity of heat shock treatment (HST) rice at 60, 70 and 80℃

for 1-month storage, then increased slightly. We considered an elevated storage temperature of 40℃ as severe and could accelerate aging and deterioration processes reflecting rapid decrease of WUR during aging for first 1 month of storage and slightly increase afterward. HST could alter the structure of rice starch making it more resistant to hydrate binding, hence lowered WUR values measured immediately after HST. However, the HST could delay the aging process by gradually decreasing the rate of WUR of HST rice samples.

4. Titratable acidity

The changes in titratable acidity are shown in Fig. 4. During storage the titratable acidity of control sample increased continuously to a high value of 85.9 mg NaOH/100 g DM after 6 months. The titratable acidity of 60 and 70℃ HST rice samples increased similarly to the control for up to 4 months, and then decreased. The 80℃ HST rice showed low titratable acidity just after HST. During storage their titratable acidity increased, reached a peak after 4 months and then decreased afterwards. Their values were lower than that of control sample.

The increase in the acidity of stored grains reported by Rehman (2006) was due to the increasing concentration of the free fatty acid and phosphate, which resulted from increased grain deterioration (Morrison, 1963). The elevated storage temperature could also promote increase of acidity due to advanced Maillard reaction (Fargerson, 1969 ; Gardner, 1979). In our experiment, HST effectively reduced titratable acidity of rice after 6 months storage. Remarkable reduction of the effect of acidity was observed in HST rice at higher temperature or with longer exposure time.

5. Soluble sugars

Figure 5 shows the change in the soluble sugars of control and HST rice. The soluble sugars of control sample decreased rapidly for first 2 months, attained value of 347.4 mg Glucose/100 g DM and then decreased slightly. The soluble sugars of HST rice, which were measured just after HST, were little higher than that of the control sample. The values however, decreased rapidly for the next 2 months and then gradually decreased afterward. Interestingly, after 1-month storage the soluble sugars of 60℃ HST rice were higher than the control while those of 70 and 80℃ HST rice were almost the same except the soluble sugars of 80℃ for 3 min HST rice which was significantly higher than the control. In general, the 80℃ HST rice showed higher soluble sugars than control

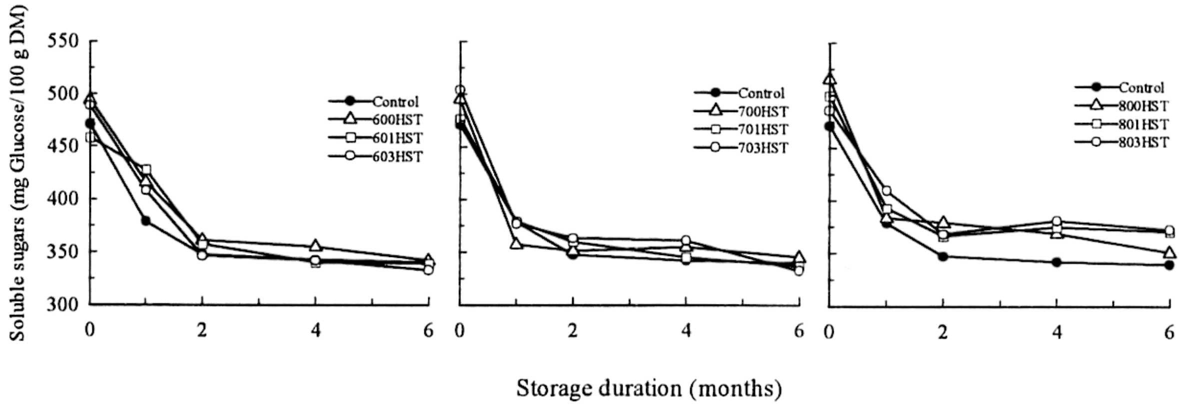

Fig. 5 Changes in the soluble sugar content of heat shock treatment (HST) rice at 60, 70 and 80℃

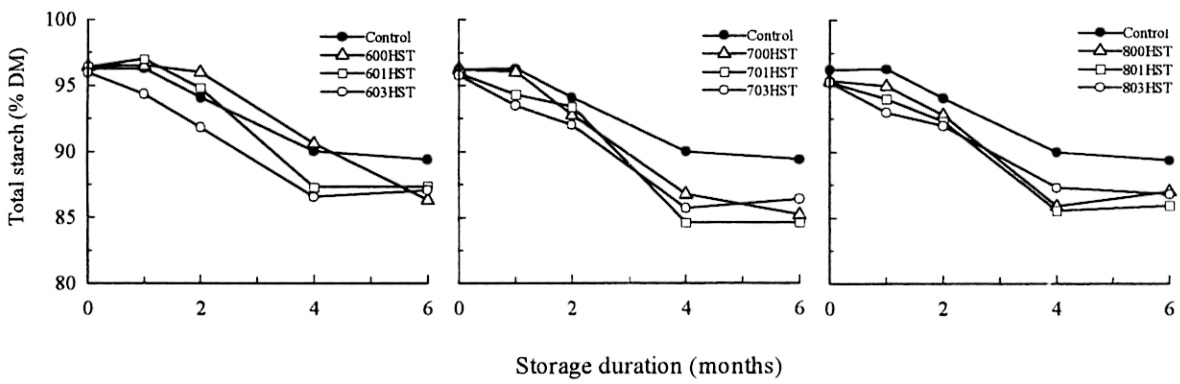

Fig. 6 Changes in the total starch content of heat shock treatment (HST) rice at 60, 70 and 80℃

sample throughout the storage period.

The decrease of soluble sugars during storage at elevated temperature has been mentioned by other researchers, and this phenomenon is attributed to the effects of Maillard reactions (Rehman, 2006 ; Glass et al., 1959). It was realized in this study that, storage temperature of 40℃ was severe therefore rice-aging processes could occur within the first 2 months followed by deterioration processes. In the case of HST rice, higher content of soluble sugars could be formed due to breaking the linkage inside polysaccharides such as amylopectin and amylose. The HST at 60℃ retarded decreasing rate of soluble sugars for first 1-month storage. The 80℃ HST provided favorable conditions for keeping higher values of soluble sugars for long-term storage.

6. Total starch

Figure 6 shows the changes in the total starch content of control and HST rice. The total starch of control rice remained high at 96.3% DM after 1-month storage and then decreased. The total starch of HST rice was similar to the control just after HST, and remained in such high value after 1 month. The 600, 601, 700 and 800 HST rice having short exposure time maintained higher values, while those exposed for longer durations maintained lower values. After 1 month of storage, the total starch of HST rice decreased continuously and was lower than control.

It was reported that during storage the total starch of rice did not change, however after longer storage some increase in starch degradation products was observed (Desikachar, 1956). In our experiment, the total amount of starch in the control rice remained high for the first 1 month at 40℃ and then decreased. We considered that, the rice aging occurred for the first 1-month storage, and then deterioration processes followed. Regarding HST rice samples, the low total starch value, which was obtained in HST samples during next 2, 4 and 6 months storage, could be due to the formation of other components such as non-starch polysaccharides (for example water-soluble polysaccharides and insoluble dietary fiber). However, further studies are required to clarify the authenticity of those changes.

7. Amylose contents

Figure 7 shows the changes in total amylose content of control and HST rice samples. The total amylose of control sample decreased slightly for first 1

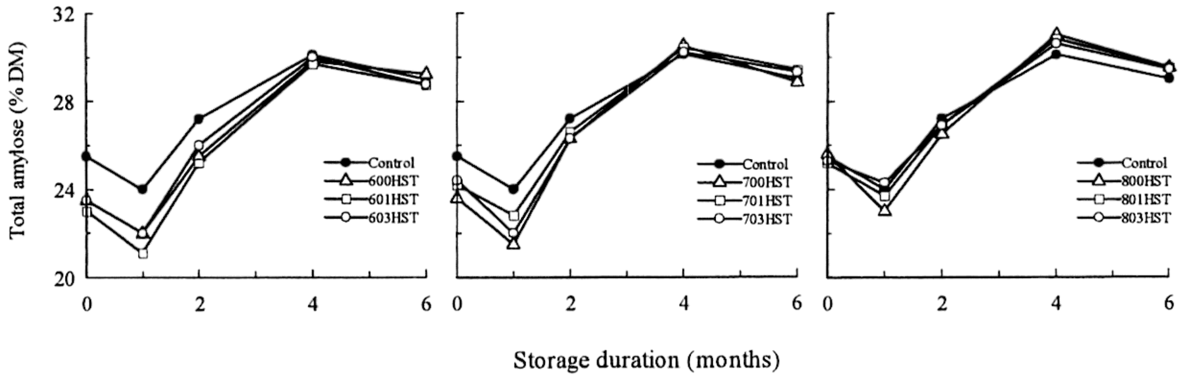

Fig. 7 Changes in the total amylose content of heat shock treatment (HST) rice at 60, 70 and 80℃

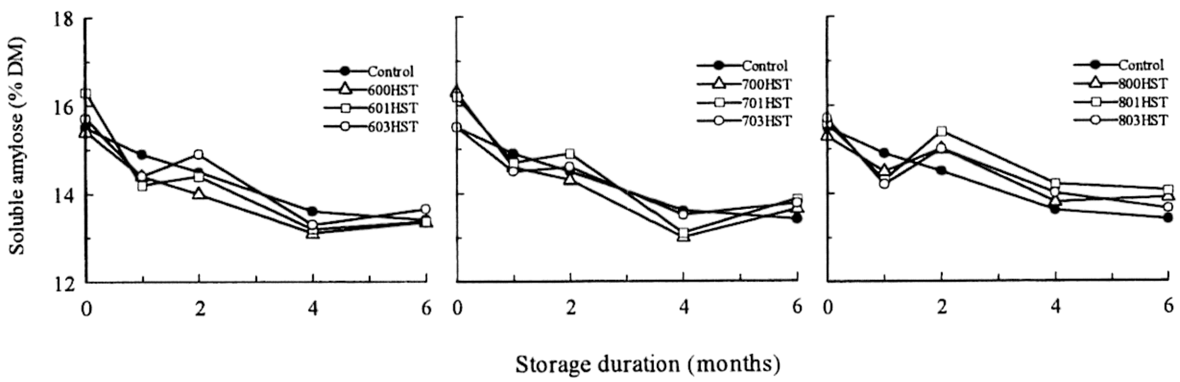

Fig. 8 Changes in the soluble amylose content of heat shock treatment (HST) rice at 60, 70 and 80℃

month, increased rapidly for next 3 months and decreased afterward. The total amount of amylose obtained under 60 and 70℃ HST was lower than the control just after HST. It decreased slightly for the first 1 month, increased rapidly for next 3 months then finally decreased. The 80℃ HST samples showed total amylose changes similar to that of control sample.

The changes in soluble amylose are shown in Fig. 8. During storage the soluble amylose of control sample decreased to attain a low value of 13.4% DM after 6 months storage. The soluble amylose of HST decreased for first 1 month, increased slightly for next 1 month and then decreased.

Figure 9 also shows the changes in insoluble amylose of both control and HST rice, which was determined as a difference between total and soluble amylose. The insoluble amylose of control rice decreased slightly for the first 1 month then increased rapidly to reach a maximum value of 16.5% DM after 4 months before decreasing. The insoluble amylose of 60 and 70℃ HST rice was significantly lower than that of control rice just after HST, remained low for the first 1 month, and then increased rapidly to a peak after 4 months and then decreased afterward. On the other hand, the 80℃ HST rice showed that the changes in insoluble amylose were similar to that of control sample.

The amylose content is the most important determinant of rice quality, in which the water-insoluble amylose content correlated very significantly with the pasting behavior and textural attributes of rice (Bhattacharya et al., 1978 ; Bergman et al., 2004). For determination of amylose content the iodine colorimetric method is commonly used and has been accepted as an official method. The method is based on the fact that iodine complexes with amylose, and this reaction can be measured spectrophotometrically. However, native lipids compete with iodine in forming a complex with amylose, and then depending on defatting or nondefatting process the reading value of amylose could be differed. Since defatting process is time consuming, for convenience the conversion factor is used to correct the result and the value of this factor is varied between 1.16–1.29 (Bergman et al., 2003). In our experiment the amylose content of rice was determined as the rice has been defatted, thus the obtained result might be higher than that of undefatted rice method, which is accepted in Japan.

It was reported that during storage the total amylose remained almost unchanged while soluble amy-

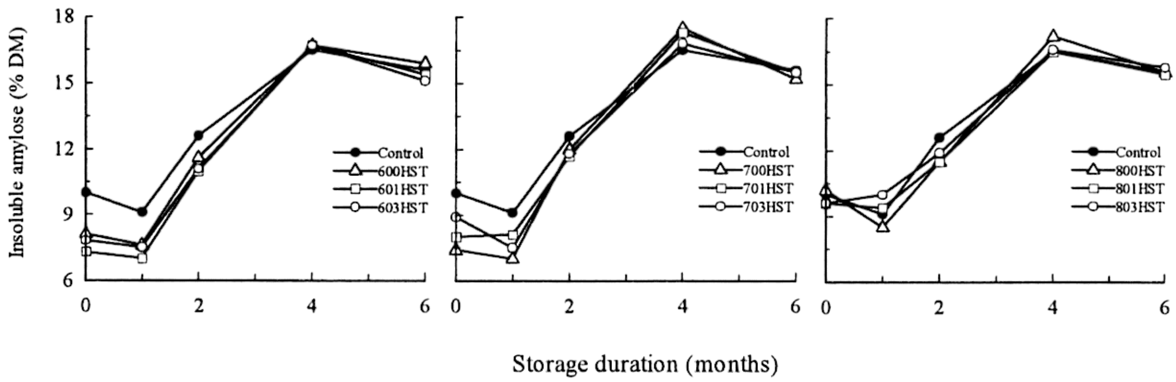

Fig. 9 Changes in the insoluble amylose content of heat shock treatment (HST) rice at 60, 70 and 80℃

lose decreased and insoluble amylose increased (Indudhara Swamy et al., 1978). However, for long-term storage or at severe storage conditions, the increase of amylose content was observed and was considered to be caused by the changing molecular weight of amylopectine by which more amylose was formed (Chrastil, 1990b). In our research the decrease of amylose content after the first 1 month of storage was related to changing storage temperatures. Before storage the amylose of rice was determined as rice at normal temperature. For the first 1 month the rice was stored at 40℃, at such high temperature some changes in amylose content occurred leading to the formation of linkage with amylopectine hence the amylose content temporary decreased.

Regarding HST in this experiment, we observed that the microwave heat-treated temperatures of 60 and 70℃ were effective in lowering initial total amylose and insoluble amylose as well as maintaining their low contents after 2-months of storage at 40℃. We also observed that the lower total amylose was accompanied with higher soluble sugars under 60 and 70℃ HST rice in relation to control sample. We suggested that these HSTs transformed rice starch, among which is the total amylose, into more simple forms such as soluble sugars. Therefore, 60 and 70℃ HSTs not only retarded the aging process but also improved quality of stored rice.

V Conclusion

In the present study, a range of physicochemical parameters, which characterize rice quality, has been examined. For the control rice, storage temperature of 40℃ was severe and the changes were accelerated. The obtained data would be useful for evaluation of rice quality during long-term storage. The effects of HST were carefully examined. The HSTs of 60 and 70℃ effectively delayed aging processes for up to 2 months storage at 40℃, which could be much longer in normal storage condition. The treated temperature and exposure time influenced strongly quality of stored rice thus their utilization should be carefully managed. More importantly, the HST could retard aging processes and improve rice quality. Therefore this technique would be practically useful. In the present research, HST was applied to the milled rice, which is one of common forms of rice storage. This research is the first step to determine the effects of HST on quality management of stored rice. A much further works are needed and now we are concentrated in evaluation the effects of HST on other rice properties as well as stored rice forms.

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「研究論文」

貯蔵米の品質維持に対するヒートショック処理効果の研究 —白米について—

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要　旨

白米（コシヒカリ，2005年岐阜県産）に対して熱処理を行い，その後の貯蔵中における品質維持に対する効果を検討した。加熱機器として，一様加熱が可能な熱源としてマイクロウェーブを使用し，加熱温度を60，70，80℃，それぞれの温度について保持時間を0，1，3分に設定した。熱処理後，40℃の過酷な条件で6ヶ月間貯蔵し，経時的に各種の品質指標の変化を測定した。無処理の対照区については高温貯蔵のため，熟成過程（aging）およびそれに続く老化過程（deterioration）は次のとおり促進された。つまり，炊飯時の容積膨張率は初期に増加し，その後ゆるやかに減少する傾向を示した。加熱吸水率，可溶性糖含量，総デンプン含量および可溶性アミロース含量は処理後の1〜2ヶ月で急激に減少し，その後は低い値で推移した。滴定酸度，総アミロース含量，不溶性アミロース含量はいずれも増加した。一方，ヒートショックを受けた米も上記のような傾向を示すが，その変化は特に処理後の1〜2ヶ月において遅延した。60℃と70℃でのヒートショックが熟成，老化過程の遅延に効果的であることが明らかとなった。今回の実験の範囲では，処理温度が同じ場合，温度の保持時間が長いほどその効果が大きい傾向が見られた。実験結果を総合的に判断すると，ヒートショックは貯蔵中の白米の品質管理に有効であることがわかった。

［キーワード］マイクロウェーブ加熱，ヒートショック処理，白米貯蔵，米品質，熟成過程，老化過程

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コ メ ン ト

[Referee comment]

The changes of the physicochemical properties 2–3% decrease in moisture content, 20–30% increase in volume of cooked rice, 5–10% decrease in total starch and 4–6% increase in total amylose content of the stored rice sample were very big changes. I wonder there were also big changes in appearance (color) and smell (aroma) of the samples. Do you have any plan to conduct sensory evaluation of the samples?

[Reply to the comment]

In this research the rice was stored at 40℃ for up to 6 months. Certainly at such severe temperature the storage period of 6 months was quite enough inducing a range of physical, physicochemical and pasting property changes of rice. Together with physicochemical measurements we conducted also some physical evaluations such as surface appearance color, fissuring degree, and others using Grain Kernel Distinction Device. We observed a significant change in surface appearance color of rice due to the decreasing whiteness of milled rice during storage. Regarding aroma of rice, the sensory evaluation also confirmed that the smell of rice was becoming bad or offensive (stale odor). We would like to document such changes in upcoming reports.