Research Paper

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# Quality Evaluation of Long-Term Stored Rice by Pasting Properties

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**Abstract**

Rough rice (cv. Hatsushimo) was stored at four moisture contents (MCs) of 11.1, 12.8, 14.7, 17.6% and three temperatures of 4, 20 and 35℃ for up to 17 months. During storage, the overall pasting properties of the rice flour changed depending on storage conditions. For the rice stored at 4℃, the peak viscosity was almost constant during the first storage period after which it increased slightly, but setback viscosity and final viscosity remained constant. Increases in the peak viscosity, setback viscosity and final viscosity were observed in the rice stored at 20℃. The rapid changes in these parameters were observed particularly in the rice stored at 35℃. The MC also affected the rate of change. The pasting temperature did not change in the rice stored at 4 and 20℃ for all MC levels, but started to increase rapidly after 3 to 9 months at 35℃. A statistical analysis showed a complicated influence of storage period, temperature, MC and their interaction to the pasting properties of long-term stored rice.

[Keywords] rice storage, aging process, pasting properties, storage temperature, moisture content

## I Introduction

Rice is produced worldwide and is a primary staple food for more than half the world's population. The rice harvest season is compressed into a relatively narrow time frame, but the grains are processed and used as food throughout 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 long-term storage and preservation of rice quality 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 et al., 1990 ; 1992). One of the most sensitive indices of the aging process in rice is the change in pasting properties by amylograph. During storage, amylograph peak viscosity of rice flour increases (Induhara Swamy et al., 1978 ; Dhaliwal et al., 1991 ; Matsue et al., 1991 ; Pearce et al., 2001), with the most significant changes during the first three months (Peres and Juliano, 1981). Storage conditions also affect the rice pasting properties. It has been reported that, the increase in storage temperature promoted the increase in the peak viscosity (Yasumatsu et al., 1964 ; Villareal et al., 1976 ; Perdon et al., 1997). Although many studies to elucidate such changes in rice pasting properties during storage have been done, most of these studies were conducted within short-term period. Thus, the obtained information could not be applied to evaluate the quality of the rice stored for long-term durations such as a period of over 1 year.

With the purpose of further investigating about the influence of temperature, MC and storage period on pasting properties of stored rice under long-term storage, we desired to evaluate the rice quality by pasting properties under different storage conditions.

## II Material and methods

### 1. Preparation of rice for storage

Rough rice (cv. Hatsushimo) was harvested from the Experimental Farm belonging to the Faculty of Agriculture, Gifu University in October 2000. Immediately after harvest, the rough rice was dried and rice samples at 17, 15, 13 and 11% MC in wet basis were taken as a subject of the study. The real MCs were measured by drying duplicate samples for 24 hrs in the air-ventilated oven at 135℃ and the obtained values were 17.6%, 14.7%, 12.8% and 11.1%, respectively. After 3 days tempering at room temperature for moisture conditioning, each lot of rice at the different MCs was divided into three K-coated nylon polyethylene bags. To minimize loss, each of the bags

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consisted of a double-layered films. For each MC, one bag of 2.5 kg rice was stored in temperature-controlled chambers at 4, 20 and 35℃ and the total of 12 lots of rough rice were under long-term storage up to 17 months.

**2. Preparation of rice samples for measurement of pasting properties**

During storage in every month, the rice sample of 160 g was taken from every lot, allowed to equilibrium to room temperature before subsequent procedures. The MC of samples was re-measured. The rough rice samples were hulled using the impeller type huller (Otake, FC1K). The obtained brown rice was separated using thickness grader (Satake, TWS) to eliminate small fractions below 1.8 mm. The selected brown rice was milled by the abrasive type rice mill (Satake, TM02A) with the milling ratio of 90±0.5%.

**3. Measurement of pasting properties**

The pasting properties were measured using the Rapid Visco-Analyzer (RVA) (Newport Scientific). The procedures are accorded to an approved method 61-02 (AACC, 2000) as follows :

i. Switch on the RVA model and allow 30 min warm up. Switch on associated computer, run the RVA control software, and enter the profile shown in Table 1. Enter a file name to save the data.
ii. Measure 25±0.05 ml of distilled water into a new cannister.
iii. Grind a representative sample into powder using the vibrating type mill (Heiko, TI-100). Weigh 3±0.01 g rice flour (12% moisture basis) into a weighing vessel and transfer sample onto the water surface.
iv. Place a paddle into the canister and vigorously jog the blade through the sample up and down 10 times. If any lumps remain on the water surface or adhere to the paddle the repeat the jogging action.
v. Record the parameters : In our experiment, the peak viscosity (PV), setback viscosity (SV), final viscosity (FV), and pasting temperature (PT), which are most typical parameters, were selected as subjects of evaluations as illustrated in Fig. 1.

Table 1 Profile of heating pattern using Rapid Visco-Analyser for measurement of pasting properties of rice during long-term storage

| Step | Temperature (℃) | Time (min) |
|---|---|---|
| | 50.0 (Idle temperature) | 0 |
| 1 | 50.0 | 1.0 |
| 2 | 95.0 | 4.8 |
| 3 | 95.0 | 7.3 |
| 4 | 50.0 | 11.1 |
| End of the test | | 12.5 |

**4. Data analysis**

Multiple regression analysis of the data was performed to determine the variables that contributed significantly ($P<0.05$) to the PV, SV, FV and PT.

## III Results and discussion

**1. Moisture contents (MCs)**

Figure 2 shows the changes in MCs of long-term stored rice at different temperatures. We observed that, during storage the MCs of rice almost remained as the initial values. We considered that in the present experiment the rice was stored in double-layered bags, which effectively prevented the penetration or diffusion of humid air.

**2. Peak viscosity (PV)**

Figure 3 shows the changes in the PV of rice stored at different storage conditions. At 4℃, the PV of rice stored at all MC levels was low and remained almost constant for the first 5 months of storage. During the following storage, the PV of rice stored at 11, 13 and 15% MC increased slightly, while a distinct increase in the PV was observed in rice stored at 17% MC. At 20℃, the PV of rice stored at 11, 13 and 15% MC increased continuously during storage and still did not reach a maximum value yet, while a rapid increase in PV was observed in rice stored at 17% MC and a maximum value was attained after 13 months storage. At 35℃, the PV in rice stored at all MC levels changed rapidly, attained the maximum value before decreasing. At this temperature, the storage period where the PV attained the maximum value was 3, 4, 5 and 7 months for the rice stored for 17, 15, 13 and 11% MC, respectively. In addition, the almost similar maximum PV values of 448, 448 and 444 RVU (rapid visco unit) were found out in the rice stored at 15, 13 and 11% MC were while the lower maximum PV value of 415 RVU was observed in rice stored at 17% MC content.

It has been reported that the PV is one of the most important pasting properties (Induhara Swamy et al., 1978 ; Matsue et al., 1991). The PV occurs at the equilibrium point between swelling and rupture of rice starch granules during the boiling process and indicates the water-binding capacity of the starch (Newport scientific, 1995). Therefore, a change in the PV would affect the water uptake and quality of cooked rice. In this experiment, an increase in PV was observed in all stored rice and was in accordance with previous studies (Perdon et al., 1997). However, in their research Perdon et al. (1997) also reported about the occurrence of a maximum value of the PV at all storage temperatures of 4, 20 and 35℃ between 1 to 3 months storage, but they could not explain this phenomenon. Regarding our data, the maximum value of

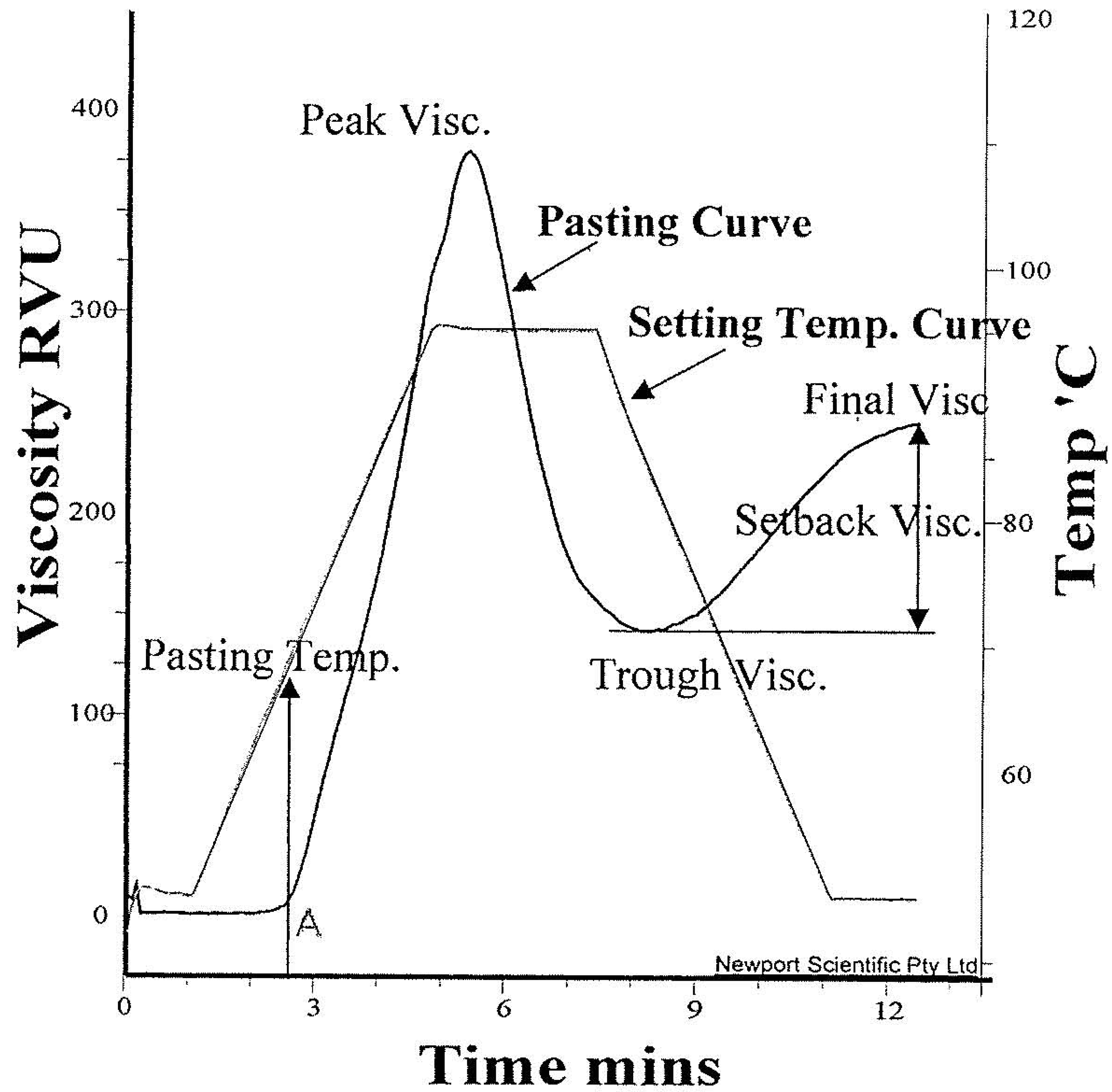


Fig. 1 Typical RVA pasting curve with the commonly measured parameters

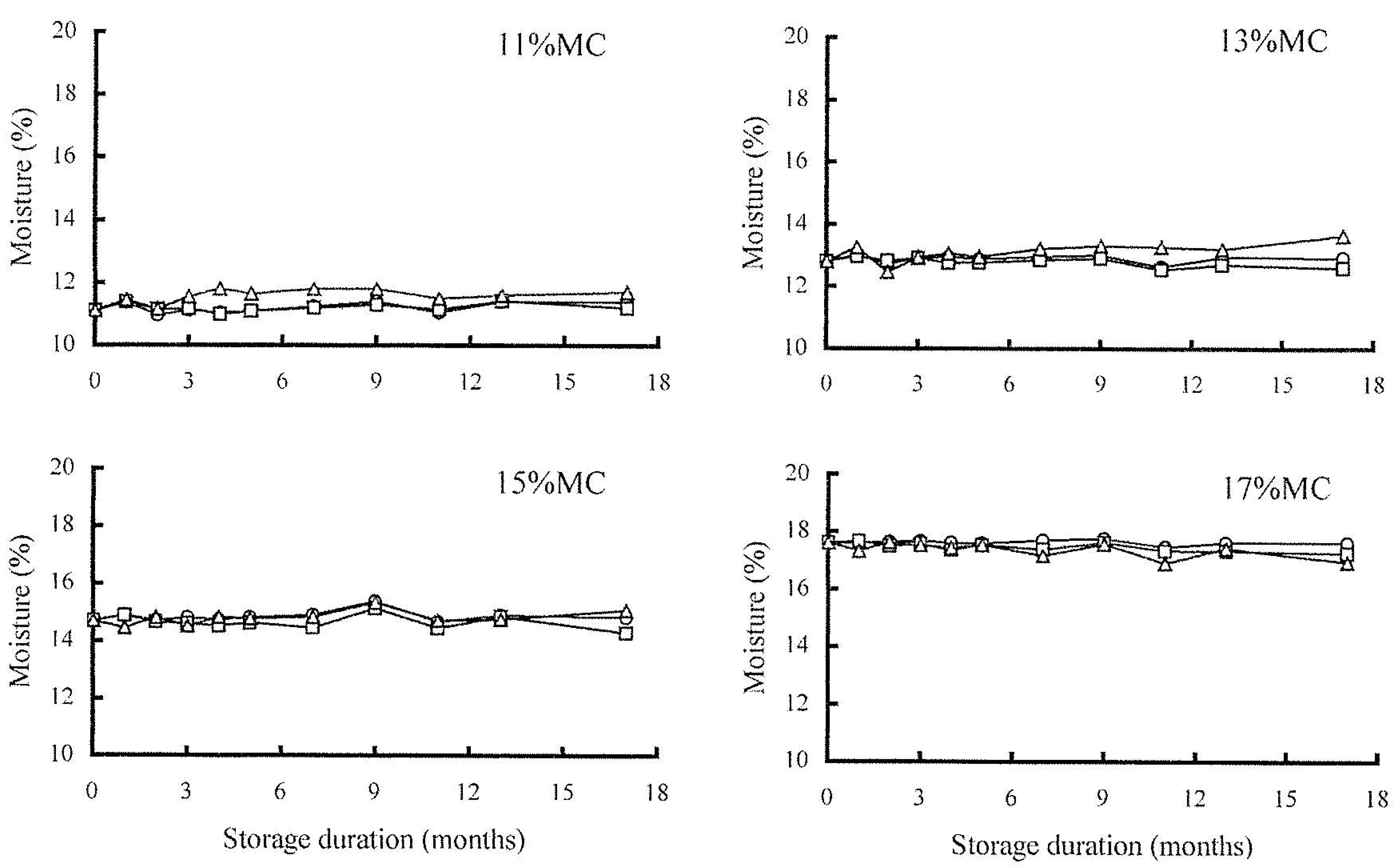


Fig. 2 Change in the moisture content of rice during storage
The (○), (□) and (△) marks represent the storage temperature of 4, 20 and 35℃, respectively

PV was detected only in rice stored at 35℃ and 17% MC rice at 20℃. We suggested that such storage conditions were severe and might provoke considerable physicochemical changes in stored rice, inducing a rapid change in PV value. Consequently, the maximum value of PV was observed firstly in these rice

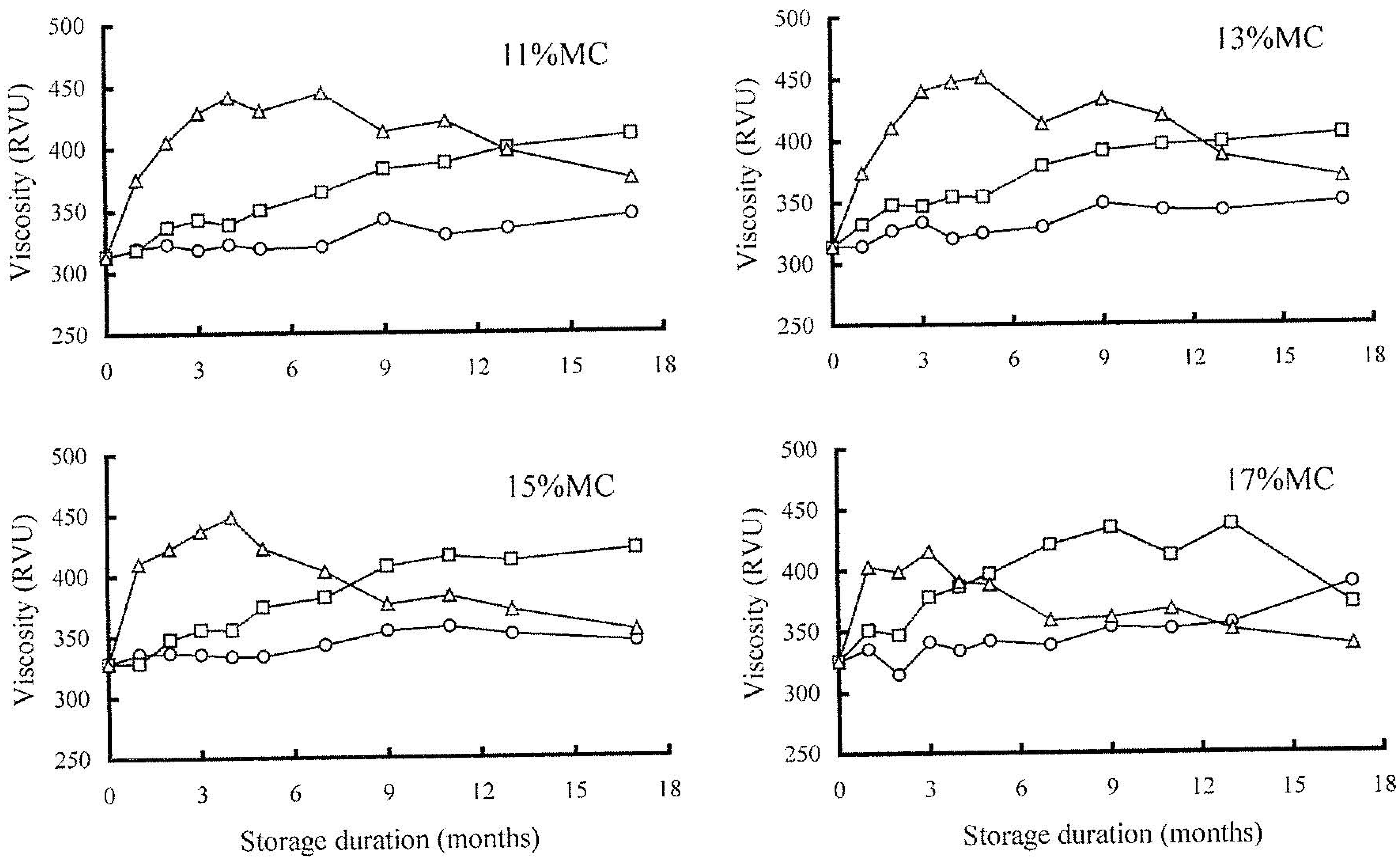


Fig. 3 Change in the peak viscosity of rice during storage at different temperatures and moisture contents (MCs) The (○), (□) and (△) marks represent the storage temperature of 4, 20 and 35℃, respectively

samples. With a decrease in storage temperature such as in the case of 20 and 4℃, the rate of these physicochemical changes was reduced so the PV changed more slowly and an increase in PV was still observed even after 17 months. The decrease in PV of the rice stored at 35℃ after reaching maximum values is another phenomenon. As the aging process has been accompanied with an increase in PV (Matsue et al., 1991 ; Pearce et al., 2001), we suggested that the decrease in PV might be related to degradation process of rice starch.

**3. Setback viscosity (SV) and Final viscosity (FV)**

Figure 4 shows the change in the SV of rice stored at different storage conditions. The SV was determined as difference in FV and trough viscosity (Fig. 1). During storage at 4℃, the SV of rice stored at all MC levels changed inconsiderably and the value was about 100 RVU. At 20℃, the SV of rice stored at 11, 13 and 15% MC remained a constant value during the first 5 months of storage, and increased slightly afterwards. On the other hand, the SV of rice stored at 17% MC increased during the first 9 months of storage, attained the maximum value then decreased. At 35℃, the SV increased steadily in rice stored at all MC levels.

Figure 5 shows the change in the FV of rice stored at different storage conditions. During storage at 4℃, the FV of rice stored at 11, 13 and 15% MC changed inconsiderably and the values fluctuated between 230-250 RVU. The FV of rice stored at 17% MC changed slightly for the first 11 months of storage, after that increased and reached a value of 283 RVU after 17 months. At 20℃, the FV of rice stored at 11, 13 and 15% MC had an increasing tendency showing values of 273, 270 and 283 RVU after 17 months storage, which were about 15% higher than the initial values. The FV of rice stored at 17% MC increased and reached its maximum value after 9 months of storage then decreased. At 35℃, the FV of rice stored at all MC levels increased rapidly during storage.

The SV and FV are other important pasting properties. These two parameters are closely related to retrogradation behavior or re-ordering of the starch molecules. The SV correlates with texture of products, while the FV directly determines the quality of cooked rice upon indication ability to form a viscous paste or gel after boiling and cooling (Newport scientific, 1995). In this experiment, the changes in both the SV and FV are strongly depended on storage temperature. During storage, the temperatures of 20 and 35℃ induced an increase in SV and FV values, while temperature of 4℃ did not affect them. It has been reported that during storage many of the physicochemical changes are temperature dependent and are minimized by cold storage (Okabe, 1979). In our experiment the stirring numbers, which represent the amylase activity, increased with increase in stored temperature (data not shown). We suggested that the temperatures of 20 and 35℃ might activate many physicochemical changes in rice such degradation of

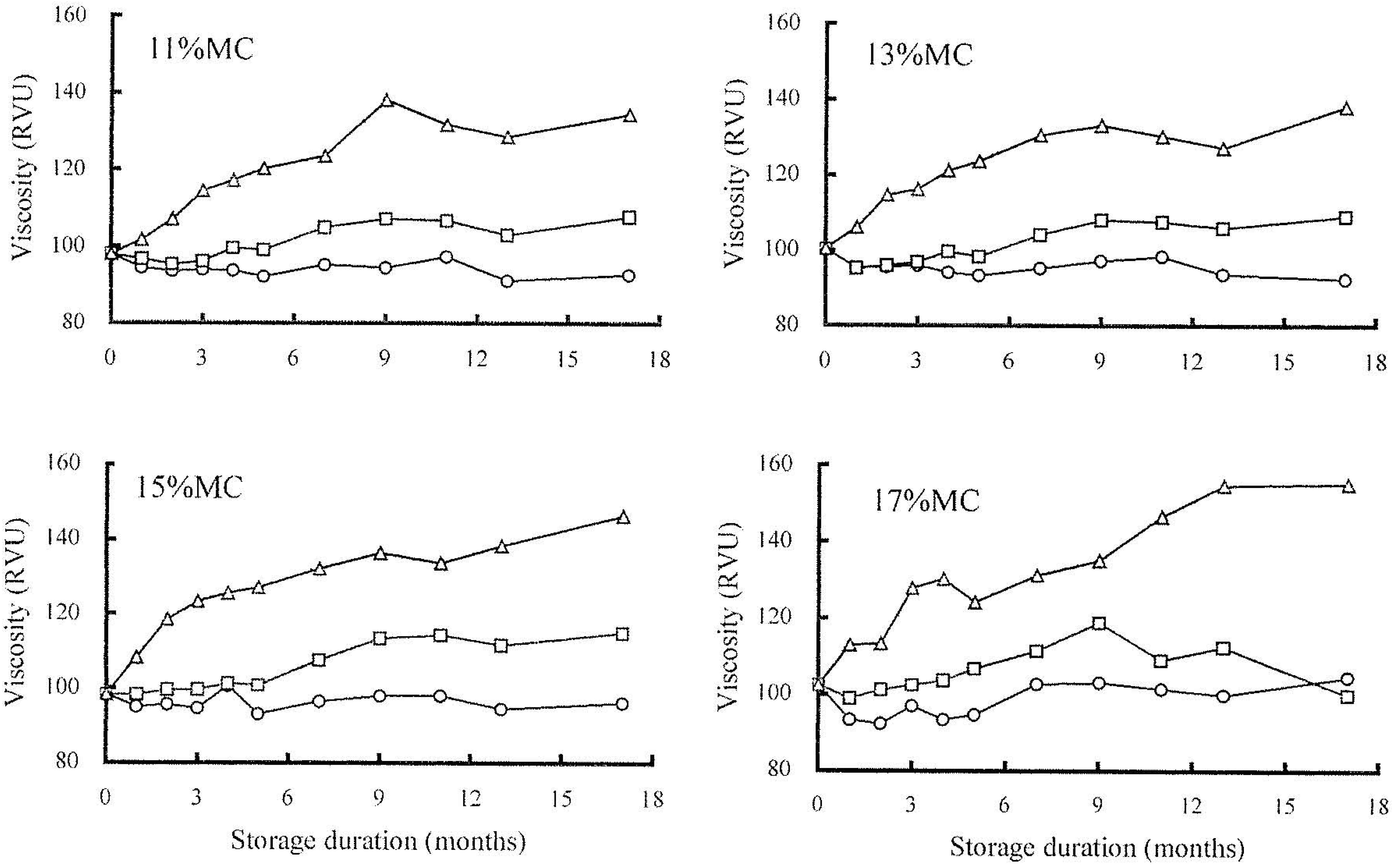


Fig. 4 Change in the setback viscosity of rice during storage at different temperatures and moisture contents (MCs) The (○), (□) and (△) marks represent the storage temperature of 4, 20 and 35℃, respectively

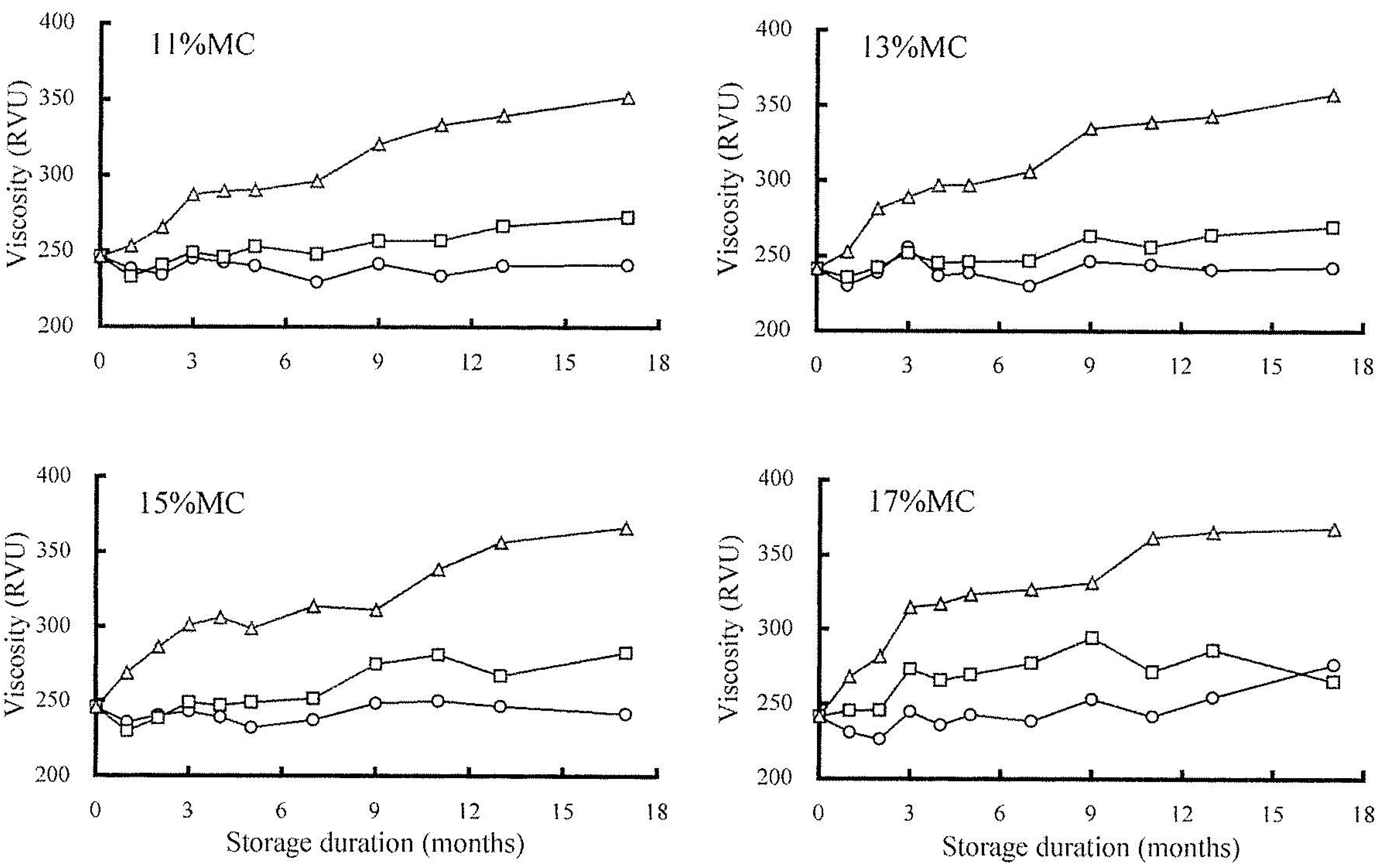


Fig. 5 Change in the final viscosity of rice during storage at different temperatures and moisture contents (MCs) The (○), (□) and (△) marks represent the storage temperature of 4, 20 and 35℃, respectively

more complex structures as starch to more simple compounds as amylose. Consequently, the existence of these compounds leads to form a more stable gel after cooking, which shows increases in SV and FV values.

**4. Pasting temperature (PT)**

Figure 6 shows the change in the PT of rice stored at different storage conditions. During storage at 4 and 20℃, the PT of rice stored at all MC levels changed inconsiderably and varied around 69℃. At 35℃, the PT remained constant for the first storage period of 2 to 9 months, after that significantly increased. The period within which PT remained constant was inversely related to MC. For example, in the case of rice stored at 17% MC, the period was 2 months, while in the case of rice stored at 11% MC the period was 9 months.

The PT is a temperature when viscosity starts to increase during boiling process (Fig. 1). This temperature relates to resistance of starch granules under high temperature (Newport scientific, 1995). The PT indicates the minimum temperature required to transfer the rice starch from beta to alpha structure. Using the PT, we could implicate the stability of rice starch as well as energy costs. Despite of its important role, the research on the PT is rare. In our experiment, the full change in the PT of the rice under different storage conditions during long-term storage was examined. We observed that the storage temperature of 4 and 20℃ did not affect the PT value. However, the temperature of 35℃ seriously affected this parameter. Interestingly, even at 35℃, the PT remained constant value for certain initial storage period, after that this value increased abruptly. The increase in the PT of rice stored at 35℃ was observed in relation with decrease in PV value (Fig. 3 and 6) and reflected the increasing resistance of starch granules during the boiling process. Furthermore, the increase in the PT in Fig. 6 also corresponded with a decrease in the milling time of rice samples (data not shown). Therefore, we suggested that the physicochemical properties of the rice might have undergone remarkable change. Consequently, future work will seek to explain the fundamental cause of this phenomenon.

**5. Aging phenomenon**

In the present study, the dynamic changes in the pasting properties were observed during long-term storage under different storage conditions. In addition, these changes differed between the examined parameters showing differences in the rice quality during storage. It has been reported that at 15℃, the changes in physicochemical properties of rice were most significant during the first 3 to 4 months of storage (Perez and Juliano, 1981). This phenomenon is known as aging. In our experiment, the changes in pasting properties were strongly dependent on stored temperatures and MCs. Higher temperatures and MCs accelerated these changes, while low temperatures such as 4℃ were effective in maintaining the values of pasting properties or changed them inconsiderably during 17 months of storage. With all the above observations, we assumed that the aging process could be a function of storage conditions such as temperature and rice MC. The statistical analysis and establishment of functional properties could be useful

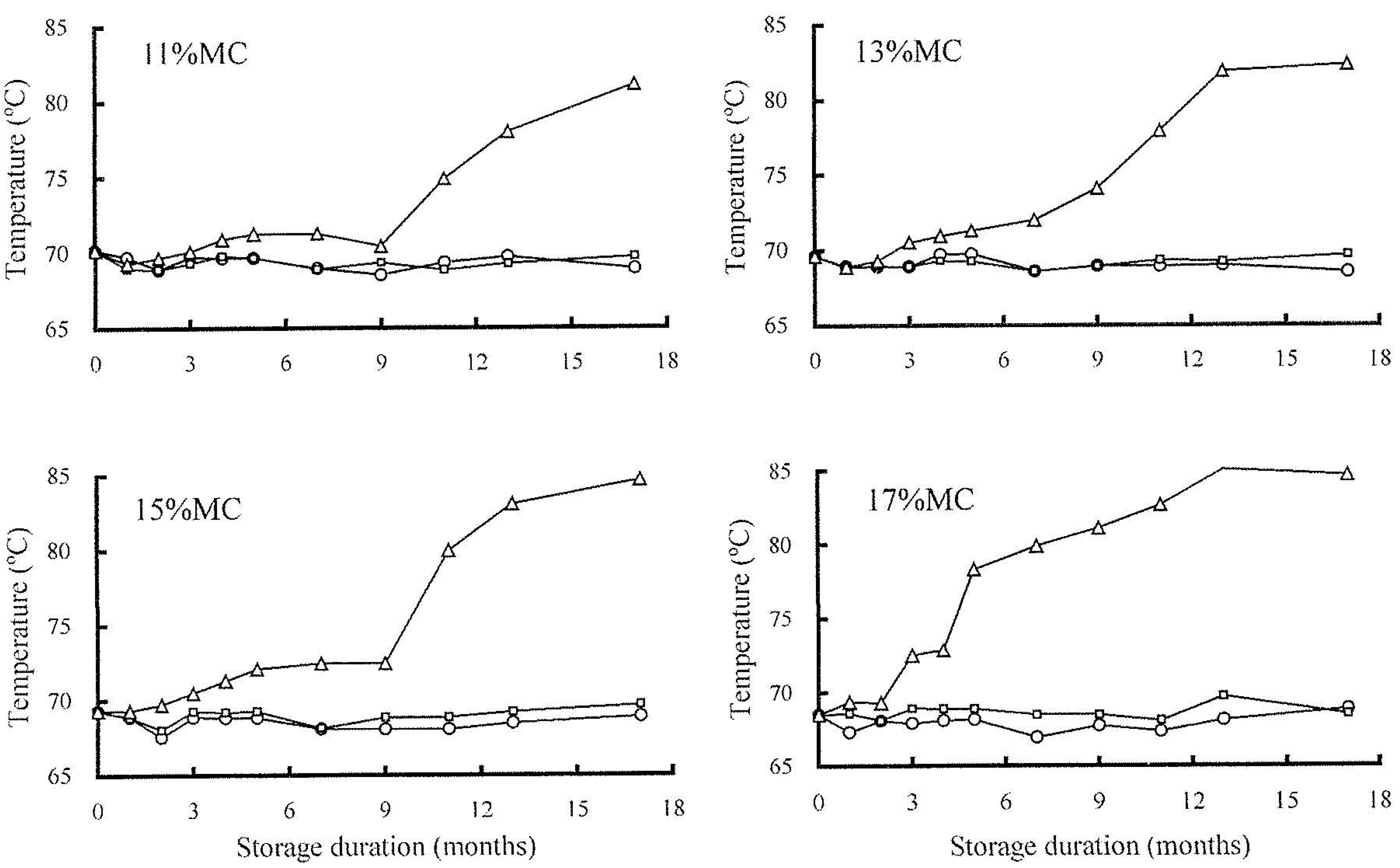


Fig. 6 Change in the pasting temperature of rice during storage at different temperatures and moisture contents (MCs)
The (○), (□) and (△) marks represent the storage temperature of 4, 20 and 35℃, respectively

Table 2 Highest order polynomial terms of significance ($P<0.05$) affecting the peak viscosity (PV), setback viscosity (SV), final viscosity (FV) and pasting temperature (PT) of rice during storage[a]

| Functional property | Highest order Polynomial term[b] | $R^2$ |
|---|---|---|
| PV | $f(T^3, T^2\times W, T^2\times t, W, W^2\times T, t^2\times T, T\times W\times t)$ | 0.84 |
| SV | $f(T^3, T^2\times W, T^2\times t, W, W^2\times T, t^2\times T, T\times W\times t)$ | 0.95 |
| FV | $f(T^3, T^2\times W, T^2\times t, W, W^2\times T, t^2\times T, T\times W\times t)$ | 0.96 |
| PT | $f(T^3, T^2\times W, T^2\times t, W, W^2\times T, t^2\times T, T\times W\times t)$ | 0.93 |

[a] All lower order terms of significant interactions and contributing individual factors were included in the polynomial model.
[b] T=storage temperature (degrees Celsius), W=moisture content of the rough rice (percent wet basis), t=storage duration (days)

for the prediction and control of the aging process during storage.

## IV Statistical model

All parameters mentioned above were analyzed by the multiple regression analyses. Table 2 shows the $R^2$ value and the highest order polynomial term of all affected parameters. Consequently, the pasting properties were significantly affected ($P<0.05$) by storage conditions such as temperature, MC, storage period and their interactions. The qualitative assessment indicated that the functional properties were not linearly related to temperature, MC and storage period. These functions show that the mechanism of rice aging is very complicated. From these functions, the degree of influence of each storage parameter could be evaluated. For example, the PV was affected mostly by temperature, while the FV was affected by all factors such as MC, temperature and storage period. Using these functions we also can compute the pasting parameters of rice sample for selected storage conditions in a selected time.

## V Conclusion

In the present study, the pasting properties changed during storage and were influenced strongly by storage temperature and rice MC. A low temperature such as 4℃ was effective in maintaining the pasting properties, while storage temperatures of 20 and 35℃ significantly affected these parameters, which could increase fluffiness and hardness in cooked rice. The MC influenced the rate of these changes. The aging process seems to be a function of storage conditions. Statistical analysis clarified that the influence of storage conditions on the pasting properties was very complex. Multiple regression analyses revealed a detailed role of storage conditions as well as their interaction. Utilizing these functions, the changes of rice quality during storage could be predicted and controlled to satisfy the consumer or processor needs.

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「研究論文」
糊化特性による長期貯蔵米の品質評価に関する研究
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## 要　旨

収穫後の籾（ハッシモ）を4段階の水分値（11.1, 12.8, 14.7, 17.6% WB）および3段階の温度（4, 20, 35℃）において，17ヶ月という長期にわたる貯蔵を行った。その間，貯蔵条件の影響を受けて白米の糊化特性に現れる変化を測定した。4℃の貯蔵においては，最高粘度がごくわずかな上昇傾向が見られた以外は，セットバック粘度，最終粘度および糊化温度のいずれもが貯蔵期間を通じてほぼ一定であった。20℃での貯蔵では最高粘度，セットバック粘度および最終粘度に緩やかな増加傾向が見られた。貯蔵温度が35℃の場合，それら指標値は素早く変化した。籾の水分値も変化率に影響を与えた。高水分であっても貯蔵温度が4℃と20℃の場合は貯蔵期間中に糊化温度の変化は見られなかった。しかし，35℃の場合は低水分の材料でさえその水分値に応じて3〜9ヶ月後から急激な変化を示した。糊化特性値を統計的に分析した結果，長期間貯蔵された米の品質変化は水分値，温度および貯蔵期間の複合的な影響を受けることが明らかとなった。

［キーワード］米貯蔵，エージング，糊化特性，貯蔵温度，水分

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## コ　メ　ン　ト

### ［閲読者のコメント］

本論文では国産のインディカ米について多くの貯蔵条件区を設けて長期貯蔵の観点から検討しておりますが，その貯蔵中における品質特性は糊化特性のみで判定されております。他の理化学特性や官能検査も含めて糊化特性との相関関係を検討すれば，長期貯蔵における国産インディカ米の老化性やテクスチャーへの影響について一層インパクトのある知見が得られたのではないかと考えます。

### ［コメントに対する著者の見解］

米の品質と食味は似て非なる特徴ですが，いずれも成分分析，理化学特性，官能試験，粘弾性それに糊化特性等により測定されています。食味はそれぞれの特性や個々人の嗜好が複雑に影響するので，各種の測定を組み合わせる必要があると思われます。米の品質変化は状態の変化の程度ですから，個々の特性値の測定によって把握することができると考えられます。ご指摘のように，複数の特性値の変化を考察すると，米の品質の総合化が可能となるでしょうが，本研究では糊化特性の観点から品質変化を検討しました。