# Change in Quality of Brown Rice Packaged in Polymeric Films (1)
## - Prediction of Change of Germination Rate -

Yutaka ISHIKAWA*, Patcharee TUNGTRAKUL** , Toshiaki SHIMIZU*** ,
Hidechika TOYOSHIMA*, Yoshinori HASEGAWA****
and Takasuke ISHITANI** ***

Germination rate is one of the quality-control indexes for brown rice. The effects of moisture content, temperature and storage time on the germination rate of brown rice were investigated and changes of germination rate during storage were predicted.

The relationship between the germination rate and time was expressed exponentially and the time coefficient kept constant, independent of temperature and moisture content. The relationship between the germination rate and temperature was likewise expressed exponentially and the temperature coefficient kept constant, independent of moisture content. In the relationship between germination rate and moisture content, the germination rate decreased markedly when the moisture content exceeded 15.5% and the exponential function was adapted. The germination rate was then expressed as a function of moisture content, storage temperature and storage time.

The mathematical model thus developed predicted the change in the rice germination rate in storage at ordinary temperatures.

**Keywords :** Brown rice, Germination rate, Storage, Prediction

## 1. Introduction

Prolonged brown rice storage must ensure that physiological activity is appropriately controlled and that the quality at harvest is maintained. The negative correlation between brown rice germination and respiration rates suggested that decreased germination was caused by self-consumption induced by respiration.[1,2] Germination rate is used as an index for objectively evaluating quality.[3,4] The decrease of rice - seed germination depends on moisture content and storage temperature.[5] Many reports have dealt quantitatively with how moisture content, temperature, and period of viability dependence relate to the germination rate.[6,7,8] If the moisture content and temperature of the

*National Food Research Institute, Ministry of Agriculture, Forestry and Fisheries, Kannondai, Tsukuba, Ibaraki 305
**Institute of Food Research and Product Development, Kasetsart University, Kasetsart, Bangkok 10903, Thailand
***OKURA INDUSTRIAL CO. , LTD. , Nakatsu-cho, Marugame, Kagawa 763
****Shikoku National Agricultural Experiment Station, Ministry of Agriculture, Forestry and Fisheries, Ikuno-cho, Zentsuji, Kagawa 765
*****Tohoku National Agricultural Experiment Station, Ministry of Agriculture, Forestry and Fisheries, Akahira, Shimo-kuriyagawa,Iwate 020-01

brown rice is known, it is possible to predict the expected life of the rice.

Our objectives were to investigate how moisture content and temperature influenced the germination rate and to develop a mathematical model that predicted changes in the germination rate.

## 2. Materials and Methods

### 2.1 Rice

Brown rice of the Koshihikari variety, japonica rice produced in Ibaraki prefecture, Japan, was used. The rice was placed in an environmental chamber kept at 15°C and 95% RH to set the moisture content at 16%, then transferred to the environmental chamber kept at 21°C and 35% RH to dehumidify the moisture content below 16% of samples for this experiment. Thus, rice of 14.0, 14.5, 15.0, 15.5 and 16.0% moisture content was prepared.

### 2.2 Moisture content

Brown rice was crushed by a roller mill. Moisture content of rice was measured by the weight loss by drying at 135°C for 3 hours.[9]

### 2.3 Packaging films and conditions

One hundred grams each of rice packaged in low density polyethylene pouches 120 by 140 mm in size and 79.5 $\mu$m thick were stored in an environmental chamber at 10, 20 or 30°C for 6 months. The initial gas within pouches was ambient air.

### 2.4 Germination rate

100 grains of rice were soaked in 1% sodium hypochlorite solution for 30 minutes, then washed 3-4 times using distilled water and placed on wet filter paper in a petri dish at 20°C. The germination rate was measured by counting the number of grains germinated within 7 days.

## 3. Results and Discussion

### 3.1 Storage time and germination rate

Changes in germination rate are shown in Fig. 1. The germination rate was kept constant at 10°C, decreased slightly at 20°C, and decreased greatly at 30°C, depending on the moisture content. Roberts[6] reported that a curve showing a frequency distribution of the death points of individual seeds is a sigmoid cumulative frequency-distribution. And they confirmed that within the limits of experimental error the theoretical curves provide a good fit to the experimental data.[10,11] Their mathematical model, however, could not be predicted the viability of rice stored at ordinary ambient temperature. This was closely approximated by the following exponential function.

$$G = Go\{\exp(\alpha t) - 1\} + 100 \qquad (1)$$

where

G = germination rate (%)

t = storage time (months)

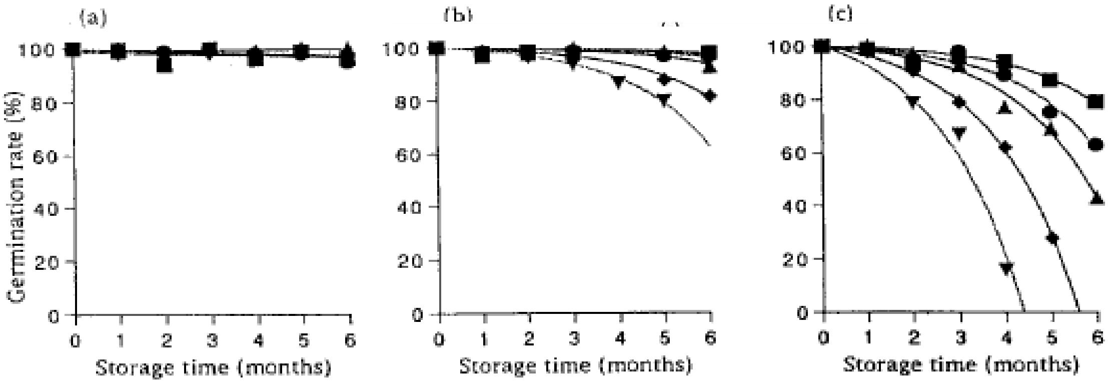


Fig. 1 Changes in rice germination rate
(a) 10°C, (b) 20°C, (c) 30℃

■ 14.0%, ● 14.5%, ▲ 15.0%, ◆ 15.5%, ▼ 16.0%

$G_0$, $\alpha$ = coefficients

All approximate equations correlated well with experimental values. Coefficients $G_0$ and $\alpha$ were calculated by the least squares method (Table 1). $\alpha$ remained almost constantly the same, independent of temperature and moisture content. $G_0$ varied with temperature and moisture content, however. A time coefficient, $\alpha$, of 0.55 was assumed by averaging.

### 3.2 Temperature and germination rate

Relationship between temperature and germination rate after 6 months are shown in Fig. 2. Germination rate had markedly declined under conditions of high temperature and moisture content, showing the same temperature dependence in all samples, independent of moisture content.

Table 1 Equation 1 coefficients obtained by least squares method

| Temperature (℃) | Moisture content (%) | Coefficient $G_0$ | Coefficient $\alpha$ | $R^2$ |
|---|---|---|---|---|
| 20 | 15.0 | -0.177 | 0.604 | 0.712 |
| 20 | 15.5 | -1.273 | 0.456 | 0.981 |
| 20 | 16.0 | -1.984 | 0.485 | 0.987 |
| 30 | 14.0 | -1.694 | 0.430 | 0.950 |
| 30 | 14.5 | -1.621 | 0.533 | 0.966 |
| 30 | 15.0 | -2.522 | 0.527 | 0.986 |
| 30 | 15.5 | -4.293 | 0.575 | 0.999 |
| 30 | 16.0 | -4.190 | 0.760 | 0.987 |

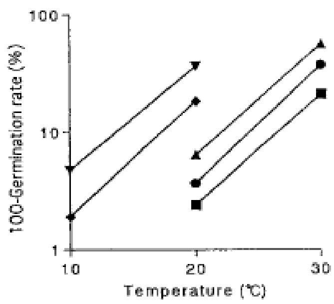


Fig. 2 Temperature dependence of germination rate in rice stored for 6 months
● 14.0%, ■ 14.5%, ▲ 15.0%, ◆ 15.5%, ▼ 16.0%

Hikida et al.[12] reported that the relationship between temperature and rice respiration rate closely fitted the Arrhenius' equation and Gore's equations.[13] The relationship between germination rate and temperature was also assumed to correlate highly because decreased germination was caused by self-consumption induced by respiration.[1,2] Gore curve adapted to express the germination rate simply is

$$100\text{-}G = G_1 \cdot \exp(\beta T) \qquad (2)$$

where

$T$ = temperature (°C)

$G_1$, $\beta$ = coefficients

Coefficients $G_1$ and $\beta$ were calculated by the least squares method (Table 2). $\beta$ remained almost constantly the same, independent of moisture content. $G_1$ varied with moisture content, however. A temperature coefficient, $\beta$, of 0.22 was assumed by averaging.

### 3.3 Moisture content and germination rate

Relationship between moisture content and rice germination rate stored at 20°C for 6 months are shown in Fig.3. Rice maintained a germination rate exceeding 60%, suggesting that rice stored at this temperature maintains a low respiration rate at a moisture content below 16%.[14] The germination rate is expressed by the following equation :

$$100-G = 3.79\times10^{-9} - \exp(1.42M) \quad (3)$$

where

$M$ = moisture content (%)

A solid line (Fig. 3) calculated using Equation 3 correlated well with experimental data.

Table 2 Equation 2 coefficient obtained by least squares method

| Moisture content (%) | Coefficient G1 | Coefficient $\beta$ |
|---|---|---|
| 14.0 | 0.030 | 0.220 |
| 14.5 | 0.034 | 0.234 |
| 15.0 | 0.080 | 0.219 |
| 15.5 | 0.195 | 0.228 |
| 16.0 | 0.612 | 0.205 |

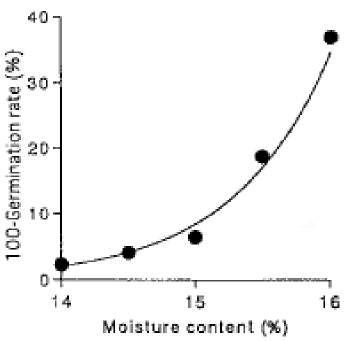


Fig.3 Moisture content dependence of germination rate in rice stored at 20℃ for 6 months

### 3.4 Germination rate as a function of time, temperature, and moismoisture content

In the relationship between moisture content and rice germination rate stored at 20°C for 6 months expressed by Equation 3, $G_1$ was calculated as a function of moisture content by putting T 20 and equation 3 into equation 2, giving the following equation :

$$100-G = 4.54\times10^{-11} \cdot \exp(1.42M)\cdot\exp(0.22T) \quad (4)$$

In the germination rate of rice stored for 6 months expressed by equation 4, G0 was calculated as a function of temperature and moisture content by putting t = 6 and equation 4 into equation 1, giving the following equation :

$$G = -1.78\times10^{-12} \cdot \exp(1.42M) \cdot \exp(0.22T)\cdot\{\exp(0.55t)-l\}+100 \quad (5)$$

In the relationship between the experimental germination rate and the value calculated using equation 5 (Fig. 4), the high correlation coefficient of r = 0.975 suggested that our mathematical model pre-

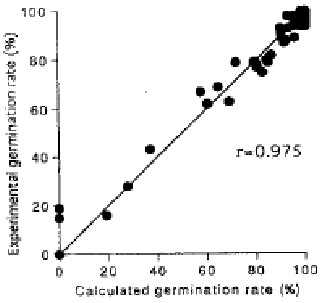


Fig.4 Correlation between experimental and calculated germination rates

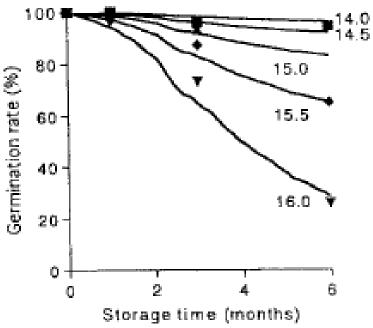


Fig .6 Predicted and actual germination rate changes
■ 14.0%, ● 14.5%, ▲ 15.0%, ◆ 15.5%, ▼ 16.0% (actual)
—— predicted

cisely predicted changes in the germination rate dur-ing storage.

### 3.5 Verification

The validity of equation 5 was evaluated using rice stored at ordinary ambient temperature from June ll for the ensuing 6 month. Temperature change in storehouse are shown in Fig. 5. Temperature remained high until September and dropped markedly after October.

The germination rate predicted by equation 5 and experimental values (Fig. 6) declined rapidly from month 1 to month 3 due to high summer temperatures. The good agreement between the predicted and experimental values indicates that the rice germination rate stored at ordinary ambient temperature can be predicted precisely. Our mathematical model was applicable over a range of 12% to 17% moisture content. Excessive low and high moisture content reportedly adversely affect germination activity[15]. Deterioration at a low moisture content appeared to have been caused by electrolyte leakage induced by loss of cell membrane integrity,[16,17] and deterioration at a high moisture content was presumably induced by microorganisms.[18,19] The mathematical model is not applicable under these specific moisture content conditions.

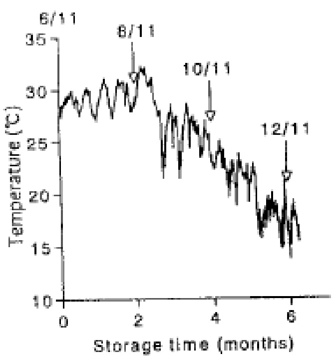


Fig. 5 Temperature changes during storage at ordinary ambient temperatures

Our mathematical model was applied only to Koshihikari rice. Because respiration rate and germination activity depend on the variety, coefficients in the model presumably change with the variety[20], so further experimentation will be required for predicting germination rates of different types of rice. At this point, in any case, our mathematical model can provide the optimum storage temperature and moisture content based on the tolerance limit of the germination rate.

## 4. Conclusion

The rice germination rate was expressed as a function of moisture content, storage temperature, and time. The mathematical model we developed reliably predicted changes in germination rate of rice stored at ordinary ambient temperatures. The mathematical model provides the optimum storage temperature and moisture content based on the tolerance limit of the germination rate. Mathematical model coefficients presumably will change with the rice variety, and further experimentation will be required for predicting germination rates of different types of rice.

## References


1) M. Kikuchi, N. Ishikura, T. Ishima and K. Iino, Rept. Natl. Food Res. Inst., 37, 9 (1980).
2) M. Kikuchi, N. Ishikura, T. Ishima and K. lino, Rept. Natl. Food Res. Inst., 38, 10 (1981).
3) S. Yanai, S. Tsubata, T. Ishitani and S. Kimura, J. Jpn. Soc. Food Sci. and Technol., 25 (10), 563 (1978).
4) S. Yanai, T. Ishitani and Y. Kakiuchi, J. Jpn. Soc. Food Sci. and Technol., 26 (1), 25 (1979).
5) T. Mikami, K. Tanabu, K. Arima, K. Yamazaki, T. Kudo and M. aaaYoshihara, Bull. Aomori Agr. Exp. St., 27, 87 (1983).
6) E. H. Roberts, Ann. Bot., 24, 12 (1960).
7) W. V. Hukill, Proc. int. Seed Test. Ass., 28, 871 (1963).
8) E. L. Watson, Can. J. Plant Sci., 50, 107 (1970).
9) T. Nagahara and C. Tsutsumi, Rep. Natl. Food Res. Inst., 14, 77 (1959).
10) E. H. Roberts, Ann. Bot., 25, 381 (1961).
ll) E. H. Robers and F. H. Abdalla, Ann. Bot., 32, 97 (1968).
12) Y. Hikida, D. H. Han and T. Abe, J. Jpn. Soc. Agric. Machin., 58 (2), 25 (1996).
13) S. Murata, K. Miyauchi and Y. Wang, J. Jpn. Soc. Agric. Machin., 55 (2), 69 (1993).
14) M. Kikuchi and H. Naito, Rept. Food Res. Inst., 16, 68 (1962).
15) I. Nishiyama, Jap. J. Crop Sci., 46 (1), 111 (1977).
16) E. W. Simon, New Phytol., 73, 377 (1974).
17) E. W. Simon and R. M. R. Harun, J. Exp. Bot., 23, 1076 (1972).
18) O. Tsuruta and A. Ishihara, Rept. Food Res. Inst., 26, 1 (1971).
19) O. Tsuruta, I. Endo, S. Takahashi and S. Chikubu, Rept. Natl. Food Res. Inst., 32, ll (1977).
20) H. Tateishi and I. Matsubara, Bull. Nagasaki Agr. Forest. Exp. St., 12, 1 (1984).


（原稿受付1998年1月22日）
（審査受理1998年3月13日）