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Respiration and Quality of Rough Rice under Unsteady Atmospheric Conditions

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The respiration rates of fresh and rehydrated rough rice under unsteady atmospheric conditions were measured by the pouch method, and quality attributes and amino acid content were also examined. Respiration rates of both fresh and rehydrated rough rice were greatly repressed under conditions of increase in CO₂ and decrease in O₂ concentrations at 20 and 30 °C. But O₂ and CO₂ concentrations were decreased quicker for rehydrated rough rice due to higher respiration rate during storage period. Respiratory quotient (RQ) was fluctuated around 0.8–1.0 at over 4.4–6.4% O₂ concentration, and anaerobic respiration was occurred at less than this O₂ level. For evaluation of quality, statistical analysis of test of significance showed that there were no significant differences in palatability between fresh and rehydrated rice for 6 items of appearance, flavor, taste, stickiness, hardness and overall evaluation. 4 and 10 kinds of free amino acids were detected from fresh and rehydrated rough rice and total free amino acid contents in fresh and rehydrated rough rice were 15.0 and 28.0 mg 100 g⁻¹, respectively.

INTRODUCTION

Rough rice is a hygroscopic, living and respiring biological material, which has an activity of respiratory metabolism to consume nourishment and oxygen, and generate carbon dioxide, water vapor and release energy in the form of heat (Daniels *et al.*, 1998; Dillahunty *et al.*, 2000). It absorbs and gives off moisture depending upon the rough rice moisture content, air relative humidity (RH) and temperature of the surrounding atmosphere. As a living biological material, respiration rate of rough rice increased with rise in moisture content (Sahay and Gangopadhy, 1985). Especially after just harvest (moisture content of 24–26% wet basis), it has a high respiration rate and is very susceptible to attack by microorganisms, insects and pests. The heat evolved during the respiration process is retained in the grain and in the bulk because of the insulating effect of the rice husk. This heat increases the temperature of the grain resulting in increased mould

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growth, fungi, insects and pests infection, which increase the quantitative loss and qualitative deterioration. Newly harvested rough rice with high moisture content must therefore be dried within 24 hours to about 14% for safe storage and milling or to at most 18% for temporary storage of up to two weeks in case the drying capacity will jeopardise the drying of the rest of the wet rough rice and thus get them spoiled (Cnossen and Siebenmorgen, 2000).

There are many theories as to what causes deterioration. Some of these include the effects of fungi or mold (Schroeder, 1963), high respiration rates (Schroeder, 1963), and elevated water activity, temperature and CO₂ concentration (Bason *et al.*, 1990). It has also been proposed that several of these factors interactively produce deterioration (Bason *et al.*, 1990). In previous literatures, mold growth and heating occurred simultaneously in rough rice with higher moisture content (Milner, 1951; Phillips *et al.*, 1988). The moisture content was one of the most important factors among environmental conditions for controlling the quality of rough rice (Hikida *et al.*, 1996). Delayed, improper drying and absorbed the moisture from high RH air can cause heat burns or heat discoloration, deterioration. In some developing country, dried rough rice absorbed the moisture from high RH air and increased the moisture content in the rainy season, which resulted in large loss of rough rice. But there are little information about the effect of rehydration on respiration rate and quality of rough rice under high moisture content, high temperature and unsteady atmospheric conditions after just harvest. The objectives of this study were to investigate respiration rate of fresh and rehydrated rough rice at different moisture contents and storage temperatures in order to clarify the effect of rehydration on respiration and quality of rough rice. The quality evaluation of white rice milled from both rough rice was also determined.

MATERIALS AND METHODS

Rough rice and storage conditions

Rough rice (cv. Hinohikari) was harvested from Farm of Kyushu University in Fukuoka Prefecture, Japan. The moisture content was 23.7 and 22.2% wet base. They were transported to laboratory within 1 h and was stored at 5 °C for use in experiment. Rehydrated rough rice was made by spraying water on the rough rice and covering it with film for 1 day to regulate the moisture content (24.6%).

Measurement of moisture content

The sample of 10 g rough rice was taken and placed into the constant temperature dryer. It was dried for 24 h under 135 °C and normal pressure. The moisture content was represented as wet base moisture content.

Measurement of package atmosphere

Samples of 300 g were placed in the pouches (20 cm × 15 cm in area, 0.0875 mm in thickness) and heat sealed. The film used for packaging was Krehalon film (Kureha Chemical Industry Co., Ltd. Tokyo, Japan), which is kind of high-barrier PVDC film that has no permeability. The pouches were stored at 20 and 30 °C, respectively.

The changes in gas concentration within the pouch were determined by gas chro-

matography (GC-390, GL Sciences Inc, Tokyo Japan) equipped with thermal conductivity detector (TCD) and D2000 integrator (Hitachi, Ltd. Tokyo Japan) during storage. Helium was used as carrier gas and the flow rate was 30 ml min⁻¹. Oven temperature was kept at 50 °C whereas injector and column temperatures were 80 and 50 °C, respectively. The column was WG100 with molecular sieve 5A and Porapak Q 80/100 mesh. The sampling intervals were 1–3 h according to changes in the gas concentration at different storage temperatures. Each time three replications were taken for the gas analysis and the average gas composition was recorded.

Mathematical model for MAP

To determine the respiration rate of rough rice under unsteady atmospheric conditions, pouch method based on the basic volume balance was used (Akimoto and Maezawa, 1997). The changes in the free volume of gas within package with time were shown in following equations.

$$\frac{dV_s}{dt} = \frac{dV_c}{dt} + \frac{dV_o}{dt} + \frac{dV_N}{dt} \quad (1)$$

$$\frac{dV_c}{dt} = \frac{A}{L} K_c (P_{ca} - P_c) + R_c W \quad (2)$$

$$\frac{dV_o}{dt} = \frac{A}{L} K_o (P_{oa} - P_o) + R_o W \quad (3)$$

$$\frac{dV_N}{dt} = \frac{A}{L} K_N (P_{Na} - P_N) \quad (4)$$

where V is the volume of gas in pouch (ml), A is surface area of pouch (m²), L is thickness of film (m), K_c , K_o and K_N are the permeability of film for CO₂, O₂ and N₂ (ml m m⁻² atm⁻¹ h⁻¹), R is respiration rate (ml kg⁻¹ h⁻¹), W is weight of product (kg), P_{ca} , P_{ca} and P_{Na} are partial pressure of CO₂, O₂ and N₂ outside pouch (atm), P_c , P_o and P_N are partial pressure of CO₂, O₂, N₂ inside pouch (atm).

Sensory evaluations

Palatability of rice was evaluated by ten people at laboratory according to evaluation standard of Japan Grain Inspection Association (JGIA). Evaluation was carried out on 6 items against those of standard rice: appearance, flavor, taste, stickiness, hardness and overall evaluation. They were scored on adding the following points based on 0 for the standard rice: slightly different ±1; a little different ±2; considerably different ±3. Standard rice was Nipponbare from Konan, Shiga Prefecture, Class 1. The samples of white rice were milled from rough rice (17.5%w.b.) and dehydrated rough rice (17.5%w.b.) from rehydrated rough rice (24.6%w.b.).

Amino acid analysis

The free amino acid was determined by extracting 10 g of grinded powder by grinder mixed with 75% ethanol, in a total volume of 100 ml. Extraction was taken 10 h from

shaking at 50 °C. The homogenate was centrifuged at 12,000×g for 30 min. The supernatant was taken as sample to measure the free amino acid content by automatic amino acid analyzer (JLC-500/V, JEOL, Tokyo Japan).

RESULTS AND DISCUSSION

Respiration rates of fresh and rehydrated rough rice

Rough rice is a living and respiring biological material. Respiration is very low at moisture content of about 12–14%. But it can absorb and give off moisture depending upon RH and temperature of the surrounding atmosphere due to its hygroscopicity. The experiment was carried out to compare the respiration of fresh rough rice to that of rehydrated rough rice.

Fig. 1 shows that changes in respiration rate, RQ and gas concentrations of fresh and rehydrated rough rice at 20 °C. O₂ concentration decreased 90% from 19.1 to 2.0%, CO₂ concentration increased 88% from 1.9 to 16.0% during storage period (Fig. 1A). Under these conditions, CO₂ production rate decreased 76% from 6.6 to 1.6 ml kg⁻¹ h⁻¹, O₂ consumption rate showed similar trend of decrease to CO₂ production rate over the initial 48 h. And then CO₂ and O₂ levels in packages were 13.2 and 4.5%, respectively. O₂ consumption rate decreased quicker than CO₂ production rate, indicating a shift to anaerobic respiration. This was confirmed by high RQ value. RQ fluctuated around 0.8 and increased up to 2.3 after 60 h. In Fig. 1B, O₂ concentration was decreased 90% from 19.5 to 1.9%, CO₂ concentration was increased 95% from 1.0 to 18.8% during storage period. CO₂ production rate decreased quickly from 29.2 to 19.3 ml kg⁻¹ h⁻¹ at initial 6 h, and then it decreased slowly. O₂ consumption rate showed similar trend of decrease to CO₂ production rate during storage period. The RQ was fluctuated around 0.9, and then increased after 30 h.

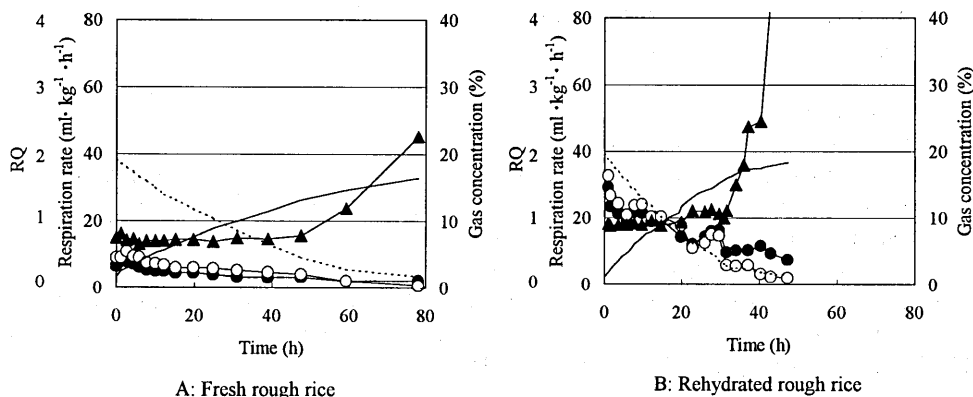


Fig. 1. Changes in respiration rate, RQ and gas concentration of fresh and rehydrated rough rice at 20 °C. (●) represents CO₂ production rate, (○) O₂ consumption rate, (□) RQ, (—) CO₂ concentration, (---) O₂ concentration.

The respiration rate, RQ and gas concentrations of fresh and rehydrated rough rice stored at 30 °C can be seen in Fig. 2. O₂ concentration decreased quickly 95% from 19.7 to 1.0%, CO₂ concentration increased 93% from 1.6 to 23.6% during storage period (Fig. 2A). CO₂ production rate decreased 64% from 30.5 to 10.9 ml kg⁻¹ h⁻¹ over initial 12 h storage period, O₂ consumption rate showed similar trend of decrease to CO₂ production rate from initial 35.3 ml kg⁻¹ h⁻¹. The RQ fluctuated around 0.8 at initial 10 h, and then it increased quickly. For rehydrated rough rice, O₂ and CO₂ concentrations were decreased quicker than that at 20 °C during storage period (Fig. 2B). CO₂ production and O₂ consumption rates decreased quickly from 54.6 and 59.6 ml kg⁻¹ h⁻¹, respectively. RQ fluctuated around 0.9, and then it increased after 18 h.

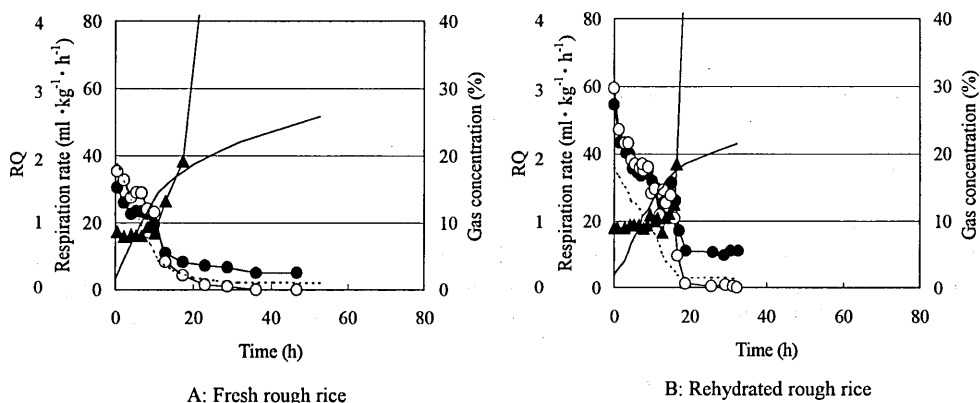


Fig. 2. Changes in respiration rate, RQ and gas concentration of fresh and rehydrated rough rice at 30 °C. (●) represents CO₂ production rate, (○) O₂ consumption rate, (□) RQ, (—) CO₂ concentration, (---) O₂ concentration.

Respiration was affected by the physiological state of rough rice as well as moisture content and temperature (Goto and Yamada, 1993). In this study, physiological metabolism activity of fresh rough rice, which was just harvested was lower than that of rehydrated rough rice. The paddy is harvested at mature stage and fresh rough rice is in certain state of dormancy. While rehydrated rough rice by absorbing water is on the contrary process from dormancy to activation. Therefore, although rehydrated rough rice had only 0.9% higher in moisture content (24.6%) than that of fresh rough rice (23.7%), rehydrated rough rice had higher physiological activity and showed relative high respiration rate. This suggests that rehydrated rough rice was used as experimental material that replaces fresh rough rice could not be ideal method.

Relationship between O₂ concentration and respiration rate of fresh and rehydrated rough rice

Fig. 3 shows changes in respiration rate and RQ with O₂ concentration at 20 °C. Respiration rate of rehydrated rough rice was higher than that of fresh rough rice. The lower oxygen limit, the lowest O₂ concentration surrounding the product that dose not in

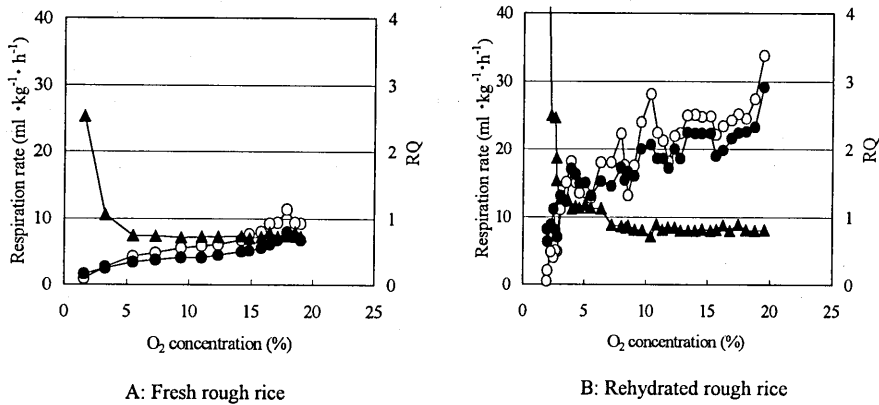


Fig. 3. Relationship between O_2 concentration and respiration rate, RQ of fresh rough rice at 20°C . (●) represents CO_2 production rate, (○) O_2 consumption rate, (□) RQ.

duce fermentation, was 5.5% for fresh rough rice and 6.4% for rehydrated rough rice, respectively. It indicated that there was higher metabolic activity and lower oxygen limit in rehydrated rough rice. It was considered that although rehydration of dried rough rice is a process of absorbed water, it also activates the process of a certain physiological metabolism.

Fig. 4 shows changes in respiration rate and RQ with O_2 concentration at 30°C . It also indicated that rehydrated rough rice had higher respiration rate than that of fresh rough rice. For lower oxygen limit, it showed similar results, both of the lower oxygen limit of rehydrated and fresh rough rice was about 4.4%. It has been reported that lower oxygen limit of fresh rough rice was about 5.5% (Hu *et al.*, 2001). In this experiment, the similar

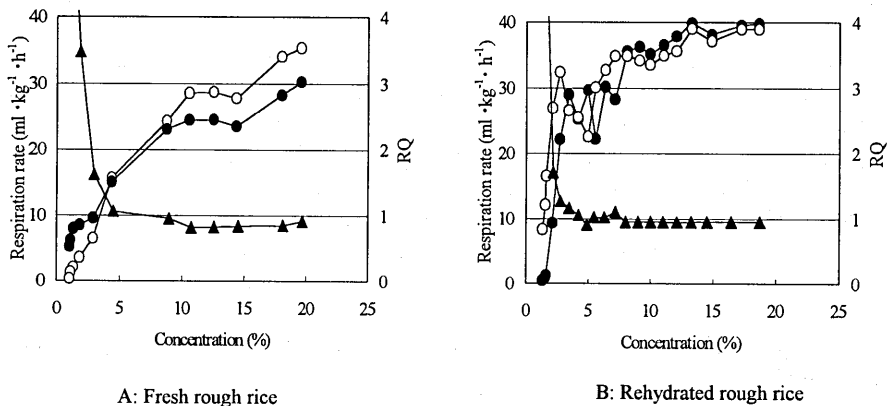


Fig. 4. Relationship between O_2 concentration and respiration rate, RQ of fresh rough rice at 30°C . (●) represents CO_2 production rate, (○) O_2 consumption rate, (□) RQ.

result of lower oxygen limit (4.4–6.4%) was showed for both rehydrated and fresh rough rice.

Effect of initial O₂ concentration on respiration of fresh rough rice (22.2% w.b.)

Fig. 5 shows changes in respiration rate, RQ and gas concentration in the package at 20 and 30°C. Respiration rate fluctuated 1.3–5.4 ml kg⁻¹ h⁻¹ for CO₂ production rate, 1.2–2.6 ml kg⁻¹ h⁻¹ for O₂ consumption rate (Fig. 5A). RQ fluctuated at large range of 0.7–3.0 from initial 1.1. At 30°C, CO₂ production rate decreased 80% from initial 9.2 to 1.8 ml kg⁻¹ h⁻¹. O₂ consumption rate decreased 89% from initial 4.6–0.5 ml kg⁻¹ h⁻¹ (Fig. 5B). RQ decreased from initial 1.8 to 0.7 over initial 10 h storage period, and then increased quickly. These results indicated that respiration rate was markedly suppressed and RQ was changed irregularly at initial lower O₂ level.

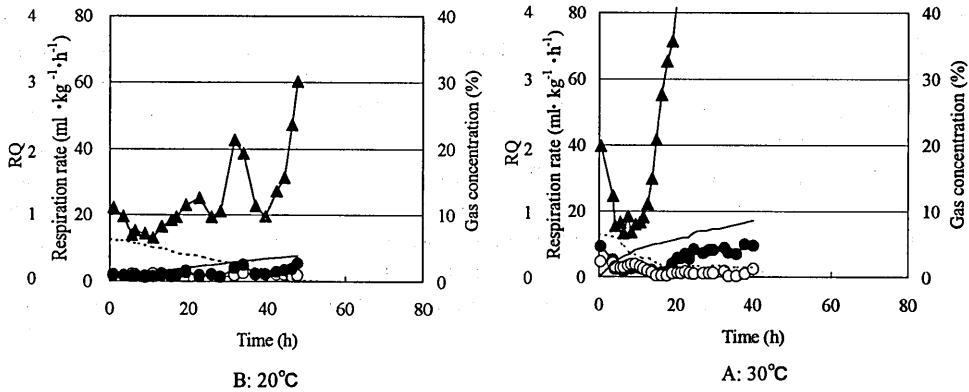


Fig. 5. Changes in respiration rate, RQ and gas concentration of fresh and rehydrated rough rice under initial lower O₂ conditions at different temperatures. (●) represents CO₂ production rate, (○) O₂ consumption rate, (□) RQ, (—) CO₂ concentration, (---) O₂ concentration.

Evaluation of rice quality

Palatability is commonly measured by sensory evaluation method based on the standard of JGIA. It involves many factors interacting with each other. Personal evaluation was carried out by actually eating rice to determine its taste. Taste of rice may vary depending on individuals' preferences and further on physiological and psychological conditions at the time of test.

Sensory evaluation of fresh and rehydrated rice and statistical analysis was showed in Table 1. Mean of overall evaluation, appearance and taste were higher for rehydrated rice than that of ordinary rice, while the values of stickiness and hardness were higher for ordinary rice than that of rehydrated rice, and mean of both flavor was the same. The statistical analysis of test of significance showed that there were no significant differences between ordinary and rehydrated rice for 6 items of appearance, flavor, taste, stickiness and overall evaluation. It was indicated that quality of white rice was not affected by rehydration of rough rice.

Table 1. Sensory evaluation of rice milled from fresh and rehydrate rough rice and statistical analysis

Items	Fresh rice	Rehydrated Rice	Standard deviation of difference	Standard error of difference	t_0
Overall evaluation	0.9	1.2	1.95	0.62	0.48
Appearance	1.0	1.1	1.66	0.53	0.19
Flavor	0.6	0.6	1.24	0.39	0.00
Taste	0.9	1.2	1.95	0.62	0.48
Stickiness	0.9	0.7	1.75	0.55	0.36
Hardness	-0.6	-1.0	1.94	0.61	0.66

-Difference is not significant difference ($p < 0.05$).

The free amino acid contents in rough rice and rehydrated rough rice were showed in Table 2. Only 4 kinds of amino acid were detected from fresh rough rice, while 10 kinds of amino acid were inspected from rehydrated rough rice. Alanine and Glitamine contents were 6.0 and 5.0 mg 100 g⁻¹ in ordinary rough rice, while in rehydrated rough rice, Alanine and Glitamine contents were 4.0 and 12 mg 100 g⁻¹ respectively. Total free amino acid content in ordinary rough rice was 15.0 mg 100 g⁻¹, and in rehydrated rough rice it was 28.0 mg 100 g⁻¹. It showed that the free amino acid content in rehydrated rough rice was 1.9 times as much as in ordinary rough rice. It has been reported that delicious rice could be gotten from higher level of some kinds of free amino acid content, while higher level of total free amino acid content in rice could not certainly be delicious (Fan *et al.*, 2000). In this experiment, it showed that mean of overall evaluation, appearance and

Table 2. Free amino acid content in fresh and rehydrated rice
(Limit of examination: 1mg·100 g⁻¹)

Kind of amino acid	Fresh rough rice (mg·100 g ⁻¹)	Rehydrated rough rice (mg·100 g ⁻¹)
Alanine	6.0	4.0
Valine	-*	2.0
Leucine	-	1.0
Isoleucine	-	-
Proline	-	1.0
Phenylalanine	-	-
Methionine	-	-
Glycine	-	1.0
Serine	1.0	1.0
Threonine	-	-
Tyrosine	-	-
Asparagine	3.0	3.0
Glutamine	5.0	12.0
Lysine	-	1.0
Arginine	-	2.0
Histidine	-	-

* Amino acid was not detected.

taste were higher for rehydrated rice than that of ordinary rice, and mean of both flavor was the same. It was considered that components in rice, especially for level of free amino acid content, played important role in quality evaluation. The values of stickiness and hardness of rehydrated rice was decreased due to the change in starch nature by absorption of water.

CONCLUSIONS

Respiration rates of both fresh and rehydrated rough rice were greatly suppressed under conditions of increase in CO₂ and decrease in O₂ concentrations at 20 and 30°C. But O₂ and CO₂ concentrations were decreased quicker for rehydrated rough rice due to higher respiration rate during storage period. RQ was fluctuated around 0.8–1.0 at over 4.4–6.4% O₂ concentration, and anaerobic respiration was occurred at less than this O₂ level. For quality evaluation, statistical analysis of significance test of difference between the two population means showed that there were no significant differences in palatability between fresh and rehydrated rice for 6 items of appearance, flavor, taste, stickiness, hardness and overall evaluation. 4 and 10 kinds of free amino acids were detected from fresh and rehydrated rough rice, and total free amino acid contents in ordinary and rehydrated rough rice were 15.0 and 28.0 mg 100 g⁻¹, respectively.

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