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간헐 분무와 음이온 방사를 가진 공기노출형 자동 현미발아시스템의 개발

임기택 김장호 정종훈

Development of an Automatic Brown Rice Germinating System of Air-Phase Type with Intermittent Water Spraying and Anion Radiation

K. T. Lim J. H. Kim J. H. Chung

Abstract

In this study an automatic germinating system for germinated brown rice (GBR) was developed for accelerating germination and sprouting of brown rice. With the developed germinating system, the effects of anion radiation treatment on germination ratio, sprout growth, color quality and γ-aminobutyric acid (GABA) content of brown rice were investigated. This system can fast produce GBR by controlling the environmental conditions such as ambient temperature, relative humidity, and proper anion radiation. Air-phase germination with intermittent water spraying improved both germination ratio and sprout growth by about 2.2 and 2.3 times, respectively, compared to the conventional water soaking method. Our results strongly suggest that this germinating system that provides air-phase germination with intermittent water spraying and anion radiation can produce germinated brown rice with good color quality, high GABA content, and fast germination ratio as well as sprout growth.

Keywords : Automatic brown rice germinating system, Air-phase germination, Intermittent water spraying, Anion radiation

1. INTRODUCTION

Effects of air-phase germination with anion radiation and water-spraying on germination ratio, sprout growth, and GABA contents of germinated brown rice (GBR) were investigated (Lim *et al.*, 2006). As a continuous work, the purpose of this study was to develop a brown rice germinating system for producing GBR with high quality in germination ratios, sprout lengths, GABA content, and color quality of brown rice. As already reported by several studies about the efficacy, GBR contains much more fiber than conventional brown rice, up to 3 times the amount of the essential amino acid lysine, 10 times the amount of γ-aminobutyric acid (GABA), and an additional amino acid known to improve kidney function (Lim *et al.*, 2006). GABA has several physiological functions, such as neuro-transmission and induction of hypotensive effects, diuretic effects, and tranquilizing effects (Jakobs *et al.*, 1993). GBR utilizes physiologically active substances that are present in bran, and the soaking process used to germinate brown rice improves its texture, making the nutrients in the seed easier to digest and adsorb (Oste, 1991). A common method for germinating brown rice is soaking in water, a slow process limited by the diffusion of water in the grain. Warm water soaking is used to shorten the soaking time since higher temperatures increase the hydration ratio (Engles *et al.*,

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1986). However, this soaking method may cause microbial contamination, which affects color, taste and smell. Suzuki and Maekawa (1999), therefore, reported that the sprout growth of brown rice under air-phase was more rapid than under liquid-phase. The air-phase germination method reduces germination time but decreases quality due to short pollination periods and the effects of air pollution (Adams, 1999). Similarly to the study, effects of germinating types of water-soaking & air-exposure and chitosan treatment (Lee *et al.*, 2006a) as well as ultrasound stimuli (Lee *et al.*, 2006b) on brown rice germination were investigated. An alternative method to accelerate the germination of brown rice and to improve the quality of germinated rice has been required. Air ions occur in moderate concentrations in clean outdoor air and in large numbers in certain locations, such as around waterfalls (Krueger *et al.*, 1975). Anions (negative air ions) inhibit the growth of bacteria and fungi, and exert a lethal effect on vegetative forms of bacteria suspended in water when they come in contact with cells and ions (Krueger and Reed, 1976). Anions also stimulate the growth of a wide variety of plants (Krueger, 1985). Shargawi *et al.* (1999) presented evidence of a germicidal effect of anions on micro-organisms. Exposure of barley seedlings (Hordeum vulgaris) growing in sand and liquid cultures to ionized air results in increased growth in terms of integral elongation and increases in fresh and dry weight (Kotaka *et al.*, 1965). This growth stimulation was accompanied by a number of biochemical changes compatible with enhanced metabolic activity. Air ion depletion slowed the rate of growth and diminished normal turgor (Krueger *et al.*, 1978). There is convincing evidence that air ions are able to affect physiological processes in bacteria, plants, animals and humans (Krueger *et al.*, 1975). Anion radiation can prevent airborne contamination from micro- organisms during air-phase germination of brown rice, as well as affect the germination ratio, sprout growth and colour of brown rice (Krueger *et al.*, 1975). In addition to methods that facilitate germination of seeds, methods to increase GABA contents have been studied recently (Jakobs *et al.*, 1993). The objectives of this study were to develop an automatic air-phase germination system that accelerates the germination ratio and sprout growth of GBR, and to investigate the effects of air-phase germination combined with intermittent water spraying and anion radiation.

2. MATERIALS AND METHODS

A. Development of an Automatic Brown Rice Germinating System of Air-phase Type with Intermittent Water Spraying and Anion Radiation

An automatic brown rice germinating system of air-phase type combined with intermittent water spraying and anion radiation was designed for producing GBR easily by controlling the environmental conditions such as ambient temperature, relative humidity, and anion radiation as shown in Figure 1.

Fig. 1 An automatic brown rice germinating system of air-phase type with anion radiation and intermittent water spraying: image of front view (A); image of inside view (B).

This system relies on the proper intermittent water spraying intervals and anion radiation. As mentioned above, the best ways to avoid problems of soaking method are to maintain a clean environment, proper ventilation and temperature control. Therefore, this germinating system for GBR consisted of the following parts: a germinating chamber; a cooling unit; water sprayers; a heater; a proportional, integral, and derivative action (PID) controller for temperature; an anion generator. The chamber of the system contained removable trays for easy handling of the brown rice, and was equipped with spray nozzles. Temperature, humidity and water spraying were operated by a PID controller with programmable step modes. The experiment was conducted with intermittent water spraying at 25℃ and 90% relative humidity condition. The entire apparatus is enclosed in a housing having walls which are made of heat insulating materials. An arrangement of control is provided for supplying water to the chamber from the tank. The brown rice to be germinated is placed on suitable trays having a perforated bottom. In Figure 1, C1 is the water tank connected to a water supply pipe. L1-4 is the water sprayers. A1 is an anion generator. F1 is a fan motor for ventilation. C2 is a clean environment chamber. C3 is a control panel for intermittent water spaying, heating, cooling, and operation setting. S1 is a water level sensor. Valves installed in this system are also provided for controlling the flow of liquid from the tank to the pipe. Table 1 shows the specification of an automatic germinating system developed in this study. Here, main instruments used for developing this system were presented.

Table 1 The specification of an automatic brown rice germinating system developed in this study

Items	Specifications
Germinating chamber	500 × 730 × 1250 (mm), Max. Capacity: 80 kg
Temperature controller	Maker: Daesung Co.,Model: FOX-1004 Range: -50 ~ 100 ℃ Output: 250 VAC 2A, Power: 220VAC - 60Hz
Anion generator	Maker: SJ-1000, SJ Co., Korea Power: 20W. Anion number: Max. 3 million pcs/cm^3
Water pump	Maker: Hanil Co.,Model: PH-100WM Flow rate: 20 liter/min, Voltage: 230 V, 60 Hz
Heater	Power: 1.5kW, Voltage : 220 V
Fan motor	Maker: LGD Blower Co.,Model: LD-B120 Power: 97 W, Air Flowrate: 3.8 m^3/min, Air Pressure: 34 mmAq
Condenser	Maker: Daeil Co., Model: DIC-02 Power: 1/2 HP, Voltage: 230 V, 60 Hz
Compressor	Maker: ACC Compressor Co., Model: P12TN Power: 1/2 HP, Voltage: 230 V, 60 Hz
Water bath	500 × 860 × 200 (mm)
Water spraying device	6 Dia. × 2000 mm, Orifice diameter: 2 mm Flowrate : 1.1 liter/min, 1.5 kg/cm^2 Spray angle: 61 degree Orifice intervals: 50 mm
Water level sensor	Water automatic supply: 100 mm Float Type Level Transmitter (DC24V, 4-20mA) Max. Temperature: 80℃, Max. Pressure: 7 Kgf/cm^2
Sample basket	445 × 350 × 98 (mm), Max. Capacity: 10 kg

The control algorithm of this system is operated with an automatic water-spraying device depending on temperature and humidity controller with program control setting. Germinating experiments were carried out with condition of 20 min intervals of intermittent water spraying at 25℃ and approximately 90% relative humidity condition.

B. Experiments of Brown Rice Germination using a Water-soaking Method

The brown rice (Dongjin variety) used in this study was harvested in 2006 at Jangsung of Chonnam Province, Republic of Korea. The rice was packed in polypropylene bags and stored at 4℃ in a refrigerator. Prior to the experiment the brown rice samples were cleaned thoroughly, and defective grains were removed. The linear dimensions and weights of the grains were measured with a digital caliper having a resolution of 0.01 mm (CD-15CD, Mitutoyo Co., Japan). Germination tests were conducted according to the standard water soaking method of the AOSA (Association of Official Seed Analysis, 1993). This water soaking method was used as a control in this study. Experiments using the water soaking method were conducted in Petri dishes (9.0 cm × 1.5 cm) with filter paper (No. 2, Whatman, Kent, England). Sprout length was measured for 50 kernels of each treatment using a digital caliper every 12 h.

C. Experiments of Brown Rice Germination under Half-Air-phase Germination with Anion Radiation

Brown rice sample was exposed to air, and its half was soaked in water, which was named as half air-phase. To investigate the effects of half-air phase germination with anion radiation on the germination ratios and sprout lengths of brown rice, experiments were conducted with 50 kernels at a 25℃ temperature and 90% humidity as shown in Figure 2. Anions were radiated using a general-purpose anion generator (SJ-1000, SJ Co., Korea) installed in the system as shown in Figure 2(a). The anion generator included a casing, an interior circuit, an ion emitting head and a discharge resistance. Anions were counted using a digital air ion counter (ITC-201A, INTI Co., Japan) with an ion count range of 10 to 1,236,000 pcs/cm^3 where pcs unit means particle concentration. The anion generator is an electrical discharger to cause the ionization of the air surrounding an electrode when the potential gradient exceeds a critical value. The electrons are generated at the electrode by the photoelectric action of photons striking its surface as shown in Figure 2(b).

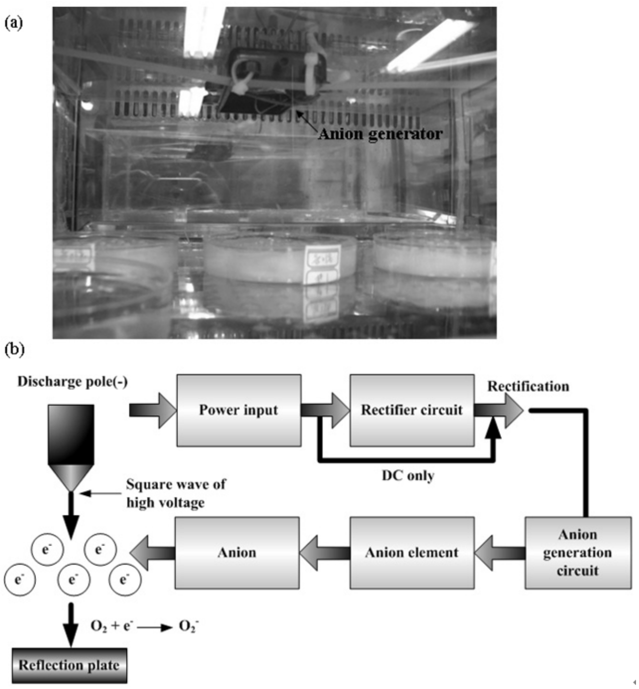


Fig. 2 Experiments of half air-phase germination with anion radiation: an anion generator (a), and schematic diagram on anion radiation from an anion generator (b).

D. Experiments of Brown Rice Germination under Air-phase Germination with Intermittent Water Spraying and Anion Radiation

To investigate the efficient brown rice germination, we classified the key factors as the four methods which carried out with the water spraying intervals (1), air-phase germination with intermittent water spraying in scale-up (2), anion radiation in half air-phase germination (3), and air-phase germination with intermittent water spraying with anion radiation (4), respectively. Experiments were conducted with brown rice samples of 100, 500, and 1,000 g in tray baskets, respectively. All the samples were pre-washed in water at 25℃. Tray baskets were placed on the overhead rack of the chamber. Intermittent water spraying was accomplished using a water pump and spray nozzles governed by a controller programmed with 10, 20, 40, and 60 min interval cycle. The experiments were performed at 25℃ and 90% relative humidity for 48 h with anion radiation after soaking at 25℃ for 6 h. The germination ratios and sprout lengths of brown rice were recorded at intervals up to 48 h.

E. Color Quality and GABA Analysis of GBR

A mean luminosity value of each treatment as color quality of GBR was calculated using Adobe Photoshop (version 7.0, Adobe Systems; San Jose, CA). GABA content was analyzed according to the method of Oh and Oh (2004) and Park and Oh (2005).

F. Statistical Analysis

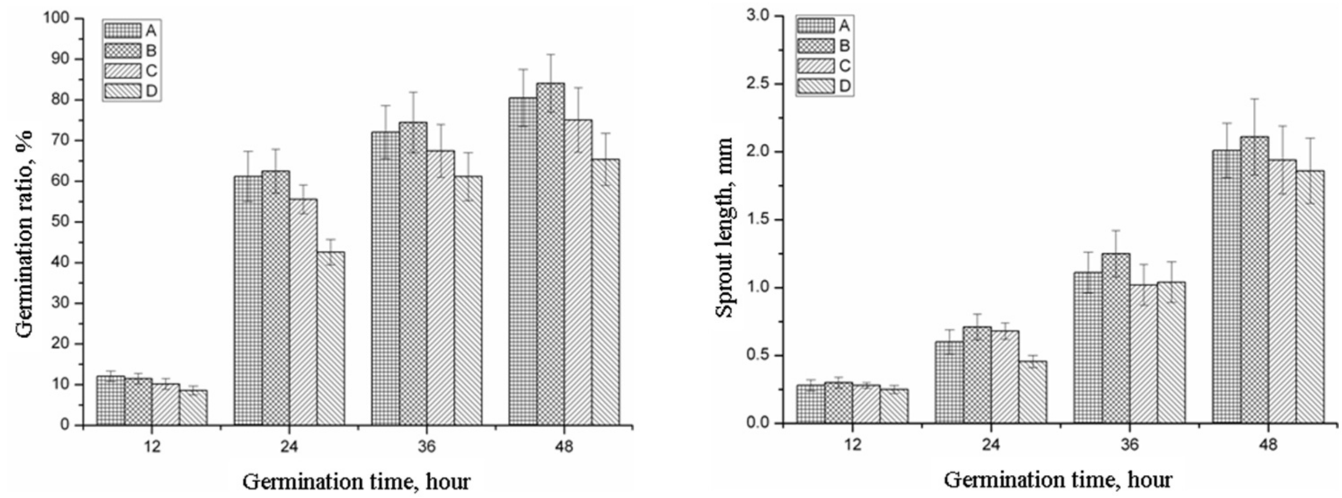
Statistical analysis was carried out using the SAS Statistical Analysis System for Windows v8.2 (SAS Institute, Inc., Cary, NC, USA). Statistically significant differences between the control and treatment groups were detected using two-way ANOVA and Duncan's multiple range tests at $p < 0.05$. These data were reported as their mean and standard deviation values.

3. RESULTS AND DISCUSSION

A. Effects of Water Spraying Interval for Air-phase Germination

It was thought that it would be very important to find out the proper intermittent water spraying intervals for controlling optimal germinating process in this system. Therefore, it was investigated that the effects of air-phase germination with various operating setting steps for the optimum intermittent water spraying interval. Germinating experiments of four types were conducted with operating conditions of a pump for intermittent water spraying ((10 min (A), 20 min (B), 40 min (C), and 60 min (D)). From experimental results, brown rice germinating process at 20 min interval (B) showed the best sprout growth and germination ratio than other experimental groups (A, C, and D) as shown in Figure 3(a and b). This germinating method clearly presented that germination ratio and sprout length of brown rice was more than doubled, compared to the water-soaking method as control.

In particular such a long germinating process interestingly indicated the negative behaviour due to exposure to air phase for a long time. The germinating process within 30 min interval showed similar results. Considering all the conditions, the germinating process at regular interval of 20 min could be determined as the most group in taking a side view of germinating speed and energy economy.

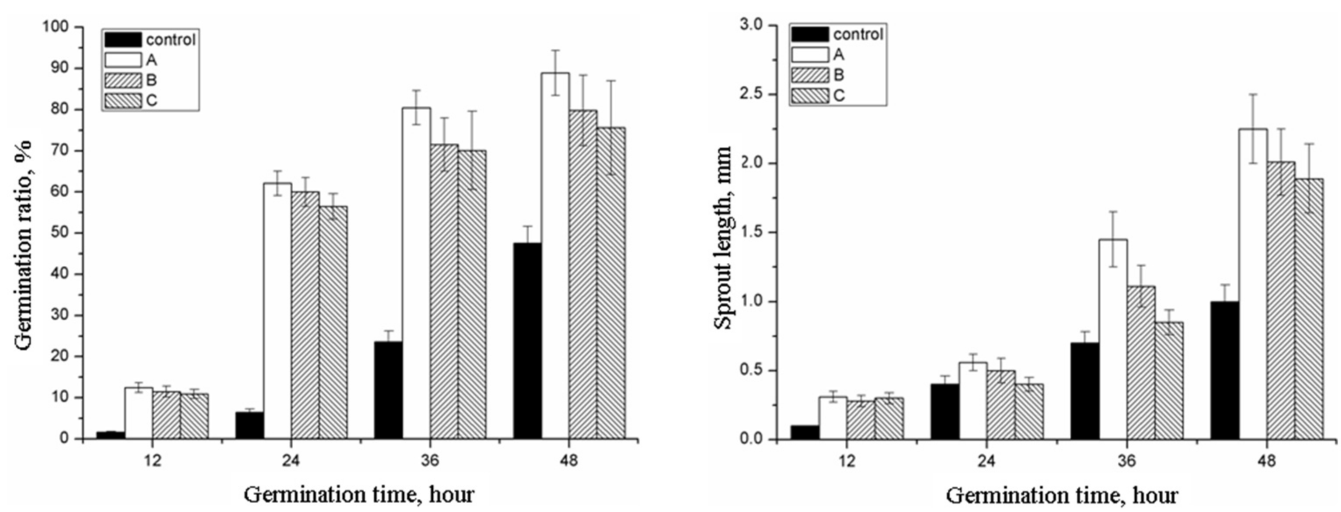


(a) (b)

Fig. 3 Comparison of germination ratio (a) and sprout growth (b) by intermittent water spraying intervals in germinating system; operating conditions of intermittent water spraying intervals (10 min (A), 20 min (B), 40 min (C) and 60 min (D)).

B. Effects of Air-phase Germination with Intermittent Water Spraying in Scale-Up

A comparison of germination ratio between the air-phase germination with intermittent water-spraying for samples of 100 g (A), 500 g (B), and 1,000 g (C) in tray baskets and the water-soaking method is shown in Figure 4(a). New experimental data for 100 g and 500 g samples were added and compared to the reported result for 1,000 g samples (Lim *et al.*, 2006). The air-phase germination with intermittent water-spraying ameliorated the germination ratio of brown rice by about 2.3 times, compared to the water-soaking method as control. The difference of the germination ratio between soaking and intermittent air-phase germinating method in the 24, 36, and 48 h treatments was found to be statistically significant ($p<0.01$). Also, the difference to the ratio of each samples for the 48 h treatment was found to be statistically significant ($p<0.05$) in Figure 4(a). Figure 4(b) also shows the comparison of sprout growth between the air-phase germination with water-spraying for samples of 100 g (A), 500 g (B), and 1,000 g (C) in tray baskets and the water-soaking method. The air-phase germination with



(a) (b)

Fig. 4 Comparison of germination ratio (a) and sprout growth (b) between the air-phase germinating with intermittent water spraying at 20 min. intervals and water soaking germination for experiment samples of 100 g (A), 500 g (B), and 1,000 g (C) in tray baskets. New experimental data for 100 g and 500 g samples were compared to the reported result for 1,000 g samples (Lim et al., 2006).

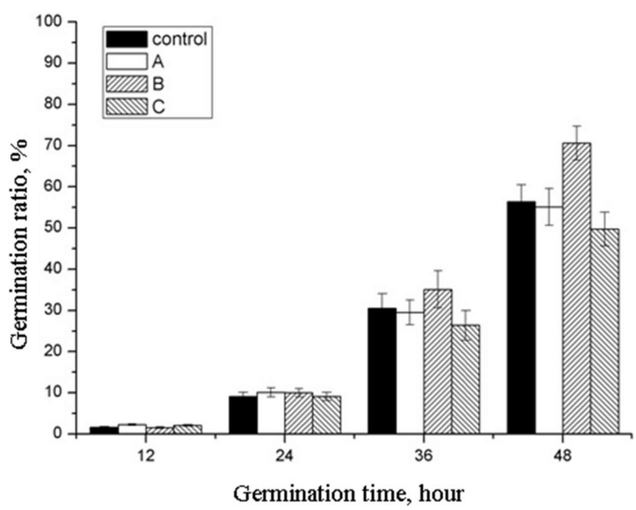
water-spraying method enhanced the sprout growth by about 2.2 times in 48 h, compared to control. The difference of the sprout length between soaking and air-phase method with water spraying in the 36 h and 48 h treatments was found to be statistically significant (p<0.01). Also, the difference to the sprout length of each samples in the 48 h treatment was found to be statistically significant (p<0.05).

C. Effects of Anion Radiation in Half Air-phase Germination of Brown Rice

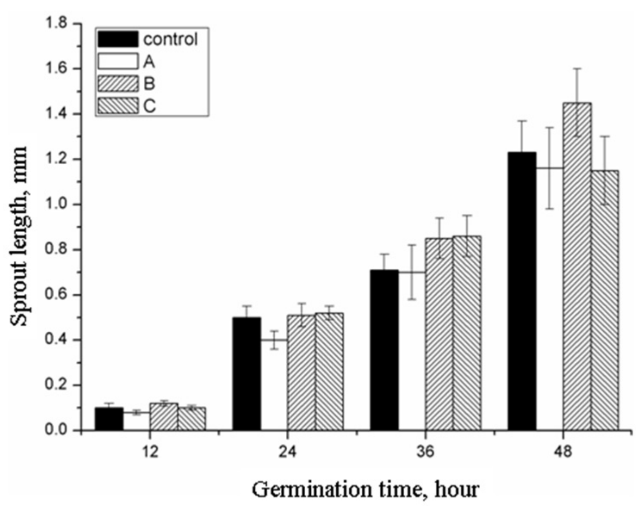
The effects of anion radiation in half air-phase germination using an incubator on the germination ratios and the sprout lengths of brown rice were investigated. Figure 5(a) showed a comparison of germination ratios between half-air phase germination with non-anion radiation (control) and half air-phase germination with anions of 100,000 (A), 500,000 (B), and 1,000,000 (C) pcs/cm^3, respectively. The effects of 24, 36, and 48 h treatments on the germination ratios were all significant (p<0.05). The anion radiation at 500,000 pcs/cm^3 improved the germination ratio by about 10% after 48 h. Figure 5(b) indicated a comparison of sprout growth between half air-phase germination with non-anion radiation (control) and half air-phase germination with anions of 100,000, 500,000, and 1,000,000 pcs/cm^3, respectively. The anion radiation at 500,000 pcs/cm^3 showed the most positive effects on the germination ratio and the sprout length. Rather, the strong anion concentration of 1,000,000 pcs/cm^3 inhibited the germination ratios and the sprout lengths.

D. Effects of Air-phase Germination with Intermittent Water Spraying and Anion Radiation

Figure 6 showed the comparison of germination ratio (Fig. 6a) and sprout growth (Fig. 6b) between the air-phase germination with intermittent water spraying at 20 min. intervals (A, C, and E) and anion radiation treatment of those (B, D, and F) according to the samples of 100 g (A, B), 500 g (C, D), and 1,000 g (E, F) in tray baskets, respectively. Among described data, it was based on already reported result of 1,000 g samples (Lim *et al.*, 2006). The effects of 24, 36, and 48 h treatments on the germination ratio and sprout growth for 100 g samples were significant (p<0.05) respectively, whereas 12 h treatment was insignificant (p<0.1). The effects of 24, 36 h treatments on the germination ratio for 500 g samples were also significant (p<0.05), whereas 48 h treatment was not significant. In results of the anion radiation experiment, the effects of anion on the germination ratio and sprout growth of brown rice in a single layer of the 100 g sample were about 15%-20% higher than that of the 1,000 g sample in tray baskets. Through this experiment with anion radiation in this study, we could determine that anion radiation affected to the surface layer in the bulk experiment as accelerating the mass transfer of the cell wall and activating the metabolisms of plant tissues (Ji, 2003).

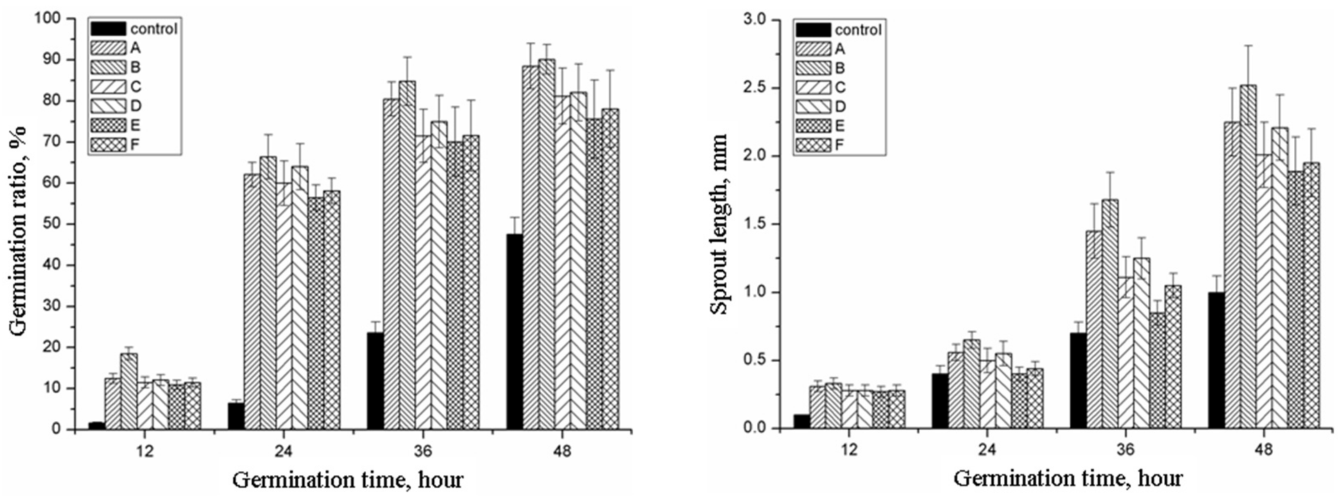


(a)



(b)

Fig. 5 Comparison of germination ratio (a) and sprout growth (b) between half air-phase germination with anion radiation (anions of 100,000 (A), 500,000 (B), and 1,000,000 (C) pcs/cm3) and half air-phase germination with non-anion radiation (control).



(a) (b)

Fig. 6 Comparison of germination ratio (a) and sprout growth (b) between the air-phase germinating with intermittent water spraying and anion treatment, as compared to water soaking method; the air-phase germination with intermittent water spraying at 20 min. intervals (A, C, and E) and anion radiation treatment of those (B, D, and F) for the samples of 100 g (A, B), 500 g (C, D), and 1,000 g (E, F). New experimental data were compared to the reported result for 1,000 g samples (Lim et al., 2006).

E. Color Quality and GABA Content of GBR

The effects of anion radiation on the color quality of GBR were investigated. The effects of anion radiation on the color quality of GBR compares the color quality of brown rice germinated using an air-phase method without anions (146 ± 36), and using an air-phase method with anion radiation (194 ± 34), compared to that of the water soaking method (207 ± 27). However, the air-phase method with water spraying and anion radiation showed higher brightness values than the air-phase method without anion radiation. In particular, the air-phase germination method with anions in a single layer had higher brightness values than air-phase germination with anion radiation in samples in bulk. This indicated that anion radiation was more effective in a single layer than in multiple layers of brown rice. The anion radiation improved the color quality of GBR by preventing airborne contamination by bacteria and fungi and caused biological activation of oxygen transfer on rice surfaces (Ji, 2003). Also, the effect on GABA content of GBR germinated by the air-phase method with water spraying and anion radiation was described in detail (Lim *et al.*, 2006). Through this result, the germinating method of the air-phase with intermittent water spraying and anion radiation showed the superiority of an efficient germinating method when germinated for the same period, relative to conventional soaking germination method.

4. CONCLUSIONS

In this study an automatic germinating system for GBR was developed to accelerate germination and sprouting of brown rice. The effects of intermittent air-phase with water spraying on brown rice were investigated using the developed system. The effect of an anion radiation on brown rice was also investigated. Interestingly, both of them showed markedly fast speed of germination ratio and sprouting growth of brown rice. First, the experiment method of air-phase germination with intermittent water spraying showed above 2.2 times in germination ratio and sprouting growth compared to a conventional soaking method. Additionally, the anion treatment group of 500,000 pcs/cm^3 improved the germination ratios and the sprout lengths by about 15% compared to the non-anion group. Consequently, this system could germinate brown rice within 48 h without water soaking and improved the germination ratio of brown rice about 2.3 times and accelerated the sprout growth of brown rice about 2.2 times, compared to those of the conventional water soaking method. The germination ratio and the sprout growth of brown rice germinated with anion radiation were improved by about 15% and 30%, respectively, compared to values achieved from the conventional soaking methods. The surface brightness of germinated brown rice was higher than that of brown rice germinated without anion radiation. The conclusions of this study were as follows:

(1) A proper anion radiation on GBR could effectively accelerate the germination ratios and the sprout lengths.
(2) Air-phase germination with intermittent water spraying could enhance the germination ratios and the sprout lengths of GBR, compared to those of the conventional water soaking method.
(3) Air-phase germination with intermittent water spraying and anion radiation improved color quality and the GABA amount of GBR.
(4) This system implementing air-phase germination with anion radiation and intermittent water spraying could improve germination ratios, sprout lengths, and color quality of germinated brown rice, compared to those of the water-soaking method.

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