1-Methylcyclopropene（1-MCP）水溶液への浸漬処理がバナナ果実の追熟に及ぼす影響
Effects of Immersion in Aqueous 1-methylcyclopropene (1-MCP) Solution on Ripening of Bananas

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The effects of immersion in aqueous 1-methylcyclopropene (1-MCP) solution on the ripening of bananas were investigated. Mature green bananas were immersed in water (control) or 0.1, 1, 10, 50, 100, or 1,000 μg (active ingredient) L⁻¹ aqueous 1-MCP solution for 10 min 2 days after the start of ethylene treatment (DASE) and stored at 20°C in the dark. In the bananas treated in 50, 100, and 1,000 μg L⁻¹ 1-MCP solutions, an increase in color score was suppressed, and the ratio of the brown spot area to the surface area increased slightly and remained low until 12 DASE. To investigate the effects of the duration of immersion on ripening, the bananas were immersed in 100 μg L⁻¹ aqueous 1-MCP solution for 0.5, 1, 3, 6, 10, or 15 min or not immersed (control) 2 DASE and stored at 20°C in the dark. In the bananas treated for 10 and 15 min, increases in the score and ratios were suppressed. The internal quality of the bananas immersed in 100 μg L⁻¹ aqueous 1-MCP solution for 10 min, which was effective and efficient in suppressing ripening, was similar to that of the control, and the edible period was prolonged by more than twofold. These results suggest that immersion of bananas in aqueous 1-MCP solution is a very practical postharvest application because of the easy availability of 1-MCP.

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Key words : banana, edible period, 1-MCP, quality, ripening

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Bananas are typically a climacteric fruit and harvested in the mature green stage, transported, and then ripened artificially with ethylene before being sent to the market. The ripening of ethylene-treated bananas proceeds by autocatalytic ethylene production, and the bananas become edible approximately 4 days after ethylene treatment. Commercially, once bananas are induced to ripen with ethylene, their marketing life is approximately 3 ~ 5 days. Thus, postharvest techniques to extend shelf-life in the market and edible life have been demanded.

1-Methylcyclopropene (1-MCP), an ethylene action inhibitor, is commercially used worldwide to suppress ethylene-mediated ripening and senescence in various fruits and vegetables, including apples, avocados, bananas, plums, tomatoes, peaches, and pears. Because the affinity of 1-MCP for the ethylene receptor is approximately 10 times greater than that of ethylene, 1-MCP competitively inhibits the binding of ethylene to the receptor and, as a result, inhibits ethylene action. Thus, 1-MCP delays ethylene-induced effects on ripening and senescence. So far, 1-MCP exposure of horticultural crops has generally been accomplished via treatment with gas in sealed containers. However, the availability of this method is limited in commercial situations because the treatment requires the use of facilities and a long period between 12 and 24 h.

Recently, preparations of 1-MCP designed for use as aqueous solutions have been formulated as a flexible treatment, and the availability of preharvest and postharvest aqueous 1-MCP treatments has been suggested. Although the efficiency of gaseous 1-MCP treatment on the ripening of bananas has been extensively researched, the effects of aqueous 1-MCP treatment on bananas have not yet been clarified. Here, we elucidated the feasibility of immersion in aqueous 1-MCP solution for extending the edible period of bananas by researching the optimum conditions for immersion, including 1-MCP concentration and immersion duration, as well as the internal quality of bananas.

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Materials and Methods

1. Plant material
Mature green bananas (Musa AAA group) imported from the Philippines were purchased from Summit Kobe Gohdo Bussan Co., Ltd. All hands were separated into fingers, and injured or brown bananas were removed. The cut surfaces of the bananas were then dipped in 1% (v/v) sodium hypochlorite solution and washed with water. The fingers were treated with ethylene and then with 1-MCP (see below). After the treatments, the bananas were stored in plastic trays (23 cm × 30 cm × 6 cm) with 8 punched holes (diameter, 5 mm) at 20°C in the dark. Each treatment used 5 replicate fingers.

2. Ethylene treatment
About 20 banana fingers from different hands for each container were treated with 100 μL L⁻¹ ethylene in a 24.8-L polyethylene container sealed with a rubber stopper at 20°C for 18 h in the dark.

3. 1-MCP treatment
The bananas were treated without (control) or with aqueous 1-MCP solution prepared from Smart Fresh™ (3.3% active ingredient, Rohm & Haas Japan Co., Ltd.) 2 days after the start of ethylene treatment (DASE). Solutions were prepared with the indicated amounts of 1-MCP powder. Different quantities of the powder containing the desired levels of the active ingredient were suspended in 10 L water at 22~24°C in a plastic container (38 cm × 47 cm × 14 cm) and stirred gently with a spatula for 1 min. The solutions after preparation were held for 10 min prior to starting the treatment. The bananas were immersed in the solutions and covered with a glass plate to ensure their complete coverage during the immersion period. After removal, the bananas were quickly wiped with a paper towel, dried, and stored. To investigate the effects of aqueous 1-MCP solution on ripening, the bananas were immersed in solutions prepared with 1-MCP powder at 0.1, 1, 10, 50, 100, and 1,000 μg (active ingredient) L⁻¹ for 10 min. Bananas immersed in water for 10 min were used as controls. To investigate the effects of immersion duration on ripening, aqueous 1-MCP solution was prepared at a concentration of 100 μg L⁻¹, and bananas were immersed for 0.5, 1, 3, 6, 10, or 15 min. Those that were not immersed in 1-MCP were used as control. For the determination of internal quality, bananas immersed in water (control) or aqueous 1-MCP solution at 100 μg L⁻¹ for 10 min were used.

4. Determination of peel color
The peel color of the bananas was assessed everyday according to a color chart (1 = Green, 2 = Green, trace of yellow, 3 = More green than yellow, 4 = More yellow than green, 5 = Yellow, green tips, 6 = Full yellow, 7 = Yellow, lightly flecked with brown, and 8 = Yellow with increasing brown areas) until the score of 2 bananas in each treatment became 8. In the case that the crown rot of the stem occurred, it was assessed until the day before the crown rot of the stem of 2 bananas in each treatment reached the top of the finger, except for determination of the edible period. The first day of the edible period was defined as the day when the score reached 5, and the last day was defined as the day when it was 7. For determination of the edible period, the edible period of each fruit was measured and, in the case that crown rot occurred, the last day of the edible period was defined as the day before it reached the top of the finger.

5. Determination of brown spots
The determination of brown spots was conducted as described previously. Brown spots on the peel were identified using digital images of each banana by ImageJ software, a public domain image analysis application (http://rsb.info.nih.gov/ij/). Images of each banana for analysis were adjusted using Adobe Photoshop Elements 4.0 (Adobe Systems). The surface and brown spot areas of the banana peel were calculated using ImageJ, and the ratio of the brown spot area to the surface area was expressed in percentage.

6. Determination of flesh firmness
Flesh firmness was measured using a penetration tester push-pull scale (Imada Seisakusho Co., Ltd.) fitted with a 3-mm-diameter plunger. The plunger was used to penetrate each banana three times. The measurement result was analyzed by Tukey’s multiple comparison test.

7. Soluble solid content and titratable acidity
Approximately 20 g of banana flesh was homogenized in an equal weight of water. The homogenate was centrifuged at 5,000 rpm for 20 min at 20°C. The supernatant was obtained and used for determining soluble solid content using a hand-held refractometer N-1 (Atago Co., Ltd.). The value was determined to be double. For determining titratable acidity (TA), the supernatant was titrated
against 0.1 N NaOH using phenolphthalein as the indicator and expressed as percent citric acid.

Results

1. Effects of aqueous 1-MCP solution on the ripening of bananas

To evaluate the efficiency of aqueous 1-MCP solution on the suppression of ripening in bananas, we investigated the changes in the peel color of bananas immersed in aqueous 1-MCP solution at various concentrations. The color score of the control bananas increased continuously during storage and reached 5 and 7 DASE, respectively (Fig. 1). The color score of the bananas treated in 0.1, 1, and 10 μg L⁻¹ 1-MCP solutions changed almost the same as that of the control. However, in the bananas treated in 50, 100, and 1,000 μg L⁻¹ 1-MCP solutions, an increase in the color score was suppressed. The color score increased slowly after 4 DASE and reached 5 7 DASE. To clarify the effects of aqueous 1-MCP solution on the development of brown spots, the ratio of the brown spot area to the surface area was investigated. In the control and bananas treated in 0.1 μg L⁻¹ 1-MCP solution, brown spots occurred 6 DASE (Fig. 2). Then, the ratio increased consistently and finally reached 9.6% and 12.0%, respectively. In the bananas treated in 1, 10, 50, 100, and 1,000 μg L⁻¹ 1-MCP solutions, brown spots occurred 7 DASE. After their occurrence, the bananas treated in 1 and 10 μg L⁻¹ 1-MCP solutions, the ratio of the brown spot area to the surface area increased continuously and became almost identical to the ratio of the control and bananas treated in 0.1 μg L⁻¹ 1-MCP solution 9 DASE. In contrast, in the bananas treated in 50, 100, and 1,000 μg L⁻¹ 1-MCP solutions, the ratio increased slightly and remained low until 12 DASE, which indicates that the treatment suppresses the development of brown spots.

2. Effects of immersion duration on the ripening of bananas

The effects of immersion duration on the ripening of the aqueous 1-MCP treatment were examined using aqueous 1-MCP solution at 100 μg L⁻¹, which was thought to be a subsaturating concentration. Immersion in aqueous 1-MCP solution at 100 μg L⁻¹, as shown in the data above, effectively delayed ripening following a 10-min immersion. The color score of the control reached 5 5 DASE and exceeded 7 7 DASE (Fig. 3). The color score of the bananas subjected to other treatments exceeded 5 6 DASE. Afterward, the scores of the bananas treated for 0.5, 1, 3, and 6 min increased continuously. In the bananas treated for 10 and 15 min, an increase in the score was suppressed, and the score remained almost constant until 8 DASE. Brown spots occurred 6 DASE in the bananas treated with 1-MCP for all durations tested (Fig. 4). The ratios of the control and bananas treated for 0.5 min increased consistently and finally reached about 9 %.
In ripening of bananas was effective and efficient for suppressing the especially 10 and 15 min were suppressed.

aqueous 1-MCP solution at 100 μL L⁻¹ was used as control (○). Vertical bars represent the standard deviation of the mean of 5 bananas. Some error bars and symbols are hidden by other symbols.

In the bananas treated for other durations, especially 10 and 15 min, increases in the ratios were suppressed.

3. Internal quality of bananas treated with 100 μg L⁻¹ aqueous 1-MCP solution for 10 min

Because it was clarified that immersion in aqueous 1-MCP solution at 100 μg L⁻¹ for 10 min was effective and efficient for suppressing the ripening of bananas, we investigated the internal quality of the control and 1-MCP-treated bananas on the first and last days of the edible period to determine whether the quality of fruit treated with aqueous 1-MCP solution was good. There were no differences in firmness on the first day of the edible period between the control and 1-MCP-treated bananas. In the control, firmness decreased during the edible period, but, in 1-MCP-treated bananas, the initial value was maintained during the edible period (Fig. 5). Throughout the edible period of both treatments, there were no significant differences in the soluble solid content (Fig. 6). In the control, TA was about 0.3% on the first day of the edible period; it decreased during the edible period (Fig. 7). In the 1-MCP-treated bananas, TA on the first day was similar to that of the control on the last day and was maintained during the edible period. The effects of the treatment on the edible period were measured by assessing each fruit. The treatment significantly prolonged the edible period by more than twofold: the period of the control was 2 days, while the period of the treated fruit was about 4.8 days (Fig. 8).

Discussion

The aqueous 1-MCP treatment of bananas affects their ripening. The 1-MCP treatment of preclimacteric mature green bananas extends their green life, and the effectiveness of 1-MCP varies with fruit maturity. Mature green bananas treated with 300 nL L⁻¹ 1-MCP after 48 h of ethylene treatment had a 6-day shelf-life (half-ripe to over-ripe), compared with 3 days for the nontreated bananas, without affecting the green life (unripe to half-ripe). Banana ripening induced by ethylene could be delayed by exposure to 0.3 μL L⁻¹ 1-MCP at color stage 3, as evaluated using the L* value of banana peel, and it has been concluded that the treatment extends the edible life to 12 days at 25°C. The period between the firm and fully ripe stages of bananas is prolonged by 1-MCP treatment at 1 μL L⁻¹ 2 DASE. Intensive research in this area has indicated that the time of 1-MCP treatment is very important for extending shelf-life and edible life. Here, 2 DASE was adopted as the immersion time of bananas based on the results of Tojo et al. Although it has been suggested that the postharvest 1-MCP treatment of bananas is feasible, it has not been used for commercial applications. Recently, research on the use of aqueous 1-MCP
formulations has been reported. Postharvest treatment with aqueous 1-MCP solution of climacteric fruits, including tomatoes, avocados, plums, and apples, suppresses ripening. Aqueous 1-MCP solution, compared with gaseous 1-MCP, markedly reduces the treatment duration, which indicates its great advantage for practical use.

In this study, the effects of aqueous 1-MCP solution on the ripening of bananas were investigated. When the immersion duration was 10 min, increases in the color score and brown spots were suppressed at aqueous 1-MCP concentrations above 50 µg L⁻¹ (Figs. 1 and 2). When the concentration of aqueous 1-MCP solution was 100 µg L⁻¹, the increases were suppressed for the immersion duration of 10 min or more (Figs. 3 and 4). These results showed that the immersion of bananas in aqueous 1-MCP solution could delay ripening and that immersion in aqueous...
1-MCP solution at 100 μg L⁻¹ for 10 min is optimum. Under these conditions, it was revealed that aqueous treatment could prolong the edible period by more than twofold (Fig. 8) similarly to gaseous treatment. Quality factors, including the firmness, soluble solid content, and acidity (Figs. 5, 6, and 7) of aqueous 1-MCP-treated bananas during the edible period, were almost the same as those of the control, as the internal quality of gaseous-1-MCP-treated bananas was similar to that of the control, which means that aqueous 1-MCP treatment has no negative impacts on fruit quality. Gaseous 1-MCP treatment could cause uneven peel degreening, which is neither desirable nor acceptable for marketers and consumers; however, in this study, aqueous 1-MCP treatment caused none of this problem. Crown rot occurred in the stem of some bananas because of the prolonged storage period, ending the edible period. The edible period could be longer if crown rot is prevented with appropriate use of sodium hypochlorite solution, which is widely used for the postharvest sanitization of horticultural crops. In this case, note that sodium hypochlorite solution affects the efficacy of aqueous 1-MCP treatment.

We conclude that aqueous 1-MCP solution is effective in delaying the ripening of ethylene-treated bananas and extends the edible period by more than twofold compared with the control. This suggests that aqueous 1-MCP treatment of bananas is a breakthrough technology with advantages of simplified equipment and shortened treatment duration. It will contribute to the economical distribution of bananas through reduction in postharvest losses.

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1-Methylcyclopropene (1-MCP) 水溶液への浸漬処理がバナナ果実の適熟に及ぼす影響

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1-methylcyclopropene (1-MCP) 水溶液への浸漬処理のバナナ果実の適熟に及ぼす影響が調べられた。エチレン処理開始後2日に、緑熟バナナは、コントロールとし
て水、または0.1, 1, 10, 50, 100, 1,000 μg L⁻¹の1-MCP水溶液に10分間浸漬処理され、その後20℃暗所下で貯蔵された。50, 100, および1,000 μg L⁻¹の1-MCP水溶液で処理された果実では、カラースコアの増加が抑制され、褐色斑点の表面積に占める割合の増加はわずかであり、エチレン処理開始後12日まで低いままであった。浸漬時間が浸漬に及ぼす影響を調べるために、エチレン処理開始後2日に、果実は100 μg L⁻¹の1-MCP水溶液に0.5, 1, 3, 6, 10または15分間浸漬処理され、20℃暗所下で貯蔵された。なお、コントロールは浸漬処理をおこなわないもののとした。10分間および15分間処理した果実では、カラースコアと褐色斑点の表面積に占める割合の増加が抑制された。適熟の抑制に効果的かつ効率的であった、100 μg L⁻¹の1-MCP水溶液に10分間浸漬処理を行った果実の内部品質はコントロールと差異は認められず、また果実の可食期間は2倍以上に延長された。これららの結果から、1-MCP水溶液によるバナナ果実への処理は、その有用性から極めて实用的な収穫後の処理であることが示唆された。

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