1-Methylcyclopropene as an Effective Ethylene Inhibitor to Extend Musa acuminata Colla ‘Muli’ Postharvest Quality

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Abstract. Musa acuminata Colla ‘Muli’ is one of the most popular banana variety in Indonesia. As a commodity that is consumed fresh, is important to regulate the ethylene production of climacteric fruit in order to extend the shelf life and reduce deterioration. 1-MCP (1-Methylcyclopropene) is a potential chemical that can effectively regulate ethylene production in Muli bananas. In this study, 1-MCP in different concentrations (0, 0.25, 0.50 and 1.00 µL L⁻¹) were applied at two maturation stages to observe the effects. Lower 1-MCP concentration was effective in delaying fruit ripening on mature green stage shown by fruit firmness maintenance and improved shelf life up to 4.5 days longer than control. The application of 1-MCP was effective in delaying fruit ripening if applied prior to climacteric stage.

1. Introduction
Bananas are a type of horticulture crop famous as a consumable fruit in Indonesia. One of the most famous banana fruit in Indonesia is Musa acuminata Colla ‘Muli’. It is a native banana in West Java and the most popular local banana in this area. It is similar with the cavendish banana however it characterized by a small fruit size, a yellow to orange fruit peel, and more sweetness than cavendish banana. Even though this fruit is small, it has a good taste and aroma and also contains high levels of macro and micronutrient such as vitamins and minerals that are important for human health and dietary. Muli banana has an economically important for farmer in Indonesia, however it has many problems such as in maintaining postharvest live quality. Compared to cavendish banana, Muli banana has not been investigated precisely, therefore the study on Muli banana is very important to resolve its problems.

For market purposes, many banana fruits have a problem such as the short of fruit shelf life, where the fruit shelf life relatively fast and finally it can’t be sold freshly in the market. This effect directly reduces the fruit price and consumer acceptance. The most important thing in reducing banana fruit quality is ethylene, where it can accelerate fruit ripening therefore the fruit shelf life will be short. Ethylene is gaseous plant hormones that accelerates fruit ripening and senescence. Besides ethylene has an effect in accelerating fruit ripening, it has effect in regulating many plant growth and development process such as the plant response to the environmental conditions and stress [1]. Moreover, ethylene effects on seed germination, flower senescence, leaves drop, formation of root nodule [2].

Based on post-harvest fruit characteristics, bananas belong to the group known as climacteric fruit, where the respiration is increased followed by higher levels of ethylene production that occur at the onset of the fruit-ripening process [3]. During ripening process, changes in biochemical and physiological process occur that influence fruit quality and flavor, color, aroma, and texture [4]. In many fruit species, ethylene accelerates fruit ripening, which contributes to changes in the nutrient content and
other compounds that has a positive effect to accelerate for fruit to be consumed, however, it has negative effects to accelerate quality deterioration by shortening the shelf life of the fruit. In banana fruit, fruit softening is one of the important factors for determining fruit quality and also harvesting time that are regulated by ethylene [5]. Chaves and Mello-Farias [6] stated that process of fruit ripening in climacteric fruit is a complex process.

To maintain banana fruit quality and to improve fruit shelf life, therefore the effect of ethylene must be minimized especially during transportation and storage. Some strategies have been conducted to minimize and prevent the ethylene effect on postharvest life of fruits such as by inhibiting ethylene biosynthesis or ethylene perception. To inhibit ethylene biosynthesis, some chemical compounds such as Aminoethoxyvinylglycine (AVG), Diazocyclopentadiene (DACP), Silver Thiosulfate (STS), etc. and also atmosphere modification have been widely used. Inhibiting ethylene biosynthesis is only effective in preventing endogenous ethylene, but it is not effective in preventing exogenous ethylene that affect in fruit ripening. 1-Methylcyclopropene (1-MCP) has been found as a potential chemical compound that inhibits the ethylene perception of both endogenous and exogenous ethylene by inactivating ethylene receptor.

1-Methylcyclopropene (1-MCP) was developed in the early 1990’s. It is not toxic and environmentally friendly, therefore it is potential used for edible crops such as fruit and vegetable. In many studies showed that 1-MCP have been widely used for improving postharvest life and quality of some horticulture crops such as rose, apple, banana, pears, onion, pelargonium, chrysanthemum and plums [7-10]. The affectivity of 1-MCP to prevent the ethylene effects depends on several factors such as cultivars, concentration, duration of exposure, temperature, stage of development and plant maturity [11, 12]. For instance in flower, the application of 1-MCP on young flowers is more effective than on old flowers in increasing the postharvest life of Pelargonium [7, 13]. High-quality postharvest life of fruit is important characters for banana, therefore in this study we reported the strategy to improving postharvest life Musa acuminata ‘Muli’ fruit by the application of 1-MCP. The objective of this study was to evaluate the effect of different concentration of 1-MCP (0; 0.25; 0.5; 0.75 and 1 µL.L⁻¹) on two stages of banana fruit maturation (mature green and mature).

2. Materials and Methods

2.1. Fruits preparation and 1-MCP application

The experiment was conducted from February until March, 2017 at Laboratory of Horticulture, Faculty of Agriculture, Universitas Padjadjaran, Indonesia. Muli banana fruit were prepared and collected based on the similarity of the stages of fruit maturation, mature green and mature. These fruit were collected from the farmer, which is cultivated with traditional cultivation technique. Those fruit were treated with five different 1-MCP concentrations (0; 0.25; 0.5; 0.75 and 1µL L⁻¹). The application of 1-MCP was prepared according to the manufactures instruction. 1-MCP powder was placed in sealed chamber that containing banana fruits for 6 hours of incubation. After 1-MCP application fruits were collected and placed on the laboratory bench under the following conditions: temperature, 22 ± 2°C; humidity, 80% for fruit shelf life analysis.

2.2. Analysis of fruit firmness

Fruit firmness is an important characteristic for determining banana fruit quality. To analyze the effect of 1-MCP in the fruit firmness, it was tested using an Ultrasonic Hardness Tester model FHR-5 (Nippon Optical Works Co., Ltd., Tokyo, Japan). The measurement was done according to the manufactures instruction.

2.3. Analysis of total soluble solid (TSS)

Analysis of the Total Soluble Solids (TSS) was measured to estimate the sugar level in the banana fruits. It was measured using a digital refractometer DRBO-45nD type (B&C 32145, Germany). The sample was grinded and the fruit liquid was dropped into the sensor of refractometer. The estimation of TSS
value was represented by the Brix value. The measurement was conducted two times at the beginning of storage or 0 days post storage (DPS) and 12 DPS.

2.4. The fruit weight lost
This analysis was evaluated over 12 days of post-harvest storage. At the beginning of storage (0 DPS), designated $W_0$, the fruits were weighed. This process was repeated at 12 DPS ($W_n$). The weight lost ($W$) by the banana fruit during post-harvest storage was calculated using the following equation:

$$W = W_0 - W_n \quad \ldots \quad (1)$$

2.5. Percentage of fruit flesh
The fruit flesh and peel were weight separately at the beginning of treatment (0 DPS) and 12 DPS. Based on these data the percentage of fruit flesh was calculating according the following equation:

$$\text{Percentage of flesh fruit (PF)} = \frac{\text{Flesh weight}}{(\text{Fruit skin} + \text{flesh weight})} \times 100\% \quad \ldots \quad (2)$$

2.6. Fruit shelf life analysis
To analyze fruit shelf life, fruits were stored on the laboratory bench under temperature at 22 ± 2°C and humidity at 80%. The fruit shelf life was determined by counting the days from the beginning of storage (0 DPS) when the fruit in the grade 0 until the fruit firstly decay as a grade 3. The characteristics of each grade as a following: $0 =$ Fruit still fresh, the color is green, and the black spot have not been appeared yet. $1 =$ Fruit still fresh, the color is turn to yellow, and the black spot have not been appeared yet. $2 =$ The base of fruit was dried, the color is yellow, and the black spot have not been appeared yet. $3 =$ Fruit starting to decay, the black spot have appeared and fruit still can be eat. $4 =$ Many black spots on the skin of the fruit have appeared, the fruit becomes soft, severe damage, and the fruit cannot be eat prepared fruit waste

2.7. Statistical data analysis
The statistical analysis was performed to analyze the effect of 1-MCP concentration for each fruit maturation stage. The completely randomized design was used in this experiment, which consisted of three biological replicates, and each replicate consisted of four individual fruit. For statistical data analysis, one factors analysis of variance (ANOVA) was conducted and followed by Duncan test at $p < 0.05$ to compare differences among investigated treatment.

3. Result and Discussion

3.1. 1-MCP was effective used to maintain the fruit firmness of mature green banana fruit
Fruit softening is one of the fruit characteristics that occurred during fruit maturation and ripening. It is represented by a firmness value, which is an important characteristic for fresh banana fruit. Based on the statistical data analysis of 12 days of post-harvest storage the fruit firmness of mature green fruit was harder than that of mature fruit, where the firmness value of the control from mature fruit was 11.50 kgf and that of mature green fruit was 0.30 kgf (Figure 1). These data indicated that the ripening process was correlated with a reduction in fruit firmness or an increase in fruit softening (ethylene regulates this process). To inhibit the effect of ethylene at maintaining fruit firmness, the application of 1-MCP was not effective when it was applied to mature fruit. It was effective on mature green fruit up until 12 days of post-harvest storage (Figure 1).
3.2. Total soluble solid of 1-MCP treated fruit was lower than control

Our data showed that in all treatments at the beginning of storage (0 DPS), the TSS value of mature green fruit was lower than that of mature fruit; the TSS of mature green fruit was 5.40–6.00 Brix and that of mature fruit was 14.80–15.50 Brix (Figure 2). The application of 1-MCP significantly inhibited the accumulation of Brix content during 12 days of storage in both mature green and mature fruit. Our data (Figure 2) showed that during 12 days of post-harvest storage the TSS of 1-MCP-treated mature fruit was higher than that of 1-MCP-treated mature green fruit. The application of 1-MCP in all concentrations significantly reduced TSS over 12 days of post-harvest storage. A concentration of 0.25 µL L⁻¹ was sufficient to inhibit the increase TSS in both fruit maturation, mature green and mature (Figure 2).

3.3. 1-MCP did not affect the ratio of fruit flesh and peel in mature fruit

In this study we investigated the percentage of fruit flesh as an effect of 1-MCP application during postharvest storage. Based on the statistical data analysis showed that in the low concentration of 1-MCP application was only effective in mature green fruit for inhibiting fruit ripening by delaying the increasing the percentage of fruit flesh, where 0.25 µL L⁻¹ has been enough and effective in delaying the increasing the percentage of fruit flesh 8.12% smaller than control at 12 days of postharvest storage that
was significantly different compared with control according Duncan test at p < 0.05. However, in mature banana fruit, the application of 1-MCP up to 1 µL L⁻¹ was not effective in delaying the increasing the percentage of fruit flesh (Figure 3). Based on this value we assumed that high value of percentage of fruit flesh indicated that the diameter of banana fruit flesh bigger than fruit skin and the ethylene affect the ripening process of banana naturally.

**Figure 3.** Effect of 1-MCP flesh and peel ratio of two stages of banana fruit maturity during 12 days of postharvest storage. The mean values in each stage of fruit maturation followed by the same letters are not significantly different according to the Duncan test at p < 0.05.

### 3.4. 1-MCP inhibited the weight loss of banana during postharvest storage

Our study demonstrated that the amount of weight lost during 12 days of storage was affected by fruit maturity. Mature fruit lost more weight (14.98 g) than mature green banana fruit (9.58 g). Water lost during post-harvest storage can be reduced by the application of 1-MCP. Our study demonstrated that for both types of banana fruit maturity, mature green and mature, 1-MCP significantly reduced the amount of water lost over 12 days of post-harvest storage. Furthermore, a low concentration 0.25 µL L⁻¹ of 1-MCP was sufficient and effective at preventing water loss; the differences between the controls and mature green fruit and mature fruit were statistically significant. This concentration reduced water loss by 1.23 g (mature green) and 2.13 g (mature) compared with the controls during 12 days of storage (Fig. 4).

**Figure 4.** The effect of 1-MCP on the weight lost of two stages of banana fruit maturity during 12 days of postharvest storage. The mean values in each stage of fruit maturation followed by the same letters are not significantly different according to the Duncan test at p < 0.05.
3.5. The application of 1-MCP significantly improved postharvest life of Muli banana in both stages of fruit maturity, mature green and mature.

The application of 1-MCP was effective at increasing the post-harvest life of both stages of the Muli banana mature green and mature (Figure 5). The old stage of fruit maturity (mature stage) results in a shorter shelf life. We demonstrated that the mature-stage controls (0 µL L⁻¹ of 1-MCP) decayed faster: they lasted for 2 days post-harvest; mature green fruit treated with 1-MCP lasted for 11 days (Figure 5). For mature green banana fruit, 1-MCP was also effective at improving fruit shelf life. We observed, however, that 1-MCP had a negative impact: it reduced skin color quality because the fruit never became yellow. The reduction in the post-harvest quality of the Muli banana can be inhibited by the application of 1-MCP, but the effect of 1-MCP depends on the stage of fruit maturity: 1-MCP was effective at improving post-harvest fruit shelf life. Based on statistical data analysis, we showed that for both types of fruit maturity, mature green and mature, the application of 1-MCP at a concentration of 0.25 µL L⁻¹ was sufficient to delay fruit maturity and fruit decay by improving post-harvest shelf life by the average value of 4.5 days (in mature green fruit) and 3.5 days (in mature fruit) compared with the control fruits (Figure 5).

Figure 5. Effect of 1-MCP on the postharvest life of two stages of banana fruit maturity. The mean values in each stage of fruit maturation followed by the same letters are not significantly different according to the Duncan test at p < 0.05.

In many climacteric fruits, ethylene accelerates fruit ripening. For market, the present of ethylene must be minimized to improve postharvest life of fruits. To inhibit ethylene effects, 1-MCP most popular to be used, however its effectivity depend on several factors such as the fruit maturation. In this study we investigated the effect of 1-MCP on two stage of fruit maturation of Muli banana. This study showed that, 1-MCP not effective in mature fruit. Infectivity of 1-MCP in mature fruit indicated that the application 1-MCP after climacteric stage cannot totally inhibit the ethylene action due to the ethylene biosynthesis reached the peak and the ethylene has been bound to the ethylene receptor. Our result correspond with Martino, Fabio, & Golding [14], who showed that ethylene production is not affected and inhibited by the application of 1-MCP over 24 hours after the initiation of fruit ripening. In tomato, 1-MCP increases ethylene production when it is applied in breaker stage and also ethylene biosynthesis increases in the stage transition of banana fruit from green to yellow in the color [15].

That the effect of 1-MCP depends on the stage of banana fruit maturity has also been presented in other studies; 1-MCP was more effective on pre-climacteric fruit than on climacteric fruit [11, 16]. From our statistical data analysis, we showed that a treatment of 1-MCP of 0.25 µL L⁻¹ was able to delay fruit
softening or maintain fruit firmness in mature green fruit (Figure 1). Therefore, we indicated that 1-MCP totally inhibits fruit ripening by inhibiting ethylene action in the pre-climacteric stage of bananas; the application of 1-MCP after the initiation of fruit ripening did not affect the ethylene-binding process. In other fruit species, 1-MCP has an effect of inhibiting fruit softening (e.g., in apples and pears) [17].

TSS is used to predict sugar level in the fruit and it is commonly associated with fruit sweetness [18]. In many mature fruits such as banana, sugar is the main constituent of dissolved solids and it is one of the important characters for determining postharvest fruit quality of banana [19]. The application of 1-MCP inhibit the change of TSS until 12 days of storage in mature green fruit, but in mature, the change of TSS occurred. Based on this study, therefore we suggest that increased the TSS in mature stage of banana due to the initiation of fruit ripening. Dadzie & Orchard stated that the variation of sugar level appeared in different cultivar and also fruit maturity [19]. We suggest that 1-MCP inhibit sugar accumulation due to the inhibition of ethylene perception in the receptor, therefore the ripening process of banana fruit was delayed or inhibited. Similar symptoms in reducing sugar content due to inhibition of ethylene perception occurs in Nr, nor and rin tomato mutant, these mutants exhibit the reduction of sugar level in the mature fruit [20]. Contrasting result reported by Mir et al, they stated that 1-MCP did not affect in the change of TSS of tomato fruit [21] and also in the hybrid line of Slettr1-2 tomato fruits [22].

In many fruits such as banana, the reduction of fruit skin width and increasing diameter of flesh occurred during ripening process. Many physiological processes occur such as the movement of water from the skin to the flesh [14], therefore the width of fruit skin decline and the diameter of flesh increases. The movement of water from skin to flesh would affects the change in the percentage of flesh and peel ratio of bananas and finally increases the size of flesh. In this study the change of percentage of fruit flesh observed at the beginning and after 12 days of postharvest storage. In mature fruit the effect of 1-MCP was not significantly changed the percentage of flesh fruit compared with control, therefore we suggested that it occurred because the morphology of Muli banana which does have fruit skin relatively thin when compared with other types of bananas, where the average of skin thickness around 1 mm. So we supposed that the transfer of water from the banana skin to the flesh of the fruit during the ripening process did not significantly affect the percentage of skin and flesh ratio of Muli banana.

Weight loss is one indicator of a reduced water content in fruit. Reducing the water content in fruits results in wrinkling, the first symptom of loss of quality in banana fruit. In many fruits, weight loss or water loss always occurs during post-harvest storage, and the amount of weight lost varies as a function of fruit maturity. Storage time affected the rate of water loss: longer storage times increased water loss [23]. Our study demonstrated that water loss during post-harvest storage in two fruit maturations of bananas can be reduced via the application of 1-MCP. Similar report found that 1-MCP significantly maintained fruit freshness over 10 days of storage at a storage temperature of 20°C [24].

Ethylene is a major problem for climacteric fruit such as bananas. It accelerates fruit decay by reducing post-harvest fruit shelf life. In many horticultural crops, 1-MCP is effective at extending the quality of post-harvest storage [11]. Low concentrations of 1-MCP or CP (0.7 nL L⁻¹) were effective at preventing bananas from ripening for 12 days at 24°C. Inhibiting ethylene can delay a loss of quality in melons for up to 15 days after harvest [5], and the combination of ethylene and 1-MCP for 24 hours was effective at reducing the growth of sprouts up to 25 weeks after harvest in onions [8]. 1-MCP was more effective than other treatments [16]. This author showed that 1-MCP was more effective at modifying atmosphere storage and increasing fruit shelf life than control. 1-MCP works as an ethylene inhibitor to inhibit the binding process of ethylene to its receptor, and it can be used to prevent the effects of ethylene on many horticultural crops [11].

4. Conclusion
All of the results show that 1-MCP exhibited had a positive effect in delaying Muli banana fruit deterioration by improving fruit shelf life with the average value of 3.5 to 4.5 days longer than control and also 1-MCP was effective in maintaining fruit firmness. We conclude that the application of 1-
MCP in Muli banana has potential as a treatment to maintain postharvest fruit quality by improving postharvest live of fruit

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