Effects of gibberellin (GA₃) on the physical quality of oil palm fresh fruit bunches

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Abstract. Gibberellin (GA3) is known as a plant growth regulator that can stimulate the plant growth and develop the cell and widely used in maintaining the storability of some types of fruit. This research aimed to study the effects of gibberellin concentration, time of gibberellin application and the interaction of both on the physical quality of oil palm fresh fruit bunches. The experiment used a factorial of randomized complete block design with three replications. The first factor was the time of gibberellin application with two levels (pre-harvest and post-harvest), while the second factor was gibberellin concentration with five levels (0, 25, 50, 100 and 200 ppm). Post-harvest treatments of 25 ppm gibberellin reduced the respiration rate, fruit weight loss, number of fruit loss of bunches and mesocarp firmness. Application of gibberellin with concentration 25 ppm after harvesting was the best treatment to maintain the physical quality of fresh fruit bunches (FFB). Time of harvesting is one of the factors affecting the quality of palm oil. After harvesting, FFB should be processed at mill within a maximum of 24 hours because it will increase the content of free fatty acids (FFA) and reduce the content Crude Palm Oil.

1. Introduction

Oil palm (Elaeis guineensis Jacq.) is an important plantation commodity in Indonesia. The area of oil palm in 2015 reached 12 million ha. The main results of oil palm are crude palm oil (CPO) and palm kernel oil (PKO). CPO and PKO production reached 25 million tons and total exports reached 13 million tons in 2014 [1]. CPO and PKO are used as raw material for various food products, health, bioenergy, and others.

The quality of CPO and PKO is influenced by the quality of the oil palm fruits. Physical and chemical damage of fruit may decrease fruit quality. Physical damaged to fruit due to harvesting and postharvest treatment, like fruit mesocarp wound, fruit weight loss, and fruit loss on fruit bunches. Physical damage to the fruit may increase lipase enzyme activity and increase free fatty acids levels (FFA), and decrease palm oil content [2]. The good postharvest handling is needed to reduce the degradation of fruit quality.

The goal of postharvest handling of fresh fruit bunches (FFB) is to maintain the physical and chemical fruit quality. The physical quality of the fruit effects on fruit chemical quality. The physical quality of FFB can be characterized at the rate of fruit respiration, fruit weight loss, fruit mesocarp firmness, fruit loss, water content, and pH levels of fruit. Good physical quality is required to maintain the chemical quality of the fruit.
One of postharvest handling that can maintain the physical quality of the fruit is the gibberellin application. Gibberellin makes the fruit mesocarp to become harder and reduce the process of cellular respiration and regulate the process of enzymes secretion. Gibberellin can inhibit the activity of ethylene so that changes in pH, temperature, colour, fruit aroma, fruit firmness, respiration and oxidation rate [3]. Gibberellin is a growth hormone that plays a role in the physiological function of stem growth (shoots). The effect of gibberellin especially in the growth of stems that is related to the growth of plant cells. In addition to stem growth, gibberellin can affect on flower and fruit growth [4]. Gibberellin can also play a role to increase fruit production and post-harvest handling of agricultural products such as fruits and vegetables.

The use of gibberellin in the cultivation of fruits is to increase production. According to Ahmed et al. [5], the use of gibberellin in date palm can increase the weight and number of fruit in fruit bunches, increase the length and diameter of the fruit, and decrease the level of fruit loss in bunches. The use of gibberellin in post-harvest handling of dates is used to maintain the physical and chemical quality of the fruit. According to Kays [6], gibberellin can inhibit the role of ethylene in fruit maturity. Gibberellin is also can reduce chlorophyll loss, increase carotenoids, and delay the softness in some fruits such as oranges and apricots.

Gibberellin application has been performed on several types of palm trees. According to El-Shiekh [7], gibberellin able to delay the maturity of dates fruit around 4-5 weeks, increases fruit weight, maintains fruit hardness, and increases fruit volume. Gibberellin with higher concentration shows better results on the physical quality of dates than lower concentration. According to Soliman and Ali [8], the concentration of 50 ppm gibberellin maintains the physical and chemical quality of dates in two different seasons. The concentration of 50 ppm gibberellin can maintain fruit weight loss, increase the size and weight of the fruit, as well as maintain the acidity, firmness, moisture, and water content of the fruit. This research aimed to study the effects of gibberellin concentration, time of gibberellin application and the interaction of both on the physical quality of oil palm fresh fruit bunches.

2. Materials and method

2.1. Experimental site and materials
The research was conducted from January to May 2017 at IPB-Cargill Teaching Farm of Oil Palm and Postharvest Laboratory, Department of Agronomy and Horticulture, Bogor Agricultural University, Indonesia. The materials used in this experiment were FFB of Dami Mas variety with uniform maturity level on a four-year-old oil palm and gibberellin hormone (GA3).

2.2. Experimental design
The experiment used a factorial of completely randomize design with three replications. The first factor was the time of gibberellin application (before and after harvesting), while the second factor was gibberellin concentration (0 ppm, 25 ppm, 50 ppm, 100 ppm and 200 ppm). Applications of gibberellin were done on FFB from each plant. Gibberellin application was performed before harvesting (fraction 1) and after harvesting (fraction 2). Gibberellin application was done by spraying on all parts of fruit bunches. Spray volume was 500 ml for each FFB.

2.3. Data Measurements
Measured variables were performed on respiration rate, fruit weight loss, number of fruit loss, fruit firmness, water content and pH level. The respiration rate was measured based on CO2 production which was produced by fruit. The measurement of respiration rate was done every day using cosmotector. The fruit weight loss was measured by measuring the difference in fruit weight before and after storage. The number of fruit loss was observed by counting the number of fruits released from the surface of bunches. The bunches were shaken to calculate the number of fruit loss. The fruit firmness was measured using a penetrometer. Part of the tested fruit was the bottom, middle and top of the fruit. The fruit was taken randomly from all parts of the bunch. The fruit firmness was expressed in mm g−1 s−1.

Water content was measured using the oven method. Mesocarp fruit was taken as much as 5 g and was inserted into the cup. It was heated for 48 hours at 70° C. The difference in weight before and after
drying was the water content of the fruit. The acidity level (pH) of the sample was measured using a pH meter. The pH meter was calibrated using buffer pH 4 and 6.

2.4. Statistical analysis
Data were statistically analyzed by with analysis of variance (ANOVA) and then were followed by the Duncan’s multiple range test at significant level $P < 0.05$ [9]. Data analysis were done by using Statistical Analysis Software (SAS) Proprietary Software 9.4 (TS 1M3).

3. Results and discussion

3.1. Respiration rate
The highest fruit respiration rate occurred at 1 day after harvesting (DAH) and showed a decrease in 7 DAH. Time of gibberellin application after harvesting gave more results than before harvesting. Time of gibberellin application after harvesting had lower respiration rate than before harvesting. The respiration rate decreased from 1 to 4 DAH on the application of 25-200 ppm gibberellin. The concentration of 25 ppm gibberellin can maintain better fruit respiration rate than the control treatment (Table 1).

| Treatment          | Respiration rate (ml CO$_2$/kg/hour) |
|--------------------|-------------------------------------|
|                    | Day 1      | Day 2      | Day 3      | Day 4      | Day 5      | Day 6      | Day 7      |
| Application time   |            |            |            |            |            |            |            |
| Before harvest     | 39,08a     | 19,85      | 16,69      | 16,64      | 20,02a     | 8,96a      | 1,88       |
| After harvest      | 33,75b     | 18,09      | 16,26      | 15,78      | 13,13b     | 6,49b      | 1,85       |
| Concentration      |            |            |            |            |            |            |            |
| 0 ppm              | 75,07a     | 25,68a     | 23,56a     | 30,23a     | 21,89a     | 8,74       | 1,96       |
| 25 ppm             | 28,63b     | 19,26b     | 17,74b     | 13,74b     | 18,00ab    | 6,31       | 1,70       |
| 50 ppm             | 26,24b     | 16,72bc    | 15,22b     | 13,39b     | 16,93b     | 6,10       | 1,98       |
| 100 ppm            | 25,52b     | 18,61b     | 15,53b     | 12,51b     | 14,62bc    | 7,25       | 1,88       |
| 200 ppm            | 26,62b     | 14,59c     | 10,32c     | 11,19b     | 11,44c     | 9,57       | 1,82       |

Means followed by the same letter in the same column are not significantly different based on Duncan Multiple Range Test at 0.05 level.

The highest respiration rate occurred at 1 DAH (26.62-75.07 ml CO$_2$ kg$^{-1}$ hour$^{-1}$) and the lowest respiration rate occurred at 7 DAH (1.82-1.96 ml CO$_2$ kg$^{-1}$ hour$^{-1}$). The respiration rate with the gibberellin concentration of 25-200 ppm decreased from 1 to 4 DAH and increased at 5 DAH. The fruit respiration decreased again at 6 and 7 DAH. The treatment of gibberellin with a concentration of 200 ppm at 7 DAH (1.82 ml CO$_2$ kg$^{-1}$ hour$^{-1}$) was the lowest respiration rate but not significantly different from gibberellin treatment at other concentrations. The 25 ppm gibberellin concentration can maintain the fruit respiration rate better than the control treatment.

The respiration rate is influenced by some internal and external factors of the fruit. One of the influential external factors is the environment around the fruit. The increase and decrease in fruit respiration rate are caused by environmental conditions such as temperature and moisture content. The increase in temperature and moisture content can increase the rate of respiration of the fruit [10]. According to Marlina et al. [11], salak fruit placed at different temperatures would have different respiration rates. According to Juanasri [12], gibberellin could maintain the rate of fruit respiration from the beginning of the application up to several days after the treatment depends on the type and size of the fruit.

3.2. Fruit weight loss
The increase in fruit weight loss was higher along with the increase in the day after harvesting both on the treatment of time and the concentration of gibberellin application. The application of gibberellin could decrease fruit weight loss. The time of gibberellin application significantly affected the fruit
weight loss at 1-6 DAH. The time of gibberellin application before harvesting had more fruit weight loss than after harvesting. The highest fruit weight loss occurred at the treatment before harvesting at 7 DAH (1.33%) and the lowest occurred on treatment after harvesting 1 DAH (0.20%).

The treatment of gibberellin concentration significantly affected the fruit weight loss at 1-7 DAH. The decrease in fruit weight loss was higher along with the increase in gibberellin concentration. The gibberellin concentration of 25 ppm showed lower fruit weight loss than the control treatment. The increase in gibberellin concentration showed the reduction of fruit weight loss (Table 2).

Table 2. Fruit weight loss to application time and concentration

| Treatment          | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 |
|--------------------|-------|-------|-------|-------|-------|-------|-------|
| **Application time** |       |       |       |       |       |       |       |
| Before harvest     | 0.220a| 0.438a| 0.656a| 0.866a| 1.010a| 1.167a| 1.327 |
| After harvest      | 0.200b| 0.399b| 0.598b| 0.782b| 0.916b| 1.090b| 1.241 |
| **Concentration**  |       |       |       |       |       |       |       |
| 0 ppm              | 0.252a| 0.500a| 0.748a| 0.990a| 1.109a| 1.244a| 1.397a|
| 25 ppm             | 0.213b| 0.426b| 0.638b| 0.839b| 1.013b| 1.167ab| 1.283ab|
| 50 ppm             | 0.204c| 0.409c| 0.613c| 0.805c| 0.930c| 1.010bc| 1.274ab|
| 100 ppm            | 0.191d| 0.381d| 0.571d| 0.755d| 0.922c| 1.114bc| 1.344a|
| 200 ppm            | 0.189d| 0.377d| 0.564d| 0.733e| 0.839d| 1.014c| 1.121b|

Means followed by the same letter in the same column are not significantly different based on the Duncan Multiple Range Test at 0.05 level.

Table 3 showed that interaction between the time and concentration of gibberellin application significantly affected the fruit weight loss. The increase in gibberellin concentration showed in the fruit weight loss before and after harvesting treatments. The application of 200 ppm gibberellin before harvesting had more fruit weight loss than after harvesting. The after harvesting treatment had lower fruit weight loss than before harvesting treatment.

Table 3. Interaction of time application and concentration on fruit weight loss

| Concentration | Time of application | Before harvest | After harvest |
|---------------|---------------------|----------------|---------------|
| 0 ppm         | 0.989a              | 0.989a         |
| 25 ppm        | 0.876b              | 0.801b         |
| 50 ppm        | 0.846b              | 0.763c         |
| 100 ppm       | 0.812c              | 0.696d         |
| 200 ppm       | 0.808c              | 0.657e         |

Means followed by the same letter in the same column are not significantly different based on the Duncan Multiple Range Test at 0.05 level.

Figure 1 showed that the increase in gibberellin concentration had a linear effect on the decrease of fruit weight loss. The fruit weight loss occurred because of water loss in fruit. The main cause of fruit weight loss is the process of respiration and transpiration in the fruit [13]. The process of respiration and transpiration leads to physicochemical changes in the form of absorption and release of water into the environment. According to Soliman and Ali [8], application of 50 ppm gibberellin at two different times could sustain the weight loss of date palm fruit.
3.3. Number of fruit loss

Time of gibberellin application significantly affected on the fruit loss of FFB from 1 to 7 DAH. Fruit loss increased with increasing days after harvesting both on gibberellin treatment before harvesting and after harvesting. However, post-harvest treatment of gibberellin (after harvesting) could decrease the fruit loss. Pre-harvest treatment (before harvesting) had more fruit loss than post-harvest treatment (after harvesting).

The treatment of gibberellin concentration significantly decreased fruit loss from 1 to 7 DAH. The fruit loss was 125 fruits at 7 DAH on the treatment of 0 ppm gibberellin. Gibberellin concentration of 25 ppm could decrease the fruit loss up to 82 fruits at 7 DAH. Increasing the gibberellin concentration might decrease fruit loss. The treatment of 25 ppm gibberellin could maintain fruit loss compared to control treatment (Table 4).

| Treatment | Fruit loss in bunches |
|-----------|-----------------------|
|           | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 |
| Time of application |       |       |       |       |       |       |       |
| Before harvesting   | 11.4a | 26.6a | 56.7a | 78.8a | 87.0a | 95.9a | 94.7a |
| After harvesting    | 8.9b  | 22.3b | 42.2b | 53.6b | 61.1b | 74.9b | 77.0b |
| Concentration |       |       |       |       |       |       |       |
| 0 ppm              | 11.7a | 33.0a | 68.0a | 91.7a | 110.0a| 126.7a| 125.0a|
| 25 ppm             | 10.1ab| 25.3b | 48.3b | 65.5b | 70.8b | 81.2b | 82.0b |
| 50 ppm             | 9.8b  | 22.5bc| 44.3bc| 59.1bc| 64.5bc| 74.3bc| 75.7bc|
| 100 ppm            | 9.9b  | 21.0c | 44.0bc| 58.8bc| 63.9bc| 73.9bc| 74.8bc|
| 200 ppm            | 9.4b  | 20.5c | 42.4c | 55.8c | 60.9c | 70.8c | 71.8c |

Means followed by the same letter in the same column were not significantly different based on Duncan’s multiple range test at significant level P<0.05

Table 5 showed that interaction between time and concentration of gibberellin application significantly affected the fruit loss at 7 DAH. Gibberellin concentration of 25 ppm could reduce the fruit loss in bunches. The concentration of 200 ppm could reduce more the fruit loss than other concentrations both before harvesting and after harvesting. Figure 2 showed that the increase in gibberellin concentration linearly affected the decrease in the fruit loss in bunches. The time of gibberellin application after harvesting had lower fruit loss than before harvesting.
Table 5. Interaction between time and concentration of gibberellin application to the number of fruit loss at 7 days after harvesting

| Concentration | Time of application |          |          |
|---------------|---------------------|----------|----------|
|               | Before harvesting   | After harvesting |
| 0 ppm         | 125.0a              | 125.0a   |
| 25 ppm        | 94.2b               | 70.0b    |
| 50 ppm        | 84.7b               | 67.2b    |
| 100 ppm       | 83.7b               | 66.0b    |
| 200 ppm       | 86.7b               | 57.0c    |

Means followed by the same letter in the same column were not significantly different based on Duncan’s multiple range test at significant level P <0.05.

According to Corley and Tinker [14], the ripe fruit will be released from the fruit bunches. Fruit released from bunches shows that there has been an increase in ethylene production that showed enzyme degradation of the fruit. Production of ethylene and enzyme degradation in ripe fruit has a correlation with lipase enzyme activity [15]. The activity of lipase enzyme influences the synthesis of oil and FFA content in fruits [16].

Table 5 showed that interaction between time and concentration of gibberellin application significantly affected the fruit loss at 7 DAH. Application of gibberellin with 25 ppm before harvesting could reduce the fruit loss in bunches that was not significantly different from 50, 100, and 200 ppm. However, the application of gibberellin with the concentration of 200 ppm after harvesting was the best treatment to reduce the fruit loss. Application of gibberellin with the concentration of 200 ppm could reduce fruit loss up to 57 fruits.

Figure 2 showed that the increase in gibberellin concentration linearly affected the decrease in the fruit loss in bunches. The time of gibberellin application after harvesting had lower fruit loss than before harvesting. According to Corley and Tinker [14], the ripe fruit will be released from the fruit bunches. There is an increase in ethylene production that shows enzyme degradation of the fruit. Production of ethylene and enzyme degradation in ripe fruit has a correlation to lipase enzyme activity [15]. The activity of lipase enzyme influences the oil synthesis and FFA content in fruits [16].

![Figure 2. Number of fruit loss at 7 days after harvesting](image-url)
3.4. Mesocarp firmness

Application of gibberellin decreased the firmness of fruit mesocarp from 5 to 7 DAH. Application of gibberellin before harvesting was significantly different from after harvesting on the fruit firmness level. Application of gibberellin before harvesting had higher fruit firmness level than after harvesting. The gibberellin concentration significantly affected the firmness of the fruit mesocarp from 2 to 7 DAH. The increase in 25 ppm gibberellin could decrease the firmness of the fruit mesocarp at 2-6 DAH. The gibberellin concentration of 200 ppm was the lowest level of fruit firmness compared to other treatments at 7 DAH (Table 6). According to Besada et al. [17], application of gibberellins before and after harvesting can maintain fruit firmness for several weeks compared to calcium nitrate treatment. Several things such as increasing moisture content and ethylene production may cause an increase in fruit firmness. The mesocarp firmness is also associated with weight loss, water loss, and transpiration process [18].

| Table 6. Mesocarp firmness on time and concentration of gibberellin application |
|---------------------------------------------------------------|

| Treatment | Mesocarp firmness (mm g⁻¹ s⁻¹) |
|-----------|---------------------------------|
|           | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 |
| Time of application |       |       |       |       |       |       |       |
| Before harvesting   | 0.073 | 0.071 | 0.074 | 0.071 | 0.079a | 0.085a | 0.085a |
| After harvesting    | 0.073 | 0.070 | 0.070 | 0.067 | 0.075b | 0.077b | 0.076b |
| Concentration       |       |       |       |       |       |       |       |
| 0 ppm               | 0.078 | 0.083a | 0.089a | 0.086a | 0.105a | 0.110a | 0.080a |
| 25 ppm              | 0.073 | 0.070b | 0.069a | 0.069b | 0.071bc | 0.075b | 0.081ab |
| 50 ppm              | 0.073 | 0.065b | 0.066b | 0.065b | 0.073b | 0.075b | 0.076b |
| 100 ppm             | 0.072 | 0.066b | 0.067b | 0.066b | 0.068bc | 0.072b | 0.082ab |
| 200 ppm             | 0.067 | 0.067b | 0.068b | 0.059b | 0.069c | 0.073b | 0.075b |

Means followed by the same letter in the same column were not significantly different based on Duncan’s multiple range test at significant level P <0.05.

3.5. Water content

The time of gibberellin application did not significantly affect a water content of the fruit mesocarp from 1 to 7 DAH. The water content of the fruit mesocarp did not have a significant difference up to 7 DAH. The time of gibberellin application had water content of mesocarp fruit ranging from 30-40%. The treatment of gibberellin concentration did not affect the water content of fruit mesocarp at 7 DAH. The increase in the concentration of gibberellin did not cause the change of water content of the fruit mesocarp (Table 7).

| Table 7. Water content on time and concentration of gibberellin application |
|---------------------------------------------------------------|

| Treatment | Water content (%) |
|-----------|------------------|
|           | Day 1 | Day 2 | Day 3 | Day 4 | Day 5 | Day 6 | Day 7 |
| Time of application |       |       |       |       |       |       |       |
| Before harvesting   | 34.36 | 36.97 | 32.94 | 35.36 | 35.28 | 33.20 | 33.74 |
| After harvesting    | 33.48 | 34.38 | 30.44 | 34.03 | 33.38 | 31.84 | 33.62 |
| Concentration       |       |       |       |       |       |       |       |
| 0 ppm               | 32.86abc | 37.00 | 31.23ab | 34.61 | 34.48 | 31.40b | 34.53 |
| 25 ppm              | 39.10a | 35.23 | 33.28a | 38.70 | 35.61 | 37.39a | 33.26 |
| 50 ppm              | 36.26ab | 36.23 | 28.27b | 34.04 | 35.22 | 30.71b | 34.30 |
| 100 ppm             | 32.30bc | 33.33 | 31.29ab | 31.21 | 31.47 | 30.71b | 33.07 |
| 200 ppm             | 29.06c | 36.60 | 34.38a | 34.92 | 34.89 | 34.14ab | 33.24 |

Means followed by the same letter in the same column were not significantly different based on Duncan’s multiple range test at significant level P <0.05.

Water is an important component of fruit. Water loss is caused by the respiration process and fruit transpiration [19]. The water content of the fruit is related to the storage time of the fruit. Gibberellin
may decrease water content and increase fruit storage time [20]. Decreasing moisture content may occur because of the respiration reducing the rate and lower ethylene production [21].

3.6. pH level

The time of gibberellin application had no significant effect on the pH level of fruit mesocarp from 1 to 7 DAH. It could not decrease the pH level of the fruit mesocarp. The pH level of fruit mesocarp was ranging 5.79-6.59 from 1 to 7 DAH.

Gibberellin concentrations significantly affected the pH level of the fruit mesocarp at 2, 3, 4, 6 and 7 DAH. The increase in gibberellin concentrations showed that pH level tended to decrease. The pH reduction caused an increase in fruit mesocarp acidity. The pH level of the fruit mesocarp was ranging 5.79-5.92 at 1 DAH, while the pH level was ranging 5.85-598 at 7 DAH. The pH level of the fruit mesocarp indicated that the longer storage will increase the mesocarp acidity of the fruit (Table 8).

### Table 8. pH level on time and concentration of gibberellin application

| Treatment | pH level |
|-----------|----------|
|           | Day 1    | Day 2    | Day 3    | Day 4    | Day 5    | Day 6    | Day 7    |
| Time of application | 5.84    | 6.59a    | 6.20    | 6.41    | 5.99    | 5.82    | 5.91    |
| Before harvesting    | 5.83    | 6.36b    | 6.17    | 6.36    | 5.98    | 5.79    | 5.86    |
| After harvesting     | 5.92    | 6.09c    | 6.08bc  | 6.06b   | 5.96    | 5.84a   | 5.86b   |
| Concentration        | 5.84    | 6.64a    | 5.96c   | 6.51a   | 6.07    | 5.83a   | 5.98a   |
| 0 ppm                | 5.83    | 6.58ab   | 6.36a   | 6.48a   | 5.95    | 5.84a   | 5.87b   |
| 25 ppm               | 5.79    | 6.57ab   | 6.27a   | 6.43a   | 6.06    | 5.84a   | 5.89b   |
| 100 ppm              | 5.79    | 6.49b    | 6.23ab  | 6.46a   | 5.91    | 5.69b   | 5.85b   |
| 200 ppm              | 5.79    | 6.49b    | 6.23ab  | 6.46a   | 5.91    | 5.69b   | 5.85b   |

Means followed by the same letter in the same column were not significantly different based on Duncan’s multiple range test at significant level P <0.05.

The pH level was related to the acidity value of the material. According to Harris [22], pH measurements are related to total acid in a distilled condition. The pH level is related to the type and content of acid in the fruit. The pH level is also associated with the process of respiration, fruit maturation, and other enzyme activity. Fruits that have a high level of maturity will have a low acidity level.

4. Conclusion

The time of gibberellin application after harvesting was better than before harvesting. Application of gibberellin with a concentration of 25 ppm after harvesting was able to maintain the fruit respiration rate, fruit weight loss, mesocarp firmness, and fruit loss. Interaction between time and concentration of gibberellin application could maintain the fruit weight loss and fruit loss.

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