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RESEARCH ARTICLE

Effects of Gibberellin on Physical and Chemical Quality of Oil Palm (*Elaeis guineensis* Jacq.) Fresh Fruit Bunches

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Abstract

The quality of crude palm oil (CPO) is influenced by the quality of fresh fruit bunches, crop culture, and postharvest handling. A delay in fruit processing can cause physical damages to the fresh fruit bunches. Gibberellic acid (GA_3) can potentially reduce the physical damage due to delayed processing of the fresh fruit bunches. Our study aims to determine how GA_3 affects the physical and chemical quality of oil palm fresh fruit bunches. The fresh fruit bunch samples were collected from the IPB-Cargill Palm Oil Education and Research, Jonggol, Bogor, Indonesia. This study used a randomized complete block design that consisted of four concentrations of GA_3: 0, 12.5, 25 and 37.5 ppm. GA_3 application reduced fruit loss, respiration rate, and maintain fruit moisture and firmness, increased the oil content, and stabilize the free fatty acid content. GA_3 concentration of 12.5 ppm is the optimal concentration. Based on the correlation analysis, fruit softness has a strong correlation with free fatty acids.

Keywords: crude palm oil, concentration, fresh fruit bunches, respiration.

Introduction

Palm oil (*Elaeis guineensis* Jacq.) is a very important crop in Indonesia. It is evident from the area of oil palm plantations which continues to increase every year, starting in 2012 with only 9,572,715 ha up to 15,380,981 ha in 2022 (Ditjenbun, 2022). The increase in area is in line with the increase in oil palm production. Production data for 2012 showed that the total crude palm oil (CPO) production was 26,015,518 tons, while in 2020 production was 48,235,405 tons (Ditjenbun, 2022).

CPO is crude palm oil that is produced from extraction or from the pressing process of palm fruits and has not been refined. CPO is generally used as a raw material for a variety of products including cosmetics, chemicals, cooking oil, margarine, chocolate, ice cream, biscuits, and animal feed. In addition, CPO is an alternative biodiesel fuel (Depperin, 2007).

Fresh fruit bunches (FFB) of oil palm are susceptible to bruising and other physical damages during harvest and at all stages of postharvest handling. The damage to the oil palm fruit results in an accelerated hydrolysis process so that the levels of free fatty acids (FFA) increase, whereas CPO with high FFA is considered as low-quality (Maulana and Susanto, 2015). The high content of FFA in CPO will cause various losses due to low refining value resulting in rancidity and odour (Fajri and Ihsan, 2019). The presence of oil FFA can cause side reactions through alkaline-catalyzed transesterification and can inhibit ester production and glycerol separation (Suriaini et al., 2021). According to SNI, the standard quality palm oil has an FFA content of <5% (SNI 01-2901-2006). Good quality FFB should have an oil content of 22.1% to 22.2% with an FFA content of 1.7% to 2.1% during processing (Depperin, 2007).

Oil palm fruit damages can occur during harvesting, transportation, loading and unloading. Several factors can accelerate the formation of FFA after the fruit bunches were harvested e.g., fruits injured by impact or hit by harvesting tools; drops of loose fruits; delays due to transportation, and delayed fruit collection (Pahan, 2008). Other factors that affects the delay in processing including shortage of manpower, particularly during periods of high production (April to July), and during long holidays. Therefore, it is crucial to streamline the postharvest handling to reduce physical damage of the FFB. One method to overcome this problem is to apply growth regulator gibberellic acid (GA_3) immediately after FFB are harvested (Sudradjat, 2017).

Gibberellic acid has been widely used to inhibit fruit ripening, and studies on the effect of GA_3 on the physical quality of oil palm FFB was reported by Sudradjat in 2017. The current study is a methodological improvement from the previous study and was conducted on the actual storage condition of oil palm fruits in the field. Sudradjat et al. (2021) showed that the application of GA_3 at 25 ppm can keep the physical quality of FFB by reducing fruit respiration rates, fruit weight loss, and by maintaining fruit mesocarp softness. The current study aims to determine the effect of GA_3 in maintaining the physical and chemical quality of fresh oil palm fruits, and to determine the correlation between the measured variables.

Material and Methods

The study was conducted at the IPB-Cargill Palm Oil Education and Research Station, Jonggol, Bogor, Indonesia, the Postharvest Laboratory of the Department of Agronomy and Horticulture IPB, and the Biochemistry Laboratory of the Department of Biochemistry of IPB from January to March 2022. The study used FFB of the “D×P Dami Mas” variety from the IPB-Cargill oil palm plantation. GA_3 hormone powder 10% (Sun Neo), PP indicator solution and 0.1N NaOH were used for field and laboratory works.

This study was arranged using a randomized complete block design with four GA_3 concentrations, i.e., 0 ppm as control or G0, 12.5 ppm as G1, 25 ppm as G2, and 37.5 ppm as G3) repeated three times. Each experimental unit consisted of 6 FFB, totalling 72 FFB. FFB used was fraction 2 with an average weight of 15-20 kg. Harvesting was conducted in the morning to reduce the transpiration rates. The harvested FFB was transported to an open field to dry.

GA_3 powder was dissolved in water to make the above concentrations. GA_3 solution was sprayed to FFB that had been harvested at an approximate volume of 500 ml using a sprayer on the surface of the bunches. Oil extraction was carried out using a hydraulic bottle jack (Haisbuan, 2020)

Measurement of physical quality consisted of the weight loss of fresh fruit bunches (%), fruit loss (kernel), and fruit mesocarp softness ($mm.g^{-1}.sec^{-1}$) using penetrometer Stanhope-SETA, followed by physiological observations of fruit which was the fruit respiration rate ($ml.CO_2^{-1}.kg^{-1}.hour^{-1}$) using a combustible gas detector XP-3140, mesocarp water content (%), and free fatty acid levels (%). All variables were measured at 6 DAA except for free fatty acid levels which were measured at 1, 3, and 5 DAA.

Collected data were analyzed by analysis of variance (ANOVA) followed by the Duncan Multiple Range Test (DMRT) 5% for the significance. Correlation analysis was done between variables. The software used was Microsoft Office Excel 2010, R Studio ver. 9.1. and SAS 9.1 portable. In addition, a correlation test was also carried out between variables at 5 DAA, this was because the FFA was analyzed only up to 5 DAA. The correlation analysis was conducted with a simple correlation according to Pearson (Saidah et al., 2023) as follows:

$$rxy = \frac{n\Sigma XiYi - (\Sigma Xi)(\Sigma Yi)}{\sqrt{[n\Sigma Xi^2 - (Xi)^2][n\Sigma Yi^2 - (Yi)^2]}}$$

R values of < 0 indicates that each variables have a close negative correlation, while the value of r > 0 indicates that each variables has a close positive correlation. The values of r = -1 ≤ r ≤ 1 (Saidah et al., 2023).

Result and Discussion

Weight Loss of Fresh Fruit Bunches

GA_3 treatment significantly reduced fruit weight loss starting one day after application (DAA, Table 1). The highest accumulative percentage of fruit weight loss at 6 DAA occurred in the control treatment, which was 29.82%. The treatment with the lowest weight loss was GA_3 at 25 ppm, which was 23.45%. Weight loss (WL) occurs due to physico-chemical changes in the fruits, including the loss of water during storage until the fruits ripened (Sutrisno et al., 2008; Aditama, 2014, Tarigan et al., 2019).

Fruit Fall

Fruit falling (FF) is reflected by the number of fall kernels (Table 2). Fruit ripening is influenced by lipase enzyme that plays important roles in oil synthesis, thus affecting free fatty acid (FFA) levels in the fruits. The fallen fruits contain higher FFA than the intact fruits

Table 1. Effect of GA_3 application on fresh fruit bunch weight loss

GA_3 (ppm)		Fruit bunch weight loss with GA^3 application at						
		1	2	3	4	5	6	
		days after application						
0	kg	22.74	22.04	20.26	18.66	18.40	17.39	16.11
	(%)		3.14a	11.00a	18.16a	19.27a	23.94a	29.82a
12.5	kg	22.49	22.16	20.60	18.99	18.16	17.10	16.63
	(%)		1.51b	8.25a	15.45a	18.92a	23.51a	25.60a
25.0	kg	22.74	22.13	20.51	19.23	18.82	17.81	17.44
	(%)		2.71a	9.84a	15.48a	17.31a	21.83a	23.45a
37.5	kg	22.42	21.74	20.66	19.24	18.80	17.36	16.29
	(%)		3.10a	7.92a	14.43a	16.19a	22.73a	27.48a
DMRT			**	ns	ns	ns	ns	ns

Note: Means in the same column followed by the same letter are not significantly different based on Duncan Multiple Range Test (DMRT); *=significant at α=0.05; **= highly significant at α=0.01; ns= not significant.

Table 2. The effect of GA_3 application on the loss of fresh fruit bunches

GA_3 (ppm)	Number of fall kernels at					
	1	2	3	4	5	6
	days after application					
0	31a	131a	233a	274a	376a	399a
12.5	27a	113b	193b	267a	359b	378b
25.0	25a	110b	192b	269a	350b	374b
37.5	27a	76c	173c	245b	328c	382ab
DMRT 5%	ns	**	**	*	**	*

Note: Means in the same column followed by the same letter are not significantly different based on DMRT at α=0.05. DAA=days after GA_3 application.

(Morcillo et al., 2013). Our study demonstrated that GA_3 suppressed fruit loss from 2 to 6 DAA, whereas the control consistently had the greatest number of fall kernels (Table 2). GA_3 at 12.5 or 25 ppm were effective to maintain kernels to remain intact until 6 DAA. In the final observation, the fallen fruits from GA_3 at 12.5 or 25 ppm was 378 and 374 kernels, respectively, whereas without GA_3 it was 399 kernels (Table 2).

According to Manurung et al., (2022) application of GA_3 at 15 ppm can reduce fruit loss rates. The process of fruit loss (abscission) is related to the ratio of auxin and ethylene content in the abscission zone, with low auxin and high ethylene resulted in senescence or abscission (Taiz and Zeiger, 2006). Ethylene induces the synthesis and secretion of cell wall-degrading hydrolases. Hydrolase enzyme may increase due to RNA transcription and cause damage to the cell walls of the abscission zone (Salisbury and Ross, 1996). GA_3 roles is to delay the formation of the separating layer in the abscission zone (Tuan et al., 2013) and to promote carbohydrate mobilization to fruits, hence reducing fruit loss (Bons et al., 2015).

Fruit Respiration Rate

Table 3 showed that GA_3 treatment can reduce fruit respiration rate (RR), except at 2-3 DAA. The highest respiration rate indicates the climacteric peak. According to Aditama (2014), climacteric fruits including oil palm experience a sudden increase in respiration rate before ripening, and the respiration rate decreases gradually after harvesting. GA_3 can effectively delay fruit maturity by reducing the respiration rate, so the FFB can be preserved for longer during storage before further processing. Almost all GA_3 treatments in this study reduced respiration rates compared to the control.

Fruit respiration rate is influenced by various internal and external factors; included in the internal factors are stages of fruit development, skin layer, cohesiveness of the cells, and fruit's physical damage

Table 3. Effect of GA_3 application on fruit respiration rate

GA_3 (ppm)	Respiration rate ($ml.CO_2^{-1}.kg^{-1}.hour^{-1}$)					
	1	2	3	4	5	6
	days after application					
0	52.77a	34.36a	25.07a	33.94a	26.98a	21.80a
12.5	40.21b	33.42a	22.55a	17.94b	22.34b	14.05c
25.0	36.45c	32.26a	24.24a	17.44b	26.31a	18.75b
37.5	52.08a	31.98a	22.40a	19.65b	25.49a	18.27b
DMRT 5%	**	ns	ns	**	*	**

Note: Means in the same column followed by the same letter are not significantly different based on DMRT at α=0.05.

Table 4. Effect of GA_3 application on fruit mesocarp water content

GA_3 (ppm)	Fruit mesocarp water content (%) at					
	1	2	3	4	5	6
	days after application					
0	33.19a	30.54a	32.00a	33.18a	36.00a	39.31a
12.5	29.32a	30.73a	31.24a	28.11b	30.24b	33.49b
25.0	30.37a	31.56a	31.29a	32.15a	31.10b	38.37a
37.5	32.29a	31.67a	30.34a	33.26a	32.73ab	36.82a
DMRT 5%	ns	ns	ns	**	*	*

Note: Means in the same column followed by the same letter are not significantly different based on DMRT at α=0.05; DAA: days after GA_3 application

(Ahmad, 2013). Respiration rate is also highly affected by ethylene, that hormone is controlled by its immediate precursor, 1-aminocyclopropane-1-carboxylic (Maduwanthi and Marapana, 2019). External factors that affect fruit respiration rates include ambient temperature, humidity, and air composition (Ahmad, 2013). Research by Marlina et al. (2014) demonstrated that salak fruits placed at different temperatures had different respiration rates; the higher the temperature, the higher the respiration rate.

Fruit Mesocarp Water Content

GA_3 significantly affect fruit mesocarp water content (WC) at 3 DAA (Table 4). GA_3 at 12.5 ppm was relatively better for reducing the water content of fruit mesocarp than the other treatments, especially at 4 DAA. In contrast, the control consistently had the highest water content. Higher GA_3 concentrations resulting in higher water content of the fruit mesocarp. Hassan et al., (2009) reported that the water content of the fruit is related to the level of maturity of the fruit: ripened fruits have higher the water content. The increase in water content occurs because the respiration rate increases due to higher ethylene production (Sutrisno et al., 2008). According to Mulyadi et al., (2017), fruit water content is affected by plant genetics, humidity, fruit maturity, and post-harvest treatments. Loss of water can cause a decrease in cell turgidity which results in shrinkage and decrease in the quality of fruits (Aji, 2016).

Fruit Mesocarp Firmness

Fruit firmness (FFs) during the ripening changes cell wall composition due to changes in cell turgor (Winarno and Wirakatakusuma, 1979). GA_3 treatment can maintain fruit firmness during the storage period. Fruit mesocarp firmness in the GA_3 at 12.5 ppm was significantly different than those in other treatments (Table 5).

According to Besada et al. (2008), application of GA_3 before and after harvesting can maintain fruit firmness for up to several weeks compared to without GA_3. The reduction of fruit firmness may be affected by several factors such as increased water content and ethylene level. Acuna and Mitcham (2008) reported that the decrease in pear hardness is affected by high ethylene levels and temperatures. It is also related to weight loss, water loss, and transpiration processes which cause the mesocarp to wither and wrinkle (Wills et al., 2007). According to Wang et al., (2018), increased fruit firmness not only relates to the rate of ethylene production but also the hydrolytic enzyme activities, degradation of pectin, cellulose, and hemicellulose.

Table 5. Effect of GA_3 application on fruit firmness between treatments

GA_3 (ppm)	Fruit mesocarp firmness ($\mu m^{-1}.g^{-1}.sec^{-1}$)					
	1	2	3	4	5	6
	Days after application					
0	71a	78a	82a	97a	98a	106a
12.5	48b	58b	60b	75b	74c	81c
25.0	64a	78a	79a	84a	87b	94b
37.5	68a	73a	77a	84a	98a	101ab
DMRT 5%	**	*	**	*	**	**

Note: Means in the same column followed by the same letter are not significantly different based on DMRT at α=0.05.

Table 7. Correlation coefficient of GA_3 application between variables at 5 DAA

Variable	WL	FF	RR	WC	FFs
FF	0.241^{ns}				
RR	0.010^{ns}	0.229^{ns}			
WC	0.276^{ns}	0.280^{ns}	0.479^{ns}		
FFs	0.091^{ns}	-0.125^{ns}	0.681*	0.664*	
FFA	0.124^{ns}	0.093^{ns}	0.584*	0.651*	0.879*

Note: *: significant α = 5%, ns: non-significant, WL: weight loss, FF: fruit fall, RR: respiration rate, WC: water content, FFs: fruit firmness, FFA: free fatty acid.

Free Fatty Acid Level

FFA content is a quality indicator used to assess CPO quality. CPO quality decreases as FFA increases. GA_3 treatment maintains CPO quality by reducing FFA, as shown in Table 6 that the control treatment had the highest FFA levels on each observation day. Increasing concentrations of GA_3 reduced the FFA, and the differences between GA_3 concentrations were significant at 5 DAA (Table 6). Our study demonstrated that G1 (GA_3 at 12.5 ppm) is the best treatment and the mesocarp FFA with this treatment met the SNI-01-2901-2006 standard of < 5%.

Correlation between Variables

There are several categories of correlation coefficient value e.g., very low (0.00 - 0.19), low (0.20 - 0.39), moderate (0.40 - 0.59), strong (0.60 - 0.79), and very strong (0.80 – 1.00). The results in Table 7 showed that the measured variables that have strong correlation are fruit mesocarp firmness, fruit respiration rate, mesocarp water content, and FFA levels. The correlation between these variables was positive/unidirectional, which means that if one variable increases, the other variable will also increase. Based on Table 7, FFA levels and fruit respiration rate have a moderate unidirectional correlation.

The strong, unidirectional relationship between variables consisted of FFs-WC, FFs-RR, and FFA-WC. Water serves as a catalyst in fat hydrolysis increase, so increases in the water content in the fruit mesocarp will promote hydrolysis that results in the increases in FFA levels as a breakdown of triglycerides by the lipase enzymes (Aji, 2016). FFA and FFs have a very strong unidirectional relationship: an increase in the fruit softness during the storage period indicates fruit ripening (Jiang et al., 2020), and FFA levels increased with fruit maturity (Hasibuan, 2020).

Conclusion

GA_3 application can maintain the physical and chemical quality of oil palm fresh fruit bunches. GA_3 at 12.5 ppm is the recommended concentration to minimize losses due to delays or waiting time in processing the oil palm fruit through reduction of fruit loss, fruit respiration rate, fruit mesocarp water content, and maintaining fruit firmness up to 6 DAA and FFA levels up to 5 DAA, hence prolonged the FFB shelf life.

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