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Analysis of Load Testing on the Fresh Fruit Bunch Catching Component of the Electric Bunch Harvester (E-Bhar) Machine and its Impact on Fresh Fruit Bunch Quality

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ABSTRACT

This study aims to test the loading on the catcher components of the E-Bhar machine, as well as estimate the bruise index (BI) and free fatty acids (FFA) in the Fresh Fruit Bunches (FFB) caught. The loading test was conducted by dropping artificial FFB weighing 35 kg from a height of 1 m for 16 trials to analyze the deformation that occurred on the catcher components. Additionally, the BI was manually observed based on variations in the height of the FFB during harvesting. The results showed that an increase in the dropping height of the FFB caused an increase in potential force, which impacted the damage to the FFB. The potential force simulation results on the E-Bhar machine's catcher components ranged from 143.35 N to 2300.38 N, with BI values between 2.38 and 6.69. The maximum BI of 6.69 at a height of 10 m indicates damage approaching the critical value, thus threatening the quality of the FFB. The percentage of FFA ranged from 2.30% to 7.85%, exceeding the maximum limit of 5% set by the palm oil mill according to (SNI 01-2901-1992). These findings emphasize the advantage of using the catcher components in the E-Bhar machine to maintain good quality of the harvested FFB.

1. INTRODUCTION

The traditional harvesting process of fresh fruit bunches (FFB) in oil palm plantations still largely relies on manual methods (Al-Jawadiab *et al*., 2018). Human labour plays a crucial role in cutting and catching the FFB, often requiring high skill and precision to avoid damage to the fruit (Goh *et al*., 2024). However, this manual approach has several drawbacks, such as a high incidence of fruit bruising due to impacts with hard surfaces, limited efficiency, and dependency on the availability of labour. Additionally, improper harvesting methods by unskilled workers can lead to production losses of up to 15%. Harvesting workers who lack skills and knowledge regarding harvesting activities significantly contribute to the loss of loose oil palm fruits (Sharif *et al*., 2017). In this context, machine technologies like the E-Bhar present a potential solution to reduce bruising losses and improve harvesting efficiency.

The E-Bhar machine is designed to aid the harvesting process through more efficient and safe mechanization (Herodian & Desrial, 2023). A key component of this machine is the catching system, which functions to prevent FFB from falling directly to the ground, as the harvesting tool is positioned close to the FFB, and the harvested fruit is temporarily held in the catcher. However, the main challenge with using the machine is ensuring that the catching component can adequately support the weight of the FFB while reducing the risk of bruising the caught fruit. Bruising or physical damage to the fruit can lower the harvest's quality and affect the palm fruit's oil yield (Ruswanto *et al*., 2020).

This research aims to test the load-bearing capacity of the catching component of the E-Bhar machine to ensure that it can support the weight of the FFB efficiently and safely without causing damage. This testing is crucial for evaluating the durability of the materials and the design of the components, which will impact the machine's longevity and performance in the long term. The results of this load-bearing test will provide insight into the optimal operational capacity of the E-Bhar machine in the field. Additionally, as the E-Bhar machine is electrically powered, it also aims to reduce environmental impacts such as noise pollution and air pollution.

Additionally, this research aims to estimate the bruise index and free fatty acid (FFA) levels that occur in FFB caught by the catching component of the E-Bhar machine. Through simulations and in-depth analysis, the extent of physical damage to the FFB can be measured to optimize the machine to minimize damage. This study will provide valuable information for further developing environmentally friendly and efficient mechanical harvesting technology.

The results of both tests will serve as a foundation for improving the design and performance of the E-Bhar machine and enhancing the quality of the harvest. Ultimately, by optimizing this machine, it is hoped that plantation productivity can be increased while maintaining the quality of the harvested FFB.

2. MATERIALS AND METHODS

This research was conducted in four phases. The study's first phase was carried out in the oil palm plantation of PT Sampoerna Agro, South Sumatra, in November 2023. The activity during the first phase involved observing the manual harvesting of FFB. The second phase was conducted at the Siswadhi Soepardjo Lewikopo field laboratory, IPB University, also in November 2023. In this phase, the focus was on testing the load-bearing capacity of the FFB-catching component of the E-Bhar machine. The third phase was also conducted at the Siswadhi Soepardjo Lewikopo field laboratory, IPB University, in July 2024. During this phase, the research involved developing a model to estimate the bruise index (BI) and free fatty acid levels in FFB harvested using the catching component of the E-Bhar machine based on observations of manually harvested FFB.

2.1. Observation of Manual FFB Harvesting in an Oil Palm Plantation

Fresh Fruit Bunches (FFB) height was measured using a laser distance meter. The measurement process began by ensuring the device was in good condition and calibrated. The laser distance meter directly measures the height of the FFB by projecting a laser towards the FFB being measured (Sales *et al*., 2020). The height observations were conducted on seven oil palm trees randomly selected from a single plantation area. An illustration of the FFB height measurement using the laser distance meter is shown in Figure 1. The FFB height measurement data were averaged after observation. The oil palm trees whose FFB height had been measured were marked to avoid mistakes during subsequent manual harvesting activities (Kumar & Normala, 2021).

Figure 1. FFB height measurement

The manual harvesting of FFB was carried out by workers using an egrek tool to harvest the FFB (Hamsi *et al.*, 2020). The weight of the FFB and any loose fruits that fell off after harvesting were measured using a digital scale to obtain the pre-harvest weight of the FFB.

2.2. Bruise Index (BI) Category for FFB Harvesting Results

In the research on the relationship between bruise categories and FFA, the fruits separated from their bunches were divided into several groups based on the size of the bruised area. The free fatty acid (FFA) content in each group was measured by utilizing the observed bruising using a tracking method with a minimum partition size of 1 mm. Based on these observations, the fruits in the FFB were then classified into several categories, as shown in Table 1 (Hadi *et al.*, 2009).

Table 1. Bruise Index (BI) Categories (Hadi *et al.*, 2009)

Categories	Information	Bruising Index Coefficient
A	Whole fruit, without skin damage,	1
B	Fruit with light bruising, total bruised area less than 1 cm	2.5
C	Fruit with moderate bruising, total bruised area 1–2 cm	5.5
D	Fruit with severe bruising, the total bruised area is more than 2 cm	10

Figure 2. Categories of level of damage: no bruises (a), light bruises (b), moderate bruises (c), severe bruises (d)

The bruise index (BI) measurement was based on the average area of the bruise and the percentage of fruit weight from various bruise categories (Figure 2). The bruise index (BI) measurement was conducted through a visual assessment of fruit samples with an average weight of 23.27 kg (including the weight of the fruit and the bunch), and the fruits were separated from the bunch and grouped based on their bruise category. The percentage weight for each category was calculated using multiplication factors of 1, 2.5, 5.5, and 10. This study set the bruise index range from 1 to 10. This calculation was performed using Equation (1) (Hadi *et al.*, 2009; Krisdiarto *et al.*, 2017).

$$BI = \frac{(1 \cdot X_1)+(2.5 \cdot X_2)+(5.5 \cdot X_3)+(10 \cdot X_4)}{100} \tag{1}$$

where X_1, X_2, X_3, and X_4 represent the percentage of fruit weight that has been grouped based on bruise categories: no bruise (a), light bruise (b), moderate bruise (c), and severe bruise (d).

2.3. Load Test on E-Bhar Engine Components

The E-Bhar harvesting machine offers a significant advantage by enabling the collection of fresh fruit bunches (FFB) from greater heights compared to manual methods. This machine improves the quality of harvested FFB due to its catcher component, which is designed to reach high fruit positions, thus reducing potential damage during harvesting. The catcher's height adjustment capability, ranging from 1 to 10 meters, helps to minimize the impact distance of falling FFB. Studies have shown that the height of the FFB drop point greatly affects the bruise index, where higher drop distances result in a greater bruise index (Hadi *et al.*, 2009).

To ensure safety, performance, and operational quality, deformation testing of the FFB catcher component is essential. Uncontrolled deformation can compromise the catcher's primary function of securely and efficiently handling loads. If deformation surpasses acceptable limits, it may lead to structural damage, diminished performance, and adverse effects on the quality of captured FFB, such as increased bruise index and higher free fatty acid content. Load testing is crucial to maintaining deformation within safe boundaries, ensuring that the catcher can effectively handle falling FFB without risking excessive impact or failure. This process validates the material's strength and the component's design in handling cumulative loads, thereby guaranteeing system reliability and prolonging the machine's operational lifespan.

The load testing on the FFB catching component was conducted by measuring deformation or changes in angle that caused a reduction in the distance between the FFB catching element and its supporting frame (Sutton *et al*., 2009). To measure the deformation, an artificial FFB weighing the same as the average weight of FFB in the field, 35 kg, was used. The artificial FFB was dropped from a constant height of 100 cm. The deformation of the FFB catching component was measured using a measuring tape. This test aimed to determine the cumulative load limit that the FFB catching component can withstand (Ellingwood, 2003). Below is an illustration of the load testing on the FFB catching component.

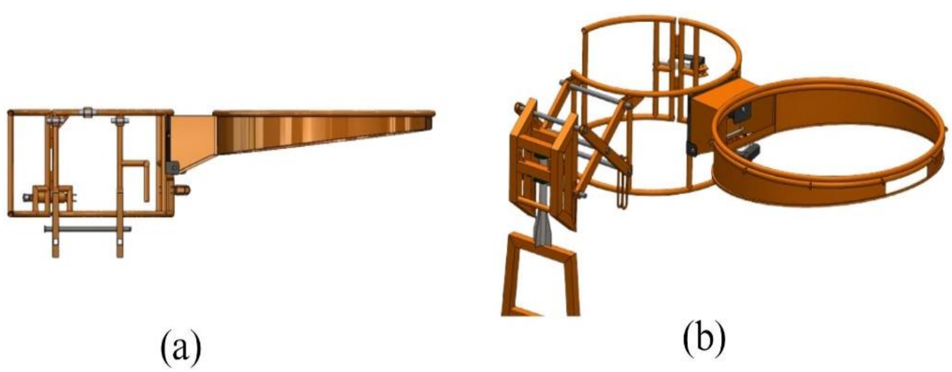


Figure 3. E-Bhar machine FFB catcher components: side view (a), Isometric view (b)

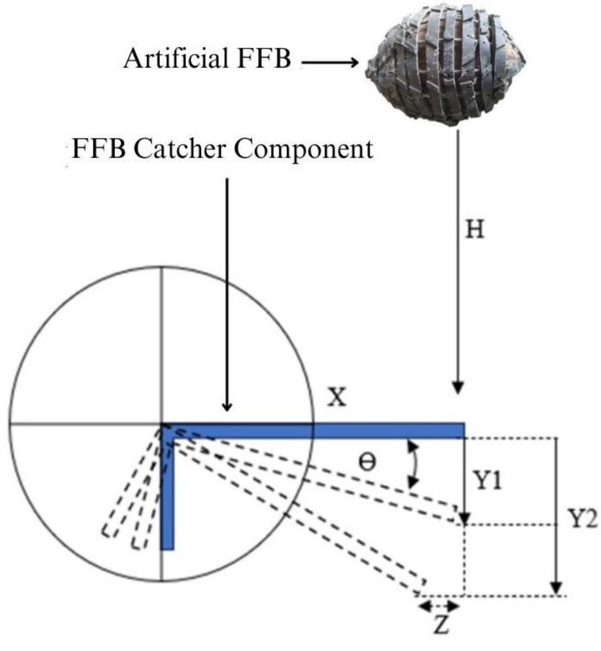


Figure 4. Load testing method for E-Bhar machine FFB catcher components

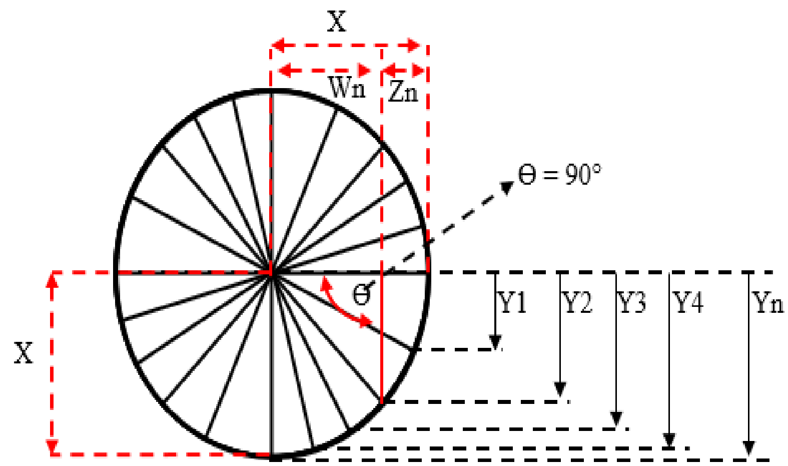


Figure 5. Tolerance analysis of deformation distance of E-Bhar machine FFB catcher components

Figures 4 and 5 illustrate that the FFB catching component will undergo deformation or a deflection of Y1 and Y2 after being subjected to a load. The deformation that can still be tolerated occurs when Zn is more excellent than half the length of the FFB. The potential force required to cause deformation in the FFB catching component is influenced by the height factor H. Below is the equation used for the load testing on the FFB catching element.

$$Y_n = Deformasi \quad (2)$$

$$W_n{}^2 = X^2 - Y_n{}^2 \quad (3)$$

$$Z = X - W_n \quad (4)$$

$$F_P = m \cdot g \cdot h \quad (5)$$

where Yn is the deformation distance (cm); Wn is the distance formed due to deformation (cm); X is the total length of the frame with a catching component ring diameter of 115 cm; Zn is the tolerance distance between the FFB and the catching component ring (cm); FP is the potential force generated by the FFB load test (N); m is the weight of the FFB (kg); g is the acceleration due to gravity (m/s²); and h is the fall height of the FFB (m).

2.4. Simulation Model for Estimating Bruise Index (BI) and Free Fatty Acids (ALB) in FFB

The simulation model for estimating the bruise index (BI) was created by analyzing the potential force from manual FFB harvesting (Foster *et al*., 2017). The potential force generated by the manually harvested FFB is measured from the height of the fruit above the ground. An analysis of the possible force affecting the FFB when harvested using the catching component of the E-Bhar is also conducted. The potential force produced by the FFB when harvested with the catching component of the E-Bhar is measured from the height of the fruit relative to the catching component.

The method used to estimate the potential force acting on the FFB is linear regression analysis based on observations from manual FFB harvesting (Abangba *et al*., 2024). Subsequently, based on the observations and calculations of the possible force in manual harvesting, an estimation of the BI is performed, considering the estimated potential force that occurs when the FFB is harvested using the catching component of the E-Bhar (Lai *et al*., 2023). The method used to calculate the BI for FFB harvested with the catching component of the E-Bhar is also linear regression analysis (Krisdiarto *et al*., 2017).

The determination of free fatty acids (FFA) is calculated based on the linear regression model established from previous research, where the regression model is derived from the relationship between the bruise index and FFA in harvesting ripe palm fruit (Hadi *et al*., 2009). The Equation used to calculate FFA is given by Equation (6):

$$ALB = -0.76 + (1.287 \cdot BI) \quad (6)$$

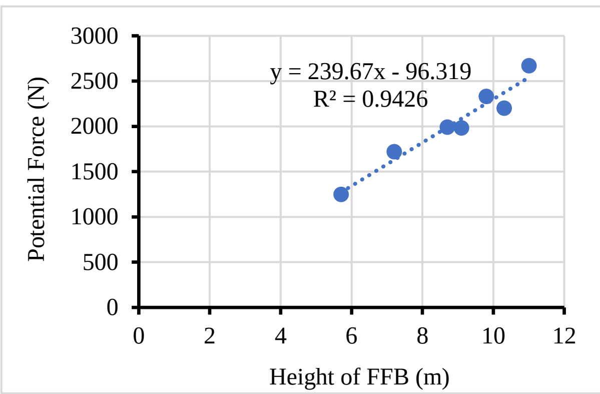
3. RESULTS AND DISCUSSION

3.1. Observation Results of Manual FFB Harvesting in Oil Palm Plantations

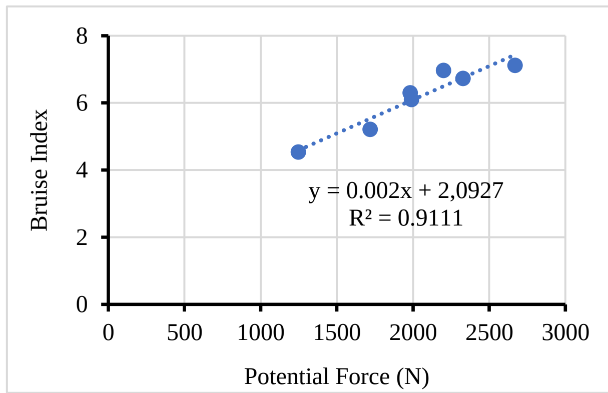
Observations of FFB harvesting in the oil palm plantation were conducted at different harvesting heights. The lowest harvesting height for the FFB was 5.7 m, while the highest was 11 m. The weight of the FFB also varied, with an average of 23.27 kg. Thus, the average potential force occurring during manual FFB harvesting is 2019.59 N.

Table 2. Observation results of FFB harvested manually at PT Sampoerna Agro Sumsel

High Harvest (m)	Weight of FFB (kg)	Potential Force (N)	Category Bruises				Bruise Index
			No Bruises (%)	Light Bruises (%)	Moderate Bruises (%)	Severe Bruises (%)	
5.7	22.30	1246.95	46.19	9.42	13.45	30.94	4.53
7.2	24.34	1719.18	26.05	14.79	20.54	34.51	5.21
8.7	23.32	1990.29	20.24	11.58	27.02	41.17	6.09
9.1	22.20	1981.82	23.42	9.91	18.92	47.75	6.30
9.8	24.22	2328.46	17.42	9.91	21.47	51.20	6.72
10.3	21.78	2200.72	17.36	3.67	26.63	52.34	6.96
11.0	24.74	2669.69	16.73	1.62	27.89	53.76	7.12



(a)



(b)

Figure 6. (a) Relationship between FFB harvesting height and potential force, and (b) Relationship between potential force and BI

The bruise index (BI) was observed by classifying the harvested FFB based on categories of no bruise, light bruise, moderate bruise, and severe bruise. The higher the distance from which the FFB was harvested, the lower the percentage of the no bruise category (Makky & Soni, 2013). Meanwhile, the light and moderate bruise categories yielded varying percentages. However, for the severe bruise category, the percentage observed is directly proportional to the increase in the distance of the harvested FFB. The increase in the percentage of the severe bruise category also leads to a higher BI (Zolfagharnassab *et al*., 2022). The results of the manually harvested FFB observations are displayed in Table 2.

Based on the results in Table 2, the relationship between the potential force occurring during manual FFB harvesting and the harvesting height can be analyzed. The potential force shows a direct relationship with the increase in harvesting height (Cherie *et al*., 2015). (Figure 6) illustrates the positive linear relationship between potential force and harvesting height. The linear regression equation derived from the relationship between potential force and harvesting height is $y = 239.67 \cdot X - 96.319$, where Y represents the potential force (N), and X represents the height of the FFB (m).

Based on the results in Table 2, the relationship between the potential force occurring during manual FFB harvesting and the bruise index (BI) can be analyzed. The potential force shows a direct relationship with the increase in BI (Cherie *et al*., 2019). (Figure 7) illustrates that the relationship between potential force and BI is positively linear. The linear regression equation derived from the relationship between potential force and BI is $y = 0.002 \cdot X + 2.0927$, where X represents the potential force (N) and Y represents the BI.

The results of this study indicate that the potential force increases linearly with the rise in harvesting height of the FFB. This relationship supports the findings from previous research, which also stated that the potential force is directly proportional to the height during the FFB harvesting process, where the higher the position of the fruit, the greater the potential energy stored (Kassim *et al*., 2014). Additionally, previous research emphasizes that harvesting height is directly proportional to the increase in the generated potential force (Mohamaddan *et al*., 2021). With these consistent results, an approach that considers height as an essential variable in the design of harvesting tools can determine the design specifications of the catching components of the E-Bhar machine and the quality of the harvested FFB.

3.2. E-Bhar Engine Catcher Component Loading Test Results

The results of the loading test observations indicate that in each trial of dropping the artificial FFB from a consistent height of 1 meter and a uniform weight of 35 kg, the catching component of the FFB repeatedly experienced a deformation of 5 cm. A potential force of 343.35 N produced the deformation of 5 cm observed in each trial. The data from the loading test observations of the catching component of the FFB are displayed in Table 3.

Table 3. Loading test results of E-Bhar machine FFB catcher components

Experiment Numbers	Height of Catcher Component (cm)	Deformation(cm)
1	110	5
2	105	10
3	100	15
4	95	20
5	90	25
6	85	30
7	80	35
8	75	40
9	70	45
10	65	50
11	60	55
12	55	60
13	50	65
14	45	70
15	40	75
16	35	80

The loading experiment, which involved dropping a weight of 35 kg from a height of 1 meter six times, consistently showed that the deformation of the FFB catching component reached 5 cm in each trial, without any variation between trials. This result indicates the presence of plastic deformation in the catching component, meaning that after the load was applied, the material did not return to its original shape and underwent a permanent change in shape of 5 cm (Mu *et al*., 2018). Several factors can explain the consistency of the deformation: First factor material used in the catching component of the FFB tends to have a low elastic limit, so once the applied load exceeds its elastic limit, the material enters the plastic deformation phase (Wang, 2012). Therefore, the deformation observed remains the same because the material has already reached its plastic limit; any additional load or repetition of loading does not produce significant extra deformation. Second factor material has reached its maximum deformation point due to the 35 kg load from a height of 1 meter. As a result, even though the trials were repeated, the deformation remained constant because the material no longer responded to increased deformation after reaching a certain point (Hearn, 1997). Third factor The forces acting on the component from the falling load are absorbed and distributed uniformly throughout the material structure, leading to deformation in the same area each time a trial is conducted (Ugural, 2016).

Since this force distribution remains unchanged and the material has already undergone plastic deformation, the results remain consistent in each repeated trial. Similar results have been found when the load applied to a material exceeds its elastic limit (Williams, 1956). For example, studies on the deformation of aluminium materials indicate that once the yield point (elastic yield point) is reached, any additional load or repetition of loading no longer causes significant shape changes; instead, the material continues to deform with consistent behaviour after reaching the plastic deformation point (Schwab & Ruff, 2013). Other research on load-bearing structures in heavy equipment also shows that deformation due to static or dynamic loading on materials surpassing their elastic limits will result in consistent plastic deformation, similar to that found in the catching components of the E-Bhar machine (Jovančić *et al*., 2011).

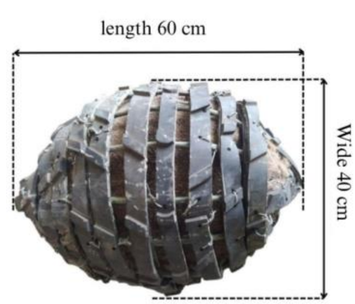
Based on the observations of the deformation of the E-Bhar machine's FFB catching component from the 35 kg load test in Table 4, an analysis of the tolerance distance of the catching element due to deformation was conducted, as shown in Table 3. Since the length of the artificial FFB is 60 cm (Figure 9), the tolerance distance between the FFB and the catching component ring is 30 cm.

This, in the 16th trial, according to the observations in Table 4, where the final height of the E-Bhar machine's catching component is 35 cm, the deformation that occurred is 80 cm, the distance formed due to deformation is 82.62 cm, and the tolerance distance of the catching component to the FFB is 32.38 cm. This indicates that in the 16th trial, with a constant loading test of 35 kg and a drop height of the artificial FFB of 1 meter, the tolerance distance of the catching component to the FFB exceeded half of the length of the FFB, which is 32.38 cm (Zn > 30 cm).

Table 4. Deformation of FFB catcher components of the E-Bhar machine based on a 35 kg load test

Experiment Numbers	Height of Catcher Component (cm)	Deformation (cm)	The distance formed due to deformation (cm)	Tolerance of the distance of the catch component to the TBS (cm)
1	110	5	114.92	0.08
2	105	10	114.58	0.42
3	100	15	114.02	0.98
4	95	20	113.2	1.8
5	90	25	112.25	2.75
6	85	30	111.04	3.96
7	80	35	109.54	5.46
8	75	40	107.86	7.14
9	70	45	105.83	9.17
10	65	50	103.56	11.44
11	60	55	101	14
12	55	60	98.12	16.88
13	50	65	94.87	20.13
14	45	70	91.1	23.9
15	40	75	87.18	27.82
16	35	80	82.62	32.38

(a)



(b)

Figure 8. (a) Load test process on FFB catcher components with artificial FFB, and (b) Dimensions of artificial FFB

Table 5. Deformation tolerance of E-Bhar machine FFB catcher components

Experiment Numbers	Weight of FFB (kg)	Height of FFB (m)	Distance Between Catching Component and FFB (cm)	Potential Force Tolerance (N)
15	525	1	27.82	5150.3
16	560	1	32.38	5493.6

Based on Table 5, it is observed that in the 16th trial, the load test with a weight of 35 kg and a drop height of the artificial FFB set at 1 meter consistently resulted in the distance of the catching component exceeding its tolerance limit (Zn > 30 cm), which is measured at 32.38 cm. This was produced by the accumulation of potential force amounting to 5493.6 N. Meanwhile, in the 15th trial, the distance of the catching component nearly exceeded its tolerance limit (Zn > 30 cm), recorded at 27.82 cm, resulting from an accumulated potential force of 5150.3 N.

3.3. Simulation Results of Bruise Index (BI) and Free Fatty Acid (ALB) Estimation Models

The estimation of potential force in Table 6 from the simulation of harvest heights ranging from 1 m to 10 m shows potential force results ranging from 143.35 N to 2300.38 N. Table 6 shows that the Bruise Index (BI) levels for the quality of harvested FFB during the simulation at drop heights from 1 m to 10 m are between 2.38 and 6.69. This result indicates a positive linear relationship between potential force and BI levels, meaning that as the likely force during FFB harvesting increases, the BI levels also increase (Figure 10). The potential height of FFB harvested using the FFB catcher component of the E-Bhar machine based on Table 6 shows that a height of 10 m produces an estimated BI level of 6.69, which means the BI estimate of 6.69 is close to the maximum BI level (severe bruising), namely 10 (Hadi *et al*., 2009).

The free fatty acid (FFA) percentage estimation shown in Table 6 explains that an increase in drop height and BI levels leads to a higher percentage of FFA. According to Table 6, the rate of FFA resulting from the simulation at drop heights from 1 m to 10 m ranges from 2.3% to 7.85%. This result demonstrates that the relationship between potential force and FFA percentage is also positively linear, indicating that as the likely force during FFB harvesting increases, the FFA percentage also rises (Figure 10). The potential height of FFB harvested using the FFB catcher component of the E-Bhar machine based on Table 6 shows that a height of 5 m produces an estimated ALB level of 4.77%, which means the estimated ALB of 4.77% is still below the threshold for FFA percentage according to the SNI standard for FFA quality in FFB, which is 5%. This SNI standard also serves as a limit to ensure that the quality of the crude palm oil (CPO) produced does not degrade (SNI 01-2901-1992) (Wulandari *et al*., 2011).

Table 6. Estimated BI and ALB on FFB harvested with the FFB catcher component of the E-Bhar machine

Height Of FFB (m)	Potential Force (N)	BI	FFA (%)
1	143.35	2.38	2.30
2	383.02	2.86	2.92
3	622.69	3.34	3.54
4	862.36	3.82	4.15
5	1102.03	4.30	4.77
6	1341.70	4.78	5.39
7	1581.37	5.26	6.00
8	1821.04	5.73	6.62
9	2060.71	6.21	7.24
10	2300.38	6.69	7.85

The results of this study indicate a positive linear relationship between the potential force generated during the harvesting of Fresh Fruit Bunches (FFB) and the Bruise Index (BI) and free fatty acid (FFA) percentage. This aligns with previous findings, which also reported that increased drop height of FFB contributes to more significant physical damage measured by BI (Thang *et al*., 2021). The research showed that higher damage to the fruit tends to occur at greater drop heights due to the increased potential force experienced during the fall (Henson, 2012). The positive relationship between potential force and BI can be physically explained. The higher the drop height, the greater the potential energy of the FFB, which is then converted into kinetic energy during the fall. This kinetic energy can result in a more significant impact on the fruit's contact with the surface, potentially damaging the fruit tissue and increasing the BI (Pakdeechot *et al*., 2020). These findings are consistent with previous study (Opara & Pathare, 2014) observing a direct correlation between BI and drop height, suggesting the need to reduce drop heights to mitigate damage.

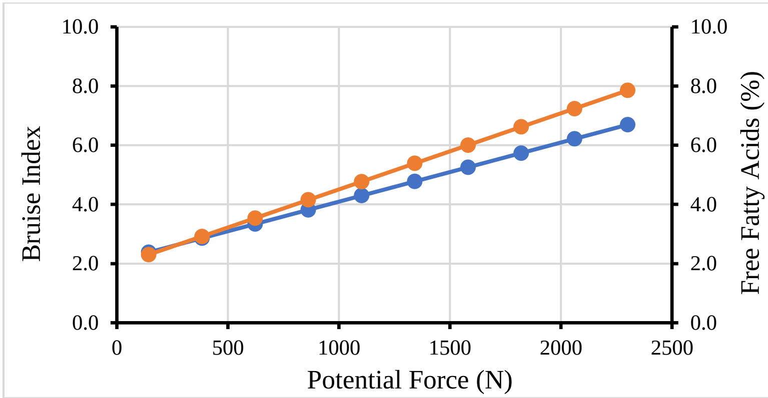


Figure 10. Relationship between potential forces and BI based on simulation

Moreover, this study's findings also show that increased potential force is directly related to an increase in the percentage of FFA. Previous research indicates that the physical damage to the fruit can affect its quality, including its chemical composition, such as FFA (Basyuni *et al*., 2017). As more damage occurs, more free fatty acids are released, increasing the FFA percentage (Bergman & Ader, 2000; Tumova *et al*., 2016). This becomes an important indicator for the processing industry, which can utilize this data to optimize harvesting processes and reduce quality loss.

4. CONCLUSION

The results of this study provide empirical evidence supporting that the development of effective harvesting techniques for Fresh Fruit Bunches (FFB), including control over the drop height of FFB using the E-Bhar machine, is crucial in maintaining the quality of harvested FFB. The drop height of FFB, as observed during manual harvesting, affects the Bruise Index (BI) of the quality of harvested FFB. The higher the drop distance of the FFB, the greater the potential force experienced. Based on observations of potential force and BI during manual harvesting of FFB, simulations estimating potential force and BI for the TBS capturing components of the E-Bhar machine can be conducted. The simulation results indicate that the potential force generated during the harvesting of FFB by the TBS capturing components of the E-Bhar machine ranges from 143.35 N to 2300.38 N for drop heights between 1 m and 10 m. Consequently, the resulting BI levels are between 2.38 and 6.69. A BI level of 6.69 for FFB harvested from a height of 10 m using the E-Bhar machine's capturing component indicates that the level of damage to the FFB is approaching the maximum BI value of 10, meaning the quality of the harvested FFB is nearing severe damage. Additionally, for the parameter of free fatty acid (FFA) percentage within the BI range of 2.38 to 6.69, the estimated FFA percentage ranges from 2.30% to 7.85%. An FFA percentage of 7.85% for FFB harvested from a height of 10 m using the E-Bhar machine's capturing component indicates that the FFA percentage exceeds the maximum desirable standard of 5% set by palm oil mills, meaning that the quality of the harvested FFB may result in poor quality crude palm oil (CPO). For future studies, to reduce the impact that leads to high BI values when FFB is positioned at excessive heights relative to the catcher component in the E-Bhar machine, it is suggested to incorporate a protective layer on the catcher. This would help lower the potential force generated. Furthermore, adding a spring mechanism could help reduce the deformation experienced by the catcher component in the E-Bhar machine.

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