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Quality Analysis of Crude Palm Oil (CPO) Processing and Proposed System Improvements to Increase Free Fatty Acid (FFA) Quality at PT. TLDN (CAP)

Bimbing Herwanto[1], Mahendrawati ER[2]

Master of Technology Management Study Program, Institut Teknologi Sepuluh Nopember Surabaya [1,2]

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ABSTRACT

Crude Palm Oil (CPO) is a strategic commodity whose quality and selling value are largely determined by the Free Fatty Acid (FFA) content. High FFA levels cause a decline in product quality and directly impact industry profitability. A CPO quality evaluation at PT. TLDN (CAP) demonstrated the inability of the production process to consistently produce premium CPO (FFA less than 3%). This study aims to identify the root causes of the increase in FFA in the CPO processing process and to formulate effective improvement strategies. The research method uses a quantitative approach with a case study, applying the Seven Tools of Quality to CPO production and quality data for March 2025. The analysis results show that the largest contribution to FFA formation comes from condensate and liquor flows with a cumulative contribution of 88%, while UnCO has a relatively stable FFA. Method factors are the dominant cause, especially mixing oil flows with different qualities in one storage tank, followed by machine and material factors. Improvement simulations through oil flow separation can reduce the FFA of premium products from 3.58% to 2.5-2.69% and increase the proportion of premium CPO to 37.44% without increasing production capacity. These results show that the integration of Seven Tools with oil flow separation effectively improves CPO quality while providing significant economic impacts.

Keywords: *Crude Palm Oil; free fatty acid; seven tools; oil stream segregation; quality control*

E-MAIL

bimbingspt@gmail.com
mahendra_w@is.its.ac.id

*Corresponding author:
Bimbing Herwanto
bimbingspt@gmail.com

PUBLISHER

LPPM- Institut Teknologi Adhi Tama Surabaya
Address:
Jl. Arief Rachman Hakim No. 100, Surabaya 60117, Tel/Fax: 031-5997244

ABSTRAK

Crude Palm Oil (CPO) merupakan komoditas strategis yang mutu dan nilai jualnya sangat ditentukan oleh kadar Free Fatty Acid (FFA). Tingginya FFA menyebabkan penurunan kualitas produk dan berdampak langsung pada profitabilitas industri. Evaluasi mut CPO di PT. TLDN (CAP) menunjukkan ketidakmampuan proses produksi dalam menghasilkan CPO premium (FFA kurang dari 3%) secara konsisten. Penelitian ini bertujuan untuk mengidentifikasi akar penyebab peningkatan FFA pada prses pengolahan CPO serta merumuskan strategi perbaikan yang efektif. Metode penelitian menggunakan pendekatan kuantitatif dengan studi kasus, menerapkan Seven Tools of Quality terhadap data produki dan kualitas CPO bulan Maret 2025. Hasil analisis menunjukkan bahwa kontribusi terbesar pembentukan FFA berasal dari aliran condensat dan liquor dengan kontribusi kumulatif sebesar 88%, sedangkan UnCO memiliki FFA relatif stabil. Faktor metode menjadi penyebab dominan,terutama pencampuran aliran minyak dengan mutu berbeda dalam satu tangki penyimpanan, diikuti faktor mesin dan material. Simulasi perbaikan melalui pemisahan aliran minyak mampu menurunkan FFA produk premium dari 3,58% menjad 2,5-2,69% serta meningkatkan proporsi CPO premium hingga 37,44$ tanpa penambahan kapasitas produksi. Hasil ini menunjukkan bahwa integrasi Seven Tools dengan pemisahan aliran minyak efektif meningkatkan mutu CPO sekaligus memberikan dampak ekonomi signifikan.

Keywords: *Crude Palm Oil; free fatty acid; seven tools; oil stream segregation; quality control.*

INTRODUCTION

Crude Palm Oil (CPO) is a global strategic commodity that serves as a primary raw material in the food, oleochemical, and bioenergy industries [1]. CPO quality is determined by several physicochemical parameters, including Free Fatty Acid (FFA) levels, water content, and impurity levels. Among these parameters, FFA is the primary indicator of quality because it is directly related to oil degradation and the selling value of CPO in both domestic and international markets. High FFA values indicate triglyceride hydrolysis due to lipase enzyme activity or suboptimal fruit handling, resulting in decreased oil quality and challenges in further refining processes. According to Indonesian National Standard (SNI) 01-2901-2006, the maximum FFA content requirement for CPO is less than 5% to meet market-acceptable quality [2]. High FFA levels in CPO not only affect the refining process but also impact the industry's added value and profitability. Previous research has shown that pre-processing activities, such as waiting time between harvest and sterilization, and fruit damage, are significant factors in the formation of FFA. Uncontrolled accumulation of FFA degrades CPO quality, resulting in economic losses through quality claims by buyers. Furthermore, high FFA in CPO limits its use in the manufacture of derivative products that meet high quality standards [3].

PT. TLDN (CAP) operates a sustainable palm oil plantation and industry located in Muara Kaman District, Kutai Kartanegara Regency, East Kalimantan. PT. TLDN operates a palm oil processing plant with a capacity of 40 tons/hour and implements a vertical sterilization system. Evaluation of CPO quality has shown instability in achieving premium FFA (FFA <3%) quality in recent years.

Tabel 1. PT. TLDN Production Data for 2023-2025

Year	Month	CPO (kg)	FFA Content (%)
2023	January	2,993,864	3.31
	February	2,589,806	3.49
	March	2,735,845	3.47
	April	2,977,675	3.61
	May	3,591,264	3.83
	June	3,193,715	3.16
	July	3,557,347	3.26
	August	3,719,151	2.98
	September	3,894,611	3.24
	October	4,261,636	3.17
	November	3,876,947	3.43
	December	2,755,980	3.42
2024	January	3,604,239	3.65
	February	3,155,080	3.10
	March	2,874,350	2.98
	April	3,194,324	3.36
	May	3,166,443	3.07
	June	2,635,495	3.18
	July	2,349,266	2.94
	August	2,787,651	3.26

Year	Month	CPO (kg)	FFA Content (%)
	September	2,725,527	3.49
	October	3,510,346	3.18
	November	3,027,179	3.08
	December	3,306,045	3.36
2025	January	2,567,158	3.53
	February	2,542,764	3.31
	March	3,321,252	3.58

Source: PT. TLDN (CAP)

The data in Table 1 shows that only three months produced CPO in the premium FFA category. This phenomenon highlights the need to identify the main factors causing low FFA quality and design effective strategies to improve the CPO processing system. Based on this condition, this study aims to identify the root causes of elevated FFA levels in CPO processing at PT. TLDN (CAP) and to formulate effective process improvement strategies. A quantitive case study approach is applied using the Seven Tools of Quality to analyze actual production and quality data, enabling systematic identification of critical processing stages that contribute to FFA formation. In addition, this research evaluates oil stream segregation as an alternative quality control strategy to improve the proportion of premium CPO and to estimate its potential impact on product selling value and profitability based on production data from March 2025.

LITERATURE REVIEW

Palm oil processing is one of the factors that determines the success of an oil palm plantation business with the main output being CPO. CPO is crude palm oil obtained from the extraction or pressing of the pulp (mesocarp) of oil palm (Elaeis guineensis) and has not undergone a refining process. CPO has a characteristic reddish color that comes from the content of carotenoid pigments (especially beta-carotene) which functions as a precursor to vitamin A and acts as a natural pigment in plants [4]. As a raw product, CPO still contains various components such as Free Fatty Acid (FFA), water, dirt, carotenoid pigments, and other minor compounds. High FFA levels indicate hydrolysis of triglycerides due to the activity of microorganisms producing lipase enzymes, which causes a decrease in oil quality in the form of rancidity and changes in color and taste [5]. Meanwhile, the relatively low levels of FFA make CPO suitable as a raw material for various industries including food, cosmetics and energy [6].

High levels of water and impurities also have a negative impact on the quality of CPO because they can speed up the hydrolysis reaction and complicate the refining process. Controlling water and impurity content requires strict supervision from storage to the processing stage, considering that some fine impurities cannot be separated mechanically because they have a specific gravity close to that of palm oil [7].Another important quality parameter is the Deterioration of Bleachability Index (DOBI), which describes the level of damage to carotenoids due to oxidation from harvest to processing. A low DOBI value indicates a decrease in the oil's bleaching ability in the advanced refining process and is generally influenced by high temperatures and less than optimal processing systems [8]. The quality of CPO has direct implications for the selling price, efficiency of the refining process, and the quality of derivative products.

The processing process carried out by palm oil factories produces several products including oil condensate, oil liquor, and Undiluted Crude Oil (UnCO). Oil condensate is condensation water from the sterilization process which contains small amounts of oil and has the potential to cause oil loss if not managed properly. Oil liquor is a mixture of oil, water and impurities resulting from pressing which requires a further clarification process. Meanwhile, UnCO is crude oil that has not been diluted and still contains high amounts of impurities so it requires a further separation process [9].

Several previous research have been conducted regarding the quality of CPO. Hudori [10] conducted research aimed at describing the impact of losses caused by low quality CPO products, especially due to high FFA levels, both through reduced selling prices and increased refining costs. In addition, the research also highlights the importance of identifying the root causes of low quality and proposes improvements based on cause-effect analysis. A more in-depth study of the production process was carried out by Levia dan Mhubaligh [11] regarding the analysis of the factors forming FFA throughout the stages of CPO production. The results of the research that has been carried out are that delays in processing palm oil fresh fruit bunches and inconsistencies in sterilization temperatures are the main causes of increased FFA. Tan also conducted research on the impact of blending CPO with high FFA content on other quality parameters such as PV, AnV and DOBI. The results obtained indicate that blending without controlling FFA levels can reduce the overall quality of the oil so that it is necessary to classify CPO based on quality.

Quality control approaches based on human, machine, material, method and environmental factors are also widely used in energy and manufacturing product quality research.. Silvia [12] also shows that variations in product quality are strongly influenced by a combination of human factors, methods and machines. This is relevant for the CPO industry because the process characteristics are both continuous and sensitive to operational variations. The Six Sigma approach with the Define, Measure, Analyze, Improve and Control (DMAIC) stages is starting to be widely applied in the palm oil industry. Tarigan [13] shows that the Six Sigma method is effective in identifying the causes of CPO quality discrepancies, especially FFA content and water content. This research succeeded in formulating proposals for process improvements that have an impact on increasing quality stability. Research related to the use of DMAIC for quality control was also carried out with a focus on defect reduction [14].

Banjarnahor dan Puspitasari [15] show a more operational and easy to implement approach through the application of Statistical Process Control (SPC). Research conducted using Seven Tools and process capability analysis succeeded in identifying dominant defects in CPO. Several studies based on Seven Tools were also applied to compare the actual quality of CPO [16], continuous improvement [17], and identify dominant defects and their root causes in the food processing and packaging industry [18][19].

In line with the theory of Total Quality Management (TQM), quality control should not stop at final product inspection, but should cover the entire process in a systematic and data-based manner [20]. The principles of fact-based decision making and continuous improvement are the main basis for applying the Seven Tools in this research. The quantitative approach used allows objective analysis of the relationship between process parameters and CPO quality, and provides a strong basis for data-based decision making. The integration of Seven Tools into the TQM framework in this research not only identifies the root causes of high FFA, but also designs control strategies that have a direct impact on increasing profitability.

The novelty of this research lies in the integration of the Seven Tools of Quality method with an oil flow separation approach as a strategy for improving CPO quality. Unlike previous studies, which generally only analyzed FFA in the final product or a single technical factor, this study quantifies the contribution of FFA based on oil source, allowing for more precise identification of critical points. Furthermore, this research goes beyond problem identification, linking the results of the Seven Tools analysis to process improvement designs, managerial implications, and economic impacts. This multidimensional approach produces an integrated FFA control framework for premium CPO that encompasses technical, operational, and managerial aspects, a topic not widely discussed in previous studies.

METHOD

Research Objective and Type

The objective of this research is the PT TLDN (CAP) palm oil mill, focusing on the CPO processing process. This study aims to analyze the effect of FFA levels on CPO quality, sales value, and profitability. This research uses a quantitative method with a case study approach, based on actual production process conditions and CPO quality data.

Timeline and Data Sources

The study was conducted using CPO production and quality data for the period March 2025. The data used consisted of primary and secondary data. Primary data were obtained through direct observation of the production process, interviews, and technical discussions with the production manager, station operators, and the laboratory department. Secondary data consisted of CPO production and quality reports at several process points: Condensate, Liquor, UnCO, and Production.

Data Collection Methods

Data collection methods were carried out through:

1. Direct observation of the CPO processing process, from receiving fresh fruit bunches to CPO storage.
2. Interviews and technical discussions with relevant parties to obtain information on operational constraints and variations in FFA quality.
3. Documentation of CPO production and quality data during the research period.

Data Analysis Technique

The data analysis technique used the Seven Tools approach as a quality control tool to evaluate the quality of CPO FFA. The analysis began with descriptive statistics to describe the characteristics of FFA levels at each process point: the Sterilizer (Condensate), Bunch Press (Oil Liquor), and Pressing (UnCO oil), including minimum, maximum, average, and frequency distribution values.

Next, the Seven Tools, consisting of stratification (Run Chart), histogram, scatter diagram, cause-and-effect diagram (fishbone diagram), and Pareto diagram, were used to identify relationships between process variables, determine the production stages most influential in increasing FFA, and identify the root causes of CPO FFA quality exceeding sales standards based on production data from March 2025. The research steps are depicted in the research flowchart in Figure 1.

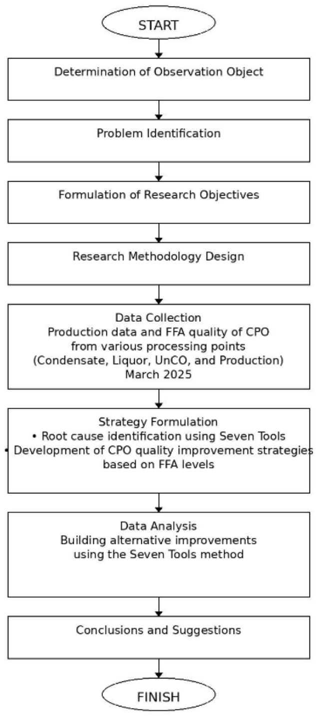

Figure 1. Research Flowchart.

RESULTS AND DISCUSSION

PT. TLDN (CAP) CPO production and quality data for March 2025 can be seen in Table 2.

Tabel 2. Production and quality of Data in CPO PT. TLDN (CAP) Maret 2025

Date	Oil Production (kg)	FFA Quality (%)			
		Condensate	Liquor	UnCO	Production
1	55,919	5.60	5.05	1.47	2.85
3	138,544	7.67	5.43	2.80	3.56
4	115,808	5.48	4.65	2.16	2.78
6	195,015	5.94	4.54	2.47	3.23
7	166,989	4.98	4.29	3.11	3.81
8	109,389	7.07	5.13	3.15	3.77
10	153,082	6.48	6.12	2.97	3.63
11	188,394	6.94	6.09	3.64	4.07
12	144,948	6.06	4.97	2.43	3.44
13	24,611	6.45	5.63	2.60	4.00
14	181,146	5.80	5.14	2.28	3.31
15	178,385	6.45	6.55	2.70	3.66
17	150,064	5.67	4.18	2.75	3.69
18	135,553	6.29	4.84	2.09	3.31
19	126,776	6.18	4.62	2.24	2.75
21	172,787	7.14	5.20	2.63	3.67
22	184,457	6.73	5.32	3.05	3.83
24	131,828	7.93	6.52	3.35	3.77
25	180,419	8.38	6.44	3.62	4.41
26	161,138	8.15	7.32	2.69	4.07
27	185,693	6.72	6.04	2.35	3.47
28	150,307	5.69	5.27	2.71	3.74
AVG	**3,231,252**	**6.54**	**5.42**	**2.69**	**3.58**

CPO Quality Analysis Results

The production data evaluation results in Table 2 show that during the observation period, no CPO had an FFA content below 3%, so all products were in the normal to claim category. This condition indicates that the processing process is not yet capable of consistently producing premium-quality CPO and has a direct impact on the decline in product sales value. Stratification of the data by oil source shows that the largest contribution to the increase in FFA came from Condensate and Oil Liquor streams, with a cumulative contribution of 88%. UnCO had a relatively low FFA content and a non-dominant contribution. This finding confirms that quality issues do not originate at all stages of the process, but are concentrated at specific points.

Table 3. CPO Quality Stratification

Oil Source	Average FFA (%)	Quality Above Standard 3%	Percentage of Total (%)	Accumulated Quality	Category
Condensate	6.54	22	44	44	High
Liquor	5.42	22	44	88	High
UnCO	2.69	6	12	100	Low
Total Production	3.58	50	100	100	

The FFA content distribution histogram (Figure 2-4) shows that FFA levels in Condensate and Liquor are predominantly in the 5-7% range, while UnCO2 consistently remains below 3%. In condensate, the highest frequency occurs in the 6-7% FFA range, followed by the 5-5.99% and 7-

7.99% intervals, indicating high FFA dominance throughout the production period. A similar pattern is also seen in Liquor, with the highest FFA distribution occurring in the 5-6.99% range, indicating uncontrolled quality at this stage. Conversely, the UnCO2 histogram shows all FFA values below 4%, with dominance in the 2-2.99% interval, indicating relatively better and more stable quality. Overall, the histogram distribution confirms that FFA variation remains high and the processing process has not been able to consistently maintain CPO quality at the premium limit (<3%).

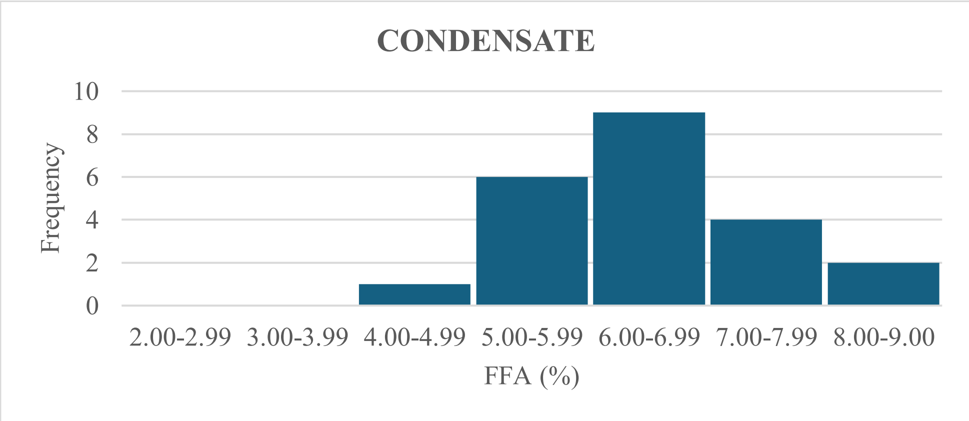

Figure 2. Histogram Condensate

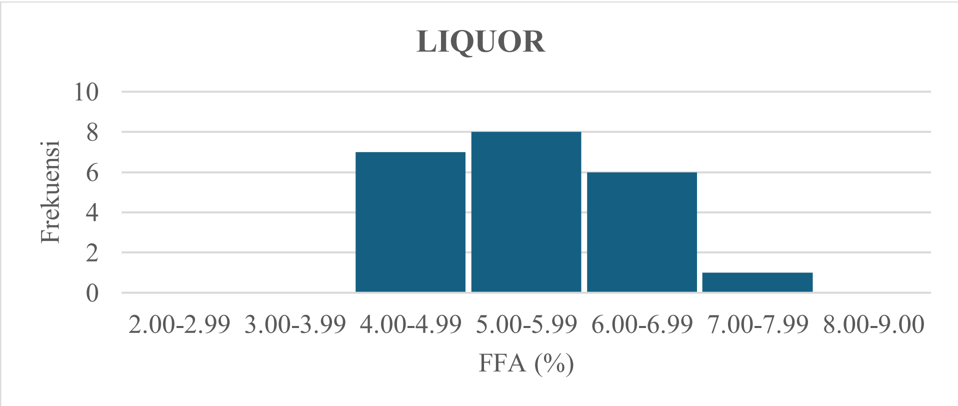

Figure 3. Histogram Liquor

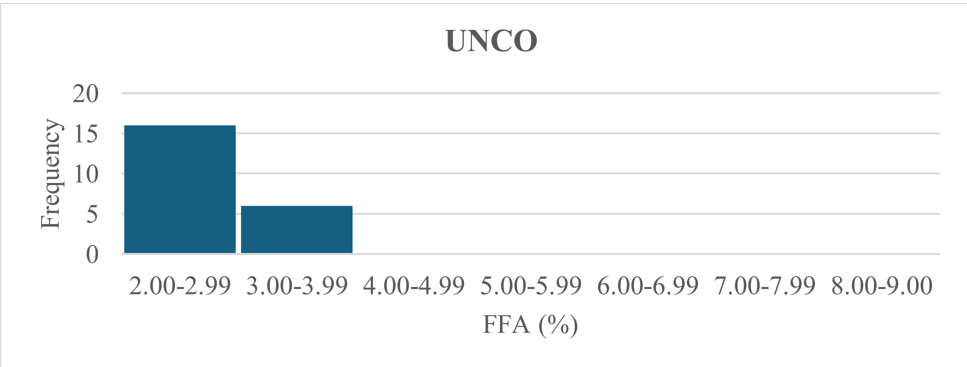

Figure 4. Histogram UnCO

The scatter diagram (Figure 5-7) shows a significant positive relationship between the FFA content of Condensate and Liquor and the FFA content of the final product, while the relationship between UnCO2 and the final product is relatively weak. The condensate plot shows a strong positive correlation, indicating that the increase in FFA in the early post-sterilization stage contributes significantly to the decline in the final CPO quality. A positive relationship is also seen in the Liquor stage, although with a wider data distribution, indicating a moderate influence due to inconsistencies in process parameters such as temperature, refining time, and moisture content. In contrast, the correlation between UnCO2 and the final product FFA tends to be low, indicating that its contribution is not dominant and rather exacerbates the FFA that has formed in the previous stage. Therefore, quality control is focused on the Condensate and Liquor stages as the main factors in efforts to reduce FFA and increase the proportion of premium CPO.

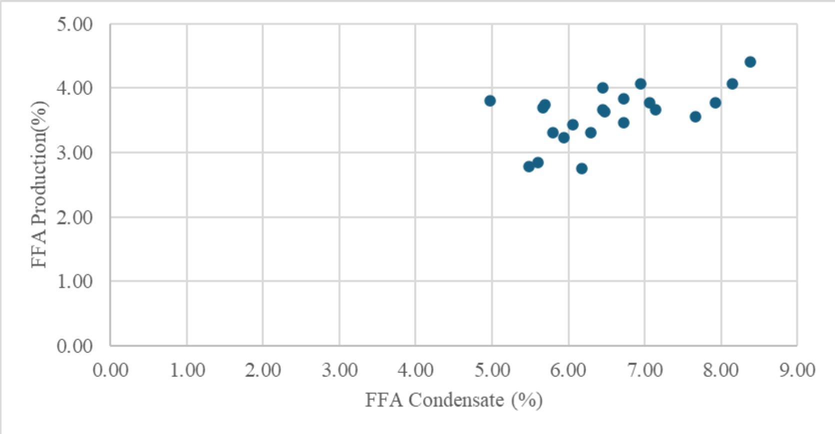

Figure 5. Scatter Diagram Condensate vs Production

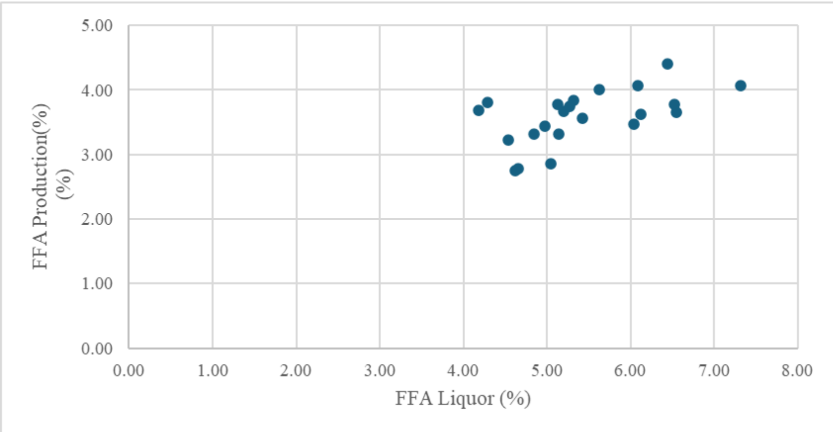

Figure 6. Scatter Diagram Liquor vs Production

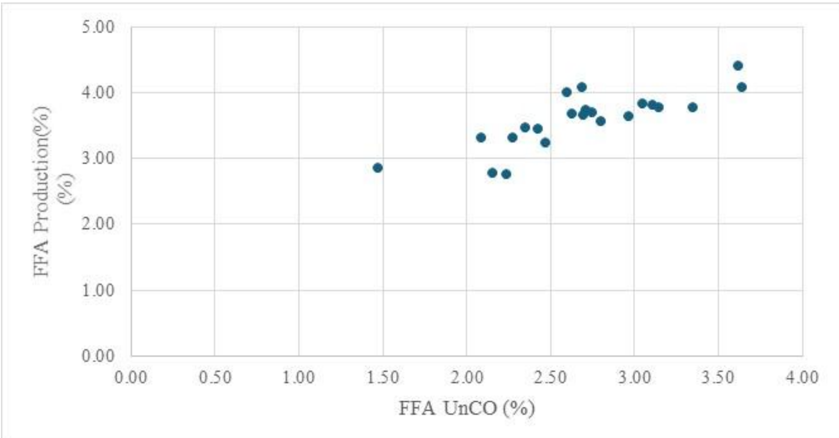

Figure 7. Scatter Diagram UnCO vs Production

Root Cause Identification

A cause-and-effect diagram (fishbone/Ishikawa diagram) was used to identify the root causes of high FFA levels in CPO. Based on the Fishbone Diagram analysis (Figure 8), the causes of the increase in FFA were grouped into method, machine, material, and human factors to obtain a comprehensive picture that serves as a basis for determining quality improvement priorities.

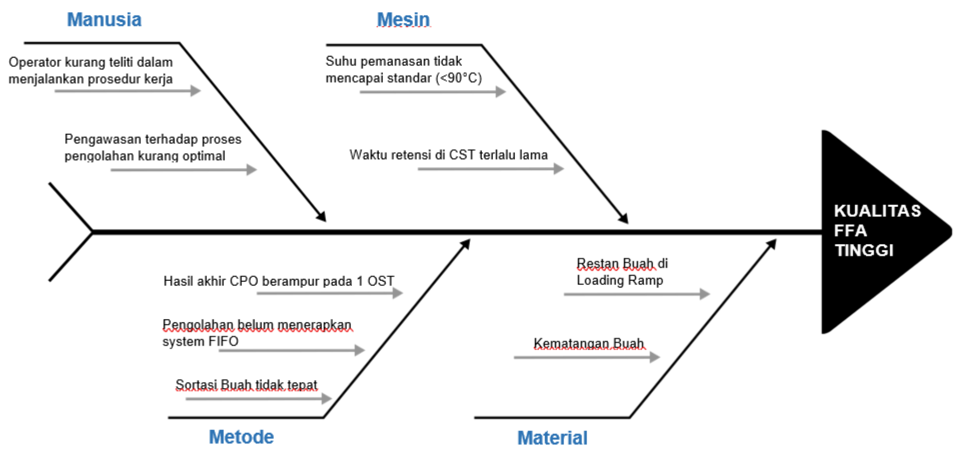

Figure 8. Fishbone Diagram

The analysis revealed that human factors contributed through inconsistent procedural implementation and weak process monitoring, which impacted the instability of production quality. Machine factors were related to uncontrolled heating temperatures and retention times in the Crude Storage Tank (CST), which allowed lipase enzyme activity and oil oxidation to continue, resulting in increased FFA. Method factors were the dominant contributors, primarily due to the mixing of oil streams with varying FFA levels, delays in processing fresh fruit bunches, and inconsistencies in sorting fruit ripeness, which affected boiling effectiveness. Meanwhile, material factors were related to the inconsistent quality of fresh fruit bunches and long waiting times at the loading ramp, which accelerated FFA formation before processing.

A Pareto diagram was used to determine the dominant factors contributing to the increase in FFA in CPO. The analysis was conducted using a Fishbone Diagram, where each cause was evaluated based on its frequency of occurrence and its impact on FFA quality. The Pareto results (Table 4) indicate that approximately 80% of the problems were caused by a few primary factors out of the total causes analyzed based on the Fishbone Diagram.

Table 4. Pareto Diagram of Causal Factors

No	Causal Factor	Category	Frequency (Cases)	Percentage (%)	Cumulative (%)
1	The final CPO result is mixed in 1 Oil Storage	Method	22	30%	30%
2	Fruit retained (delayed processing of fruit)	Material	14	19%	49%
3	Heating Temperature <90°C	Machine	11	15%	64%
4	Retention time in CST too long	Machine	7	10%	74%
5	Fruit Over-Ripe	Material	7	10%	84%
6	Operator Inattention	Human	5	7%	90%
7	Lack of Human Supervision	Human	5	7%	97%
8	Processing does not implement the FIFO system	Method	1	1%	99%
9	Incorrect fruit sorting	Method	1	1%	100%

The method factor is the biggest contributor, especially the mixing of CPO results in one storage tank which reduces the overall oil. Machine factors followed, related to uncontrolled heating temperatures and long retention times in the CST. Material factors also had a significant impact, particularly due to delayed processing of remaining fruit, which accelerated FFA formation.

Conversely, human factors contributed relatively less, but still played a role in maintaining operational consistency and effective process monitoring.

Discussion and Evaluation of Proposed Improvements

Based on the analysis results, a quantitative simulation was conducted using a mass balance approach, implementing oil flow separation based on FFA characteristics. The final product FFA value under existing conditions was obtained from the following weighted average calculation:

$$FFA_{mix} = \frac{(FFA \times MB \text{ to Oil (Condensate)}) + (FFA \times MB \text{ to Oil (Liquor)}) + (FFA \times MB \text{ to Oil (UnCO)})}{\text{Total Material Balance to Oil}} \quad \dots (1)$$

The calculations show that the existing conditions result in a final product FFA of 3.58%, which falls within the normal CPO category, potentially reducing its selling value. Meanwhile, the oil flow separation scheme can reduce the FFA of premium CPO to 2.5-2.69% and increase the proportion of premium CPO to approximately 37%.

These results demonstrate that oil flow separation is an effective strategy for reducing FFA without requiring changes in production capacity. This approach allows for more flexible and data-driven CPO quality management and reduces the risk of quality claims from buyers.

Quantitative Comparison of Existing and Proposed Conditions

A quantitative comparison shows that the FFA content under existing conditions without stream separation reached 3.58%. After the implementation of oil flow separation, the FFA of premium CPO (ST1) ranged from 2.5-2.69%, while that of non-premium CPO (ST2) ranged from 3.5-5%. These results demonstrate that oil flow separation can reduce the FFA content of premium products by around 0.8-1%, increase the proportion of premium CPO to 37.44%, and control oil with high FFA content so as not to affect quality and sales claims.

Integrative Discussion of Quality Improvement

The quantitative analysis confirms that the implementation of the Seven Tools integrated with oil flow separation provides measurable improvements in CPO quality. This approach enables data-driven quality management without relying on total blending, so the proposed improvements are not merely conceptual but have been proven effective in reducing FFA and increasing the product's economic value compared to the initial condition.

Proposed Improvement Plan

The improvement plan was developed based on the results of the Seven Tools analysis, starting with stratification, histograms, and scatter diagrams, which indicated that the condensate and liquor streams significantly contributed to the increase in FFA. Therefore, the focus of the improvements was directed at controlling the sources of FFA formation. Root cause identification using a fishbone diagram and prioritization using a Pareto diagram indicated that method and material factors were the dominant causes, particularly mixing of oil streams, delays in fresh fruit bunch processing, and suboptimal FIFO implementation.

Quantitative validation using a mass balance and weighted average calculation showed that oil water separation could reduce the FFA content of premium products to below 3% and shift 40% of production to premium CPO, while preventing quality contamination by high-FFA oil. This demonstrated that the proposed improvements had a strong scientific basis and were feasible to implement to improve the company's quality and profitability.

The selected improvement alternatives included separating CPO streams by source, reducing retention time at the CST, strengthening FIFO implementation, optimizing sterilization and heating processes, improving human resource competency and supervision, and developing a real-time quality control system. Although some recommendations require investment and operational design changes, the long-term benefits are considered to outweigh the potential losses resulting from high FFA.

Managerial Implications

The research results have direct implications for operational policies, quality control systems, human resource management, and business strategy at PT. TLDN (CAP). Operationally, a restructuring of the process flow with oil flow separation is necessary to maintain consistent FFA quality without reducing production capacity. From a quality control perspective, the Seven Tools approach can be implemented as a routine evaluation tool to encourage root-cause-based preventive control.

From a human resource perspective, improving operator competency and strengthening supervision are key to successful SOP implementation. Strategically, reducing FFA and increasing the proportion of premium CPO has the potential to increase selling prices, reduce the risk of quality claims, and strengthen the company's competitiveness. Therefore, the managerial implications of this research not only impact the technical aspects but also support the company's sustainability and profitability.

CONCLUSION

Pareto diagram analysis indicates that the increase in FFA in CPO at PT. TLDN is primarily driven by several key factors: mixing of oil streams with high FFA from condensate and liquor, delays in processing fresh fruit bunches that cause residue, and weak control of process parameters at critical points, particularly retention time and temperature settings. These factors contribute significantly to the increase in final product FFA, so improvement strategies are directed at controlling the primary sources of FFA formation.

Quantitative evaluation results indicate that implementing improvements through oil flow separation and strengthening process control significantly improved CPO quality. The existing FFA value of 3.58% was successfully reduced to a range of 2.5-2.69% in premium CPO products, a reduction of approximately 0.8-1%. In addition to lowering the average FFA content, these improvements also improved process stability and reduced product quality variation.

Economically, implementing this strategy allows for changes in product composition, with approximately 37.44% of CPO production being categorized as premium CPO and the remaining 62.56% as normal CPO. These findings confirm that increased profitability can be achieved through optimizing product quality without requiring increased production volume.

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