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Quality analysis of crude palm oil based on ffa, moisture, and impurity parameters in a 60 t/h palm oil mill

Maria Magdalena Sinaga[1], Chintia Agrefina Brilian[2], Warastra Nur Annisa[3]
[1,2,3] Department of Agricultural Technology, Study Program of Integrated Plantation Product Processing, Pontianak State Polytechnic, Pontianak City, West Kalimantan, Indonesia

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ABSTRACT

CPO is the main product of the palm oil industry, in the form of crude oil, and serves as a raw material for various food and non-food products. The quality of CPO is affected by several key factors, including free fatty acid (FFA) levels, moisture content, and impurity levels, which directly influence the product's stability, shelf life, and market value. This study employed a quantitative-descriptive approach to evaluate the quality of Crude Palm Oil (CPO) produced from the processing of fresh fruit bunches (FFB) at Company XYZ in Nunukan Regency, Indonesia. Data collection was conducted from January to June 2025.The analytical focus was on three main quality parameters: free fatty acids (FFA), moisture content, and impurity levels. To support the analysis, bar charts and a fishbone diagram were used as tools to identify and illustrate the causal factors that have the potential to affect CPO quality. The evaluation results showed variations in quality, affected by processing factors, the quality of fresh fruit bunches, and storage conditions. Although CPO quality standards have been established, many production mills still experience quality instability due to differences in harvesting practices, post-harvest handling, and processing conditions. The research showed that FFA values ranged from 4.21% to 5.07%. Moisture content ranged from 0.29% to 0.33%. Meanwhile, impurity levels ranged from 0.029% to 0.039%. Therefore, this study recommends strengthening supervision, improving operator training, enhancing equipment maintenance, and enforcing SOP implementation to improve and maintain the consistency of CPO quality.

Corresponding Author:

Maria Magdalena Sinaga
Department of Agricultural Technology, Study Program of Integrated Plantation Product Processing, Pontianak State Polytechnic
Jl. Jenderal Ahmad Yani, Bansir Laut, Kec. Pontianak Tenggara, Kota Pontianak, Kalimantan Barat 78124
Email: mariasinaga@polnep.ac.id

1. INTRODUCTION

Indonesia is known as the country that has the largest area of oil palm plantations in the world (Suandi, 2016). The palm oil processing industry plays a vital role in the global vegetable oil market, with Crude Palm Oil (CPO) serving as a primary edible oil and a key feedstock for biodiesel and oleochemical industries.

The production process involves transforming fresh fruit bunches (FFB) of oil palm (*Elaeis guineensis*) into crude oil through a series of mill operations including sterilization, threshing, digestion, pressing, clarification, and purification (García-Maza et al., 2025). The palm oil milling process consists of a series of interconnected unit operations designed to extract oil from fresh fruit bunches (FFB) and convert it into crude palm oil (CPO). Each step involves specific operational variables—often referred to as process parameters—which directly impact oil yield and quality. Understanding the influence of these parameters is crucial for identifying critical process drivers in mill performance. Several process parameters to identify critical factors affecting palm oil mill performance include (Yodpijit et al., 2025)

The quality of CPO is affected by many factors throughout the processing stages, from the reception and handling of fresh fruit bunches to sterilization, digestion, pressing, clarification, and storage.Thus, the application of appropriate harvesting practices is essential for ensuring efficient extraction and maintaining the quality of CPO. (Akbar et al., 2023). Inaccuracy at any of these stages can affect oil quality, particularly in key parameters such as free fatty acid (FFA) levels, moisture content, and impurity levels. The increase in FFA is affected by factors such as improper storage, contamination, and suboptimal machinery, showing how the rise in FFA affects the decline in CPO quality in a factory (Panjaitan et al., 2025). The results of the study by (Novelena & Komari, 2022) indicate that the presence of impurities can reduce the clarity and stability of the oil, increase the risk of oxidation, accelerate the formation of free fatty acids (FFA), and decrease the Deterioration of Bleachability Index (DOBI) value.

FFA levels indicate the occurrence of hydrolytic degradation, which can reduce the quality of the refined oil.(Lukito & Sudradjat, 2017); (Nanda et al., 2020); (Morcillo et al., 2013); (Sampaio et al., 2017);(Tan et al., 2023). A common issue in palm oil production is the failure to comply with predetermined quality standards. Such nonconformities may include elevated moisture content, excessive impurities, and increased levels of free fatty acids (Rahma Yuliati Kashi, 2019) Elevated moisture content in Crude Palm Oil (CPO) can adversely influence the stability and overall quality of the oil. Consequently, the acidity level of the oil increases, leading to a decline in product quality. Moreover, high moisture levels can facilitate microbial activity and enzymatic reactions that further degrade the oil during storage. The presence of water in CPO may also create complications in the refining process, shorten the storage life of the oil, and increase its susceptibility to oxidation and rancidity(Akbar et al., 2023). A high level of impurities in Crude Palm Oil (CPO) can negatively affect the oil's quality and stability. Contaminants such as fiber, sand, and other solid particles may accelerate oxidation processes and contribute to faster quality deterioration during storage. Furthermore, elevated impurity levels can disrupt refining operations and increase processing costs due to the need for additional purification steps. Therefore, effective control of impurity content is crucial to preserve the quality and commercial value of CPO (Jaya & Khairiah, 2025);(Jaya & Khairiah, 2025);(Sitorus et al., 2023)

The quality of Crude Palm Oil (CPO) continues to be a major concern in the palm oil industry, as it directly affects the efficiency of refining processes and the economic value of the final product. Although quality standards and control procedures have been implemented, many palm oil mills continue to experience variations in the quality of Crude Palm Oil (CPO). These fluctuations are often associated with differences in harvesting practices, handling of raw materials, and processing conditions during production. Such variations suggest that maintaining consistent CPO quality remains a persistent challenge in industrial palm oil processing (Darma Jaya, 2025). Previous research has examined various factors that influence the quality of Crude Palm Oil (CPO), such as fruit maturity level, delays in the processing of Fresh Fruit Bunches (FFB), and post-harvest handling practices. However, many of these studies have certain limitations, particularly the limited number of plant-specific investigations that evaluate how operational factors—such as equipment performance, operator practices, and processing methods—collectively affect CPO quality under actual production conditions. Although several studies have identified potential contributing factors, only a few have systematically assessed critical process parameters within a particular mill capacity or production setting.This study aimed to evaluate the quality of Crude Palm Oil (CPO) produced from the processing of fresh fruit bunches (FFB) at company XYZ in Nunukan Regency, with an analytical focus on free fatty acids (FFA), moisture content, and impurity content.

2. METHOD

2.1 Research Design

The research applied a quantitative-descriptive method to evaluate the quality of Crude Palm Oil (CPO) produced from the processing of Fresh Fruit Bunches (FFB) at XYZ Co., located in

Nunukan Regency, Indonesia. The assessment emphasized three principal quality indicators, namely Free Fatty Acid (FFA) levels, moisture content, and impurity levels. To support the analysis, bar charts and fishbone diagrams were used as analytical tools to illustrate data patterns and identify possible factors contributing to variations in CPO quality.

Primary information was obtained through direct observation of the CPO quality testing activities carried out at the processing facility of XYZ Co. Data collection was conducted over a six-month period, from January to June 2025. The qualitative data obtained were analyzed using a descriptive analytical approach. This analysis involved evaluating the values of Free Fatty Acid (FFA), moisture content, and impurity levels in CPO samples. The findings were subsequently presented using bar charts to facilitate comparison among the data, while fishbone diagrams were employed to identify and analyze potential root causes contributing to variations in CPO quality.

2.2 Analysis of CPO Quality Parameters:

2.2.1 Free Fatty Acid (FFA)

The determination of free fatty acid (FFA) levels in crude palm oil was carried out using an acid-base titration method. The samples were taken from the storage tank, and each analysis was performed in three repetitions (triplicate). A total of 5 grams of CPO was dissolved in a warm mixture of 95% ethanol and diethyl ether (1:1, v/v), and the mixture was then treated with the phenolphthalein indicator. The mixture was titrated using 0.1 N NaOH solution until a stable pink color appeared. The FFA level was calculated as a percentage of palmitic acid, based on the volume of NaOH used in the titration (AOCS., 1998);(Che Man et al., 1999);(Kristono et al., 2020)

2.2.2 Moisture Content

The moisture content of crude palm oil was measured using the oven-drying method. Approximately 5 grams of homogenized CPO sample was placed into an aluminum dish with a known weight, then heated at 105°C for 1.5 hours. After completion, the sample was cooled in a desiccator before being reweighed. The moisture content was determined as the difference in weight before and after drying, expressed as a percentage of the initial weight. Each analysis was conducted in triplicate or three repetitions. (MPOB, 2004); (Kristono et al., 2020);

2.2.3 Impurity Content

To determine the impurity content in CPO, 10 grams of warm oil was filtered through a previously weighed Whatman No. 42 filter paper. The remaining solid residue was then dried at 105°C, cooled in a desiccator, and reweighed. The percentage of impurities was calculated based on the weight of the residue relative to the initial weight of the sample. Each test was carried out in triplicate in three repetitions. (MPOB, 2004); (Kristono et al., 2020)

2.3 Fishbone Diagram Analysis

To deepen understanding of the main causes of CPO quality deviations at Company XYZ, a fishbone diagram (Ishikawa Diagram) was used as a systematic analytical tool. This diagram groups the factors that have potential effects on increases in FFA levels, moisture content, and impurities into four main aspects: human, material, machine, and method (Darma Jaya, 2025)

3. RESULTS AND DISCUSSION

3.1 Quality Parameters of Crude Palm Oil (CPO)

Table 1. Changes in FFA, Moisture and Impurity Levels by Observation Month

Month	FFA (%)	Moisture (%)	Impurity (%)
January	4.38	0.31	0.031
February	4.84	0.29	0.029
March	4.44	0.31	0.031
April	5.07	0.33	0.038
May	4.43	0.33	0.033
June	4.21	0.31	0.039

Based on the table, it can be seen that the highest FFA value occurred in April, at 5.07%, while the lowest value occurred in June, at 4.21%. The increase in FFA in April was likely influenced by several processing factors at the palm oil mill. One of the main factors contributing to the increase in FFA is the delay in processing Fresh Fruit Bunches (FFB) after harvest. This delay can trigger the activity of the lipase enzyme, which accelerates the hydrolysis of triglycerides into free fatty acids.

The data presented in the table indicate that the highest moisture content was recorded in April and May, reaching 0.33%, whereas the lowest value was observed in February at 0.29%. The comparatively elevated moisture levels in April and May is likely to be related to several operational conditions occurring during the oil clarification stage. One possible explanation is the less efficient removal of water from the oil throughout the clarification and purification processes. Furthermore, increased moisture content may also result from suboptimal performance of the vacuum dryer or inadequate heating during the drying stage.

The table shows that the highest impurity content was recorded in June at 0.039%, while the lowest level occurred in February at 0.029%. The rise in impurity levels may be associated with the effectiveness of the clarification and purification stages in removing solid particles from the oil. In general, impurities consist of insoluble substances such as fibers, sand, and other fine particles that are carried over during the oil extraction process.

Additionally, overripe fruit, suboptimal handling of raw materials during transportation, and inappropriate process parameters during the sterilization or clarification stages can also contribute to the increase in FFA levels. Moisture and impurity content also showed a relatively consistent trend following the increase in FFA, with the highest values in April. This suggests that the efficiency of the oil refining process (clarification) may not have been optimal during this period, resulting in increased moisture and impurity content in CPO.

3.2 Free Fatty Acid

Referring to the bar chart below, the lowest free fatty acid level was obtained in June at 4.21%. Meanwhile, the highest free fatty acid level was obtained in April at 5.07%. These results were still outside the company's standard limit, with the maximum allowable FFA level for CPO set at 3.5%. (Figure 1). The highest FFA value was recorded in April at 5.07%, suggesting that the hydrolysis reaction in crude palm oil was more pronounced during this month compared with the other observation periods. This increase in FFA content may be influenced by several factors related to the processing conditions.

One important factor is the delay in processing fresh fruit bunches (FFB). When harvested fruits are not immediately processed, lipase enzymes naturally present in the fruit start to hydrolyze triglycerides into free fatty acids. Consequently, a longer interval between harvesting and sterilization can result in a higher concentration of FFA in the produced oil.

Another contributing factor may be less effective sterilization conditions. The sterilization stage is designed to deactivate lipase enzymes and prevent further hydrolysis reactions. However, if the sterilization temperature, pressure, or duration is inadequate, enzyme activity may persist and continue converting triglycerides into free fatty acids.

These results are in line with findings from previous studies. (Akbar et al., 2023) reported that delays in processing fresh fruit bunches play a significant role in increasing FFA levels in crude palm oil. Likewise, (Lukito & Sudradjat, 2017) stated that improper raw material handling and inefficient sterilization processes can intensify hydrolysis reactions, thereby raising the FFA content. Other studies have also highlighted that processing time, fruit maturity, and mill operational conditions are critical factors affecting CPO quality, particularly the formation of free fatty acids.

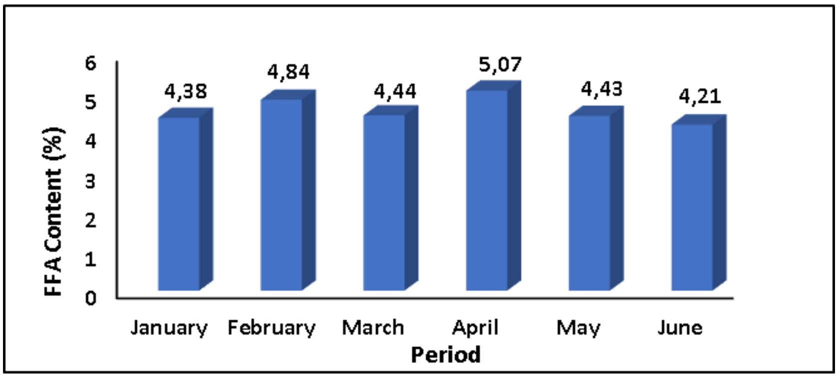

Figure 1. Free fatty acid result analysis

3.3 Moisture Content

Referring to the bar chart below, the lowest moisture content was obtained in February at 0.29%. Meanwhile, the highest moisture content was obtained in April and May at 0.33%. These results were still within the company's standard limit, with the maximum allowable moisture content for CPO set at 0.35%. (Figure 2). The results show that the highest moisture content occurred in April and May (0.33%), suggesting that the clarification and drying stages of the processing system may not have functioned optimally during this period. The moisture level in crude palm oil is influenced by several operational conditions within the palm oil mill.

One important factor affecting moisture content is the effectiveness of the clarification stage. During this process, oil must be separated from water and solid particles through settling and purification mechanisms. If the separation process is not performed efficiently, residual water can remain in the oil, leading to higher moisture levels in the final CPO product. Previous studies indicate that the moisture level in crude palm oil is closely associated with the efficiency of oil–water separation during clarification.

These results are in agreement with findings reported in earlier research. (Jaya & Khairiah, 2025) stated that poor performance in clarification and drying processes can contribute to increased moisture levels in crude palm oil. Likewise,(Lukito & Sudradjat, 2017) explained that inadequate control of separation and drying operations during processing may lead to elevated moisture content in CPO.

Several other studies have also emphasized that moisture levels in crude palm oil are largely affected by operational conditions in the mill, especially the efficiency of clarification and vacuum drying systems. Excessive moisture is undesirable because it can accelerate hydrolysis reactions and decrease the storage stability of crude palm oil.

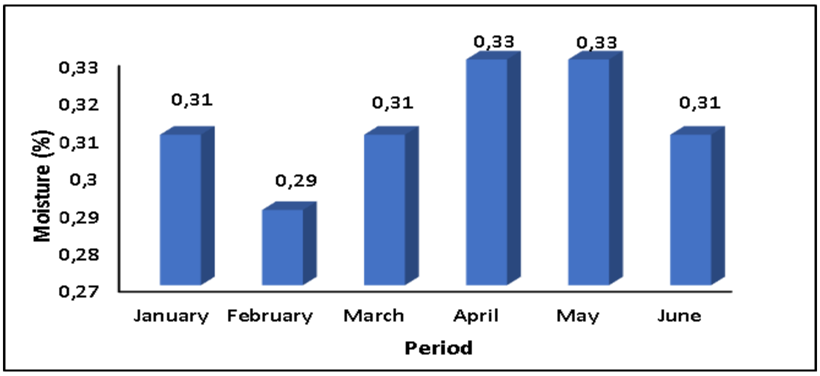

Figure 2. Moisture result analysis

3.4 Impurity Content

Referring to the bar chart below, the lowest impurity content was obtained in February at 0.029%, while the highest impurity content was obtained in June at 0.039%, where the impurity level remained at 0.035%, which was still outside the company's standard limit. (Figure 3) .

The highest impurity level occurred in June (0.039%), suggesting that the removal of solid particles from crude palm oil was less efficient during this period. Impurity content in CPO is generally affected by raw material quality and processing conditions in the palm oil mill.

One possible cause is ineffective clarification and purification, where solid residues such as fiber and shell fragments are not completely separated from the oil. In addition, the condition and handling of fresh fruit bunches (FFB) may also contribute to higher impurity levels, especially when the raw materials contain dirt or excessive fiber residues. Operational factors such as high production loads or suboptimal performance of separation equipment can further reduce the efficiency of particle removal.

These results are consistent with previous studies. (Hamid et al., 2023) reported that the performance of clarification and purification systems plays an important role in controlling impurity levels in crude palm oil. High impurity levels can reduce oil clarity, accelerate oxidation, and negatively affect the refining process.

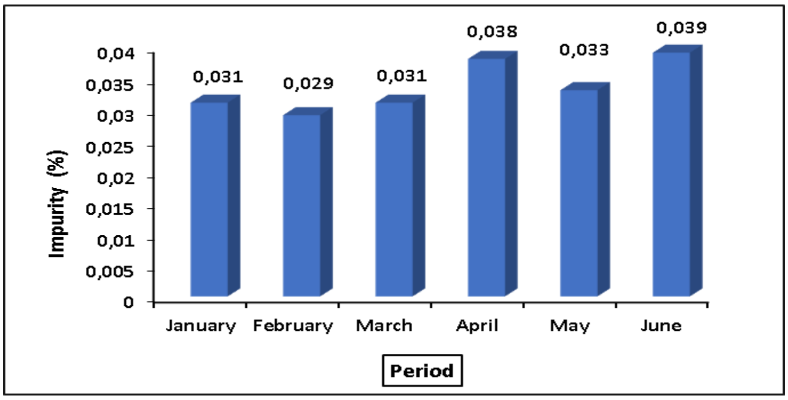

Figure 3. Impurity result analysis

3.5 Analysis of Quality Parameter Using The Fishhbone Diagram

3.5.1 Free Fatty Acid

The fishbone diagram, or Ishikawa diagram, was used to identify the causal factors of the increase in FFA levels in CPO at Company XYZ. Based on the interview results, four main groups of causal factors were identified: human factors, raw materials, machinery, environment, and methods. To address the issue of free fatty acid levels, the identification of contributing factors was carried out through several approaches, namely operator interviews, process observation, and analysis of production data.

Operator interviews are conducted to collect primary information from personnel directly involved in the production process. This method enables researchers to identify operational conditions that may contribute to the increase in Free Fatty Acid (FFA) levels, including delays in processing Fresh Fruit Bunches (FFB), improper sterilization procedures, and inadequate control of processing time. Furthermore, operators can provide valuable insights regarding operational constraints and recurring issues encountered during mill activities.

Process observation involves the direct assessment of operational activities throughout the production process in order to identify factors that may affect product quality. Through this method, several key aspects can be examined, including machine-related conditions, material characteristics, human performance, and the methods applied during processing.

The material factor includes FFB that is wet due to rain or improperly handled at the loading ramp, which introduces additional water into the extraction process. This condition increases the separation unit's workload and, if uncontrolled, results in oil with a higher moisture content. In addition, the longer the CPO with high moisture content is stored, the longer the hydrolysis process continues, leading to FFA levels that continue to increase over time.

This explains why oil processed from fresh fruit and produced with low moisture content has low FFA, whereas CPO with high moisture content experiences a faster decline in quality. The increase in FFA levels caused by high moisture content directly affects oil quality. The oil becomes more susceptible to oxidation, develops a rancid odor, darkens in color, and loses market value. In addition, during the refining stage, CPO with high FFA requires more energy for bleaching and deodorizing, thereby increasing production costs. (Sari et al., 2019)

The machine factor includes palm oil processing equipment such as the screw press, decanter, and purifier, which directly affect the separation of oil, water, and solids. Inefficiency or damage to the machines can cause water to fail to separate properly, leading to its being carried into the final CPO. The purifier also becomes a critical factor. If the purifier's rotation speed is not adjusted correctly or the heating system is not operating optimally, the water that should be separated will remain mixed with the oil. This condition is exacerbated if steam pipes leak or if excessive condensation enters the oil flow.

All of these conditions cause the moisture content in the CPO to exceed the standard of 0.2–0.5%. Due to machine factors that do not operate optimally, the oil quality decreases. High moisture content triggers the accelerated hydrolysis of triglycerides into free fatty acids (FFA), reduces storage stability, accelerates rancidity, and lowers the economic value of CPO. In addition, purification processes such as bleaching and deodorizing become more difficult and require higher energy to remove residual water. (Hairiyah & Ratus Sholikhah, 2023)

Meanwhile, the method factor includes, as one example, a clarification procedure that does not follow the standard. If the residence time in the clarification pit is too short, the oil does not have sufficient time to separate completely from water and sludge. The temperature in the clarification tank that is too low also inhibits water sedimentation, causing water to be carried into the oil. The handling method of FFB before processing also has a substantial effect. Storing FFB for too long or in open areas during rain can make the fruit wet, increasing the amount of moisture entering the extraction process. Moreover, pre-drying methods or improper temperature settings before pressing will add an additional water load to the system.(Kristono et al., 2020)

Production data, including monthly Free Fatty Acid (FFA) values, processing time records, sterilization temperatures, and equipment performance indicators, are analyzed to determine trends and recurring patterns. The analysis of these data can reveal potential relationships between processing conditions and oil quality. For instance, an increase in FFA levels during specific months may suggest issues associated with raw material quality, equipment efficiency, or the implementation of operational procedures.

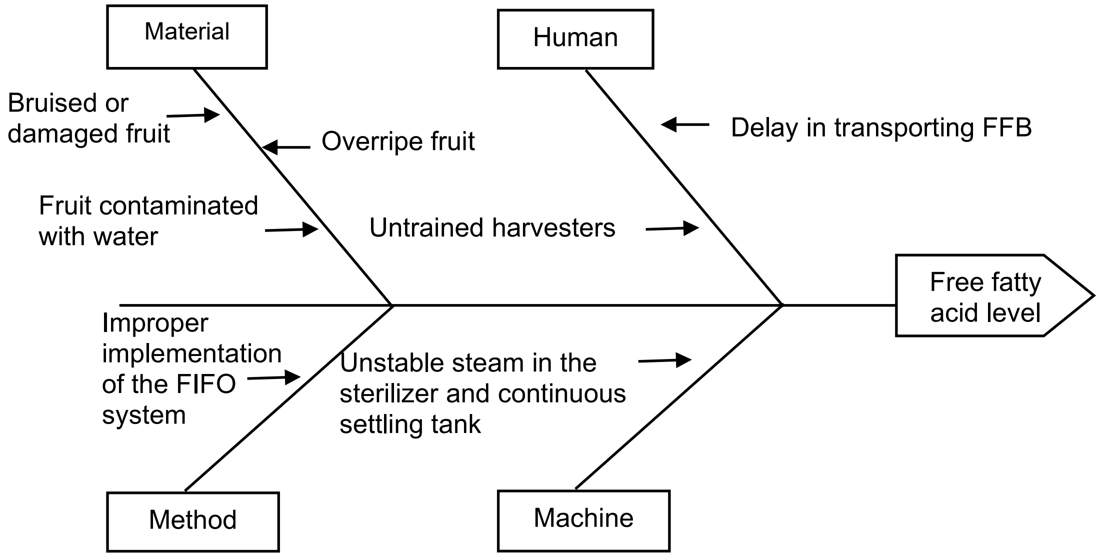

Figure 4. Fishbone Diagram of Free Fatty Acid Results

To address these issues, several corrective actions were proposed, namely (Nainggolan et al., 2025) : Human factor: Providing intensive training to operators regarding process control, decanter and purifier settings, as well as implementing strict SOPs for inspecting tank conditions, drainage, and routine sludge cleaning. Material factor: Selecting fresh FFB of good quality and avoiding the accumulation of fruit in open areas during rain, as well as accelerating the processing steps to reduce water absorption. Machine factor: Performing regular maintenance and calibration of the decanter, purifier, and screw press so that oil–water separation runs optimally, and ensuring that steam pipes, valves, and the condensate system are free from leaks so that water does not enter the oil line. Method factor: Establishing proper FFB handling methods, such as storing the fruit in a dry place and processing it immediately after harvesting to reduce moisture content, as well as establishing appropriate standard operating procedures, including the correct setting of residence time in the clarification pit and proper stirring.

3.5.2 Impurity Level

Figure 5 shows a cause-and-effect (fishbone) diagram illustrating the various causal factors contributing to increased impurity levels in CPO. To address the issue of impurity levels, the identification of contributing factors was carried out through several approaches, namely operator interviews, process observation, and analysis of production data. Operator interviews were carried out to collect information related to operational practices that may affect impurity levels in Crude Palm Oil (CPO). Through this approach, data concerning operator discipline, work experience, and the degree of compliance with established standard operating procedures during the processing stages were obtained.

Process observation involves the direct examination of production activities within the mill to identify operational conditions that may lead to impurity formation. This observation emphasizes several key aspects, including machine factors, such as the performance and cleanliness of processing equipment; material factors, including the condition and cleanliness of the Fresh Fruit Bunches (FFB) received; human factors related to operator handling during processing; and method factors, particularly the effectiveness of clarification, screening, and separation processes that influence the removal of solid impurities from Crude Palm Oil (CPO).

From the raw material aspect, Fresh Fruit Bunches (FFB) that are not handled properly, for example, being left to accumulate on wet ground or not being separated from stalks and branches, can carry solid particles into the extraction process. The method factor can be caused by sterilization and pressing processes that are not optimal, which also become contributing factors. If sterilization is not uniform, fibers and kernels do not separate completely, and low screw press pressure causes fibers to remain in the oil.

The machine factor also plays a role. Incorrect settings on the decanter and separator, such as improper bowl speed and flow rate, can reduce solid separation efficiency, leading to sludge being carried into the oil layer. Overload conditions in the machine further worsen this problem. In addition, the cleanliness of storage tanks and pipelines also affects impurity levels. Storage tanks or oil channels that are rarely cleaned allow solid residues to accumulate and mix with newly processed CPO.

One of the main causes is the lack of operator understanding of the procedures for handling Fresh Fruit Bunches (FFB). Operators who do not pay attention to the condition of the FFB, for example, by storing the fruit in open areas during rain or allowing wet fruit to accumulate for too long, will increase the likelihood of soil, fibers, and other particles being carried into the extraction process.

Human factor is the is the lack of understanding on the part of operators, who do not adjust or monitor the screw press, decanter, and purifier in accordance with standards can result in suboptimal solid separation. Errors in setting the bowl speed, feed rate, or flow rate cause sludge and fibers to be carried into the oil line. A lack of discipline in inspecting and cleaning storage tanks and pipelines also increases the risk of impurities entering newly processed CPO. A lack of monitoring of cleanliness and drainage procedures is also a significant human factor. Operators who do not conduct routine tank cleaning or inspect the drain valve allow solid residues from previous batches to mix with newly produced oil, thereby increasing impurity levels.

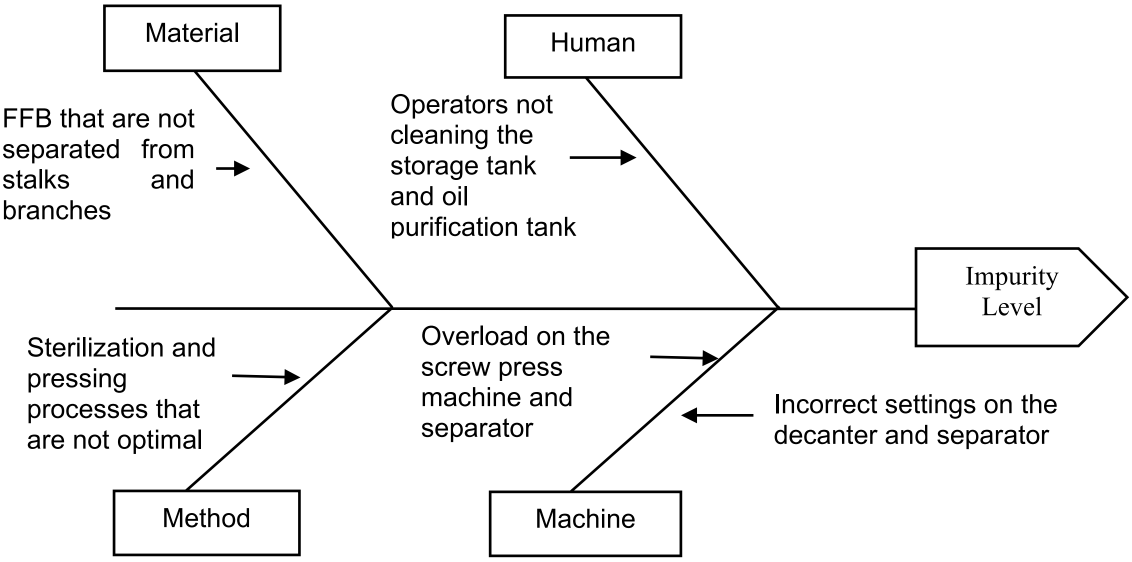

Figure 5. Fishbone Diagram of Impurity Level Test Results

The impurity level in Crude Palm Oil (CPO) is an important quality parameter that must be controlled. These impurities generally include fruit fibers, shell fragments, kernels, sludge, soil, and residual solids from the oil-separation process. The presence of impurities not only affects the physical properties of CPO, such as clarity, color, and odor, but also affects the oil's chemical quality, including an increase in free fatty acids (FFA).

Based on the results of the fishbone diagram analysis, the recommended improvement steps include: Human: Providing training related to process control, decanter and purifier settings, as well as monitoring temperature and flow rate. Discipline in following proper Fresh Fruit Bunch (FFB) handling procedures is also required to reduce the entry of water and solids. Material: Conduct sorting by removing stalks, branches, and damaged fruit so that the size and condition of the fruit become uniform, thereby facilitating solid separation, as well as sorting out damaged, rotten fruit, or fruit that contains a large amount of soil and fibers. Machine: Regular maintenance, equipment calibration, and inspection of the heating system and condensate system must be carried out so that the separation of oil, water, and solids is optimal. Worn or damaged equipment must be replaced to maintain process efficiency. Method: Establishing appropriate standard operating procedures, including the setting of residence time, clarification tank temperature, decanter/purifier flow rate, as well as routine cleaning of tanks and pipelines. Proper handling of FFB, such as storing the fruit in a dry place and processing it immediately after harvesting, also becomes an important step. Strengthening the implementation of SOPs through training and pre-production supervision (Frank et al., 2013);(Darma Jaya, 2025);(Sofiyanurriyanti et al., 2021);(Usman et al., 2025).

3.5.3 Moisture Content

Figure 6 shows a cause-and-effect (fishbone) diagram illustrating the various causal factors contributing to increased moisture levels in CPO. To address the issue of impurity levels, the identification of contributing factors was carried out through several approaches, namely operator interviews, process observation, and analysis of production data. Operator interviews were carried out to collect firsthand information from mill personnel regarding operational activities that may affect moisture levels in Crude Palm Oil (CPO). Through these discussions, researchers obtained insights into routine operational practices, monitoring of processing parameters, and the handling of equipment used during the clarification and drying stages. This approach enables the identification of potential human-related issues, such as inadequate supervision of the water separation process, delayed operational responses, or inconsistencies in adhering to established procedures that may lead to increased moisture content in the final product.

Process observation involves the direct assessment of mill operations to identify operational conditions that may lead to increased moisture content in the product. The observation emphasizes several important aspects, including machine factors, such as the performance and operational condition of clarification tanks, vacuum dryers, and other related equipment; material factors, including the quality and ripeness of Fresh Fruit Bunches (FFB); human factors associated with operator practices during processing; and method factors, particularly the effectiveness of clarification, separation, and drying procedures applied to reduce the water content in Crude Palm Oil (CPO).

Human factors that affect moisture content include the operator's lack of understanding of operational standards, particularly related to settings on the decanter or purifier, such as improper bowl speed and flow rate adjustments, which further worsen the oil purification process. As a result of these incorrect settings, water and sludge that should be separated are instead carried into the oil. This condition significantly reduces separation efficiency, resulting in increased moisture content in the CPO. Another cause originates from the lack of inspection of the drainage and condensate system. When operators do not routinely drain steam pipes, tanks, or the clarification pit, the condensate that should be discharged instead accumulates and enters the oil system. As a result, water increases the oil flow and causes the CPO to exceed the specified moisture content limit.

The material factor includes FFB that is wet due to rain or improperly handled at the loading ramp, which introduces additional water into the extraction process. This condition increases the separation unit's workload and, if uncontrolled, results in oil with a higher moisture content. In addition, the longer the CPO with high moisture content is stored, the longer the hydrolysis process continues, leading to FFA levels that continue to increase over time. This explains why oil processed from fresh fruit and produced with low moisture content has low FFA, whereas CPO with high moisture content experiences a faster decline in quality. The increase in FFA levels caused by high moisture content directly affects oil quality. The oil becomes more susceptible to oxidation, develops a rancid odor, darkens in color, and loses market value. In addition, during the refining stage, CPO with high FFA requires more energy for bleaching and deodorizing, thereby increasing production costs. (Sari et al., 2019).

The machine factor includes palm oil processing equipment such as the screw press, decanter, and purifier, which directly affect the separation of oil, water, and solids. Inefficiency or damage to the machines can cause water to fail to separate properly, leading to its being carried into the final CPO. The purifier also becomes a critical factor. If the purifier's rotation speed is not adjusted correctly or the heating system is not operating optimally, the water that should be separated will remain mixed with the oil. This condition is exacerbated if steam pipes leak or if excessive condensation enters the oil flow. All of these conditions cause the moisture content in the CPO to exceed the standard of 0.2–0.5%. Due to machine factors that do not operate optimally, the oil quality decreases. High moisture content triggers the accelerated hydrolysis of triglycerides into free fatty acids (FFA), reduces storage stability, accelerates rancidity, and lowers the economic value of CPO. In addition, purification processes such as bleaching and deodorizing become more difficult and require higher energy to remove residual water. (Hairiyah & Ratus Sholikhah, 2023).

Meanwhile, the method factor includes, as one example, a clarification procedure that does not follow the standard. If the residence time in the clarification pit is too short, the oil does not have sufficient time to separate completely from water and sludge. The temperature in the clarification tank that is too low also inhibits water sedimentation, causing water to be carried into the oil. The handling method of FFB before processing also has a substantial effect. Storing FFB for too long or in open areas during rain can make the fruit wet, increasing the amount of moisture entering the extraction process. Moreover, pre-drying methods or improper temperature settings before pressing will add an additional water load to the system (Kristono et al., 2020).

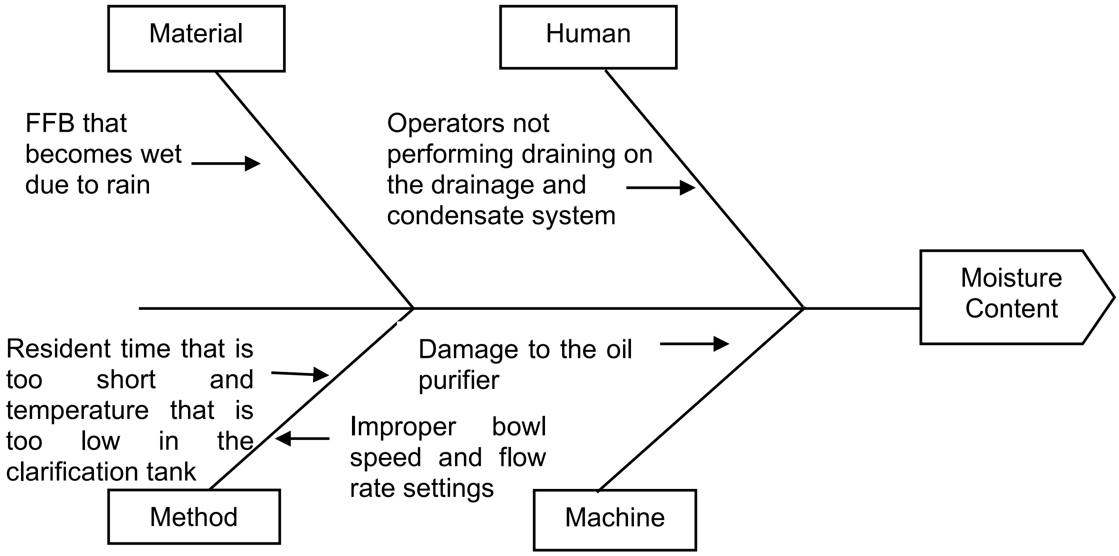

Figure 6. Fishbone Diagram of Moisture Results

To address these issues, several corrective actions were proposed, namely (Nainggolan et al., 2025) : Human factor: Providing intensive training to operators regarding process control, decanter and purifier settings, as well as implementing strict SOPs for inspecting tank conditions, drainage, and routine sludge cleaning. Material factor: Selecting fresh FFB of good quality and avoiding the accumulation of fruit in open areas during rain, as well as accelerating the processing steps to reduce water absorption. Machine factor: Performing regular maintenance and calibration of the decanter, purifier, and screw press so that oil–water separation runs optimally, and ensuring that steam pipes, valves, and the condensate system are free from leaks so that water does not enter the oil line. Method factor: Establishing proper FFB handling methods, such as storing the fruit in a dry place and processing it immediately after harvesting to reduce moisture content, as well as establishing appropriate standard operating procedures, including the correct setting of residence time in the clarification pit and proper stirring.

4. CONCLUSION

This study evaluated the quality of Crude Palm Oil (CPO) produced in a 60 t/h palm oil mill using three main parameters: Free Fatty Acid (FFA), moisture content, and impurity levels. The results show that CPO quality fluctuated throughout the observation period, with several samples exceeding the established quality standards. The FFA values ranged from approximately 4.21% to 5.07%, while the moisture content varied between 0.29% and 0.33%. Meanwhile, impurity levels were recorded in the range of about 0.029% to 0.039%. These variations suggest that the quality of CPO was not consistently maintained within the recommended standard limits. Further analysis revealed several key factors contributing to the increase in these quality parameters. Human factors were associated with operator performance and the effectiveness of monitoring practices during the processing stages. Machine factors were related to equipment efficiency and maintenance conditions, particularly within the sterilization and clarification systems. Material factors were influenced by the condition and freshness of Fresh Fruit Bunches (FFB), especially delays occurring between harvesting and processing. Additionally, method factors were linked to operational procedures, including sterilization duration, clarification performance, and overall process control. Overall, the findings indicate that improvements in operator supervision, regular equipment maintenance, proper management of raw material freshness, and optimization of processing procedures are crucial to ensure that CPO quality consistently meets the required standards.The primary quality parameters of Crude Palm Oil (CPO) typically include Free Fatty Acid (FFA) content, moisture level, and impurity content. Based on the results of the analysis of the quality of Crude Palm Oil (CPO) produced at PT XYZ, it can be concluded that the quality parameters observed include Free Fatty Acid (FFA), moisture content, and impurity content. The test results show that the quality of CPO produced generally does not meet the quality standards set by PT XYZ, namely FFA ≤3.5%, moisture ≤0.35%, and impurity ≤ 0.05%.

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REFERENCES

Akbar, A. R. M., Wibowo, A. D., & Santoso, R. (2023). Investigation on the Optimal Harvesting Time of Oil Palm Fruit. *Jurnal Teknik Pertanian Lampung (Journal of Agricultural Engineering)*, *12*(2), 524. https://doi.org/10.23960/jtep-l.v12i2.524-532

AOCS. (1998). *AOCS Ca 5a-40 Free Fatty Acids in Crude and Refined Fats and Oils. AOCS Publication.*

Che Man, Y. B., Moh, M. H., & Voort, F. R. Van de. (1999). Determination of free fatty acids in crude palm oil and refined-bleached-deodorized palm olein using fourier transform infrared spectroscopy. *JAOCS*, *76*(4), 486–492.

Darma Jaya, J. (2025). Quality Evaluation and Causal Analysis of Crude Palm Oil Based on Critical Quality Parameters: Free Fatty Acids, Moisture, and Impurities. *Jurnal Teknologi Agro-Industri*, *12*(1), 20–30.

Frank, N.-E. G., Albert, M.-M. E., & Astride, E. M. (2013). Some quality parameters of crude palm oil from major markets of Douala, Cameroon. *African Journal of Food Science*, *7*(12), 473–478. https://doi.org/10.5897/ajfs2013.1014

García-Maza, S., Rojas-Flores, S., & González-Delgado, Á. D. (2025). Technical Insights into Crude Palm Oil (CPO) Production Through Water–Energy–Product (WEP) Analysis. *Sustainability (Switzerland)*, *17*(10), 1–12. https://doi.org/10.3390/su17104485

Hairiyah, N., & Ratus Sholikhah, M. ’. (2023). Perbaikan kualitas kadar air dan kadar kotoran crude palm oil (CPO) pada mesin purifier menggunakan Kaizen di PT. ACL. *Agrointek*, *17*(2), 458–465. https://doi.org/10.21107/agrointek.v17i2.13165

Hamid, A., Saragih, R., & Syahputra, S. (2023). Measuring the Maturity Level of Oil Palm Fruit For CPO Production Based on Color With Using the LVQ Method. *Journal of Artificial Intelligence and Engineering Applications (JAIEA)*, *3*(1), 255–261. https://doi.org/10.59934/jaiea.v3i1.303

Jaya, J. D., & Khairiah. (2025). Quality Evaluation and Causal Analysis of Crude Palm Oil Based on Critical Quality Parameters: Free Fatty Acids, Moisture, and Impurities. *Jurnal Teknologi Agro-Industri*, *12*(1), 20–30. https://doi.org/10.34128/jtai.v12i1.227

Kristono, S. N., Rahardja, I. B., & Darmawan, A. (2020). The Effect of Oil Thickness in the Cylindrical Settling Tank on the Moisture and Impurities of Crude Palm Oil (CPO). *Journal of Applied Science and Advanced Technology Journal Homepage*, *3*(1), 21–29. https://doi.org/10.24853/JASAT.3.1.21-28

Lukito, P. A., & Sudradjat. (2017). Pengaruh Kerusakan Buah Kelapa Sawit terhadap Kandungan Free Fatty Acid dan Rendemen CPO di Kebun Talisayan 1 Berau. *Akuntansi, 11(1)*, 37–44.

Morcillo, F., Cros, D., Billotte, N., Ngando-Ebongue, G. F., Domonhédo, H., Pizot, M., Cuéllar, T., Espéout, S., Dhouib, R., Bourgis, F., Claverol, S., Tranbarger, T. J., Nouy, B., & Arondel, V. (2013). Improving palm oil quality through identification and mapping of the lipase gene causing oil deterioration. *Nature Communications*, *4*, 1–8. https://doi.org/10.1038/ncomms3160

MPOB. (2004). *Determination of moisture and volatile matter content: MPOB Test Methods of Sampling and Chemical Analysis of Palm Oil Products. Bangi: Malaysian Palm Oil Board.* (p. MPOB p2.1).

Nainggolan, M., Sofitra, M., & Budiman, R. (2025). PENGENDALIANKUALITAS CRUDE PALM OIL (CPO) DI PKS PARINDU PT PERKEBUNAN NUSANTARA IV REGIONAL V. *INTEGRATE: Industrial Engineering and Management System*, *9*(2), 167–181. https://jurnal.untan.ac.id/index.php/jtinUNTAN/issue/view/2642

Nanda, D., Kansci, G., Rafflegeau, S., Bourlieu, C., Ngando Ebongue, G., & Genot, C. (2020). Impact of post-harvest storage and freezing of palm fruits on the extraction yield and quality of African crude palm oil extracted in the laboratory. *OCL - Oilseeds and Fats, Crops and Lipids*, *27*(4). https://doi.org/10.1051/ocl/2020046

Novelena, T. A., & Komari, N. (2022). Analisis Hubungan Antar Parameter Kualitas Crude Palm Oil di PT. Laguna Mandiri Rantau Factory. *Jurnal Natural Scientiae*, *2*(1), 32–40. https://doi.org/10.20527/jns.v2i1.4864

Panjaitan, N., Faris, M. Z., Lubis, J. A., & Silitonga, N. K. (2025). Quality Analysis of Crude Palm Oil Using Free Fatty Acid Content Parameters with Failure Mode and Effect Analysis †. *Engineering Proceedings*, *84*(1). https://doi.org/10.3390/engproc2025084098

Rahma Yuliati Kashi, D. (2019). Pengendalian Kualitas Crude Palm Oil (CPO) Dengan Diagram Kontrol Multivariat Exponatially Weighted Moving Avarage (MEWMA). *PRISMA, Prosiding Seminar Nasional*, *2*, 848–853. https://journal.unnes.ac.id/sju/index.php/prisma/article/view/29278

Sampaio, K. A., Ayala, J. V., Van Hoed, V., Monteiro, S., Ceriani, R., Verhé, R., & Meirelles, A. J. A. (2017). Impact of Crude Oil Quality on the Refining Conditions and Composition of Nutraceuticals in Refined Palm Oil. *Journal of Food Science*, *82*(8), 1842–1850. https://doi.org/10.1111/1750-3841.13805

Sari, M., Ritonga, Y., & Saragih, S. W. (2019). Pengaruh Kadar Air Pada Proses Pemucatan Minyak Kelapa Sawit. *Talenta Conference Series: Science and Technology (ST)*, *2*(1), 79–83. https://doi.org/10.32734/st.v2i1.317

Sitorus, J. A., Prasetya, A., Nur’aini, H., & Azhari, D. (2023). Analisis Konsistensi Rendemen dan Mutu CPO (Crude Palm Oil) pada Pengolahan Kelapa Sawit di PT. Agricinal Bengkulu Utara. *Agritepa*, *10*(2), 441–

454.

Sofiyanurriyanti, Putra, G., & Arifin, A. R. (2021). Quality control of palm oil crude (CPO) using six sigma method in PT Karya Tanah Subur West Aceh regency. *IOP Conference Series: Materials Science and Engineering*, *1072*(1), 012052. https://doi.org/10.1088/1757-899x/1072/1/012052

Tan, B. A., Nair, A., Zakaria, M. I. S., Low, J. Y. S., Kua, S. F., Koo, K. L., Wong, Y. C., Neoh, B. K., Lim, C. M., & Appleton, D. R. (2023). Free Fatty Acid Formation Points in Palm Oil Processing and the Impact on Oil Quality. *Agriculture (Switzerland)*, *13*(5), 1–12. https://doi.org/10.3390/agriculture13050957

Usman, M., Julianti, E., & Elisabeth, J. (2025). IMPROVEMENT OF CPO QUALITY USING PHYSICAL PURIFICATION MATERIAL OF SHELL POWDER FOR RED COOKING OIL PRODUCTION. *BIOLINK (Jurnal Biologi Lingkungan Industri Kesehatan)*, *11*(2), 197–208. https://doi.org/10.31289/biolink.v11i2.13913

Yodpijit, S. N., Wangrakdiskul, S., Charoensuk, N., Phromphat, K., & Boonmee, C. (2025). JURIT Jurnal Riset Ilmu Teknik Sustainable Quality Transformation In Agro-Industrial Manufacturing: A Six Sigma-Kaizen Model For Thailand’s Crude Palm Oil Sector. *JURIT : Jurnal Riset Ilmu Teknik*, *3*(2), 125–140. https://doi.org/10.59976/jurit.v1i1.195