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Article

Association Between Screw-Press Operating Pressure And Oil Loss In Press Fibre At PTPN IV Kebun Mayang Palm Oil Mill

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A B S T R A C T

Screw-press operation is a major determinant of oil recovery at the pressing station of a palm oil mill, but field comparisons may be distorted when pressure levels are observed on different machines. This study re-examined the relationship between operating pressure and residual oil in press fibre at PTPN IV Kebun Mayang using an observational dataset comprising 15 once-daily measurements from three screw presses over five recorded sampling dates in 2025. Operating pressure was recorded at the time of sampling, and press-fibre oil, moisture, and non-oil solids were measured on a wet basis using a FOSS NIRS DA1650 instrument with the installed mill calibration. Mean pressure and oil loss were 40.4 ± 1.82 bar and 3.756 ± 0.804% for Machine 1, 45.0 ± 4.00 bar and 3.404 ± 0.476% for Machine 2, and 50.0 ± 1.58 bar and 3.176 ± 0.423% for Machine 3. An unadjusted linear regression indicated a decrease of 0.088 percentage points in oil loss per 1-bar increase in observed pressure (95% CI: −0.142 to −0.034; $p = 0.004$). After adjustment for machine and sampling date, the estimated pressure coefficient was smaller and statistically uncertain (−0.039 percentage points per bar; 95% CI: −0.164 to 0.086; $p = 0.485$). The data therefore suggest an inverse descriptive relationship between pressure and oil loss, but they do not establish a causal pressure effect or identify an optimum pressure because pressure was confounded with machine identity and kernel damage, oil impurities, energy consumption, throughput, and equipment wear were not quantified.

1. Introduction

Mechanical pressing is the principal solid–liquid separation step in conventional crude palm oil production. Digested fruit mash is compressed in a screw press to release crude oil while producing a press cake composed mainly of mesocarp fibre and nuts. The performance of this operation affects oil recovery, downstream clarification load, kernel recovery, and the mechanical condition of the press. Comparative studies have shown that screw-press systems can provide high throughput and extraction efficiency, while industrial surveys have also identified wear, corrosion, handling, and irregular maintenance as recurring sources of performance variation (Owolarafe et al., 2002; Harun et al., 2015).

Pressure is an operational variable of particular interest because insufficient compression leaves recoverable oil in the fibre, whereas excessive compression may increase nut or kernel breakage and accelerate wear of the screw and press cage. Previous field and experimental reports generally indicate an inverse relationship between press pressure and residual oil, but they also show that the apparent relationship depends on fruit condition, digestion, throughput, screw geometry, cone setting, and machine condition (Baryeh, 2001; Kurniawan, 2022; Tarigan et al., 2025). Consequently, a pressure value cannot be classified as optimal from oil loss alone. A defensible optimum requires simultaneous measurement of oil recovery, broken nuts or kernels, impurities, energy use, production capacity, and equipment reliability.

The original study at PTPN IV Kebun Mayang compared three screw presses that operated at different average pressures. Because each pressure profile was linked to a different machine, machine identity and pressure were partly confounded. The present revision therefore treats the dataset as an exploratory observational study rather than a controlled pressure experiment. The objectives were to (1) describe the observed pressure and press-fibre composition for each machine, (2) examine the association between actual pressure and wet-basis oil loss, and (3) determine whether the available evidence is sufficient to identify an optimum operating pressure. The working hypothesis was that higher observed pressure would be associated with lower oil loss, while recognizing that machine and date effects could attenuate or explain this association.

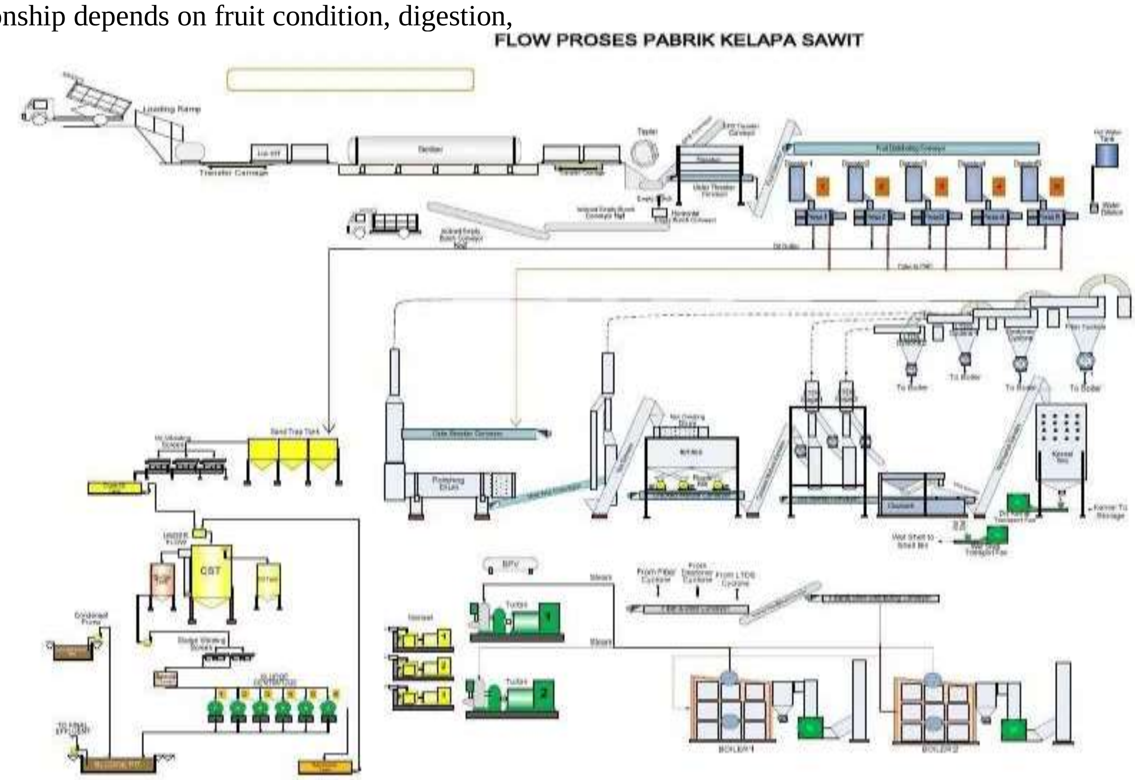

Figure 1. Palm oil milling process flow used to contextualize the pressing station.

2. Literature Review

The screw-press stage should be understood as an integrated separation system rather than as a single-pressure operation. In conventional palm oil milling, digestion prepares the sterilized fruit mash for mechanical expression, after which the press separates crude oil from a fibre–nut cake. The performance of this stage influences not only residual oil in fibre but also clarification load, kernel recovery, press throughput, and equipment condition (Poku, 2002; Owolarafe et al., 2002; Mba et al., 2015). The literature therefore supports evaluating pressure within a wider set of material, process, and machine variables.

2.1. Screw-Press Operation and Oil-Loss Mechanisms

Oil expression occurs when mechanical compression disrupts the digested mesocarp structure and forces the released liquid phase through the perforated press cage. The resulting separation depends on the resistance of the fibre matrix, the drainage area of the cage, the residence time of the material within the press, and the continuously changing solids content along the screw. Comparative work on palm-fruit processing has shown that screw-press performance is linked to both extraction efficiency and processing capacity, confirming that pressure cannot be interpreted independently of the mechanical configuration of the press (Owolarafe et al., 2002).

Residual oil in press fibre is widely used as an operational loss indicator because it represents oil that remains in the solid discharge after pressing. Its interpretation, however, requires a clearly stated analytical basis. Choo et al. (1996) reported recoverable residual oil from palm-pressed fibre on a dry-matter basis, whereas routine mill measurements may be expressed on a wet basis. These values are not directly interchangeable because moisture changes the denominator used to calculate the reported percentage. A scientifically reproducible assessment must therefore specify whether oil loss is reported relative to wet sample mass, dry solids, or another defined process basis.

Pressure generally increases the driving force for liquid removal, but its operational effect is not necessarily linear or universally beneficial. Lower pressure may leave more oil entrained in fibre, while excessive compression may increase nut breakage, kernel damage, solids carryover, and wear of the screw or press cage. Studies examining palm oil processing parameters and industrial press performance have reported that oil yield or residual loss varies with pressure, yet the observed response also reflects fruit condition, equipment design, maintenance status, and operating practice (Baryeh, 2001; Harun et al., 2015; Kurniawan, 2022; Tarigan et al., 2025). Consequently, the lowest measured fibre oil loss does not by itself establish the most advantageous plant operating point.

2.2. Interaction of Pressure with Process and Machine Parameters

Evidence from mechanical oil expression shows that pressure operates together with other machine variables rather than as an isolated determinant. In a factorial study of palm-kernel oil expression, Akinoso et al. (2009) evaluated compressive stress, feed rate, and screw rotational speed simultaneously and found that compressive stress significantly affected oil yield, while feed rate and rotational speed still had to be selected appropriately for efficient operation. Although palm-kernel expression differs from mesocarp pressing, the study demonstrates why comparisons of industrial presses should report throughput and screw speed together with pressure.

Press geometry can further modify the apparent response to pressure. Owolarafe et al. (2007) showed that crude palm oil yield and volumetric flow were influenced not only by expression pressure but also by press-cage diameter and wall-pore diameter. This finding is directly relevant to comparisons among different machines because variation in cage geometry, drainage area, screw wear, or component condition may generate performance differences that could otherwise be attributed incorrectly to operating pressure.

Conditions upstream of pressing also affect both oil recovery and product quality. In controlled hydraulic-expression experiments, Owolarafe et al. (2008) reported that sterilization time, digestion time, and expression pressure jointly influenced oil yield, while some combinations of longer digestion and higher pressure increased solid impurities. These findings indicate that press performance partly reflects the preparation of the fruit mash before it enters the press. Fruit maturity, sterilization effectiveness, digester temperature, residence time, and feed uniformity should therefore be controlled or documented in studies that compare pressure conditions.

The physical coexistence of mesocarp fibre and nuts in the digested mash creates a further engineering trade-off. Wondi et al. (2024) developed and tested a kernel-free digestion process and evaluated separation performance together with kernel disintegration. Their approach illustrates that an improvement in oil recovery should be assessed alongside preservation of nuts and kernels. For industrial screw-press optimization, broken-nut percentage, broken-kernel percentage, kernel loss, and press-cake characteristics are therefore necessary response variables rather than optional observations.

2.3. Near-Infrared Spectroscopy for Press-Fibre Analysis

Near-infrared spectroscopy (NIRS) is used for rapid, non-destructive or minimally destructive estimation of oil and moisture in palm-derived materials. Its analytical validity depends on the representativeness of the calibration samples, the accuracy of the reference method, spectral pretreatment, sample presentation, and independent validation of the prediction model (Agelet & Hurburgh, 2010). Accordingly, a numerical output from an installed mill calibration should be treated as an analytical estimate whose uncertainty depends on the documented performance of that calibration.

Applications of NIRS to oil-palm fruits, mesocarp, and kernels have shown that the technique can provide rapid compositional information when the calibration is developed against appropriate laboratory measurements (Silalahi et al., 2016; Sudarno et al., 2017; Novianty et al., 2023). For press-fibre monitoring, reliable reporting should identify the instrument model, sample preparation procedure, number of scans or analytical replicates, calibration range, reference extraction method, prediction error, bias, and the basis on which oil, moisture, and non-oil solids are calculated. Without these details, NIRS remains useful for operational screening but provides limited traceability for comparison across machines, mills, or studies.

2.4. Research Gap and Positioning of the Present Study

The reviewed literature establishes that pressure can influence mechanical oil expression, but it also demonstrates that pressure effects are conditional on feed properties, digestion, throughput, screw speed, press geometry, machine wear, and analytical method. Many field studies report average pressure and oil-loss values without experimentally varying pressure within the same machine or measuring the broader performance trade-offs required for optimization. This design limitation makes it difficult to determine whether differences are caused by pressure itself or by persistent differences among machines and operating periods.

The present study addresses this gap cautiously by treating the PTPN IV Kebun Mayang records as observational evidence. Rather than asserting a universally optimal pressure, it examines the descriptive association between recorded pressure and wet-basis oil loss, evaluates how the relationship changes after accounting for machine and sampling date, and identifies the additional measurements required for a controlled optimization study. This positioning aligns the research claim with the strength of the available data while preserving the practical value of the mill observations.

3. Methodology

3.1. Study Site and Research Design

The study was conducted at the pressing station of PTPN IV Kebun Mayang, North Sumatra, Indonesia. The mill was reported to operate at a nominal processing capacity of 30 t fresh fruit bunches h^{-1}. The dataset represents an observational field study of three operating screw presses. Pressure was not randomized or experimentally imposed on the same machine; instead, the actual operating pressure of each machine was recorded once daily when a press-fibre sample was collected. Five observations were obtained from each machine, giving 15 machine-date observations. Four records per machine were dated 7, 8, 9, and 12 August 2025, whereas the fifth was entered as 13 May 2025. Because the same anomalous date appeared in the August sequence for all three machines, it was provisionally harmonized to 13 August 2025 for the present reanalysis; the authors must verify this date against the raw operating log before resubmission.

3.2. Process Context and Sampling Point

At the study site, sterilized fruitlets were conveyed to the digester, where the mesocarp was mechanically disrupted under heated conditions before entering the double-screw pressing stage. Crude oil flowed through the press cage to the oil gutter, while the fibre–nut press cake was discharged to the cake breaker conveyor. Samples were taken from the press-fibre stream after discharge from each screw press. The original study documentation did not provide the screw-press manufacturer, model, screw speed, cone setting, wear condition, sensor accuracy, sample mass, within-day sampling interval, fruit maturity distribution, throughput at the sampling moment, dilution-water rate, or digester residence time. These unrecorded variables were therefore not treated as controlled factors

Figure 2. Equipment and process context at the study site: (a) press station, (b) top cross conveyor, (c) digester, (d) screw-press components, (e) screw press, (f) cake breaker conveyor, and (g) oil gutter.

3.3. Press-Fibre Preparation and NIRS Measurement

Press-fibre samples were collected separately from the three machines and manually sorted to remove visibly dissimilar coarse components before instrumental analysis. The available laboratory photographs show a FOSS NIRS DA1650 analyser and the installed product routine labelled “Ampas Press 1.” The instrument reported oil on wet material (O/WM), volatile matter or moisture (VM), and non-oil solids (NOS), each as a percentage of the wet sample. For every observation, the three reported components summed to approximately 100%, confirming that the values represent a wet-basis compositional measurement. Oil loss was therefore defined as the percentage mass fraction of oil retained in the wet press-fibre sample.

The original records did not include the number of replicate scans, spectral preprocessing, reference extraction method, calibration-set size, coefficient of determination, root-mean-square calibration or prediction error, bias, or repeatability. The measurements are consequently interpreted as routine mill laboratory outputs from the existing calibration rather than as an independently validated analytical method developed within this study.

(a) Press-fibre samples collected from the three machines

(b) Sorted and prepared press-fibre sample

Figure 3. Press-fibre sampling and preparation: (a) samples collected from the screw presses and (b) sorted sample prior to instrumental analysis.

Figure 4. FOSS NIRS DA1650 instrument used for routine measurement of oil, moisture, and non-oil solids in press fibre.

3.4. Statistical Analysis

Actual pressure observations were analysed as a continuous predictor. Descriptive statistics are reported as mean ± standard deviation (SD), together with the observed ranges. The primary response was wet-basis oil loss. First, an unadjusted ordinary least-squares model was fitted as Oil loss = $\beta 0 + \beta 1(\text{Pressure}) + \varepsilon$. Second, an adjusted exploratory model included fixed effects for machine and sampling date: Oil loss = $\beta 0 + \beta 1(\text{Pressure}) + \text{Machine} + \text{Date} + \varepsilon$. The second model was used to test whether the pressure coefficient remained distinguishable from machine- and date-associated variation. Because pressure profiles differed systematically among machines and the sample size was small, the adjusted coefficient was interpreted cautiously rather than as a causal effect.

Residual normality was assessed using the Shapiro–Wilk test, and heteroscedasticity was assessed using the Breusch–Pagan test. Regression coefficients are reported with 95% confidence intervals (CI), exact p-values, and R^2. Moisture and NOS were summarized descriptively because oil, moisture, and NOS form a closed composition that sums to approximately 100%; analysing these components as independent outcomes without a compositional-data framework would be inappropriate. Statistical calculations were performed from the raw values reproduced in Table 1.

4. Results and Discussion

4.1. Raw Observations

Across all 15 observations, screw-press pressure ranged from 38 to 52 bar, oil loss from 2.65 to 4.50% wet basis, moisture from 39.55 to 57.38%, and NOS from 39.74 to 56.46%. The harmonized dataset used for reanalysis is presented in Table 1.

Table 1. Observed screw-press pressure and press-fibre composition.

Machine	Date	Pressure (bar)	Oil loss (% wet basis)	Moisture, VM (%)	NOS (%)
Machine 1	2025-08-07	39	4.50	45.88	49.62
Machine 1	2025-08-08	42	2.65	52.56	44.79
Machine 1	2025-08-09	41	3.18	53.81	43.01
Machine 1	2025-08-12	38	4.36	44.39	51.25
Machine 1	2025-08-13	42	4.09	40.63	55.28
Machine 2	2025-08-07	46	3.49	50.31	46.20
Machine 2	2025-08-08	50	2.81	52.94	44.25
Machine 2	2025-08-09	47	3.05	55.84	41.11
Machine 2	2025-08-12	42	3.68	51.58	44.74
Machine 2	2025-08-13	40	3.99	39.55	56.46
Machine 3	2025-08-07	49	3.54	52.06	44.40
Machine 3	2025-08-08	52	2.68	54.09	43.23
Machine 3	2025-08-09	51	2.88	57.38	39.74
Machine 3	2025-08-12	48	3.67	50.75	45.58
Machine 3	2025-08-13	50	3.11	44.97	51.92

Note. VM = volatile matter/moisture; NOS = non-oil solids.

4.2. Descriptive Comparison among Machines

Machine 1 operated at the lowest mean pressure and had the highest mean oil loss. Machine 3 operated at the highest mean pressure and had the lowest mean oil loss. Moisture increased across the machine means, while NOS decreased, consistent with the compositional closure of the three NIRS outputs. These differences are descriptive and cannot be attributed to pressure alone because the three machines may have differed in wear, geometry, feed condition, throughput, and operating control.

Table 2. Descriptive statistics by screw-press machine (mean ± SD, n = 5 per machine).

Machine	Pressure (bar)	Oil loss (% wet basis)	Moisture, VM (%)	NOS (%)
Machine 1	40.4 ± 1.82	3.756 ± 0.804	47.454 ± 5.588	48.790 ± 4.957
Machine 2	45.0 ± 4.00	3.404 ± 0.476	50.044 ± 6.216	46.552 ± 5.841
Machine 3	50.0 ± 1.58	3.176 ± 0.423	51.850 ± 4.588	44.974 ± 4.455

4.3 Regression Analysis of Pressure and Oil Loss

In the unadjusted model, each 1-bar increase in observed pressure was associated with a 0.088-percentage-point decrease in wet-basis oil loss ($\beta = -0.088$; 95% CI: -0.142 to -0.034; $p = 0.0039$; $R^2 = 0.486$). Residuals did not show strong evidence of non-normality (Shapiro–Wilk $p = 0.135$) or heteroscedasticity (Breusch–Pagan $p = 0.237$).

When machine and sampling date were included as fixed effects, the pressure coefficient was attenuated and statistically uncertain ($\beta = -0.039$ percentage points per bar; 95% CI: -0.164 to 0.086; $p = 0.485$; model $R^2 = 0.863$). Diagnostic tests again did not indicate strong residual non-normality (Shapiro–Wilk $p = 0.196$) or heteroscedasticity (Breusch–Pagan $p = 0.395$). The wide adjusted confidence interval reflects the small sample and strong overlap between pressure, machine identity, and date-specific operating conditions.

Table 3. Linear regression models for wet-basis oil loss.

Model	Pressure coefficient	SE	95% CI	p-value	R²	Interpretation
Unadjusted	-0.088	0.025	-0.142 to -0.034	0.0039	0.486	Descriptive inverse association
Adjusted for machine and date	-0.039	0.053	-0.164 to 0.086	0.485	0.863	Pressure effect not distinguishable from confounding

Note. Coefficients are percentage-point changes in oil loss per 1-bar increase in observed pressure. The adjusted model includes categorical fixed effects for the three machines and five sampling dates.

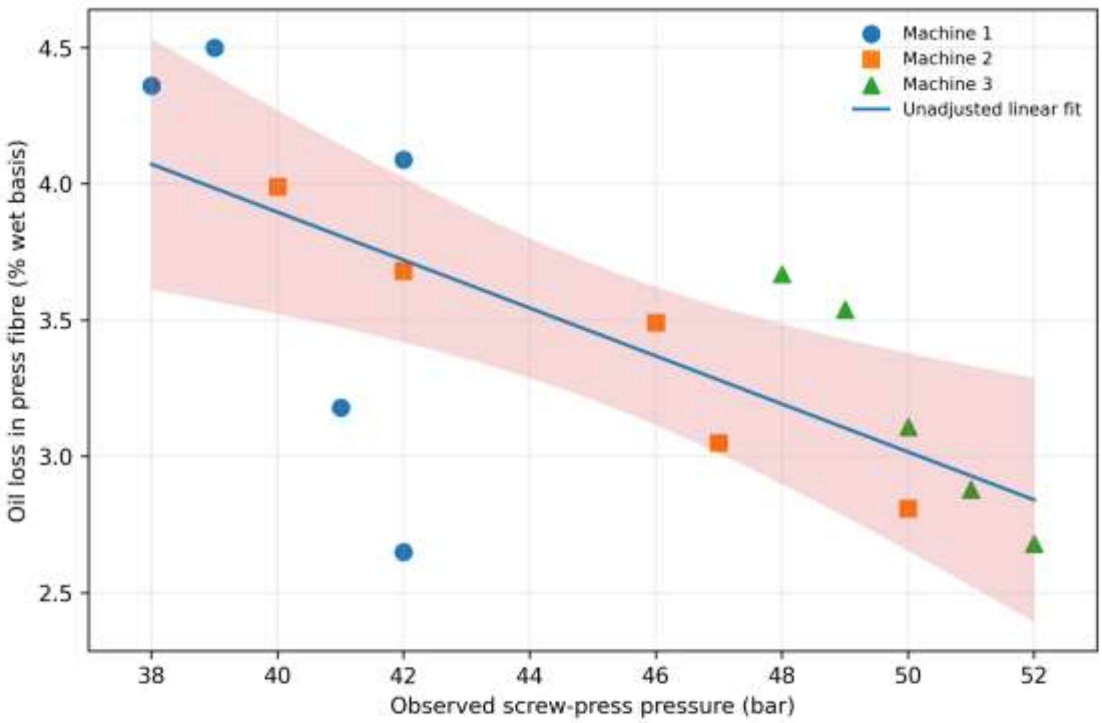

Figure 5. Observed screw-press pressure and wet-basis oil loss for all 15 machine-date observations. The line and shaded band show the unadjusted linear fit and

4.4. Interpretation of the Pressure–Oil Loss Relationship

The descriptive data show a consistent ordering across machine averages: the machine with the highest mean pressure had the lowest mean residual oil, and the machine with the lowest mean pressure had the highest mean residual oil. The unadjusted regression likewise indicated a moderate inverse association. This pattern is mechanically plausible because greater compression can promote drainage of oil from disrupted mesocarp tissue. It is also broadly consistent with previous studies reporting lower press-fibre oil losses at higher press pressure or more intensive expression conditions (Baryeh, 2001; Kurniawan, 2022; Tarigan et al., 2025).

The adjusted analysis, however, materially changes the interpretation. Once machine and date were included, the pressure coefficient became smaller and its confidence interval crossed zero. This result does not prove that pressure has no influence. Instead, it shows that the available 15 observations cannot separate pressure from machine-specific and day-specific variation with adequate precision. Industrial screw presses differ through screw-flight wear, press-cage condition, cone response, alignment, maintenance history, and operator control. Harun et al. (2015) documented the prevalence of wear and maintenance-related malfunction in commercial palm oil screw presses, supporting the reviewer's concern that machine condition may explain part of the observed differences.

The original conclusion that 45 bar was optimal is not supported by the reported measurements. The lowest mean oil loss occurred for Machine 3 at a mean pressure of 50 bar, not for Machine 2 at 45 bar. At the same time, the dataset contains no quantitative measurement of broken nuts, broken kernels, kernel loss, crude-oil impurities, clarification quality, power consumption, throughput, vibration, or component wear. These missing responses are the variables required to determine whether lower oil loss at higher pressure is offset by losses elsewhere in the process. Claims that the 45-bar condition produced clearer oil, lower impurities, better boiler fibre, or more intact kernels were therefore removed because they were not directly measured.

The moisture results also contradict the original qualitative claim that higher-pressure operation produced drier fibre. Mean moisture increased from 47.454% for Machine 1 to 51.850% for Machine 3. Because oil, moisture, and NOS were reported as a closed wet-basis composition, a decrease in one component necessarily changes the proportional shares of the others. The moisture and NOS values should therefore not be interpreted independently without a compositional framework and without controlling feed and operating conditions.

Interpretation of residual-oil values also depends on the reporting basis. Choo et al. (1996) recovered residual oil equivalent to approximately 5–6% of palm-pressed fibre on a dry basis and showed that the oil contained carotenoids, vitamin E, and sterols. Those dry-basis values are not directly comparable with the wet-basis NIRS percentages reported here, but they confirm that basis specification is necessary and that residual oil in fibre has both process-loss and resource-recovery significance.

The NIRS method provides rapid operational data, but the absence of calibration and validation statistics limits analytical traceability. Published NIRS studies in oil palm materials demonstrate that reliable prediction requires calibration against reference chemical methods and reporting of validation statistics such as prediction error and bias (Silalahi et al., 2016; Sudarno et al., 2017; Novianty et al., 2023). Future work should retain the speed advantage of NIRS while verifying the installed press-fibre calibration against a recognized solvent-extraction and moisture reference method.

4.5. Study Limitations and Implications for Experimental Redesign

This study has four principal limitations. First, pressure was not randomized within the same machine, so machine identity and pressure were confounded. Second, only five once-daily observations were available per machine, which is insufficient to characterize within-shift variability or transient operating conditions. Third, key process covariates were not recorded, including fruit ripeness, feed rate, digester temperature and residence time, dilution-water addition, throughput, screw speed, cone position, and maintenance condition. Fourth, the study did not quantify the product-quality and reliability trade-offs needed for optimization.

A stronger follow-up experiment should apply at least three controlled pressure settings to each of the same screw presses in randomized or counterbalanced order after steady state is reached. Multiple independent samples should be collected at each machine–pressure combination across several batches and shifts. The recorded responses should include oil loss on a clearly defined basis, broken-nut and broken-kernel percentages, kernel loss, crude-oil dirt or solids, moisture, oil extraction rate, throughput, motor power, vibration, and wear indicators. A mixed-effects or blocked regression model could then separate pressure effects from machine, batch, date, and shift effects, while a pre-specified multi-response optimization method could identify an operating compromise.

5. Conclusion

Within the observed operating range of 38–52 bar, wet-basis oil loss tended to decline as recorded screw-press pressure increased. The unadjusted relationship was statistically detectable, but the pressure coefficient was no longer precise after adjustment for machine and sampling date. The current observational dataset therefore does not establish a causal pressure effect and cannot demonstrate that 45 bar, 50 bar, or any other setting is optimal. Determination of an optimum pressure requires a controlled within-machine experiment and quantitative measurement of kernel damage, oil impurities, energy use, throughput, and equipment condition. The present results are best interpreted as preliminary field evidence that supports more rigorous process-optimization work rather than as proof of a single recommended pressure.

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