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Article

Performance Analysis of OTR Machine In The Black Tea Leaf Rolling Process At PTPN IV Bah Butong Unit

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A B S T R A C T

This study aims to analyze the performance of the Open Top Roller (OTR) machine in the black tea leaf rolling process at PTPN IV Bah Butong Unit. The OTR machine is essential in black tea processing, functioning to grind and roll tea leaves after the withering process to shape and release cell sap. The recorded variables were material input, scheduled batch duration, downtime, operating time, and good output. The batches processed 3,020 kg of withered leaves; recorded duration ranged from 40 to 50 min per batch, with a mean of 44.4 min, while total downtime was 5 min and good output was 3,010 kg. Availability, Performance, and Quality were 98.87%, 91.12%, and 99.67%, respectively, producing an OEE of 89.79%. Performance was the lowest component because most batches exceeded the selected ideal cycle time of 40 min, although all remained within the plant's operational range of 40–50 min. Average loading was 302 kg per batch, equivalent to 80.53% of the 375 kg nominal maximum. These results identify cycle-time consistency, rather than downtime or recorded mass yield, as the immediate improvement priority. The result must nevertheless be interpreted as a short observational snapshot: the Quality factor represents mass yield rather than sensory or biochemical tea quality, and the widely cited 85% OEE benchmark is a comparative convention rather than a universal acceptance limit. The findings describe only this ten-batch observation window.

1. Introduction

Tea processing is an important stage in producing black tea with desirable physical, chemical, and sensory characteristics. The processing of black tea generally consists of withering, rolling, oxidation or fermentation, drying, and sorting. Differences in processing techniques can influence the phytochemical composition and final quality of tea (Wong et al., 2022; Aaqil et al., 2023). The rolling process is one of the important stages in black tea processing because mechanical action causes maceration of tea leaves and facilitates the release of cellular components. The released components subsequently participate in oxidation reactions during the following processing stage. Ozdemir et al. (2017) reported that rolling contributes to uniform maceration of tea leaves and supports oxidation reactions during black tea processing. Similar findings have been reported in studies examining the chemical changes occurring during rolling and other stages of black tea manufacture (Liu et al., 2020; Wong et al., 2022).

Figure 1. Open Top Roller (OTR) machine used in the black tea leaf rolling process at PTPN IV Bah Butong Unit.

Black tea manufacture transforms freshly harvested shoots through withering, rolling, enzymatic oxidation, drying, and sorting. Each operation conditions the next. Withering changes moisture and leaf flexibility, rolling ruptures cells and mixes oxidative enzymes with phenolic substrates, and controlled oxidation supports the formation of theaflavins and thearubigins that contribute to liquor colour, briskness, astringency, and aroma. Consequently, rolling is not a purely mechanical size-reduction step. Its pressure, rotational action, duration, and loading can alter both production throughput and the biochemical pathway that determines final tea quality (Ozdemir et al., 2017; Wong et al., 2022; Aaqil et al., 2023; Mahdavi et al., 2026).

The Open Top Roller (OTR) applies rotational movement and pressure to withered leaves. At PTPN IV Bah Butong Unit, the machine supports orthodox black tea production across repeated batches. Unplanned stops reduce the time available for rolling, while slow cycles constrain throughput. Excessive attempts to shorten the cycle may also be counterproductive if maceration becomes non-uniform or if the rolling conditions alter oxidation precursors. Recent metabolomic and aroma studies confirm that rolling speed, method, duration, and re-rolling treatments influence pigments, organic acids, phenolic acids, volatile compounds, and other quality-related metabolites (Chen et al., 2023, 2024; Wu et al., 2023; Yang et al., 2024). Equipment evaluation must therefore distinguish operational speed from product quality rather than treating higher speed as an unconditional objective.

Overall Equipment Effectiveness integrates three loss dimensions: Availability represents losses from stoppages, Performance represents losses from operation below the ideal rate, and Quality represents losses from nonconforming output (Nakajima, 1988; Muchiri & Pintelon, 2008). OEE is useful because the product of these factors reveals both the aggregate effectiveness and the component that constrains

it. Its validity, however, depends on explicit definitions of planned time, downtime, ideal cycle time, total output, and good output. Comparisons between plants or periods become misleading when these definitions differ (Jonsson & Lesshammar, 1999; Dal et al., 2000; de Ron & Rooda, 2006).

Zulfikri et al. (2019) previously evaluated an OTR at the same production unit and reported Availability of 89.74%, Performance of 75.79%, Quality of 100%, and OEE of 67.99%. That study also examined Six Big Losses and failure modes. The present work provides a new field observation based on 10 current production batches and focuses on processing duration, downtime, material input, mass-based good output, and capacity utilization. Because the observation periods and operational conditions are not identical, the earlier value is used as contextual evidence rather than as a controlled before-and-after baseline.

This study aimed to quantify the Availability, Performance, Quality, and OEE of the OTR machine; determine whether observed batch durations remained within the plant standard of 40–50 min; examine utilization relative to the nominal 375 kg capacity; and identify the principal operational improvement priority. The study adds value by interpreting OEE within the process requirements of orthodox black tea rather than evaluating the machine independently of tea transformation.

2. Literature Review.

2.1 Black Tea Processing and Open Top Roller (OTR) Machine

The Black tea processing involves several stages that influence the physical, chemical, and sensory characteristics of the final product. The main stages generally include withering, rolling, fermentation or oxidation, drying, and sorting. The processing method determines the degree of chemical transformation occurring in tea leaves and consequently affects the phytochemical profile of the final tea product (Wong et al., 2022; Aaqil et al., 2023).

Rolling is an important mechanical operation in black tea processing. During rolling, mechanical pressure and movement cause the tea leaves to become damaged and macerated. This process facilitates the release of cellular components and supports subsequent oxidation reactions. Ozdemir et al. (2017) reported that rolling provides uniform maceration and promotes oxidation reactions catalyzed by enzymes during black tea processing. The chemical characteristics of tea leaves also change during the rolling stage. Liu et al. (2020) observed changes in cellulase activity and major quality components during the processing of black tea, including significant changes occurring during rolling and fermentation. Therefore, maintaining appropriate processing conditions is important to obtain consistent processing results. The rolling method and operating conditions may also affect tea quality. Wu et al. (2023) investigated the influence of rolling speed on Congou black tea and found that rolling speed affected several quality-related compounds, including tea pigments, organic acids, and phenolic acids. Yang et al. (2024) also demonstrated that rolling method and rolling time were associated with changes in aroma compounds and other chemical components of black tea. Recent research has further demonstrated that rolling treatment can influence the development of aroma quality. Chen et al. (2023) reported that re-rolling during fermentation improved the aroma quality of black tea. Meanwhile, Chen et al. (2024) summarized the dynamic changes of key aroma compounds during black tea processing and showed that volatile compounds change throughout the processing stages. The OTR machine is designed to perform mechanical rolling of withered tea leaves. The machine operates by applying rotational movement and mechanical pressure to the tea material. Mahdavi et al. (2026) investigated the orthodox tea rolling process and demonstrated that rolling parameters, including rotational speed and pressure, can influence the chemical characteristics of processed tea. The OTR machine at PTPN IV Unit Bah Butong has a nominal capacity of 275–375 kg per process, with a rotational speed of 44 rpm and an OTR drive power of 20 HP. The machine is driven by a 30 HP motor with a rotational speed of 1450 rpm and a frequency of 50 Hz. These specifications indicate the operational characteristics of the machine used in the rolling process. Previous research at PTPN IV Unit Bah Butong reported an OEE value of 67.99%, with Availability of 89.74%, Performance of 75.79%, and Quality of 100% (Zulfikri et al., 2019). The study also identified several machine components associated with failure risk, including the rolling cylinder, grinding table,

crankshaft, electric motor, and V-belt. Therefore, the performance of an OTR machine should not only be evaluated from its ability to operate, but also from processing speed, downtime, material capacity, and output quality. These parameters provide an important basis for evaluating the effectiveness of OTR operation.

2.2 Overall Equipment Effectiveness (OEE)

Overall Equipment Effectiveness (OEE) is a performance measurement method used to evaluate the effectiveness of production equipment. OEE combines three major components, namely Availability, Performance, and Quality. The use of these three components enables machine performance to be evaluated from operating time, operating speed, and output quality simultaneously (Ng Corrales et al., 2020; Cheah et al., 2020). Singh et al. (2018) explained that OEE can be used as a measurement basis for evaluating operational efficiency. The method provides information regarding losses associated with machine availability, performance, and quality. Therefore, OEE can be applied to identify the main areas requiring improvement in production equipment. Availability represents the proportion of planned production time during which the machine is actually available for operation. Downtime caused by equipment failure, adjustment, maintenance, or other interruptions reduces Availability. A high Availability value indicates that the machine can operate for most of the planned production period. Performance evaluates the operating speed of the machine compared with its ideal cycle time. A machine may have high Availability but still have reduced Performance when its actual processing time is longer than the ideal cycle time. Hung et al. (2022) emphasized that OEE includes Performance as one of the major dimensions associated with production losses and equipment capacity. Quality represents the proportion of good output compared with the total processed material. Therefore, a machine with high Availability and Performance may still have reduced overall effectiveness if a substantial portion of its output does not meet the defined production criteria.

The OEE value is obtained by multiplying Availability, Performance, and Quality:

OEE = Availability × Performance × Quality

The OEE approach has been applied in various production systems. Maknunah et al. (2016), for example, applied OEE to evaluate machines in the milling station of a sugar factory and found that reduced speed was an important factor affecting OEE. This finding is relevant to the present study because processing speed is also evaluated as one of the main performance indicators of the OTR machine. Cheah et al. (2020) also emphasized that OEE can be combined with systematic improvement approaches to identify and prioritize improvement opportunities. Thus, OEE is not only a numerical measurement but can also serve as a basis for determining which aspect of machine operation should receive further attention.

2.3 Availability, Performance, and Quality

The effectiveness of an OTR machine can be evaluated through the three main OEE indicators: Availability, Performance, and Quality. Each indicator represents a different source of production loss, so all three indicators need to be evaluated together.

1. Availability

Availability describes the ability of the machine to operate during the planned production period. Availability is calculated as:

Availability = (Operating Time / Planned Production Time) × 100%

Downtime caused by machine failure, component replacement, adjustment, or other operational interruptions reduces the operating time of the machine.

2. Performance

Performance represents the operating speed of the machine compared with its ideal cycle time. It can be calculated using:

Performance = (Ideal Cycle Time × Total Count / Operating Time) × 100%

In the present study, the standard OTR rolling time is 40–50 minutes per batch. The 40-minute value is used as the ideal cycle time, representing the fastest processing time within the established standard range.

The distinction between standard processing time and ideal cycle time is important. The 40–50 minute range is used to evaluate whether actual processing remains within the operational standard, while 40 minutes is used as the reference for the Performance calculation.

Research on black tea has demonstrated that rolling time and rolling conditions can influence tea quality (Yang et al., 2024; Wu et al., 2023). Therefore, processing time needs to be controlled so that improvements in machine speed do not compromise the rolling process and final tea quality.

3. Quality

Quality represents the proportion of good output relative to the total processed material and is calculated as:

Quality = (Good Output / Total Input) × 100%

In this study, the difference between input material and recorded good output is treated as a mass difference in the production measurement. It is not directly classified as a product defect because the present study does not separately analyze the physical or chemical causes of the mass difference.

4. Overall Equipment Effectiveness

The three indicators are combined to determine overall machine effectiveness:

OEE = Availability × Performance × Quality

The use of OEE allows the performance of the OTR machine to be evaluated comprehensively. Previous OEE research has demonstrated that the three indicators can be used to identify whether equipment losses are primarily related to downtime, operating speed, or output quality (Cheah et al., 2020; Ng Corrales et al., 2020; Singh et al., 2018).

2.4 Research Gap and Positioning of the Present Study

Previous research has established that both tea-processing conditions and machine operating conditions can influence the effectiveness and quality of tea production. Studies on black tea have examined the effects of rolling method, rolling speed, rolling time, and re-rolling treatment on tea quality and chemical characteristics (Ozdemir et al., 2017; Wu et al., 2023; Yang et al., 2024; Chen et al., 2023). From the equipment-performance perspective, OEE provides an integrated approach for evaluating Availability, Performance, and Quality. Previous studies have demonstrated the usefulness of OEE in identifying equipment losses and determining improvement priorities (Maknunah et al., 2016; Singh et al., 2018; Cheah et al., 2020; Ng Corrales et al., 2020). More specifically, Zulfikri et al. (2019) previously evaluated the effectiveness of an OTR machine at PTPN IV Unit Bah Butong and obtained an OEE value of 67.99%, with Performance of 75.79% being lower than Availability and Quality. The previous research also incorporated Six Big Losses and FMEA to identify machine failure risks. However, the present study differs in its focus and observation approach. The current research focuses on direct operational observations of 10 OTR processing batches, including material input, actual processing time, downtime, and good output. The study specifically evaluates the current machine performance using OEE and examines processing-time variation as an important factor affecting the Performance component. The research also considers the operational standard of 40–50 minutes per batch and evaluates the actual processing time against this range. This is relevant because recent tea-processing research indicates that rolling conditions and duration can affect tea quality and chemical characteristics (Liu et al., 2020; Yang et al., 2024; Mahdavi et al., 2026). Therefore, the research gap addressed by this study is the need for an updated operational evaluation of OTR machine performance at PTPN IV Unit Bah Butong based on direct production observations. The study does not primarily focus on failure-risk ranking as in the previous research, but instead emphasizes the measurement of Availability, Performance, Quality, and OEE using current field data. The present study is expected to complement previous research by providing an updated assessment of OTR machine effectiveness and identifying the OEE component with the greatest potential for improvement. The results can subsequently be used as a basis for improving processing-time

consistency while maintaining high machine Availability and product Quality.

3. Research Methodology

3.1 Research Location and Time

This single-machine descriptive study was conducted at PTPN IV Bah Butong Unit, Simalungun Regency, North Sumatra, from August 3 to September 2, 2026. Ten rolling batches were recorded within this period. The available records do not identify the observation dates, selection sequence, shifts, operators, or leaf moisture for individual batches. These sampling details require confirmation from the field log before submission; the observations cannot be assumed to represent the full month.

3.2 Research Method

The batch was the unit of analysis. Recorded input masses, batch durations, and stoppage time were summarized descriptively. An illustrative availability and cycle-time performance calculation was made using the reported 444 min and a 40-min reference; both depend on time-boundary and reference-cycle verification. Post-rolling mass divided by input mass was calculated separately as material yield. Without a conformity-based good-output measure, conventional OEE cannot be established from these records.

3.3 Data Collection

The source table records input mass, a 40–50 min plant operating range, actual duration, and downtime for each of ten batches. It does not state the scale resolution or calibration, stopwatch or log source, clock start and end events, observer, stop-coding threshold, or whether recorded durations include interruptions. These details should be recovered from the observation sheets. The stated maximum batch capacity is 375 kg; its nameplate or operating-standard source also requires verification. The aggregate post-rolling mass of 3,010 kg is reported without batch-level values or conformity criteria.

3.4 Research Flow

The analysis sequence was to transcribe ten batch records, check the sums of input mass and duration, summarize the batch durations, reconcile each stop with the corresponding elapsed and running times, and calculate the reported ratios. The time reconciliation and output classification remain incomplete because the underlying log and batch-level output records are unavailable.

4. Results and Discussion

4.1 Results

4.1.1 OTR Machine Observation Data

Observations were conducted on the Open Top Roller (OTR) machine during the black tea leaf rolling process at PTPN IV Bah Butong Unit. The observed data included the amount of material processed, standard processing time, actual rolling time, and downtime.

Table 4.1 Observation Data of the OTR Machine Rolling Process

Batch	Input (kg)	Standar (menit)	Aktual (menit)	Downtime(menit)
1	300	40 – 50	40	5
2	300	40 – 50	43	0
3	300	40 – 50	43	0
4	320	40 – 50	50	0
5	300	40 – 50	45	0
6	300	40 – 50	45	0
7	300	40 – 50	45	0
8	300	40 – 50	45	0
9	300	40 – 50	45	0
10	300	40 – 50	43	0
Total	3.020	400 – 500	444	5
Rata – rata	302	40 – 50	44,4	0,5

Across ten batches, input mass totaled 3,020 kg and recorded duration totaled 444 min. Batch duration averaged 44.4 min (sample SD 2.55 min; range 40–50 min). Nine batches had

300 kg input and one had 320 kg. All reported durations fall within the stated 40–50 min operating range. Whether each duration includes interruption time has not been documented.

4.1.2 Rolling Processing Time Analysis

The ten recorded durations were 40, 43, 43, 50, 45, 45, 45, 45, 45, and 43 min. Their sum is 444 min, mean is 44.4 min, and sample standard deviation is 2.55 min. The sole 50-min batch had a 320 kg input; one observation at this load cannot establish that loading increased duration.

Average Actual Processing Time

The average actual processing time was calculated using the following equation:

$$t = \frac{\sum t}{n}$$

where:

t = average actual processing time (minutes/batch)

∑t = total actual processing time (minutes)

n = number of batches

Based on the observation data:

$$t = \frac{444}{10}$$

t = 44,4 minutes / batch

Therefore, the average actual processing time for the OTR rolling process was 44.4 minutes per batch.

Based on the observation results, the shortest actual processing time was 40 minutes, while the longest actual processing time was 50 minutes. Both values remain within the established standard processing-time range of 40–50 minutes per batch. The average actual processing time of 44.4 minutes per batch also falls within this standard range. Therefore, the actual rolling process observed during the study generally complied with the established processing-time standard. Therefore, it can be concluded that the actual processing time of the OTR machine during the observation period remained within the established processing-time standard. The variation in rolling time observed for each batch remained within the standard limits and did not indicate any processing-time deviation exceeding the established standard. In Batch 4, the rolling time reached 50 minutes with a material input of 320 kg. This value represents the longest actual processing time during the observation period; however, it remained at the maximum limit of the established standard. This indicates that although there was a difference in the amount of material processed, the rolling time could still be maintained within the standard processing range.

4.1.3 Availability

The sum of recorded batch durations was 444 min, and one batch recorded a 5-min stop. If the recorded duration for batch 1 includes this stop and all ten durations describe scheduled elapsed rolling intervals.

Operating Time = 444 – 5

Operating Time = 439

Therefore:

Availability = $\frac{439}{444}$ x 100%

Availability = 98.87%

The high Availability value indicates that the machine was relatively available for operation during the observation period. Availability is calculated based on the ratio of operating time to planned production time. The value of 98.87% indicates that only a small proportion of the observed production time was lost due to downtime.

4.1.4 Performance

In the calculation of Overall Equipment Effectiveness (OEE), the standard processing time is used as a reference for determining the ideal cycle time. Based on the observation results, the OTR machine rolling process had a processing-time range of 40–50 minutes per batch, while 40 minutes per batch was used as the ideal cycle time because it represents the fastest processing time observed and the lower limit of the established standard range. This value is used as the reference for evaluating the Performance of the OTR machine. The operating time after deducting downtime was calculated as follows:

Operating Time = 444 – 5 Operating Time = 439

The Performance value was then calculated using the following equation:

Performance = $\frac{ideal\ Cycle\ x\ Number\ of\ Batches}{Operating\ Time}$ x 100%

Performance = $\frac{40\ x\ 10}{439}$ x 100%

Performance = 91,12%

Based on the calculation, the Performance value of the OTR machine was 91.12%. This value indicates that the machine performance based on the actual cycle time had not yet reached the ideal condition of 40 minutes per batch. This can be observed from the average actual processing time of 44.4 minutes per batch. Nevertheless, the actual processing time of all batches remained within the established standard processing range of 40–50 minutes per batch. Therefore, there is a distinction between the standard processing time and the ideal cycle time. The 40–50 minute range is used to determine whether the rolling process remains within the established standard limits, whereas 40 minutes is used as the ideal cycle time in the OEE Performance calculation.

4.1.5 Quality and Mass Difference

Total amount of material processed: Total = 3.020 kg Total good output: Good = 3.010 kg Mass difference: 3.020 – 3.010 = 10 kg Therefore:

$$\text{Quality} = \frac{3010}{3020} \text{ x } 100\% \text{ Quality} = 99{,}67\%$$

The Quality value of 99.67% indicates that the proportion of good output was very high compared with the total material processed during the 10 observed batches. The recorded mass difference was 10 kg, which represents the difference between the total input material and the good output in the production measurement.

4.1.6 Overall Equipment Effectiveness

The OEE value was determined based on three main components, namely Availability, Performance, and Quality.

Table 4.2 OEE Values Based on Three Components

Parameter	Nilai	Operational interpretation
Availability	98,87%	Limited observed downtime
Performance	91,12%	Lowest component; cycle-time opportunity
Quality	99,67%	High mass-based good-output yield
OEE	89,79%	High short-period equipment effectiveness

Calculation:

OEE = 98,87% X 91,12% X 99,67%

OEE = 89,79%

The OEE value of 89.79% indicates that the OTR machine demonstrated a good level of effectiveness during the observation period. However, the OEE value should not be interpreted only as a single number, because its three components provide information regarding the sources of productivity losses. In this study, Availability, Performance, and Quality provide a more detailed description of the machine's operational effectiveness. For comparison, a value of approximately 85% is commonly used as a reference for world-class OEE. However, this value should not be considered a universal limit for determining whether every machine or industrial process can be classified as “good.” The interpretation of OEE should also consider the characteristics of the production process, machine conditions, operating conditions, and the measurement period. Based on the results, the OTR machine achieved an OEE value above the commonly used 85% reference. Nevertheless, the Performance value of 91.12% was the lowest among the three OEE components. Therefore, improvement efforts can be directed primarily toward maintaining consistent processing time and reducing variations in the rolling process while maintaining the existing levels of Availability and Quality.

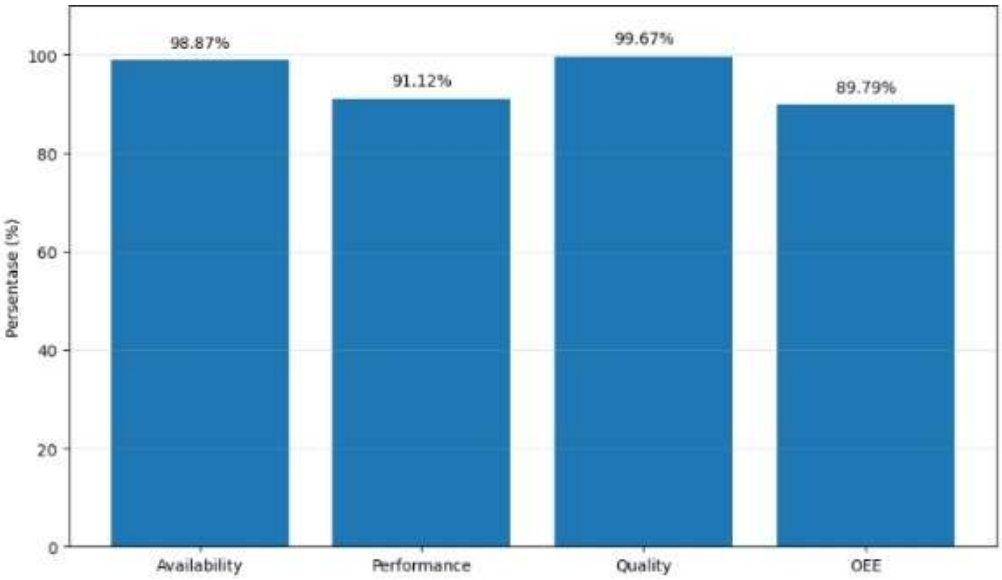

Figure 2. OEE Calculation Results

Based on the calculation results, the Availability value was 98.87%, while the Quality value was 99.67%. The Performance value of 91.12% was the lowest among the three OEE components. This result indicates that the main performance improvement opportunity during the observation period was not associated with high downtime or low output quality, but rather with the processing speed of the OTR machine relative to the selected ideal cycle time. Although all actual processing times remained within the established standard range of 40–50 minutes per batch, most batches required more than the 40-minute ideal cycle time. Therefore, improving processing-time consistency may increase the Performance component and subsequently improve the overall OEE value.

4.8 Mechanical Condition and Downtime

During the observation period, 5 minutes of downtime was recorded in one batch. In addition, observations of the machine condition identified several mechanical conditions that require attention, particularly the condition of the bearing and loose bolts. Mechanical disturbances can affect the stability of machine operation and may contribute to variations in processing time or machine stoppage. Therefore, periodic inspection of important components, such as bearings, belts, pulleys, bolts, and the drive system, is necessary to maintain stable OTR machine operation. However, the 5-minute downtime recorded in the observation data represents the downtime during the 10 observed batches. Therefore, this value should not be combined with broader monthly operational downtime data if a separate monthly analysis is conducted. Keeping the observation-period data separate from monthly operational data ensures that the OEE calculation remains consistent with the defined observation period.

4.9 Capacity Utilization

The maximum capacity of the OTR machine based on its nameplate specification is 375 kg/process. Based on the observation results, most batches used a material input of 300 kg, while one batch used an input of 320 kg. For the batches with 300 kg of input:

Utilization = $\frac{300}{375}$ x 100%

Utilization = 80%

For the batch with 320 kg of input:

Utilization = $\frac{320}{375}$ x 100%

Utilization = 85,33%

The average material input during the observation period was calculated as:

$\frac{3020}{10}$ = 302 kg/batch

Therefore:

$\frac{302}{375}$ x 100% = 80,53%

Thus, the average capacity utilization of the OTR machine during the observation period was

80.53% of its maximum capacity of 375 kg/process. This indicates that the machine was not operated at its maximum nominal capacity during the observation period, as the average amount of material processed was 302 kg per batch. The capacity utilization result also shows that the material loading varied between batches. Most batches were loaded at approximately 80% of the maximum capacity, while the 320 kg batch reached 85.33% of the maximum capacity. These differences in material loading may contribute to variations in processing time and should therefore be considered when evaluating OTR machine performance.

4.2 Discussion

4.2.1 Diagnostic Meaning of the OEE Profile

The OTR produced a high OEE profile dominated by Availability and mass-based Quality. Only 5 min of downtime were recorded, so stoppage loss contributed little to the aggregate result. The lower Performance component shows that elapsed operating time above the 40 min ideal accumulated more loss than either downtime or recorded mass difference. This pattern confirms why OEE should be decomposed rather than reported as a single score (Muchiri & Pintelon, 2008; Cheah et al., 2020).

The current OEE of 89.79% is 21.80 percentage points higher than the 67.99% reported by Zulfikri et al. (2019), with particularly higher Performance and Availability. This numerical contrast is informative but not causal. Differences in observation length, leaf condition, production schedule, maintenance state, loss classification, and cycle-time assumptions could influence the result. A defensible longitudinal comparison would require the same operational definitions and repeated measurement across comparable seasons and shifts.

The 85% reference provides context but should not be treated as proof that the system is optimal. OEE is sensitive to the chosen denominator and ideal cycle time (Dal et al., 2000; de Ron & Rooda, 2006). Here, 40 min is the plant's fastest standard boundary, not an experimentally demonstrated optimum for every loading and leaf condition. The useful conclusion is therefore narrower: within the selected definitions and 10-batch window, the machine showed limited stop loss, high mass yield, and a measurable cycle-time gap.

4.2.2 Balancing Throughput with Tea Quality

Reducing duration toward 40 min may raise the Performance factor, but the intervention must preserve maceration and oxidation requirements. Rolling speed and mechanical pressure affect tea pigments, phenolic acids, organic acids, soluble solids, theaflavins, thearubigins, and volatile compounds (Wu et al., 2023; Yang et al., 2024; Mahdavi et al., 2026). The appropriate objective is stable processing at a validated cycle, not the shortest possible cycle.

The current Quality calculation does not resolve this trade-off because it uses mass yield. Internationally credible evaluation should distinguish equipment yield from product quality. Future monitoring should pair OEE with moisture after withering and rolling, dhool particle distribution, grade recovery, colour indices, theaflavin and thearubigin concentrations, volatile profiles, and sensory scores. Such integration would show whether faster cycles maintain the chemical and sensory outcomes expected from orthodox tea.

4.2.3 Maintenance and Capacity Implications

High short-term Availability does not remove the need for preventive maintenance. Loose bolts and bearing concerns can precede vibration, misalignment, thermal damage, belt instability, or unplanned failure. A practical maintenance response is to record inspection results, lubrication, tightening, bearing temperature or vibration where feasible, failure mode, repair duration, and recurrence. These leading and lagging indicators would permit a more informative link between maintenance work and OEE (Muchiri et al., 2011). Capacity should also be tested systematically. The observed 80.53% mean loading leaves nominal capacity unused, but increasing input may lengthen cycles or change rolling uniformity. A controlled factorial trial across representative loads, leaf moisture levels, and rolling conditions would be more defensible than assuming that maximum loading improves productivity.

4.2.4 Limitations

The study covers one machine and ten batches. The nine-to-one imbalance between 300 and 320 kg loading prevents a defensible load-duration association. Missing batch-level output and acceptance data prevent calculation of conventional OEE Quality; an unvalidated 40-min reference and ambiguous time boundaries make Availability and Performance conditional. The short, selectively documented window cannot establish monthly reliability or maintenance effects.

5. Conclusion

In ten recorded batches, the OTR received 3,020 kg of leaves over 444 min of reported batch duration, with one five-minute stop and 3,010 kg of aggregate post-rolling material. Duration was 44.4 ± 2.55 min per batch (sample SD), within the stated 40–50 min range. On the unverified assumption that batch durations include the stop, Availability is 98.87%; using an unvalidated 40-min reference gives Performance of 91.12%. The 99.67% mass yield is not conventional OEE Quality. Their 89.79% product is therefore provisional and should not be cited as verified OEE. Future measurement should reconcile batch timestamps, validate a condition-specific ideal cycle, and classify conforming output before comparing equipment effectiveness or testing operational interventions.

References

Aaqil, M., Peng, C., Kamal, A., Nawaz, T., Zhang, F., & Gong, J. (2023). Tea harvesting and processing techniques and its effect on phytochemical profile and final quality of black tea: A review. Foods, 12(24), 4467. https://doi.org/10.3390/foods12244467

Bamber, C. J., Castka, P., Sharp, J. M., & Motara, Y. (2003). Cross-functional team working for overall equipment effectiveness. Journal of Quality in Maintenance Engineering, 9(3), 223–238. https://doi.org/10.1108/13552510310493684

Cheah, C. K., Prakash, J., & Ong, K. S. (2020). Overall equipment effectiveness: A review and development of an integrated improvement framework. International Journal of Productivity and Quality Management, 30(1), 46–71. https://doi.org/10.1504/IJPQM.2020.107240

Chen, Q., Yu, P., Li, Z., Wang, Y., Liu, Y., Zhu, Y., & Fu, H. (2023). Re-rolling treatment in the fermentation process improves the aroma quality of black tea. Foods, 12(19), 3702. https://doi.org/10.3390/foods12193702

Chen, Z., Li, Z., Zhao, Y., Zhu, M., Li, J., & Wang, K. (2024). A meta-analysis of dynamic changes of key aroma compounds during black tea processing. Food Bioscience, 58, 103784. https://doi.org/10.1016/j.fbio.2024.103784

Dal, B., Tugwell, P., & Greatbanks, R. (2000). Overall equipment effectiveness as a measure of operational improvement: A practical analysis. International Journal of Operations & Production Management, 20(12), 1488–1502. https://doi.org/10.1108/01443570010355750

de Ron, A. J., & Rooda, J. E. (2006). OEE and equipment effectiveness: An evaluation. International Journal of Production Research, 44(23), 4987–5003. https://doi.org/10.1080/00207540600573402

Deb, S., & Pou, K. R. J. (2016). A review of withering in the manufacture of black tea. Journal of Biosystems Engineering, 41(4), 365–372. https://doi.org/10.5307/JBE.2016.41.4.365

Huang, S. H., Dismukes, J. P., Shi, J., Su, Q., Razzak, M. A., Bodhale, R., & Robinson, D. E. (2003). Manufacturing productivity improvement using effectiveness metrics and simulation analysis. International Journal of Production Research, 41(3), 513–527. https://doi.org/10.1080/00207540210000042391

Hansen, R. C. (2001). Overall equipment effectiveness: A powerful production/maintenance tool for increased profits. Industrial Press.

Hung, Y. H., Li, L. Y. O., & Cheng, T. C. E. (2022). Uncovering hidden capacity in overall equipment effectiveness

management. International Journal of Production Economics, 248, 108494. https://doi.org/10.1016/j.ijpe.2022.108494

International Organization for Standardization. (2014). ISO 22400-2:2014 Automation systems and integration—Key performance indicators for manufacturing operations management—Part 2: Definitions and descriptions. ISO.

Jeong, K. Y., & Phillips, D. T. (2001). Operational efficiency and effectiveness measurement. International Journal of Operations & Production Management, 21(11), 1404–1416. https://doi.org/10.1108/EUM0000000006223

Jonsson, P., & Lesshammar, M. (1999). Evaluation and improvement of manufacturing performance measurement systems: The role of OEE. International Journal of Operations & Production Management, 19(1), 55–78. https://doi.org/10.1108/01443579910244223

Liu, Y., Zhou, H., Wang, H., Hu, S., Huang, J., Lei, P., Li, M., & Li, S. (2020). Dynamic changes of cellulase and main quality components in processing of black tea. Science and Technology of Food Industry, 41(6), 66–70. https://doi.org/10.13386/j.issn1002-0306.2020.06.011

Mahdavi, M., Azadbakht, M., & Abbaszadeh-Mayvan, A. (2026). The orthodox tea rolling process. Journal of Food Process Engineering, 49(5), e70532. https://doi.org/10.1111/jfpe.70532

Maknunah, L. U., Achmadi, F., & Astuti, R. (2016). Penerapan overall equipment effectiveness untuk mengevaluasi kinerja mesin-mesin di stasiun giling Pabrik Gula Krebet II Malang. Jurnal Teknologi Industri Pertanian, 26(2), 189–198. https://doi.org/10.24961/j.tek.ind.pert.2016.26.2.189

Muchiri, P., & Pintelon, L. (2008). Performance measurement using overall equipment effectiveness: Literature review and practical application discussion. International Journal of Production Research, 46(13), 3517–3535. https://doi.org/10.1080/00207540601142645

Muchiri, P., Pintelon, L., Gelders, L., & Martin, H. (2011). Development of maintenance function performance measurement framework and indicators. International Journal of Production Economics, 131(1), 295–302. https://doi.org/10.1016/j.ijpe.2010.04.039

Nakajima, S. (1988). Introduction to TPM: Total productive maintenance. Productivity Press.

Ng Corrales, L. C., Lambán, M. P., Hernandez Korner, M. E., & Royo, J. (2020). Overall equipment effectiveness: Systematic literature review and overview of different approaches. Applied Sciences, 10(18), 6469. https://doi.org/10.3390/app10186469

Obanda, M., Owuor, P. O., & Mang'oka, R. (2001). Changes in the chemical and sensory quality parameters of black tea due to variations of fermentation time and temperature. Food Chemistry, 75(4), 395–404. https://doi.org/10.1016/S0308-8146(01)00223-0

Ozdemir, F., Tontul, I., Balci-Torun, F., & Topuz, A. (2017). Effect of rolling methods and storage on volatile constituents of Turkish black tea. Flavour and Fragrance Journal, 32(5), 362–375. https://doi.org/10.1002/ffj.3385

Singh, R. K., Clements, E. J., & Sonwaney, V. (2018). Measurement of overall equipment effectiveness to improve operational efficiency. International Journal of Process Management and Benchmarking, 8(2), 246–261. https://doi.org/10.1504/IJPMB.2018.090798

Tanaka, T., & Kouno, I. (2003). Oxidation of tea catechins: Chemical structures and reaction mechanism. Food Science and Technology Research, 9(2), 128–133. https://doi.org/10.3136/fstr.9.128

Tsarouhas, P. H. (2013). Evaluation of overall equipment effectiveness in the beverage industry: A case study. International Journal of Production Research, 51(2), 515–523.

Wong, M., Sirisena, S., & Ng, K. (2022). Phytochemical profile of differently processed tea: A review. Journal of Food Science, 87(5), 1925–1942. https://doi.org/10.1111/1750-3841.16137

Wu, S., Yu, Q., Zhu, J., Hua, J., Shen, S., Jiang, Y., Yuan, H., & Li, J. (2023). Analysis of the effect of rolling speed on the Congou black tea quality using electronic tongue and metabolomics. Food Science, 44(6), 301–310. https://doi.org/10.7506/spkx1002-6630-20220503-019

Yang, S., Pathak, S., Tang, H., Zhang, D., Chen, Y., Ntezimana, B., Ni, D., & Yu, Z. (2024). Non-targeted metabolomics reveals the effects of different rolling methods on black tea quality. Foods, 13(2), 325. https://doi.org/10.3390/foods13020325

Zulfikri, M., Siregar, A. H., Lubis, Z., & Siregar, A. H. (2019). Studi efektivitas pada mesin pencacah daun teh Open Top Roller menggunakan metode Overall Equipment Effectiveness. DINAMIS, 7(1), 11. https://doi.org/10.32734/dinamis.v7i1.7144