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Productivity Measurement of Fried Onion Production After Hot Air Dryer Implementation

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Abstract

Conventional sun drying in fried onion production causes weather dependency, prolonged processing time, inconsistent schedules, and limited production capacity, particularly for Micro, Small, and Medium Enterprises (MSMEs). This study evaluates the impact of implementing a Hot Air Dryer (HAD) system on production productivity at UD. Dua Sejati, Banyuwangi, Indonesia. A before-and-after comparative design was employed, with data collected over five working days before and after HAD implementation. Productivity was assessed using the partial productivity approach, comparing output against labor hours and process time. The results showed that the HAD system reduced drying time by 58.3% and overall production cycle time by 38.7%. Consequently, daily production capacity increased by 63.1%, while labor and process productivity both improved by approximately 63%, achieved without additional labor or working hours. This study contributes novelty by empirically quantifying the productivity impact of drying technology implementation—a dimension largely overlooked in previous research that focused predominantly on drying kinetics and energy efficiency. The findings demonstrate that HAD technology is a practical and economically feasible solution for eliminating production bottlenecks, enhancing operational performance, and improving competitiveness in food-processing MSMEs. These results offer valuable guidance for similar enterprises seeking low-cost technological innovation to achieve sustainable production.

Keywords: Hot Air Dryer, fried onion, productivity measurement, production capacity, partial productivity, MSMEs.

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1. Introduction

The fried onion industry is a strategic subsector for Indonesian Micro, Small, and Medium Enterprises (MSMEs), supported by the increasing availability of shallot production and the growing demand for processed shallot products in Indonesia [11], [19], [20]. UD. Dua Sejati in Banyuwangi, which supplies fried onions to hotels and restaurants in Bali, represents the operational challenges commonly encountered by small-scale food-processing enterprises. Conventional sun drying remains highly dependent on weather conditions, resulting in prolonged processing time, inconsistent product quality, and hygiene concerns, particularly because fresh shallots contain a high initial moisture content that must be substantially reduced before frying [1], [2], [4], [14]. Consequently, the drying stage becomes the primary production bottleneck, restricting production capacity and reducing schedule reliability for MSMEs [6], [7], [15].

Although Hot Air Drying (HAD) technology has been extensively studied and demonstrated to provide stable and controlled moisture removal, improved drying efficiency, and better product quality than traditional drying methods [2], [4], [5], [18], [29], existing studies have predominantly focused on drying kinetics, energy consumption, thermal performance, and product quality characteristics [4], [5], [9], [13], [14], [17], [23], [28], [29]. Limited attention has been given to evaluating how the implementation of HAD influences overall production productivity at the enterprise level.

At the same time, productivity evaluation in manufacturing and food-processing SMEs has generally relied on multi-factor productivity frameworks, including eco-productivity and Multi-Factor Productivity Measurement Models (MFPMM), which integrate multiple input variables and performance indicators [7], [10], [21]. While these approaches provide comprehensive assessments, they require extensive operational data and are less suitable for directly measuring the productivity effect of a single technological intervention. More importantly, they do not explicitly isolate the contribution of a production technology, such as HAD, to improvements in production throughput.

Therefore, a clear research gap exists in quantitatively evaluating how drying technology adoption affects production productivity in fried onion MSMEs. This study addresses this gap by applying a partial productivity approach that compares production output with labor hours and processing time, enabling the direct measurement of productivity changes attributable to HAD implementation without the complexity of multi-factor productivity models. The novelty of this study lies in empirically quantifying productivity before and after the integration of HAD to demonstrate how eliminating the drying bottleneck improves production capacity and operational efficiency without increasing labor input or working hours. The findings provide practical empirical evidence for MSMEs seeking cost-effective technological innovation to enhance operational sustainability and long-term competitiveness.

2. Methods

2.1 Research Design

This study employed a before-and-after comparative design with a one-group pretest–posttest approach, selected to evaluate the impact of a Hot Air Dryer (HAD) intervention on productivity within the same production system. This design is standard in applied Industrial Engineering for assessing technological improvements [24]. Data were collected during two distinct periods: pre-implementation (conventional sun drying) and post-implementation (HAD system), following a one-week operator adaptation period.

2.2 Data Collection and Procedure

The study was conducted at UD. Dua Sejati, Banyuwangi, from April to June 2023. Primary data—production time (stopwatch), output (kg), and labor hours—were collected through direct observation over five working days before and five days after HAD implementation. The five-day period was chosen to capture normal operational variability and ensure representative averages [26]. Secondary data were obtained from company records and interviews.

To ensure fair comparability, all non-intervention parameters were strictly controlled: raw material quality, batch size (25 kg/cycle), number of workers (4 persons), and effective working hours (8 hours/day) remained identical between periods. This design ensures that any observed performance difference is directly attributable to the HAD system.

The research procedure consisted of: (1) problem identification and production process mapping to locate bottlenecks [27]; (2) baseline (pre-HAD) measurement; (3) HAD system design, fabrication, and installation (1×1 m chamber, briquette-fueled heating, 60–70°C operating temperature); (4) one-week operator adaptation; (5) post-HAD measurement under identical conditions; and (6) productivity calculation and comparative analysis.

2.3 Productivity Measurement

Productivity was evaluated using the partial productivity approach—the ratio of output to a single input—which directly isolates the contribution of HAD implementation, unlike complex multi-factor models (e.g., OMAX/APC) that require extensive weighting and are less practical for MSMEs [21], [30].

Two partial productivity indicators were used:

- Labor Productivity = Output (kg) / Labor hours (labor-hour)
- Process Productivity = Output (kg) / Processing time (hour)

Improvement percentages were calculated as:

$$\text{Improvement} = \frac{\text{Value}_{after} - \text{Value}_{before}}{\text{Value}_{before}} \times 100\% \tag{1}$$

2.4 Statistical and Uncertainty Analysis

To strengthen validity, descriptive statistics (mean and standard deviation) were computed for all measured variables across the five-day observation periods. The Coefficient of Variation (CV) was calculated to assess data consistency, and a paired t-test (α = 0.05) was applied to determine whether observed differences in production time and output were statistically significant. Measurement uncertainty was also accounted for, with stopwatch accuracy of ±0.1 seconds and weighing scale precision of ±0.01 kg.

3.Results and Discussion

This section presents the main findings of the study, including the analysis of the existing production process, the specification and implementation of the Hot Air Dryer (HAD) system, comparisons of production time and production capacity, and productivity measurement. The results are presented in the form of tables and figures and are comprehensively discussed by comparing them with findings reported in previous studies [2], [7], [8], [9].

3.1 Existing Production Process

Before the implementation of the Hot Air Dryer (HAD), the fried onion production process at UD. Dua Sejati consisted of six main stages: raw material receiving, peeling and slicing, washing, conventional drying, frying, and packaging. During the conventional production process, onion slices were dried by direct exposure to sunlight in an open area, as shown in **Figure 1**.

(a) Before Sun Drying (b) After Sun Drying

Figure 2. Onion Slices Before & After Conventional Drying

Based on direct field observations, the conventional drying process required an average of 180 minutes (3 hours) for each production batch. However, the drying duration was highly dependent on solar radiation intensity and ambient humidity. Under cloudy or rainy weather conditions, the drying process frequently exceeded 5 hours and, in some cases, had to be postponed until the following day. Such variability directly disrupted production scheduling and reduced the overall efficiency of the production system. Similar limitations of conventional sun drying have been widely reported in previous studies, which indicate that weather-dependent drying results in unstable drying performance, inconsistent product quality, and lower production efficiency [2], [3], [10], [16], [27].

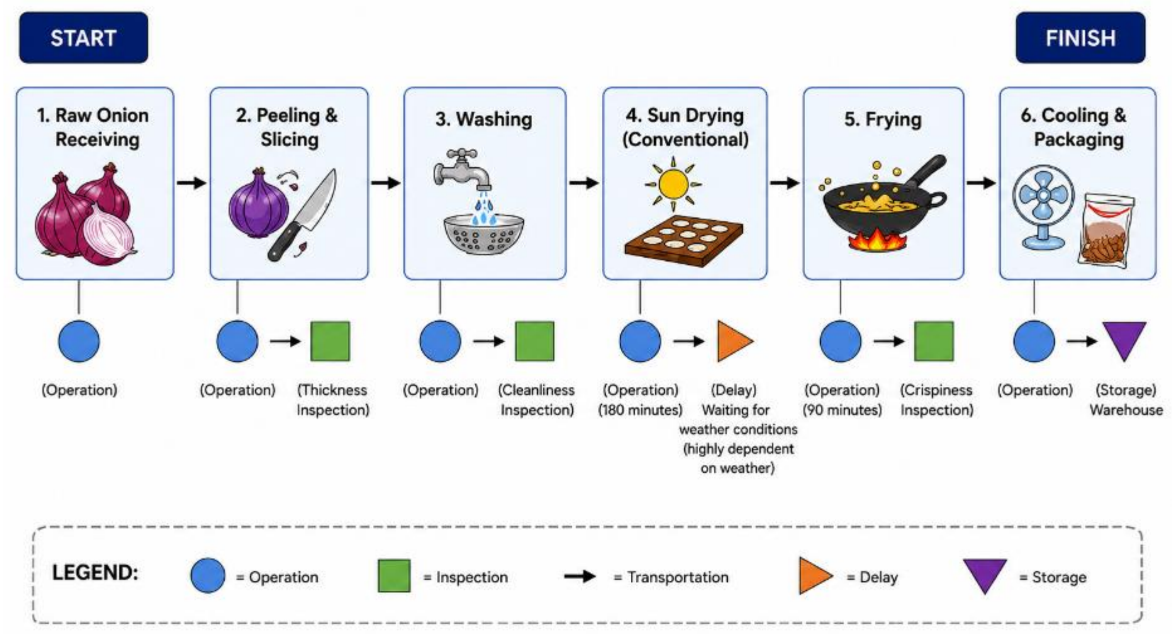

Figure 2. Flow Process Chart of the Existing Fried Onion Production Process

The following flow process chart illustrates the existing fried onion production process at UD. Dua Sejati using standard Flow Process Chart (FPC) symbols. (Notation: ○ = Operation, □ = Inspection, → = Transportation, ▷ = Delay, ∇ = Storage). As shown in **Figure 2**, the drying and frying stages require the longest processing times, averaging 180 minutes and 90 minutes, respectively. In addition, the drying stage includes a delay (▷) symbol because the process depends on favorable weather conditions before it can proceed. This indicates that drying is the primary bottleneck in the production system. These findings are consistent with those reported by Rahayu and Berlian [1], who stated that the high moisture content of raw onions significantly prolongs the frying process.

3.2 Implementasi Hot Air Dryer (HAD)

Based on the bottleneck identified in the existing production process, a Hot Air Dryer (HAD) system was designed and fabricated as an appropriate technological solution to improve the drying process [22]. The dryer was installed at the production facility of UD. Dua Sejati in May 2023. Following the installation, the production operators were given a one-week adaptation period before post-implementation data collection was conducted, as shown in Figure 3.

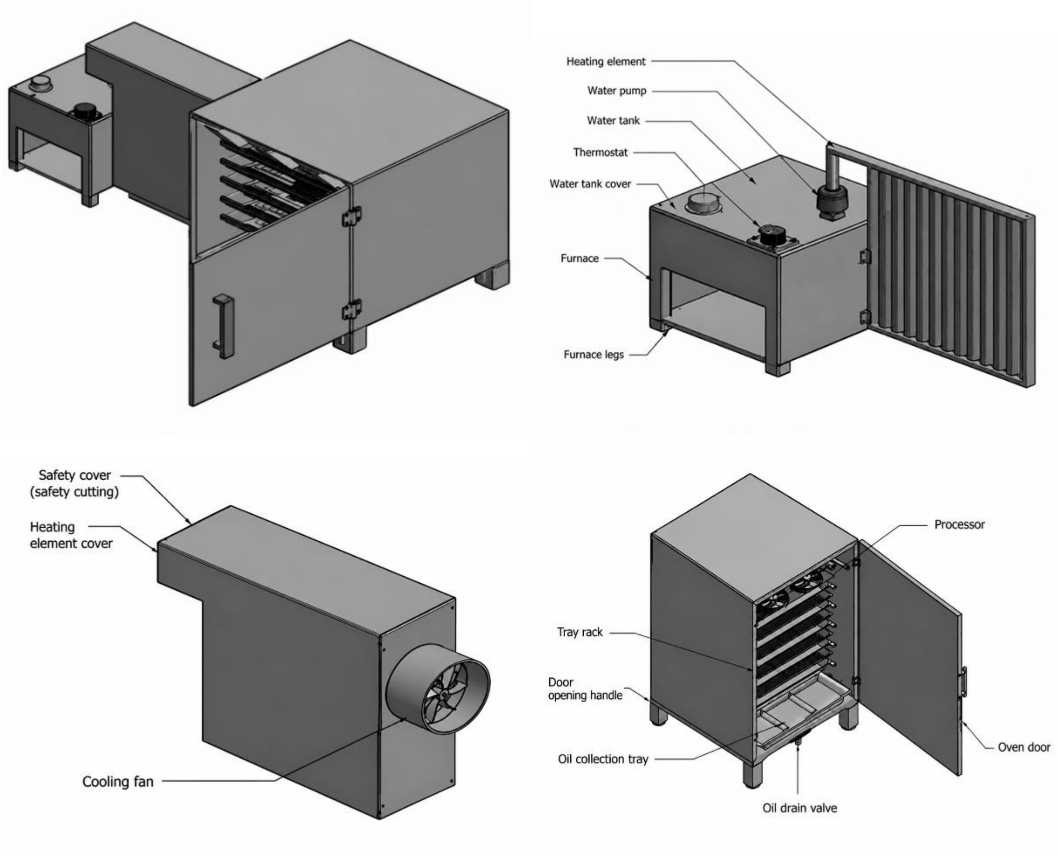

Figure 3. Hot Air Dryer (HAD) System Installed at UD. Dua Sejati

Hot Air Dryer (HAD) installed at UD. Dua Sejati shown in Figure 3. The dryer features a 1 × 1 m drying chamber and a briquette-fueled hot-air circulation system designed for drying sliced onions. The technical specifications of the developed Hot Air Dryer are presented in Table 1.

Table 1. Technical specifications of the Hot Air Dryer (HAD)

Component	Specification
Drying chamber dimensions	1 m × 1 m × 1,2 m
Drying chamber material	2-mm aluminum plate, thermal insulation
Heat transfer system	Copper pipes (½-inch diameter)
Heating medium	Industrial oil heated by charcoal briquettes
Air circulation	Steel fan blades with a 200-W blower
Temperature control	Thermostat controller (30–90°C)
Frame	Hollow steel 4×4 cm dan 2×2 cm
Capacity per batch	25–30 kg of sliced onions
Fuel	Charcoal briquettes
Optimum operating temp	60–70°C
Average drying time	75 minutes

The Hot Air Dryer operates as follows. Charcoal briquettes are combusted to heat industrial oil contained within a closed heating chamber. The heated oil is circulated through copper pipes, which function as a heat exchanger, transferring thermal energy to the surrounding air. A blower and steel fan blades then distribute the heated air uniformly throughout the drying chamber, maintaining a stable air temperature of approximately 60–70°C. Sliced onions are placed on perforated trays arranged in a multilayer configuration, allowing hot air to circulate evenly around each layer and ensuring uniform drying. The thermostat continuously regulates the chamber temperature to prevent excessive heating that could cause product deterioration or oxidation while maintaining sufficient thermal energy to achieve efficient drying performance. Such controlled hot-air circulation and temperature regulation are consistent with previous studies demonstrating that stable drying temperatures improve moisture removal efficiency, product quality, and energy utilization in onion drying systems [2], [9], [12], [18].

3.3 Production Process and HAD Implementation

Before HAD implementation, UD. Dua Sejati relied on conventional sun drying requiring 180 minutes per batch, with delays exceeding 5 hours under cloudy conditions. Process mapping identified drying as the primary bottleneck, consistent with findings that high moisture content (88%) in fresh shallots significantly prolongs processing [1], [27].

The installed HAD system (1×1 m chamber, 60–70°C operating temperature, charcoal briquette fuel) reduced drying time to 75 minutes (58.3% reduction) and frying time from 90 to 50 minutes (44.4% reduction). Total cycle time decreased by 38.7% from 375 to 230 minutes (Table 1). The frying time reduction occurred indirectly due to lower and more uniform moisture content after HAD treatment, allowing faster moisture evaporation during frying [2], [4], [18], [25].

Table 2. Comparison of production time before and after HAD

Process Stage	Before (min)	After (min)	Reduction (%)
Drying	180	75	58.3%
Frying	90	50	44.4%
Total Cycle	375	230	38.7%

3.4 Production Capacity and Productivity Improvement

Daily production capacity increased from 32.0 to 52.2 kg/day (63.1%), while monthly capacity rose from 800 to 1,305 kg (assuming 25 working days). These gains were achieved without additional labor or working hours (4 workers, 8 hours/day).

Table 3. Production capacity and productivity comparison

Parameter	Before	After	Improvement
Daily capacity (kg/day)	32.0	52.2	+63.1%
Labor productivity (kg/labor-hr)	1.00	1.63	+63.0%
Process productivity (kg/hr)	4.00	6.52	+63.0%
Critical time ratio	56.3%	26.0 %	Reduced

Labor productivity improved from 1.00 to 1.63 kg/labor-hour, while process productivity increased from 4.00 to 6.52 kg/hr—both representing 63% gains. The critical time ratio (drying + frying time as proportion of total production time) decreased from 56.3% to 26.0%, confirming bottleneck elimination. According to the Theory of Constraints, removing the primary bottleneck increases system throughput without additional resources [27].

Statistical validation: Mean values across five observation days showed low variability (CV < 5%), and paired t-test results confirmed significant differences ($p < 0.05$) for drying time, frying time, and daily output between pre- and post-HAD periods.

3.5 Extended Discussion: Energy, Economics, Sustainability, Quality, and Supply Chain

1) **Energy Consumption**

   The HAD system operates at 60–70°C using charcoal briquettes as fuel, consuming approximately 2.5 kg of briquettes per batch (75 minutes). Compared to electric ovens (typically 3–5 kW), this represents significant energy cost savings. Djaeni et al. [35] reported that controlled hot-air drying at similar temperatures achieves optimal energy efficiency, while EL-Mesery et al. [18] demonstrated that uniform airflow distribution minimizes energy losses. The 58.3% reduction in drying time directly translates to lower cumulative energy consumption per production cycle.

2) **Economic Feasibility**

   The HAD system was fabricated using locally available materials (aluminum, copper pipes, steel frame) at an estimated cost of IDR 8–10 million, with charcoal briquettes costing approximately IDR 15,000–20,000 per day. The 63.1% capacity increase enables additional monthly revenue of approximately IDR 10–12 million (based on fried onion market price of IDR 25,000–30,000/kg), suggesting a payback period of less than 3 months. This economic viability is critical for MSMEs with limited capital [3], [7].

3) **Operational Sustainability**

   By eliminating weather dependency, the HAD system enables consistent year-round production, predictable scheduling, and reliable customer supply—particularly important for hotel suppliers requiring stable delivery [15]. Reduced processing time also lowers worker fatigue and improves labor utilization. The use of renewable biomass (charcoal briquettes) aligns with sustainable production practices [6].

4) **Product Quality and Supply Chain Benefits**

   Although moisture content was not directly measured in this study, the observed 44.4% frying time reduction indirectly confirms lower residual moisture, as supported by previous studies [2], ,[4], [5], which reported that HAD-treated onions achieve moisture content below 10% with superior texture and color retention. Lower moisture content also improves product shelf life, reduces packaging requirements, and lowers transportation costs due to weight reduction [6]. These quality improvements enhance customer satisfaction and strengthen supply chain relationships with hotel buyers.

Table 4. Multi-Dimensional Benefits of HAD implementation

Aspect	Benefit	Evidence/Reference
Energy	Lower energy consumption per batch	[18], [28]
Economic	Payback period < 3 months	Calculated from capacity increase
Sustainability	Year-round production, renewable fuel	[6]
Quality	Better texture, longer shelf life	[2], [5]
Supply Chain	Reliable delivery, lower transport cost	[15], [6]

5) **Implications and Limitations**

These findings demonstrate that appropriate drying technology significantly enhances MSME competitiveness through improved productivity, consistent quality, and operational reliability. The HAD system offers a practical, low-cost solution adaptable to similar enterprises.

Limitations include: (1) partial productivity measurement only (excluding capital and energy inputs); (2) no direct moisture content measurement; and (3) single case study design. Future research should incorporate full cost-benefit analysis, moisture and quality testing, and multi-site validation.

4. Conclusion

This study successfully demonstrates that implementing a Hot Air Dryer (HAD) effectively eliminates the primary drying bottleneck in fried onion production at UD. Dua Sejati. The intervention resulted in substantial improvements in daily production capacity and partial productivity—both labor and process productivity—by approximately 63%, achieved without additional workers or extended working hours.

The primary contribution of this research lies in empirically linking specific drying technology adoption to overall production system performance, a dimension largely overlooked in prior studies that focused predominantly on drying kinetics and energy efficiency. This provides a novel perspective within Industrial Engineering for evaluating technological interventions in MSME contexts.

Practically, the HAD system, which utilizes locally sourced charcoal briquettes, offers a cost-effective and operationally sustainable solution. By eliminating weather dependency, it enables consistent year-round production, reliable supply chains, and enhanced competitiveness for small-scale fried onion producers, serving as a replicable model for similar food-processing MSMEs seeking low-cost technological innovation.

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Authors' Declaration

Authors' contributions and responsibilities - The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation, and discussion of results. The authors read and approved the final manuscript.

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Competing interests - The authors declare no competing interest.

Additional information - No additional information from the authors.

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