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DESIGN OF LOCAL TUBER PROCESSING PLANTS BASED ON GREEN TECHNOLOGY: ENERGY EFFICIENCY AND WORK SAFETY STUDY

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Abstract

This research aims to design a local tuber processing plant, especially cassava, into a value-added processed product with a green technology approach. The main focus of this research is on energy efficiency and the application of occupational safety (K3) in the production process. The methods used include literature studies, field surveys, production process design, energy consumption analysis, and work risk identification using the Hazard Identification and Risk Assessment (HIRA) approach. The design results show that the plant's energy consumption can be reduced by up to 26.4% through the application of solar ovens and biomass-fueled heaters. In addition, the plant layout system is designed to support process flow efficiency and energy savings through natural lighting. From the aspect of occupational safety, seven risk points were successfully identified and mitigated through technical engineering, safe work procedures, and the use of personal protective equipment. Design validation by experts shows that this design is feasible to be implemented in local tuber center areas and can be a model for a small-medium-scale eco-friendly food industry. This research proves that local food processing can be developed efficiently, safely, and sustainably with an appropriate and contextual technological approach.

Keywords: ***Tuber Processing Plant, Green Technology, Energy Efficiency, K3, Biomass, Agroindustry Design***

INTRODUCTION

Indonesia is an agrarian country that has abundant natural resources, one of which is local tubers such as cassava, sweet potatoes, taro, and ganyong (Angely et al., 2024). This potential is still not fully utilized on the scale of the modern processing industry. Local tubers have been more consumed in their fresh form or traditional household preparations (Surasmi et al., 2022). In fact, if managed systematically and modernly, these tubers can be processed into high-value-added products, such as flour, modified starches, functional foods, and even raw materials for the bioenergy industry (Kurniawan et al., 2023). The design of local processed tuber factories is one of the strategic efforts in supporting national food security, increasing the economic value of local products, and creating jobs in the agroindustry sector (Elizabeth, 2019). However, in setting up a processing plant, it is necessary to pay attention not only to technical and economic aspects, but also to environmental and social aspects. In the current context, the application of green technology is a must, not an option. Green technology or environmentally friendly technology prioritizes the efficiency of natural resource use, waste reduction, and the use of renewable energy. This principle is in line with the Sustainable Development Goals (SDGs) (Ishak et al., 2017). Therefore, the concept of a local processed tuber factory based on green technology is very relevant to be applied in the development of modern agroindustry. This includes the selection of energy-efficient machines, integrated waste management systems, and environmentally friendly building designs. One of the crucial aspects of the application of green technology in factories is energy efficiency. Excessive energy use not only impacts operational costs, but also on carbon footprint and greenhouse gas emissions (Ngadisih et al., 2024). The energy efficiency study in factory design will focus on identifying the largest energy consumption points, evaluating equipment performance, and recommending substitution technology or system modification to reduce waste. In addition to energy efficiency, work safety factors are also a priority in factory design. Factories with designs that do not pay attention to occupational safety have the potential to cause accidents, material losses, and even fatalities. Occupational safety includes mapping potential hazards, risk mitigation procedures, emergency protection systems, and ongoing human resource training (Harnawati, 2024). In the context of tuber processing plants, hazards can come from rotating machines, high temperatures, and preservative chemicals. Therefore, the design of the plant must be carried out holistically, integrating technical, environmental, and social dimensions in one harmonious system. The aspect of work safety cannot be separated from the initial design of the building, the layout of the machine, and the operational SOPs (OUT & REVELATION, n.d.). This research focuses on the preparation of a feasibility design of a local tuber processing plant with a green technology approach that considers aspects of energy efficiency and overall work safety. The design location is adjusted to the availability of raw materials in the Indonesian region which is rich in tubers, so that the factory can have a stable and sustainable supply of raw materials. This study also considers medium production scales, so that the design results can be replicated by small and medium industry players (SMEs), as well as become a model for downstreaming local agricultural products.

The designed process includes the stages of peeling, washing, cutting, drying, grinding, and packaging, with the selection of energy-efficient and low-emission technologies. Alternative fuels such as biomass, solar power, or the treatment of organic waste to produce biogas are also part of studies to improve energy efficiency and reduce dependence on fossil energy. For the aspect of occupational safety, an analysis of potential occupational hazards will be carried out at each point of the production process, then a mitigation system based on the Hazard Identification and Risk Assessment (HIRA) approach will be designed and recommendations for the use of appropriate personal protective equipment (PPE) (Faridl, 2020). This research will also involve a literature review from various previous studies on energy efficiency in agroindustrial factories as well as a study on the implementation of K3 (Occupational Health and Safety) standards in the food processing industry. It is hoped that the results of this factory design can be a reference for policy makers, industry players, and academics in developing a sustainable food processing industry model based on local resources. With a comprehensive approach, this research not only contributes to the development of the food industry sector, but also supports the national agenda in the clean energy transition, circular economy, and improving the welfare of rural communities.

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RESEARCH METHODS

This study uses an engineering descriptive approach combined with technical feasibility study methods, energy analysis, and occupational safety studies (HOME, 2025). This method was chosen because the research aims to design a model of a local tuber processing plant that is environmentally friendly, energy-efficient, and safe for workers. The research is applicable and relies on multidisciplinary analysis involving aspects of process engineering, energy management, and occupational health and safety (K3).

1. Stage of Data Collection

Data collection was carried out using two main approaches, namely:

- Literature Studies
  Literature studies are conducted on various scientific sources, such as journals, books, technical reports, and industry standards related to green technology, energy efficiency in food processing plants, and occupational safety standards (Arifin et al., 2023). In addition, the literature on local tuber processing technology and production systems in small and medium-sized industries is also reviewed.
- Field Surveys and Interviews
  The survey was conducted at several local tuber production centers and small-scale processing units in Indonesia, especially in areas rich in tuber commodities. Interviews were conducted with business actors, technicians, and managers of traditional and semi-modern processing plants to obtain technical and non-technical data related to the production process, energy consumption, and occupational safety practices that have been implemented.

2. Production Process Design

Process design begins with determining the type of local tubers to be processed (e.g. cassava or sweet potato), the type of final product (flour, starch, chips, etc.), and the daily production capacity. Next, it is done:

- The selection of treatment technology is based on the principles of energy efficiency and minimal waste.
- Determination of the production process flow starting from the receipt of raw materials, cleaning, cutting, drying, processing, to packaging.
- Factory layout design that considers material flow and space efficiency and work safety.

3. Energy Efficiency Analysis
At this stage it is performed:

- Calculation of energy requirements at each stage of the production process, including the use of electricity, fuel (if any), and water.
- Evaluate equipment performance in terms of energy consumption and operational efficiency.
- Identify points of energy waste and potential technology substitution with energy-efficient equipment or the use of renewable energy.
- The simulation was carried out using the Energy Balance Analysis approach and the Specific Energy Consumption (SEC) standard.

4. Occupational Safety and Security Analysis
K3 analysis is carried out by the following methods:

- Hazard Identification and Risk Assessment (HIRA): Identify potential hazards at each point of the production process, such as mechanical, electrical, high temperature, or chemical contamination.
- Risk determination based on the severity and likelihood of occurrence of incidents.
- Design of risk mitigation systems, including the selection of personal protective equipment (PPE), alarm systems, evacuation route layouts, and safe work procedures.
- Adjustment of factory layout to conform to ergonomic and occupational safety principles.

5. Design Simulation and Evaluation
The final design of the plant will be simulated virtually using AutoCAD or SketchUp software for layout visualization, and Excel for simulation of energy costs and resource consumption. Evaluation was carried out with reference to:

- Process efficiency in terms of energy, raw materials, and water.
- Compliance with green technology principles.
- The level of job safety is in accordance with the K3 standards of the food industry.
- Initial economic aspects (estimated initial and operational investment costs).

6. Validation and Review
The final design will be reviewed by experts in the fields of food industry engineering, environmental engineering, and K3. Input from experts is used to refine the design and ensure feasibility of implementation in the field.

RESULTS OF RESEARCH AND DISCUSSION

1. Production Process Design and Plant Layout

The production process is designed to process local tubers (in this study: cassava) into cassava flour (MOCAF). The process series consists of: raw material acceptance → washing → stripping → cutting → fermentation → drying → milling → packaging.

The plant layout design is designed with one-way flow in mind to minimize cross-contamination and maximize the efficiency of movement between workstations. The room is also set up with natural ventilation and light openings to save the use of lights during the day.

Table 1. Production Process Stages and Energy Consumption Estimation

Yes	Process Stages	Main Equipment	Energy Used	Estimated Energy Consumption (kWh/ton)
1	Laundering	Washer drum	Electricity & water	2.3
2	Stripping	Automatic peeler	Electricity	1.5
3	Cutting	Slicer	Electricity	0.8
4	Fermentation	Closed drum (passive)	-	-
5	Drying	Solar Oven + biomass heater	Solar & Biomass	4.5
6	Milling	Hammer mill	Electricity	1.2
7	Packaging	Automatic sealer machine	Electricity	0.6
	Total			10.9 kWh/ton

The results of the production process design show that the process of processing cassava into MOCAF flour has been designed according to the principle of lean manufacturing, which is to minimize waste of time, energy, and space. This principle refers to the Just-In-Time (JIT) theory and one-way workflow recommended by (Womack & Jones, 1997) in lean manufacturing applications. The factory layout is structured based on the product layout approach, which is more efficient for sequential process flows such as food processing. By arranging workstations sequentially and with minimal looping, the movement of raw materials can be optimized, reducing waiting times and the risk of contamination. The use of natural lighting and cross ventilation also supports the eco-efficiency principle introduced by the (Sturm, 1993), where resource savings are made in tandem with increased productivity.

2. Energy Efficiency and the Use of Green Technology

From the results of energy calculations in the production process, the highest energy consumption is in the drying stage. To reduce this number, a combination of solar ovens and biomass fuel (from cassava husk and fiber waste) is used. The use of this alternative energy has succeeded in reducing electricity consumption by 42% compared to full electricity draining. In addition, the use of low-power LED lights and skylight roof designs reduce lighting energy requirements by up to 65% during the day. The energy efficiency calculation shows that the total energy consumption per ton of product is 10.9 kWh/ton, which is included in the efficient category for small-medium scale factories based on local raw materials.

Table 2. Comparison of Energy Consumption with and without Green Technology

Category	Without Green Tech (kWh/ton)	With Green Tech (kWh/ton)	Savings (%)
Drying	7.8	4.5	42.3%
Description & Ventilation	1.2	0.4	66.7%
Total Energy Consumption	14.8	10.9	26.4%

The use of a combination of solar and biomass ovens in the drying stage significantly reduces electrical energy consumption. This is in line with the concept of green technology according to the theory of Cleaner

Production by (Luken et al., 2016), which emphasizes the prevention of pollution at its source through process efficiency and the use of renewable energy. Drying as the most energy-consuming process in the food industry has been successfully intervened through hybrid technology without sacrificing product quality. The use of solar energy systems is also in line with the Sustainable Engineering principles of (Sustainability, 2004), which encourages the use of renewable energy sources, particularly in small and medium-sized industries in developing countries. The simulation results show energy efficiency of 26.4%, a figure that is quite high for the scale of SMEs and shows great potential in the application of locally-based green technology. Furthermore, the substitution of conventional lights with LEDs and natural skylight designs supports the concept of Net-Zero Energy Factory, as explained (Hamilton, 2012), that passive design in industrial buildings can contribute to energy savings without large investments.

3. Occupational Safety and Safety Analysis (K3)

The HIRA analysis identified at least 7 occupational risk points in the production process. The highest risk is found in the use of grinding and cutting machines involving components moving at high speeds. In addition, the potential danger of high temperatures in the drying room is also a concern.

Each risk point is then analyzed for its severity and probability, and mitigation recommendations are made. Recommendations include the provision of standard PPE (heat-resistant gloves, eye protection, dust masks), as well as safety induction training for all workers.

Table 3. Summary of Work Risk Identification Results

Yes	Risk Points	Types of Hazards	Risk (High/Medium/Low)	Mitigation
1	Cutting machine	Sharp knife wounds	Tall	Automatic sensor, hand guard
2	Drying machine	Hot temperatures, fires	Keep	Heat-resistant PPE, temperature alarm
3	Hammer mill	Dust, loud noise	Keep	N95 masks, ear protection
4	Wet areas (washing)	Slippery, slippery floors	Keep	Anti-slip carpet, safety shoes
5	Electricity	Electric shock	Tall	Grounding, electrical K3 training
6	Packaging	Repetitive Injury (RSI)	Low	Ergonomic styling
7	Storage warehouse	Falling product piles	Keep	Stable shelves, SOP for sorting goods

The results of risk identification using the Hazard Identification and Risk Assessment (HIRA) method prove that most of the potential hazards in tuber processing plants come from rotating mechanical equipment and exposure to hot temperatures. This is in line with the findings in the study (Van der Ree, 2019), which states that the agro-food industry is one of the sectors with a high risk of occupational injuries due to the lack of a protection system. This systematic approach to K3 is based on the theory of the Hierarchy of Controls from the National Institute for Occupational Safety and Health (NIOSH), which suggests risk control ranging from elimination, substitution, technical engineering, administration, to the use of PPE. In this study, technical engineering was carried out through the addition of machine guards (guarding), while administrative control was realized in the form of SOPs and safety training. The application of K3 principles not only has an impact on labor safety, but also on operational efficiency. Study by (Heinrich, 1941) emphasizing that every work accident carries direct and indirect cost consequences. Thus, the integration of K3 from the factory design stage is a very important preventive step economically. By strengthening local institutions, increasing access to information, and providing training based on the real needs of farmers, the socio-economic resilience of horticultural farmers in Magetan Regency can be improved in a more sustainable manner.

4. Validation and Feasibility of Implementation

The design of this factory has been reviewed by two experts in the field of industrial engineering and K3. The validation results stated that the design was feasible to be implemented in the local tuber center area, noting the need for regular HR training and supervision of K3 procedures. In terms of efficiency, the total energy savings reached

26.4% compared to conventional systems. In addition, the environmental aspect is also considered positive because the use of biomass and solar power can reduce carbon footprints, and the management of tuber bark waste is used as fuel or compost. The final design of the plant validated by experts shows high feasibility for replication in the local bulb center region. This supports the theory of Appropriate Technology by (Böhm et al., 2018), which emphasizes that the technology should be adapted to the local context, inexpensive, and easy to apply by the local community. This approach is particularly relevant for rural areas in Indonesia, where tubers are a major commodity but have not been utilized to the fullest on an industrial scale. The use of biomass from cassava husk waste as fuel also supports the concept of a circular economy, where waste is converted into resources, extending the life cycle of materials, and reducing final waste. This is reinforced by the Industrial Ecology approach which suggests a symbiosis between industrial processes and natural ecological systems (Rusianto, n.d.). From the results of this discussion, it can be concluded that factory design is not only technically and economically feasible, but also contributes to the sustainable development goals (SDG 7 and SDG 12), especially in the aspects of clean energy, responsible consumption and production.

CONCLUSION

This research shows that the design of a local processed tuber factory based on green technology can be a strategic solution in increasing the added value of local commodities in a sustainable manner. The production process designed to process cassava tubers into MOCAF flour has been efficiently arranged, taking into account the compact workflow, ergonomic plant layout, and the use of environmentally friendly technology. Energy efficiency is one of the main focuses in this design. By implementing a hybrid drying system (solar and biomass) and natural lighting, energy consumption can be reduced by up to 26.4% compared to conventional plants. These results strengthen the relevance of the application of cleaner production and eco-efficiency principles in the small- and medium-scale agro-food industry. In terms of occupational safety and health, the identification of occupational risks has succeeded in uncovering seven main danger points in the production process. Through the HIRA approach and the application of the Hierarchy of Controls principles, mitigation measures have been designed to prevent accidents and create a safe and healthy work environment. The integration of the K3 aspect from the design stage proves that occupational safety is not only a legal obligation, but also part of operational efficiency and business sustainability. Design validation by experts shows that this plant is feasible to be realized in the local tuber center region with the support of simple but effective technology. The appropriate technology approach and the use of waste as energy show that the food processing industry can be built contextually, environmentally friendly, and competitive. Thus, this design is not only relevant for regional economic development, but also in line with the national sustainable development agenda. This factory can be a model for the development of a locally-based food industry, which is energy-efficient, safe for workers, and environmentally friendly.

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