2.0 CHAPTER TWO

2.1 Introduction

The drying of cocoa seeds is a critical step in the post-harvest processing of cocoa beans, which significantly affects the quality and flavor of the final product (Afoakwa, 2014). Traditional drying methods, such as sun drying, are often time-consuming, labor-intensive, and susceptible to weather conditions, which can lead to inconsistent quality and potential contamination (Bart-Plange et al., 2012). Solar drying, on the other hand, offers a promising alternative, providing a controlled environment that can enhance the quality and efficiency of the drying process (Duffie & Beckman, 2013).

The integration of automation in solar drying systems can further improve the drying process by ensuring optimal temperature, humidity, and air flow conditions, thereby reducing drying time and improving product quality (Shahzad et al., 2019). This chapter focuses on the development of a prototype solar automated cocoa seed dryer, designed to optimize the drying process and improve the quality of cocoa beans.

2.1.2 Importance of Solar Drying in Cocoa Production

Solar drying can improve the quality of cocoa beans by reducing moisture content and preventing mold growth. This method is particularly beneficial in tropical regions where sunlight is abundant. According to Afoakwa (2014), traditional drying methods can result in significant post-harvest losses, which can be reduced by using solar dryers [1].

2.1.3 Benefits of Automated Solar Dryers

Automated solar dryers can further improve the drying process by ensuring optimal temperature, humidity, and air flow conditions. This can lead to reduced drying time, improved product quality, and increased efficiency. Shahzad et al. (2019) emphasize the importance of testing and debugging in ensuring the optimal performance of solar dryers.

2.2 Design Considerations

The design of a solar automated cocoa seed dryer requires careful consideration of several factors to ensure optimal performance and product quality. Climate and environmental factors, such as temperature, humidity, and solar radiation, play a significant role in determining the drying rate and quality of cocoa beans (Afoakwa, 2014). The design should also take into account the specific drying requirements of cocoa seeds, including temperature, humidity, and air flow rates (Bart-Plange et al., 2012).

2.2.1 Climate and Environmental Factors

The solar dryer's design should be tailored to the local climate and environmental conditions. For example, in tropical regions with high solar radiation, the dryer can be designed to maximize heat gain and minimize heat loss (Duffie & Beckman, 2013). In regions with high humidity, the design should incorporate features that enhance moisture removal, such as adequate ventilation and air flow (Shahzad et al., 2019).

2.2.2 Cocoa Seed Drying Requirements

Cocoa seeds require specific drying conditions to preserve their quality. The optimal temperature range for drying cocoa beans is between 40°C and 60°C, with a relative humidity of 50-60% (Afoakwa, 2014). The air flow rate should be sufficient to remove moisture from the drying chamber without causing excessive drying rates, which can lead to bean damage (Bart-Plange et al., 2012).

2.2.3 Solar Collector Design

The solar collector is a critical component of the solar dryer, responsible for capturing solar radiation and converting it into heat. The design of the solar collector should consider factors such as collector type, size, and material (Duffie & Beckman, 2013). Flat plate collectors or evacuated tube collectors can be used, depending on the desired temperature range and efficiency requirements.

2.2.4 Automation System Requirements

The automation system should be designed to monitor and control the drying process, ensuring optimal temperature, humidity, and air flow conditions. The system should include sensors for temperature, humidity, and air flow measurement, as well as control algorithms to adjust the drying conditions accordingly (Shahzad et al., 2019).

2.3 System Components

The solar automated cocoa seed dryer consists of several key components, including the solar collector, drying chamber, automation system, and other auxiliary components.

2.3.1 Solar Collector

The solar collector is responsible for capturing solar radiation and converting it into heat. Flat plate collectors or evacuated tube collectors can be used, depending on the desired temperature range and efficiency requirements (Duffie & Beckman, 2013). The collector should be designed to maximize heat gain while minimizing heat loss.

2.3.2 Drying Chamber

The drying chamber is where the cocoa seeds are dried. It should be well-insulated to minimize heat loss and designed to ensure uniform air flow and temperature distribution (Shahzad et al., 2019). The chamber should also be equipped with trays or racks to hold the cocoa seeds.

2.3.3 Automation System

The automation system is responsible for monitoring and controlling the drying process. It should include sensors for temperature, humidity, and air flow measurement, as well as control algorithms to adjust the drying conditions accordingly (Patel & Gami, 2017). The system can also include actuators to control fans, heaters, or other components.

2.3.4 Other Components

Other components that may be included in the solar automated cocoa seed dryer are:

- Fans or blowers to enhance air flow and moisture removal (Kumar et al., 2016)
- Heaters or backup heating systems to supplement the solar collector during periods of low solar radiation (Duffie & Beckman, 2013)

- Moisture removal systems, such as vents or condensers, to enhance drying rates (Shahzad et al., 2019)

2.4 Prototype Development

The development of a prototype solar automated cocoa seed dryer involves several key stages, including three-dimensional modeling, control module design, displacement module design, and removal module design. A study on the construction of an automated removal robot for natural drying of cacao beans highlights the importance of a modular design, comprising control, displacement, and removal modules, to ensure efficient and uniform drying (Tuanama-Aguilar, J., Ríos-López, C., Pasquel-Reátegui, J. L., Rodríguez-Grández, C., Santa-Maria, J. C., Cotrina-Linares, J., García-Estrella, C., & Fermin-Perez, F.-A. 2025)

2.4.1 Three-Dimensional Modeling

The first stage of prototype development is three-dimensional modeling, which allows designers to detail the structural and functional characteristics of the robot. This stage is crucial in ensuring that the robot meets specific requirements for automatic removal of cacao beans during natural drying. Software such as Blender can be used for 3D modeling, providing a widely used tool in design and simulation due to its versatility (Tuanama-Aguilar, J., Ríos-López, C., Pasquel-Reátegui, J. L., Rodríguez-Grández, C., Santa-Maria, J. C., Cotrina-Linares, J., García-Estrella, C., & Fermin-Perez, F.-A. 2025)

2.4.2 Control Module Design

The control module is a critical component of the prototype, responsible for driving the motor and directing the robot's operations. It includes a controller programmed in ladder language, a display for monitoring and adjusting parameters, and a communications switch for system interaction and control. A 24-volt power supply guarantees the robot's continuous power supply, while a 10 kΩ potentiometer allows for adjusting speed parameters in the frequency converter. (Tuanama-Aguilar, J., Ríos-López, C., Pasquel-Reátegui, J. L., Rodríguez-Grández, C., Santa-Maria, J. C., Cotrina-Linares, J., García-Estrella, C., & Fermin-Perez, F.-A. 2025)

2.4.3 Displacement Module Design

The displacement module comprises a motor connected to a reducing box, enabling the removal support to move forward and backward based on the motor's rotation direction. This system utilizes shafts with bearings linked to a drag chain, allowing for smooth and efficient movement. (Tuanama-Aguilar, J., Ríos-López, C., Pasquel-Reátegui, J. L., Rodríguez-Grández, C., Santa-Maria, J. C., Cotrina-Linares, J., García-Estrella, C., & Fermin-Perez, F.-A. 2025)

2.4.4 Removal Module Design

The removal module consists of fingers distributed in two batteries, with a vertical movement that allows them to adapt to the surface of the drying bed. Each finger has stops at the bottom and top to limit travel, ensuring efficient removal of cacao beans. (Tuanama-Aguilar, J., Ríos-López, C., Pasquel-Reátegui, J. L., Rodríguez-Grández, C., Santa-Maria, J. C., Cotrina-Linares, J., García-Estrella, C., & Fermin-Perez, F.-A. 2025)

2.4.5 Solar Power Supply

The prototype can be powered by solar panels, reducing dependence on non-renewable energy sources and minimizing the carbon footprint. A study on the construction of an automated removal robot for natural drying of cacao beans used twelve TrinaSolar TSM-455DE17M solar panels, each 455 W, and a Growatt SPF 5000 ES 48 V 100 A inverter charger. (Tuanama-Aguilar, J., Ríos-López, C., Pasquel-Reátegui, J. L., Rodríguez-Grández, C., Santa-Maria, J. C., Cotrina-Linares, J., García-Estrella, C., & Fermin-Perez, F.-A. 2025).

2.5 Control System Design

The control system design is a critical component of the solar automated cocoa seed dryer, responsible for monitoring and controlling the drying process. A well-designed control system ensures optimal temperature, humidity, and air flow conditions, thereby improving the quality and efficiency of the drying process (Shahzad et al., 2019).

2.5.1 Hardware Components

The control system hardware typically includes:

- Temperature sensors (e.g., thermocouples or thermistors) to measure the temperature of the drying chamber (Duffie & Beckman, 2013)

- Humidity sensors (e.g., capacitive or resistive) to measure the relative humidity of the drying chamber (Patel & Gami, 2017)
- Air flow sensors (e.g., anemometers) to measure the air flow rate in the drying chamber (Kumar et al., 2016)
- Actuators (e.g., fans, heaters, or valves) to control the drying conditions (Shahzad et al., 2019)

2.5.2 Software Components

The control system software typically includes:

- ➢ Control algorithms (e.g., PID or fuzzy logic) to adjust the drying conditions based on sensor feedback (Patel & Gami, 2017)
- ➢ Data acquisition and logging capabilities to monitor and record the drying process (Kumar et al., 2016)
- ➢ User interface capabilities to allow operators to set drying parameters and monitor the drying process (Shahzad et al., 2019)

2.5.3 Control Algorithms

The control algorithms used in the control system can significantly impact the performance of the solar automated cocoa seed dryer. Common control algorithms include:

- PID (Proportional-Integral-Derivative) control, which adjusts the drying conditions based on the difference between the setpoint and the actual value (Patel & Gami, 2017)
- Fuzzy logic control, which uses fuzzy logic rules to adjust the drying conditions based on sensor feedback (Kumar et al., 2016)

2.6 Prototype Testing and Debugging

Prototype testing and debugging is a crucial stage in the development of a solar automated cocoa seed dryer. This process involves evaluating the performance of the dryer under various conditions to identify and rectify any issues.

2.6.1 Testing Phase

The testing phase of the solar collector for drying cocoa involved installing two prototypes in different locations, Tumaco and Policarpa, with varying ambient temperatures and relative humidity. The results showed that the prototypes achieved a grain moisture content of 7% in 12 days, reducing the drying time by 4 days compared to traditional methods (Solar collector for Drying Cocoa: Prototype testing 2012).

2.6.2 Performance Evaluation

The performance evaluation of the automated removal robot for natural drying of cacao beans involved assessing its effectiveness in reducing moisture content and preserving phenolic compounds. The results showed that the robot-dried beans had lower standard deviations in moisture content, indicating more uniform drying. Additionally, the total phenolic content was higher in the robot-dried beans, suggesting better preservation of bioactive compounds (José Tuanama-Aguilar et al. Sensors 2025)

2.6.3 Debugging and Improvement

Based on the testing and performance evaluation, several areas for improvement were identified, including:

- Control of Airflow: The need to control airflow inside the panel to prevent humidity from affecting the drying process.
- Tilt Angle: Adjusting the tilt angle of the solar collector to optimize energy gain.
- Sensory Analysis: Conducting sensory analysis and cutting tests to evaluate the quality of the dried cocoa beans (Solar collector for Drying Cocoa: Prototype testing 2012).

2.7 Cost-Benefit Analysis

A cost-benefit analysis is essential to determine the economic feasibility of the solar automated cocoa seed dryer. This analysis compares the costs of developing and operating the dryer with the benefits of improved drying efficiency, reduced labor costs, and enhanced product quality.

2.7.1 Costs

The costs associated with the solar automated cocoa seed dryer include:

Initial investment costs (design, materials, and labor)

Operating costs (energy, maintenance, and repairs)

Replacement costs (components and parts)

According to Shahzad et al. (2019), the initial investment cost of a solar dryer can be higher than traditional drying methods, but the operating costs can be significantly lower

2.7.2 Benefits

The benefits of the solar automated cocoa seed dryer include:

Improved drying efficiency and reduced drying time (Shahzad et al., 2019)

Reduced labor costs and improved working conditions (Kumar et al., 2016)

Enhanced product quality and reduced post-harvest losses (Afoakwa, 2014)

Environmental benefits from using renewable energy (Duffie & Beckman, 2013)

2.7.3 Economic Feasibility

The economic feasibility of the solar automated cocoa seed dryer can be evaluated using various economic indicators, such as:

- Net present value (NPV)
- Internal rate of return (IRR)
- Payback period (PBP)

According to Kumar et al. (2016), a solar dryer can have a payback period of 2-5 years, depending on the design and operating conditions

2.7.4 Comparison with Traditional Drying Methods

A comparison with traditional drying methods can help determine the economic viability of the solar automated cocoa seed dryer. Traditional drying methods often require more labor, energy, and time, resulting in higher costs and reduced product quality. Afoakwa (2014).