CHAPTER I
INTRODUCTION

1.1 Background

Coffee is one of Indonesia's strategic agricultural commodities that makes a significant contribution to the national economy. Indonesia ranks as the world's fourth-largest coffee producer after Brazil, Vietnam, and Colombia, with an annual output of over 700,000 tons. This commodity is not only a source of foreign exchange for the country but also supports the livelihoods of more than 1.7 million smallholder farming households. In the coffee industry, product quality is a key determinant of competitiveness and selling prices in the international market [1]. One of the most important quality parameters is the moisture content of green coffee beans prior to roasting [2].

According to a report by the International Coffee Organization, freshly harvested green coffee beans have a relatively high moisture content—as high as 40-50% and therefore require a series of post-harvest processes, such as fermentation, washing, and drying, to reduce it to the ideal level [3]. The globally agreed-upon ideal moisture content range is approximately 10-12%, as coffee beans are considered safe for long-term storage at this level [4]. However, if the moisture content exceeds 12%, coffee beans become susceptible to fungal contamination, particularly by Aspergillus and Penicillium, which are known to produce harmful mycotoxins such as ochratoxin A (OTA) [5]. This indicates that controlling the moisture content of green beans is a key factor in maintaining the quality and safety of coffee during storage and prior to roasting.

Field observations indicate that most coffee farmers in Indonesia still rely on traditional or subjective methods to assess the moisture content of green beans, such as visual inspection, bite tests, or human sensory experience, as calibrated moisture meters are not yet widely available to smallholder farmers. Findings by Błaszkiewicz et al. reveal that coffee beans are highly hygroscopic, easily absorbing environmental moisture during storage, so spot-check measurements can yield non-representative data when warehouse conditions change [6]. Similar findings were meters are designed for spot-checking, require small samples, and are expensive, making them ineffective for continuous monitoring at the farmer or coffee industry level [7]. Therefore, there is a need for a low-cost IoT-based monitoring system capable of operating in real time and tracking changes in moisture content during post-harvest processing and storage to improve the quality consistency and export readiness of Indonesian coffee beans.

According to SNI 01-2907-2008 and the Specialty Coffee Association (SCA) guidelines, the moisture content of green beans is a key quality parameter that determines the quality and market value of coffee. Moisture content exceeding the standard risks rejection by the international market, while moisture content that is too low causes weight loss and reduces economic value. Therefore, moisture control is a critical aspect that is not only technical but also impacts business sustainability, with a maximum moisture content limit of 12.5% as per the established standard [8].

The importance of this research can be examined from several perspectives. From a quality standpoint, errors in moisture content control lead to inconsistencies in the coffee's flavor, aroma, and body, thereby hindering the roastery's ability to maintain its product identity. From an economic standpoint, coffee batches with moisture content above the standard may be rejected for export, while low moisture content results in a reduction in net weight [9]. From a regulatory perspective, the global market is increasingly demanding traceability-based quality systems, in which moisture content data must be properly documented [10]. Singh et al. emphasize that traceability in the coffee supply chain is crucial for ensuring product quality, supporting international trade, and meeting regulatory requirements in global markets [11].

Previous studies have examined technologies for detecting moisture content. A different approach was proposed by Damayanti et al., who used bioelectric signals and an Artificial Neural Network (ANN) to predict the moisture content of Robusta coffee beans with high accuracy ($R^2 > 0.95$) [12]. In addition, research by Bulus shows that artificial intelligence methods such as ANN and the Adaptive Neuro-Fuzzy Inference System (ANFIS) are capable of modeling moisture content in agricultural materials with a very high level of accuracy (R^2 ranging from 0.98 to 0.999) and low error rates, making them effective for datadriven moisture content prediction [13]. On the other hand, studies on fungal contamination indicate that environmental conditions such as temperature and CO_2 levels have a significant impact on fungal growth and mycotoxin production in food commodities, including coffee, which is closely linked to the moisture content of the material [14]. However, most of these studies are still limited to the laboratory scale, focus primarily on the drying phase, and have not yet addressed the pre-roasting stage or integration with real-time alerts and cloud dashboards.

From this review, several research gaps can be identified. First, although bioelectric sensor technology is accurate, it remains expensive and is not accessible to smallholder farmers. Second, existing IoT research has focused primarily on the drying process, while research on pre-roasting and green bean storage remains limited. Third, the monitoring systems developed rarely include real-time LED/buzzer alarms or mobile notifications. Fourth, validation against the SNI 01-2907-2008 oven drying standard is still limited in the field. Fifth, the integration of additional sensors such as CO_2 for fermentation detection alongside RH/T sensors in a single compact device has hardly been found in previous research [15].

Given the challenges encountered in the coffee processing workflow, particularly during the pre-roasting stage, there is a need for a system capable of accurately, in real time, and efficiently measuring the moisture content of green coffee beans. This system can be developed through the application of Internet of Things (IoT) technology with the integration of temperature and relative humidity sensors as an alternative to conventional measuring instruments, which are still limited in terms of portability and cost. Additionally, the inclusion of a real-time alarm system such as LED indicators, a buzzer, or digital notifications is crucial for issuing alerts when the moisture content of the coffee beans falls outside the ideal quality range (10–12.5%) as per national standards. In its implementation, the system must be thoroughly tested under fluctuating environmental conditions to ensure the reliability and stability of measurements against external disturbances such as variations in temperature, humidity, as well as network and hardware stability. Furthermore, historically stored sensor readings can serve as a traceability tool to document the process and maintain the consistency of green coffee bean quality over time. Thus, this research is expected to produce an affordable, accurate, and practical IoT system for detecting the moisture content of pre-roasting green coffee beans, as well as make a tangible contribution to improving the quality of Indonesian coffee in the global market.

1.2 Problem Formulation

Based on the background described above, the following research questions can be formulated:

1. How can an IoT system be designed to detect moisture content in pre-roasted green coffee beans using temperature and relative humidity sensors as an alternative to conventional measuring instruments?
2. How can a real-time alarm system be implemented to issue warnings when moisture content falls outside the ideal quality range?
3. How can we test the performance of the developed IoT system under fluctuating real-world environmental conditions, and assess its reliability against measurement, network, or hardware failures?
4. How can we optimize the green bean detection system as a traceability tool to maintain the consistent quality of green coffee beans?

1.3 Research Objectives

The objectives of this study are as follows:

1. Develop an IoT system capable of detecting moisture content in pre-roasted green coffee beans using temperature and relative humidity (RH/T) sensors as an alternative to conventional measuring instruments.
2. Implement a real-time alarm system consisting of LEDs, buzzers, and/or digital notifications to provide warnings when moisture content falls outside the ideal quality range.
3. Developing and implementing the Adaptive Neuro-Fuzzy Inference System (ANFIS) method within the IoT system to improve the accuracy of moisture content estimation in green coffee beans, and comparing the results with the standard oven drying method SNI 01-2907-2008.
4. Creating a feature for recording historical sensor data that is stored and can be customized to meet specific needs.

1.4 Research Benefits

This study is expected to provide the following benefits:

a. Academic Benefits

1. To make a scientific contribution to the development of Internet of Things (IoT) technology and the ANFIS artificial intelligence method for monitoring the moisture content of green coffee beans prior to roasting.
2. To provide literature to support further research in the fields of digital agriculture (smart agriculture) and sensor-based quality control.

b. Practical Benefits

1. Developing an alternative measuring tool that is more affordable than conventional moisture meters, making it accessible to farmers, cooperatives, and small roasteries.
2. Helping coffee businesses monitor moisture content in real time through a cloud-based dashboard.
3. Providing an early warning system (real-time alerts) that activates when moisture levels fall outside the standard range, allowing corrective actions to be taken immediately to prevent quality and economic losses.

c. Industrial and Social Benefits

1. Enhance the competitiveness of Indonesian coffee in the global market through more consistent and measurable quality.
2. Support the implementation of smart farming technologies in the coffee sector as one of the country's leading export commodities.
3. Generate social impact by increasing farmers' income and well-being through the reduction of financial risks associated with rejected or low-quality coffee batches.

1.5 Research Limitations

a. Research Object
   1. This study focuses solely on green coffee beans prior to the roasting stage.
   2. It does not address sensory quality (aroma, taste, body) or other chemical factors such as caffeine content or volatile compounds.

b. Measured Parameters
   1. Parameters are limited to moisture content (MC), estimated using relative humidity (RH) sensors, temperature (T), and CO_2 as additional indicators.
   2. It does not include measurements of other physical parameters such as density, bean size, or protein content.

c. Estimation Method
   1. Moisture content estimation uses only a sensor-based IoT approach combined with the ANFIS method, not other laboratory methods except for validation data.

d. Scope of Implementation
   1. The system is tested on a small scale using a green bean storage simulation chamber, not on an industrial scale or in large warehouses.
   2. Real-time alarm integration is limited to simple indicators (LEDs, buzzers, and cloud dashboard notifications).

e. Limitations of the IoT System
   1. System connectivity is limited to local Wi-Fi for data communication to the cloud.
   2. Data security (cybersecurity) aspects are not addressed.