Development of Intelligent Coffee Roasting System for Optimal Consumer Satisfaction

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***Abstract*—Roasting coffee beans is a crucial step in the coffee production process, as it significantly impacts the physical properties, aroma, and flavor of the beans [3, 4, 9]. This study aimed to investigate the physical characteristics of coffee beans before and after roasting and identify optimal roasting conditions for maximizing consumer satisfaction [1] and taste acceptance through heat and time control. The research involved designing and developing a hardware system, implementing a software control system, and incorporating intelligent algorithms to enhance the coffee roasting process.**

Three roasting conditions were examined based on color quality: light roasting at 200 ± 5 °C for 8 minutes, medium roasting at 220 ± 5 °C for 8 minutes, and dark roasting at 240 ± 5 °C for 8 minutes [1, 4, 14]. The intelligent system utilized sensory analysis and feedback to optimize the roasting profile for each condition. The hardware and software components were successfully integrated, resulting in an effective and reliable automatic coffee roasting system.

A taste acceptance test was conducted with a sample group of 20 students or personnel from Chiang Mai University, who drank at least one cup of coffee daily and were willing to participate in the study. The results revealed that consumers preferred the medium roast level. This research highlights the potential of intelligent systems in optimizing the coffee roasting process, enhancing consumer satisfaction, and expanding the understanding of taste preferences.

Keywords - Coffee Roasting Machine, Intelligent System, Consumer Satisfaction Optimization, Taste Acceptance.

I. INTRODUCTION

Thailand is one of the world's largest coffee producers with a vibrant coffee industry. Coffee roasting is a crucial step in the coffee production process that affects the aroma and flavor of coffee [1]. Traditionally, coffee roasting in Thailand is done with manual or semi-automatic machines, which do not allow for precision and consistency in roasting. However, with the advancement of technology, automated coffee roasting machines have been introduced to improve the quality and efficiency of coffee roasting. In this context, the research team aims to develop an innovative intelligent coffee roasting system that incorporates artificial intelligence technology to optimize the coffee roasting process.

The development of an innovative intelligent coffee roasting system that the research team will develop is a research project to use the knowledge of researchers to create software [2, 4, 5] to control the coffee roaster to become AI-powered so that the coffee roasting machine can learn how to roast the coffee by checking the values of various variables measured from the coffee, which are humidity, density, and color values of coffee, using the knowledge base in roasting coffee from entrepreneurs, which is the use of the same knowledge in roasting coffee from coffee entrepreneurs. The system will be developed into a coffee roasting tank to use hot air to roast coffee and use gas as an energy source to produce heat. The amount of coffee that can be roasted once is not more than 5 kilograms as an AI-generated machine that uses an embedded system to control variables in coffee roasting, whether it is the appropriate temperature, humidity, as well as related values to reduce the loss of coffee wasted from improper roasting and reduce the time to find the right profile for coffee roasting. It also strengthens research to reduce technology imports from abroad to increase the potential of the coffee industry in Chiang Mai and enhance Thailand's policy of creating more innovative technology to truly respond to the industry.

II. LITERATURE REVIEW

A. Coffee Roasting Process

The coffee roasting process plays a crucial role in determining the final taste, aroma, and quality of coffee by inducing chemical changes in the coffee beans [1]. Green coffee beans undergo a series of complex reactions during roasting, which are primarily influenced by temperature, time, and roasting method [4]. Two key reactions that take place during the process are the Maillard reactions and caramelization, responsible for the development of flavor and color compounds in the roasted beans [2]. The roasting process transforms the raw beans into the characteristic brown, aromatic coffee beans, which are then ground and brewed to make the beverage [3].

B. Roasting methods and techniques

Roasting methods and techniques have significant impacts on the flavor, aroma, and overall quality of the final coffee product [6]. There are two primary roasting methods: drum roasting and hot air roasting. Drum roasting involves rotating

beans in a heated drum, while hot air roasting utilizes heated air to transfer heat to the beans [4] . The choice of method, roasting temperature, and duration can significantly affect the development of desirable flavor compounds and the degradation of undesirable ones [2] . Furthermore, the control of these parameters is essential for achieving the desired roast level and maximizing the sensory qualities of the coffee [7].

C. Automatic and intelligent coffee roasting systems

Automatic and intelligent coffee roasting systems have gained attention in recent years due to their potential to improve the quality and consistency of roasted coffee beans [8]. These systems incorporate advanced technologies such as artificial intelligence, machine learning, and embedded systems to optimize the roasting process by controlling temperature, time, and other parameters [9]. Such systems allow for a higher degree of precision and adaptability, enabling the development of customized roasting profiles based on the specific characteristics of the coffee beans [4]. Moreover, automatic roasting systems can help reduce waste and improve efficiency, making them an attractive option for both small-scale and large-scale coffee producers [10].

III. METHODOLOGY

A. CALCULATION AND DESIGN

a) *Design and create a prototype for an automatic coffee roaster system [1, 2, 11, 12]:* Automatic coffee roaster prototype system. It is designed by Embedded Systems as a control system. The research team will design and develop software to control embedded systems and automate their operations. To control the coffee roaster to be able to control the roasting according to the user-defined program Along with creating hardware prototypes, using CAD/CAM software to design and simulate hardware systems. After that, the prototypes will be built by the system that has been designed. It will look like that shown in Figure 1.

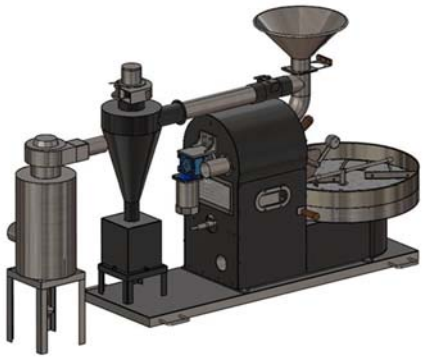

Fig. 1. shows a sketch of a coffee roaster.

The characteristics of the coffee roasting system are as follows [12, 13, 14, 15].

1) Before roasting coffee, coffee variables must be measured. The optimum starting temperature for coffee roasting is determined by measuring the density, color of coffee, and moisture value and putting variable values into the roaster in order to calculate the optimum temperature for roasting coffee and send information to the display to recommend it to the coffee roaster.

2) The roaster will adjust the temperature and roasting profile for the appropriate coffee. After that, the machine will take command from the user to adjust the roasting temperature profile to the desired temperature and humidity profile. According to the temperature and humidity values that are wanted to roast coffee.

3) The machine can adjust the roasting temperature from 100 degrees Celsius to about 300 degrees Celsius.

4) The system will adjust the temperature and adjust the machine according to the settings as in the profile, where the system will be involved in measuring the temperature of the coffee. in order to adjust the roasting according to the profile so that the coffee has the right level of roasting. The system stops roasting coffee and reduces the temperature of the coffee beans to stop the coffee roasting process.

5) After the user has adjusted the profile until the desired value is obtained, users will then be able to save their profile settings for future roasts.

b) Evaluate the quality of roasted coffee:

Use a group of experts to test and optimize the coffee roaster to the highest efficiency according to user needs. The test will use a verification method called Sensory Analysis in conjunction with the Faculty of Agro-Industry. Chiang Mai University.

In the process of evaluating coffee roasting from this automatic coffee roaster, there must be standardization of fresh coffee before roasting and after roasting so that it can be used as a standard for the use of automatic coffee roasters.

Development of the Hardware part of the coffee roasting machine

B. Development of the Hardware part of the coffee roasting machine.

The development of hardware for automatic coffee roasters is the creation and assembly of the machine by using the CNC system in forming each workpiece and then assembling them as shown in the figure 2.

(a) (b)

Fig. 2. show the hardware development of coffee roaster systems.

(a) Shows a sieve used to cool the coffee beans.

(b) Shows the production of coffee roasting tanks.

The design concept of the roaster should be made of cast iron, taking into account the heat value of the coffee beans in the roaster for the best aroma and flavor. (Based on preliminary testing by using hot air tanks with coffee beans and direct heated roasting tanks, it was found that direct heated roasting tanks gave the best smell and flavor) and to have a horizontal orientation in order to dissipate heat throughout the

tank while the tank is rotating. to prevent the burning of coffee beans.

Fig. 3. shows the installation of roaster tank to the cooling rack.

Fig. 4. shows the hardware system of the fully assembled coffee roaster.

C. *Software Development for Machine Control*

The main machine control system uses a Micro Controller system to control the machine, with a diagram as shown in Figure 5.

The primary focus of this part is on the implementation of an Arduino Microcontroller as the central component for managing the entire coffee roasting system. This microcontroller is responsible for various tasks, such as temperature monitoring using temperature sensors, regulating the roasting process, and interfacing with the touch screen display system, allowing users to adjust roasting profiles effectively.

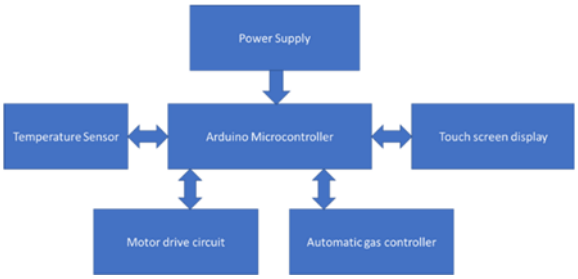

Fig. 5. shows the Block Diagram of the control software system of the coffee roaster.

The motor drive circuit plays a crucial role in managing the rotational movement of the motor system utilized in the coffee roasting process. This motor control helps optimize roasting conditions across different stages, ensuring consistency and uniformity in the final product. In conjunction with the motor drive circuit, an automatic gas controller is integrated to maintain the roasting temperature based on the predefined roasting profiles set by the user through the touch screen display system.

Furthermore, the software is designed to support an automatic coffee roasting feature, streamlining the process by following the selected roasting profile without the need for constant user input. This functionality is visually represented in Figure 6, which illustrates the touch screen interface and the various controls available for automatic coffee roasting.

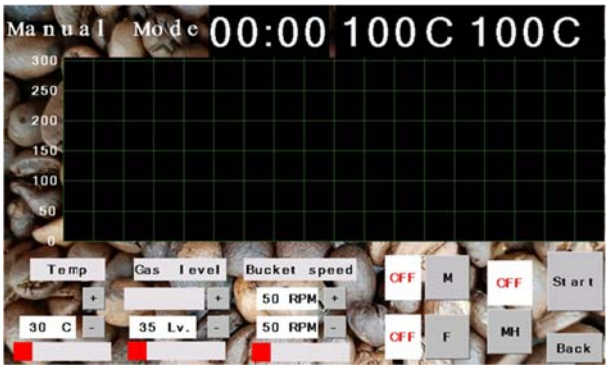

Fig. 6. shows the automatic coffee roasting screen.

IV. Result

A. *Coffee Roaster Acceptance Test*

The study explores the sensory evaluation [16,17] of coffee roasted using an automatic roaster across three distinct roasting levels. For each level, 1 kg of coffee beans were roasted, with the degree of roasting determined by the percentage weight reduction post-roasting. The roasting levels investigated included light roasting at 200 ± 5 °C for 8 minutes, medium roasting at 220 ± 5 °C for 8 minutes, and dark roasting at 240 ± 5 °C for 8 minutes.

To assess the acceptance and preference of the roasted coffee, a hot coffee taste test was conducted. Sensory analysis techniques, such as evaluating aroma, flavor, body, acidity, and aftertaste, were incorporated to provide a comprehensive understanding of each roast's sensory profile. The test panel comprised 20 individuals, including students and staff from Chiang Mai University, aged between 18 and 50 years. These participants were regular coffee drinkers, consuming at least one cup daily and willing to participate in the study.

The sensory evaluation results were collected and analyzed using a preference rating scale ranging from 1 to 3, where 1 signified dislike and 3 represented the highest level of liking. This approach allowed for a thorough examination of the sensory attributes of coffee produced by the automatic roaster, yielding valuable insights into the impact of different roasting levels on consumer preferences and overall coffee quality.

TABLE I. SHOWS THE RESULTS OF COFFEE TASTING TESTS FOR 1 KG OF ROASTED COFFEE.

Humidity	Roasting level	Score from 20 consumer sample group			Test result
		Dislike	Like	Most like	
10%	Light roasting	6	10	4	Liked
	Medium roasting	0	5	15	Most liked
	dark roasting	16	4	0	Disliked
12%	Light roasting	4	15	1	liked
	Medium roasting	0	5	15	Most liked
	dark roasting	17	3	0	Disliked
18%	Light roasting	1	15	4	Liked
	Medium roasting	0	5	15	Most liked
	dark roasting	15	5	0	Disliked

From the results of the coffee tasting test at all three levels, it was found that in coffee roasted with humidity levels of 10%, 12% and 18%, the medium roasting level is accepted the most, followed by light roast and dark roast, respectively [15, 18, 19).

This is because the medium roasting level results in an aroma, a clean cup, and flavor scores that are appropriate. while the dark roasting level is the lowest in the rating of these three levels. This is because the roasting process produces volatile substances that cause roasted coffee to have an unpleasant smell and taste, especially pyridine, which makes it bitter, astringent, and burnt. As for acidity, the score level decreased when adjusting to a weak level. Coffee is not fully developed because the citric, malic, lactic, pyruvic, and acetic acids contained in the coffee beans have not yet been decomposed from the beans due to the low heat rate. Meanwhile, the sweetness level was highest at the medium roasting level and decreased as the roast darkened. The dark roasting level produces more Maillard reactions. level of light roasting The Maillard reaction produces many compounds that are brown and may produce an unpleasant odor. Therefore, the medium roast level in the developed prototype is the optimum setting for coffee roasting. However, if there is a change in coffee type in addition to the coffee tested, we may need to adjust the profile to be suitable for roasting coffee to get the right taste.

V. CONCLUSION

The findings from this study demonstrate that the developed automatic coffee roaster effectively allows for the customization of various roasting profiles. However, for large-scale coffee production, a larger roasting chamber would be required. Additionally, identifying an appropriate roasting profile for mass coffee production is vital to achieve optimal results.

Selecting high-quality coffee beans prior to roasting, such as choosing ripe coffee cherries or premium coffee husks, can further enhance the efficiency and outcome of the roasting process. It is important to consider the entire coffee production process, from cultivation to roasting, in order to develop suitable tools and standardize the process. This comprehensive approach can improve the overall quality of Thai coffee, enabling it to compete on a global scale.

Moreover, the study contributes valuable knowledge to the coffee production process, which can be leveraged for future research and development in other agricultural processes. By focusing on holistic improvements across the production chain, the findings of this study have the potential to drive innovation and enhance the competitiveness of Thai coffee in the international market.

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REFERENCES

[1] Várhegyi, G., Szabó, P., & Mészáros, E. (2011). Coffee roasting as a chemical reaction engineering process. Journal of Analytical and Applied Pyrolysis, 92(1), 273-281.
[2] Bicho, N. C., Lidon, F. C., & Ramalho, J. C. (2019). Coffee roasting and aroma formation: Application of different time-temperature conditions. Journal of Food Engineering, 240, 105-116.
[3] Illy, A., & Viani, R. (2005). Espresso coffee: The science of quality. Elsevier.
[4] Oliveira, R. C., Franca, A. S., Mendonça, J. C. F., & Martins, M. L. (2020). A review of the impacts of coffee processing and roasting on the volatile composition of green and roasted coffee beans. Journal of Agricultural and Food Chemistry, 68(24), 6381-6398.
[5] Agtron-SCAA. (1995). Roast Color Classification System: Color Disk System
[6] Baggenstoss, J., Poisson, L., Kaegi, R., Perren, R., & Escher, F. (2008). Coffee roasting and aroma formation: A review. Journal of Food Chemistry, 111(3), 530-539.
[7] Severini, C., Ricci, I., Marone, M., Derossi, A., & De Pilli, T. (2017). Changes in the aromatic profile of espresso coffee

as a function of the grinding grade and extraction time: A study by the electronic nose system. Journal of Agricultural and Food Chemistry, 65(12), 2531-2539.
[8] Toledo, Paulo RAB, et al. "Relationship between the different aspects related to coffee quality and their volatile compounds." Comprehensive Reviews in Food Science and Food Safety 15.4 (2016): 705-719.
[9] Bicho, N. C., Lidon, F. C., & Ramalho, J. C. (2019). Coffee roasting and aroma formation: Application of different time-temperature conditions. Journal of Food Engineering, 240, 105-116.
[10] Kim, Su-Yeon, et al. "Prediction of key aroma development in coffees roasted to different degrees by colorimetric sensor array." Food chemistry 240 (2018): 808-816.
[11] Anino, S. V., Salvatori, D. M., and Alzamora, S. M. (2006). Changes in calcium level and mechanical properties of apple tissue due to impregnation with calcium salts. Food Research International, 39, 154-164.
[12] Yusof, S., and Ibrahim, N. (1994). Quality of soursop juice after pectinase enzyme treatment. Food Chemistry, 51, 83-88.
[13] Bekalo, S. A., and Reinhardt, H. W. (2010). Fibers of coffee husk and hulls for theproduction of particleboard. Materials and Structures, 43, 1049-1060.
[14] Clifford, M. N. (1985). Chemical and physical aspects of green coffee and coffee products, pp. 305-374. In Clifford, M. N. and Wilson, K. C., eds. Coffee Botany Biochemistry and Production of Beans and Beverage. AVI Publishing Co., Inc, West Port, CN.
[15] Upadhyay, R., Ramalakshmi, K., and Jagan Mohan Rao, L. (2012). Microwave-assisted extraction of chlorogenic acids from green coffee beans. Food Chemistry, 130(1), 184-188.
[16] Leino, M., Lapvetelaeinen, A., Menchero, P., Malm, H., Kaitaranta, J., and Kallio, H. (1992). Characterization of stored arabica and robusta coffee by headspace-GC and sensory analysis. Food Quality and Preference. 3, 115-125.
[17] Mayer, F., Czerny, M., and Grosch, W. (2000). Sensory study of the character impact aroma compounds of a coffee beverage. European Food Research and Technolgy, 211, 272-276.