An Exploratory Study: Factor Analysis for Roasting Machine Development and Its Impact on Robusta Coffee Product Quality

Iwan Hermawan[1], Gita Hindrawati[2], Yusuf Dewantoro[3], Sartono[4]
Politeknik Negeri Semarang, Indonesia

Abstract. The lack of effective approaches used by coffee roasting machine developers is a problem gap in this study. Machines need to be engineered to be easy for the coffee industry business actors to use to create quality coffee drinks. The approach of this study is exploratory to find factors that shape the effectiveness of roasting machine engineering. This qualitative study explores the perspectives of 31 coffee shop owners in Indonesia who use roasting machines in their serving process. This study provides design implications for roasting machine developer manufacturers to design machines that align with user expectations that represent the market. The study's results provide empirical evidence that there are four main factors for machine manufacturers in developing coffee roasting machines: temperature management, building automatic control, stirring speed, heat distribution and machine capacity working on various coffee bean materials. This study has practical implications for machine manufacturer managers to engineer the design, automation and algorithms injected into the roasting machine. This study fills the body of knowledge in the coffee roasting machine engineering domain.

Keywords: Coffee, Roasting Machine, Exploratory Study, Factor Analysis, Qualitative

INTRODUCTION

Coffee is still a leading commodity with significant global consumption, impacting the rapidly growing and increasingly complex coffee industry ecosystem (Daviron & Ponte, 2005; Jha et al., 2011). The coffee industry ecosystem includes the agribusiness chain from upstream to downstream, from coffee plantations to restaurants/café tables, and it involves farmers and the barista profession. The coffee processing process does not stop when coffee beans are ready to sell; it includes how coffee is served and the sophistication of the technology used, such as roasting machines. Roasting machines are one of the critical elements in the coffee industry (Nogueira & Koziorowski, 2019). The coffee industry has recently focused on innovation in developing coffee roasting machines. Attention to roasting machine innovation is increasingly attracting the interest of researchers, considering its significant influence on the quality of taste and efficiency of coffee production (Bottazzi et al., 2012; Casilimas et al., 2021; Lubis & Syafii, 2023; Rodríguez et al., 2018). Several important issues are relevant to the problems in the design of coffee roasting machines developed by local workshops with the type of SMEs business. SMEs, in the form of machine workshops, design roasting machines where coffee beans are sensed using organoleptics during the roasting phase, which are often inconsistent in terms of taste, aroma, and color (Baggenstoss et al., 2007). In addition to taste, aroma, and color, the role of temperature is a major factor in determining coffee quality (Bottazzi et al., 2012). The color and aroma of coffee are relevant to the roasting temperature of the coffee (Mendes et al., 2001). The roasting process is influenced by (1) the components in the coffee beans and (2) the roasting method applied. In general, the initial composition determines the flavor compounds formed, while physical parameters mainly affect the rate of formation (Bekedam et al., 2006). Until now, no perfect roasting machine has produced an optimal coffee flavor profile. Each machine has its own advantages and disadvantages, both in terms of temperature control, consistency of results, and operational efficiency. This is an issue that has attracted the attention of many parties, both among machine manufacturers, professional roasters, and coffee lovers. Technological developments continue to drive innovation in this field, but the search for creating the ideal roasting machine continues, opening up space for discussion and opportunities for future improvement.

Coffee has become a special concern in the eyes of the world, especially in Indonesia, there has been an increasing focus on improving the quality of coffee to meet global market demand. Arabica coffee dominates the global coffee trade cycle in the global market, while Robusta coffee has contributed to 25% of coffee exports in the last decade (Mendes et al., 2001). Robusta coffee in Indonesia has its own uniqueness, with an aftertaste that is influenced by various environmental factors. Given the environmental factors, tropical climate and biodiversity in coffee-producing regions in Indonesia, controlling the roasting process is becoming increasingly important to highlight the distinctive character of coffee from each region, both for domestic and international markets (Freitas et al., 2024). Indonesia's rapidly growing coffee industry is driving the increasing need for quality roasting machines. Along with the growing demand for quality coffee, the market opportunities for roasting machines are increasingly wide open, providing opportunities for roasting machine manufacturers to meet the increasing needs in this sector.

The roasting machine itself tends not to be easily damaged, if given intensive care. The problem of damage to the roasting machine often arises due to high humidity levels, inaccurate temperature calibration to use that is not in accordance with capacity. Basically, there is no perfect roasting cycle, because each roasting cycle can vary depending on the taste, aroma, color, and other characteristics of the coffee beans (Okamura et al., 2021). In coffee, the distinctive aroma and taste are developed during roasting as a result of pyrolytic reactions, and therefore it is necessary to carry out adequate roasting, an adequate roasting process for the type of coffee being roasted (Mendes et al., 2001). Instability of roasting machine performance and suboptimal coffee results can cause significant differences in quality, creating gaps in production standards. reduce customer satisfaction and harm the reputation and profitability of the business. This can cause a gap problem phenomenon.

This study focuses on identifying important factors that form a reliable coffee roasting machine that complies with standard operating procedures (SOP). This study aims to find key elements such as temperature precision, time stability, heat efficiency, and automatic control capabilities needed for a roasting machine to produce consistent coffee quality. These findings will be implied to roasting machine development companies as a basis for more optimal design recommendations, in order to improve the performance and competitiveness of their products in the industry.

LITERATURE REVIEW

Coffee roasting models.

Coffee roasting is a production process that is primarily responsible for shaping the flavor and aroma of a cup of coffee (Yeretzian, 2017). The process has been the object of numerous research projects, so research interest in roasting processes is increasing. Important aspects of the roasting process affiliated with the roasting machine model will address energy consumption needs, roasting temperature control, flavor prediction, and even intelligent design with application-connected devices (Bobkov & Dli, 2022). Several studies have been carried out to model the behavior of the coffee roasting chamber, since the applications embedded in the machine require models for their design and testing (Botha, 2018). Solid physical models are provided in several physical parameters, such as specific heat or transfer coefficient, and are still closely related to a certain coffee bean quality such as Robusta or Arabica and a certain factory size such as 120 kg, 360 kg or 600 kg that are used to identify the model. A strong relationship between the quality of the coffee beans, the size of the standard factory needs. Such a relationship greatly limits the application of the model to different factories, which requires new parameters. This is especially relevant in food industry processes where data collection requires a significant consumption of resources. To avoid waste of resources and materials, several studies consider advanced process control techniques (Palma et al., 2021).

Coffee Roasting Control.

The roasting process is one of the crucial stages in coffee processing that affects its quality characteristics. During the roasting process, heating causes Maillard reactions, caramelization reactions, and oxidation of several polyphenolic compounds, which develop the typical properties of coffee beans, such as aroma, flavor, and color (Bruhns et al., 2019; Farah & Donangelo, 2006; Fisk et al., 2012). However, on the other hand, the roasting process can result in the degradation of proteins, polysaccharides, caffeine, trigonelline, and CGA as well as the formation of 5-hydroxymethyl furfural. Many studies aim to optimize the roasting process where one of the keys is time and temperature. by studying its effect on the kinetics of roasting color formation, total phenolics (TPC), total flavonoids (TFC), CGA, and 5-HMF of coffee beans (Choi & Je, 2024)

Most of the studies aimed at finding solutions for controlling coffee roasting deal with the modeling phase of the roasting process or sensory methods developed for real-time roasting classification (Botha et al., 2024; Kelly, 2018; Lynch & Motha, 2023). Roasting monitoring is essential for batch roasting control. Recent advances in monitoring include: real-time process monitoring with near infrared spectroscopy using multivariate statistical analysis, laser mass spectrometry as an online sensor for determining real-time roasting, and increasing interest in validating chemical indicators for real-time roasting monitoring (Catelani et al., 2018; Grassi et al., 2023). In most real-world applications, thermocouples are used as temperature sensors to monitor the roasting profile. In addition, a craftsman controls the temperature inside the roaster to produce coffee with a specific flavor. To facilitate manual control, step changes are induced in variables such as heat flow, drum rotation speed, and air flow during the coffee roasting process by applying manual controls. The development of this strategy is supported by insights from a recent study on controller performance in thermal systems (Botha et al., 2024).

Design Concept and Components in Roasting Machine

A coffee roasting machine is an instrument used to roast raw coffee beans, where during the roasting process it is called coffee roasting (Samodro et al., 2020). The way a coffee roasting machine works is by heating the coffee beans in a rotating roasting chamber at a certain temperature. Heating in the roasting process aims to release the aroma and flavor locked in the coffee beans, as well as remove oil and other content. The process carried out by this roasting machine is an important part of coffee processing because it affects the aroma, flavor, and aftertaste of the coffee. The level of roasting maturity of the coffee determines the taste of the coffee, which can be divided into light, medium, and dark (Botha et al., 2024). Some parts of the coffee roasting machine include: Control panel: Regulates the coffee bean roasting process, such as the duration of heating and cooling, Feed port: The place where the coffee beans enter the roasting machine, Barrel: The place where the coffee bean heating process takes place, Observation window: Window to see the coffee bean heating process. Sampling spoon: A tool for taking coffee bean samples during the roasting process. Discharge port: A channel for distributing heated coffee beans. Dust collector: A place where the outer skin of coffee beans that comes off during roasting collects. Cooling plate: A place for heated coffee beans to cool (Okamura et al., 2021).

In the construction of a coffee roasting machine, several main aspects in many studies (Baggenstoss et al., 2008; Sagita et al., 2024) such as: roasting intensity settings to achieve the desired coffee taste (F1); accurate temperature settings (F2); Taste testing (cupping) after the roasting process (F3); the roasting machine is able to distribute heat evenly (F4); using a roasting machine with accurate temperature control (F5); the roasting machine has the right duration (F6); roasting machine with easy temperature settings (F7); coffee storage period and coffee roasting results (F8); the machine produces a consistent taste (F9); the right roasting process (F10); automatic control on the machine (F11); the cooling process after the roasting process is carried out quickly (F12). roasting machines are classified based on the type of coffee (F13); the temperature of the roasting machine must refer to the type of coffee beans being processed (F14); Roasting duration is important (F15); Roasting machines that ensure an even stirring process (F16); roasting machines that cause significant shrinkage (F17); The quality of the product produced by my roasting machine still depends on the humidity of the surrounding air (F18); The quality of the coffee beans (F19); the quality of the machine affects the results (F20).

RESEARCH METHOD

This study departs from the philosophy of interpretivism with an exploratory study approach (Creswell & Poth, 2018) to find out the design factors of roasting machines that effectively have ideal values used by coffee roasting entrepreneurs. The type of sampling approach used is purposive sampling (Sekaran & Bougie, 2016), with the criteria of business owners who carry out coffee roasting activities and have been established for more than two years and have employees. Two years of experience refers to their expertise in using the roasting machine used for work. The number of samples is 31 coffee business actors in Central Java, Indonesia. The analysis tool used in line with the nature of the exploratory study is to use factor analysis. In simple terms, the use of factor analysis is to determine several factors in such a way that multivariate data with many components can be summarized by using data based on several selected factors (Hair, 2011). Triangulation is done by ensuring that the answers of business owner respondents are consistent and relevant when compared with their employees (Creswell, 2012). Practically in this study, factor analysis is used to extract the many variables that have been developed in Table 1 and Table 2 into only a few variables, so that they are easier to observe more simply. In addition, factor analysis will also produce an order of importance of all the variables formed. In the context of the objectives of this study, this analysis instrument helps find a model of character variable groups from the design of coffee roasting machines that must be considered first for the development of roasting machine designs that effectively meet the needs of the coffee market in Indonesia. Data collection was carried out in the period August-November 2024 with research letter number: 1693 / PL.4.7.2 / KP / 2024 as a code of ethics to work by ensuring the security of respondent data.

FINDING AND DISCUSSION

Descriptive Analysis

Table 1 describes the characteristics of respondents based on gender and age. The majority of respondents are male, but the number of both does not have a significant difference. This shows that coffee entrepreneurs do not only focus on men, but are also engaged in by women by 45.16%. In addition, when viewed from age, most respondents are in the productive age of 70.98%. It means that the development of the coffee business has started since a young age, and in line with the demographic bonus in Indonesia due to the dominance of young entrepreneurs (Saputra, 2021).

Table 1. Demographic Profile of Respondent

Identification	Number of Respondents	Percentage
Gender		
Male	17	54.84%
Female	14	45.16%
Total	31	100%
Age		
<25 years	22	70.98%
25 – 45 years	6	19.35%
>45 years	3	9.68%
Total	31	100%

In the initial data validity analysis, all of the 20 factors were obtained, there were 18 factors that had a significance of > 0.05 (Hair et al., 2014). The results of the validity test showed that there were two invalid factors (> 0.05), so the two factors were removed and retested on the 18 final factors. The test results showed that all factors had met, namely <0.05. In addition, the reliability test showed that both the initial factor and the final factor had met the minimum (> 0.06), although when viewed from the Cronbach Alpha value if item deleted there is a recommendation to delete several factors, the increase in the Cronbach Alpha value is not significant, especially since it has shown high consistency at 0.929 on the initial factor and 0.939 on the final factor (Hair et al., 2014). Thus, the data has met the eligibility, and all factors can be used to conduct further analysis.

Table 2. Validity and Reliability Test

Initial Factor				Final Factor			
Indicator	Sig.	Cronbach Alpha	Cronbach Alpha if Item Deleted	Indicator	Sig.	Cronbach Alpha	Cronbach Alpha if Item Deleted
F1	.000	0.929	,926	F1	.000	0.939	,937
F2	.000		,924	F2	.000		,934
F3	.000		,925	F3	.000		,935
F4	.000		,925	F4	.000		,936
F5	.000		,925	F5	.000		,936
F6	.000		,923	F6	.000		,934
F7	.000		,925	F7	.000		,936
F8	.000		,925	F8	.000		,935
F9	.000		,923	F9	.000		,934
F10	.003		,930	F10	.003		,940
F11	.001		,925	F11	.001		,936
F12	.000		,930	F12	.013		,942
F13	.013		,924	F13	.000		,935
F14	.000		,924	F14	.000		,937
F15	.161		,936	F15	.002		,938
F16	.002		,927	F16	.000		,937
F17	.000		,925	F17	.000		,932
F18	.000		,921	F18	.000		,933
F19	.000		,923				
F20	.317		,932				

Factor Analysis for Effectiveness of Roasting Machine Design

The purpose of factor analysis in this study is to group aspects of the design of the development of coffee roasting machine designs formed in the study of theory and roasting machine capabilities into one, two or several factors. The concept of factor analysis, variables will be built, grouped if the variable is correlated with other variables that are included in a certain factor group. Data obtained from the owner of the roasting machine before the factor analysis was carried out were first tested for anti-image correlation values on 20 variables tested in the model and all of these variables had values above 0.5 with an interval of 0.536-0.816. The sample adequacy test was carried out through the Kaiser Meyer Oklin Measure Adequacy (KMO) value. The KMO value is 0.630 greater than 0.5 (Hair et al., 2014). This means that the sample taken, namely 31 respondents from coffee shop owners whose production process uses a roasting machine with a variable unit of 20 variables, is quite feasible to be analyzed. The Bartlett's Test of Sphericity figure is 417.743 and Sig 0.000 indicates that the correlation matrix is not an identity matrix, so it is feasible to continue to the factor analysis stage.

Tabel 3. KMO and Bartlett's Test

KMO and Bartlett's Test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.630
Bartlett's Test of Sphericity	Approx. Chi-Square	417.743
	df	153
	Sig.	.000

Referring to Thickness 3 shows that factor analysis based on eigenvalues greater than or equal to one (Hair et al., 2014), resulting in four factors formed capable of explaining 18 multivariate data variables of 73.67%. The variables are presented in Table 4.

Table 4. Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	9.228	51.266	51.266	9.228	51.266	51.266	5.370	29.832	29.832
2	1.605	8.918	60.184	1.605	8.918	60.184	3.353	18.629	48.461
3	1.434	7.964	68.148	1.434	7.964	68.148	2.446	13.591	62.052
4	.994	5.522	73.671	.994	5.522	73.671	2.091	11.619	73.671
5	.842	4.677	78.347						
6	.738	4.100	82.448						
7	.641	3.561	86.009						
8	.529	2.941	88.951						
9	.393	2.184	91.135						
10	.369	2.050	93.185						
11	.327	1.817	95.001						
12	.282	1.565	96.566						
13	.225	1.252	97.818						
14	.132	.733	98.551						
15	.116	.643	99.194						
16	.071	.393	99.588						
17	.056	.312	99.899						
18	.018	.101	100.000						
Extraction Method: Principal Component Analysis.									

Referring to Table 4 regarding the component rotation matrix shows the formation of three factors, with factor 1 component group, including Roasting intensity settings (.819), Accurate temperature settings (.734), Taste testing after the roasting process (.775), The machine distributes heat evenly (.790), using a roasting machine with accurate temperature control (.634), The machine has the right time duration (.734), The machine has easy temperature settings (.689), Machine work depends on the coffee storage period (.502), The machine is able to produce consistent taste (.638), Accurate roasting process (.611), Fast roasting machine duration (.739), and Roasting machine depends on humidity (.775). Factor 2 components, include: There is automatic control on the machine (.803); The cooling process after roasting is fast (.790); The roasting machine is classified based on the type of coffee (.772). Factor 3 components consist of: The machine temperature is easy to adjust to the type of coffee beans (.845), The roasting machine ensures an even stirring process (.573) and factor 4 components include: The roasting machine causes significant weight loss (.871), The roasting machine has no problem with the quality of the coffee beans (.641) and The quality of the machine material is important (.898).

Table 5. Rotated Component Matrix

Rotated Component Matrix[a]				
	Component			
	1	2	3	4
Roasting intensity setting (F1)	**.819**			
Accurate temperature setting (F2)	**.734**			
Taste testing after roasting process (F3)	**.775**			
The machine distributes heat evenly (F4)	**.790**			
Using a roasting machine with accurate temperature control (F5)	**.634**			
The machine has the right time duration (F6)	**.734**			
The machine has easy temperature settings (F7)	**.689**			
The machine's performance depends on the coffee storage period (F8)	**.502**			
The machine is able to produce consistent taste (F9)	**.638**			
Accurate roasting process (F10)	**.611**			
There is automatic control on the machine (F11)		**.803**		
The cooling process after roasting is fast (F12)		**.790**		
Roasting machines are classified based on the type of coffee (F13)		**.772**		
The temperature of the machine is easy to adjust to the type of coffee beans (F14)			**.845**	
The duration of the roasting machine is fast (F15)	**.739**			
The roasting machine ensures an even stirring process (F16)			**.573**	
Roasting machines that cause significant weight loss (F17)				**.871**
Roasting machines depend on humidity (F18)	**.775**			
Roasting machines do not have problems with the quality of the coffee beans (F19)				**.641**
Machine material quality is important (F20)				**.898**
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.[a]				
a. Rotation converged in 7 iterations.				

To conduct the analysis in the next step, the variables of the construct that drives the design of the roasting machine that is formed will then be converted into one group of variables in the form of main factors. The construction design in the engineering of the roasting machine is empirically formed into four main factors, namely: (1) temperature management; (2) building automatic machine control; (3) fast and even stirring process and (4) the machine is able to work on any type of coffee bean material.

Theoretical implications (1) Temperature management becomes a crucial part in the design needs of roasting machines that are affiliated with how operators realize the ripeness of coffee beans, when operators should stop cooking and enter the next phase related to cooling. The issue of temperature management in roasting machines will also be relevant to how machines can work as efficiently as possible in absorbing fuel and converting it into heat. (2) The second implication that is relevant to the design of roasting machines is building automation, automation will make it easier for machine operators to control optimal temperatures, cooling fans after roasting and be able to intelligently adjust the type of coffee material with automatic temperature adjustments. (3) The coffee bean stirring process works effectively. The machine ensures the stirring process such as the material and direction of movement of the stirrer integrated in the coffee roasting machine, both those in the tube for even heat distribution to the coffee beans and the continued process outside the tube, so the stirring process will be more intended to break down hot air so that the roasting temperature drops quickly. (4) Another challenge for roasting machines is that each coffee bean material has a different character and requires a different approach. This process depends on how the sensors intelligently provide adjustments to the roasting temperature and how the machine stops at the right time when the aroma and color texture qualities have been achieved.

CONCLUSION

The coffee industry creates a wide market potential from the side of farmers, cafe owners and consumers of coffee products, in this industry the engineering design of roasting machines that provide support for coffee quality in the industry is usually executed based on specific needs and is carried out in lathe workshops and is very limited in engineering design in line with the needs that effectively produce coffee quality with superior taste and aroma. Empirically there are four main factors in building coffee roasting machine engineering including building the ability to manage temperature accurately, building automatic control on the machine, building instruments that ensure a fast and even stirring process and ensuring that the designed machine is able to work on any material while maintaining its quality in the form of taste and aroma. The managerial implications for roasting machine workshop managers are the need to conduct trial and error on various automatic sensors such as temperature, and timers that ensure coffee quality is maintained, workshop managers need to provide algorithm injections that measure weight, volume of coffee beans to adjust the temperature distributed in the roasting tube and the character of the coffee post-roasting cooling instrument.

LIMITATION AND FURTHER RESEARCH RECOMMENDATION

Although it has shown the feasibility of the sample, the number of samples used in this study is very minimal. This study is based on the perspective of coffee shop owners who use roasting machines in their presentation, this opinion needs to be confirmed by coffee roasting machine engineers in the workshop so that there is a match between the perspective of the needs of market players and roasting machine developers. Future studies are recommended to be developed using a mix method by testing existing factors on the quality of roasting results longitudinally.

REFERENCES

Baggenstoss, J., Poisson, L., Kaegi, R., Perren, R., & Escher, F. (2008). Coffee roasting and aroma formation: application of different time− temperature conditions. *Journal of Agricultural and Food Chemistry*, *56*(14), 5836–5846.

Baggenstoss, J., Poisson, L., Luethi, R., Perren, R., & Escher, F. (2007). Influence of water quench cooling on degassing and aroma stability of roasted coffee. *Journal of Agricultural and Food Chemistry*, *55*(16), 6685–6691.

Bekedam, E. K., Schols, H. A., Van Boekel, M. A. J. S., & Smit, G. (2006). High molecular weight melanoidins from coffee brew. *Journal of Agricultural and Food Chemistry*, *54*(20), 7658–7666.

Bobkov, V., & Dli, M. (2022). *Calculation Features for the Heat and Power Balance in the Cyber-Physical System of*

Pellets Roasting on the Roasting Machine Conveyor BT - Cyber-Physical Systems: Modelling and Industrial Application (A. G. Kravets, A. A. Bolshakov, & M. Shcherbakov (eds.); pp. 337–347). Springer International Publishing. https://doi.org/10.1007/978-3-030-95120-7_28

Botha, C. M. (2018). *A model-based control system design for a coffee roasting process*.

Botha, C. M., van der Merwe, A. F., & Uren, K. R. (2024). A model-based control strategy for batch coffee roasting processes using a novel controlled variable. *Results in Engineering*, *23*, 102575. https://doi.org/https://doi.org/10.1016/j.rineng.2024.102575

Bottazzi, D., Farina, S., Milani, M., & Montorsi, L. (2012). A numerical approach for the analysis of the coffee roasting process. *Journal of Food Engineering*, *112*(3), 243–252. https://doi.org/https://doi.org/10.1016/j.jfoodeng.2012.04.009

Bruhns, P., Kanzler, C., Degenhardt, A. G., Koch, T. J., & Kroh, L. W. (2019). Basic Structure of Melanoidins Formed in the Maillard Reaction of 3-Deoxyglucosone and γ-Aminobutyric Acid. *Journal of Agricultural and Food Chemistry*, *67*(18), 5197–5203. https://doi.org/10.1021/acs.jafc.9b00202

Casilimas, L., Corrales, D. C., Solarte Montoya, M., Rahn, E., Robin, M.-H., Aubertot, J.-N., & Corrales, J. C. (2021). HMP-Coffee: A Hierarchical Multicriteria Model to Estimate the Profitability for Small Coffee Farming in Colombia. In *Applied Sciences* (Vol. 11, Issue 15). https://doi.org/10.3390/app11156880

Catelani, T. A., Santos, J. R., Páscoa, R. N. M. J., Pezza, L., Pezza, H. R., & Lopes, J. A. (2018). Real-time monitoring of a coffee roasting process with near infrared spectroscopy using multivariate statistical analysis: A feasibility study. *Talanta*, *179*, 292–299. https://doi.org/https://doi.org/10.1016/j.talanta.2017.11.010

Choi, S., & Je, Y. (2024). Association between coffee consumption and metabolic syndrome in Korean adults. *European Journal of Clinical Nutrition*, *78*(10), 905–915.

Creswell, J. W. (2012). *Educational research*. pearson.

Creswell, J. W., & Poth, C. N. (2018). *Qualitative inquiry & research design (Fourth edi)*. Sage Publications.

Daviron, B., & Ponte, S. (2005). *The coffee paradox: Global markets, commodity trade and the elusive promise of development*. Zed books.

Farah, A., & Donangelo, C. M. (2006). Phenolic compounds in coffee. *Brazilian Journal of Plant Physiology*, *18*, 23–36.

Fisk, I. D., Kettle, A., Hofmeister, S., Virdie, A., & Kenny, J. S. (2012). Discrimination of roast and ground coffee aroma. *Flavour*, *1*, 1–9.

Freitas, V. V., Borges, L. L. R., Vidigal, M. C. T. R., dos Santos, M. H., & Stringheta, P. C. (2024). Coffee: A comprehensive overview of origin, market, and the quality process. *Trends in Food Science & Technology*, *146*, 104411. https://doi.org/10.1016/j.tifs.2024.104411

Grassi, S., Giraudo, A., Novara, C., Cavallini, N., Geobaldo, F., Casiraghi, E., & Savorani, F. (2023). Monitoring Chemical Changes of Coffee Beans During Roasting Using Real-time NIR Spectroscopy and Chemometrics. *Food Analytical Methods*, *16*(5), 947–960. https://doi.org/10.1007/s12161-023-02473-w

Hair, J. F. (2011). *Multivariate Data Analysis: An Overview BT - International Encyclopedia of Statistical Science* (M. Lovric (ed.); pp. 904–907). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-04898-2_395

Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E., & Tatham, R. L. (2014). *Multivariate data analysis* (Vol. 5, Issue 3). Prentice hall Upper Saddle River, NJ.

Jha, S., Bacon, C. M., Philpott, S. M., Rice, R. A., Méndez, V. E., & Läderach, P. (2011). *A Review of Ecosystem Services, Farmer Livelihoods, and Value Chains in Shade Coffee Agroecosystems BT - Integrating Agriculture, Conservation and Ecotourism: Examples from the Field* (W. B. Campbell & S. Lopez Ortiz (eds.); pp. 141–208). Springer Netherlands. https://doi.org/10.1007/978-94-007-1309-3_4

Kelly, C. B. D. (2018). *The art of coffee roasting: Investigations into sensor development for the application of controlling coffee roasting*. The University of Waikato.

Lubis, M. S., & Syafii, M. (2023). Analysis of Factors Influencing Indonesian Coffee Export Volume Abroad. *International Journal of Scientific Multidisciplinary Research*, *1*(9), 1201–1210. https://doi.org/10.55927/ijsmr.v1i9.6557

Lynch, R., & Motha, S. (2023). Epistemological entanglements: Decolonizing understandings of identity and knowledge in English language teaching. *International Journal of Educational Research*, *118*, 102118. https://doi.org/https://doi.org/10.1016/j.ijer.2022.102118

Mendes, L. C., de Menezes, H. C., Aparecida, M., & da Silva, A. P. (2001). Optimization of the roasting of robusta coffee (C. canephora conillon) using acceptability tests and RSM. *Food Quality and Preference*,

12(2), 153–162. https://doi.org/10.1016/S0950-3293(00)00042-2
Nogueira, V. M. C., & Koziorowski, T. (2019). Roasting Equipment for Coffee Processing. In *Drying and roasting of cocoa and coffee* (pp. 235–266). CRC Press.
Okamura, M., Soga, M., Yamada, Y., Kobata, K., & Kaneda, D. (2021). Development and evaluation of roasting degree prediction model of coffee beans by machine learning. *Procedia Computer Science*, *192*, 4602–4608. https://doi.org/10.1016/j.procs.2021.09.238
Palma, F. Di, Iacono, F., Toffanin, C., Ziccardi, A., & Magni, L. (2021). Scalable model for industrial coffee roasting chamber. *Procedia Computer Science*, *180*, 122–131. https://doi.org/10.1016/j.procs.2021.01.362
Rodríguez, J. P., Corrales, D. C., & Corrales, J. C. (2018). A process for increasing the samples of coffee rust through machine learning methods. *International Journal of Agricultural and Environmental Information Systems (IJAEIS)*, *9*(2), 32–52.
Sagita, D., Mardjan, S. S., Suparlan, Purwandoko, P. B., & Widodo, S. (2024). Low-cost IoT-based multichannel spectral acquisition systems for roasted coffee beans evaluation: Case study of roasting degree classification using machine learning. *Journal of Food Composition and Analysis*, *133*, 106478. https://doi.org/https://doi.org/10.1016/j.jfca.2024.106478
Samodro, B., Mahesworo, B., Suparyanto, T., Atmaja, D. B. S., & Pardamean, B. (2020). Maintaining the quality and aroma of coffee with fuzzy logic coffee roasting machine. *IOP Conference Series: Earth and Environmental Science*, *426*(1), 12148.
Saputra, D. (2021). *BPS: Indonesia Alami Masa Keemasan Bonus Demografi, Tapi..* Ekonomi.Bisnis.Com. ekonomi.bisnis.com/read/20211217/9/1478624/bps-indonesia-alami-masa-keemasan-bonus-demografi-tapi#:~:text=Adapun%2C Indonesia telah memasuki era,kerja produktif mendukung 100 penduduk.
Sekaran, U., & Bougie, R. (2016). *Research methods for business: A skill building approach*. john wiley & sons.
Yeretzian, C. (2017). *Coffee BT - Springer Handbook of Odor* (A. Buettner (ed.); pp. 21–22). Springer International Publishing. https://doi.org/10.1007/978-3-319-26932-0_6