Methods for quality coffee roasting degree evaluation: a literature review on risk perspective

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Abstract. The demand for specialty coffee has increased over the past few years, and several cafes and coffee roasteries are starting to enter the market. Coffee roasting is considered art rather than science that requires a lot of experience from a master roaster. The key parameters used to identify the roast status of the beans are the initial temperature and roasting time from bean samples. The degree of roasting is often the first consideration for consumers when buying coffee. Some of the flavor attributes used to assess coffee are body, aroma, and acidity. Many studies have been done to evaluate the quality of roasted coffee experimentally using different parameters. However, these techniques could not be implemented in real-time and have their limitations. The current need for roasteries is a method of controlling the quality of roasted coffee through risk and a real-time approach. This paper presents a review carried out the methods used to determine roasting degree on risk perspective. This review has covered recent research on coffee roasting evaluation methods on physical, physicochemical, and chemical composition changes.

1. Introduction
Coffee is a commercial commodity that grows and is traded in the global market [1]. Worldwide coffee consumption reaches three billion cups of coffee drinks every day [2,3]. Coffee consumers vary widely, depending on age, culture, and geographic distribution. With the increasing demand for coffee, especially specialty coffee around the world, scientific sensory evaluation methods for coffee are increasingly being sought to meet consumer demands [4]. The key quality factor of coffee is influenced by its sensory quality. The sensory quality of coffee is influenced by all the links in the coffee production chain, namely plant genetics, handling of coffee cultivation, post-harvest handling, transportation, roasting, grinding, storage, and brewing. The final consumer experience is influenced by social, psychological, and situational factors [5,6,7,8].

Food processing is an important factor in improving sensory quality and nutritional quality by eliminating some compounds that are bad for health [1,9]. The roasting process is the most important processing method for developing color, flavor, and aroma. From a sensory perspective, the roasting process can create aromatic compounds through several reactions, such as the Maillard reaction, Strecker degradation, the degradation of sugars, and the breakdown of amino acids [10,11].

The roasting and cooling stages require precise control to avoid excessive coffee ripeness. Burnt coffee beans will produce a bitter taste [12]. Burnt coffee beans will produce a bitter taste. The degree of roasting was assessed qualitatively by color standard and classified as a light roast, medium roast,
and dark roast [13]. The ideal roasting process is very complicated because different processes will produce different coffee qualities. Roasters must have the skills to develop physical properties, chemical composition, and biological activity when roasting coffee beans. The degree of roasting is controlled by temperature and roasting time [14]. The distinctive flavor and sensory qualities of the world's coffees vary widely due to differences in genetic strain, geographic location, agricultural practices, climate, and variations in the processing methods applied [15].

Therefore, control activities during the roasting process are very important to stop the roasting process properly so that the desired coffee aroma has fully developed and the color of the coffee beans is homogeneous. Control of the roasting process is done by creating a method to evaluate the degree of roasting coffee in real-time. The need for roasters so far is a method of controlling the quality of roasted coffee with risk and real-time approach. This review presents the various methods used to determine roasting degrees from a coffee quality risk perspective.

2. Material and methods

The method used to review the methods for quality coffee roasting degree evaluation is a systematic review. A systematic review is one of the research methods that identifies, evaluates, and interprets all research results that have a specific topic. A systematic review will be very useful for synthesizing various relevant research results so that the facts presented are more comprehensive and balanced [16].

The literature study was carried out by collecting qualitative and quantitative empirical studies and published in several leading journals internationally such as Food research international, food science and technology, the craft and science of coffee, trends in food science and technology, and other journals. Journal publications within the scope of the review were collected and extracted using aggregator databases including Scopus, and in publisher databases including Elsevier, Emerald Insight, Springer, MDPI, and Wiley. The paper traced using several keywords such as “quality of roasted coffee”, “degree of coffee roasting”, “quality of coffee”, “coffee roasting”, and “coffee agroindustry”. Journal publications were analyzed for the period between 2010 and 2020. However, after screening the abstracts and reading the contents of these articles, only 20 articles were admitted as the final samples for further review and analysis. This article discusses the methods used to determine roasting degrees and evaluate the quality of roasted coffee beans from a risk perspective. The distribution of the sample articles by publication source is presented in Table 1.

| Journal title                                      | Articles (n=20) | Percentage (%) |
|---------------------------------------------------|-----------------|----------------|
| Food research international                        | 3               | 15             |
| LWT-Food science and technology                    | 1               | 5              |
| The craft and science of coffee                    | 1               | 5              |
| British food journal                               | 1               | 5              |
| Trends in food science and technology               | 1               | 5              |
| Journal study of sensory                           | 1               | 5              |
| Beverages                                          | 2               | 10             |
| International food research journal                | 1               | 5              |
| Food science and nutrition                         | 1               | 5              |
| IOP conference series earth and environmental science | 1           | 5              |
| Food chemistry                                     | 1               | 5              |
| Journal of food sciences                           | 1               | 5              |
| Foods                                              | 1               | 5              |
| Analytical and bioanalytical chemistry             | 1               | 5              |
| African journal of plant science                   | 1               | 5              |
| American journal of chemistry                      | 1               | 5              |
| Press and environmental safety protection           | 1               | 5              |
| **Total**                                         | **20**          | **100**        |
3. Results and discussion

3.1. Failure mode on roasted coffee quality

Coffee quality is very difficult to define because the definition of quality in each stakeholder, from farmers to consumers, varies greatly. At the farm level, coffee quality is assessed based on the level of uniformity of green bean size. The quality of green beans is influenced by the process of cultivation and post-harvest processing. At the exporter or importer level, coffee quality is assessed based on the size of the green beans, product availability, physical characteristics, the number of green beans with defects, and price [17]. At the roastery level, coffee quality depends on moisture content, geographical origin, price, stability characteristics, organoleptic qualities, and biochemical compounds. At the consumer level, coffee quality is determined by geographical origin, taste, aroma, price, environmental and sociological aspects such as organic coffee, fair trade, etc [17,18]. Coffee quality is not only assessed based on physical attributes but also involves assessing social, environmental, safety, and other issues. It can be concluded that quality is the main link between various stakeholders in the coffee sector. Coffee quality assessment is an important step in the coffee business world. Coffee quality is influenced by factors such as variety/species, environmental conditions such as rainfall, soil fertility, elevation, slope aspect, etc., geographical conditions such as latitude and longitude, as well as processing methods such as wet process, dry process, semi wash process, etc [12,17,18,19].

Coffee quality has a complex nature because it involves sensory characteristics and chemical characteristics. The coffee roasting process plays a role in producing aroma and activating biological compounds in coffee so that it produces a distinctive taste. Knowledge of roasting degrees is very important for roasters [22]. The degrees of roasting are controlled by roasting time and temperature [18]. Failure to produce roasted coffee quality is caused by several factors, such as the raw materials, human resources, production process, packaging, and storage [22,23,24]. The failure roasted coffee quality the author illustrates in Figure 1.

![Figure 1. Failure modes on roasted coffee quality (designed by author).](image)

Raw material failure relates to risks ranging from receiving raw materials, quality, availability of quantities, sorting and grading activities. Production failure is related to the failure of roasting conditions such as machines or production equipment (type of roaster), process control (drum speed and cooling bean), a process critical points (time and temperature), availability of automatic control, presence or absence of an early warning system, etc. Human resources failure relates to operating the roasting machine and knowledge of product innovation and diversification is low. Packaging failure relates to
damage and leaky. Storage failure relates to environmental risks and disturbances to the quality of roasted coffee.

3.2. Coffee roasting degree evaluation methods

Coffee roasting level based on a color scale or table called the Agtron Color Classification System from the Specialty Coffee Association of America (SCAA), a system with several roasting colors from light to dark to simplify and standardize the coffee roasting process. The roasting profile or level is adjusted to the needs and demands of consumers. It’s not just about making coffee beans turn brown. Agtron number consists of a scale of 0 to 100. The determination of the color is the darker the type of roast, the lower the value. Agtron developed an infrared spectrometer to determine the degree of roasting and fabricated discs of different colors according to standards specified in the scale. Thus, SCAA standardized roasting control through visual comparison using an infrared spectrometer [22].

Several parameters used to evaluate the quality of roasted coffee include taste, color, aroma, bean temperature, pH, chemical composition, etc. However, the weakness of the coffee quality evaluation process is that it cannot be done online/in real-time. The current need for roasters is related to the method of controlling the quality of roasted coffee through risk and real-time approaches. Studies on evaluating the degree of roasting of coffee have been extensively researched in recent years. Various parameters have been used to determine the degree of roasting, and these parameters are categorized into three groups: physical properties, physicochemical properties, and chemical compositions. Research on evaluating roasting degrees is summarized in Table 2.

| Methodology                  | Description                                                                 | Results                                                                 |
|------------------------------|----------------------------------------------------------------------------|------------------------------------------------------------------------|
| Physical properties [25]     | Physical properties of coffee roasting degree such as weight loss, density, moisture content and surface color were predicted using electronic nose (EN), and Artificial Neural Network (ANN). | Changes in roasted coffee degree can be predicted using EN and ANN data processing. |
| Physical properties [26]     | A Fourier Transform Infrared (FTIR) spectrometer is used to analyze physical changes such as weight loss, surface temperature, color change, cracking sound, and changes in spectral characteristics. | Changes in spectral characteristics were significantly observed after the first cracking sound in 6 minutes (207°C) and the second cracking sound in 10 minutes (219°C). Changes in spectral characteristics indicate the emergence of important compounds when the roasting period approaches the optimal roasting degree. |
| Physico-chemical [27]        | The method used to analyze the physicochemical properties of coffee is Resonant-enhanced multiphoton ionization time-of-flight mass spectrometry (REMPI-TOFMS). This method aims to analyze the roasting gas from a small-scale coffee roaster. Changes in coffee color are analyzed using a colorette so that roast degree results can be obtained. Chemical properties such as antioxidants from coffee drinks were tested using Folin – Ciocalteu (FC) | Resonant-enhanced multi-photon ionization time-of-flight mass spectrometry (REMPI-TOFMS) is suitable for predicting changes in the color of coffee beans and changes in antioxidant capacity in real-time by looking at the Colorette and FC values during the coffee bean roasting process. |
| Physico-chemical [28]        | Artificial vision techniques are used to control and predict the coffee roasting process. Variables observed consisted of color, acidity that can be titrated, humidity, chlorogenic acid, caffeine content, and PH. | The algorithms used in artificial vision techniques are able to correlate the chemical composition of coffee beans at each roasting time through image changes. The results obtained are very promising in modeling the coffee roasting process. |
Methodology | Description | Results
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Chemical Composition [29] | Volatile organic compounds (VOCs) in the off-gas roaster are monitored online by linking the flavor profile and roast degree. The development of this technology can provide information about the aroma of coffee in real-time. | A detailed picture of roast process changes and real-time process control creation can result in high roast consistency. |
Chemical Composition [30] | Substantial changes in coffee composition were observed using nuclear magnetic resonance (NMR). | There were 12 (acetate, formic acid, trigonelline, citric acid, caffeine, 5-CQA, fatty acid, malic acid, 3-CQA, lactate, 1-methyl pyridinium, 5-HMF) different compounds from the four (Fast, medium, slow, baked) observed samples. |

The study in Table 2 above investigates the relationship between the physical properties of coffee beans, physicochemical, chemical composition, and cup quality. Some studies were conducted experimentally, and most of the papers measured the physical attributes of coffee beans after roasting related to weight loss, density, moisture content, surface color, and cracking sound. Data processing using electronic nose (EN) and Artificial Neural Network (ANN) is effective for monitoring and predicting coffee roasting degrees [25]. FTIR can indicate the emergence of important compounds when the roasting period is close to the optimum roasting degree [26].

Changes in the physicochemical properties of coffee are characterized by changes in color, acidity that can be titrated, pH, humidity and chlorogenic acid, and caffeine content. Some of the technologies used to analyze these changes are Artificial Vision Techniques and Resonant-enhanced multiphoton ionization time-of-flight mass spectrometry (REMPI-TOFMS). The artificial vision technology is used to control and model the coffee roasting process algorithm. Coffee samples were used to create roasting curves: each image was taken at a different time. Coffee sample data were processed by (i) Principal component analysis (PCA) to observe time-dependent roasting aggregation, and (ii) partial least squares regression (PLS) to correlate analytical determination values with image information. The proposed algorithm can correlate the chemical composition of coffee beans at each roasting time with image changes [27]. In addition, resonance-enhanced multiphoton ionization time-of-flight mass spectrometry (REMPI-TOFMS) at 248 nm and 266 nm aims to analyze the roasting gas composition of small-scale coffee roasters. Changes in coffee color are analyzed using a colorette so that roast degree results can be obtained. Chemical properties such as antioxidants from coffee drinks were tested using Folin – Ciocalteu (FC) [28]. Chemical composition analysis is carried out using technology that can provide information on changes in aroma during coffee roasting in real-time. The approach proposed here is online monitoring of volatile organic compounds (VOCs) in the off-gas roaster and relating them to the flavor profile and roast degree [29]. In addition, chemical composition analysis can also be carried out using nuclear magnetic resonance (NMR). NMR can observe substantial changes in coffee [30].

4. Conclusions
Quality roasted coffee beans have complex properties due to changes in sensory characteristics and biochemical content. The failure factors in producing roast coffee quality include raw materials, production processes, machinery/equipment, packaging techniques, and storage methods. This review describes some of the latest research on methods of evaluating quality coffee roasting in real-time. Evaluation of the roasting process includes changes in physical, physicochemical, and chemical composition. Future research is expected to build a database that can be used to determine the most important coffee sensory compounds during the roasting process. In addition, the initiation of machines/equipment are also needed to monitor changes in the properties of coffee beans during the roasting process in real-time.

References
[1] Endeshaw H and Belay A 2020 Optimization of the roasting conditions to lower acrylamide
content and improve the nutrient composition and antioxidant properties of Coffea arabica

PloS One 15 1–18

[2] International Coffee Organization 2019 Country Coffee Profile: Vietnam Int. Coffee Coun. 25

[3] Al-Dalain S Y, Haddad M A, Parisi S, Al-Tarawneh M A and Qaralleh H 2020 Determination of macroelements, transition elements, and anionic contents of commercial roasted ground coffee available in jordanian markets Beverages 6 1–7

[4] Chambers IV E, Sanchez K, Phan U X T, Miller R, Civille G V and Di Donfrancesco B 2016 Development of a “living” lexicon for descriptive sensory analysis of brewed coffee J. Sens. Stud. 31 465–80

[5] Bhumiratana N, Adhikari K and Chambers IV E 2011 Evolution of sensory aroma attributes from coffee beans to brewed coffee LWT-Food Sci. Technol. 44 2185–92

[6] Poisson L, Blank I, Dunkel A and Hofmann T 2017 The chemistry of roasting—Decoding flavor formation The craft and science of coffee (Elsevier) pp 273–309

[7] Giacalone D, Fosgaard T R, Steen I and Münchow M 2016 “Quality does not sell itself”: Divergence between “objective” product quality and preference for coffee in naïve consumers Br. Food J.

[8] Cheng B, Furtado A, Smyth H E and Henry R J 2016 Influence of genotype and environment on coffee quality Trends Food Sci. Technol. 57 20–30

[9] Gökmen V 2014 A perspective on the evaluation of safety risks in thermal processing of foods with an example for acrylamide formation in biscuits Qual. Assur. Saf. Crop. Foods 319–25

[10] Madihah K Y K, Zaibunnisa A H, Norashikin S, Rozita O and Misnawi J 2013 Optimization of roasting conditions for high-quality Arabica coffee Int. Food Res. J. 20 1623

[11] Palungan M, Dising J and Lande S 2013 Design of Skin Horn Coffee Peeler Machine to Improve Industria 9–15

[12] Sunarharum W B, Williams D J and Smyth H E 2014 Complexity of coffee flavor: A compositional and sensory perspective Food Res. Int. 62 315–25

[13] Bolka M and Emire S 2020 Effects of coffee roasting technologies on cup quality and bioactive compounds of specialty coffee beans Food Sci. Nutr. 8 6120–30

[14] Bauer D, Abreu J, Jordão N, Rosa J S da, Freitas Silva O and Teodoro A 2018 Effect of roasting levels and drying process of Coffea canephora on the quality of bioactive compounds and cytotoxicity Int. J. Mol. Sci. 19 3407

[15] da Rosa J S, Freitas-Silva O, Rouws J R C, da Silva Moreira I G, Novaes F J M, de Almeida Azvedo D, Schwab N, de Oliveira Godoy R L, Eberlin M N and de Rezende C M 2016 Mass spectrometry screening of Arabica coffee roasting: A non-target and non-volatile approach by EASI-MS and ESI-MS Food Res. Int. 89 967–75

[16] Kamble S S, Gunasekaran A and Gawankar S A 2018 Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives Process Saf. Environ. Prot. 117 408–25

[17] Santosol I, Afifa Y N, Astuti R and Deoranto P 2021 Development model on upstream-downstream integration of coffee agroindustry using dynamics modelling approach IOP Conf. Ser. Earth Environ. Sci. 733

[18] da Silva C Q, Fernandes A da S, Teixeira G F, França R J, Marques M R da C, Felzenszwalb I, Falcão D Q and Ferraz E R A 2021 Risk assessment of coffees of different qualities and degrees of roasting Food Res. Int. 141

[19] Abebe Y, Juergen B, Endashaw B, Kitessa H and Heiner G 2020 The major factors influencing coffee quality in Ethiopia: The case of wild Arabica coffee (Coffea arabica L.) from its natural habitat of southwest and southeast afromontane rainforests African J. Plant Sci. 14 213–30

[20] Belay S, Mideksa D, Gebrezgiabher S and Seifu W 2016 Factors Affecting Coffee (Coffea Arabica L.) Quality in Ehtiopia: a Review J. Multidiscip. Sci. Res. 4 22–8

[21] Tolessa K, Dheer J, Duchateau L and Boeckx P 2017 Influence of growing altitude, shade and harvest period on quality and biochemical composition of Ethiopian specialty coffee J. Sci.
Laukaleja I and Kruma Z 2019 Influence of the roasting process on bioactive compounds and aroma profile in specialty coffee: A review Conference Proceedings. Foodbalt 2019. 13th Baltic Conference On Food Science And Technology" Food, Nutrition, Well-Being", Jelgava, Latvia, 2-3 May 2019 (Latvia University of Life Sciences and Technologies) pp 7–12

Choirun A, Santoso I and Astuti R 2020 Sustainability risk management in the agri-food supply chain: Literature review IOP Conf. Ser. Earth Environ. Sci. 475

Santoso I, Prahatutti I Y and Pusfitasari D A 2020 Identification of institutional risks of SMEs supply chain using the fuzzy failure mode and effect analysis IOP Conf. Ser. Earth Environ. Sci. 475

Romani S, Cevoli C, Fabbri A, Alessandrini L and Dalla Rosa M 2012 Evaluation of Coffee Roasting Degree by Using Electronic Nose and Artificial Neural Network for Off-line Quality Control J. Food Sci. 77 1–6

Edzuan A M F, Majid N A A and Bong H L 2015 Physical and Chemical Property Changes of Coffee Beans during Roasting Am. J. Chem. 5 56–60

Hendryk Czech, Jan Heide, Sven Ehlert T K and and Zimmermann R 2020 Smart Online Coffee Roasting Process Control : Modelling Coffee Roast Degree and Brew Antioxidant Capacity for Real-Time Prediction by Foods 9 627

Ivorra Martínez E, Sarria-González J C and Girón Hernández J 2020 Computer vision techniques for modelling the roasting process of coffee (Coffea arabica L.) var. Castillo Czech J. Food Sci. 38 388–96

Wieland F, Gloess A N, Keller M, Wetzel A, Schenker S and Yeretzian C 2012 Online monitoring of coffee roasting by proton transfer reaction time-of-flight mass spectrometry (PTR-ToF-MS): Towards a real-time process control for a consistent roast profile Anal. Bioanal. Chem. 402 2531–43

Alstrup J, Petersen M A, Larsen F H and Münchow M 2020 The Effect of Roast Development Time Modulations on the Sensory Profile and Chemical Composition of the Coffee Brew as Measured by NMR and DHS-GC–MS Beverages 6 70