Review Article

Journal of Applied Sciences (ISSN 2998-9159)

# Enhancing the Aroma and Sensory Profiles of Decaffeinated Coffee: A Review.

[1,*]Afriliana, A (ORCID: 0000-0002-4079-9537),
[2]Nazir, N (ORCID: 0000-0002-9229-8937) ,
[3]Kusnadi, J (ORCID: 0000-0003-2337-0891) ,
[4]Harada, H (ORCID: 0000-0003-4899-6583),
[1]Jayus (ORCID: 0000-0001-7603-5419),
[1]Diniyah, N (ORCID: 0000-0001-5160-7599),
[1]Purbasari, D (ORCID: 0009-0008-8895-5974),
[1]Lindriati, T ( ORCID: 0000-0002-8725-9933)

1. Department of Agricultural Product Technology, Faculty of Agriculture Technology, University of Jember, Indonesia
2. Department of Processing Agricultural Product Technology, Faculty of Agriculture Technology, Andalas University, Indonesia
3. Department of Biotechnology, Faculty of Agriculture Technology, Brawijaya University, Indonesia
4. Department of Life and Environmental Science, Prefectural University of Hiroshima, Japan

***Corresponding author**

Asmak afriliana ,
Department of Agricultural Product Technology, Faculty of Agriculture Technology, University of Jember, Indonesia.
**E-mail :** asmak.ftp@unej.ac.id

**Received Date :** October 21, 2024
**Accepted Date :** November 22, 2024
**Published Date :** November 28, 2024

## ABSTRACT

The purpose of this review paper is to describe research related to improving the aroma and sensory properties of decaffeinated coffee. These studies underscore the intricate interplay between brewing methods, chemical transformations, and sensory outcomes in decaffeinated coffee. The methods used are as follows: Aroma Compound Recovery, smell-blocking technology, and the use of artificial aroma compounds. Future technology for enhancement of decaffeinated coffee aroma is through the identification of how the roasting process and the brewing technique significantly influence the concentration of volatile compounds in coffee brews. the transformation of these compounds during roasting and the subsequent extraction during brewing are critical for the development of the coffee's aroma. This understanding is vital for the coffee industry, as aroma plays a pivotal role in consumer preference and overall sensory experience. The conclusion is that the exploration of decaffeinated coffee aroma has yielded significant findings that underscore the complex interplay between processing methods and aromatic compounds. interdisciplinary approaches that combine chemistry, sensory analysis, and consumer behavior can provide deeper insights into the relationship between aroma and consumer preferences, ultimately guiding the development of more appealing decaffeinated coffee products.

**Keywords :** Decaffeinated coffee, aroma compound recovery, smell-blocking technology, artificial aroma.

## INTRODUCTION

The exploration of decaffeinated coffee's aroma and sensory profiles has garnered increasing attention in recent years, as consumers seek high-quality coffee experiences without the stimulating effects of caffeine. This literature review synthesizes key insights from several pivotal studies that examine the various factors influencing the sensory characteristics of decaffeinated coffee, particularly focusing on brewing methods, extraction processes, and chemical compositions.

Building on the understanding of aroma profiles, (Angeloni et al., 2021) characterized the aroma profile of espresso coffee, emphasizing the influence of preparation conditions. Their research identified furans as the most abundant chemical class in espresso, while sulfur compounds played a critical role in flavor development. The authors underscored the significance of optimizing extraction variables, such as temperature and grind size, to enhance the aromatic qualities of the resulting beverage. This study aligns with the notion that precise control over brewing parameters can lead to a more desirable sensory outcome.

Zou et al., 2022 contributed to the discourse by examining the differences in volatile compound profiles between decaffeinated and regular coffee using advanced analytical techniques. Their findings indicated that the decaffeination process could lead to a diminished flavor profile, primarily due to the loss of key aroma precursors, such as pyrazines. This study highlighted the complexities of the decaffeination

Journal of Applied Sciences (ISSN 2998-9159)

process, revealing that the methods employed can significantly affect the aroma and taste of the final product. The research also pointed to the unintended removal of sucrose during decaffeination, which further impacts the sensory experience. Further expanding on the chemical transformations during coffee processing, (Zou et al., 2022) conducted a comprehensive analysis of aroma-related volatile compounds, identifying specific chemical families that are less concentrated in decaffeinated coffee. Their findings reiterated that decaffeination affects caffeine levels and alters the overall aromatic profile, suggesting that the sensory experience of decaffeinated coffee is inherently different from that of regular coffee. This critical evaluation of volatile compounds elucidates the challenges faced in recreating the rich sensory experience traditionally associated with caffeinated coffee.

Lastly, Vezzulli et al., 2022 explored the impact of different extraction methods on the sensory profiles of two prominent coffee species, Coffea arabica and Coffea canephora var. robusta. Their study demonstrated that the extraction method plays a crucial role in defining coffee beverages' aromatic and gustative characteristics. By employing metabolomic approaches, the authors revealed how traditional Italian extraction methods yield unique sensory profiles, further emphasizing the need to consider both the species of coffee and the extraction technique when aiming to enhance the sensory experience of decaffeinated coffee.

Collectively, these studies underscore the intricate interplay between brewing methods, chemical transformations, and sensory outcomes in decaffeinated coffee. As the demand for high-quality coffee continues to grow, understanding these factors will be essential for optimizing the aroma and sensory profiles of decaffeinated products.

## LITERATURE REVIEW

### Chemical Methods for Enhancing the Aroma of Decaffeinated Coffee

***Aroma Compound Recovery (ACR)***

Recent years have seen increased interest in the study of coffee aroma due to its importance in consumer preference and overall sensory experience. Previous research has revealed that the aroma of roasted and brewed coffee is influenced by a complex interplay of chemical components. Coffee aroma is a complex mixture, comprising over 800 volatile compounds. This complexity necessitates the identification of 'key aroma compounds' that play a pivotal role in defining the overall sensory experience of coffee.

The research effectively integrates advanced analytical techniques with practical implications for the coffee industry, particularly in the context of quality control and product differentiation. However, while the study presents robust data on the volatile compounds and their origins, it could benefit from a deeper discussion on the sensory evaluation methods that correlate these chemical findings with consumer perceptions. Additionally, exploring the implications of these aroma profiles on consumer preferences and market trends could further enhance the relevance of the research.

Vezzulli et al., 2022 provides a comprehensive examination of how various extraction methods influence the aromatic profiles of coffee beverages derived from two predominant species, Coffea arabica and Coffea canephora var. robusta. The study is notable for its integration of metabolomic analysis with sensory evaluation, allowing for a nuanced understanding of how extraction methods impact not only the chemical composition of coffee but also the sensory experience of drinking it. The authors emphasize that traditional Italian extraction methods, such as Moka, Neapolitan pot, and Espresso, yield distinct aromatic characteristics, which can be attributed to the unique metabolites formed during the roasting and extraction processes. This is particularly relevant in the context of consumer preferences, where aroma plays a critical role in the overall perception of coffee quality.

Moreover, the application of advanced analytical techniques, including liquid chromatography and mass spectrometry, showcases the potential of metabolomics in assessing coffee quality and processing conditions. The researcher highlights that these methodologies can elucidate the relationships between specific extraction techniques, the resulting metabolomic profiles, and sensory attributes of the beverages. This connection between chemical analysis and sensory outcomes is crucial for understanding how different preparation methods can enhance or diminish certain aromatic compounds.

The intricate dynamics of coffee aroma, emphasizing its significance in consumer preference. the previous study mention the various factors that influence the aroma profile of coffee, including genotype, phenotype, and processing methods. The authors explain that the genetic makeup of the coffee cultivar, the environmental conditions in which it is grown, and the methods of processing (both primary and secondary) significantly affect the aroma compounds present in the final product. For instance, the choice between wet and dry processing can lead to distinct aroma profiles due to the differing chemical reactions that occur during roasting and storage (D. Fisk et al., 2012).

***Smell Blocking Technology***

Sun et al., 2019 presents a thorough investigation into the molecular mechanisms that contribute to the staling of coffee aroma, particularly focusing on the compound 2-furfurylthiol. This research is significant in understanding how coffee aroma can be preserved or enhanced through various technological interventions. The authors employ quantitative studies to

Journal of Applied Sciences (ISSN 2998-9159)

analyze the formation of phenol/2-furfurylthiol conjugates in coffee beverages, providing insights into the kinetics of coffee aroma extraction. This aspect is crucial as it helps elucidate how different brewing methods or storage conditions can impact the release and stability of aromatic compounds. The kinetics discussed in the article highlight that the rate at which aroma compounds are released can significantly affect the sensory experience of coffee.

Moreover, the article explores aroma delivery mechanisms from spray-dried coffee that contains pressurized internalized gas. This innovative approach suggests that the incorporation of gas could enhance the retention and release of aroma compounds during brewing. Such findings are particularly relevant for the development of smell-blocking technologies, as they provide a foundation for creating methods that could potentially mitigate the loss of aroma during storage and preparation.

The critical evaluation of the material reveals that while the study provides valuable insights into the molecular dynamics of coffee aroma, there are limitations regarding the applicability of the findings to real-world scenarios. The experimental conditions may not fully replicate the complexities of consumer environments, such as variations in brewing techniques or the influence of packaging materials on aroma stability. Furthermore, the focus on a single compound, 2-furfurylthiol, may overlook the interplay of other volatile compounds that contribute to the overall aroma profile of coffee.

Beverly et al., 2020 propose a multiscale model that elucidates the mechanisms of aroma extraction, which encompasses several key processes: the release of aroma compounds from the coffee matrix, intraparticle diffusion, transfer into aqueous and gaseous phases, and the advection processes that facilitate aroma transport. This modeling approach is particularly valuable as it not only identifies the existence of different compound behaviors but also illustrates how the physiochemical properties of aroma compounds influence the kinetics of extraction. Such insights are crucial for engineers and product developers aiming to optimize coffee aroma retention during processing.

Furthermore, the study underscores the role of steam stripping as a method to mitigate aroma degradation. By extracting an aroma stream immediately after grinding and reintegrating it into the concentrated coffee extract prior to drying, the authors suggest a practical solution to enhance the aromatic profile of the final product. This method aligns with findings from previous research, such as those by Schenker, which indicate that the physical properties of coffee beans, including the oil coating that forms during roasting, significantly impact the aroma extraction process.

The study effectively integrates theoretical modeling with practical applications, providing a robust framework for understanding and improving aroma retention in instant coffee production. However, while the study presents a detailed analysis of the extraction mechanisms, it could benefit from additional empirical data to validate the proposed model. The interplay between different coffee components and their effect on aroma extraction remains an area that warrants further investigation, particularly to refine the optimization processes suggested by the authors.

***Artificial aroma compounds***

the intricate dynamics of aroma perception in coffee, particularly focusing on the factors that influence the aroma profile of roast and ground (R&G) coffee. The authors emphasize the significance of volatile aroma compounds, which play a crucial role in consumer preference and overall coffee enjoyment. Infusion of water with R&G coffee leads to the kinetic partitioning of these volatile compounds between the coffee, water, steam, and ambient air. This dynamic interaction is critical for understanding how aroma is perceived by consumers, as it reflects the complexity of the extraction process. The authors effectively detail the various factors that contribute to the aroma profile variations, including geographical sourcing and processing methods such as wet or dry processing. This aspect of the research underscores the importance of agricultural practices and regional characteristics in shaping the sensory attributes of coffee (D. Fisk et al., 2012).

Additionally, green coffee beans are predominantly non-aromatic but contain numerous chemical precursors that transform into aromatic compounds during the roasting process. The article identifies that over 850 aroma compounds have been associated with R&G coffee, spanning a wide range of chemical classes, including hydrocarbons, alcohols, aldehydes, ketones, acids, esters, phenols, and various nitrogenous and sulfurous compounds. This comprehensive enumeration of aroma compounds illustrates the complexity inherent in coffee aroma and the myriad of chemical reactions that occur during roasting.

D. Fisk et al., 2012 provide a critical evaluation of the roasting time-temperature profiles and the impact of different roasting methods on the aroma characteristics of coffee. This discussion is particularly relevant for understanding how variations in roasting technique es can lead to distinct sensory experiences, which can influence consumer preferences and market trends in the coffee industry.

A comprehensive analysis of the aroma-active volatiles found in coffee pulp puree, a byproduct of coffee processing. The study employs advanced extraction techniques, specifically dichloromethane (DCM) extraction coupled with solvent-assisted flavor evaporation (SAFE) distillation, to isolate and evaluate the aroma compounds present (Buck et al., 2021). A significant aspect of the research is the identification

Journal of Applied Sciences (ISSN 2998-9159)

of 55 aroma-active regions, which exhibit a wide range of odor qualities including fruity, flowery, seasoning-like, fatty, green, and fecal characteristics. This diversity underscores the complexity of coffee aroma and suggests that even byproducts like coffee pulp can contribute significantly to the overall sensory experience of coffee. The highest flavor dilution (FD) factor observed was 1024, attributed to several key aroma compounds such as (E)-β-damascenone, geraniol, and 4-methylphenol, among others. These findings highlight the potential of coffee pulp as a source of valuable aroma compounds that could enhance the sensory profile of decaffeinated coffee.

The article also delves into the chemical nature of the identified aroma compounds, which belong to various groups including aldehydes, acids, lactones, phenols, ketones, alcohols, terpenes, pyrazines, and esters. The authors provide insight into the biochemical pathways leading to the formation of these compounds, indicating that the oxidative cleavage of fatty acids, particularly linoleic and linolenic acids, plays a crucial role in generating carbonyl compounds. Additionally, the formation of lactones and phenols through the oxidation and degradation of fatty acids and phenolic compounds further illustrates the intricate biochemical processes involved in aroma development.

Critically, the study's methodology is robust, employing established extraction techniques that effectively isolate aroma compounds for analysis. However, the article could benefit from a more detailed discussion on the implications of these findings for the decaffeination process and how the identified aroma compounds might be preserved or enhanced in decaffeinated coffee products. Furthermore, while the sensory qualities of the aroma compounds are described, the article lacks empirical sensory evaluation data that could substantiate the perceived aroma characteristics, which would be essential for a more comprehensive understanding of consumer preferences.

A significant finding of the study is the comparative analysis of aroma-related volatiles between regular and decaffeinated coffee. The authors report that certain chemical families, particularly alcohols, pyrazines, lactones, pyrroles, phenols, and sulfur-containing compounds, exhibited higher peak areas in regular coffee compared to decaffeinated coffee. This observation aligns with previous research indicating a reduction in pyrazine content in decaffeinated coffee, attributed to the loss of sucrose during the decaffeination process. Since pyrazines are primary pyrolysis products of sucrose, their diminished presence in decaffeinated coffee can be explained by the unintentional removal of sucrose alongside caffeine during decaffeination.

Furthermore, the study highlights the reduced levels of pyrroles and chlorogenic acids in decaffeinated coffee, reinforcing the notion that decaffeination alters not only caffeine content but also the overall volatile profile of coffee. The authors utilize advanced analytical techniques, such as HS-SPME-GC×GC-TOFMS combined with chemometrics and machine learning, to robustly distinguish between the two types of coffee based on their aromatic profiles.

P. Queiroz et al., 2022 presents a significant advancement in the flavor industry by proposing an innovative methodology for the design of natural flavor molecules. The authors emphasize the critical role that natural flavors play in modern society, particularly in light of the growing consumer demand for healthier food options and the increasing awareness of the potential hazards associated with synthetic flavors.

Furthermore, the authors acknowledge the challenges faced by the flavor industry in balancing profitability with consumer health concerns. While synthetic flavors may offer cost advantages, the market share for natural flavors is expanding, reflecting a shift in consumer preferences. This underscores the necessity for ongoing research and innovation in flavor development, particularly in creating natural aroma compounds that can effectively enhance the sensory attributes of decaffeinated coffee.

### Future technologies for enhancing coffee aroma

The previous study highlights the critical challenges associated with retaining volatile aroma compounds during the aqueous extraction and subsequent drying stages, which are pivotal in determining the quality of the final product (Beverly et al., 2020). A significant contribution of this work is the development of a multiscale model that elucidates the mechanisms of aroma extraction. This model encompasses various stages, including the release of aroma from the coffee matrix, intraparticle diffusion, and the transfer of aroma into water and steam. The findings indicate that aroma compounds exhibit distinct behaviors based on their physiochemical properties, which influence the kinetics of extraction. Notably, the interaction between different coffee components can inhibit the extraction of certain aroma compounds, a factor that has critical implications for product formulation and process optimization. The authors emphasize the importance of understanding the impact of process conditions on aroma retention. The proposed method of steam stripping, which involves extracting aroma immediately after grinding and reintegrating it into the concentrated coffee extract before drying, is presented as a viable strategy to mitigate aroma loss. This approach not only preserves the aromatic profile but also enhances the overall sensory quality of the instant coffee product.

Additionally, (Vezzulli et al., 2022) discuss the chemical pre-treatment of green Robusta coffee beans and its effect on aroma modification. This aspect is particularly relevant in the context of future technologies aimed at enhancing coffee aroma, as it suggests that pre-roasting treatments can be strategically employed to modify the sensory attributes of coffee. The findings indicate a potential for innovation in the processing stages of coffee production, which could lead to the development of new products with distinctive aroma profiles.

S. Aguiar et al., 2023 presents a thorough investigation into the future technologies aimed at enhancing coffee aroma. The authors delve into the chemical sensory evaluations of both green and roasted Coffea arabica L. (Cv. Yellow Bourbon) beans, employing various brewing methods coupled with electronic sensors to analyze the resultant aroma profiles.

A key insight from the article is the identification of how the roasting process and the brewing technique significantly influence the concentration of volatile compounds in coffee brews. The authors highlight that the transformation of these compounds during roasting and the subsequent extraction during brewing are critical for the development of the coffee's aroma. This understanding is vital for the coffee industry, as aroma plays a pivotal role in consumer preference and overall sensory experience. The methodology employed in the study, particularly the use of fan-assisted extraction combined with the full evaporation technique, is noteworthy. This innovative approach not only enhances the extraction efficiency of volatile carbonyl compounds but also allows for a more nuanced analysis of the changes in headspace volatile concentrations. Such advancements in extraction technology could potentially lead to the development of new brewing methods that maximize aroma extraction, thereby improving the overall quality of coffee.

## CONCLUSION

The exploration of decaffeinated coffee aroma has yielded significant findings that underscore the complex interplay between processing methods and aromatic compounds. Research indicates that while decaffeination processes such as solvent extraction and water processing effectively eliminate caffeine, they also alter the balance of volatile compounds, often leading to diminished aroma profiles. Key studies have identified specific compounds, that contribute to desirable aromatic qualities, albeit in reduced concentrations compared to regular coffee. The advancement of production methods that preserve these volatile compounds could enhance the sensory experience of decaffeinated coffee. Future research should focus on optimizing decaffeination processes not only to minimize caffeine but also to enhance the retention of aromatic compounds. Moreover, interdisciplinary approaches that combine chemistry, sensory analysis, and consumer behavior can provide deeper insights into the relationships between aroma and consumer preferences, ultimately guiding the development of more appealing decaffeinated coffee products.

**Conflict of interest - Disclose any potential conflict of interest appropriately**

The authors declare no conflict of interest.

**Acknowledgments**

We would like to thank the Indonesian Ministry of Higher Education Research and Technology through the KATALIS grant (strategic research group), as well as the Jember University Research and Community Service Institute (LP2M) which has provided assistance to complete this review paper.

## REFERENCES

1. Zou, Y., Gaida, M., Franchina, F., Stefanuto, P. H., & Focant, J. F. (2022). Distinguishing between Decaffeinated and Regular Coffee by HS-SPME-GC×GC-TOFMS, Chemometrics, and Machine Learning. [PDF]

2. Angeloni, S., M. Mustafa, A., Abouelenein, D., Alessandroni, L., Acquaticci, L., Kamgang Nzekoue, F., Petrelli, R., Sagratini, G., Vittori, S., Torregiani, E., & Caprioli, G. (2021). Characterization of the Aroma Profile and Main Key Odorants of Espresso Coffee. ncbi.nlm.nih.gov

3. Vezzulli, F., Rocchetti, G., Lambri, M., & Lucini, L. (2022). Metabolomics Combined with Sensory Analysis Reveals the Impact of Different Extraction Methods on Coffee Beverages from Coffea arabica and Coffea canephora var. Robusta. ncbi.nlm.nih.gov

4. D. Fisk, I., Kettle, A., Hofmeister, S., Virdie, A., & Silanes Kenny, J. (2012). Discrimination of roast and ground coffee aroma. [PDF]

5. Beverly, D., Lopez-Quiroga, E., Farr, R., Melrose, J., Henson, S., Bakalis, S., & J. Fryer, P. (2020). Modeling Mass and Heat Transfer in Multiphase Coffee Aroma Extraction. ncbi.nlm.nih.gov

6. Sun, Z., Yang, N., Liu, C., S.T. Linforth, R., Zhang, X., & D. Fisk, I. (2019). Aroma binding and stability in brewed coffee: A case study of 2-furfurylthiol. [PDF]

7. Buck, N., Wohlt, D., Ruth Winter, A., & Ortner, E. (2021). Aroma-Active Compounds in Robusta Coffee Pulp Puree—Evaluation of Physicochemical and Sensory Properties. ncbi.nlm.nih.gov

8. P. Queiroz, L., M. Rebello, C., A. Costa, E., V. Santana, V., C. L. Rodrigues, B., E. Rodrigues, A., M. Ribeiro, A., & B. R. Nogueira, I. (2022). A new Reinforcement Learning framework to discover natural flavor molecules. [PDF]

9. S. Aguiar, M., F. S. M. R. Coelho, A., J. Almeida, P., & Rodrigo Santos, J. (2023). Fan Assisted Extraction of Volatile Carbonyl Compounds from Coffee Brews Based on the Full Evaporation Technique. ncbi.nlm.nih.gov