Review Article

Disruption, Diversity, and Due Diligence: Charting the Course for Coffee's Future—Key Takeaways from the International Coffee Convention 2024 (ICC2024)

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The International Coffee Convention 2024 (ICC2024) continued the discussions initiated at ICC2023, focusing on coffee's transition and the industry's challenges. The event, held on October 17-18 in Mannheim, started with a welcome speech from Vanúsia Nogueira, the Executive Director of the International Coffee Organization (ICO), and brought together leading industry figures, experts, and stakeholders. The convention examined multiple aspects of the coffee sector, including the future landscape of coffee species, particularly the potential of Coffea canephora and other species such as C. racemosa and C. stenophylla. A key highlight was an exclusive satellite workshop, organized in partnership with the Global Crop Diversity Trust, the Coffee Consulate, RD2Vision, and supported by the ICO, which addressed the use of coffee genetic resources within the framework of the Nagoya Protocol. Coffee production's environmental footprint emerged as a central theme of the conference, with discussions covering deforestation policies, fermentation techniques, and processing methods. The sessions explored innovations in coffee preparation and business, from roasting techniques to crafting the perfect Café Crème. The program included analyses of coffee's nutritional impacts, health benefits and risks, and the evidence supporting health claims. Sustainable use of coffee by-products was also featured, stressing both challenges and opportunities. ICC2024 gathered international experts who shared scientific knowledge and practical insights. The convention ended with the presentation of the Kaldi Award, recognizing significant contributions to the coffee industry. Through

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this comprehensive program, ICC2024 contributed to shaping coffee's future by facilitating truly interdisciplinary knowledge exchange and addressing key industry challenges and opportunities.

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1. Introduction

Following the successful inaugural International Coffee Convention 2023 (ICC2023) in Mannheim, Germany[1], which evolved from previous Coffee Consulate symposia including the Stuttgart Coffee Symposia 2018 and 2020, and the Virtual Coffee Symposium 2021[2], the 2nd International Coffee Convention 2024 (ICC2024) further advanced the scientific discourse on coffee. Meeting at the Reiss-Engelhorn-Museen in Mannheim, Germany, from 17-18 October 2024, ICC2024 addressed crucial challenges in the coffee sector under the theme "Coffee in Transition." The convention built upon ICC2023's foundation while expanding into new areas of investigation, particularly focusing on sustainable production methods, climate resilience, and the potential of alternative coffee species.

The ICC2024 conference featured 32 oral and 9 virtual presentations across eight thematic sessions, accessible to a wider audience through video recordings, addressing critical challenges in the coffee sector through interdisciplinary perspectives[3]. Key focus areas included the sustainable adaptation to climate change through exploration of multiple coffee species beyond traditional Arabica and Canephora (Robusta), innovative approaches to reducing the environmental footprint of coffee production, and compliance with new regulatory frameworks such as the European Union (EU) Deforestation Regulation. Additional topics encompassed advances in coffee preparation technology, health implications of coffee consumption, sustainable utilization of coffee by-products, and novel developments in fermentation and processing methods. The scientific program was complemented by two CEO think tank discussions examining future perspectives of coffee machine manufacturers and roasters. The conference demonstrated particular emphasis on emerging analytical technologies, including artificial intelligence applications for deforestation monitoring and metabolomic profiling of coffee and its by-products. The 2024 Kaldi Award was presented during the convention, recognizing exceptional achievements in coffee science and industry.

This report, compiled by the scientific advisory board members of the conference, synthesizes the key discussions and outcomes of the ICC2024. It offers a comprehensive overview of the 41 presentations at

the convention, which attracted participation from over 180 people (Austria, Belgium, Brazil, Canada, China, Columbia, Costa Rica, Croatia, Denmark, El Salvador, France, Germany,, Guatemala, Hongkong, Hungary, India, Indonesia, Italy, Korea, Malaysia, Mexico, Netherlands, Philippines, Portugal, Saudi Arabia, Spain, Switzerland, Taiwan, Thailand, Turkey, Uganda, United Kingdom and USA), facilitating a dynamic exchange of ideas.

2. Venue and Highlights of ICC2024

The 2024 International Coffee Convention found an exceptional home at the Reiss-Engelhorn-Museen (rem) in Mannheim, Germany's largest municipally supported museum complex in the southern region[4]. The conference sessions, held in the prestigious Anna-Reiß-Saal at the Museum für Weltkulturen, and the evening reception in the modern Atrium of the Peter & Traudl Engelhornhaus, provided an inspiring backdrop that bridged scientific discourse with cultural heritage. The timing of the convention proved particularly significant, coinciding with the opening days of rem's groundbreaking exhibition "Essen und Trinken" (Food and Drink), running from 13 October 2024 through 27 July 2025, which explores the cultural and scientific dimensions of human nutrition across time. This synergy between the convention's focus on coffee's future and the museum's comprehensive exploration of food culture created a unique interdisciplinary environment for delegates.

The International Coffee Convention 2024 opened with a welcome address from Dr. Vanúsia Nogueira, Executive Director of the International Coffee Organization (ICO) (Figure 1). Dr. Nogueira, who has led the ICO since May 2022, brings extensive experience in promoting global cooperation among coffee-producing and consuming countries. Her opening remarks set the tone for the convention's theme "Coffee in Transition," highlighting the critical challenges and opportunities facing the global coffee sector. Dr. Nogueira's participation underscores the ICO's commitment to fostering international dialogue and collaboration in addressing key issues such as sustainability, market transparency, and economic development within the coffee industry.

Figure 1. Opening of the ICC2024 conference with a welcome address from Dr. Vanúsia Nogueira, Executive Director of the International Coffee Organization (ICO).

The conference program included a Corporate Night, hosted at Coffee Consulate's facilities in Mannheim on the evening of 17 October 2024. The venue provided an appropriate setting for scientific discourse and professional networking among registered conference participants. Coffee Consulate, an independent training and research center, facilitated interactions between academia and industry representatives during this evening event. The Corporate Night complemented the scientific sessions by providing an informal platform for knowledge exchange and collaboration building among coffee experts and stakeholders. A memorable highlight of the Corporate Night was the presentation by students from Mannheim Youth Academy's "Lörn Coffee" project. The participants were notably impressed by the students' enthusiasm and their innovative approach to developing coffee products specifically tailored to young consumers' preferences, particularly focusing on less bitter taste profiles. The project demonstrates how coffee education can effectively engage young people while contributing to social causes through its revenue-sharing model.

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A highlight of the first conference day was the exclusive laboratory tour at Curt-Engelhorn-Centre of Archaeometry (CEZA), where participants gained firsthand insight into the facility's specialized analytical capabilities. As a nationally and internationally recognized research institute, CEZA's expertise in scientific analysis extends to cultural and consumer goods, including coffee[5], as well as geological, environmental, and climate research. Their state-of-the-art laboratories and analytical services exemplify the kind of cutting-edge scientific support that the coffee industry increasingly relies upon, making the rem complex an ideal venue for this forward-looking convention.

The first conference day concluded with a reception in the elegant Atrium Museum Peter & Traudl Engelhornhaus of the rem. The informal setting encouraged dynamic interactions among international participants, who experienced regional specialties including local wines and beers from the palatinate region, accompanied by high-quality refreshments. This relaxed atmosphere proved particularly conducive to establishing new professional connections and continuing scientific discussions.

3. Satellite Workshop on Advancing Coffee Genetic Resource Conservation and Exchange: Global Perspectives and Strategies

A satellite workshop on coffee genetic resource conservation was held on October 16, 2024, at the Coffee Consulate in Mannheim, Germany, preceding the International Coffee Convention 2024. The workshop, co-organized by the Crop Trust and RD2Vision, with support by the International Coffee Organization, brought together key stakeholders to address challenges in coffee genetic resource conservation and exchange within the framework of the Nagoya Protocol (Figure 2). The meeting commenced with Christophe Montagnon (RD2Vision) stressing the ambiguities in current regulations and emphasizing the need for clear governmental guidelines regarding access and benefit-sharing. Sarada Krishnan (Crop Trust) presented the current status of coffee conservation strategies and outlined priority actions needed to advance global conservation efforts. The afternoon session, including several remote participants and presentations, featured extensive discussions on pathways to globalize coffee collections, including the development of best practices for coffee variety research and the establishment of a comprehensive database distinguishing between varieties subject to and exempt from Nagoya Protocol requirements. Participants, including representatives from the African Union, International Coffee Organization, National Research and Development Center for Sustainable Agriculture (Estidama, Saudi Arabia) and various research institutions, emphasized the importance of transparency and partnerships in

navigating international regulations. A key outcome was the proposed development of a global platform to facilitate the exchange and use of coffee genetic resources. The workshop emphasized the critical need for industry involvement in supporting conservation efforts and the importance of harmonizing international access and benefit-sharing legislation to enable effective research and development in the coffee sector. The outcomes of the workshop were presented to the plenary of ICC2024 participants in the first session of the conference[6].

Figure 2. On-Site Participants of the Satellite Workshop on Advancing Coffee Genetic Resource Conservation and Exchange (from left to right; Budour A. Alghamdi, Aaron P. Davis, Vanúsia Nogueira, Steffen Schwarz, Sarada Krishnan, Romain Guyot and Christophe Montagnon).

4. Summary of the Scientific Topics of ICC2024

4.1. Future Landscape of Multiple Coffee Species

The topic "Future Landscape of Multiple Coffee Species" pointed out the critical role of genetic diversity in addressing challenges facing coffee cultivation, particularly in light of climate change (Figure 3). Montagnon[7] opened the discussion by tracing the historical journey of coffee genetic material

exchange, from the initial crossing of Arabica seeds from Ethiopia to Yemen, to the modern-day spread of varieties like Gesha. He emphasized that contemporary challenges necessitate new exchanges of plant material, particularly from wild species adapted to extreme conditions. Davis[8] expanded on this theme by discussing the limitations of relying solely on Coffea arabica and C. canephora, which have dominated the coffee sector for 125 years. He identified promising alternative species, particularly highlighting C. liberica and C. dewevrei (Excelsa) for their climate resilience potential, while also noting C. stenophylla's future promise. Guyot et al.[9] presented cutting-edge genomic approaches to understanding wild Coffea species, revealing that the genus comprises 130 recognized species with potential expansion to 141. Their research demonstrated remarkable adaptive characteristics among wild species, particularly in Madagascar's Baracoffea alliance, which shows exceptional drought tolerance. The presentations concluded with Montagnon and Serito[10] presenting results from the "Coffee Genetic Discovery" project, which analyzed samples from 24 countries, revealing that while 73% of farmers could identify their cultivars, genetic conformity was only confirmed in two-thirds of cases. This finding underscored the need for professionalizing the coffee seed sector. Throughout the presentations, speakers emphasized that accessing and utilizing genetic resources must comply with international regulations like the Nagoya Protocol while meeting the urgent need for climate-resilient coffee varieties.

Figure 3. Live session speakers on the topic of Future Landscape of Multiple Coffee Species (left panel: Davis; upper right panel: Guyot; lower right panel: Montagnon).

4.2. Coffee Production's Environmental Footprint and Addressing EU Deforestation Regulation (EUDR)

The topic "Coffee Production's Environmental Footprint and Addressing EU Deforestation Regulation" highlighted several complementary technological approaches to combat and monitor deforestation in coffee production (Figure 4). The presentations revealed a unified focus on leveraging artificial intelligence and remote sensing technologies, though with different implementation strategies. Furniss and Browning[11] and Kalamandeen et al.[12] concentrated on the fundamental detection and monitoring aspects using remote sensing technologies, with the latter specifically demonstrating applications in

Ethiopian coffee landscapes. Two presentations introduced practical tools for EUDR compliance: Rothe and colleagues[13] presented the "EUDR Coffee Check," emphasizing automated analysis methodologies combined with a structured risk assessment approach, while Ilowski[14] proposed Deforestation Regulation Open Platform (DROP) as an open-source alternative, specifically designed to make compliance accessible to smallholder farmers through a Linux-inspired business model. All four approaches shared common elements in utilizing satellite imagery and machine learning, but differed in their scope and target users. The EUDR Coffee Check focused on comprehensive supply chain documentation, while DROP prioritized accessibility and cost-effectiveness. Together, these presentations demonstrated how technological solutions can address both regulatory compliance and practical monitoring needs, though questions remained about standardization and integration of these different approaches.

The additional presentations broadened the environmental perspective beyond deforestation. The Kajve Initiative, presented by Maggioni and colleagues[15], illustrated a practical example of implementing sustainable practices while maintaining smallholder livelihoods in Chiapas, Mexico, achieving significant improvements in yields and disease resistance. Ten Bosch and Fox[16] outlined long-term strategies for achieving net-zero emissions in coffee agriculture, emphasizing that less than 10% of reductions can come from direct tree planting, highlighting the need for broader interventions. Krischkowsky et al.[17] proposed a digital coffee atlas utilizing crowdsourced data and artificial intelligence (AI)-based image recognition to support sustainable farming practices. Addressing climate adaptation, Salinas-Velandia et al.[18] presented spatial modeling research for potential Canephora coffee cultivation in Colombia, identifying suitable areas below 600 m elevation to avoid competition with traditional Arabica regions. Tsai[19] provided insights from Taiwan's specialty coffee sector, demonstrating how agricultural innovation can enhance sustainability despite environmental challenges.

Figure 4. Live session speakers on the topic of Coffee Production's Environmental Footprint and Addressing EU Deforestation Regulation (EUDR) (from left to right; upper panels: Furniss, Rothe; middle right panel: Ilowski; lower panels: ten Bosch, Maggioni).

4.3. Advancements in Coffee Preparation and Business: A Journey from Roasting to the Perfect Café Crème

Several significant developments in coffee preparation and business strategies were presented, encompassing post-roast maturation, community development initiatives, regional coffee cultures, and alternative coffee species commercialization (Figure 5).

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Zimmermann and Schwarz[20] challenged the traditional perception of "freshly roasted" coffee quality through a controlled study. Using triangle test methodology combined with hedonic preference testing, the study demonstrated a significant sensory difference between freshly roasted and matured coffee samples, with 71% of participants able to distinguish between them. Notably, 53% of participants who correctly identified the mature samples expressed a preference for them over freshly roasted ones, suggesting potential benefits of post-roast maturation periods.

Martínez-Castaño et al.[21] presented the "Coffee Grower's Laboratory" initiative in Ituango, Colombia, which implemented 13 participatory methodologies to enhance local coffee farmers' capabilities. The program successfully increased farmer profits from less than 10% to approximately 50% through direct buyer relationships and value-added processing. The initiative included innovative approaches such as brand co-creation, roasting technique development, and experimentation with fruit-based fermentations.

Peluso[22] examined the historical development and regional variations in Italian coffee culture, particularly focusing on the north-south divide in Canephora-Arabica preferences. The research revealed how historical factors, including trade routes and cultural influences, shaped distinct regional preferences, with northern regions favoring lighter Arabica-based blends while southern regions prefer darker Canephora-dominated coffees.

Lee[23] detailed innovations in Liberica coffee processing in Sarawak, Malaysia, adapting techniques for the humid tropical climate where annual rainfall exceeds 4000 mm. The study demonstrated successful development of processing and roasting methods specifically tailored for Liberica coffee, creating high-quality beans suitable for premium café offerings and potentially opening new market opportunities in the specialty coffee sector.

Figure 5. Live session speakers on the topic of Advancements in Coffee Preparation and Business: A Journey from Roasting to the Perfect Café Crème (left panel: Lee; right panel from top to bottom: Martínez-Castaño, Peluso, Zimmermann.

4.4. Coffee and Health: Exploring the Nutritional Impacts, Benefits, and Health Claim Substantiation

The topic featured six presentations centered around coffee's health effects, safety considerations, and regulatory aspects. A key theme was the complex relationship between coffee's beneficial compounds, potential contaminants and health outcomes (Figure 6).

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Farah[24] provided a historical perspective on coffee and health, noting that despite historical controversies, epidemiological and clinical evidence increasingly supports coffee's protective effects against various degenerative diseases, including type 2 diabetes, Parkinson's, Alzheimer's, liver diseases, and certain cancers. These benefits stem from coffee's complex bioactive compound profile, including caffeine, chlorogenic acids, quinolactones, trigonelline, and melanoidins. She also highlighted the steps that can be taken at the farm and industry levels to increase the contents of bioactive compounds and reduce the presence of detrimental compounds in the beverage.

Abalo[25] investigated coffee components' effects on the brain-gut axis, finding sex-dependent influences on gastrointestinal motility and visceral sensitivity. The research demonstrated that melanoidins and spent coffee grounds accelerated gastro-intestinal transit in male rats, while instant cascara showed female-specific effects on colonic responses. These findings have implications for developing functional foods from coffee by-products. Coreta-Gomes[26] focused on coffee's cardioproductive properties, particularly investigating how coffee compounds like arabinogalactans and galactomannans influence cholesterol metabolism. The research demonstrated that coffee extracts could decrease cholesterol bioaccessibility through various mechanisms.

Mesias et al.[27] examined acrylamide bioaccessibility in coffee products, reporting ranges of 73-90% for soluble coffees and 78-99% for coffee substitutes. Their research emphasized the importance of understanding interactions between acrylamide and food matrix components in assessing exposure risks. Breitling-Utzmann et al.[28] investigated acrylamide levels in Arabic coffee roasts, finding that very light roasts contained significantly higher levels (646 μg/kg) compared to medium (154 μg/kg) and dark roasts (62 μg/kg). This research highlighted potential health risks associated with traditional Arabic coffee preparation methods.

Höfflin et al.[29] analyzed unregulated caffeine health claims in coffee products, revealing gaps in current regulatory frameworks and the need for better oversight of health-related marketing claims.

Figure 6. Live session speakers on the topic of Coffee and Health (left panel: Coreta-Gomez; upper panel: Abalo; lower panel: Farah; right panel: Mesias).

4.5. Coffee in Transition

The disruptive transformation of the coffee industry emerged as a central theme of the conference, with three key presentations highlighting how traditional practices and business models are being fundamentally challenged across multiple dimensions (Figure 7).

Preibisch[30] directly addressed the imperative for disruption, arguing that the coffee industry has reached a critical juncture where incremental changes are insufficient. Traditional business models must

undergo radical transformation to remain competitive and sustainable. The presentation emphasized that disruptive innovation is required across the entire value chain - from implementing precision farming techniques and digital traceability platforms to revolutionizing roasting processes with renewable energy integration. These changes are not optional but essential for survival in an evolving market landscape.

This need for disruption was further reinforced by Fabian[31], who outlined how multiple external forces are compelling unprecedented change in the sector. The EU Deforestation Regulation represents a disruptive shift in compliance requirements, fundamentally changing how coffee origins must be documented and traced. The potential reclassification of dichloromethane threatens to disrupt established decaffeination processes. Perhaps most significantly, traditional market dynamics are being upended, with C. canephora coffee - historically considered a lower-cost alternative - now sometimes commanding higher prices than Arabica, disrupting conventional pricing models and supply chain strategies.

Lachenmeier et al.[32] presented research that challenges one of the most fundamental assumptions in coffee service - that hotter is better. Their extensive sensory trials demonstrated that lower brewing temperatures were often preferred, and most consumers could not distinguish between temperatures. This finding disrupts long-standing industry practices and challenges coffee businesses to reconsider their brewing protocols, especially given the health implications and the potential for the International Agency for Research on Cancer (IARC) to upgrade its carcinogenicity classification of very hot beverage consumption.

These presentations collectively emphasized that the coffee industry is experiencing disruption on multiple fronts - regulatory, technological, market dynamics, and even basic preparation methods. The message was clear: businesses that fail to embrace and adapt to these disruptive changes risk becoming obsolete. This industry-wide transformation requires not just technological innovation but a fundamental rethinking of how coffee is produced, processed, prepared, and served.

Figure 7. Live session speakers on the topic of Coffee in Transition (upper left panel: Lachenmeier; lower left panel: Preibisch; right panel: Fabian).

4.6. CEO Think Tank session "Brewing the Future"

The CEO Think Tank session "Brewing the Future" at ICC 2024, chaired by Professor Yves Zimmermann from the Heilbronn University (Germany), brought together leading executives from both coffee machine manufacturing and roasting companies for two focused round-table discussions (Figure 8). The first panel featured CEOs from major coffee machine manufacturers including Melanie Aselmann (Franke Coffee Systems, Germany & Austria), Oliver Welschar (Simonelli Group, Germany), Frank Rückl

(Provenero, Germany), and Christian Matzke (Reneka International, France). The second panel comprised industry leaders from the roasting sector, including Dr. Stefan Scholle (roastmarket, Germany), Duje Dadic (Dylan & Harper, Germany), and Ennio Cantergiani (Carasso-Bossert, Switzerland). The discussions fostered open dialogue between competitors in the coffee industry. A notable observation was the successful integration of both technical expertise and business perspectives. The session format facilitated substantive exchange between manufacturers and roasters, addressing current market challenges and future industry developments. Participants particularly noted the value of combining scientific and entrepreneurial viewpoints from different segments of the coffee sector.

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Figure 8. CEO Think Tank session speakers (from left to right; upper panel: Zimmermann, Matzke, Rückl, Welschar, Aselmann; lower panel: Scholle, Zimmermann, Dadic, Cantergiani).

4.7. Sustainable Utilization of Coffee By-Products: Challenges and Opportunities

This topic included innovative approaches to valorize various coffee by-products, addressing both environmental sustainability and potential health benefits. Several key presentations focused on different aspects of by-product utilization and valorization strategies (Figure 9).

Del Castillo[33] presented a novel approach to coffee cherry utilization through the development of instant cascara powder using the 5S methodology (sort, set, shine, standardize, sustain). The research

emphasized cascara's anti-inflammatory properties and potential health benefits, suggesting it as a viable alternative for individuals seeking lower caffeine intake while maintaining beneficial effects. The standardized production method aims to ensure consistent quality and safety of the final product.

Acuña-Gutiérrez et al.[34] demonstrated the feasibility of converting fresh coffee cherries into fruit spreads. Their research developed three formulations with varying sugar contents, achieving products that qualified for the "source of fiber" label under EU regulations. The high-sugar versions showed better stability, with caffeine content remaining within safe consumption limits.

Reineke et al.[35] investigated coffee cherry flour as a functional ingredient in pastries. While incorporating coffee cherry flour reduced yeast dough volume and specific volume of pastries, it significantly enhanced their nutritional profile through increased mineral and dietary fiber content. The study demonstrated the potential for coffee by-products in food applications, though requiring careful formulation adjustment.

Rovelli et al.[36] employed metabolomic approaches to analyze coffee leaves. Their research utilized advanced analytical techniques including liquid chromatography coupled with mass spectrometry to identify and quantify bioactive compounds, supporting the development of new products and supply chain diversification.

Ayour[37] presented research on coffee grounds valorization, focusing on their diverse chemical composition and potential applications across various sectors including health, food, agriculture, and materials. The study demonstrated high antioxidant activity and significant levels of bioactive compounds in coffee grounds.

Kull and Lachenmeier[38] provided crucial regulatory context by discussing EU labeling requirements for coffee by-products, particularly addressing novel food regulations and correct labeling practices.

Figure 9. Live session speakers on the topic of Sustainable Utilization of Coffee By-Products (left panel: Acuña-Gutiérrez; right panel, from top to bottom: Reineke, Rovelli, del Castillo).

4.8. Advancing Fermentation Techniques, Enhancing Processing Methods, and Green Bean Treatment

The topic included four presentations centered around a comprehensive exploration of emerging fermentation techniques, processing innovations, and green bean treatments (Figure 10).

Kiefer et al.[39] presented a cross-platform metabolomic approach for evaluating the changes in the sensory metabolomes of green and roasted coffees produced through controlled, cultured-yeast

fermentation versus spontaneous fermentation. Their preliminary results revealed substantial differences in the volatile organic compound (VOC) profiles, indicating the potential to increase the quality of underutilized Coffea species through targeted fermentation strategies.

Mhlanga[40] introduced an innovative post-harvest processing method for upgrading C. canephora coffee. Key innovations included a 75-80% reduction in water consumption and effluent emission compared to traditional wet washing, achieved through a controlled two-stage fermentation using the natural microflora on sun-dried beans. Sensory evaluation demonstrated the ability to produce a pleasantly balanced single-origin cup with full body and rich flavor.

Fabian et al.[41] presented a study on dichloromethane (DCM) residues in decaffeinated coffee. Analysis of 34 commercial products showed DCM levels well below the maximum limits set in the EU and USA. They also quantified the DCM mass transfer rates from the coffee matrix into the final brewed beverages, reporting an average of 24.7% for drip coffee and 41.9% for French press.

Velazquez Escobar et al.[42] reported the first case of mistaken identity between caffeine crystal growth and biological spoilage on high-end roasted C. arabica beans. Using UV-Vis spectroscopy, they identified the "mold" as conglomerates of needle-like caffeine crystals, which were found to be influenced by the roast degree. This naturally occurring crystal formation relates to the migration of caffeine towards the bean surface during germination, activating the seeds' antibacterial defenses.

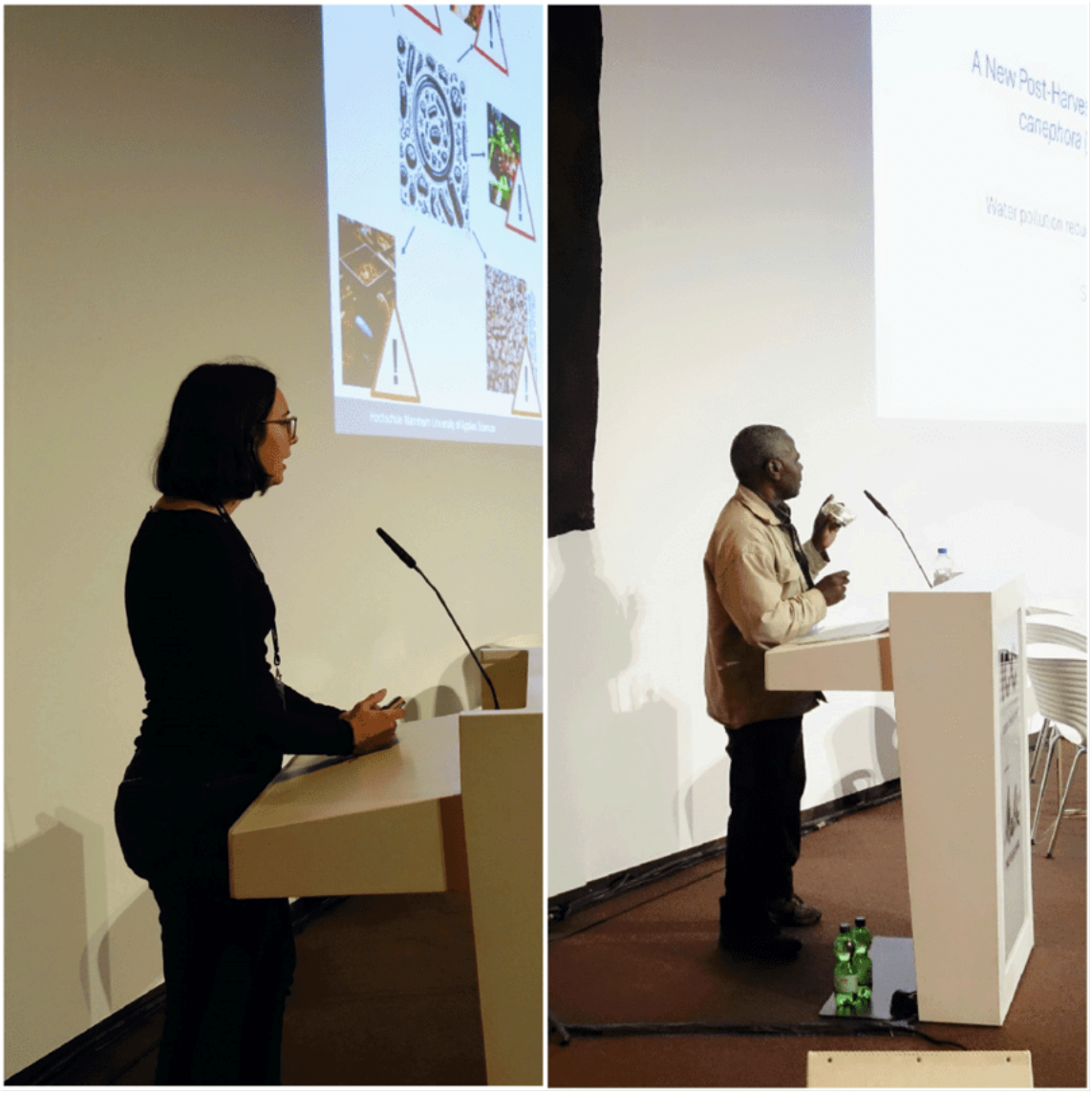

Figure 10. Live session speakers on the topic of Advancing Fermentation Techniques, Enhancing Processing Methods, and Green Bean Treatment (left panel: Kiefer, right panel: Mhlanga).

4.9. Coffee Research: From Screening Methods to Sensory Profiles

The final topic focused on advanced analytical techniques and their application to understanding the complex chemistry and sensory profiles of coffee (Figure 11).

Bieber et al.[43] presented on the use of mass spectrometric non-target screening as a powerful analytical strategy for gaining new insights into the chemical composition of coffee samples. Their approach employed orthogonal serial HILIC-RPLC coupled to high-resolution mass spectrometry to identify

"features" that reflect the polarity, accurate mass, intensity, and structural information of unknown molecules. This allowed them to track compound formation and degradation during coffee fermentation processes and identify potential markers for quality and authenticity.

Triachini et al.[44] investigated the impact of roasting speed on the safety, sensory quality, and energy efficiency of C. canephora coffee. Using a multi-omics approach with untargeted metabolomics, they were able to accurately discriminate coffee samples based on market quality and roasting speed. Notably, the interaction between these factors was a significant discriminant, with lipid and lipid-like molecules playing a key role in the chemical signature of C. canephora. Additionally, they evaluated the efficacy of a roasting program's "Energy Calculator" in estimating actual energy consumption.

Bichlmaier et al.[45] focused on the degradation of mozambioside, a potent bitter compound found in Arabica coffee, during the roasting process. They identified newly formed pyrolysis products with even lower activation thresholds for bitter taste receptors compared to mozambioside itself. Advanced analytical techniques, including mass spectrometry and NMR, were used to elucidate the structures and quantify these compounds in coffee powders and brews, providing insights into the complex chemistry underlying coffee's unique flavor profile.

Özpınar et al.[46] presented a study on the determination of chlorogenic acids, caffeine, and antioxidant capacities in Turkish-style coffee bean samples. This work provides the first in-depth characterization of the key compounds in traditional Turkish coffee.

Figure 11. Live session speakers on the topic of Coffee Research: From Screening Methods to Sensory Profiles (left panel: Bieber; right panel, from top to bottom: Özpınar, Bichlmaier, Triachini).

5. Kaldi Award 2024

The Kaldi Award, inspired by the legendary story of Kaldi, an Ethiopian goatherd discovering coffee's stimulating effects and aromatic potential[2], honors significant scientific contributions to the coffee industry. The award was initiated by Coffee Consulate and decided by an international jury of coffee experts. It acknowledges the advancements and research that continue to shape the understanding and enjoyment of coffee, much like the legendary Kaldi's initial encounter with this now-global phenomenon.

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The Kaldi Award 2024 honors distinguished professionals for their exceptional contributions to the field of coffee science and the coffee industry, and normally includes 4 different categories[2]. For 2024, the jury has decided exceptionally to award 2 prizes in the “Green Coffee/Cultivation and Processing” category and not to award any prize in the "Roasting and Analytics" category. The laureates were as follows:

- Lifetime Achievement Award: María Dolores del Castillo
- Green Coffee (Cultivation and Processing) Award #1: Aaron P. Davis,
- Green Coffee (Cultivation and Processing) Award #2: Romain Guyot
- Preparation and Consumption Award: Mariano Peluso

This year’s Kaldi Award recipients (Figure 12) have made influential contributions that extend beyond their specific research areas, impacting the coffee industry and shaping global practices.

Figure 12. Kaldi Award laureates 2024 pictured with the award presenters (from left to right: Montagnon, Schwarz, Guyot, Davis, del Castillo, Peluso, Farah, Lachenmeier).

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6. Conclusions

The International Coffee Convention 2024 marked a significant advancement from its predecessor. The convention successfully addressed critical challenges facing the coffee industry through eight comprehensive thematic topics including additional virtual presentations.

The convention highlighted several key developments in the coffee sector. The discussions on multiple coffee species beyond Arabica and Canephora demonstrated the increasing recognition of species diversity as a strategy for climate resilience. The presentations on genetic material exchange and conservation emphasized the urgent need for international collaboration while respecting the Nagoya Protocol framework.

Environmental sustainability emerged as a central theme, with significant attention devoted to the European Union Deforestation Regulation (EUDR) and innovative technological solutions for compliance. Several presentations introduced novel digital platforms and AI-driven approaches for monitoring and preventing deforestation in coffee-producing regions.

The scientific sessions revealed important advances in coffee processing techniques, particularly in fermentation methods and roasting technologies. New insights into the relationship between roasting parameters and the formation of process contaminants such as acrylamide were presented. The health aspects of coffee consumption were extensively discussed, including new findings on bioactive compounds and their potential benefits.

Coffee by-product valorization showed significant progress, with multiple presentations demonstrating novel applications. The convention also addressed crucial business aspects, including market development strategies and the challenges faced by coffee companies in an increasingly complex regulatory environment.

The interdisciplinary nature of the presentations, combining fundamental research with practical applications, provided valuable insights for researchers, industry professionals, and policymakers. The discussions highlighted the coffee sector's commitment to addressing climate change, sustainability, and health concerns while maintaining economic viability.

Looking ahead, the coffee community anticipates the next International Coffee Convention, with planning underway for a future edition. The exact date and location will be announced pending coordination with key stakeholders and consideration of global circumstances.

Statements and Declarations

Author Contributions

Conceptualization, D.W.L. and S.S.; writing—original draft preparation, D.W.L.; writing—review and editing, S.S., C.M., A.F., Y.Z., M.F., and M.D.d.C. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

M.F. is currently employed by Demus S.p.A., Trieste, Italy. C.M. is currently employed by RD2 Vision, Valflaunes, France. S.S. is currently employed by Coffee Consulate, Mannheim, Germany. M.F., C.M. and S.S. affirm that the research was conducted without any commercial or financial relationships that could be perceived as potential conflicts of interest. The remaining authors also declare no conflicts of interest.

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Informed Consent

Not applicable.

Data Availability

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Claude 3.5 Sonnet, an AI language model developed by Anthropic PBC (San Francisco, CA, USA), was utilized through its Projects feature, which enables systematic processing of multiple documents in a dedicated workspace. The Projects feature allowed for the comprehensive analysis of all 41 conference abstracts and proceedings documents simultaneously, maintaining context across the entire collection of materials. The system was provided with direct access to the complete proceedings database through document upload functionality, enabling accurate extraction and synthesis of information while maintaining source attribution. Claude 3.5 Sonnet assisted in organizing and structuring the conference content, processing complex scientific concepts, and ensuring consistent scientific language usage throughout the report. The AI tool's contribution was limited to language processing and text organization; all scientific content, research findings, and conclusions remained under human editorial control. The system demonstrated particular utility in maintaining factual accuracy when synthesizing information from multiple presentations and abstracts, while adhering to formal scientific writing conventions and style guidelines.

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Declarations

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