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Editorial

Coffee—From Plant to Cup

Douglas Silva Domingues [1,*], José C. Ramalho [2,3,*] and Fábio Luiz Partelli [4,*]

1 Department of Genetics, "Luiz de Queiroz" College of Agriculture (ESALQ), University of São Paulo (USP), Av. Pádua Dias, 11, Piracicaba 13418-900, SP, Brazil
2 Laboratório de Interações Planta-Ambiente & Biodiversidade (PlantStress & Biodiversity), Centro de Estudos Florestais (CEF), Laboratório Associado TERRA, Instituto Superior de Agronomia (ISA), Universidade de Lisboa (ULisboa), Quinta do Marquês, Av. da República, 2784-505 Oeiras, Portugal
3 Unidade de Geobiociências, Geoengenharias e Geotecnologias (GeoBioTec), Faculdade de Ciências e Tecnologia (FCT), Universidade NOVA de Lisboa (UNL), Monte de Caparica, 2829-516 Caparica, Portugal
4 Department of Agricultural and Biological Sciences, Centro Universitário Norte do Espírito Santo, (CEUNES), Universidade Federal do Espírito Santo (UFES), Rodovia BR-101, Km 60, Litorâneo, São Mateus 29932-900, ES, Brazil
* Correspondence: dougsd@usp.br (D.S.D.); cochichor@isa.ulisboa.pt or cochichor@mail.telepac.pt (J.C.R.); partelli@yahoo.com.br (F.L.P.)

1. Introduction

To date, there were identified 130 species included in the *Coffea* genus [1], although only two support cultivation and trade, accounting for 99% of global production. *C. arabica* L (Arabica coffee) makes up the bulk of this production, with *ca*. 60%, with *C. canephora* Pierre (Robusta/Conilon coffee) contributing the remaining *ca*. 40%. In addition to differing in appearance and origin, these two species also show notable divergence in beverage quality attributes, namely body, aroma and taste [2–5].

Coffee cultivation promotes the valorization of individuals through wealth generation, work provision, and life quality improvement. Coffee farmers, the "warriors" in this arena, confront ongoing challenges in producing and marketing coffee. Thus, they warrant profits, a better quality of life, especially in rural areas, and respect from society at large.

World coffee annual yields have already overcome *ca*. 10 million tons, generating an income of *ca*. USD 200 billion [6], while supporting the livelihoods of about 25 million smallholder farmers in the tropical region, who account for about 60% of the coffee farms [7–9]. All of this is taking place under a growing uncertainty due to climate changes that threaten agricultural activities in general, including coffee growing and quality. Given the evolving climate patterns, shifts in technological level, and consumer demands, the need for continuous studies to obtain additional knowledge is evident. Therefore, the need for enhanced coffee research and a broader discussion involving farmers, scientists, and the industry is urgent, to which this Special Issue aims at contributing. In the mid- to long-term, this can lead to a significant expansion of the knowledge base. This will allow the cultivation of superior/elite plants for diverse management situations, optimize procedures throughout the production chain, and ultimately achieve more economic and environmental sustainable operations.

In this context, we have the pleasure of delivering 18 papers published in the thematic series "Coffee—From Plant to Cup". The encompassing studies shed light on the complexities involved in the journey of coffee, spanning from its cultivation under multifaceted environmental conditions to the post-harvest processing that eventually defines the taste and aroma attributes of the final beverage.

2. Published Articles

This Special Issue brings together a wide variety of studies and research perspectives under a common subject: the coffee crop.

Starting the series, given the increased global trend towards water scarcity, Marques et al. [10] studied the effects of drought on cultivars of the two main producing

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coffee species, *C. canephora* cv. Conilon Clone 153 and *C. arabica* cv. Icatu coffee plants.. Using label-free quantitative shotgun proteomics, nearly 3000 proteins were identified in both genotypes, with a small fraction contributing significantly to the entire proteome size, and showcasing the importance of certain proteins in drought response. Interestingly, while moderate water deficits have minimal impact, severe drought brings substantial proteomic changes, particularly in *C. arabica*. In fact, although both species exhibited stress-responsive proteins under severe drought, *C. arabica* showed a greater antioxidant detoxification protein response, which was associated with the better resilience found in earlier ecophysiological analysis [11]. These results highlight the immediate implications of drought and the need for more resilient coffee varieties in the face of climate change, especially given the potential acclimation capability of *C. arabica*.

Complementing this, Schmidt et al. [12] examined the relationship between coffee's genetic diversity and mineral nutrient concentrations, specifically in Robusta (*C. canephora*) coffee genotypes grown in the Amazon. This study uncovers the importance of understanding genetic variability and nutrient needs during key growth periods for coffee plants, a subject with minor attention given to it in the literature. They showed that leaf nutrient levels, particularly iron, could indicate genetic divergence among genotypes. In addition to this nutritional perspective, Schmidt et al. [13] studied variations in root distribution among *C. canephora* cv. Conilon genotypes, informing strategies for improved mineral fertilization. They found roots concentrated within a certain depth and distance from the plant, and the highest concentration of roots was near irrigation drippers. These insights suggest that targeted/localized fertilizer application could enhance plant nutrition and crop efficiency.

Disease resistance and productivity are also key parameters in coffee cultivation and management. Here, Moreira et al. [14] charted new territory by suggesting an innovative selection method for developing disease-resistant coffee plants, in *C. arabica* progenies derived from the Icatu and Catimor groups. The authors proposed a selection method that considers multiple harvests and disease resistance. They found correlations between coffee leaf rust and brown eye spot, pointing to the possibility of selecting for resistance to both diseases simultaneously. Their work provides a fresh approach for breeding disease-resistant coffee cultivars, promoting sustainable coffee production and reducing pesticide use.

Despite significant strides in understanding the growth and adaptation of the coffee plant, environmental challenges continue to hinder coffee production. Under this scope, León-Burgos et al. [15] indicated the harmful effects of soil waterlogging on the growth and physiological performance of *C. arabica* Cenicafé 1 variety plants. Their findings revealed that 16 days of waterlogging resulted in a considerable reduction in the total dry mass of the plant. Furthermore, decreases in the total leaf area were detected after 12 days of waterlogging. Other factors, such as leaf water potential and the maximum efficiency of photosystem II, were also noticeably impacted by waterlogging. Overall, their findings demonstrate the importance of comprehending the impact of this environmental stressor on the coffee plants, emphasizing the need to devise strategic interventions to augment plant resilience.

Filete et al. [16] made a relevant contribution, challenging the traditional perception associating a *C. canephora* variety with inferior sensory quality. By exploring diverse fermentation methods across multiple production regions, they unveiled the potential to improve the sensory quality of this coffee variety. The study demonstrated that local characteristics such as altitude and temperature directly influence sensory quality, and also revealed that natural fermentation in a specific altitude zone delivered good results, emphasizing the 'terroir' factor. Additionally, induced fermentation proved beneficial in enhancing sensory quality in higher altitude areas, indicating the potential for reformulating the 'terroir' of Conilon coffee production. Thus, the 'terroir,' or the physical environment in which coffee is grown, does not solely dictate the coffee's sensory profile, but rather involves the interplay of numerous other factors, including fermentation techniques, that determine the final coffee experience.

Likewise, Silva et al. [17] focused on identifying a strategy for enhancing drought tolerance in Arabica coffee genotypes. Recognizing the importance of developing resilient crops in an era of escalating climate change, this research represents a significant contribution towards future-proofing the coffee industry. The team deployed a dual-pronged research approach, combining field trials conducted under natural conditions and experiments executed under controlled greenhouse conditions. This comprehensive evaluation revealed that under water deficit conditions, a significant proportion of the examined traits demonstrated substantial genetic variance. High heritability coefficients, estimated from the mean of the progeny, supported the robustness of these findings. Comparisons between selection results in the greenhouse and in water-deficit field conditions highlighted two genotypes, H419-3-3-7-16-11 and H516-2-1-1-7-2. These genotypes combined high productivity with morpho-anatomical traits that confer enhanced drought tolerance. This study underscores the critical role of strategic selection in developing drought-resilient coffee cultivars and provides valuable insights for future research in this area.

Shifting the focus to the improvement of coffee quality, the study by Gomes et al. [18] examined the potential of carbonic maceration in enhancing the sensory profile of *C. canephora*. Implemented under anaerobic conditions, the study varied both fermentation times and temperatures. Following this, the processed grains underwent both sensory analysis and medium infrared spectroscopy. Intriguingly, the results indicated significant linear relationships between the total score and temperature across multiple fermentation times. An increase in the total score coincided with an increase in the fermentation temperature, suggesting a direct correlation between these variables. The findings from the study by Gomes et al. [18] contribute to the broader understanding of post-harvest processing techniques, paving the way for potential improvements in coffee quality through the application of carbonic maceration.

Another set of studies, from Cassano et al. [19] to Alberto et al. [20], continued to explore diverse aspects of coffee production and quality, with works envisaging the potential for the coffee crop in a newly producing country, Mozambique. They explored the impact of altitude and light conditions on the fruit maturation, physical, chemical and sensory quality attributes of coffee beans. The investigation of the influence of roasting profiles on coffee quality, the development of genetic markers for disease resistance, and the analysis of the effects of altitude on soil quality and microbial communities further enriched our understanding of coffee production and quality. In this sense, Ferreira et al. [21] also explored the influence of environmental factors such as altitude and solar radiation on the sensory and physical quality of Arabica coffee. In an era where consumer preference for specialty coffees is burgeoning, the researchers highlighted the nuanced role that the environment plays in shaping the sensory experience of coffee. The study, conducted in a Minas Gerais municipality in Brazil, analyzed Arabica coffee grown at three altitudes and two solar radiation exposures. They found that, at an altitude of 1150 m, the plant side that received the afternoon sun produced a higher-quality coffee compared to the side that received the morning sun. This underscores the potential of geographical and climatic elements in determining coffee quality.

Further addressing quality issues, Debona et al. [22] examined the impact of four roasting profiles using two roasters on the chemical and sensory quality of coffee beans. Roasting profiles, including baked, light, medium, and dark, were evaluated using medium infrared spectroscopy and cupping tests. The findings indicated that specific regions in the infrared spectrum served as markers for the roasting profiles and the type of roaster used. However, no significant differences were found in the final sensory notes between the roasters.

Pérez et al. [23] conducted an insightful study into the chemical and sensory characteristics of coffee in relation to the degree of fruit maturity. Their research revealed a wide range of properties within fruits considered mature, identifying the lack of changes in several components such as organic acids, free fatty acids, lipids, total chlorogenic acids, proteins, and alkaloids across different maturity states. However, they observed an intriguing variation in fructose and glucose levels, with higher levels corresponding to more mature states. These specific sugar variations stood out among the otherwise consistent chemical profiles of the fruits across different maturity levels. Notably, regardless of these chemical differences, the sensory attributes or overall sensory quality of the coffee remained unaffected by the degree of fruit maturity.

Remarkably, genetic diversity was found to play a significant role in determining the agronomic value and environmental resilience of coffee, as underscored by Al-Ghamedi et al. [24]. The study conducted on local coffee populations in Saudi Arabia utilized 30 sequence-related amplified polymorphism (SRAP) markers on 56 accessions from Saudi Arabia, revealing a high degree of polymorphism and demonstrating substantial genetic diversity. Structural and cluster analyses further presented the broad genetic diversity amongst coffee populations, particularly those in the southwestern mountain terraces of Saudi Arabia. The study emphasizes the need for further research to enhance the understanding of the evolution and value of local Arabica coffee diversity. Ssremba et al. [25] investigated the variation in drought stress tolerance in *C. canephora* half-sibs exposed to water deficit at the germination stage. The study incorporated half-sib seeds from selected commercial and pipeline clones, evaluated later for tolerance to deficit watering across various temperature environments. The KR7 family showed the best performance, while the research identified ten top-performing individuals for drought and heat tolerance. The study underscores the untapped potential of *C. canephora* half-sibs' diversity for abiotic stress tolerance breeding.

In a distinct study, Ariyoshi et al. [26] focused on combating bacterial halo blight (BHB), a disease prominent in major coffee-producing regions, and caused by Pseudomonas syringae pv. garcae. Chemical control, though effective, is environmentally unsound and costly. Developing BHB-resistant cultivars offers a more sustainable and economical solution. The researchers developed a pair of Allele-Specific-Polymerase Chain Reaction (AS-PCR) primers linked to qualitative resistance against the pathogen in *Coffea arabica* breeding populations. The primers showed a high accuracy rate in segregating populations, suggesting their potential for Marker-Assisted Selection (MAS) in a robust, simple, fast, and low-cost manner. Bento et al. [27] explored the genetic diversity and drought tolerance in different *Coffea canephora* genotypes. This line of research reveals the significance of tapping into this diversity to breed drought-resistant cultivars. Also, Alberto et al. [20] emphasized the importance of nutrient management in ensuring high yields and coffee quality, demonstrating how the understanding of fruit characteristics and nutrient accumulation can guide nutritional management practices.

Lastly, the work conducted by Ge et al. [28] explored also the influence of altitude on the physical-chemical characteristics of rhizospheric soil and the microbial communities in *Coffea arabica* plantations, thus complementing the studies previously mentioned studies [19,20]. Soil samples from lower altitudes were more nutrient-deficient and acidic compared to those taken from medium-high altitudes. The study also shed light on the changing bacterial communities across altitudes, with the proteobacteria-to-acidobacteria ratio increasing from lower to medium-high altitudes. The study emphasized the correlation of microbial phyla with pH. Based on these findings, Ge et al. proposed that cultivating *C. arabica* at medium-high altitudes could be beneficial for sustainable management practices and the production of high-quality coffee beans.

3. Conclusions

Altogether, the research presented in these 18 papers from this Special Issue spotlights the essential role of continual research in genetic selection, environmental management, nutrition, and post-harvest processes to boost coffee bean quality and yield. They bring new insights with the potential to mitigate the impact of predicted environmental changes. A focused future approach on regions susceptible to climate change and tailored adaptation strategies should be undertaken, using such knowledge and management practices to supports a sustainable global coffee industry, ensuring our shared enjoyment of superior coffee.

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