FEDERAL UNIVERSITY OF ESPÍRITO SANTO
UNIVERSITY CENTER NORTH OF ESPÍRITO SANTO
POSTGRADUATE PROGRAM IN TROPICAL AGRICULTURE

HENZO PEZZIN SALVADOR

DYNAMIC OF DRY MATTER AND NUTRIENTS ACCUMULATION IN BERRY, BEAN AND HUSK OF SIX *COFFEA CANEPHORA* GENOTYPES DURING FRUIT MATURATION

São Mateus, ES
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HENZO PEZZIN SALVADOR

Dissertation presented to the Federal University of Espírito Santo, as part of the requirements of the Graduate Program in Tropical Agriculture, to obtain a master's degree in Tropical Agriculture

Supervisor: Prof. Ph.D. Fábio Luiz Partelli

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Prof. Dr. Fábio Luiz Partelli
Universidade Federal do Espírito Santo
Orientador

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Prof. Dr. Henrique Duarte Vieira
Universidade Estadual do Norte Fluminense Darcy Ribeiro

Prof. Dr. José Cochicho Ramalho
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SUMMARY

ABSTRACT

SALVADOR, Henzo Pezzin; M.Sc.; Federal University of Espírito Santo; March 2024; **Dynamic of dry matter and nutrients accumulation in berry, bean and husk of six *coffea canephora* genotypes during fruit maturation**; Supervisor: Fábio Luiz Partelli, Co-supervisor: Miroslava Rakocevic.

Knowledge about dry matter (DM) accumulation in berry and its main parts (bean and husk) is crucial to understand the dynamics of the fruit throughout the maturation process and to adjust the harvesting time to achieve a higher grain yield, while knowledge related to nutrient accumulation provides important information for better fertilizer management. Therefore, the aim of this study was to evaluate the effect of the maturation process on the accumulation of dry matter, macro, and micronutrients in fruit, bean, and husk of six genotypes of *Coffea canephora*. The study was conducted in an experimental plantation at the UFES campus, São Mateus. Fruit samples were collected every two weeks, starting at 33 weeks after flowering, until the complete maturation of the six genotypes, totaling nine collection dates (periods), with the last at 49 WAF. The rate of DM accumulation was initially higher for the fruit and bean, and later for the husk. Second order polynomial regressions were fitted for DM accumulation in the fruit, bean, and husk over time. DM accumulation in the fruit, bean, and husk increased as fruit maturation progressed, reaching the highest values in the final stages of red berries. The nutrient accumulation data were subjected to two-way analysis of variance (ANOVA). It was found that maturation influences the concentration and accumulation of nutrients in the beans, husk, and fruits. In general, the highest concentrations were observed in fully ripe fruits.

Keywords: Conilon coffee, Dry matter, Bean yield, Nutrient accumulation, Dry matter dynamics.

RESUMO

SALVADOR, Henzo Pezzin; M.Sc.; Universidade Federal do Espírito Santo; Março de 2024; **Dinâmica do acúmulo de matéria seca e nutrientes em fruto, grão e palha de seis genótipos de *Coffea canephora* durante a maturação dos frutos**; Orientador: Fábio Luiz Partelli, Co-orientadora: Miroslava Rakocevic.

O conhecimento sobre o acúmulo de matéria seca (MS) no fruto e suas partes principais (grão e casca) é fundamental para compreender as dinâmicas do fruto ao longo do processo de maturação e ajustar o momento de colheita para obter um maior rendimento de grãos, enquanto o conhecimento relacionado ao acúmulo de nutrientes proporciona informações importantes para um melhor manejo de adubação. Diante disto, o objetivo deste trabalho foi avaliar o efeito do processo de maturação no acúmulo de matéria seca, macro e micronutrientes em fruto, grão e palha de seis genótipos de *Coffea canephora*. O trabalho foi conduzido em lavoura experimental do campus da UFES, São Mateus. Amostras de frutos foram coletadas a cada duas semanas, começando às 33 semanas após a floração, até a maturação completa dos seis genótipos, totalizando nove datas de coleta (períodos), sendo a última aos 49 WAF. A taxa de acúmulo de MS foi inicialmente mais alta para o fruto e grão, e posteriormente para palha. Foram ajustadas regressões polinomiais de segundo grau para a acúmulo de MS no fruto, grão e palha ao longo do tempo. O acúmulo de MS no fruto, grão e palha aumentou conforme avanço da maturação dos frutos, atingindo os valores mais altos nos estágios finais de frutos vermelhos. Os dados de acúmulo foram submetidos à análise de variância (ANOVA) two-way. Constatou-se que a maturação influencia na concentração e acúmulo dos nutrientes nos grãos, palha e frutos. Em geral, as maiores concentrações foram observadas com os frutos completamente maduros.

Palavras-chave: Café conilon, Matéria seca, Rendimento de grãos, Acúmulo de nutrientes, Dinâmica de acúmulo.

1. CHAPTERS

1.1. A CLIMATE CHANGE PERSPECTIVE ON THE SELECTION, DEVELOPMENT, AND MANAGEMENT OF *COFFEA CANEPHORA* GENOTYPES: A REVIEW

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Abstract

Coffee is the second most consumed beverage in the world and thus occupies a central role in the global economy. After *Coffea arabica*, *C. canephora* is the second most important coffee species, cultivated in several South American, African and Asian countries. Although *C. canephora* originates from warm areas in Africa, drought and heat stresses can limit its productivity and quality, leading to social and economic vulnerability of the smallholder farmers who produce most of this coffee species worldwide. In recent years, the impact of global warming has been more pronounced, affecting rainfall distribution regularity in several coffee zones and temperature extremes more frequently, thus increasing the demand for innovative crop management and the release of more tolerant coffee varieties. Here, we review a) the economic and social importance of coffee in several countries in a historical context, b) the relevance of genetic diversity for *C. canephora* breeding, c) management strategies that can mitigate the impacts of climate change on coffee, and finally d) we propose strategies to improve the field performance of coffee trees, along with possible future research directions. When relevant, the importance of investments in research and training of human resources, which are urgently needed

to promote the expansion of a socio-economically viable and sustainable coffee, was also highlighted.

Keywords: Adaptation, Climate change, *Coffea canephora*, Conilon, Genetic diversity, Global coffee production, Robusta, Shaded coffee.

Introduction

The recent decades suggest that notable shifts in global climate have arisen from increased human activities, leading to modifications in the composition of the Earth's atmosphere, causing significant climate changes such as irregular rainfall distributions and increasing frequency of temperature extremes (IPCC, 2023). As the demand for crop products continues to rise, agricultural productivity is endangered by a variety of stress factors, frequently tied to the effects of global warming (ZHAO et al., 2017). Under the context of predicted climate changes and global warming, modern agriculture must concurrently increase productivity and breed plants with increased tolerance to biotic and abiotic stresses (MALHI et al., 2021).

Heat stress is defined as the temperature condition above a critical threshold for a period long enough to cause irreversible damage to plant growth and development (WAHID et al., 2007). Coffee trees are tropical plant species that depend on a specific climate for optimal development (GILES et al., 2018; GILES et al., 2019; MARTINS et al., 2019). Extreme environmental conditions, such as high temperatures and intense solar irradiance, may impact their physiological development (DAMATTA et al., 2016). Under such conditions, stomatal closure in addition to chronic photoinhibition (often associated with the triggering of oxidative stress) may occur, limiting photosynthetic processes (RODRIGUES et al., 2016; MARTINS et al., 2016), ultimately with the potential to reduce plant productivity (DAMATTA et al., 2019).

Of the 130 known coffee species (DAVIS & RAKOTONASOLO, 2021), only two are commercially cultivated and account for approx. 99% of the production in the world. *Coffea arabica* L. (Arabica coffee) accounts for most of the production (56%) and *C. canephora* L. Pierre ex A. Froehner (Robusta and Conilon coffees) for the remaining 44% (ICO, 2023). In contrast to *C. arabica*, which is autogamous, *C. canephora* is allogamous, and cultivation is made by mixing compatible clones (MORAES et al., 2018). 'Robusta' is the most widely cultivated variety of *C. canephora* in the world, so the name of this variety is usually used to refer to the species. Nevertheless, in Brazil, 'Conilon' (also known as 'Kouillou') is the main cultivated variety of *C. canephora* (DAMATTA & RAMALHO, 2006). *C. arabica* species is considered more sensitive to climate change and global warming than *C. canephora* (DAMATTA et al., 2018). Two major distinct genetic groups, Guinean and

Congolese, within the *C. canephora* species, were described by Berthaud (1986). The Congolese group was further divided into five subgroups, *i.e.,* SG1, SG2, B, C and Uganda (Labouisse et al., 2020), so that Conilon (subgroup SG1) and Robusta (subgroup SG2) were introduced in Brazil. *Coffea arabica* species is considered more sensitive to climate change and global warming than *C. canephora* (DAMATTA et al., 2018). Therefore, significant losses in bean yield and quality are expected in many suitable areas for *C. arabica* cultivation (CASSAMO et al., 2022). In contrast, the superior tolerance of *C. canephora* to climate change may be related to its primary centre of diversity in African countries' warm, low-latitude regions (CHARRIER & BERTHAUD, 1985). Therefore, *C. canephora* may be seen as an alternative for areas where water scarcity and elevated temperature limit *C. arabica* cultivation. Notably, environmental changes caused by climate warming can also limit crop productivity by increasing diseases and pest attacks (ZHANG et al., 2023); thus, the planning of strategic adaptations to biotic and abiotic stresses for future scenarios has become increasingly relevant (BUNN et al., 2015; ARMAREGO-MARRIOT, 2021; TOURNEBIZE et al., 2022; ZHU et al., 2022).

Along with the environmental challenge, the narrow genetic background caused by the lack of selection of superior seed-propagated plants, especially in African countries, is also an important issue for the coffee crop. In addition, the number of seed-grown plantations in countries such as Brazil and Vietnam, which are the largest *C. canephora* producers in the world, is very low. Although the *C. canephora* clones grown in these countries often yield uniformly, their genetic diversity is low, leading to a decline in *C. canephora* diversity. Such low diversity exposes the crops to great risks related to climate change and increased susceptibility to pest and disease attacks.

The use of shelter trees in coffee plantations may be an alternative strategy to mitigate the effects of climate change on coffee cultivation, which can also favour the beverage quality (CAMPANHA et al., 2004; MOAT et al., 2017) In fact, cultivating shaded coffee in agroforestry systems (AFS) or intercropped with other tree crops is common in Asia, Africa, and Central and South American countries and is a suitable alternative to improve microclimatic conditions close to the coffee trees. This could reduce the radiation loads and temperature at leaf/plant level, together with an increase in air humidity closer to the plant (PARTELLI et al., 2014; OLIOSI et al., 2016; CHARBONNIER et al., 2017). Therefore, increased attention is being paid to

adequate shade density in AFS as an alternative to protect coffee plantations against climate change (KOUTOULEAS et al., 2022a; KOUTOULEAS et al., 2022b; CASSAMO et al., 2023).

This chapter will address the breeding and management practices in *C. canephora* cultivation aiming to mitigate the effects of climate change on coffee productivity. The narrow genetic diversity and shaded management are also discussed.

Evolution of *Coffea canephora* production in the world

In the last 30 years, global coffee production has increased, reaching the highest production in 2019, about 10.3 million tons. In this context, *C. canephora* contribution increased approx. 30% in the 1990s, up to 44% of all yielded coffee in 2022 (Figure 1). In the last five years, the domestic significantly consumption, *i.e.,* coffee consumed within the producing countries, was around three million tons of dry beans, and the remaining amount was exported, mainly to Europe and North America, which have consumed almost 50% of all coffee produced worldwide (ICO, 2023).

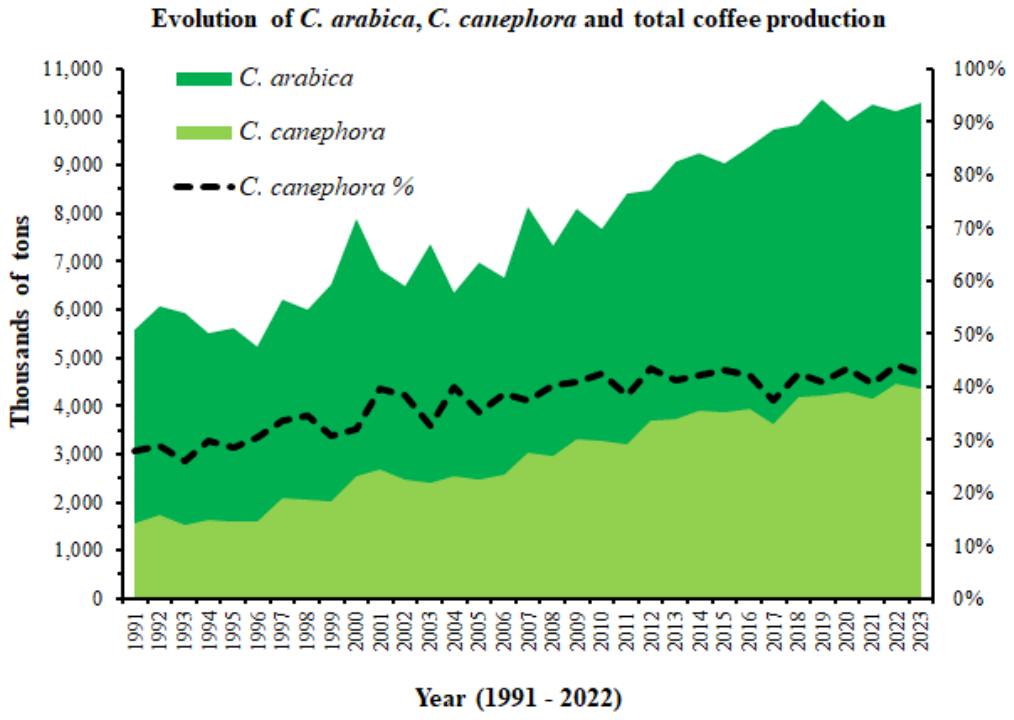

Figure 1. Yield evolution of *C. arabica*, *C. canephora* and total coffee production from 1991 to 2023 in thousands of tons (dry beans). The dotted line corresponds to the

secondary axis and shows the representativeness of *C. canephora* coffee in relation to the total production (%) (ICO, 2023).

South America dominates the world coffee production, mainly due to the high output of *C. arabica*. In the last five growing seasons, Brazil and Colombia were among the five largest producers (Figure 2). Given that Brazil displays favourable climatic conditions for coffee production, in addition to the expressive number of available varieties (SANTOS et al., 2021), coffee plantations have been successfully spread over several regions across the country. Brazil's coffee accounts for about 35% of the global production (*C. arabica* and *C. canephora* together). In Colombia, production declined in the 1990s and remained low over the following 20 years due to price variations, forcing coffee growers to change to alternative income-generating activities such as animal husbandry, mining and forestry (RODRÍGUEZ et al., 2022). In Asia, coffee production is dominated by Vietnam and Indonesia, which mainly cultivate *C. canephora*. In Africa, Ethiopia (the centre of genetic diversity of *C. arabica*) is the largest coffee producer, exporter and consumer and the fifth largest global producer; Ethiopia produces only *C. arabica* and is the third largest producer of this species, behind Brazil and Colombia.

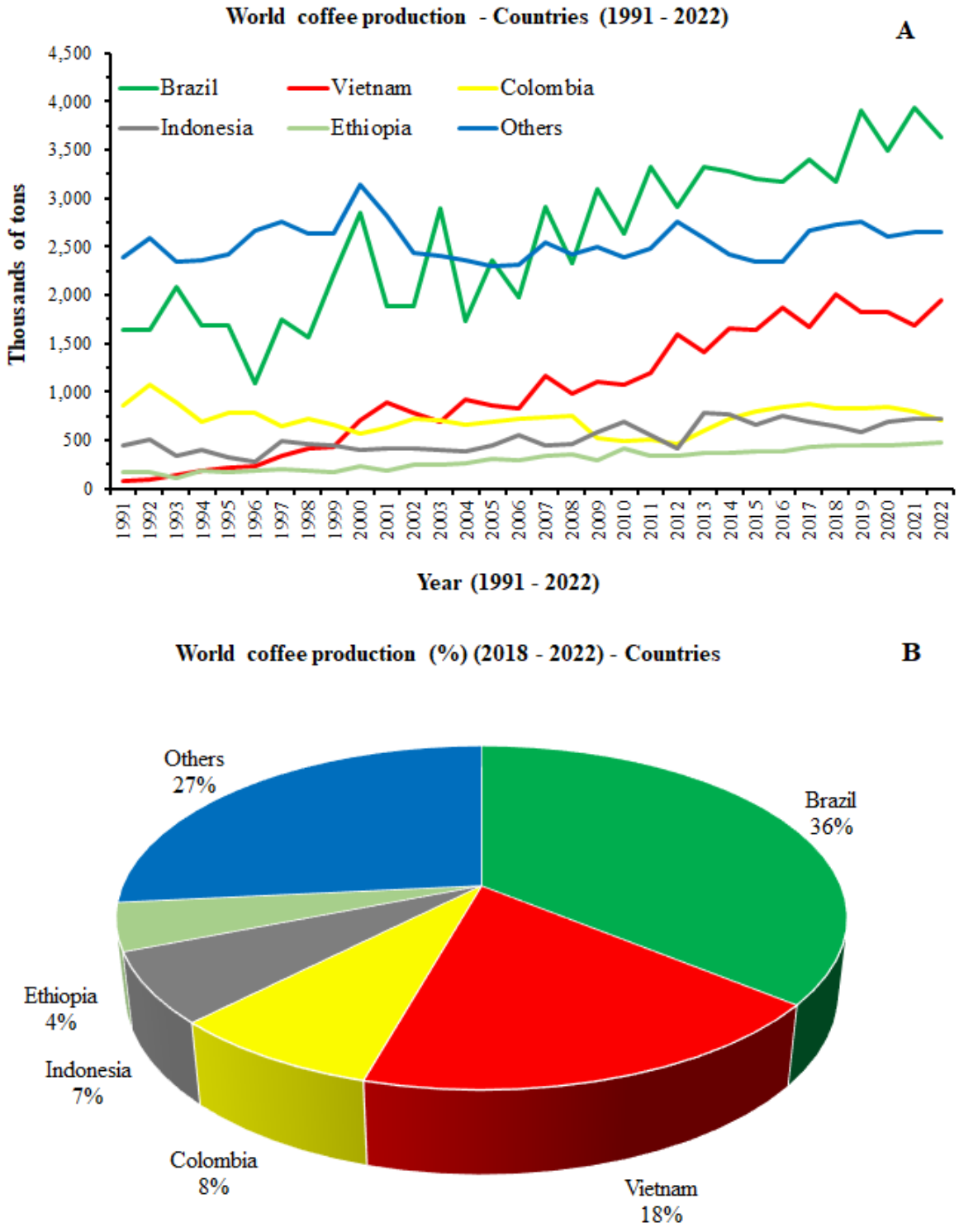

Figure 2. Evolution of the total coffee production of the five largest current producers (Brazil, Vietnam, Colombia, Indonesia, Ethiopia and others) in thousands of tons from 1991 to 2022 (A). Representativeness (%) of the five largest coffee-producing countries based on the average output of the last five growing seasons (2018 to 2022) (B) (ICO, 2023).

Specifically, regarding *C. canephora*, the current largest global producers are Vietnam, Brazil, Indonesia, Uganda and India, which account for more than 90% of worldwide production (Figure 3). Among these countries, Vietnam and Uganda dominate the global export trade, given that other producing countries, such as Brazil, retain and consume a significant part of their production. Investments in research and the development of new cultivars since the 1990s boosted the production in Vietnam, which has been, since 1998, the largest producer of *C. canephora*. In Vietnam, production is marked by a biennial cycle, *i.e.,* a year of high is followed by a year of low production. This phenomenon of coffee production also occurs in Brazil, particularly with *C. arabica*.

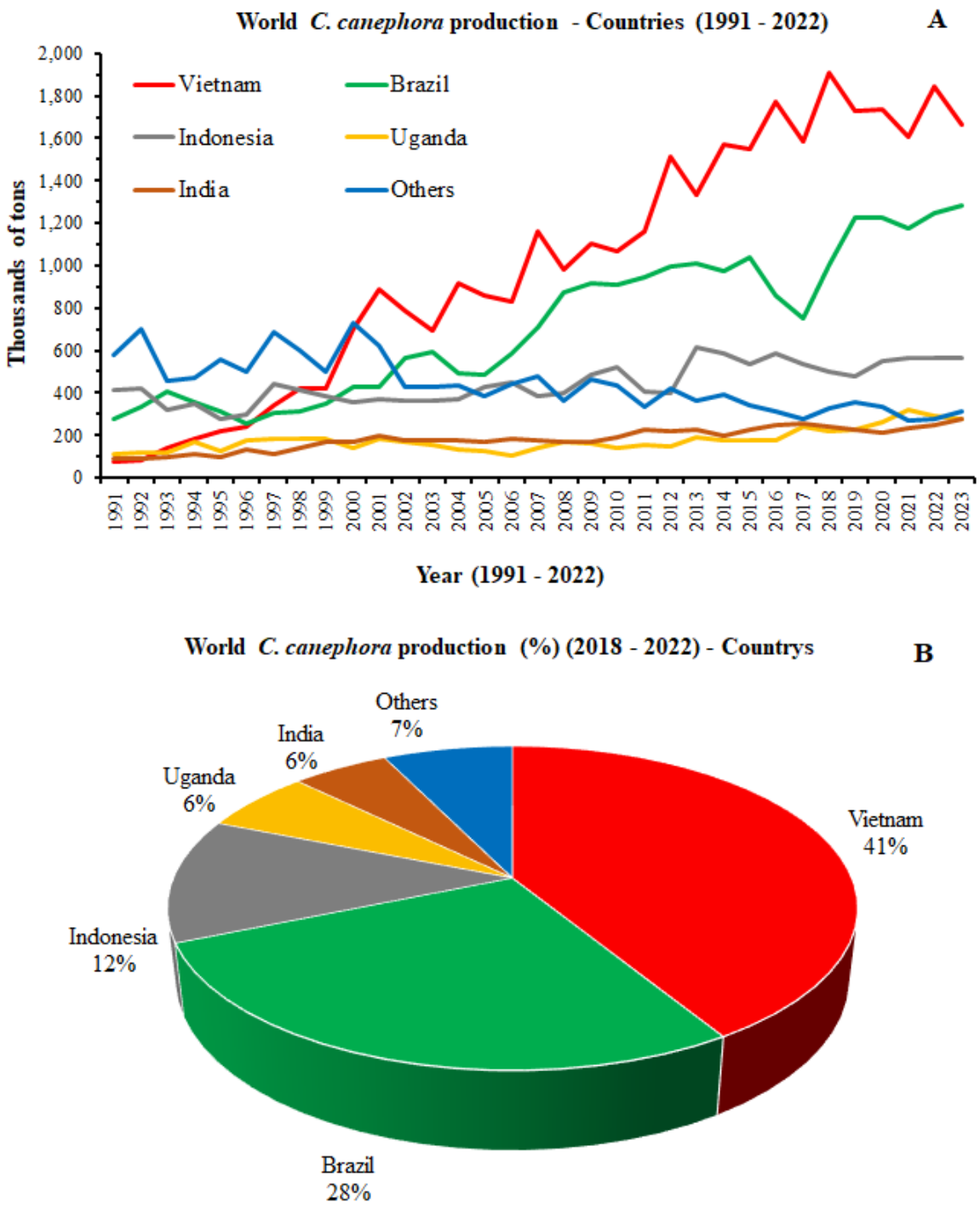

Figure 3. Evolution of *C. canephora* production of the five largest current producers (Vietnam, Brazil, Indonesia, Uganda, India and others) from 1991 to 2022 in thousands of tons (dry beans) (A). Representativeness (%) of the five largest *C. canephora* coffee-producing countries based on the average output of the last five growing seasons (2018 to 2022) (B) (ICO, 2023).

The decline in the volume of *C. canephora* produced in Brazil in 2016-2017 was due to a severe drought occurring in 2014-2015 in Espírito Santo, the largest *C.*

canephora state producer in Brazil. The production drop in Espírito Santo was around 50%, whereas the impact on Brazilian coffee production was smaller (40%) because of the counterbalance of other producing regions (CONAB, 2016). Production returned to normal levels only in 2019 when the *C. canephora* cultivation areas had recovered from the drought-induced damages. This scenario serves as an illustrative example of how climate change conditions can profoundly affect coffee production.

Major *Coffea canephora* producers

Although we know that some *C. canephora* producer countries (Ivory Coast, Ghana, Togo, and Nigeria) have breeding programs to improve quality and agronomical traits, in this section, we focused chiefly on the top-five main producers.

Vietnam

In Vietnam, *C. canephora* occupies 93% of the total coffee-producing area and accounts for 97% of the national production, whereas *C. arabica* accounts for the remaining. The total area under coffee is estimated at 670,000 ha, and the main coffee-growing provinces, namely Dak Lak (209,000 ha), Lam Dong (162,000 ha), Dak Nong (135,000 ha), Gia Lai (98,000 ha) and Kon Tum (18,500 ha) lie in the Central Highlands. Vietnam is currently the most productive *C. canephora*-growing country in the world, with an average yield of 2.880 kg ha^{-1} (GSOV, 2022).

For the past 30 years, coffee has been one of the pillars of Vietnam's agricultural revenue and overall Gross Domestic Product (GDP). The coffee sector in Vietnam employs around 1.5 million people, *i.e.,* 2.7% of all workers in the country, 44% of which are women. Regarding local impact, in 2020, the Central Highlands region of Vietnam was responsible for employing 91.7% of all coffee workers and 37.3% of all workers (PINEDO, 2020). With a projected export turnover surpassing US$3 billion, coffee exports typically contribute approximately 15% to the overall volume of agricultural exports. Over recent years, coffee has consistently represented more than 10% of the agricultural GDP (MARD, 2024).

Two coffee farming systems are used in Vietnam: monoculture and polyculture (intercropping). Intercropping is found in two systems. In the first, coffee trees are intercropped with other crops on the same plot of land, known as "synchronised farming"; in the second, crop diversification is done by planting different crops on separate plots, called "segregated farming system". Farmers are

trained to intercrop coffee with other crops, such as pepper, durian, avocado, and passion fruit. Intercropping with trees, like durian and avocado, provides shade, blocks the wind, limits water loss by soil evaporation and contributes to a sustainable coffee development in the context of climate change (DINH et al., 2022). However, it should be mentioned that producers are tending to move on to more profitable crops such as durian. Therefore, it is highly unlikely that production in Vietnam will continue to grow (Rigal et al., 2023).

Since early in the 1990s, when coffee was widely grown in the Central Highland provinces, many research institutes for agricultural seedlings, particularly the Institute of Agroforestry Sciences of the Central Highlands (WASI), have studied and introduced many different *C. canephora* genotypes. The selective breeding process resulted in dozens of new *C. canephora* lines differing in plant size, adaptability to soil and climate, pest and disease resistance, and yield. Vietnam's most cultivated genotypes are TR4, TR9, TRS1 and TS5, which produce large fruits and grains. Among them, genotype TRS1 has responded well to pruning for plant renewal and currently is considered a superior material for cultivation (CHUNG et al., 2021).

Brazil

Coffee was introduced in northern Brazil in 1727, with seedlings coming from French Guiana (MAPA, 2022). *C. canephora* was first introduced in Brazil in the state of Espírito Santo. The first seedling was brought by Jerônimo Monteiro in 1912, but only in 1972, a significant yield was recorded on Espírito Santo. Brazilian micro-regions specialized in *C. canephora* are primarily concentrated in the states of Rondônia and particularly Espírito Santo. The latter is the largest *C. canephora* producer, having *ca.* 54% of all *C. canephora* suitable cultivation areas in Brazil since nearly the entire state territory is appropriate for *C. canephora* cultivation (VOLSI et al., 2019). Over the last three decades, production and yield of *C. canephora* have increased remarkably in Brazil, with Espírito Santo, Rondônia and Bahia states producing as much as 96% of the total output of *C. canephora* in Brazil (CONAB, 2024). This species is planted on an acreage of 392,000 ha, with a productivity of 2,580 kg ha^{-1}. The pillars of this evolution consisted of the generation of knowledge, as well to the diffusion and transfer of technologies and the aggregation of efforts of the different institutions, strengthening the coffee chain of value.

The cultivation of *C. canephora* in Brazil occurs at a maximum altitude of 500 m a.s.l., mainly under full sunlight. The currently unpredictable climatic conditions, with long periods of water deficits for the crop, associated with the development of very productive but not very drought-tolerant genotypes, make irrigation for *C. canephora* cultivation practically indispensable. Consequently, *C. canephora* has been grown predominantly under irrigation, which enhances flower bud production (COVRE et al., 2016) and improves grain development and formation (PEZZOPANE et al., 2010). Therefore, irrigation generally ensures high yields (SAKAI et al., 2015) and a final product with a better beverage quality (FERNANDES et al., 2012). Most coffee producers in Brazil use surface or buried drip irrigation systems.

After harvest, *C. canephora* beans are usually processed through the dry method (POLTRONIERI & ROSSI, 2016). The berries are dried on terraces or in mechanical dryers before husk (pericarp) removal. Subsequently, the husk and other impurities are separated from the beans (PIMENTA et al, 2018). This process should be carefully monitored as impurities and remaining husks are negative aspects for commercialisation.

Forty-seven highly productive cultivars of *C. canephora* are recommended for cultivation in different Brazilian regions (MAPA, 2023). Based on genetic structure studies, the Brazilian germplasm of *C. canephora* represents only a small portion of the total diversity of this species (FERRÃO et al. 2019), therefore, expanding the genetic basis is crucial to breeding programs in the light of climate change. The endeavor of the UFES staff in scientific production and training of human resources has intensified the transfer of technologies to the field and to *C. canephora* farmers. One example is the recent release of six *C. canephora* cultivars. The first was the cultivar Tributun, released by UFES in 2017, which has several desirable traits, especially high yield (PARTELLI et al., 2020). Other outstanding cultivars are 1) cv. Andina, the first *C. canephora* cultivar adapted to high elevation and relatively cool temperatures (PARTELLI et al., 2019); 2) cv. Monte Pascoal, which is the first recommended for the state of Bahia, where production conditions are different from othe Brazilian states cultivating *C. canephora* (PARTELLI et al., 2021), and 3) cv. Salutar, the first cultivar selected for soluble coffee production and health-related characteristics (PARTELLI et al., 2022a). Recently, UFES registered two other new cultivars with desirable traits: cv. Forte Guarani, the first with high caffeine levels in the bean and cv. Plena has genotypes with high mean yields (> 6 tons ha^{-1}). All lines

from which the cultivars were derived are available to producers on the experimental field of UFES, in São Mateus municipality, Espírito Santo state (Figure 4).

Figure 4. Coffee trees on an experimental field of the Federal University of Espírito Santo (Ufes) - Brazil. Upper: plants displaying high uniformity of flowering. Lower: plants with high yielding potential and high uniformity of fruit maturation.

Indonesia

C. canephora was introduced in Indonesia in 1900 from the Belgian Congo (now Zaire) and was planted in Malang region. The *C. canephora* which was first

developed in Indonesia in 1911-1930 resulted from breeding activities at the experimental station of the Dutch government in Bangelan, Malang, East Java (SUGIANTO et a., 2022).

The area under coffee in Indonesia has remained stable in recent years, at around 1.2 million ha. Indonesian coffee plantations are primarily performed in smallholder farms of about 1-2 ha (USDA, 2024). *C. canephora* is grown predominantly in the Southern Sumatra provinces, namely in Lampung, South Sumatra and Bengkulu, and accounts for *ca.* 60% of the national total coffee area and *ca*. 75% of the national *C. canephora* production (BYRAREDDY et al., 2019).

Ongoing climate change has caused variations in air temperature and changes in rainfall patterns and intensity in Indonesia (RUNTUNUWU & SYAHBUDDIN, 2012). These changes have been associated with a higher frequency of extreme climate events such as El-Niño and La-Niña, which can disrupt coffee production, affecting the economic livelihood of Indonesian coffee farmers (YULIASMARA et al., 2017). Sarvina et al. (2023) suggested that climate change impacts will reduce suitable areas for *C. canephora* in the provinces of Aceh, North Sumatra, South Sumatra and Lampung by 2050. Therefore, knowledge about climate change and the projection of climate suitability is essential for Indonesia's crop sustainability.

Uganda

In Africa, Uganda is the second-largest producer of *C. arabica,* behind Ethiopia, and the largest producer of *C. canephora* coffee (PHIONA & ABMROSE, 2023). In 2022, coffee contributed 18% to the country's GDP and was the second most exported commodity, only behind sugarcane (UBOS, 2022). Of the coffee produced in Uganda, 80% is *C. canephora* and 20% is *C. arabica*. The Central Region is the main producing region, where over 30% of the country's coffee is grown (UCDA, 2020). It appears that a significant portion of cultivated coffee in Uganda can trace its origins back to the southern-central forests such as Malabigambo, Kalangala, and Mabira. Additionally, there is evidence suggesting the introduction of cultivated genotypes from Congo into Uganda (Kiwuka et al., 2021).

Coffee is produced in diversified forms on farms in Uganda, associated with several other crops, in tiny areas with low input levels. The average size of coffee fields is 0.25 ha, and 90% of the farmers have plots of less than 0.5 ha, representing

60% of the total cultivation area. The largest producers account for 10% of the total output and occupy 40% of the coffee area, with fields of approx. 1.0 ha. Only 25% of the farmers contract workers (UBOS, 2022). Problems related to the organisational level, poor use of technologies, and the low income of coffee grower families impair coffee growth as a crop in Uganda. The farmers also have limited access to quality training and information.

Climate change has prevented coffee production improvements and reduced suitable areas in Uganda. Rainfall alteration was the main factor limiting suitability for coffee in the central southwest and northeast. Heat has limited the suitability of *C. canephora* coffee at lower elevations (WICHERN at al., 2019). In this context, cultivation systems involving shading coffee trees are useful to mitigate the effects of climate change. Projects with shaded coffee in Uganda are already underway, including the training of farmers under Agroforestry for Food Security program to promote a more positive view of the management costs and benefits provided by shelter trees (BUYINZA et al., 2022).

India

India is the sixth largest global coffee producer and the fifth *C. canephora* producer, exporting around 70% of its production (ICO, 2023). *C. canephora* was introduced in India from Java in the early 20th Century. However, commercial cultivation of *C. canephora* only became significant after 1925 due to the establishment of the Coffee Research Station in Chikmagalur. Over the years, the proportion of *C. canephora* to *C. arabica* acreage has drastically changed. During the 1950s, only 27% of the Indian area under coffee cultivation was used for *C. canephora* and the remaining 73% for *C. arabica*. During 2018-2019, *C. canephora* was planted on *ca*. 50% of the total coffee-producing area. In addition, *C. canephora* production leaped from only 18% in 1950 to 70% in 2018-2019, highlighting the significance of *C. canephora* cultivation in India (HUDED et al., 2020). More recently, *C. congensis* has also been farmed in India as a niche market coffee (BERTRAND et al., 2022). Coffee is mainly cultivated in the southern states, namely Karnataka, Kerala and Tamil Nadu. To a lesser extent, coffee is also grown in non-traditional areas such as Andhra Pradesh, Orissa and the north-eastern states, mainly to promote tribal development and afforestation (GAIRHE & REDDY, 2012). India produces some of the best coffee in the world, cultivated under shaded conditions.

With over 3 million coffee growers, coffee cultivation is a source of employment in the country (ASIF & PANAKAJE, 2022).

Coffee harvesting in India is mainly done by multiple harvests when only the fully ripe fruits are hand-picked. This practice has reduced the percentage of overripe and green fruits to only about 15% of the total crop. On the other hand, this harvesting method causes stress in that the trees must bear the fruit for much longer and have no resting period before flowering begins again, reducing Indian coffee productivity. According to the 2015 Global Climate Risk Index (KREFT et al., 2015), India is one of the countries most affected by climate change, particularly the southern states (ARUMUGAM et al., 2014), where coffee is grown. The magnitude of the impact will be multiple, given that Indian agriculture contributes 13.9% to the GDP, supports 600 million people directly or indirectly and accounts for 14.2% of the total exports (CHENGAPPA & DEVIKA, 2017).

India seems to be ahead of other countries regarding alternatives to coffee production in response to the ongoing climate change. In contrast to other coffee-producing countries, *e.g*., Brazil and Vietnam, where coffee is grown under full sunlight in combination with intense cultivation practices to increase productivity, in India, coffee has been grown in a more sustainable way by double-shading layers that consist of two shade crop species with different plant heights, *e.g*., neem (*Azadirachta indicates* A. Juss.) associated with orange (*Citrus sinensis* L. Osbeck) or banana (*Musa* spp.), for centuries thus potentially improving both the soil fertility and microclimate on coffee plantations. Because coffee is cultivated in hilly terrain, not allowing mechanisation, it ensures daily employment for the local inhabitants of the mountainous region.

Angola

Coffea canephora is produced in monoculture with agroecological management in rainfed, shaded plantations. The first *C. canephora* plantations were established in the 1830s in the Cazengo region and quickly expanded throughout the forest region in northern Angola. Native *C. canephora* trees that grew in these forests were used to establish coffee plantations (VOS, 2023). In Angola, *C. canephora* is grown in semi-deciduous, humid and dense forest regions. There are five local varieties: Amboim, Ambriz, Cazengo, Cabinda and Makokola. Amboim and Ambriz are spontaneous, native to Angola, and can only be grown in this country. These

varieties are adapted to the local conditions of mild climate, given by the latitude and elevation of the growing areas. The granulometric characteristics are unique and the final product is highly appreciated by coffee lovers. Amboim is planted in a foggy climate in a region with the same name in the center of the country. It is suited for elevations of up to 800 m and in forest environments with mountainous topography for up to 1100 m a.s.l. In addition to the genetic aspects, elevation also influences the bean quality and caffeine content. Amboim coffee ripens in a climate of constant fog, almost at the same time of the year as *C. canephora* varieties in Central and West Africa, but results in a sweeter coffee (BESSOU et al., 2020). In turn, production of the *C. canephora* variety Ambriz is concentrated in the region of Urge, at elevations of up to 1300 m a.s.l., under abundant rainfall (annual mean 1600 mm). This variety is the most planted coffee in the country, cultivated in about 56% of the producing regions. It extends to parts of the province of Bengo.

Coffee production in Angola was once considerable and ranked third in global production, so the exports of *C. canephora* reached 220,000 tons in 1973, grown on 2000 company farms and more than 60,000 small farms. However, despite the enormous potential, several factors, mainly the long-lasting civil war, have reduced current yields (about 3,000 tons in 2022) (ICO, 2023). Furthermore, Angolan *C. canephora* has been traditionally produced on low-tech family farms, mostly in monoculture (although scattered banana, citrus and avocado trees can be found without applying agrochemicals such as pesticides and fertilizers, this is why the Angolan *C. canephora* can claim the title of organic coffee (KURIYAN, 2021).

Genetic Diversity and Climate Change

Coffea canephora, a self-sterile and allogamous plant species with diploid characteristics (2n=2x=22 chromosomes), exhibits a gametophytic self-incompatibility system that promotes allogamy, fostering extensive genetic variability among its plants (NOWAK et a., 2011; VÁZQUEZ et al., 2019). Despite this natural inclination towards genetic diversity, the predominant method of crop establishment involves vegetative propagation, primarily driven by the imperative trait of yield (BRAGANÇA et al., 2001; PARTELLI et al., 2019; PARTELLI et al., 2020). Regrettably, this prevalent practice contributes to a reduction in the overall genetic diversity of the species (SILVA et al., 2020). However, the potential for vegetative propagation presents a unique advantage in utilizing elite individuals of *C. canephora* within

breeding programs, allowing for immediate incorporation. This speeds up achieving genetic improvements compared to many other perennial species. Nevertheless, while laden with benefits, this strategy introduces the inherent risk of genetic narrowing due to inbreeding and genetic drift. Such narrowing poses a potential threat to the adaptability of coffee plants to diverse environmental stresses, including those associated with climate change, such as elevated temperatures and shifting precipitation patterns. As a result, it becomes imperative to explore the genetic diversity inherent in coffee plantations worldwide strategically. This exploration serves as a proactive measure to enhance adaptability to anticipated climate changes, ultimately safeguarding the sustainability of coffee cultivation.

The number of studies to investigate the genetic diversity of *C. canephora* has increased, focusing on morpho-agronomic, physiological, chemical, and molecular characters to verify the genetic basis of coffees (GILES et al., 2018; PARTELLI et al., 2019; STARLING et al., 2019; SSEREMBA et al., 2023). Genotypes with distinct phenotypic characteristics show genetic variability in *C. canephora* germplasms (LEROY et al., 2014). Thus, considering that commercial plantations of *C. canephora* clonal varieties (different genotypes in the same area) are planted to ensure satisfactory pollination, the phenotypic characteristics, if observed carefully, can make differentiated management possible (BELAN et al., 2015). For example, fertilization of genotypes can be differentiated according to the maturation cycle, optimizing production costs. The maturation cycle of *C. canephora* varies (Figure 5) and is defined according to the period between flowering and full ripening of the fruits.

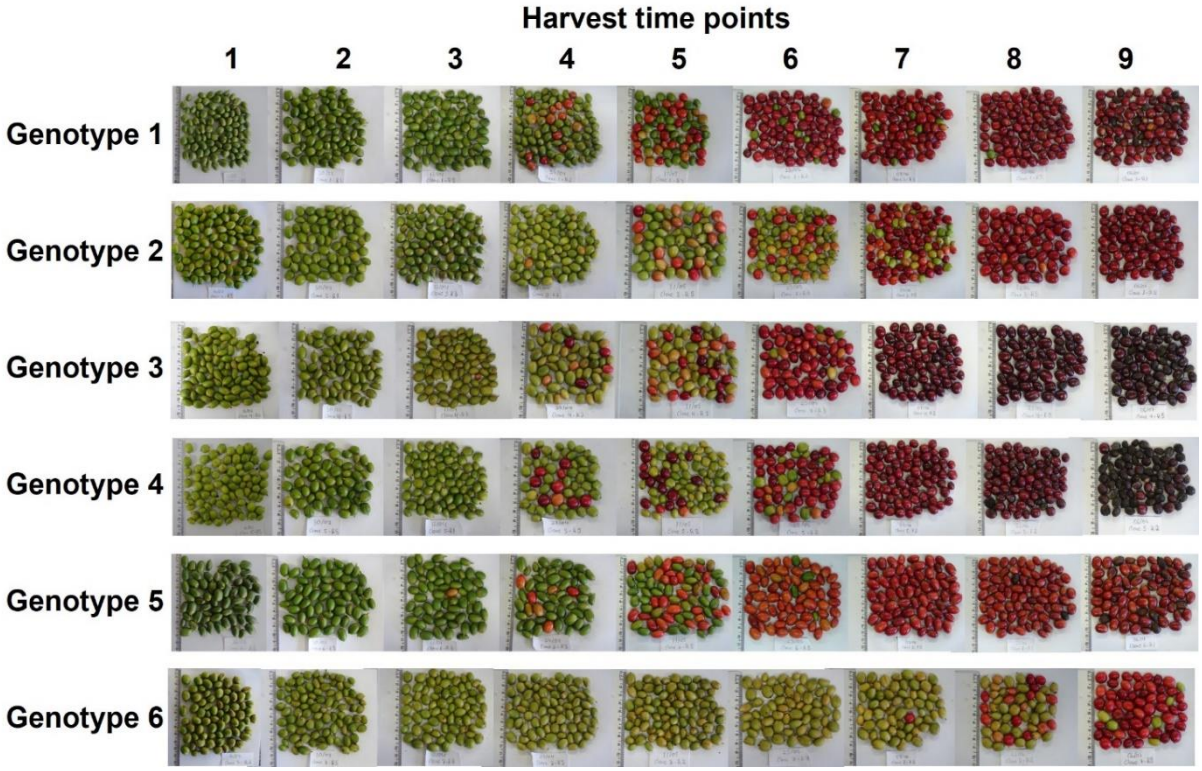

Figure 5. Different fruit maturation stages of six genotypes (rows) of *Coffea canephora* harvested at nine time points (columns) during maturation.

The global expanse of coffee cultivation spans diverse regions, each distinguished by unique climate and soil conditions. This diversity offers opportunities for the widespread cultivation of *C. arabica* and *C. canephora* varieties, emphasizing the need to develop high-yielding coffee genotypes finely tuned to the specific conditions of each region. While some studies shed light on the significance of regional adaptation, a broader perspective within global coffee production underscores the persistent requirement for extensive research on genetic diversity. The exploration of genetic diversity extends beyond cultivated varieties, necessitating further exploration into seed-grown plants and wild species within *Coffea* spp. As highlighted by Sseremba et al. (2023), substantial untapped potential exists in the genetic diversity harbored in its wild populations, indicating a broader scope for future research initiatives focused on understanding and harnessing coffee genetic diversity on a global scale.

According to Bertrand et al. (2021), the genetic diversity of wild coffee species is critical for the long-term sustainability of the coffee sector, mainly because of the changing climate. In this sense, Depecker et al. (2023) reported that the

genetic diversity contained in wild populations is crucial for sustainable coffee production worldwide. In their research with 256 coffee trees found in Congo forests, the authors observed high genetic diversity among plants and high heterozygosity rates. On the other hand, they also emphasized that careful monitoring of the plant responses to ongoing Congolese forest degradation is necessary. The study also reported lower allelic richness of coffee trees in regenerating forests than in primary forest populations.

Several studies on coffee breeding have greatly influenced the development of cultivars with different agronomic traits of interest for coffee cultivation. The achievements included coffee plants adapted to different edaphoclimatic conditions, higher yields, stability and earliness, increased disease resistance, drought and frost tolerance, better-suited tree architecture for high-density plantations, shorter plants, and a suitable canopy shape for mechanised harvesting. Selection targets such as traits related to bean and beverage quality have also been addressed.

At temperatures below 17 ºC and above 31 ºC, the growth rate of *C. canephora* decreases significantly, limiting development and productivity (COVRE et al., 2016). The impact of cold on coffee physiology is profound, especially concerning temperatures below 13 ºC (Figure 6). These conditions can significantly influence a vast number of components of the photosynthetic pathway in *Coffea* spp., including stomata opening, photochemical efficiency of photosystem II, the thylakoid electron transport, enzymatic activities, composition and structure of photosynthetic pigment complexes, membrane lipid profile, etc., at different levels in a genotypes/species-dependent manner, ultimately impairing C-assimilation (BATISTA-SANTOS et al., 2011; RAMALHO et al., 2014; SCOTTI-CAMPOS et al., 2014). However, recent studies on *C. canephora* at an elevation of 850 m a.s.l. (cooler altitude) Some genotypes have shown a relevant tolerance to lower temperatures than usually expected (MARTINS et al., 2020).

Figure 6. Studies evidencing tolerance to cold and drought in *C. canephora* genotypes. Upper: cold-susceptible (left) and cold-tolerant *C. canephora* plants. Lower: drought-tolerant (left) and drought-susceptible *C. canephora* plants.

In contrast with the cold sensitivity of most *C. canephora* genotypes, remarkable heat tolerance was reported to temperatures up to 37 or 39 ºC in *C. canephora* (cv. Conilon CL153), with an absence of clear aggravated impacts upon the superimposition of drought also up to 37 ºC (DUBBERSTEIN et al., 2020; RODRIGUES et al., 2024). However, relevant physiological and biochemical negative impacts were reported at 42 ºC, with particular emphasis on the enzymes involved in C-assimilation (MARTINS et al., 2016; RODRIGUES et al., 2016; SCOTTI-CAMPOS et al., 2019). Additionally, elevated CO_2 was found to mitigate the impacts at physiological and biochemical levels of both heat (MARTINS et al., 2016;

RODRIGUES et al., 2016), or drought (AVILA et al., 2020; SEMEDO et al., 2021), allowing the plant to thrive better, and denoting a lower impact of such environmental constraints than previously predicted.

Intending to face the challenge of reconciling productivity with beverage quality from the climate change perspective, Bertrand et al. (2021) evaluated the sensory traits of three wild coffee species based on four independent sensory panels. These authors concluded that the sensory qualities of the three wild species make them suitable for commercialisation. In addition, the data detected the agronomic potential of *C. stenophylla*, especially in climates warmer than tolerated by *C. arabica*. *C. brevipes* and *C. congensis* can easily be crossed with *C. canephora* to form interspecific hybrids capable of adapting to different climatic and agronomic conditions.

The genetic variation of *C. canephora* between and within breeding populations must be known since the so-called adaptive diversity is extremely important when dealing with climate change. However, strategies must be sought to improve the conservation and *in situ* characterisation of *C. canephora* worldwide (AL-GHAMEDI et al., 2023).

Shaded Cultivation

Greenhouse gas (GHG) emissions are associated with the ongoing phenomenon of climate change and global warming. The latter, either in isolation or with water scarcity, can significantly compromise coffee plants' metabolic processes and yield (COVRE et al., 2016; MARTINS et al., 2016; RODRIGUES et al., 2016). Consequently, substantial reductions in suitable cultivation areas for coffee are anticipated (BUNN et al., 2015; CASSAMO et al., 2023). This decline is expected to be particularly pronounced for *C. arabica*. In contrast, for *C. canephora*, despite the potential loss of some areas, there is a possibility that the global suitable areas may even expand due to the possible cultivation extension of this species to new regions (MAGRACH & GHAZOUL, 2015).

Even though coffee has evolved as a shade species, intensive cultivation usually involves full-sun systems, where coffee grows almost entirely under full sunlight, with great success and high yield. However, shading cultivation can be used as an alternative, a mitigation strategy to cope with the harmful effects of climate change (JAWO et al., 2022). In recent years, coffee has been used in AFS, a form of

land use that combines agricultural and/or animal crops with forest species, simultaneously or in sequence, in the same area, and it is expected to become a significant practice in sustainable agricultural production.

The world's demand for sustainable systems is rising, requiring a new conception of how agricultural properties can be maintained productive and economically viable without harming the environment (MACHADO et al., 2020). Recent initiatives, particularly government initiatives in Vietnam, have supported the transformation of extensive full-sun *C. canephora* areas into shaded systems and the incorporation of fruit trees in intercropping with coffee trees (RIGAL et al., 2018; THUY et al., 2021). Coffee cultivation in consortium with different tree species used for shading also increased the abundance and diversity of arbuscular mycorrhizal fungi, owing to the crop abundance and diversity (MULETA et al., 2007; DOBO et al., 2017).

C. canephora cultivation in AFS is seen as a promising alternative since these systems guarantee a more sustainable agricultural production, with improved soil quality, increased biodiversity and income diversification of rural producers (LIMA et al., 2011; DUBBERSTEIN et al., 2018), aside from leading to the establishment of milder microclimatic conditions for the crop (PARTELLI et al., 2014; OLIOSI et al., 2016). For example, intercropping *Acrocomia aculeata* with coffee modifies the plantation microclimate, reducing temperature and photosynthetically active radiation while promoting yields (MOREIRA et al., 2018). Recently Piato et al. (2020) analysed the impact of shade trees on the growth, yield, and quality of *C. canephora*. They successfully identified clones demonstrating increased productivity, with 41-65% of interception of the solar radiation, contrasting with the advised 10-39% shade levels recommended for *C. arabica* to avoid negative impacts on productivity (KOUTOULEAS et al., 2022b). On the other hand, Araújo et al. (2016) showed that coffee cultivation with shading by rubber trees promoted losses in coffee yield. Thus, although considered a promising alternative to decrease stresses, shaded coffee cultivation still requires adjustments, primarily related to the level of shading and genotypes adapted to this system.

The yield of coffee trees in shaded systems is less affected by biennial oscillations since the production is regulated by reducing solar radiation and temperature variations (which are usually associated) and by reducing the effects of wind. In addition, larger fruits, a slower maturation, a greater accumulation of sugars

and changes in other compounds might enhance bean quality (PIATO et al., 2020; CASSAMO et al., 2022). Additionally, these shaded systems favour the conservation of the farm's natural resources (Figure 7). However, Vaast & Raghuramulu (2012) showed that shading levels over 30% promoted by exotic species associated to *C. canephora* in India significantly reduced beans size and beverage quality. Shading cultivation can also reduce coffee-related pests and coffee-effecting diseases within coffee farms (MARÍN-CASTRO et al., 2016; GOMES et al., 2016; SCHOOLER et al., 2020; KOUTOULEAS et al., 2022a; MANSON et al., 2024). Nevertheless, shade tree type has been shown to significantly impact the infestation of black coffee twig borer, *Xylosandrus compactus* (Eichhoff.), a pest that severely affects robusta coffee plantations (BUKOMEKO et al., 2018). For coffee leaf rust (*Hemileia vastatrix* Berkeley & Broome) Avelino et al. (2020) found that under shade tree *Chloroleucon eurycyclum* the fungi sporulation was more abundant than at full sun, resulting in a higher incidence and severity found below shade trees. This fact underscores the necessity of continuing research to identify the most suitable tree species to promote the shading of coffee plants in a more sustainable and beneficial way.

Figure 7. *C. canephora* plantations in excellent vegetative state, shaded with African mahogany (Khaya grandifolia C. DC.) (upper photo) and rubber tree (Hevea brasiliensis Muell. Arg.) (lower photo).

The Potential of Research and Innovation

New *C. canephora* genotypes are frequently generated in the field, resulting from the coffee growers' selection, multiplication and empirical exploitation. Therefore, scientific studies assessing agronomic traits can help identify promising and/or distinct genotypes to compose new commercial cultivars for different regions with different agronomical traits (MISTRO et al., 2019; SILVA et al., 2020; PARTELLI et al., 2022b).

The main advantage of *C. canephora* over *C. arabica* regarding breeding is the gametophytic self-incompatibility system of this species. As a *C. canephora* variety combines compatible clones, the clones may carry both productivity and different degrees of drought tolerance, for example. Thus, it seems essential that clones under selection should be carefully characterized for physiological traits associated with productivity. Such characterization should be supported by molecular markers (ACHAR et al., 2015; SOUSA et al., 2022). It is even possible to consider genetically modified clones in a variety since *C. canephora* is more amenable to biotechnological applications, as suggested by the number of publications with this species, compared to *C. arabica* (MISHRA & SLATER, 2012). Additionally,

CRISPR/Cas9 technology has already been used to obtain genetically modified *C. canephora* plants (CASARIN et al., 2022). The potentiality of this technique in *C. canephora* was recently suggested as a significant number of CRISPR guides were identified in the genome draft of the species (BREITLER et al., 2018).

Some researchers are underway in order to obtain new drought-tolerant cultivars of *C. canephora*, as is the case of cultivar Marilândia ES 8143 (FERRÃO et al., 2019). It is a new cultivar from INCAPER that may offer greater security to coffee growers because it combines drought tolerance and high productivity. In addition, searching for genotypes with greater genetic potential and better adaptation to new cultivation systems will allow greater stability and sustainability for the coffee chain (VAN DER VOSSEN et al., 2015). Research focused on selection for superior *C. canephora* genotypes in multiple environments, specifically for tolerance to biotic and abiotic stresses (FERNANDES et al., 2021; MOLINA & RIVERA, 2022), high-density plantations (ESPÍNDULA et al., 2021) or suitability for intercropping in AFS (FLORE et al., 2023), elevation (PARTELLI et al., 2019), better beverage quality associated with the chemical compounds of the bean, etc., would contribute to a sustainable development of the coffee crop. Thus, a range of traits may be explored in *C. canephora* to overcome the environmental constraints expected to be imposed by climate changes in the near future. Clearly, a significantly broader genetic base should be obtained in the medium- to long-term, allowing elite genotypes to be obtained for various management situations. Thus, as discussed as an advantage of *C. canephora* over *C. arabica*, the most effective way to do it is by planting several seed-propagated varieties with high diversity associated with productivity and seed quality. Depending on the trait, short-, medium- and long-term studies should be planned, involving a multidisciplinary team. In this context, studies focused on the evaluation and identification of superior genotypes concerning tolerance to extreme conditions of temperature, shading, water availability, pest and disease resistance, desirable agronomic traits (*e.g*., uniformity of fruit maturation, good beverage quality, high yield), plant architecture and others, are indispensable to keep the pace of yield and quality with the impact of climate changes.

Conclusions and Perspectives

Given the uncertainty of the effects caused by climate change on the world's crops, it is important to prioritise research on the adaptability and stability of coffee

trees, as well as to expand the selection of plants from seeds to explore the natural genetic variability contained in these genotypes, thus increasing the chances of selecting genotypes that are more tolerant or resistant to such changes.

Many research works have demonstrated that the coffee plant (particularly elite cultivars) can show a greater intrinsic tolerance to drought and heat than what was usually believed. Furthermore, elevated CO_2 (associated with global warming) can also mitigate to some extent such stress impacts, turning less catastrophic the predicted scenarios for this crop. Nevertheless, climate change will have an important impact, demanding further multidisciplinary development and collaborative research programs to unveil/characterise the impacts on coffee. Additionally, measures must be put in place in the entire chain of values in order to mitigate those impacts. At the agronomical level, among ready-to-use mitigation strategies against climate change, the use of intercropping (with trees) and AFS practices have been proposed as a nature-based strategy for coffee farmers to mitigate and adapt to future climate conditions. This system has already been implemented in many countries as regards *C. arabica* cultivation, and African countries have shown that shaded cultivation of *C. canephora* could be a promising alternative, although in the greatest 'Robusta' producers (Vietnam and Brazil) this practice is not yet widely used. In addition, the breeding and selection of new *C. Canephora genotypes* that are better adapted to shading will enable the implementation of more sustainable cultivation systems and the possibility of planting higher-yielding genotypes under these conditions. This will increase profitability and encourage coffee growers to use AFS management. We should also start working with coffee genetic transformation as an alternative to cope with climate change, and *C. canephora* has been proven to be a suitable plant material for advanced techniques such as CRISPR-Cas9. Finally, investment in research and training of human resources are urgently needed to promote the expansion of a socio-economically viable and sustainable coffee that combines high yields with quality, *i.e.,* we should not lose sight of the demands of the expanding consumer market.

Overall, although much information has been gathered, particularly in recent years (bringing together the advantages of both classical methods and new molecular ones), the above-mentioned studies also highlight that much remains to be unveiled and the need for future research to explore the potential of genetic diversity in *Coffea* spp., and management systems, in order to overcome the important

constraints imposed by harsher environmental conditions due to the ongoing and future climate changes.

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1.2. DYNAMIC OF DRY MATTER ACCUMULATION IN BERRY, BEAN, AND HUSK OF SIX *COFFEA CANEPHORA* GENOTYPES DURING FRUIT MATURATION

Abstract

During post-harvest process, coffee berries are dried and separated in green commercial beans and husk. The dynamics of dry matter (DM) accumulation in the berry components along the maturation process is important to the definition of the most adequate moment for the harvest, which is genotype-dependent. To better understand it, DM accumulation dynamics for berry, bean, and husk was studied in six *Coffea canephora* genotypes during the fruit maturation process, aiming at to identify the best fruit harvesting stage where the highest bean yield will be obtained. Berry samples were collected every two weeks at nine maturation moments/stages starting from 33 weeks after flowering (green berry stage). The DM accumulation was the highest for berry and bean at the first collections, while the highest increases in husk DM happens in the final stage of maturation. Second order polynomial regressions were fitted for berry, bean, and husk DM accumulation over time. DM accumulation of all components increased as fruit maturation progressed, attaining the highest values in the final stages of red berries, but occurring earlier for

early/medium and medium maturation cycle genotypes. Beira Rio 8 genotype presented the highest DM accumulation in all components, whereas. Bamburral and P1 showed the lowest berry fresh mass (FM) to bean DM ratios, and A1 showed the greatest berry FM to bean DM ratio, being a genotype with the lowest DM and bean mass performances and bean yield. It was found that not only the absolute berry and bean yield must be considered for high productive genotype selection, but also bean DM performance must account in the characterization of commercial coffee yields.

Keywords: Bean mass performances, Fresh mass, Fruit maturation cycle, Overripe berries, Polynomial regressions.

Introduction

The Rubiaceae family include the genus *Coffea* and their 130 species (DAVIS and RAKOTONASOLO, 2021). Among them, the two species, *C. arabica* (Arabic coffee) and *C. canephora* (Robusta coffee) that supports almost entirely the coffee trade (CASSAMO et al., 2022). Currently, one or both commercial coffee species are grown in about 80 tropical climate countries, with Robusta recently representing *ca*. 44% of world coffee production (ICO, 2023).

Coffee tree architecture is botanically described by the Roux model, considering a continuous growth and dimorphism of branches - orthotropic (1st order) and plagiotropic (2nd to 5th order) (Hallé et al., 1978). In *C. canephora*, branching is usually limited up to the 3rd order axes (RAKOCEVIC et al., 2023), unlike to what happens to *C. arabica*, which can develop 2nd to 5th order axes in three to four years after pruning (RAKOCEVIC et al., 2021).

C. arabica is an allotetraploid self-compatible species, while *C. canephora* is a diploid allogamic, characterized by gametophytic self-incompatibility and synchronized flowering, mechanisms that naturally favor cross-pollination (SOUZA et al., 2017). The coffee berries start to develop after a main flowering, usually occurring after the in first spring rains (EIRA et al., 2006). Due to successive blossoms, it is possible to find berries with different degrees of maturation in the same branch at each time of harvest, compromising yield and quality (MIRANDA et al., 2020).

Coffee tree phenology was firstly defined for *C. arabica* (CAMARGO and CAMARGO, 2001; PEZZOPANE et al., 2003) and adapted for *C. canephora* (MARCOLAN et al., 2009; ABREU et al., 2023), being considered six phases: 1) branch and flower bud induction and formation, 2) maturation of flower buds, 3) anthesis, 4) berry and leaf expansion, 5) berry maturation and 6) winter rest). Additionally, the coffee maturation process was subdivided into another five stages (MORAIS et al., 2008), being M_1 for green berries, that is, without evidence of color change; M_2 for cane green berries, which have already begun to ripe; M_3 for berries in the "cherry" stage, light red in color and physiologically ripe; M_4 for berries in the "raisin" stage (overripe), dark red in color and with onset of dehydration; M_5 for dried berries, dehydrated with dark external coloration. Coffee fruits turn red, or yellow in some few genotypes, when mature due to the replacement of chlorophyll in the exocarp by red (flavonoid) or yellow (xanthophylls) pigments, respectively (CASTRO

and MARRACCINI, 2006; ESQUIVEL et al., 2020). The color of the cherry is a good marker of maturation and is correlated with the development of high-quality flavors in the final coffee beverage after roasting (AMORIM et al., 2009).

The berry of the coffee is morphologically composed of the pericarp, (*i.e*., exocarp, mesocarp and endocarp), the perisperm likewise called spermoderm, and the bean (endosperm), where is the structure that holds the embryo (CASTRO and MARRACCINI, 2006). In each berry of *C. canephora* usually are presented two seeds (beans), but cases of only one are also possible (HALL et al., 2022). Coffee berries are usually harvested according to the color of the berry's pericarp. In the mature coffee fruit (drupe, also called coffee cherry or berry), the exocarp is red or yellow. To obtain the commercial coffee beans, the pericarp outer skin, pulp, pectic adhesive layer, and parchment (usually together with bean silverskin) are removed, through either dry or wet processing (KITSBERGER et al., 2020).

Robusta coffee, mainly in Brazil, is almost entirely subjected to dry processing, which is the cheapest form of transforming ripe berries into processed beans (POLTRONIERI and ROSSI, 2016). In this process, the berries are dried in terraces or mechanical dryers, without the removal of the husk (pericarp), followed by the mechanical separation of the beans from husk and other impurities (ALVES et al., 2013; PIMENTA et al., 2018). This process should be conducted with caution to not to break beans, as well as to prevent berries with husks or fragments from mixing with the clean beans, impairing their quality.

Dry matter (DM) accumulation dynamics of berry components (beans, and husk), as well as their proportion in the bean during the maturation phase, can be used to predict the most adequate harvesting time, in order to ensure a high quality of yielded beans. Throughout the whole berry formation process, the DM accumulation follows a sigmoidal trend, where the highest values are found in the final stage of berry formation, at M_3 phase (LAVIOLA et al., 2008; PARTELLI et al., 2014). However, there is still a gap of knowledge regarding the dynamics of DM accumulation in the components of the berry throughout maturation process. Lacking comprehension of how dry matter accumulates throughout the maturation process, it can be challenging to accurately predict the optimal harvest time, which can lead to losses in quality and yield. It was hypothesized that the 1) different genotypes may show different dynamics in DM accumulation throughout the maturation process, *i.e.* that the genotypes with a late maturation cycle will present a slower accumulation

when compared to the early ones, 2) the highest values of dry mass of berries and beans will be obtained when the berries reach full ripeness, and 3) the husk dry mass dynamics will compete to bean dry mass accumulation, presenting different pattern. In this sense, the aim of this study was to evaluate the effect of maturation process on the dry matter accumulation in berry, bean, and husk of six genotypes of *Coffea canephora*, aiming at contributing to identify the best harvesting time to obtain the highest bean yield.

Material and methods

The experiment was carried out in the experimental field of Federal University of Espírito Santo, São Mateus (18°40’23’’ S, 39°51’22’’ W, 36 m.a.s.l.), state of Espírito Santo, Brazil. The region climate is tropical, with dry winter and rainy summer,, characterized as Aw according to Köppen’s classification (ALVARES et al., 2013; SEKI et al., 2021). The soil was classified as a Yellow Dystrophic Argisol (SANTOS et al., 2018).

Five plants per each of the six genotypes of *Coffea canephora* (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1), that are part of two cultivars, Andina and Tributun (PARTELLI et al., 2019; PARTELLI et al., 2020) were used. These genotypes, propagated by cuttings, show different maturation cycles, being Pirata, A1 and Beira Rio 8 early/medium, Bamburral and Clementino medium and P1 late cycle. Coffee seedlings were planted in the field in 2018, at a row spacing of 2 m and 1 m between two plants in the row, totaling in a population of 5,000 plants ha^{-1}. All plants were conducted with the two orthotropic axes, resulting in 10,000 orthotropic axes ha^{-1}.

The irrigation hoses were located 5 cm away from the coffee trunks, in the planting rows, and the emitters were spaced every 1.0 m. Irrigation was executed, when necessary, based on soil water balance method, with use of drip irrigation, reference evapotranspiration was calculated according to Penman-Monteith method (ALLEN et al., 1998).

The nutritional and phytosanitary control were done according to the crop needs to obtain the best conditions for plants development. Plant needs and phenological stages were also considered, using around 300 - 500 of N, 50 - 80 of P_2O_5 and 200 - 400 K_2O_2 kg ha^{-1}, divided into six equal times, starting applications from flowering to early maturation phenophases.

Berries collection started in the end of grain filling stage, *ca*. 33 weeks after flowering (WAF), and continued afterwards with samplings every 14 days, until complete berry maturation of all six genotypes, totaling nine collection dates (periods), being the last one at 49 WAF. The berries were harvested manually on five plants for each genotype, from previously marked 2nd order plagiotropic axes localized in the medium third of the plant, one branch for every period of collection.

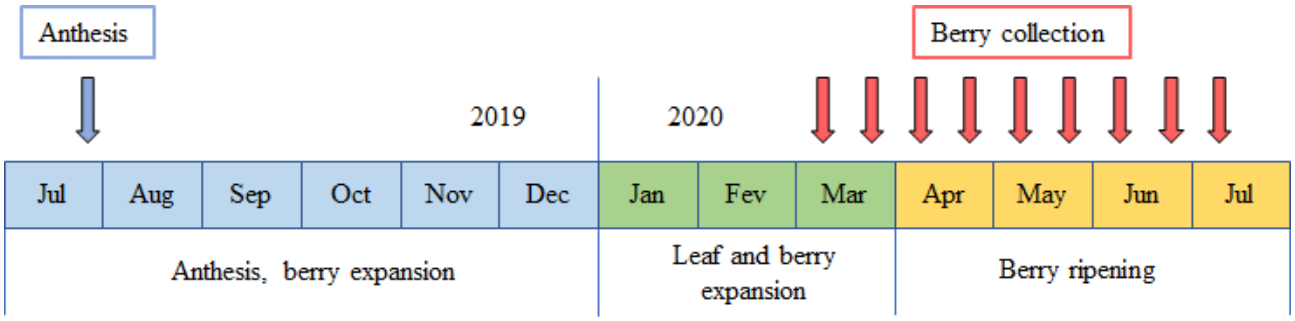

Figure 1: Phenological calendar of *Coffea canephora* during experimental period with indications of sampling / collection dates. Adapted from Abreu et al. (2023).

Each berry sample collected per plant was counted, photographed, and weighted (fresh mass, FM), registering the mass in g (scale precision of 1 mg). After that, the samples were dried in a ventilated oven at 50 °C for seven days to achieve constant mass (dry mass, DM). The separation of the beans from the husk was executed manually. Beans were photographed and weighted, while the husk mass was calculated from the difference between the dry berry and bean mass.

Dry matter parameters were standardized for a single berry. The dry berry mass, dry mass of beans per one berry, dry mass of husk and proportion of beans and husk were calculated for each genotype. Afterwards, the berry FM to bean DM ratio was also calculated. The initial berry moisture was calculated from difference of the berry FM to DM. The dry and processed beans and husk mass performances were calculated as percent of bean DM to berry DM (DM performance), percent of bean to berry FM (BDM performance) and percent of husk DM to berry FM (HDM performance) as proposed in Rakocevic et al. (2023).

For each genotype, samples in all nine-time observations were collected from the same five plants randomly distributed in experimental field. Each plant was considered as a repetition. The R Core (2023) software was used for all statistical analyses.

To analyze the dynamic responses of berry DM, bean DM per berry, husk DM per berry and berry FM to bean DM ratio, the ANOVA with a double factorial scheme (fat2.crd) was performed, using package ‘ExpDes’ (FERREIRA et al., 2014), after testing the hypothesis of variance homogeneity. Second order polynomial regression models were fitted, considering six genotypes and nine sampling times. Multiple comparison test ‘Tukey’ was used to compare means for the genotype effects inside every of nine sampling times, and the time effects inside of each genotype.

For percentage of bean and husk in berry, the data were submitted to two-way ANOVA (percentage of each component x time of collection) considered a mixed linear model ('nlme' package) and maximum likelihood to test the significance of differences between the accumulated mass of two berry parts (bean and husk), for each of the nine sampling times (33, 35, 37, 39, 41, 43, 45, 47 and 49 WAF). In figure 7 with bean and husk percentage in dry mass of one berry, only interaction *p*-value was considered once the factors were not independently compared (PERECIN et al., 2008; TAVARES et al., 2016), trying to make the presentation the clearest possible. Finally, yield parameters were submitted to one-way ANOVA, where multiple Tukey comparison test was used to compare means among genotypes. All tests were performed for a 95% confidence level. In figures and tables, the modeled mean, standard error (SE), and estimated *p*-values are shown.

Results

At 45 WAF, most of the berries have reached full ripeness, except for the P1 genotype, which requires more time, reaching full maturity at 49 WAF (Figure 2). The corresponding beans of each berry sample showed also visual modifications along the experimental period, with green berries usually having deformed and dark beans, while mature berries showed a lighter color and fully formed beans, the latter with commercial acceptance.

The berries took from four to six weeks from the beginning of the maturation stage until reaching at least 90% of mature fruits (Figure 2). In genotypes with early/medium (Pirata, A1 and Beira Rio 8) and medium (Bamburral and Clementino) cycles, the change on exocarp color initiated between 39 and 43 WAF, while by 45 and 47 WAF most of them reached full maturation. The exocarp of late cycle genotype P1 only turned red between the 45 and 47 WAF, reaching full maturation in the last collection date (49 WAF).

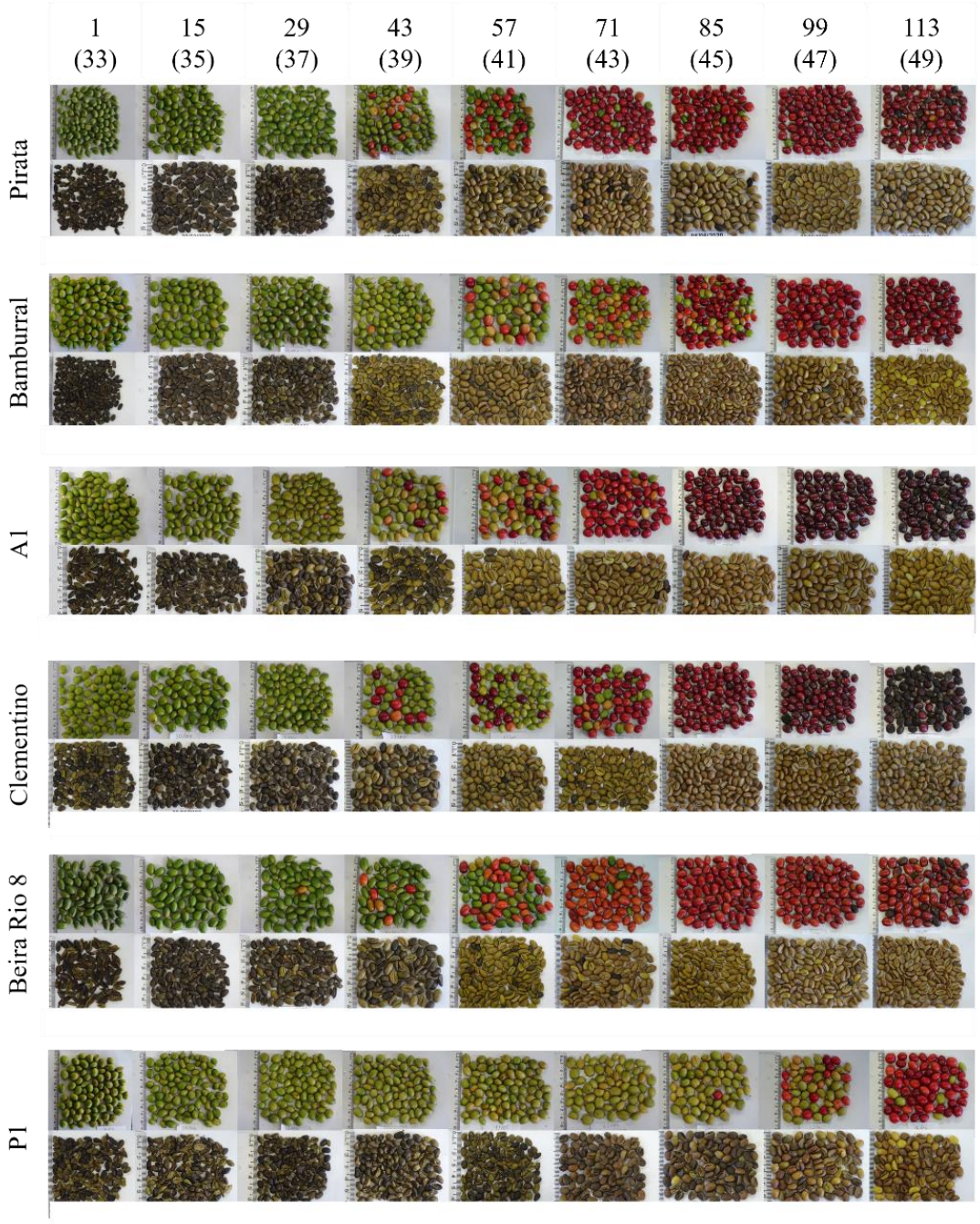

Figure 2: Visual evolution of the maturation of berries, and their dry beans of six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) of *Coffea canephora* collected from end of berry expansion to full maturation phenophase, corresponding to 33, 35, 37, 39, 41, 43, 45, 47 and 49 weeks after flowering. The upper line of each genotype represents the fresh collected berries, while the lower line the dry beans.

The studied genotypes exhibited similar patterns of DM accumulation along the berry maturation process (Figure 3). The highest berry DM investment rate was mostly observed between the end of 'leaf and berry expansion' and beginning of 'maturation' phenophase (33rd to 41st WAF). Afterwards, during maturation

phenophase, the rate of DM accumulation in berries was reduced, reaching stable DM values at the end of maturation stage.

Amongst the studied genotypes, Beira Rio 8 presented the greatest berry DM values along the entire experiment, varying between 291 and 542 mg berry^{-1}, and a 86% increase between the 33 and 45 WAF (Figure 3). By contrast, P1 showed the lowest berry DM in all the nine collecting dates, presenting a difference of 278 mg berry^{-1} to Beira Rio 8 by the end of the trail. Maximum berry DM values were found at fully ripe stage, which differed in time among the six genotypes. This value was attained by 45 WAF in Clementino and Beira Rio 8, by 47 WAF in Pirata, Bamburral and A1, and by 49 WAF in P1, due to differences in their maturation cycles length.

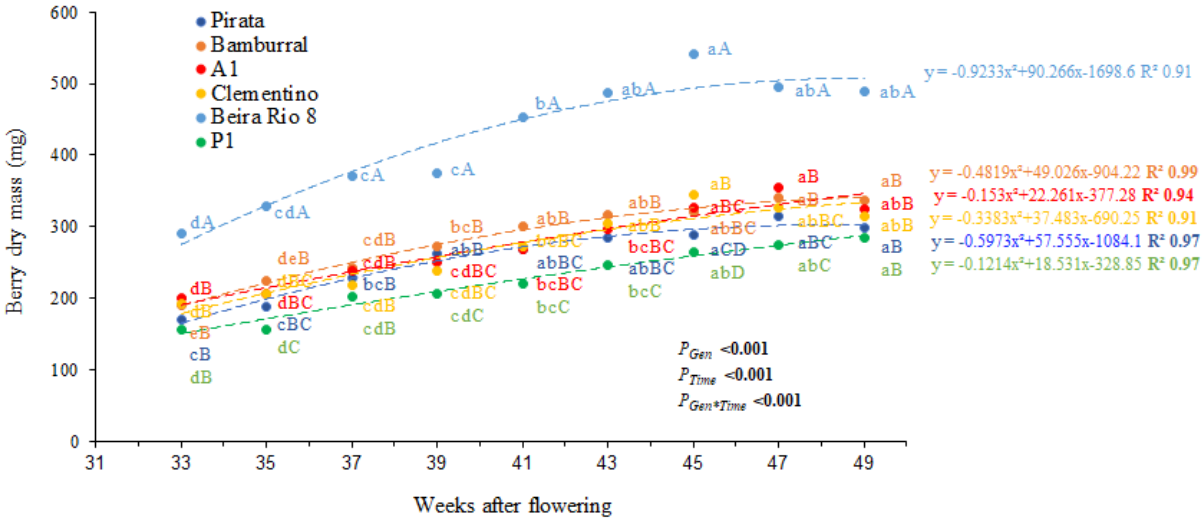

Figure 3: Dry mass accumulation (mg) per berry of six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) of *Coffea canephora* collected from end of berry expansion to full maturation (33 to 49 weeks after flowering). Lower-case letters compare time effect inside each genotype, whilst upper-case letters compare genotype effect in each sampling time the by Tukey's test, while P-values in bold indicate significant statistical difference (n=5). Dashed lines, equations and R2 represent polynomial regression adjusted to each genotype, which were graphically presented in colors to facilitate genotype differentiation.

Bean accumulation rate of DM per berry was higher during pre-maturation period, starting from a final moment of berry expansion phenophase (33 WAF) up to 41 WAF, when the increase of bean DM per berry was above 70% in the mean of all genotypes (Figure 4). The greatest values of bean DM per berry in early/medium and medium maturation cycle genotypes occurred when berries were fully ripe, between

43 and 47 WAF. Afterwards the beans begin to lose some weight until the end of experimental period. Late maturation cycle genotype P1 had a different pattern of variation, since bean DM accumulation per berry continuously increased until the last collection period.

Evolution of DM accumulation in beans (Figure 4) was very similar to DM accumulation in berries (Figure 3). As for berry DM accumulation, the Beira Rio 8 also had the greatest DM bean accumulation among all studied genotypes (Figure 4), however, the difference of accumulated bean DM to the other genotypes was less expressive when compared to DM difference in the berries (Figure 3). P1 showed lower bean mass than the other genotypes until the 41st WAF, but since continued to gain weight until the last evaluated week finished with higher bean weight than Pirata, A1 and Clementino, positioning only behind Bamburral and Beira Rio 8 (Figure 4).

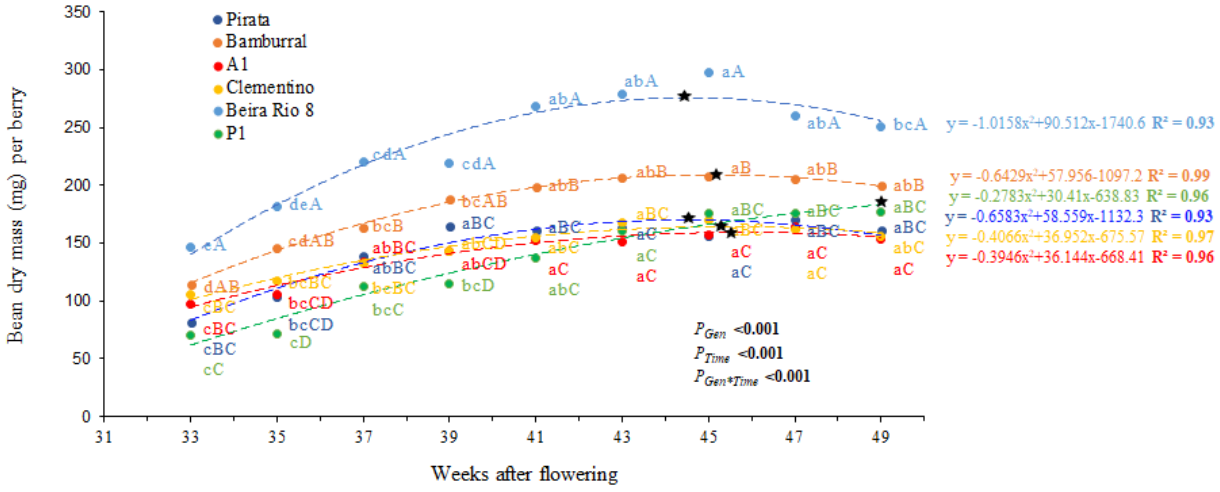

Figure 4: Bean dry mass accumulation (mg) per berry in six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) of *Coffea canephora* collected from end of berry expansion to full maturation (33 to 49 weeks after flowering). Lower-case letters compare time effect inside each genotype, whilst upper-case letters compare genotype effect in each sampling time the by Tukey's test, while P-values in bold indicate significant statistical difference (n=5). Dashed lines, equations and R^2 represent polynomial regression adjusted to each genotype, which were graphically presented in colors to facilitate genotype differentiation. Black stars in dashed lines represent the estimated point for maximum of bean dry mass accumulation in each genotype.

During a transient period between the leaf and berry expansion and the maturarion penophases, husk had low rates of increment (Figure 5), differently from

DM accumulation in beans, with repercussion in the whole bean (Figures 3 and 4). From 41 WAF (when berries exocarp started to become red) and onwards, Beira Rio 8 significantly increased the husk mass, up to maximal values at full maturation (45 WAF), being maintained afterwards (Figure 5). Similar DM pattern of variation for husk occurred in Bamburral, A1, Clementino and Pirata, although with lower values than Beira Rio 8. In contrast, P1 showed no significant DM variations in husk during the experimental period, presenting the lowest values among all genotypes from 41 WAF onwards. That contrasts with the greatest value in Beira Rio 8, while the other genotypes showed intermediate values between these two genotypes, which did not statistically frequently differ among themselves (Figure 5). The greatest difference between genotypes occurred by 45 WAF, when Beira Rio 8 had a husk DM berry^{-1} that was 156 mg higher than that of P1 (Figure 2).

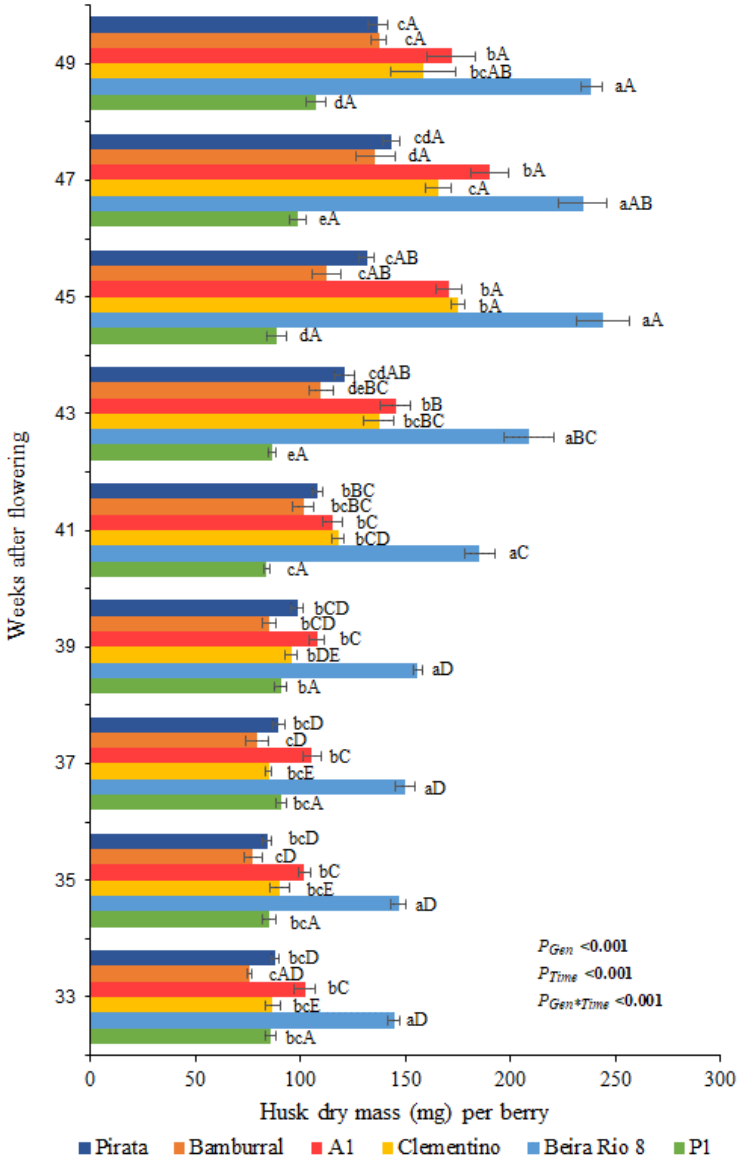

Figure 5: Husk dry mass (mg) per berry of six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) of *Coffea canephora* collected from end of berry expansion to full maturation (33 to 49 weeks after flowering). Values (coloured bars) represent the mean ± SE, and P-values (n=5) are also shown. Lower-case letters compare time effect within each genotype, whilst upper-case letters compare genotype effect in each experimental period the by Tukey's test, whilst the significant p-values are marked in bold.

The berry FM to bean DM ratio is considered an important index for determining bean yield, as a higher ratio value indicates a greater amount of fresh berries required to obtain a certain quantity of dry beans. P1 presented high values of the berry FM to bean DM ratio at the beginning of the fruit harvest (33 WAF), which was gradually reduced along the berry expansion and maturation up to 45 WAF

(Figure 6). Among all studied genotypes, the lowest value of berry FM to bean DM ratio was found in Clementino at 49 WAF, due to the over ripe berries for this genotype (Figure 2), resulting in a low ripe berry FM. Similar dynamic to Clementino was observed in A1 genotype.

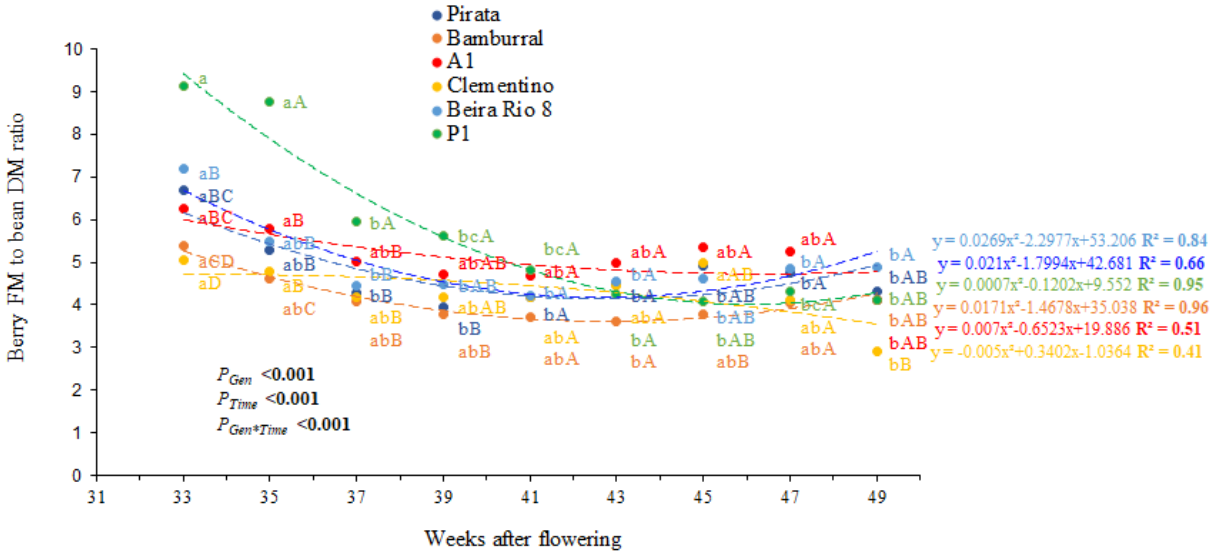

Figure 6: Second order polynomial regression for the berry fresh mass to bean dry matter ratio of six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) of *Coffea canephora* collected from end of berry expansion to full maturation (33 to 49 weeks after flowering). Lower-case letters compare time effect inside each genotype, whilst upper-case letters compare genotype effect in each sampling time the by Tukey's test at 5% probability, while P-values in bold indicate significant statistical difference (n=5). Dashed lines, equations and R2 represent polynomial regression adjusted to each genotype, which were graphically presented in colors to facilitate genotype differentiation.

Bean and husk percentage in berry DM did not follow a same pattern over the experimental time among genotypes (Figure 7). The highest values for bean percentage were obtained in pre-maturation period, after the end of berry expansion. Among genotypes, Bamburral and P1 had the highest percentage of beans in the fruit, reaching 69 and 66% by 39 and 45 WAF, respectively. Pirata, Clementino and Beira Rio 8 showed maximal values close to 60% between 37 and 41 WAF, all decreasing to *ca*. 50% by the last harvest (Figure 7). A1 was the genotype with the lowest performance in bean percentage over the experimental period, having the husk content greater than 50% in the last evaluated weeks.

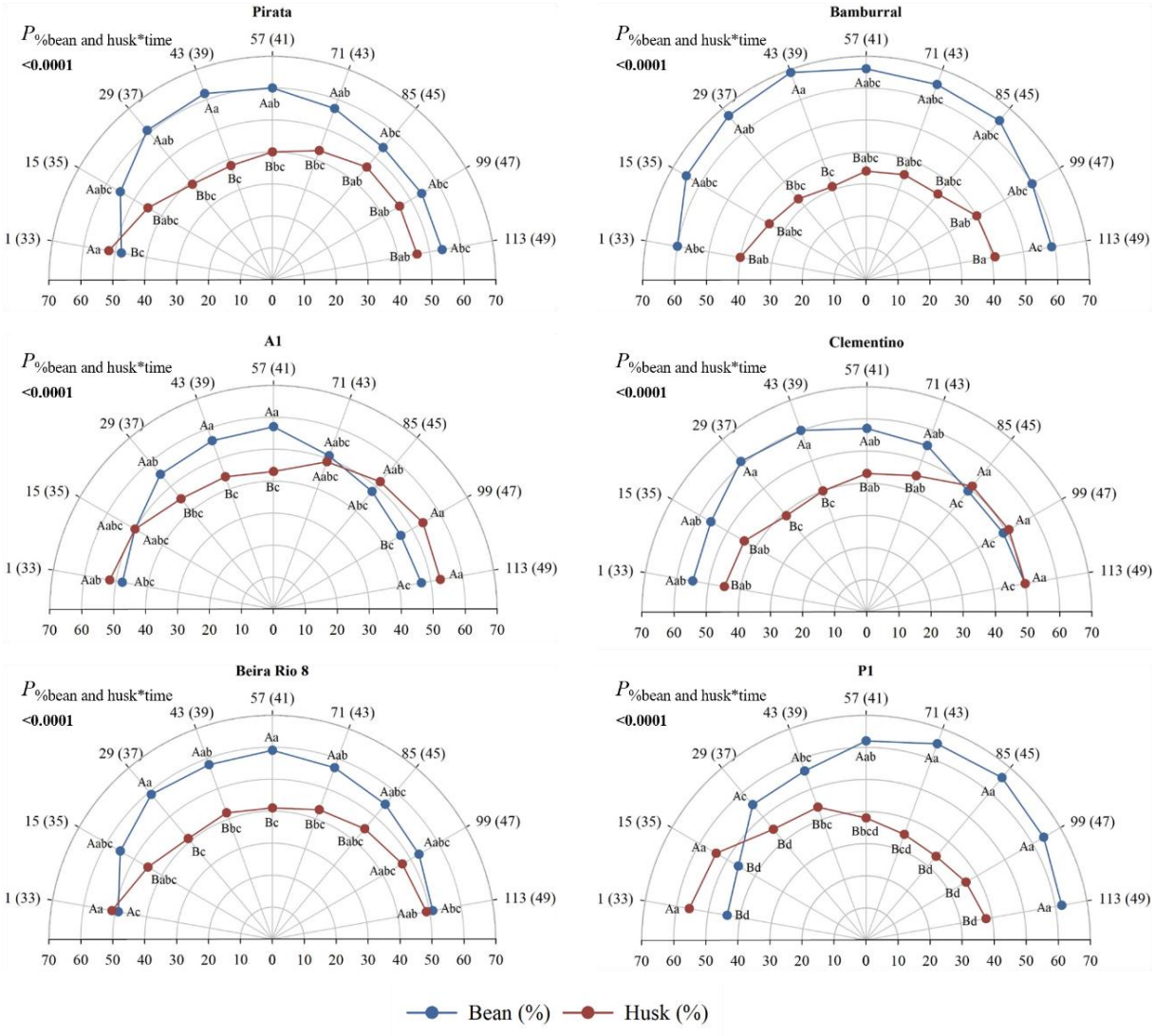

Figure 7: Bean and husk percentage in dry mass of one berry of six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) of *Coffea canephora* collected from end of berry expansion to full maturation (33, 35, 37, 39, 41, 43, 45, 47 and 49 weeks after flowering shown in external radius of the chart). For each genotype lower-case letters compare sampling time effect inside bean and husk percentage, whilst upper-case letters compare bean and husk percentage effect in each sampling time by Tukey's test at 5% probability, while the p-values in bold indicate statistical difference of interaction (n=5).

The yield components (berry fresh mass, berry dry mass, processed bean mass (BDM) and mass performances) significantly differed among the studied genotypes (Table 1). The highest FM, DM, BDM and HDM were obtained in Beira Rio 8, while the lowest DM and HDM values were obtained in P1, and for BDM in A1. The initial berry moisture (field berry moisture) was around 60%, being A1 with the highest value and Bamburral with the lowest. DM performance was the highest for P1 and Bamburral, and the lowest for A1 due to the high husk content per berry in the

last genotype. P1 and Bamburral presented the highest values for DM and BM performance, and lowest values of HDM performance.

Table 1: Components of the berry and bean yields: fresh berry mass (FM), dry berry mass (DM), processed bean mass (BDM) and husk dry mass (HDM) (mg berry^{-1}), initial berry moisture (%), DM, BM and HM performances (%) of six genotypes analyzed at the collecting point closest to the moment of the highest DM in beans (45 WAF for Pirata, Bamburral, A1, Clementino and Beira Rio 8, and at 49 WAF for P1). Means attributed to each genotype followed by a same letter in a column do not differ from each other by the Tukey's test (n = 5).

Genotype	FM	DM	BDM	HDM	Initial berry moisture	DM perform-ance	BM perform-ance	HM perform-ance
Pirata	768.1 b	287.6 bc	155.8 c	131.8 c	62.5 a	54.2 b	20.3 bc	17.2 b
Bamburral	785.5 b	220.8 bc	208.2 b	112.6 c	59.1 b	64.8 a	26.5 a	14.4 c
A1	833.4 b	327.6 bc	156.6 c	171.0 b	60.7 ab	47.7 c	18.7 c	20.5 a
Clementino	848.7 b	445.1 b	170.1 c	175.0 b	59.3 b	49.3 c	20.0 bc	20.6 a
Beira Rio 8	1377 a	542.2 a	298.0 a	244.2 a	60.6 ab	55.0 b	21.7 b	27.7 b
P1	727.2 b	284.6 c	177.2 bc	107.4 c	60.9 ab	62.2 a	24.4 a	14.8 c

Discussion

This work novelty was associated with the quantification and modelling of traits regarding the dry matter accumulation of berry components (bean and husk) from the end of the leaf/berry expansion phenophase until the stage of complete maturation, and its association with the exocarp red color in six genotypes of *Coffea canephora*, to identify the best harvesting time associated with the highest bean yield, which is also genotype-dependent.

The association of the DM dynamics to the berries exocarp color, brought a very practical reference to assist farmer's decision regarding the ideal time to start berry harvesting (Figure 2), that is, using the change in the color of the berries as a benchmark of maturation process. In fruits of the *Coffea arabica* Colombia variety of early maturation cycle, a decrease of berry chlorophyll content to less than half of observed between 26 WAF (16 μg g^{-1} DM) and 29 WAF (7 μg g^{-1} DM), followed by a rapid and sudden accumulation of berry anthocyanin between the 30 and 32 WAF, from 1.5 to 47 μg g^{-1} DM (MARÍN-LOPEZ et al., 2003). In fact, it is long known that the complete change in the color of the berries is the main visual criterion to identify the berry maturity, although difficulted by the absence of synchrony between the

maturation of the exocarp - husk, and the endosperm - bean (CASTRO and MARRACCINI, 2005). The accumulation of DM in beans usually occurred earlier when compared to husk, leading to a greater percentage of bean DM in the berry in the period preceding the change in the color of the pericarp (Figure 7). This was clearly expressed in an early/medium genotype Pirata that presented the highest bean percentage at 37-39 WAF, and only reached red berries stage latter on (43-45 WAF). However, the berry DM alone did not fully characterize the values of harvested commercial bean yield, once the berry DM genotype responses was not equal to BDM genotype responses (Table 1). This occurred due to the percentage of bean and husk in the berry DM variation according to the point of ripeness that varied among all genotypes (Figure 7). Therefore, we proposed to consider berry DM and BDM together in estimations of commercial coffee bean yield and genotype potential.

During the drying process, the berries lost on average 60% of their fresh mass in all genotypes. The water content in the fresh fruits gradually decreased and the lowest values were observed in the fully mature fruits, where the mean weight loss on drying was 54% at 49 WAF. The processed bean DM per berry represented only 23% of initial berry FM, being the highest value obtained at 49 WAF with 24% and lowest at 33 WAF with 16%. The accumulation of DM in the berries increased as the maturation progressed, obtaining the highest values in the final weeks, with 45 (Beira Rio 8 and Clementino), 47 (A1, Bamburral and Pirata) and 49 WAF (P1). The increase in berry DM is mainly due to an increase in bean DM per berry and shows a steeper percentage of DM or reserves accumulation during maturation as compared to the whole berry (EIRA et al., 2006).

Although acting as strong sinks (ALVES et al., 2011), the dynamics of accumulation in the two berry components (beans and husks) followed distinct patterns (Figure 4 and 5). The beans had a faster initial DM growth, and after reaching the maximum weight value around 45 WAF (with exception of late P1), they slightly lost dry mass in process of metabolic bean reorganization during the maturation (Figure 4 and 5). Once the full maturation stage was reached, slight decreases in bean DM per berry can be explained by an interruption of the translocation of photoassimilates from the berry to the bean, as well as by substrate consumption necessary for respiration during the fully maturation stages (CARVALHO and NAKAGAWA, 1980; EIRA et al., 2006; PÉREZ et al., 2023). The respiration produces ATP that can be used in metabolic processes related to

expensive secondary metabolite production in beans, namely various phenolic components with protective roles in plants (FARAH and DONANGELO, 2006). It is worthy to underline that the accessible metabolic analyses in coffee beans are executed, up today, only at the end of berry maturation, suggesting ideas of future research themes related to physiological functions (photosynthesis and respiration).

The husk DM pattern of variation contrasted with that of bean, with the beginning being stable, and reaching the highest values at the end of the experiment, when the berries were fully ripe (Figure 5). This late investment in husk DM maturation would have the sense of biological protective role of the husk against predators and diseases (CARRERA-CASTAÑO et al., 2020). Husks are considered a residual product of coffee processing by many coffee producers, but due to their high mineral content (P, N, Ca) (COVRE et al., 2016), their use in crop fertilization management can reduce the amount of mineral fertilizers provided to coffee plantations, turning the coffee plantations more economically and environmentally sustainable.

The final stage of maturity presented some overripe berries (Figure 2), which might have lower quality characteristics to coffee beverage (MARTÍNEZ et al., 2017). The overripe berries were especially presented in this work in the late sampling stages in A1 and Clementino genotypes, which have early/medium and medium maturation cycles, respectively, whereas the opposite was found for P1, a late maturation genotype. The lower water content in overripe berries might additionally lead to physical problems in beans processing, resulting in a higher percentage of broken beans, what depreciate coffee quality (PÉREZ et al., 2023). The defective coffee beans represent about 15-20% of coffee production on weight basis, being rejected as undesirable for good beverage (RAMALAKSHMI et al., 2007; WORKU et al., 2022). Interestingly, chlorogenic acids, which are characterized by their antioxidant activity, are found to be intact in defective coffee beans compared to high quality ones, potentially indicating triage of berries and beans in conserving food systems (RAMALAKSHMI et al., 2007), as sustainable line of acting.

From the point of view of the final coffee bean quality, the objective is to ensure that the grain harvest of the highest quality (even if it has less DM), otherwise there is a risk of having maximum DM but not quality (HAILE and KANG, 2019). The optimum moment of berry harvest was when the highest bean DM per berry was attained, which was between 43 and 47 WAF for the studied genotypes, a period in

which the berry FM to bean DM ratio was the lowest (Figure 6). The average increase in bean DM per berry was about 15% of all genotypes between 41 and 45 WAF (Figure 4). The 45 WAF will be the best stage for berry harvest, with exception of Pirata (47 WAF) and P1 (49 WAF) (Figure 4). The proportion of beans and husk in DM of berry (Figure 6) indicated that it can be considered as excellent index characterizing superior coffee genotypes, together with high bean yield and high productivity.

Considering only the fully ripe berries, the Pirata, A1, Clementino and Beira Rio 8 genotypes had the elevated DM performances (~50%), while P1 (late maturation cycle) and Bamburral (medium cycle) were characterized with even higher values, above 60%, similarly already shown by one similar parameter, percentage of beans in berries (PARTELLI et al., 2021). Although the self-incompatibility is an important trait for plant populations of *C. canephora*, this trait should be managed to avoid the reduction of efficiency of plant pollination, which affects yield in coffee fields (DEPOLO et al., 2022). Considering that DM accumulation and bean yield were influenced by the maturation cycle of the genotypes, it could be recommended a crop organization in rows for the different genotypes, starting with the early cycle genotypes and ending with the late cycle ones, facilitating the manual or semi-mechanized harvesting operations/management.

Conclusions

Second order polynomial regressions were fitted for berry, bean, and husk DM accumulation over the maturation time. The dynamics of DM accumulation in berry, bean and husk were influenced by the genotype maturation process, differing among different classes of maturation cycles. The accumulation of dry matter in the berries increased as the maturation progressed, attaining the highest values in the final weeks of maturation process: 45-47 WAF for Beira Rio 8, A1, Pirata Bamburral and Clementino, (early/medium and medium maturation cycle genotypes), and 49 WAF for late maturation P1 genotype. The DM accumulation was initially the highest for berry and bean DM per berry (33 – 41 WAF), while the highest increases in husk DM accumulations happened latterly (41 – 49 WAF). High late husk DM investments can be related to necessity of the embryo protection, as one theme for eventual future research.

Beira Rio 8 genotype presented the highest values for DM accumulation in berries, beans, and husk. Bamburral and P1 showed the lowest berry FM to bean DM ratios, while A1 showed the highest berry FM to bean DM ratio, being a genotype with lowest DM and BM performances and bean yield. To obtain a higher bean yield, the indicated harvesting period for the genotypes Pirata, Bamburral, A1, Clementino and Beira Rio 8 was between 43 and 47 WAF, while for P1 only at 49 WAF, when the fruits were ripe above 90%.

Not only the absolute berry and bean yield must be considered for high productive genotypes, but also bean dry mass performance must be included in characterization of commercial yields and selection of the high-quality genotypes. This means that the bean and husk proportions in berry mass must be identified as an index charactering superior genotypes. Finally, the sustainable usage of all products, even husk, must be rethought in new environmental conscience.

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1.3. MACRO AND MICRONUTRIENT ACCUMULATION IN BERRY, BEAN, AND HUSK OF SIX *COFFEA CANEPHORA* GENOTYPES DURING FRUIT MATURATION

Abstract

The coffee plant is considered a plant with high nutritional demands due to the significant amount of nutrients exported with the removal of the berries. Understanding the nutrient accumulation behavior in the entire fruit and its components (beans and husk) along the maturation process is of utmost importance to understand the mineral need at each phase and, thus, to fertilizer management. To this end, the accumulation of dry matter, macro- (N, P, K, Ca, Mg and S) and micro- (Cu, Fe, Mn, Zn and B) nutrients in beans, husk, and berries of six genotypes of *Coffea canephora* were evaluated, in the experimental field at São Mateus region, Brazil, in a two-year-old plantation. Fruit collection began at the end of the grain filling stage, approximately 33 weeks after flowering (WAF), and continued with samplings every 14 days until complete maturation of the six genotypes, totaling nine collection dates (periods), with the last at 49 WAF. Our findings reveal that maturation process influences the concentration and accumulation of nutrients in beans, straw, and fruits.

In general, the highest concentrations were observed in fully mature fruits. Beans showed a higher accumulation of N while straw and fruit demonstrated a greater accumulation of K throughout maturation.

Keywords: Nutrient accumulation, Fertilizer management, Nutritional demands, Maturation process, Macro and micronutrients.

Introduction

In the agricultural sector of the world economy, Brazil is the largest producer and exporter of coffee (ICO, 2023). The two most important species of genus *Coffea* are *C. arabica* L (Arabica coffee) and *C. canephora* Pierre ex A. Froehner (Conilon/Robusta coffee) that together support the entire coffee trade (CASSAMO et al., 2022). *Coffea canephora* is an allogamous species and exhibits gametophytic self-incompatibility (SOUZA et al., 2017; MORAES et al., 2018). Therefore, *C. canephora* cultivars consist of at least five genotypes (when compatibility is known) and at least nine (when compatibility is unknown) to achieve greater pollination efficiency (TEIXEIRA et al., 2020). However, it is rare for a single cultivar to encompass all desired characteristics.

The berry of the coffee is morphologically composed of the pericarp, (*i.e*., exocarp, mesocarp and endocarp), the perisperm likewise called spermoderm, and the bean (endosperm), where is the structure that holds the embryo (CASTRO & MARRACCINI, 2006). In each berry of *C. canephora* usually are presented two seeds (beans), but cases of only one are also possible (HALL et al., 2022). Coffee berries are usually harvested according to the color of the berry's pericarp. In the mature coffee fruit (drupe, also called coffee cherry or berry), the exocarp is red or yellow. To obtain the commercial coffee beans, the pericarp outer skin, pulp, pectic adhesive layer, and parchment (usually together with bean silverskin) are removed, through either dry or wet processing (KITZBERGER et al., 2020).

The coffee plant is considered a plant of high nutritional requirement due to the large amount of nutrients exported with the removal of the berries. However, the nutritional requirements may not always be the same for every coffee genotype and managing them in the same way can lead to imbalances in plant metabolism (CARVALHO et al., 2010). Recent advancements in technology, such as liming and precise fertilizer application, efficient irrigation, strategic pruning methods, increased planting density, selection of superior genotypes, and effective plant health management, have led to significant yield improvements in Conilon coffee plantations (PARTELLI ET AL., 2018). Consequently, there is an increased emphasis on the importance of proper nutritional management. As high-yielding lines have elevated nutritional demands (GOMES et al., 2016), which can vary among genotypes (GILES et al., 2018; GILES et al., 2019).

Generally, in *C. canephora* plants, higher amounts of nitrogen (N), calcium (Ca), and potassium (K) are absorbed, while lesser amounts of phosphorus (P), magnesium (Mg), and sulfur (S) are required (PARTELLI et al., 2014; COVRE et al., 2016). Understanding the nutrient contents in different plant organs allows for conclusions about the development of metabolic requirements in each compartment. This knowledge provides a basis for comprehending variations and their implications in plant responses (AMARAL et al., 2011). Quantifying the nutrient accumulation in bean, husk, and berry is essential as it provides valuable insights for soil fertilization practices. For instance, it can promote the utilization of husks in plantations to enrich soil fertility and facilitate nutrient cycling (COVRE et al., 2016). Moreover, it assists in refining fertilization techniques to replace part of the nutrients extracted through harvesting and pruning. In this sense, the aim of this study was to evaluate the effect of maturation process on the dry matter, macro and micronutrients accumulation in berry, bean, and husk of six genotypes of *Coffea canephora*.

Material and Methods

The experiment was carried out in the experimental field of Federal University of Espírito Santo, São Mateus (18°40’23’’ S, 39°51’22’’ W, 36 m.a.s.l.), state of Espírito Santo, Brazil. The region climate is tropical, with dry winters and rainy summers, characterized as Aw according to Köppen’s classification (ALVARES et al., 2013; SEKI et al., 2021). The soil was classified as a Yellow Dystrophic Argisol (SANTOS et al., 2018).

Five plants per each of the six genotypes of *Coffea canephora*, integrating two cultivars, Andina (Pirata, Bamburral, A1, Clementino and Beira Rio 8) and Tributun (P1) (PARTELLI et al., 2019; PARTELLI et al., 2020) were used. These genotypes, propagated by cuttings, show different maturation cycles, being Pirata, A1 and Beira Rio 8 early/medium, Bamburral and Clementino medium and P1 late cycle. Coffee seedlings were planted in the field in 2018, at a row spacing of 2 m and 1 m between two plants in the row, totaling in a population of 5,000 plants ha^{-1}. All plants were conducted with the two orthotropic axes, resulting in 10,000 orthotropic axes ha^{-1}.

The irrigation hoses were located 5 cm away from the coffee trunks, in the planting rows, and the emitters were spaced every 1.0 m. Irrigation was executed, when necessary, based on soil water balance method, with use of drip irrigation,

reference evapotranspiration was calculated according to Penman-Monteith method (ALLEN et al., 1998).

The nutritional and phytosanitary control were done according to the crop needs to obtain the best conditions for plants development. Phenological stages were also considered, using around 300 - 500 of N, 50 - 80 of P_2O_5 and 200 - 400 K_2O_2 kg ha^{-1}, divided into six equal times, starting applications from flowering to early maturation phenophases.

Berries collection started in the end of grain filling stage, *ca*. 33 weeks after flowering (WAF), and continued afterwards with samplings every 14 days, until complete berry maturation of all six genotypes, totaling nine collection dates (periods), being the last one at 49 WAF. The berries were harvested manually on five plants for each genotype, from previously marked 2nd order plagiotropic axes localized in the medium third of the plant, one branch for every period of collection.

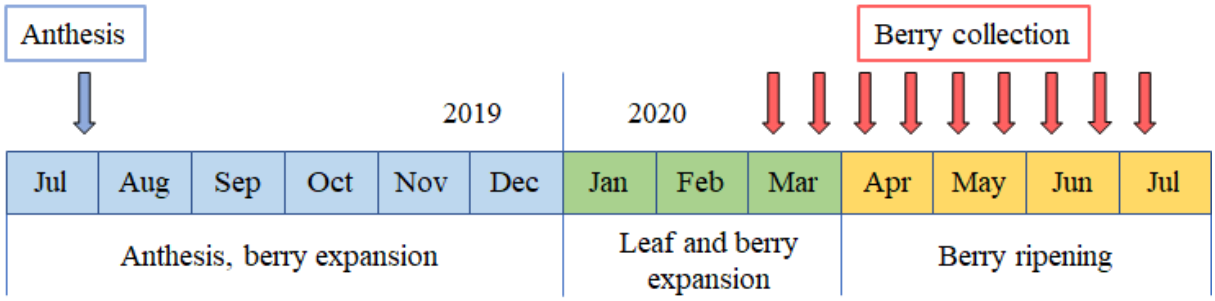

Figure 1: Phenological calendar of *Coffea canephora* during experimental period with indications of collection dates. Adapted from Abreu et al. (2023).

Each berry sample collected per plant was counted and photographed. After that, the samples were dried in a ventilated oven at 50 °C until constant mass. The dry berries were weighted registering the mass in g (scale precision of 1 mg). Separation of the beans from the husk was executed manually. Beans were photographed and weighted, while the husk mass was calculated from the difference between the dry berry and bean mass. The concentration of the macro and micronutrients were determined according to the methodology described by Silva (2009) which can be summarized as follows: nitrogen (N) content was carried out by the Kjeldahl distillation method, phosphorus (P), sulfur (S) and boron (B) was determined by optical emission spectroscopy (OES), while potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) were determined by atomic absorption spectrometry (AAS). With concentration of macro

and micronutrients and dry matter values, it was possible to determinate the accumulation of nutrients in beans (Eq. 1), husk (Eq. 2) and berries (Eq. 3) per berry and considering 1000 kg of beans at 49 WAF (Eq. 4, 5, and 6).

Macro (g/berry) and micronutrient (mg/berry) accumulation on bean:

$$\text{Bean DM } (g) \div \text{Berry DM } (g) \times \text{Nutrient concentration (g/kg) or (mg/kg)} \quad \text{(Eq. 1)}$$

Macro (g/berry) and micronutrient (mg/berry) accumulation on husk:

$$\text{Husk DM } (g) \div \text{Berry DM } (g) \times \text{Nutrient concentration (g/kg) or (mg/kg)} \quad \text{(Eq. 2)}$$

Macro (g/berry) and micronutrient (mg/berry) accumulation on berry:

$$\text{Nutrient accumulation on bean} + \text{Nutrient accumulation on husk} \quad \text{(Eq. 3)}$$

Macro (kg) and micronutrients (g) accumulation on beans considering 1000 kg of beans at 49 WAF:

$$(\text{Bean DM (g)} \times 1000 \div \text{Bean DM 49 WAF(g)}) \times \text{Nutrient concentration on bean (g/kg) or (mg/kg)} \quad \text{(Eq. 4)}$$

Macro (kg) and micronutrients (g) accumulation on husk considering 1000 kg of beans at 49 WAF:

$$(\text{Husk DM (g)} \div \text{Bean DM (g)}) \times (\text{Bean DM (g)} \times 1000 \div \text{Bean DM 49 WAF (g)}) \times \text{Nutrient concentration on husk (g/kg) or (mg/kg)} \quad \text{(Eq. 5)}$$

Macro (kg) and micronutrients (g) accumulation on berry considering 1000 kg of beans at 49 WAF:

$$\text{Nutrient accumulation on bean} + \text{Nutrient accumulation on husk} \quad \text{(Eq. 6)}$$

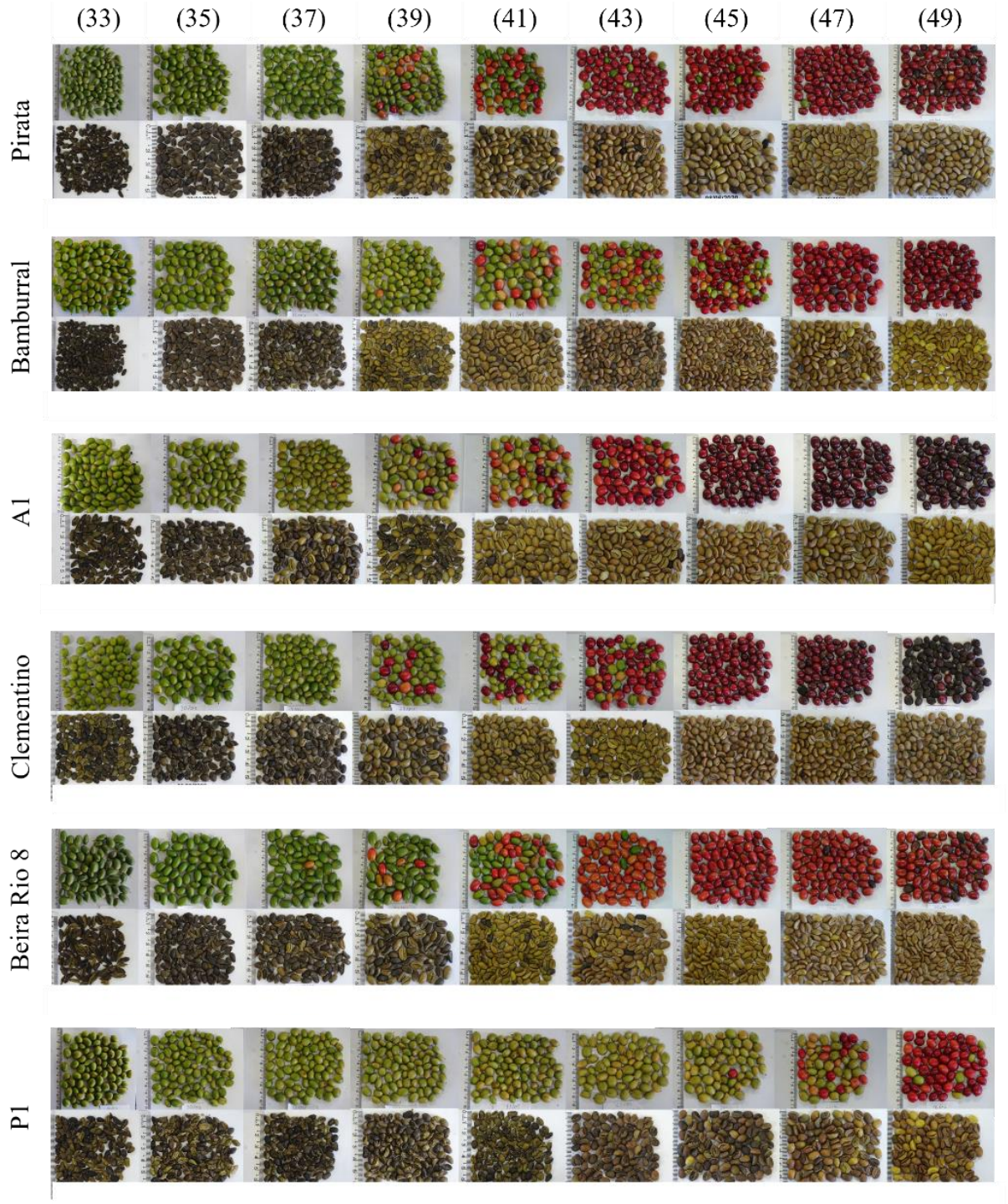

Figure 2: Evolution of visual ripening of berries and corresponding dry beans of six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) of *Coffea canephora* collected from end of berry expansion to full ripening phenophase, corresponding to 33, 35, 37, 39, 41, 43, 45, 47 and 49 weeks after flowering. The upper line of each genotype represents the fresh collected berries, while the lower line the dry beans.

In general, fruits maturation varied according to the cycle of each genotype. In genotypes with early/medium (Pirata, A1 and Beira Rio 8) and medium (Bamburral

and Clementino) cycles, the maturation initiated between 39 and 43 WAF when the first berries started to present red exocarp, while at 45 and 47 WAF they reached a full maturation. Late cycle genotype P1 initiated the maturation between the 45 and 47 WAF, reaching full maturation in the last collection date (49 WAF).

For each genotype, samples in all nine-time observations were collected from the same five plants randomly distributed in experimental field. Each plant was considered as a repetition (n=5). The R Core (2023) software was used for all statistical analyses.

The data were submitted to two-way analysis of variance (ANOVA), after testing the hypothesis of variance homogeneity. ANOVA considered a mixed linear model ('nlme' package) and maximum likelihood to test the significance of differences of macro and micronutrients accumulation between the six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) and nine collection times (33, 35, 37, 39, 41, 43, 45, 47 and 49 weeks after flowering). For the comparison among the averages estimated by the ANOVA, the Tukey's test with 0.05 significance were used supported by 'lsmeans' and 'multcompView' packages.

Results

During the maturation process, the berries continued to accumulate DM (Table 1). The berries of the genotype P1 had the highest accumulation of DM throughout the evaluated period, with an 81% increase between 33 and 45 WAF. The genotype A1 was the least expressive among the others, showing a 62% increase in berry DM. The Beira Rio 8 genotype stood out by having berries with the highest DM content at all evaluated time points, ranging from 291 to 542 mg per berry. In comparison, the P1 genotype recorded the lowest DM at all nine collection times, presenting a difference of 278 mg per berry when compared to Beira Rio 8 at 45 WAF.

High rates of dry matter accumulation in beans were observed during the pre-maturation period, starting at the end of the fruit expansion period (33 WAF) and extending until 41 WAF (Table 1). During this period, the Pirata, Beira Rio 8, and P1 genotypes almost doubled the DM in beans. After reaching the maximum value, the beans stabilized and lost weight in the last assessment, except for the P1 genotype, which continued to accumulate DM until the final collection.

The accumulation of DM in husk was later compared to beans, remaining relatively stable until 41 WAF. From this point onward, the accumulation rate

increased, with the highest values observed between 45 and 49 WAF (Table 1). The Beira Rio 8 genotype exhibited the highest values of DM in husk throughout the entire experimental period, being up to 150 mg higher than the P1 genotype, which had the lowest accumulation of DM in husk, showing no significant differences throughout the evaluated maturation period.

Table 2: Bean, husk and berry dry mass (DM) accumulation of six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) of *Coffea canephora* collected from end of berry expansion to full maturation (33, 35, 37, 39, 41, 43, 45, 47 and 49 WAF).

Dry matter accumulation (mg berry^{-1})							
Berry component	**Time (WAF)**	**Genotype**					
		Pirata	**Bamburral**	**A1**	**Clementino**	**Beira Rio 8**	**P1**
Bean	33	81.6 BCc	114.8 ABd	97.8 BCc	105.6 BCc	146.6 Ae	70.7 Cc
	35	104.0 CDbc	145.9 ABcd	104.9 CDbc	117.1 BCbc	181.2 Ade	71.7 Dc
	37	138.5 BCab	163.4 Bbc	133.5 BCab	132.5 BCbc	220.7 Acd	112.1 Cbc
	39	164.4 BCa	187.8 ABab	142.7 CDab	142.8 CDab	218.7 Acd	114.8 Dab
	41	161.0 BCa	198.4 Bab	152.0 Ca	154.0 Cab	267.9 Aab	136.5 Ca
	43	163.4 Ca	206.8 Bab	151.6 Ca	167.3 BCa	278.4 Aab	159.6 Ca
	45	155.8 Ca	208.2 Ba	156.6 Ca	170.0 BCa	298.0 Aa	175.9 Ba
	47	170.1 BCa	205.9 Bab	164.2 Ca	161.5 Ca	260.1 Aab	175.8 BCa
	49	161.0 BCa	199.8 Bab	153.0 Ca	155.8 Cab	250.4 Abc	177.2 BCa
Husk	33	88.1 BCd	76.0 Cd	102.3 Bc	86.9 BCe	144.7 Ad	86.1 BCa
	35	84.1 BCd	77.5 Cd	101.8 Bc	90.0 BCe	146.7 Ad	85.0 BCa
	37	89.6 BCd	79.5 Cd	105.6 Bc	85.0 BCe	150.0 Ad	90.8 BCa
	39	98.6 Bcd	85.0 Bcd	107.9 Bc	95.9 Bde	155.8 Ad	90.7 Ba
	41	108.0 Bcd	101.5 BCbc	115.7 Bc	118.0 Bcd	185.4 Ac	83.9 Ca
	43	121.1 CDbc	109.9 DEbc	145.3 Bb	137.6 BCbc	208.9 Abc	86.6 Ea
	45	131.8 Cab	112.6 Cab	171. Ba	175.0 Ba	244.2 Aa	88.4 Da
	47	143.7 CDa	135.8 Da	190.2 Ba	165.8 Ca	234.5 Aab	99.0 Ea
	49	136.8 Ca	137.6 Ca	172.0 Ba	158.5 BCab	238.8 Aa	107.4 Da
Berry	33	169.8 Bc	190.8 Be	200.0 Bd	192.5 Bd	291.2 Ad	156.8 Bd
	35	188.1 BCc	223.4 Bde	206.7 BCd	207.2 BCd	327.9 Acd	156.8 Cd
	37	228.2 Bbc	242.8 Bde	239.1 Bcd	217.5 Bcd	370.8 Ac	202.9 Bcd
	39	263.0 Bab	272. 8 Bd	250.7 BCcd	238.7 BCcd	374.6 Ac	205.5 Ccd
	41	269.0 BCab	299.9 Bbc	267.7 BCbc	272.0 BCbc	453.3 Ab	220.4 Cbc
	43	284.5 BCab	316.6 Bab	296.8 BCbc	304.8 Bab	487.3 Aab	246.5 Cab
	45	287.6 CDa	320.8 BCab	327.6 BCa	345.1 Ba	542.2 Aa	264.4 Dab
	47	313.8 BCa	341.8 Ba	354.4 Ba	327.3 BCab	494.6 Aab	274.8 Cab
	49	297.8 Ba	337.4 Ba	325.1 Bab	314.3 Bab	489.1 Aab	284.6 Ba

Upper-case letters compare genotype effect inside each time, whilst lower-case letters compare time effect for each genotype by Tukey's test at 5% of probability. Bean CV = 13.7%, Husk CV= 10.3% and Berry CV = 10.3%.

The nutrient concentrations in the beans showed changes due to the fruit maturation process (Table 3). For four out of the six evaluated genotypes, the

concentration of N decreased as maturation progressed, with only the A1 and Beira Rio 8 genotypes not showing significant differences over the evaluated period.

The analysis of K concentrations also revealed a gradual reduction during the maturation process, a trend observed for all evaluated genotypes. This decrease in K concentration occurred more drastically than in the case of N, highlighting a specific dynamic for this nutrient during fruit ripening. There was also a reduction in Mg concentration, but with the particularity of occurring up to 45 WAF, after that, there was a slight increase in the following two weeks.

The micronutrient Zn exhibited a distinctive trend, showing an increase in concentration throughout maturation, especially between 35 and 37 WAF, with an increase exceeding 100% for most genotypes. After this period, there was still a gradual, although smaller, increase until the end of the evaluated period.

The nutrients Ca, S, Fe, and Mn, despite showing significant differences, did not exhibit a well-defined trend, with concentration values remaining practically stable in relation to maturation. The nutrients P, Cu, and B did not show any statistical differences, however, B demonstrated a gradual reduction in concentration values in the bean, being significantly lower at the end of maturation when compared to the initial stage.

Table 3: Nutrients concentration on beans of six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) of *Coffea canephora* collected from end of berry expansion to full maturation (33 to 49 Weeks After Flowering).

Time (WAF)	Genotype	Macronutrients (g kg^{-1})						Micronutrients (mg kg^{-1})				
		N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn	B
33	Pirata	26.8 Aa	2.20 Aa	24.6 BCa	3.57 Aa	2.53 ABa	1.77 Aa	21.8 Aa	367 Aa	24.9 Aa	5.07 Ab	45.5 Aa
	Bamburral	28.9 Aa	2.20 Aa	22.7 Cab	3.17 ABa	2.47 ABa	1.80 Aa	24.3 Aa	246 Ba	23.0 Aa	6.23 Acd	32.0 Aa
	A1	25.9 Aa	2.23 Aa	23.8 Cab	3.30 ABa	2.20 Bab	1.60 Aab	17.2 Aa	261 Ba	20.9 Aa	4.27 Ac	46.0 Aa
	Clementino	28.7 Aab	2.77 Aa	28.0 ABa	3.20 ABa	2.67 Aa	1.60 Abc	27.6 Aa	222 Bab	22.8 Aa	5.40 Ac	32.4 Aa
	Beira Rio 8	25.4 Aa	2.50 Aa	27.4 ABa	3.20 ABab	2.40 ABa	1.73 Aab	18.1 Aa	248 Ba	22.2 Aa	5.50 Ac	47.8 Aa
	P1	29.4 Ab	2.67 Aa	30.0 Aa	2.73 Bbc	2.67 Aa	1.83 Aa	25.9 Aa	210 Ba	21.4 Aab	3.57 Ad	31.1 Aa
35	Pirata	22.9 Bab	2.07 Aa	22.6 Bab	2.93 Ab	2.50 ABab	1.67 Aa	19.2 Aa	184 Ab	21.1 ABab	3.90 Ab	28.7 Aa
	Bamburral	25.7 Bab	2.27 Aa	23.8 ABa	3.00 Aa	2.40 ABab	1.77 Aa	22.7 Aa	182 Aa	22.1 ABa	5.17 Ad	25.5 Aa
	A1	26.6 Ba	2.27 Aa	25.9 ABa	3.17 Aa	2.37 ABa	2.00 Aa	21.6 Aa	204 Aa	21.6 ABa	3.77 Ac	26.3 Aa
	Clementino	27.5 Bbc	2.53 Aa	23.1 Bb	3.03 Aa	2.33 ABab	1.93 Aab	22.9 Aa	204 Aab	20.9 ABa	5.13 Ac	32.9 Aa
	Beira Rio 8	25.2 Ba	2.30 Aa	23.4 Bb	2.93 Ab	2.23 Bab	1.73 Aab	18.3 Aa	184 Aa	19.3 Bab	3.93 Ac	39.9 Aa
	P1	36.2 Aa	2.83 Aa	27.2 Aa	3.40 Aa	2.63 Aa	1.87 Aa	28.2 Aa	225 Aa	23.8 Aab	7.87 Acd	29.6 Aa
37	Pirata	23.8 Aab	1.97 Aa	20.5 ABbc	3.37 Aab	2.37 Aabc	1.67 Ab	18.3 Aa	204 Ab	19.6 Ab	11.4 Aa	32.6 Aa
	Bamburral	24.7 Aab	1.97 Aa	22.7 Aab	3.17 ABa	2.37 Aabc	1.17 Bb	19.2 Aa	237 Aa	18.6 Aa	11.2 Abc	33.5 Aa
	A1	25.2 Aa	2.27 Aa	22.2 Aab	3.17 ABa	2.10 Aab	1.37 ABbc	19.9 Aa	205 Aa	18.1 Aa	10.5 Ab	34.0 Aa
	Clementino	25.0 Abc	2.33 Aa	20.8 ABbc	3.20 ABa	2.40 Aab	1.47 ABbc	22.6 Aa	206 Aab	20.4 Aa	12.9 Aab	38.9 Aa
	Beira Rio 8	23.3 Aa	2.23 Aa	18.6 Bc	3.00 ABab	2.10 Aabc	1.37 ABb	16.0 Aa	181 Aa	18.7 Aab	11.6 Ab	45.6 Aa
	P1	27.3 Abc	2.37 Aa	23.3 Ab	2.73 Bbc	2.23 Abc	1.67 Aa	23.6 Aa	182 Aa	21.2 Aab	12.3 Aabc	26.4 Aa
39	Pirata	22.9 Bab	1.90 Aa	17.9 BCcd	3.03 Aab	2.17 ABbcd	1.47 Aab	16.8 Aa	183 Ab	20.2 Bb	12.4 ABa	34.7 Aa
	Bamburral	23.8 Bab	2.00 Aa	21.07 ABabc	3.20 Aa	2.27 ABabc	1.63 Aab	19.2 Aa	190 Aa	19.3 Ba	13.3 ABb	35.2 Aa
	A1	22.9 Ba	2.37 Aa	21.7 Ab	3.23 Aa	2.03 Bab	1.57 Aabc	18.8 Aa	184 Aa	18.2 Ba	11.7 Bab	33.3 Aa
	Clementino	24.5 ABbc	2.33 Aa	18.6 ABCcd	3.20 Aa	2.13 ABbc	1.63 Abc	19.5 Aa	199 Ab	20.7 ABa	14.5 ABab	29.7 Aa
	Beira Rio 8	21.9 Ba	2.13 Aa	16.7 Ccd	3.30 Aab	2.07 ABabc	1.57 Aab	17.2 Aa	205 Aa	21.1 ABab	13.1 ABab	36.9 Aa
	P1	29.4 Ab	2.60 Aa	21.9 Abc	3.13 Aab	2.40 Aab	1.83 Aa	25.9 Aa	210 Aa	24.3 Aa	16.9 Aa	32.1 Aa
41	Pirata	21.0 Bb	1.97 Aa	15.9 Bd	2.97 Aab	1.97 Ad	1.73 Aa	17.6 Aa	219 Ab	22.7 ABab	14.7 Aa	38.3 Aa
	Bamburral	25.4 ABab	2.10 Aa	19.7 Abc	3.00 Aa	2.03 Acde	1.63 Aab	22.1 Aa	204 Aa	21.4 ABCa	13.2 Ab	27.2 Aa

	A1	22.4 Ba	1.87 Aa	17.4 ABc	2.73 Aa	1.60 Bd	1.70 Aab	15.0 Aa	182 Aa	18.1 Ca	13.5 Aab	29.9 Aa
	Clementino	22.9 Bc	2.37 Aa	19.4 ABbcd	3.20 Aa	2.20 Abc	1.73 Aabc	21.3 Aa	204 Aab	23.2 Aa	14.2 Aab	29.4 Aa
	Beira Rio 8	22.2 Ba	2.07 Aa	17.2 ABcd	2.83 Ab	1.90 ABbcd	1.57 Aab	16.4 Aa	176 Aa	19.1 BCab	11.8 Ab	34.5 Aa
	P1	28.7 Abc	2.30 Aa	20.3 Abcd	2.67 Abc	2.03 Ac	1.90 Aa	23.0 Aa	184 Aa	21.7 ABCab	13.9 Aab	23.5 Aa
43	**Pirata**	21.7 Aab	1.97 Aa	15.9 Ad	3.03 Aab	2.03 Acd	1.80 Aa	16.9 Aa	193 Ab	21.0 ABab	12.9 Aa	35.1 Aa
	Bamburral	22.4 Ab	1.97 Aa	18.8 Ac	2.90 Aa	1.93 ABde	1.57 Aab	19.4 Aa	192 Aa	20.4 Aba	12.5 Ab	34.3 Aa
	A1	23.8 Aa	2.00 Aa	15.5 Ac	2.90 Aa	1.67 Bcd	1.50 Abc	14.0 Aa	199 Aa	20.4 ABa	11.6 Aab	29.1 Aa
	Clementino	24.3 Abc	2.20 Aa	15.8 Ade	2.93 Aa	1.87 ABcd	1.83 Aabc	17.3 Aa	237 Aab	22.4 ABa	13.9 Aab	30.7 Aa
	Beira Rio 8	20.5 Aa	1.93 Aa	15.0 Acd	3.00 Aab	1.83 ABcd	1.47 Ab	15.1 Aa	174 Aa	18.8 Bab	11.4 Ab	39.4 Aa
	P1	23.6 Ac	2.07 Aa	18.4 Acd	2.87 Aabc	1.93 ABcd	1.77 Aa	20.4 Aa	198 Aa	23.6 Aab	13.1 Aab	24.9 Aa
45	**Pirata**	20.1 Cb	1.93 Aa	15.7 Ad	2.93 Ab	1.87 Ad	1.63 Cab	14.3 Aa	184 Ab	21.0 Aab	11.6 ABa	30.5 Aa
	Bamburral	21.5 BCb	2.30 Aa	17.4 Ac	2.87 Aa	1.80 Ae	1.63 Cab	17.2 Aa	190 Aa	20.9 Aa	12.3 ABb	28.6 Aa
	A1	21.7 BCa	2.10 Aa	15.0 Ac	2.70 Aa	1.57 Ad	1.73 Bcab	12.2 Aa	254 Aa	19.5 Aa	10.6 Bb	27.6 Aa
	Clementino	32.9 Aa	2.43 Aa	14.7 Ae	2.93 Aa	1.77 Ad	2.20 Aa	15.8 Aa	190 Ab	22.0 Aa	11.6 ABab	28.5 Aa
	Beira Rio 8	22.9 BCa	2.10 Aa	14.3 Ad	2.83 Ab	1.63 Ad	2.03 Ca	13.1 Aa	200 Aa	20.2 Aab	15.5 Aab	33.8 Aa
	P1	26.4 Bbc	2.07 Aa	17.5 Ad	2.43 Ac	1.60 Ad	2.13 ABa	17.0 Aa	181 Aa	21.1 Aab	11.2 ABbc	22.9 Aa
47	**Pirata**	24.0 ABab	1.90 Aa	15.0 Ad	2.93 Ab	1.87 BCd	1.83 Aa	12.4 Aa	187 Bb	20.8 Aab	11.3 BCa	24.8 Aa
	Bamburral	28.5 Aa	1.97 Aa	17.7 ABCc	2.93 Aa	1.80 BCe	1.77 Aa	15.3 Aa	180 Ba	21.2 Aa	12.0 ABCb	24.0 Aa
	A1	22.2 Ba	2.03 Aa	15.3 BCc	3.03 Aa	1.53 Cd	1.60 Aab	13.2 Aa	235 ABa	20.5 Aa	15.5 ABa	22.7 Aa
	Clementino	26.4 ABbc	2.13 Aa	18.7 ABcd	3.43 Aa	2.33 Aab	0.87 Bd	19.1 Aa	286 Aa	20.8 Aa	15.9 Aab	25.0 Aa
	Beira Rio 8	22.9 Ba	1.97 Aa	17.6 ABCcd	3.33 Aab	2.03 ABbc	0.80 Bc	15.4 Aa	215 Aba	17.2 Ab	12.5 ABCab	25.3 Aa
	P1	23.6 ABc	2.00 Aa	20.7 Abcd	3.03 Aabc	2.00 ABc	0.80 Bb	18.3 Aa	221 ABa	19.7 Ab	9.9 Cbc	14.9 Aa
49	**Pirata**	21.0 Ab	1.90 Aa	18.1 Acd	3.33 ABab	2.33 ABabc	1.50 ABab	16.5 Aa	211 Ab	18.9 Ab	13.6 BCa	21.7 Aa
	Bamburral	21.7 Ab	1.87 Aa	19.1 Abc	3.13 ABa	2.07 ABCcde	1.37 ABab	17.6 Aa	249 Aa	19.9 Aa	19.7 Aa	12.9 Aa
	A1	22.4 Aa	2.07 Aa	17.4 Ac	3.30 ABa	1.97 Cbc	1.10 Bc	15.7 Aa	213 Aa	18.4 Aa	13.7 BCab	14.1 Aa
	Clementino	24.0 Abc	2.17 Aa	18.0 Acde	3.30 ABa	2.40 Aab	1.40 ABc	16.7 Aa	212 Aab	20.0 Aa	17.5 ABa	19.6 Aa
	Beira Rio 8	21.0 Aa	2.10 Aa	16.6 Acd	3.60 Aa	2.20 ABCab	1.73 Aab	16.8 Aa	215 Aa	19.8 Aab	16.8 ABa	31.6 Aa
	P1	24.3 Abc	2.03 Aa	20.0 Abcd	2.83 Babc	2.00 BCc	1.73 Aa	20.5 Aa	191 Aa	19.8 Ab	10.1 Cbc	15.4 Aa
CV(%)		8.42	9.14	7.49	7.94	6.68	11.3	19.2	15.7	8.2	17.0	17.3

Upper-case letters compare genotype effect inside each time, whilst lower-case letters compare time effect for each genotype by Tukey's test at 5% of probability.

In general, the concentration values of N in the husk (Table 4) were lower than those observed in the beans (Table 3). Throughout the maturation period, there was a fluctuation in N concentration values within a stable range for all genotypes. Therefore, despite some punctual differences, it was not possible to establish a specific trend. The genotypes Bamburral, Beira Rio 8, and P1 did not show significant differences.

The concentration of K in husk stood out as the nutrient with the highest concentration when compared to the others, even exceeding the concentration values of K observed in the bean. The concentration of K increased until the 43rd WAF, after that, there was a reduction and stabilization of values until the last collection date. This can be explained by the greater accumulation of dry matter in the husk, noted from this point onward (Table 1), resulting in a dilution effect of K in the husk, stabilizing concentration values. The Bamburral genotype obtained the highest values for K concentration in most of the evaluated moments.

Different to what occurred in the beans, the concentration of Zn in the husk decreased during maturation, with a significant reduction starting from 45 WAF. The opposite behavior observed in the concentration of Zn between the husk and the bean suggests a possible migration of this nutrient from the husk to bean between 39 and 43 WAF. The concentration of the micronutrient B in the husk also gradually decreased as the fruit matured, following a similar trend to what was observed in the bean. However, no statistical difference in the concentration of B in the husk was observed for the A1, Bamburral, and P1 genotypes over time.

For P, Ca, Mg, S, Cu, Fe, and Mn, despite some slight changes, there was a trend of stability in the concentration of these nutrients. However, it is worth noting that the concentration of Fe, both in the husk and in the bean, is significantly higher than the other micronutrients, indicating that Fe is a micronutrient in high demand within the maturation process.

Tabela 4: Nutrients concentration on husk of six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) of *Coffea canephora* collected from end of berry expansion to full maturation (33 to 49 Weeks After Flowering).

Time (WAF)	Genotype	Macronutrients (g kg^{-1})						Micronutrients (mg kg^{-1})				
		N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn	B
33	Pirata	12.4 ABa	2.30 Aa	19.7 Bb	8.53 Aa	3.10 Aa	2.53 Aa	13.1 Aa	734 Aa	35.1 Aa	15.4 Aa	78.8 Aa
	Bamburral	12.8 Aa	2.10 Aa	28.0 Ac	5.03 Ba	1.23 BCa	2.07 ABbc	12.7 Aa	496 Bb	17.3 Bab	9.23 ABb	26.8 Ba
	A1	9.6 BCabc	1.60 Aa	20.0 ABc	4.93 Babc	1.77 Bab	1.60 Bbc	9.07 Aa	371 BCa	16.6 Aa	5.4 Bb	39.5 Ba
	Clementino	9.6 BCb	2.90 Aa	20.7 ABb	4.30 Ba	1.83 Ba	2.03 Bab	12.4 Aa	390 BCa	21.9 Ba	5.3 Ba	42.3 Bbc
	Beira Rio 8	10.5 ABCa	1.20 Aa	18.5 Bb	4.90 Bb	1.33 BCa	1.70 Babc	8.53 Aa	386 BCab	17.3 Ba	4.50 Bc	36.9 Bc
	P1	9.1 Ca	1.70 Aa	23.3 ABab	4.43 Ba	1.07 Cab	1.70 Bab	12.8 Aa	327 Ca	19.0 Babc	4.53 Bab	26.7 Ba
35	Pirata	9.6 Aab	2.23 Aa	23.4 BCab	5.63 Ab	1.73 ABCb	2.20 Aabc	12.6 Aa	347 Ab	21.0 ABb	6.93 Ab	41.5 Ac
	Bamburral	11.7 Aa	1.97 Aa	33.3 Aabc	6.27 Aa	0.90 Da	2.33 Aab	8.60 Aa	324 Ac	15.6 Bab	6.83 Ab	37.6 Aa
	A1	9.80 Aab	2.10 Aa	30.1 ABab	6.47 Aab	2.10 Aa	2.20 Aa	12.3 Aa	347 Aa	19.4 ABa	9.17 Ab	35.9 Aa
	Clementino	8.87 Abc	2.67 Aa	25.1 BCab	4.73 Aa	1.90 ABa	2.13 Aa	12.4 Aa	392 Aa	19.6 ABa	6.57 Aa	44.6 Ab
	Beira Rio 8	10.3 Aa	1.40 Aa	25.7 ABCab	5.37 Aab	1.33 BCDa	1.97 Aa	9.70 Aa	445 Aab	17.2 Ba	11.6 Aab	54.3 Aabc
	P1	11.7 Aa	1.87 Aa	19.5 Cb	5.07 Aa	1.23 CDa	1.83 Aa	13.9 Aa	439 Aa	24.9 Aa	11.1 Aa	37.0 Aa
37	Pirata	8.17 Bb	2.30 Aa	26.4 Aab	6.00 Aab	1.53 ABb	2.47 Aa	9.63 Aa	410 Ab	19.2 Ab	8.80 Bab	48.9 ABbc
	Bamburral	12.1 Aa	1.83 Aa	25.8 Ac	5.47 Aa	1.13 BCa	2.07 ABbc	9.53 Aa	346 Ac	17.1 Aab	7.63 Bb	32.1 BCa
	A1	9.10 ABabc	1.53 Aa	21.3 Abc	5.47 Aabc	1.37 ABb	1.73 Babc	7.07 Aa	429 Aa	17.7 Aa	21.6 Aa	35.6 ABCa
	Clementino	8.17 Bbc	2.70 Aa	26.0 Aab	4.83 Aa	1.80 Aa	1.97 Babc	11.7 Aa	412 Aa	20.2 Aa	9.23 Ba	42.8 ABCbc
	Beira Rio 8	9.33 ABa	1.30 Aa	27.2 Aab	5.60 Aab	1.07 Bca	2.00 ABa	7.00 Aa	325 Ab	16.5 Aa	6.67 Babc	54.6 Aabc
	P1	9.10 ABa	2.47 Aa	24.4 Aab	3.70 Aa	0.57 Cab	2.03 ABa	11.4 Aa	332 Aa	19.0 Aabc	6.93 Bab	28.2 Ca
39	Pirata	9.10 BCab	2.23 Aa	32.0 ABa	7.46 ABab	1.87 Ab	2.60 Aa	9.87 Aa	342 Ab	19.8 ABb	5.93 Ab	63.4 Aab
	Bamburral	12.6 Aa	1.53 Aa	38.0 Aab	7.43 ABa	0.90 CDa	2.03 Bbcd	8.63 Aa	338 Ac	15.1 Bb	6.97 Ab	34.8 Ba
	A1	7.93 Cbcd	1.67 Aa	22.7 Cabc	4.97 Babc	1.20 BCDb	1.93 Bab	6.23 Aa	405 Aa	15.6 Ba	9.53 Ab	36.3 Ba
	Clementino	8.17 Cbc	2.26 Aa	26.5 BCab	5.63 ABa	1.73 ABa	1.97 Babc	10.9 Aa	357 Aa	20.6 ABa	7.40 Aa	67.7 Aa
	Beira Rio 8	9.33 BCa	1.37 Aa	30.0 ABCa	7.80 Aa	1.50 ABCa	1.83 Bab	7.70 Aa	350 Ab	16.8 Ba	6.43 Abc	67.1 Aa
	P1	11.4 ABa	1.93 Aa	24.8 BCab	6.27 ABa	0.83 Dab	1.70 Bab	11.9 Aa	386 Aa	24.3 Aab	6.53 Aab	31.4 Ba
41	Pirata	8.63 Bb	2.40 Aa	30.9 Aa	5.50 ABb	1.67 ABb	2.40 ABa	13.1 Aa	452 BCb	18.2 ABb	7.17 Cb	51.1 ABbc
	Bamburral	13.1 Aa	2.20 Aa	34.0 Aabc	6.93 Aa	1.17 BCa	2.63 Aa	14.6 Aa	708 Aa	22.2 Aa	21.4 Aa	35.8 BCa

	A1	10.7 ABa	2.37 Aa	30.4 Aa	6.97 Aa	1.83 Aab	2.13 Bab	12.0 Aa	376 BCa	17.9 ABa	7.73 BCb	39.5 ABCa
	Clementino	13.3 Aa	2.23 Aa	31.4 Aa	6.23 ABa	1.80 Aa	2.30 Aba	11.8 Aa	368 Ca	21.0 ABa	7.87 BCa	48.9 ABab
	Beira Rio 8	9.1 Ba	1.77 Aa	32.4 Aa	5.83 ABab	0.90 CDa	2.23 ABa	11.2 Aa	505 Ba	19.4 ABa	13.6 Ba	59.5 Aab
	P1	10.7 ABa	1.97 Aa	28.4 Aab	4.00 Ba	0.50 Db	2.03 Ba	10.8 Aa	325 Ca	15.7 Bc	7.27 BCab	27.4 Ca
43	**Pirata**	12.1 Aa	2.30 Aa	31.5 Ba	5.60 Ab	1.67 ABb	2.30 ABab	14.3 Aa	338 Ab	17.4 Ab	5.13 Bb	43.1 Abc
	Bamburral	11.4 ABa	2.07 Aa	41.3 Aa	5.67 Aa	1.17 BCa	2.40 Aab	14.6 Aa	341 Ac	15.3 Ab	7.03 Bb	17.6 Ba
	A1	8.63 BCabc	1.37 Aa	23.4 Babc	6.60 Aab	1.40 ABab	1.90 Bab	8.53 Aa	415 Aa	18.7 Aa	19.9 Aa	31.1 ABa
	Clementino	8.17 Cbc	2.13 Aa	25.0 Bab	5.13 Aa	1.83 Aa	1.23 Cd	12.6 Aa	326 Aa	18.2 Aa	6.30 Ba	37.0 ABbc
	Beira Rio 8	8.87 BCa	1.57 Aa	26.3 Bab	5.10 Aab	1.23 ABCa	1.20 Cc	10.8 Aa	325 Ab	13.6 Aa	2.70 Bc	44.9 Abc
	P1	8.63 BCa	2.17 Aa	31.5 Ba	4.97 Aa	0.67 Cab	1.23 Cb	12.5 Aa	326 Aa	16.4 Ac	2.97 Bb	28.6 ABa
45	**Pirata**	7.00 ABb	2.00 Aa	26.6 ABab	5.73 Ab	1.83 Ab	1.67 ABcd	10.3 Aa	326 Ab	17.0 Ab	2.77 Ab	38.6 Ac
	Bamburral	10.0 Aa	2.10 Aa	33.4 Aabc	6.00 Aa	1.37 Aa	1.73 Acd	14.3 Aa	336 Ac	14.1 Ab	2.70 Ab	27.4 Aa
	A1	6.30 Bcd	1.63 Aa	25.6 ABabc	3.47 Ac	1.23 Ab	1.23 Bc	9.00 Aa	325 Aa	13.0 Aa	3.03 Ab	22.1 Aa
	Clementino	5.83 Bc	2.30 Aa	25.0 Bab	4.53 Aa	1.80 Aa	1.33 ABd	14.8 Aa	325 Aa	17.8 Aa	3.07 Aa	32.6 Abc
	Beira Rio 8	7.00 ABa	1.50 Aa	24.2 Bab	4.27 Ab	1.23 Aa	1.40 ABbc	11.8 Aa	326 Ab	14.7 Aa	3.07 Ac	38.1 Abc
	P1	8.40 ABa	2.13 Aa	28.7 ABa	4.60 Aa	0.60 Bab	1.70 ABab	13.5 Aa	325 Aa	17.9 Abc	2.87 Ab	26.4 Aa
47	**Pirata**	7.23 BCb	1.83 Aa	27.1 Aab	5.30 Ab	1.53 Ab	1.80 Abcd	11.3 Aa	325 Ab	16.7 Ab	2.93 Ab	36.0 Ac
	Bamburral	11.0 Aa	1.63 Aa	26.2 Ac	5.33 Aa	1.27 ABa	1.50 ABd	13.3 Aa	304 Ac	15.1 Ab	2.63 Ab	27.3 Aa
	A1	4.9 Cd	1.40 Aa	21.8 Aabc	4.23 Aabc	1.37 ABb	1.23 Bc	9.90 Aa	339 Aa	15.4 Aa	2.77 Ab	26.0 Aa
	Clementino	6.77 BCbc	2.13 Aa	21.7 Ab	3.50 Aa	1.57 Aa	1.53 ABbcd	13.1 Aa	271 Aa	17.9 Aa	3.10 Aa	22.3 Ac
	Beira Rio 8	9.33 ABa	1.37 Aa	25.3 Aab	4.23 Ab	1.13 ABa	1.30 Bbc	9.77 Aa	354 Ab	14.8 Aa	2.93 Ac	33.1 Ac
	P1	10.5 Aa	1.90 Aa	25.3 Aab	4.97 Aa	0.77 Bab	1.63 ABab	13.3 Aa	388 Aa	17.6 Abc	5.90 Aab	24.1 Aa
49	**Pirata**	8.40 Bb	2.17 Aa	25.7 ABab	4.97 Ab	1.63 Ab	1.53 Ad	12.5 Aa	322 Ab	20.0 Ab	2.47 Ab	30.0 Ac
	Bamburral	11.7 Aa	1.90 Aa	30.0 Abc	4.67 Aa	1.27 ABa	1.70 Acd	14.8 Aa	282 Ac	14.4 Ab	4.00 Ab	23.7 Aa
	A1	7.23 BCbcd	1.43 Aa	20.2 Bc	3.83 Abc	1.23 ABb	1.33 Ac	9.13 Aa	369 Aa	15.2 Aa	3.07 Ab	24.2 Aa
	Clementino	7.47 Bbc	1.90 Aa	20.3 Bb	4.20 Aa	1.73 Aa	1.47 Acd	13.8 Aa	303 Aa	18.4 Aa	3.00 Aa	29.3 Abc
	Beira Rio 8	9.33 ABa	1.50 Aa	24.9 ABab	4.33 Ab	1.20 ABa	1.37 Abc	13.2 Aa	337 Ab	16.2 Aa	2.83 Ac	34.2 Ac
	P1	9.80 ABa	2.20 Aa	29.2 Aa	4.27 Aa	0.93 Bab	1.80 Aa	15.8 Aa	347 Aa	19.2 Aabc	2.57 Ab	27.8 Aa
	CV(%)	14.0	20.4	12.9	20.2	18.9	11.3	24.3	15.5	14.6	40.0	22.5

Upper-case letters compare genotype effect inside each time, whilst lower-case letters compare time effect for each genotype by Tukey's test at 5% of probability.

The accumulation of nutrients in the bean, husk and berry per berry considers the concentration of nutrients in the bean, husk and berry relative to the accumulation of dry matter in the berry. Due to this consideration, Beira Rio 8, the genotype that exhibited the highest accumulation of dry matter in the fruit, stood out for also accumulating the largest quantity of nutrients throughout the phenophase of fruit maturation.

Nitrogen appeared to be the most accumulated nutrient by the bean during the maturation phase (Table 4). Despite the reduction in the concentration of N in the bean (Table 2), there was compensation through the accumulation of dry matter in the beans (Table 1), resulting in a continuous accumulation of N throughout maturation, reaching the highest values at 45 (Clementino and Beira Rio 8) and 47 WAF (Pirata, Bamburral, A1, and P1).

The second most accumulated nutrient by the beans was K, being minimally influenced by the maturation process; genotypes A1 and Clementino did not show significant differences in K accumulation throughout maturation. Ca was the third most accumulated nutrient by the beans, obtaining the highest values at 47 and 49 WAF, with the accumulation in fully matured fruits almost double that observed at 33 WAF when the fruits were still green. Among the macronutrients P, Mg, and S were the least accumulated by the beans throughout the maturation process.

The most accumulated micronutrients in the bean were Fe and B, which showed the highest values from 39 WAF when the visual maturation of fruits began for most genotypes. The late-maturing genotype P1 achieved the highest accumulation of Fe and B only at 47 and 45 WAF, respectively. Cu and Mn demonstrated similar accumulation scales with very close values. Zn stood out for its high accumulation rate for all genotypes between 35 and 39 WAF.

Table 5: Nutrients accumulation on beans of six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) of *Coffea canephora* collected from end of berry expansion to full maturation (33 to 49 Weeks After Flowering).

Time (WAF)	Genotype	Macronutrients (mg berry^{-1})						Micronutrients (µg berry^{-1})				
		N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn	B
33	Pirata	2.19 Cc	0.18 Cc	2.01 Cb	0.29 BCb	0.21 BCc	0.15 BCd	1.78 Bc	29.9 ABa	2.03 BCd	0.41 ABd	3.72 Bde
	Bamburral	3.32 ABd	0.25 BCc	2.61 BCb	0.37 ABc	0.28 ABb	0.21 ABde	2.79 Ac	28.3 ABcd	2.64 ABd	0.72 Ad	2.49 CDe
	A1	2.53 BCb	0.22 BCc	2.33 BCa	0.32 BCc	0.21 BCa	0.16 BCb	1.68 Bb	25.5 Bcd	2.04 BCc	0.42 ABd	1.26 Dc
	Clementino	3.03 Abc	0.29 ABb	2.96 Ba	0.34 Bc	0.28 ABab	0.17 BCde	2.91 Aa	23.4 Bd	2.41 Bd	0.57 ABe	3.42 BCbc
	Beira Rio 8	3.73 Ae	0.37 Ad	4.02 Aab	0.47 Af	0.35 Ad	0.25 Aef	2.65 Ad	36.3 Aef	3.25 Ad	0.81 Ad	7.00 Ade
	P1	2.53 Ce	0.19 Cd	2.12 BCde	0.20 Cf	0.19 Cc	0.13 Ce	1.83 Bc	14.8 Ce	1.51 Cd	0.25 Bc	2.20 CDb
35	Pirata	2.38 Cbc	0.22 CDbc	2.35 Cab	0.30 Cb	0.26 Cbc	0.18 CDcd	1.99 Bbc	19.1 BCb	2.20 Ccd	0.41 Ad	2.99 CDe
	Bamburral	3.74 ABcd	0.33 ABbc	3.47 ABab	0.44 ABbc	0.35 ABab	0.26 ABcd	3.32 Abc	26.5 ABd	3.23 ABcd	0.75 Ad	4.67 Bcd
	A1	2.79 BCab	0.24 CDbc	2.72 BCa	0.33 BCbc	0.25 Ca	0.21 BCab	2.27 Bab	21.3 BCd	2.27 Cbc	0.39 Ad	4.83 Ba
	Clementino	3.22 BCbc	0.30 BCb	2.70 BCa	0.36 BCbc	0.27 BCb	0.22 BCcd	2.68 ABa	23.8 BCcd	2.45 BCcd	0.60 Ae	3.86 BCbc
	Beira Rio 8	4.57 Ade	0.42 Acd	4.23 Aab	0.53 Aef	0.41 Acd	0.31 Ade	3.32 Acd	33.4 Af	3.49 Ad	0.71 Ad	7.23 Ade
	P1	2.59 Cde	0.20 Dcd	1.95 Ce	0.25 Cef	0.19 Cc	0.13 De	2.03 Bc	16.3 Cde	1.71 Cd	0.57 Ac	2.13 Db
37	Pirata	3.30 Bab	0.27 Bbc	2.83 Cab	0.47 Ba	0.33 BCab	0.16 Bd	2.54 Bab	28.2 Bab	2.72 Bbc	1.58 Bc	4.51 BCbc
	Bamburral	4.04 Bcd	0.32 Bbc	3.71 ABa	0.52 Bab	0.39 ABa	0.19 Be	3.14 ABc	38.7 Ab	3.04 Bcd	1.82 Bc	4.17 BCd
	A1	3.36 Bab	0.3 Bab	2.97 BCa	0.42 BCab	0.28 Ca	0.18 Bb	2.65 Ba	27.3 Bcd	2.42 Bbc	1.40 Bc	3.52 CDab
	Clementino	3.31 Bbc	0.31 Bb	2.75 Ca	0.42 BCbc	0.32 BCab	0.19 Bde	2.99 ABa	27.3 Bcd	2.70 Bbc	1.71 Bd	5.15 Ba
	Beira Rio 8	5.15 Abc	0.49 Abc	4.10 Aab	0.66 Ade	0.46 Abc	0.30 Ade	3.54 Abc	40.0 Ade	4.13 Acd	2.57 Ac	10.06 Aab
	P1	3.06 Bcd	0.27 Bbc	2.61 Cde	0.31 Cde	0.25 Cbc	0.19 Bde	2.65 Bbc	20.4 Bde	2.37 Bcd	1.38 B	2.96 Dab
39	Pirata	3.76 Ba	0.31 Bab	2.95 BCa	0.50 BCa	0.36 BCa	0.24 BCbc	2.77 Cab	30.1 BCa	3.33 BCab	2.04 Cab	5.35 BCab
	Bamburral	4.47 ABbc	0.37 Bb	3.95 Aa	0.60 ABa	0.42 ABa	0.31 ABcd	3.60 ABbc	35.7 Bbc	3.62 Bab	2.50 ABb	6.28 Bab
	A1	3.27 Cab	0.34 Ba	3.10 BCa	0.46 CDab	0.29 Ca	0.23 Cab	2.68 Ca	26.2 Ccd	2.60 Cbc	1.67 Cbc	4.75 CDa
	Clementino	3.50 BCbc	0.33 Bab	2.66 Ca	0.46 CDab	0.30 Cab	0.23 Ccd	2.78 Ca	28.5 BCcd	2.95 BCbc	2.07 BCcd	4.24 CDab
	Beira Rio 8	4.80 Acd	0.47 Aab	3.66 ABb	0.72 Acd	0.45 Abc	0.34 Acd	3.75 Abc	44.8 Acd	4.61 Abc	2.91 Abc	8.07 Acd
	P1	3.37 Cbc	0.30 Bab	2.51 Cde	0.36 Dcd	0.28 Cbc	0.21 Ccd	2.97 BCab	24.2 Ccd	2.79 BCbc	1.94 Cb	3.69 Da
41	Pirata	3.38 Bab	0.32 Ca	2.55 Bab	0.48 CDa	0.32 CDab	0.28 Bab	2.84 BCa	35.3 BCa	3.66 BCa	2.36 BCa	5.58 Cab
	Bamburral	5.04 Aab	0.42 Bab	3.92 Aa	0.60 Ba	0.40 Ba	0.32 Bab	4.38 Aa	40.5 ABb	4.24 Ba	2.62 Bb	6.99 Bab
	A1	3.41 Bab	0.28 Cbc	2.64 Ba	0.42 CDab	0.24 Da	0.26 Ba	2.28 Cab	27.6 CDcd	2.75 Dab	2.05 CDb	4.54 CDa
	Clementino	3.52 Bbc	0.36 BCab	2.98 Ba	0.49 BCa	0.34 BCab	0.27 Bbd	3.28 Ba	31.4 CDbc	3.57 BCab	2.18 CDbc	4.53 CDab

	Beira Rio 8	5.94 Aab	0.55 Aab	4.60 Aa	0.76 Abc	0.51 Aab	0.42 Ab	4.38 Aa	47.0 Acd	5.11 Ab	3.16 Ab	9.23 Abc
	P1	3.92 Bab	0.31 Cab	2.76 Bcd	0.37 Dcd	0.28 CDbc	0.26 Bbd	3.13 Bab	25.1 Dcd	2.96 CDbc	1.89 Da	3.20 Dab
43	**Pirata**	3.55 Ca	0.32 BCa	2.59 Bab	0.49 BCa	0.33 BCab	0.29 BCab	2.77 CDab	31.5 BCa	3.43 BCab	2.10 CDab	6.25 Ba
	Bamburral	4.63 Bbc	0.41 Bab	3.90 Aa	0.60 Ba	0.40 Ba	0.32 Bab	4.01 ABab	39.7 Bb	4.21 Ba	2.58 Bb	5.63 BCbc
	A1	3.61 Cab	0.31 Cab	2.36 Ba	0.44 Cab	0.25 Ca	0.23 Cab	2.13 Dab	30.1 Cbc	3.09 Cab	1.75 Dbc	4.41 CDa
	Clementino	4.06 BCbc	0.37 BCab	2.64 Ba	0.49 BCa	0.31 Cab	0.31 Bab	2.89 Ca	39.6 Bab	3.75 BCa	2.33 BCab	5.14 BCa
	Beira Rio 8	5.71 Abc	0.54 Aab	4.45 Aab	0.84 Aab	0.51 Aab	0.41 Abc	4.21 Aab	48.6 Acd	5.23 Aab	3.16 Ab	10.96 Aa
	P1	3.77 BCab	0.33 BCab	2.95 Bcd	0.46 Cbc	0.31 Cab	0.28 BCb	3.26 BCab	31.6 BCab	3.77 BCa	2.09 CDa	3.98 Da
45	**Pirata**	3.13 Dbc	0.30 Dab	2.45 Cab	0.46 Ca	0.29 BCab	0.25 Cab	2.22 DEbc	28.6 Ca	3.27 Cab	1.80 Cbc	5.47 Cab
	Bamburral	4.47 Cbc	0.48 Ba	3.62 ABa	0.60 Ba	0.38 Bab	0.34 Bab	3.57 ABab	39.5 Bb	4.36 Ba	2.57 Bb	7.14 Ba
	A1	3.40 Dab	0.33 CDab	2.35 Ca	0.42 Cab	0.24 Ca	0.27 Ca	1.92 Eab	39.7 Ba	3.05 Cab	1.66 Cbc	4.32 CDa
	Clementino	5.59 Ba	0.41 BCa	2.50 Ca	0.50 BCa	0.30 BCab	0.37 Ba	2.69 CDa	32.3 BCbc	3.74 BCa	1.97 Ccd	4.85 CDab
	Beira Rio 8	6.81 Aa	0.63 Aa	4.27 Aab	0.84 Aab	0.48 Abc	0.61 Aa	3.91 Aab	59.5 Aa	6.03 Aa	4.61 Aa	10.07 Aab
	P1	4.64 Bca	0.37 CDa	3.07 BCbc	0.43 Cbc	0.28 Cbc	0.37 Ba	2.99 BCab	31.8 BCab	3.71 BCa	1.97 Ca	4.03 Da
47	**Pirata**	4.09 Ba	0.32 Ba	2.55 Cab	0.50 Ba	0.32 BCab	0.31 ABa	2.10 Cbc	31.8 Ca	3.54 BCab	1.92 Cbc	5.18 BCbc
	Bamburral	5.86 Aa	0.41 Bab	3.63 Ba	0.60 Ba	0.37 Bab	0.36 Aa	3.15 Bc	37.1 Cbc	4.36 ABa	2.47 Bb	5.90 ABbc
	A1	3.64 Ba	0.33 Bab	2.52 Ca	0.50 Ba	0.25 Ca	0.26 BCa	2.17 Cab	38.5 BCab	3.37 Ca	2.55 Ba	3.73 DEa
	Clementino	4.26 Bb	0.34 Bab	3.02 BCa	0.55 Ba	0.38 Ba	0.14 De	3.09 Ba	46.1 Ba	3.35 Cab	2.56 Bab	4.04 CDbc
	Beira Rio 8	5.95 Aab	0.51 Abc	4.58 Aab	0.86 Aab	0.53 Aab	0.21 CDf	4.01 Aab	55.8 Aab	4.48 Abc	3.24 Ab	6.59 Ae
	P1	4.14 Bab	0.35 Bab	3.63 Ba	0.53 Ba	0.35 Ba	0.14 Dde	3.23 Bab	38.8 BCa	3.47 Cab	1.73 Cab	2.62 Eab
49	**Pirata**	3.38 Bab	0.31 Bab	2.91 BCab	0.54 Ba	0.37 BCa	0.24 Cbc	2.66 Bab	34.0 Ba	3.04 Cbc	2.19 Cab	3.99 BCde
	Bamburral	4.34 ABcd	0.37 Bb	3.82 Aa	0.63 Ba	0.41 Ba	0.27 BCcd	3.52 Aab	49.8 Aa	3.98 Bab	3.93 Aa	4.79 Bcd
	A1	3.43 Bab	0.32 Bab	2.67 Ca	0.51 Ba	0.30 Ca	0.17 Db	2.40 Bab	32.5 Bbc	2.82 Cab	2.10 Cab	2.16 Dbc
	Clementino	3.74 Bbc	0.34 Bab	2.80 BCa	0.51 Ba	0.37 BCa	0.22 CDcd	2.60 Ba	33.0 Bbc	3.12 Cab	2.73 Ba	3.06 CDc
	Beira Rio 8	5.26 Abc	0.53 Aab	4.15 Aab	0.90 Aa	0.55 Aa	0.43 Ab	4.21 Aab	53.9 Aab	4.95 Abc	4.21 Aa	7.91 Acd
	P1	4.30 ABab	0.36 Bab	3.54 ABab	0.50 Bab	0.36 BCa	0.31 Bab	3.64 Aa	33.8 Bab	3.51 BCab	1.79 Cab	2.72 CDab
	CV (%)	13.9	14.2	15.7	13.9	14.2	14.2	14.1	13.9	13.7	12.7	15.1

Upper-case letters compare genotype effect inside each time (WAF), whilst lower-case letters compare time effect for each genotype by Tukey's test at 5% of probability.

When comparing the accumulation of nutrients per berry on husk (Table 4) with beans (Table 5), notable differences were observed. K stood out as the most accumulated nutrient in the husk (Table 4). Consistently, the highest values of K accumulation were recorded in the genotype Beira Rio 8 throughout all evaluated periods. Due to its late maturation cycle, the genotype P1 exhibited the lowest accumulation of K among the genotypes, particularly from 41 WAF onward.

The second most accumulated nutrient throughout the maturation process in the husk was N. The dynamics of N accumulation showed a growing trend over the period, with the notable exception between 43 and 45 WAF, when a slight reduction in N content in the husk was observed. This temporary decrease was followed by a subsequent increase in the two following collections. This fluctuation in nitrogen content in the husk highlights the complexity of interactions during specific phases of maturation.

The third nutrient with the highest accumulation in the husk was Ca. Notably, this nutrient exhibited little variation in its content throughout the maturation process, with the most expressive values occurring from 41 WAF, except for the genotype Pirata, which showed the highest value only 33 WAF. A similar pattern was observed for P, where the lowest values for its content in the husk were observed at the beginning of the maturation period, and a more prominent increase occurred from 41 WAF onward. Therefore, the highest values were observed at 45 WAF (A1, Clementino, and Beira Rio 8) and 49 WAF (Pirata, Bamburral, and P1).

The macronutrients Mg and S exhibited values and patterns of behavior remarkably similar to each other, as well as with P. No clearly established accumulation trend was observed. Throughout the maturation process, the content values of Mg and S in the husk showed no significant variations despite being statistically significant. This stability suggests a consistent response of these nutrients to maturation, with minimal changes over the evaluated period.

The genotype Beira Rio 8 demonstrated the highest values for nutrient accumulation in practically all maturation phases. Considering that this was also the behavior for beans, we can infer that this genotype is the one that accumulates the most nutrients in the fruit. Genotype Pirata stood out for presenting the highest values for Fe, Mn, Zn, and B at 33 WAF, as well as for Ca and Mg, while the other genotypes showed much lower values in the same phase of maturation.

Among the micronutrients, Fe stood out for having significantly higher accumulation than the others, similar to what occurred with beans, with the highest values observed after 41 WAF, except for the genotype Pirata. Expressive values of B in the husk were also observed, mainly from 39 WAF. The other micronutrients (Cu, Mn and Zn) showed lower accumulation values in the husk and less variation throughout the maturation phenophase when compared to Fe and B.

Table 6: Nutrients accumulation on husks of six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) of *Coffea canephora* collected from end of berry expansion to full maturation (33 to 49 Weeks After Flowering).

Time (WAF)	Genotype	Macronutrients (mg berry^{-1})						Micronutrients (µg berry^{-1})				
		N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn	B
33	Pirata	1.09 Bbc	0.20 Bc	1.74 Bc	0.75 Aa	0.27 Aa	0.22 Abc	1.16 ABde	64.7 Aa	3.82 Aa	1.35 Aa	6.95 Aa
	Bamburral	0.97 BCef	0.16 Cb	2.13 ABd	0.38 Cb	0.09 Dde	0.16 Bd	0.97 ABd	37.7 Cbc	1.31 Dde	0.70 Bbc	2.28 Dde
	A1	0.98 BCb	0.16 BCd	2.05 Be	0.50 Bd	0.18 BCb	0.16 Bd	0.93 Bd	38.0 Cbc	1.69 CDd	0.55 BCd	2.42 Dc
	Clementino	0.83 Ccd	0.25 Ade	1.80 Bd	0.37 Ce	0.16 Cd	0.18 Bc	1.08 ABe	33.9 CDd	1.90 Cd	0.46 CDd	3.67 Ce
	Beira Rio 8	1.52 Acd	0.17 BCb	2.68 Ad	0.71 Ad	0.19 Bde	0.25 Ae	1.23 Acd	55.9 Bd	2.50 Bb	0.65 Bde	5.34 Bd
	P1	0.78 Cbc	0.15 Cc	2.00 Bcd	0.38 Cbc	0.09 Dab	0.15 Bb	1.10 ABbc	28.1 Dc	1.64 CDcd	0.39 Dc	2.30 Da
35	Pirata	0.80 Bd	0.19 BCc	1.96 Dc	0.47 Cc	0.15 Ce	0.19 BCc	1.06 Be	29.2 BCe	1.76 Be	0.58 Ccd	3.49 BCe
	Bamburral	0.90 Bf	0.15 Cb	2.58 BCd	0.48 Cb	0.07 Ee	0.17 Ccd	0.66 Ce	25.1 Cd	1.21 Ce	0.53 Cd	2.08 De
	A1	1.00 Bb	0.21 ABbc	3.07 Bcd	0.66 Bc	0.21 Ab	0.22 Bbc	1.25 ABc	35.3 Bc	1.98 Bcd	0.93 Bc	4.02 Bb
	Clementino	0.80 Bcd	0.24 Ae	2.26 CDcd	0.42 Cde	0.17 BCd	0.19 BCbc	1.12 Bde	35.3 Bcd	1.76 Bd	0.59 Ccd	4.01 Bde
	Beira Rio 8	1.51 Acd	0.21 ABb	3.77 Ac	0.79 Acd	0.20 ABd	0.29 Acd	1.42 Ac	65.2 Ac	2.52 Ab	1.70 Ab	7.97 Ac
	P1	0.99 Bab	0.16 Cc	1.66 Dd	0.43 Cbc	0.11 Da	0.15 Cab	1.18 ABbc	37.3 Bab	2.12 Bab	0.95 Ba	3.14 Ca
37	Pirata	0.73 Cd	0.20 ABc	2.37 Bc	0.54 BCc	0.14 Ae	0.22 Bbc	0.86 BCe	36.7 Bcd	1.72 BCe	0.79 Cb	4.39 Bde
	Bamburral	0.96 Bef	0.15 Cb	2.05 Bd	0.43 CDb	0.09 Bde	0.16 Ccd	0.76 BCde	27.5 Cd	1.41 Cde	0.60 Ecd	2.99 CDcd
	A1	0.96 Bb	0.16 BCd	2.25 Be	0.58 Bcd	0.15 Ac	0.18 Ccd	0.75 Cd	45.3 Ab	1.87 BCd	2.28 Ab	3.79 BCb
	Clementino	0.70 Cd	0.23 Ae	2.21 Bcd	0.41 De	0.15 Ad	0.17 Cc	0.99 ABe	35.0 BCcd	1.72 BCd	0.79 Cab	3.64 BCe
	Beira Rio 8	1.40 Ad	0.20 ABb	4.09 Abc	0.84 Ac	0.16 Ae	0.30 Abc	1.05 Ad	48.8 Ad	2.47 Ab	1.00 Bc	8.19 Ac
	P1	0.83 BCbc	0.23 Aab	2.22 Bcd	0.34 Dc	0.05 Ccd	0.18 Cab	1.03 ABbc	30.1 BCbc	1.73 BCbc	0.63 DEb	2.56 Da
39	Pirata	0.90 CDcd	0.22 Abc	3.16 Bb	0.74 Ba	0.18 Bd	0.26 Aab	0.97 ABe	33.7 Cde	1.95 BCde	0.58 Bcd	6.25 Bab
	Bamburral	1.07 Bde	0.13 Cb	3.24 Bc	0.63 BCa	0.08 De	0.17 BCcd	0.73 BCde	28.8 Ccd	1.28 Dde	0.59 Bcd	2.73 Dcd
	A1	0.86 CDb	0.18 ABcd	2.45 Cde	0.54 Ccd	0.13 Cc	0.21 Bbc	0.67 Cd	43.7 Bbc	1.68 Cd	1.03 Ac	3.92 Cb
	Clementino	0.78 Dd	0.22 Ae	2.54 Cc	0.54 Ccd	0.17 Bd	0.16 Cc	1.04 Ae	34.2 Cd	1.97 BCd	0.71 Bbc	6.49 Ba
	Beira Rio 8	1.45 Ad	0.21 ABb	4.67 Ab	1.22 Aa	0.23 Ac	0.28 Acd	1.20 Acd	54.6 Ad	2.62 Ab	1.00 Ac	10.46 Aa
	P1	1.04 BCa	0.17 Bc	2.25 Ccd	0.57 Ca	0.08 Dab	0.16 Cab	1.08 Abc	35.0 Cab	2.21 Ba	0.59 Bb	2.85 Da
41	Pirata	0.93 Cbc	0.26 BCab	3.34 Bab	0.60 Cbc	0.18 ABd	0.26 Bab	1.42 Bbc	48.8 Cb	1.96 Cde	0.77 Cb	6.85 Ba
	Bamburral	1.32 Bbc	0.22 Ca	3.45 Bc	0.70 BCa	0.12 Ccd	0.27 Ba	1.48 Bc	71.8 Ba	2.25 BCa	2.17 Ba	3.53 Ebc
	A1	1.24 Ba	0.27 Ba	3.51 Bbc	0.81 Bb	0.21 Ab	0.24 Bab	1.38 Bab	43.5 Cbc	2.07 Ccd	0.89 Cc	4.57 Dab
	Clementino	1.57 Aa	0.26 BCcd	3.71 Bb	0.74 Ba	0.21 Ac	0.27 Ba	1.39 Bd	43.5 Cbc	2.48 Bc	0.93 Ca	5.77 Cab

	Beira Rio 8	1.69 Abc	0.33 Aa	6.00 Aa	1.08 Ab	0.17 Bde	0.42 Aa	2.08 Ab	93.7 Aa	3.59 Aa	2.53 Aa	11.03 Aa
	P1	0.90 Cab	0.17 Dc	2.39 Cbc	0.33 Dc	0.04 Dd	0.17 Cab	0.90 Cc	27.3 Dc	1.32 Dd	0.61 Db	2.30 Fa
43	**Pirata**	1.47 Ba	0.28 Ba	3.81 Ca	0.68 Bab	0.20 Bcd	0.28 Aa	1.73 Ba	40.9 Bbc	2.10 Bcd	0.62 CDbc	6.19 Bab
	Bamburral	1.26 Ccd	0.23 Ca	4.54 Ba	0.62 Ba	0.13 Cbc	0.26 Aa	1.60 Bbc	37.5 Bbc	1.68 Ccd	0.77 BCb	3.93 Da
	A1	1.25 Ca	0.20 CDbc	3.39 Cc	0.96 Aa	0.20 Bb	0.28 Aa	1.24 Cc	60.2 Aa	2.72 Aa	2.89 Aa	4.52 CDab
	Clementino	1.12 Cb	0.29 Bcd	3.44 Cb	0.71 Ba	0.25 Ab	0.17 Bc	1.74 Bc	44.8 Bb	2.51 Abc	0.87 Bab	5.09 Cbc
	Beira Rio 8	1.82 Ab	0.33 Aa	5.49 Aa	1.06 Ab	0.26 Abc	0.25 Ade	2.25 Ac	67.9 Ac	2.84 Ab	0.56 De	9.37 Ab
	P1	0.75 Dc	0.19 Dbc	2.73 Dab	0.43 Cbc	0.06 Dcd	0.10 Cc	1.08 Cbc	28.3 Cbc	1.42 Cd	0.26 Ec	2.48 Ea
45	**Pirata**	0.92 CDbc	0.26 BCab	3.50 Cab	0.76 Ba	0.24 Bab	0.22 Bbc	1.37 CDcd	42.9 Cbc	2.24 Ccd	0.37 CDe	5.68 Bbc
	Bamburral	1.13 Bde	0.24 Ca	3.76 Cbc	0.68 BCa	0.16 Cab	0.20 Ba	1.61 Cbc	37.8 Cbc	1.59 Dcd	0.30 De	1.98 De
	A1	1.08 BCab	0.28 Ba	4.38 Ba	0.59 Cbc	0.21 Bb	0.21 Bbc	1.54 Cbc	55.5 Ba	2.22 Cbc	0.52 BCd	3.78 Cb
	Clementino	1.02 BCbc	0.40 Aa	4.38 Ba	0.79 Ba	0.32 Aa	0.23 Bbc	2.59 Ba	56.9 Ba	3.11 Ba	0.54 Bd	5.71 Bab
	Beira Rio 8	1.71 Abc	0.36 Aa	5.91 Aa	1.04 Ab	0.30 Aa	0.34 Ab	2.89 Aa	79.5 Ab	3.59 Aa	0.75 Ad	9.30 Ab
	P1	0.74 Dc	0.19 Dbc	2.54 Dbc	0.40 Dbc	0.05 Dcd	0.15 Cab	1.19 Dbc	28.8 Cbc	1.58 Dd	0.25 Dc	2.34 Da
47	**Pirata**	1.04 Cab	0.26 BCab	3.89 Ba	0.76 Ba	0.22 Bbc	0.26 Bab	1.63 Bab	46.7 Cb	2.40 Cbc	0.42 CDde	5.54 Bbc
	Bamburral	1.49 Bab	0.22 CDa	3.56 Bbc	0.72 Ba	0.17 Ca	0.20 Cbc	1.81 Bab	41.3 Cb	2.05 CDab	0.36 De	3.72 Cab
	A1	0.94 Cb	0.27 Ba	4.15 Bab	0.81 Bb	0.26 Aa	0.24 BCab	1.88 Ba	64.4 Ba	2.92 Ba	0.53 BCd	4.94 Ba
	Clementino	1.12 Cb	0.35 Ab	3.59 Bb	0.58 Cbc	0.26 Ab	0.25 Ba	2.17 Ab	44.9 Cb	2.97 Ba	0.51 BCd	3.69 Ce
	Beira Rio 8	2.19 Aa	0.32 Aa	5.92 Aa	0.99 Ab	0.26 Abc	0.30 Abc	2.29 Ab	83.0 Ab	3.48 Aa	0.69 Ade	7.76 Ac
	P1	1.04 Ca	0.19 Dbc	2.51 Cbc	0.46 Cab	0.08 Dab	0.16 Dab	1.32 Cb	38.4 Ca	1.74 Dbc	0.59 ABb	2.39 Da
49	**Pirata**	1.15 Cb	0.30 Ba	3.52 Cab	0.68 Bab	0.22 Bbc	0.21 BCc	1.71 Cab	44.1 CDbc	2.73 Bb	0.34 Cde	4.92 Bcd
	Bamburral	1.61 Ba	0.26 BCa	4.13 Bab	0.64 Ba	0.18 Ca	0.24 Bab	2.04 Ba	38.8 Db	1.98 Cab	0.55 ABcd	3.75 Cab
	A1	1.24 Ca	0.25 Cab	3.48 Cc	0.66 Bc	0.21 Bb	0.23 BCb	1.57 Cb	63.5 Ba	2.61 Bab	0.53 ABd	4.16 BCab
	Clementino	1.18 Cb	0.30 Bc	3.22 Cb	0.67 Bab	0.28 Ab	0.23 BCbc	2.18 Bb	48.1 Cab	2.92 Bab	0.47 BCd	4.64 Bcd
	Beira Rio 8	2.23 Aa	0.36 Aa	5.95 Aa	1.03 Ab	0.29 Aab	0.33 Abc	3.14 Aa	80.4 Ab	3.87 Aa	0.68 Ade	8.17 Ac
	P1	1.05 Ca	0.24 Ca	3.13 Ca	0.46 Cab	0.10 Da	0.19 Ca	1.69 Ca	37.3 Cab	2.06 Cab	0.28 Dc	2.66 Da
	CV(%)	10.0	10.1	10.0	9.9	10.3	9.7	10.6	10.0	9.8	11.1	9.7

Upper-case letters compare genotype effect inside each time, whilst lower-case letters compare time effect for each genotype by Tukey's test at 5% of probability.

Summing up the accumulation of nutrients in the bean and husk per fruit, we conducted a comprehensive assessment of accumulation, considering the fruit as a whole (Table 6). This approach provided a more comprehensive analysis, offering insights into the total contribution needed from the plant for the complete development of the fruit. In this context, it becomes evident that, overall, there was a progressive increase in nutrient accumulation throughout the maturation process.

The macronutrients K and N stood out as the most accumulated in the fruits, both exhibiting a growing pattern of accumulation throughout development. Notably, K showed accumulation rates higher than those of N, highlighting a more pronounced difference in the accumulated quantity between these two nutrients in the later stages of the experimental period compared to the beginning. This observed discrepancy can be attributed, in part, to the higher concentration of N in the beans and K in the husk (Table 2 and 3). Genotypes that displayed a higher proportion of husk in the fruits consequently showed a more significant accumulation of K compared to N.

Although the accumulation of P did not show individually in the bean and husk a marked growth trend, the analysis of the fruit as a whole revealed a noticeable increasing accumulation throughout maturation, reaching the highest values at the end of the cycle. In contrast, the accumulation of Ca and Mg exhibited a growth trend until the 41st WAF, followed by stabilization until the end of the evaluation period.

In general, the accumulation of micronutrients in the fruit increased gradually until the end of maturation for all genotypes. The exception was B, which showed an increase in the initial phase of maturation, reaching the peak of accumulation around 43 WAF, followed by a decline until the last week.

Table 7: Nutrients accumulation on berries of six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) of *Coffea canephora* collected from end of berry expansion to full maturation (33 to 49 Weeks After Flowering).

Time (WAF)	Genotype	Macronutrients (mg berry^{-1})						Micronutrients (µg berry^{-1})				
		N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn	B
33	Pirata	3.28 BCb	0.38 Bc	3.75 Bc	1.04 Aab	0.48 ABbc	0.37 Bd	2.93 BCc	94.7 Aa	5.85 Aa	1.77 Ac	10.7 Aab
	Bamburral	4.30 ABe	0.41 Bb	4.73 Bd	0.75 BCb	0.38 CDc	0.37 Bd	3.76 ABc	66.0 Bcd	3.96 BCc	1.42 ABd	4.77 Cd
	A1	3.51 BCb	0.38 Bc	4.38 Bc	0.83 Be	0.39 BCb	0.31 BCd	2.61 Cb	63.48 Bbc	3.74 BCd	0.97 BCe	3.69 Cc
	Clementino	3.86 BCd	0.54 Acd	4.76 Bc	0.71 BCd	0.44 ABCc	0.35 BCe	3.99 Abc	57.3 Bd	4.32 Bc	1.03 BCc	7.09 Bb
	Beira Rio 8	5.25 Ad	0.54 Ad	6.70 Ac	1.18 Ac	0.54 Ae	0.50 Ae	3.88 Ad	92.2 Ac	5.75 Ae	1.46 ABe	12.3 Ad
	P1	2.86 Cd	0.34 Bc	4.13 Bde	0.57 Cd	0.28 Dc	0.27 Cf	2.93 BCd	43.0 Cd	3.15 Ce	0.64 Cc	3.49 Cb
35	Pirata	3.18 Cb	0.40 CDc	4.31 CDbc	0.78 CDc	0.41 Bc	0.36 BCd	3.06 Cc	48.27 Bd	3.96 Bc	0.99 Cd	6.48 CDc
	Bamburral	4.65 Bde	0.48 BCb	6.05 Bbc	0.92 BCb	0.42 Bbc	0.43 Bcd	3.99 ABc	51.6 Bd	4.43 Bc	1.28 BCd	6.75 CDcd
	A1	3.79 BCab	0.45 BCDbc	5.79 Bab	0.99 Bde	0.46 Bab	0.43 Babc	3.51 BCab	53.5 Bc	4.24 Bcd	1.33 BCe	8.85 Ba
	Clementino	4.03 BCcd	0.54 ABd	4.96 BCbc	0.78 CDcd	0.44 Bc	0.42 Bcde	3.79 BCc	59.1 Bd	4.21 Bc	1.19 BCc	7.87 BCb
	Beira Rio 8	6.07 Acd	0.62 Acd	8.00 Ab	1.32 Abc	0.60 Ade	0.60 Acd	4.74 Acd	98.6 Ac	6.01 Ae	2.41 Ad	15.2 Ac
	P1	3.59 BCcd	0.36 Dbc	3.61 De	0.67 Dbcd	0.29 Cc	0.29 Cef	3.20 BCcd	53.5 Bcd	3.82 Bde	1.51 Bb	5.27 Dab
37	Pirata	4.03 BCab	0.48 Bbc	5.20 Bab	1.00 Bb	0.47 Bbc	0.39 Bcd	3.40 Bbc	64.9 Bc	4.44 Bbc	2.37 Bb	8.90 Bb
	Bamburral	5.00 Bcde	0.47 Bb	5.77 Bcd	0.95 Bb	0.48 Babc	0.36 Bd	3.89 Abc	66.1 Bcd	4.45 Bc	2.43 Bc	7.16 BCbc
	A1	4.33 BCab	0.47 Bbc	5.21 Bbc	1.00 Bde	0.42 Bab	0.36 Bcd	3.40 Bab	72.6 Bb	4.29 Bcd	3.69 Ab	7.31 BCab
	Clementino	4.00 BCcd	0.54 Bd	4.97 Bbc	0.84 BCcd	0.47 Bbc	0.36 Bde	3.98 ABbc	62.3 BCcd	4.42 Bc	2.50 Bb	8.79 Bab
	Beira Rio 8	6.55 Abc	0.69 Ac	8.18 Ab	1.50 Ab	0.62 Ade	0.60 Acd	4.59 Acd	88.8 Ac	6.60 Ade	2.57 Ac	18.3 Ab
	P1	3.89 Cbcd	0.49 Aa	4.84 Bcde	0.64 Ccd	0.30 Cc	0.37 Bcde	3.68 Bbcd	50.5 Ccd	4.10 Bcde	2.01 Bab	5.52 Cab
39	Pirata	4.66 BCa	0.53 Bab	6.10 BCa	1.24 Ba	0.54 Bab	0.50 Bab	3.74 BCabc	63.8 Bc	5.28 Bab	2.62 BCab	11.6 Ba
	Bamburral	5.54 ABbcd	0.51 Bb	7.20 ABab	1.23 Ba	0.50 BCab	0.48 BCbc	3.34 ABbc	64.4 Bcd	4.91 Bbc	3.09 Bb	9.02 CDab
	A1	4.12 Cab	0.52 Bab	5.55 CDabc	1.00 Cde	0.42 CDab	0.43 BCDabc	3.35 Cab	69.9 Bbc	4.28 Bcd	2.70 BCcd	8.68 Da
	Clementino	4.28 Cbcd	0.55 Bcd	5.20 CDbc	1.00 Cbc	0.47 BCbc	0.39 CDcde	3.83 BCc	62.7 Bcd	4.93 Bbc	2.78 BCab	10.7 BCa
	Beira Rio 8	6.25 Acd	0.68 Ac	8.33 Ab	1.94 Aa	0.69 Abcd	0.63 Ac	4.96 Ac	99.3 Ac	7.23 Acd	3.91 Ac	18.5 Aab
	P1	4.41 Cabc	0.48 Bab	4.76 Dcde	0.93 Ca	0.35 Dabc	0.36 Dcde	4.05 BCbc	59.2 Bbc	5.00 Babc	2.53 Ca	6.54 Ea
41	Pirata	4.31 Cab	0.58 BCab	5.89 CDa	1.07 Cab	0.50 Babc	0.54 Bab	4.25 BCab	84.0 Cab	5.62 BCa	3.14 Ca	12.4 Ba
	Bamburral	6.37 Bab	0.64 Ba	7.36 Ba	1.30 Ba	0.53 Bab	0.59 Ba	5.87 Aa	112 Ba	6.50 Ba	4.80 Ba	10.5 Ca
	A1	4.64 Cab	0.56 BCab	6.15 CDab	1.22 BCabc	0.45 Bab	0.51 BCa	3.66 Ca	71.1 Cbc	4.83 CDbcd	2.95 CDc	9.12 Ca
	Clementino	5.09 Cbc	0.63 Bbcd	6.69 BCa	1.23 BCa	0.55 Babc	0.54 Bab	4.67 Babc	74.8 Cbc	6.05 Bab	3.11 Ca	10.3 Ca

	Beira Rio 8	7.63 Aab	0.88 Aab	10.6 Aa	1.84 Aa	0.68 Acd	0.83 Ab	6.46 Aab	141 Aa	8.70 Aab	5.68 Aa	20.3 Aa
	P1	4.82 Cab	0.45 Cab	5.15 Dbcd	0.70 Dbcd	0.32 Cbc	0.43 Cbc	4.04 BCbc	52.3 Dcd	4.28 Dbcd	2.50 Da	5.50 Dab
43	**Pirata**	5.02 BCa	0.60 BCab	6.41 Ca	1.17 Cab	0.53 BCab	0.57 Ba	4.50 Ba	72.4 CDbc	5.53 BCab	2.73 DEab	12.4 Ba
	Bamburral	5.89 Bbc	0.63 Ba	8.43 Ba	1.22 BCa	0.53 BCab	0.59 ABa	5.62 Aa	77.2 BCbc	5.89 BCab	3.36 BCb	9.56 Ca
	A1	4.86 BCa	0.50 Cabc	5.76 Cab	1.40 Ba	0.46 CDab	0.50 BCa	3.37 Cab	90.4 Ba	5.81 BCab	4.64 Aa	8.92 Ca
	Clementino	5.18 BCbc	0.66 Bbc	6.08 Cab	1.20 Cab	0.56 Bab	0.47 CDbc	4.63 Babc	84.4 BCab	6.26 Ba	3.19 Cda	10.2 Ca
	Beira Rio 8	7.53 Aab	0.87 Ab	9.93 Aa	1.90 Aa	0.77 Aabc	0.66 Ac	6.45 Aab	116 Ab	8.07 Abc	3.73 Bc	20.3 Aa
	P1	4.51 Cabc	0.52 Ca	5.68 Cabc	0.89 Dab	0.37 Dabc	0.39 Dcd	4.34 Bb	59.9 Dbc	5.19 Cabc	2.35 Ea	6.46 Dab
45	**Pirata**	4.05 Eab	0.56 Dab	5.95 CDa	1.21 BCab	0.53 BCab	0.47 Cbc	3.59 Cabc	71.6 DEbc	5.51 Cab	2.17 Cbc	11.2 Ba
	Bamburral	5.60 BCbcd	0.72 BCa	7.37 Ba	1.27 Ba	0.53 BCab	0.53 BCab	5.18 Bab	77.3 CDbc	5.95 BCab	2.87 Bbc	9.12 CDab
	A1	4.48 DEab	0.61 CDa	6.73 BCDa	1.02 CDcde	0.46 Cab	0.48 Cab	3.45 Cab	95.2 Ba	5.27 Cabc	2.17 Cd	8.10 DEab
	Clementino	6.61 Ba	0.82 Ba	6.87 BCa	1.29 Ba	0.62 Ba	0.61 Ba	5.28 Ba	89.3 BCab	6.85 Ba	2.51 BCb	10.6 BCa
	Beira Rio 8	8.52 Aa	0.99 Aa	10.2 Aa	1.89 Aa	0.78 Aabc	0.95 Aa	6.80 Aab	139 Aa	9.62 Aa	5.36 Aab	19.4 Aab
	P1	5.38 CDa	0.55 Da	5.61 Dabc	0.83 Dabc	0.33 Dbc	0.53 BCa	4.18 Cb	60.6 Ebc	5.30 Cab	2.22 Ca	6.37 Eab
47	**Pirata**	5.13 Ba	0.59 BCab	6.44 Ba	1.26 Ba	0.54 BCab	0.57 Aa	3.73 Cabc	78.5 CDbc	5.94 BCa	2.34 Cb	10.7 Bab
	Bamburral	7.35 Aa	0.63 BCa	7.19 Bab	1.33 Ba	0.54 BCa	0.57 Aab	4.95 Bab	78.4 CDbc	6.41 Ba	2.82 BCbc	9.62 BCa
	A1	4.56 Bab	0.60 Bca	6.66 Ba	1.30 Bab	0.51 CDa	0.50 Aa	4.05 Ca	103 Ba	6.30 Ba	3.08 Bc	8.67 CDa
	Clementino	5.28 Bb	0.70 Bab	6.62 Ba	1.14 BCab	0.64 Ba	0.39 Bcde	5.26 Ba	91.0 BCa	6.32 Ba	3.08 Ba	7.73 Db
	Beira Rio 8	8.14 Aa	0.84 Ab	10.5 Aa	1.86 Aa	0.79 Aab	0.51 Ade	6.31 Ab	139 Aa	7.96 Abc	3.93 Ac	14.3 Ac
	P1	5.18 Ba	0.54 Ca	6.14 Bab	1.00 Ca	0.43 Dab	0.30 Cdef	4.54 BCab	77.2 Da	5.21 Cabc	2.32 Ca	5.01 Eab
49	**Pirata**	4.53 Ca	0.60 Ba	6.43 Ca	1.21 Bab	0.60 BCa	0.45 BCbcd	4.37 Ca	78.1 CDbc	5.78 Ba	2.53 CDb	8.91 Bb
	Bamburral	5.94 Bbc	0.64 Ba	7.95 Ba	1.27 Ba	0.59 BCa	0.51 Babc	5.56 Ba	88.6 BCb	5.96 Bab	4.49 Aa	8.64 Babc
	A1	4.67 Cab	0.56 Bab	6.15 Cab	1.17 Bbcd	0.51 CDa	0.40 Cbcd	3.98 Ca	96.1 Ba	5.44 Bab	2.63 Ccd	6.32 CDb
	Clementino	4.93 BCbcd	0.64 Bbcd	6.02 Cabc	1.18 Bab	0.65 Ba	0.45 BCbcd	4.79 BCab	81.1 CDab	6.04 Bab	3.20 Ba	7.70 BCb
	Beira Rio 8	7.50 Aab	0.89 Aab	10.1 Aa	1.94 Aa	0.84 Aa	0.76 Ab	7.36 Aa	134 Aa	8.82 Aab	4.88 Ab	16.1 Ac
	P1	5.35 BCa	0.59 Ba	6.67 Ca	0.96 Ca	0.45 Da	0.50 Bab	5.33 Ba	71.1 Dab	5.58 Ba	2.07 Da	5.39 Dab
CV(%)		11.7	10.5	10.2	9.50	10.9	10.0	11.0	9.52	10.2	10.4	10.4

Upper-case letters compare genotype effect inside each time (WAF), whilst lower-case letters compare time effect for each genotype by Tukey's test at 5% of probability.

When analysing the accumulation of nutrients in beans considering the production of 1000 kg of beans at 49 WAF (Table 7), it is possible to determine the quantity of nutrients provided by the beans at each evaluated moment, considering a production of 1000 kg of beans at 49 WAF. Within this analysis, it was possible to identify a unique behavior for each genotype, primarily influenced by the accumulation of dry matter in beans of each one. However, some genotypes did not show significant differences in the accumulation of certain nutrients. Genotype Bamburral and Clementino did not demonstrate significant differences in the accumulation of Cu, genotype A1 for Mn, and P1 for Cu and B

Nitrogen was the most accumulated nutrient in the beans considering 1000 kg of beans at 49 WAF, and its accumulation increased with the progression of maturation. The Pirata genotype had a more pronounced accumulation rate at the beginning of the maturation phenophase, reaching the peak accumulation at 39 WAF, while the Bamburral, Clementino, Beira Rio 8, and P1 genotypes showed a continuous increase until 45 and 47 WAF. These accumulation rates were similar to what was observed for the accumulation of dry matter in the bean (Table 1).

The accumulation of K reached its maximum values earlier when compared to N, with the exception of genotype P1. An increase in K was observed in the beans of Pirata, Bamburral, and A1 genotypes up to 37 and 39 WAF, and for Beira Rio 8 up to 41 WAF, followed by a slight reduction until the last evaluation. The genotype P1 increased the K content until 47 WAF when they reached the highest observed value.

Overall, the accumulations of Ca, Mg, and S were similar. In general, the genotypes showed an increase until the mid-maturation phase with a slight reduction towards the end. The micronutrient Zn stood out for its significant increase in the bean between 35 and 39 WAF, a behaviour influenced by the rise in the concentration of this nutrient in bean (Table 2).

Table 8: Nutrients accumulation on beans standardized to 1000 kg of dry beans collected at 49 WAF of six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) of *Coffea canephora* collected from end of berry expansion to full maturation (33 to 49 Weeks After Flowering).

Time (WAF)	Genotype	Macronutrients (kg)						Micronutrients (g)				
		N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn	B
33	Pirata	17.2 BCc	1.41 Cc	15.8 Ccd	2.29 Ade	1.63 Ce	1.14 ABb	14.0 Bab	236 Aa	16.0 Ade	3.26 Ac	29.2 BCab
	Bamburral	21.8 ABcd	1.64 BCd	17.1 BCd	2.39 Abc	1.86 BCd	1.36 Aab	18.3 ABa	186 Aab	17.4 Ab	4.71 Ac	24.2 CDbcd
	A1	22.1 ABb	1.91 ABc	20.3 ABbcd	2.82 Acd	1.88 BCbcd	1.37 Aab	14.7 Bab	222 Aab	17.8 Aa	3.64 Ab	39.3 ABa
	Clementino	24.1 Abc	2.32 Aab	23.5 Aa	2.69 Abc	2.24 Aab	1.34 Acd	23.1 Aa	186 Abc	19.2 Ade	4.53 Ab	27.2 BCab
	Beira Rio 8	21.6 ABd	2.11 Ab	23.3 Aab	2.71 Ae	2.03 ABd	1.47 Acd	15.3 ABb	210 Ab	18.8 Ae	4.66 Ad	40.5 Abc
	P1	14.0 Cd	1.27 Cc	14.3 Cc	1.30 Bd	1.27 De	0.87 Bd	12.3 Ba	99.9 Ac	10.2 Bd	1.70 Ac	14.8 Da
35	Pirata	16.3 Cc	1.47 Cc	16.1 CDcd	2.09 BCe	1.78 BCde	1.19 BCb	13.6 Aab	131 Ab	15.0 BCe	2.77 Ac	20.4 Bb
	Bamburral	20.3 BCd	1.79 BCcd	18.8 BCcd	2.37 BCc	1.90 Bcd	1.40 ABCab	18.0 Aa	144 Ab	17.5 ABb	4.09 Ac	20.2 Bcd
	A1	22.3 ABb	1.90 ABCc	21.7 ABbc	2.66 ABd	1.99 ABbc	1.68 Aa	18.1 Aab	171 Ab	18.1 ABa	3.16 Ab	22.1 Bcd
	Clementino	22.6 ABc	2.08 ABb	18.9 BCcde	2.50 ABc	1.92 ABb	1.59 ABbc	18.8 Aa	167 Ac	17.2 ABe	4.22 Ab	27.0 Bab
	Beira Rio 8	25.4 Acd	2.32 Ab	23.6 Aab	2.95 Ade	2.25 Acd	1.02 Cc	18.4 Aab	186 Ab	19.4 Ade	4.00 Ad	40.2 Abc
	P1	19.8 BCc	1.56 Cbc	14.92 Dc	1.86 Ccd	1.44 Cde	1.02 Ccd	15.5 Aa	124 Abc	13.1 Ccd	4.31 Abc	16.2 Ba
37	Pirata	24.0 Bab	1.98 CDab	20.6 BCab	3.39 ABab	2.39 Aab	1.18 Bb	18.4 Aab	205 ABab	19.8 ABbcd	11.5 ABab	32.8 Bab
	Bamburral	25.2 ABabc	2.00 CDbcd	23.1 ABab	3.22 Ba	2.41 Aab	1.19 Bb	19.5 Aa	241 Aa	18.9 BCb	11.4 ABb	34.0 Bab
	A1	29.1 Aa	2.62 ABa	25.7 Aa	3.65 ABab	2.42 Aa	1.58 ABab	23.0 Aa	236 Aab	20.9 ABa	12.1 ABa	39.3 Ba
	Clementino	25.0 ABbc	2.33 BCab	20.8 Babc	3.20 Bab	2.40 Aa	1.47 ABc	22.6 Aa	205 ABbc	20.4 ABcde	12.9 ABa	38.8 Ba
	Beira Rio 8	29.8 Abc	2.85 Aa	23.7 ABab	3.82 Abc	2.68 Aab	1.75 Ac	20.4 Aab	231 Aab	23.9 Acd	14.8 Abc	58.2 Aa
	P1	20.4 Bbc	1.78 Dab	17.5 Cbc	2.05 Cc	1.67 Bbcd	1.25 Bbcd	17.7 Aa	136 Bbc	15.8 Cbc	9.23 Bab	19.7 Ca
39	Pirata	26.9 Aa	2.24 ABa	21.1 ABa	3.57 Aa	2.55 Aa	1.73 Aa	19.8 Aa	216 Aa	23.8 Aab	14.6 Aab	40.9 Aa
	Bamburral	26.5 Aabc	2.23 ABabc	23.5 Aa	3.57 Aa	2.53 ABa	1.82 Aa	21.4 Aa	212 Aab	21.5 ABab	14.8 Aab	39.3 Aa
	A1	24.6 Aab	2.55 Aab	23.4 Aab	3.48 Aab	2.19 BCab	1.68 Aa	20.2 Aab	198 Aab	19.6 Ba	12.6 Aa	35.9 ABab
	Clementino	25.4 Abc	2.42 ABab	19.3 BCbcd	3.47 Aab	2.21 ABCab	1.69 Abc	20.2 Aa	207 Abc	21.4 ABbcd	15.0 Aa	30.7 ABab
	Beira Rio 8	23.1 Ad	2.25 ABb	17.6 Cc	3.31 Acd	2.18 Ccd	1.65 Ac	18.1 Aab	216 Ab	22.3 ABcde	13.8 Abc	38.9 Abc
	P1	23.1 Aabc	2.04 Bab	17.2 Cbc	2.46 Bbc	1.89 Cabc	1.44 Abc	20.3 Aa	166 Aabc	19.1 Bab	13.3 Aa	25.3 Ba
41	Pirata	23.1 Cab	2.16 Ca	17.4 Dbc	3.25 BCab	2.16 Cbc	1.91 Ba	19.4 ABab	241 Aa	25.0 ABa	16.1 ABa	42.0 ABa
	Bamburral	28.1 Bab	2.32 BCab	21.8 BCabc	3.32 BCa	2.25 BCabc	1.81 Ba	24. 4 Aa	226 ABab	23.6 BCa	14.6 ABab	30.1 BCabc
	A1	24.14 BCab	2.01 Cc	18.71 CDcde	2.95 Cbcd	1.72 Dcd	1.83 Ba	16.1 Bab	196 ABab	19.5 CDa	14.5 ABa	32.2 BCabc

	Clementino	26.2 BCbc	2.71 ABa	22.2 Bab	3.67 Ba	2.52 Ba	1.99 ABb	24.4 Aa	233 Aabc	26.5 ABa	16.2 ABa	33.7 Ba
	Beira Rio 8	33.8 Aab	3.15 Aa	26.1 Aa	4.31 Aab	2.89 Aab	2.39 Ab	24.9 Aa	268 Aab	29.0 Aab	18.0 Ab	52.5 Aab
	P1	24.6 BCabc	1.97 Cab	17.4 Dbc	2.28 Dbc	1.74 Dbcd	1.63 Bb	19.7 ABa	157 Babc	18.6 Dab	11.9 Ba	20.1 Ca
43	**Pirata**	22.7 Aab	2.06 Aab	16.6 ABc	3.18 Aabc	2.13 Abcd	1.89 ABa	17.7 Aab	202 Aab	22.0 Aabc	13.5 Aab	36.8 ABa
	Bamburral	23.5 Abcd	2.07 Abcd	19.8 Abcd	3.05 Aa	2.03 Abcd	1.65 ABab	20.4 Aa	202 Aab	21.4 Aab	13.1 Ab	36.1 ABab
	A1	24.1 Aab	2.03 Ac	15.8 Be	2.94 Abcd	1.69 Bcd	1.52 Bab	14.2 Aab	202 Aab	20.7 Aa	11.7 Aa	29.5 BCabc
	Clementino	26.2 Abc	2.37 Aab	17.0 ABde	3.16 Aab	2.01 ABb	1.98 Ab	18.6 Aa	255 Aab	24.2 Aabc	15.0 Aa	33.2 ABab
	Beira Rio 8	22.4 Ad	2.11 Ab	17.4 ABc	3.27 Acde	2.00 ABd	1.60 ABcd	16.5 Aab	190 Ab	20.5 Ade	12.4 Ac	42.9 Abc
	P1	22.6 Aabc	1.98 Aab	17.7 ABbc	2.75 Aab	1.85 Ababc	1.69 ABab	19.6 Aa	189 Aab	22.6 Aa	12.6 Aa	23.9 Ca
45	**Pirata**	19.6 Cbc	1.89 Dabc	15.3 Ccd	2.86 BCbcd	1.82 BCDde	1.59 Dab	13.9 Aab	179 Cab	20.5 Cbcd	11.3 Bab	29.7 Bab
	Bamburral	24.0 BCbcd	2.58 BCa	19.4 ABcd	3.21 Ba	2.02 Bcd	1.83 Cda	19.2 Aa	212 BCab	23.5 BCa	13.8 Bb	32.1 Babc
	A1	22.9 BCb	2.22 CDbc	15.9 Ce	2.85 BCcd	1.65 CDcd	1.83 CDa	12.9 Ab	268 ABa	20.5 Ca	11.2 Ba	29.1 Babc
	Clementino	37.1 Aa	2.74 Ba	16.6 BCe	3.30 Bab	1.99 BCb	2.48 Ba	17.8 Aa	214 BCbc	24.8 Bab	13.0 Ba	32.2 Bab
	Beira Rio 8	35.5 Aa	3.26 Aa	22.2 Ab	4.40 Aab	2.53 Abc	3.15 Aa	20.4 Aab	310 Aa	31.4 Aa	24.0 Aa	52.5 Aab
	P1	26.5 Ba	2.08 Da	17.5 BCbc	2.44 Cbc	1.61 Dcde	2.14 BCa	17.0 Aa	182 Cabc	21.2 BCa	11.2 Ba	23.0 Ba
47	**Pirata**	21.0 Cbc	1.66 Cbc	13.1 Ed	2.56 Dcde	1.63 De	1.60 ABab	10.8 Cb	163 Cab	18.1 Bcde	9.85 Cb	21.6 Bb
	Bamburral	29.3 ABa	2.02 BCbcd	18.1 CDd	3.02 CDab	1.85 CDd	1.82 Aa	15.7 ABCa	185 BCab	21.8 ABab	12.3 BCb	24.7 ABbcd
	A1	23.0 Cb	2.11 BCbc	15.9 DEe	3.15 Cabc	1.59 Dd	1.66 Aa	13.7 BCb	243 ABab	21.3 ABa	16.1 ABa	23.5 Bbcd
	Clementino	28.7 ABb	2.32 Bab	20.4 BCabc	3.74 Ba	2.54 Ba	0.94 Cd	20.8 ABa	311 Aa	22.6 Aabc	17.3 Aa	27.2 ABab
	Beira Rio 8	33.1 Aab	2.85 Aa	25.5 Aab	4.83 Aa	2.94 Aa	1.16 BCd	22.4 Aab	311 Aa	25.0 Abc	18.1 Ab	36.7 Ac
	P1	25.4 BCab	2.15 Ba	22.2 Ba	3.26 BCa	2.15 Ca	0.86 Cd	19.8 ABa	238 ABa	21.2 ABa	10.6 Ca	16.0 Ba
49	**Pirata**	21.0 Abc	1.90 Aabc	18.1 ABbc	3.33 ABab	2.33 ABab	1.50 ABab	16.5 Aab	211 Aab	18.9 Acde	13.6 BCab	21.7 ABb
	Bamburral	21.7 Acd	1.87 Abcd	19.1 ABcd	3.13 ABa	2.07 ABCbc	1.37 ABab	17.6 Aa	249 Aa	19.9 Aab	19.7 Aa	12.9 Bd
	A1	22.4 Ab	2.07 Abc	17.4 ABde	3.30 ABabc	1.97 Cbc	1.10 Bb	15.7 Aab	213 Aab	18.4 Aa	13.7 BCa	14.1 Bd
	Clementino	24.0 Abc	2.17 Ab	18.0 ABcde	3.30 ABab	2.4 Aa	1.40 ABcd	16.7 Aa	212 Abc	20.0 Acde	17.5 ABa	19.6 ABb
	Beira Rio 8	21.0 Ad	2.10 Ab	16.6 Bc	3.60 Ac	2.20 ABCcd	1.73 Ac	16.8 Aab	215 Ab	19.8 Ade	16.8 ABbc	31.6 Ac
	P1	24.3 Aabc	2.03 Aab	20.0 Aab	2.83 Bab	2.00 BCab	1.73 Aab	20.5 Aa	191 Aab	19.8 Aab	10.1 Ca	15.4 Ba
CV(%)		8.62	8.98	7.08	7.98	7.00	11.8	18.8	15.4	8.48	17.5	17.5

Upper-case letters compare genotype effect inside each time (WAF), whilst lower-case letters compare time effect for each genotype by Tukey's test at 5% of probability.

Considering the accumulation in the husk proportional to the production of 1000 kg of beans at 49 WAF, we observed that K was confirmed as the most accumulated nutrient in the husk (Table 8), as also noted in the accumulation per berry (Table 5). The accumulation of K was increasing, reaching the highest values at 41 WAF (Beira Rio 8), 43 (Pirata and Bamburral), and 45 (A1 and Clementino). After the peak accumulation, there was a tendency for stability in the K content in the husk. The P1 genotype did not show a significant difference in the accumulation of K over time.

It was observed a trend of increase until 41 WAF for A1 and Clementino, and until 43 WAF for Pirata genotype, followed by a decline in the N content, while the Bamburral and Beira Rio 8 genotypes showed an increase in accumulation until 47. There was no significant difference in the accumulation of P for all genotypes over the evaluated time.

Among the micronutrients, there was an increase in Cu accumulation for Bamburral, A1, Clementino, and Beira Rio 8 genotypes, while for Pirata, and P1 there was no significant difference along maturation period for Cu accumulation. For Fe, Mn, Zn, and B, the Pirata genotype showed high values already in the first evaluation, and these values are related to the high concentration observed for these nutrients in the husk of this genotype during the same period (Table 3). For the other genotypes and nutrients, there were no expressive changes in accumulation throughout the evaluated period.

Table 9: Nutrients accumulation on husk standardized to 1000 kg of dry beans collected at 49 WAF of six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) of *Coffea canephora* collected from end of berry expansion to full maturation (33 to 49 Weeks After Flowering).

Time (WAF)	Genotype	Macronutrients (kg)						Micronutrients (g)				
		N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn	B
33	Pirata	8.62 ABab	1.60 Aa	13.7 Ac	5.95 Aa	2.16 Aa	1.76 Aab	9.16 Aa	512 Aa	24.5 Aa	10.7 Aa	55.0 Aa
	Bamburral	6.31 BCab	1.03 Aa	13.8 Abc	2.48 Ba	0.60 Ca	1.01 BCb	6.26 Aab	244 BCb	8.49 Cab	4.54 Bb	13.2 Da
	A1	8.56 ABa	1.43 Aa	17.9 Ad	4.42 ABab	1.58 Ba	1.43 Aa	8.12 Aab	333 Bab	14.8 Bab	4.83 Bb	35.3 Ba
	Clementino	6.53 BCb	1.98 Aa	14.2 Ad	2.93 Bc	1.25 Bbc	1.39 ABbc	8.47 Abc	266 BCab	15.0 Bbcd	4.54 Ba	28.9 BCbc
	Beira Rio 8	8.74 Abc	1.00 Aa	15.4 Ac	4.08 ABa	1.11 BCab	1.41 Abc	7.10 Abcd	322 Bcd	14.4 Bbc	3.75 Bc	30.8 BCd
	P1	5.26 Cbc	0.98 Aa	13.4 Aa	2.56 Ba	0.62 Ca	0.98 Cab	7.37 Aa	189 Cab	11.0 BCabc	2.62 Bab	15.4 CDa
35	Pirata	5.51 CDc	1.29 Aa	13.5 Cc	3.24 ABb	1.00 Bb	1.27 BCc	7.27 ABa	200 BCc	12.1 Ab	3.99 Bb	23.9 Bc
	Bamburral	4.91 Db	0.83 Aa	14.0 Cbc	2.64 Ba	0.38 Ca	0.98 Cb	3.63 Bb	136 Cb	6.56 Bb	2.87 Bb	15.8 Ba
	A1	7.90 ABab	1.69 Aa	24.3 Aabc	5.21 Aab	1.69 Aa	1.77 Aa	9.89 Aab	279 ABb	15.6 Aab	7.39 ABb	28.9 Ba
	Clementino	5.58 CDb	1.68 Aa	15.8 BCcd	2.98 Bc	1.20 ABbc	1.34 BCbc	7.78 ABc	247 Bb	12.3 Ad	4.14 Ba	28.1 Bbc
	Beira Rio 8	8.58 Abc	1.17 Aa	21.5 ABbc	4.49 ABa	1.12 Bab	1.64 ABbc	8.11 ABbcd	372 Abcd	14.3 Abc	9.67 Aab	45.4 Abcd
	P1	7.58 ABa	1.21 Aa	12.7 Ca	3.29 ABa	0.80 BCa	1.19 Ca	9.01 ABa	285 ABa	16.17 Aa	7.23 ABa	24.0 Ba
37	Pirata	5.33 Cc	1.50 Aa	17.2 BCbc	3.91 ABab	1.00 ABb	1.61 ABabc	6.29 Aa	267 BCbc	12.5 BCb	5.74 Bab	31.9 ABbc
	Bamburral	6.04 BCab	0.91 Aa	12.9 Cc	2.72 Ba	0.57 BCa	1.03 Cb	4.74 Aab	172 Cb	8.52 Cab	3.80 Bb	16.0 Da
	A1	8.45 Aab	1.42 Aa	19.8 ABbcd	5.08 Aab	1.27 Aab	1.61 ABa	6.56 Aab	398 Aab	16.5 Aab	20.1 Aa	33.1 ABa
	Clementino	5.28 Cb	1.74 Aa	16.8 BCcd	3.12 ABbc	1.16 Ac	1.27 BCbc	7.54 Ac	266 BCab	13.1 ABcd	5.97 Ba	27.7 BCbc
	Beira Rio 8	8.16 ABbc	1.14 Aa	23.8 Ab	4.90 Aa	0.93 ABb	1.75 Ab	6.12 Acd	284 Bd	14.4 ABbc	5.83 Bbc	47.8 Aabc
	P1	5.52 Cbc	1.50 Aa	14.8 BCa	2.24 Ba	0.34 Ca	1.23 BCa	6.89 Aa	201 BCab	11.5 BCabc	4.20 Bab	17.1 CDa
39	Pirata	6.44 Abc	1.58 Aa	22.7 Aab	5.28 ABab	1.32 Ab	1.84 Aa	6.98 Aa	242 ABbc	14.0 Ab	4.20 Ab	44.9 ABab
	Bamburral	6.37 Aab	0.78 Aa	19.2 ABabc	3.76 Ba	0.46 Ca	1.03 Cb	4.37 Aab	171 Bb	7.62 Bab	3.52 Ab	17.6 Ca
	A1	6.51 Aab	1.37 Aa	18.7 ABcd	4.08 ABb	0.98 ABb	1.59 ABa	5.12 Ab	333 Aab	12.8 Ab	7.83 Ab	29.8 BCa
	Clementino	5.69 Ab	1.58 Aa	18.4 ABbcd	3.92 ABabc	1.20 Abc	1.37 BCbc	7.57 Ac	249 ABb	14.3 Abcd	5.15 Aa	47.2 Aa
	Beira Rio 8	6.99 Ac	1.02 Aa	22.4 Ab	5.84 Aa	1.12 Aab	1.37 BCbcd	5.77 Ad	262 ABd	12.6 Ac	4.82 Abc	50.2 Aab
	P1	6.93 Aab	1.17 Aa	15.1 Ba	3.80 Ba	0.51 BCa	1.03 Cab	7.19 Aa	234 ABab	14.7 Aab	3.96 Aab	19.0 Ca
41	Pirata	6.33 Cbc	1.76 Aa	22.7 BCab	4.03 BCab	1.22 ABb	1.76 BCab	9.60 ABa	331 Bb	13.3 Cb	5.25 Cab	37.5 Bbc
	Bamburral	7.34 BCab	1.24 Aa	19.1 CDabc	3.90 BCa	0.65 CDa	1.48 CDa	8.20 ABab	398 Ba	12.5 CDa	12.0 ABa	20.1 CDa
	A1	8.77 Ba	1.93 Aa	24.8 BCabc	5.69 ABab	1.50 Aab	1.74 BCa	9.78 ABab	307 Bab	14.6 BCab	6.32 Cb	32.3 BCa

	Clementino	11.8 Aa	1.98 Aa	27.9 Ba	5.52 ABa	1.60 Aabc	2.04 ABa	10.46 ABbc	326 Bab	18.6 ABab	6.97 BCa	43.4 Bab
	Beira Rio 8	9.62 ABb	1.87 Aa	34.2 Aa	6.17 Aa	0.95 BCb	2.36 Aa	11.8 Aabc	534 Aa	20.5 Aa	14.4 Aa	62.9 Aa
	P1	5.74 Cbc	1.05 Aa	15.2 Da	2.14 Ca	0.27 Da	1.09 Da	5.75 Ba	174 Cab	8.41 Dc	3.89 Cab	14.7 Da
43	**Pirata**	9.52 Aa	1.81 Aa	24.7 Aa	4.40 BCab	1.31 ABb	1.81 Aa	11.2 Aa	265 BCbc	13.6 ABb	4.03 Bb	33.8 Abc
	Bamburral	6.47 BCab	1.17 Aa	23.4 Aa	3.20 BCa	0.66 CDa	1.36 Bab	8.26 Aab	193 BCb	8.64 Cab	3.98 Bb	9.94 Ca
	A1	8.32 ABab	1.32 Aa	22.6 Abcd	6.36 Aa	1.51 ABab	1.83 Aa	8.22 Aab	400 Aa	18.0 Aab	19.2 Aa	30.0 ABa
	Clementino	7.30 ABb	1.91 Aa	22.3 ABabc	4.59 ABabc	1.64 Aabc	1.10 Bc	11.3 Aabc	291 ABab	16.3 Abcd	5.63 Ba	33.1 ABabc
	Beira Rio 8	7.22 ABbc	1.28 Aa	21.4 ABbc	4.15 BCa	1.01 BCb	0.98 BCd	8.77 Abcd	265 BCd	11.1 BCc	2.20 Bc	36.5 Abcd
	P1	4.45 Cbc	1.12 Aa	16.3 Ba	2.56 Ca	0.34 Da	0.64 Cb	6.43 Aa	168 Cab	8.46 Cc	1.53 Bb	14.8 BCa
45	**Pirata**	5.79 BCc	1.65 Aa	22.0 Bab	4.74 Aab	1.51 Bb	1.38 BCbc	8.57 Ca	269 BCbc	14.1 Bb	2.29 Ab	31.9 BCbc
	Bamburral	6.01 BCab	1.26 Aa	20.0 BCab	3.59 ABa	0.82 Ca	1.04 CDb	8.56 Cab	201 Cb	8.46 Cab	1.62 Ab	16.4 CDa
	A1	7.23 ABab	1.87 Aa	29.4 Aa	3.98 ABb	1.42 Bab	1.42 BCa	10.3 BCab	373 ABab	14.9 Bab	3.48 Ab	25.4 BCa
	Clementino	6.78 ABb	2.67 Aa	29.0 Aa	5.26 Aab	2.09 Aa	1.55 ABb	17.2 Aa	378 ABa	20.6 Aa	3.56 Aa	37.9 ABabc
	Beira Rio 8	8.95 Abc	1.92 Aa	30.9 Aa	5.45 Aa	1.58 Ba	1.79 Ab	15.1 ABa	416 Aabc	18.8 ABab	3.92 Ac	48.7 Aabc
	P1	4.27 Cc	1.08 Aa	14.6 Ca	2.34 Ba	0.30 Da	0.86 Dab	6.85 Ca	165 Cb	9.08 Cc	1.46 Ab	13.4 Da
47	**Pirata**	5.35 Bc	1.36 Aa	20.0 BCab	3.92 ABab	1.14 BCb	1.33 ABbc	8.39 Ba	240 Bbc	12.4 Bb	2.17 Ab	26.6 BCc
	Bamburral	7.54 Ba	1.12 Aa	18.0 CDabc	3.66 ABa	0.87 CDa	1.03 Bb	9.14 ABab	209 Bb	10.4 Bab	1.81 Ab	18.7 BCa
	A1	5.92 Bb	1.68 Aa	26.2 Bab	5.08 Aab	1.64 ABab	1.48 Aa	11.9 ABa	407 Aa	18.4 Aa	3.32 Ab	31.2 ABa
	Clementino	7.43 Bb	2.34 Aa	23.8 BCab	3.84 ABabc	1.72 Aab	1.69 Aab	14.34 Aab	297 Bab	19.6 Aab	3.40 Aa	24.4 BCc
	Beira Rio 8	12.2 Aa	1.79 Aa	33.2 Aa	5.56 Aa	1.49 ABab	1.71 Abc	12.8 ABab	464 Aab	19.5 Aab	3.85 Ac	43.4 Abcd
	P1	6.37 Bab	1.15 Aa	15.4 Da	3.01 Ba	0.46 Da	0.99 Bab	8.05 Ba	235 Bab	10.7 Bbc	3.58 Aab	14.6 Ca
49	**Pirata**	7.03 ABabc	1.81 Aa	21.5 Aab	4.16 Aab	1.37 ABb	1.28 Ac	10.5 Aa	270 BCbc	16.7 Ab	2.07 Ab	25.1 ABc
	Bamburral	8.09 ABa	1.32 Aa	20.8 Aa	3.24 Aa	0.88 BCa	1.18 Aab	10.3 Aa	196 Cb	9.98 Cab	2.77 Ab	16.9 ABa
	A1	8.07 ABab	1.60 Aa	22.6 Abcd	4.28 Aab	1.37 ABab	1.49 Aa	10.2 Aab	412 Aa	17.0 Aab	3.42 Ab	27.0 ABa
	Clementino	7.28 ABb	1.85 Aa	19.8 Abcd	4.10 Aabc	1.69 Aabc	1.43 Abc	13.4 Aabc	296 BCab	18.0 Aabc	2.93 Aa	28.6 ABbc
	Beira Rio 8	8.85 Abc	1.42 Aa	23.6 Ab	4.11 Aa	1.14 Bab	1.30 Acd	12.5 Aab	319 ABcd	15.4 ABabc	2.70 Ac	32.4 Acd
	P1	5.98 Bab	1.34 Aa	17.8 Aa	2.60 Aa	0.57 Ca	1.10 Aa	9.62 Aa	212 BCab	11.7 BCabc	1.57 Ab	16.4 Ba
CV(%)		14.1	20.8	12.9	21.0	19.7	12.0	26.7	16.1	14.9	42.7	22.9

Upper-case letters compare genotype effect inside each time (WAF), whilst lower-case letters compare time effect for each genotype by Tukey's test at 5% of probability.

The Pirata and A1 genotypes exhibited a remarkable performance in N accumulation, reaching their peaks between 37 and 39 WAF (Table 9). On the other hand, the Bamburral, Clementino, and Beira Rio 8 genotypes showed a later accumulation dynamic, reaching their maximum values between 45 and 47 WAF. This temporality indicates genetic variations in nitrogen assimilation processes throughout the growth cycle, highlighting specific adaptations of each genotype to environmental conditions or nutritional requirements.

Similar to what occurred for N, there was also an increase in P accumulation throughout maturation. The period of highest accumulation occurred after 41 WAF, especially for the Pirata genotype, while the Bamburral, Clementino, and Beira Rio 8 genotypes had higher accumulation at 45 WAF, and the P1 genotype at 47 WAF. The accumulation values of P for the A1 genotype over time did not differ statistically. There was also a positive accumulation of K throughout maturation, with a more accelerated accumulation rate in the beginning and stability in the last weeks of maturation. As in the bean, Zn accumulation in the fruit was increasing, with a high accumulation rate between 35 and 39 WAF.

We can observe that, when producing 1000 kg of grains, potassium is the most exported nutrient from the crop at all evaluated moments, followed by N and Ca. Although initially the accumulation of P in the fruit for some genotypes is lower than that of Mg, the accumulation of P becomes more significant throughout maturation, making it the fourth most accumulated nutrient by the berry from 41 WAF onwards. With some exceptions, S was the least accumulated macronutrient by the fruits throughout maturation. Overall, we can establish the order for macronutrient accumulation in the fruit during maturation as K > N > Ca > P ≈ Mg > S.

Among micronutrients, Fe was the most accumulated, with a significant lead over the others. The second most accumulated micronutrient was B, followed by Mn, Cu, and Zn, establishing the following order for micronutrient accumulation in the fruit: Fe > B > Mn > Cu > Zn.

Table 10: Nutrients accumulation on berries standardized to 1000 kg of dry beans collected at 49 WAF of six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and P1) of *Coffea canephora* collected from end of berry expansion to full maturation (33 to 49 Weeks After Flowering).

Time (WAF)	Genotype	Macronutrients (kg)						Micronutrients (g)				
		N	P	K	Ca	Mg	S	Cu	Fe	Mn	Zn	B
33	Pirata	25.9 Acd	3.02 BCab	29.6 Bc	8.24 Aa	3.79 Aa	2.90 Abc	23.1 Aa	748 Aa	40.5 Aa	14.0 Aabc	84.2 Aab
	Bamburral	28.16 Acd	2.67 BCb	30.9 Bd	4.87 CDb	2.47 Cab	2.37 ABbc	24.6 Aa	430 Bb	25.9 CDbc	9.25 ABde	37.4 CDab
	A1	30.7 Ab	3.34 Ba	38.3 Ab	7.24 ABab	3.46 ABa	2.80 Abc	22.8 Aa	555 Bab	32.6 BCa	8.48 ABd	74.6 ABa
	Clementino	30.6 Acd	4.30 Ab	37.7 Acd	5.62 BCc	3.49 ABbcd	2.73 Ab	31.6 Aa	452 Bbc	34.1 ABcd	8.15 ABb	56.1 BCab
	Beira Rio 8	30.3 Ad	3.12 BCc	38.7 Ae	6.79 ABd	3.14 Bd	2.88 Abc	22.4 Aa	532 Bb	33.2 Bc	8.41 ABe	71.2 ABde
	P1	19.3 Bb	2.25 Cb	27.7 Bb	3.86 Db	1.88 Cc	1.85 Bc	19.7 Aa	289 Cb	21.2 Db	4.32 Bb	30.2 Da
35	Pirata	21.8 Cd	2.76 BCb	29.6 BCc	5.33 BCb	2.78 BCb	2.45 BCc	20.9 Aa	330 BCd	27.1 ABd	6.77 Ac	44.3 Bd
	Bamburral	25.2 BCd	2.62 Cb	32.9 BCcd	5.01 Cab	2.28 Cb	2.38 BCbc	21.6 Aa	280 Cc	24.1 Bc	6.96 Ae	36.0 Bab
	A1	30.2 ABb	3.59 ABa	46.0 Aa	7.87 Aab	3.69 Aa	3.45 Aab	28.0 Aa	450 ABb	33.8 Aa	10.5 Acd	51.0 Bab
	Clementino	28.2 Bd	3.76 Ab	34.7 Bd	5.47 BCc	3.11 ABd	2.93 ABb	26.6 Aa	414 BCc	29.6 ABd	8.35 Ab	55.1 Bab
	Beira Rio 8	34.0 Acd	3.49 ABc	45.0 Ade	7.44 ABcd	3.37 ABcd	3.39 Ab	26.6 Aa	557 Ab	33.8 Ac	13.6 Ade	85.6 Abcd
	P1	27.4 BCa	2.76 BCab	27.6 Cb	5.16 Cab	2.25 Cabc	2.22 Cbc	24.5 Aa	409 BCab	29.2 ABa	11.5 Aab	40.3 Ba
37	Pirata	29.3 Babc	3.48 ABab	37.8 Bab	7.30 ABab	3.38 ABab	2.79 BCc	24.7 Aa	473 BCbcd	32.3 ABbcd	17.2 BCab	64.7 BCbcd
	Bamburral	31.2 Bbcd	2.91 Bab	36.0 Bbcd	5.94 Bcab	2.97 Ba	2.21 Cc	24.3 Aa	413 BCbc	27.4 Bbc	15.2 BCbcd	50.0 CDab
	A1	37.5 Aa	4.04 Aa	45.4 Aa	8.73 Aab	3.69 Aa	3.19 ABabc	29.5 Aa	634 Aa	37.4 Aa	32.2 Aa	72.3 Ba
	Clementino	30.2 Bcd	4.08 Ab	37.6 Bcd	6.32 BCbc	3.56 ABbcd	2.74 BCb	30.1 Aa	472 BCabc	33.4 ABcd	18.9 BCa	66.5 BCab
	Beira Rio 8	37.9 Abc	3.99 Abc	47.5 Acd	8.72 Aabc	3.61 Abcd	3.49 Ab	26.6 Aa	516 ABb	38.3 Abc	20.7 Bbcd	106 Aab
	P1	26.0 Ba	3.27 ABab	32.3 Bab	4.29 Cab	2.01 Cabc	2.48 Cabc	24.6 Aa	337 Cab	27.4 Bab	13.4 Ca	36.8 Da
39	Pirata	33.4 Aa	3.82 ABa	43.8 Aa	8.86 Aa	3.88 Aa	3.57 Aab	26.8 Aa	458 ABbcd	37.8 Aabc	18.8 Aab	85.8 ABa
	Bamburral	32.9 Aabc	3.01 Bab	42.7 Aab	7.33 Aba	2.98 BCa	2.85 BCabc	25.8 Aa	383 Bbc	29.2 Babc	18.4 Abc	56.9 CDa
	A1	31.1 Ab	3.92 ABa	42.1 Aab	7.56 ABab	3.18 Ba	3.27 ABab	25.3 Aa	530 Aab	32.4 ABa	20.4 Ab	65.7 CDa
	Clementino	31.1 Acd	3.99 Ab	37.7 ABcd	7.24 ABabc	2.98 BCcd	3.06 ABb	27.7 Aa	455 ABbc	35.7 ABbcd	20.1 Aa	77.9 ABa
	Beira Rio 8	30.1 Ad	3.27 ABc	40.1 Ae	9.32 Aabc	3.30 ABcd	3.03 BCbc	23.9 Aa	478 ABb	34.8 ABc	18.6 Acd	89.2 Abcd
	P1	30.1 Aa	3.22 ABab	32.3 Bab	6.26 Ba	2.39 Cabc	2.47 Cabc	27.5 Aa	399 ABab	33.9 ABa	17.3 Aa	44.3 Da
41	Pirata	29.4 Dabc	3.92 BCa	40.1 Ca	7.29 Bab	3.38 BCab	3.66 BCa	29.0 Aa	572 Bb	38.3 BCab	21.4 BCa	79.6 Bab
	Bamburral	35.5 BCab	3.56 Cab	40.9 Cab	7.21 Bab	2.90 Cab	3.29 CDa	32.6 Aa	623 Ba	36.1 Ca	26.7 ABa	50.2 CDab
	A1	32.9 CDab	3.94 BCa	43.5 Cab	8.64 ABab	3.22 Ca	3.58 BCa	25.9 Aa	503 Bab	34.2 Ca	20.9 BCb	64.5 BCab

	Clementino	38.0 ABab	4.69 ABab	50.1 Ba	9.19 ABa	4.11 Aab	4.03 Ba	34.8 Aa	560 Babc	45.2 ABa	23.2 Ba	77.0 BCa
	Beira Rio 8	43.4 Aab	5.02 Aa	60.4 Aa	10.5 Aa	3.85 ABabc	4.75 Aa	36.8 Aa	802 Aa	49.5 Aa	32.4 Aa	115 Aa
	P1	30.3 CDa	3.02 Cab	32.6 Dab	4.42 Cab	2.01 Dabc	2.71 Dab	25.4 Aa	331 Cab	27.0 Dab	15.8 Ca	34.8 Da
43	**Pirata**	32.3 ABab	3.87 ABa	41.4 Aa	7.58 ABab	3.44 ABab	3.69 Aa	29.0 Aa	467 BCbcd	35.6 ABabc	17.5 Bab	70.6 Aabc
	Bamburral	30.0 ABbcd	3.24 Bab	43.2 Aa	6.25 BCab	2.69 CDab	3.00 BCab	28.6 Aa	395 Cbc	30.0 Babc	17.1 Bbc	46.0 BCab
	A1	32.4 ABab	3.34 Ba	38.3 ABb	9.29 Aa	3.20 BCa	3.35 ABab	22.4 Aa	601 Aa	38.7 Aa	30.9 Aa	59.4 ABab
	Clementino	33.5 Abcd	4.28 Ab	39.3 ABbcd	7.75 ABabc	3.65 Abcd	3.08 BCb	29.9 Aa	546 ABabc	40.5 Aabc	20.6 Ba	66.2 ABab
	Beira Rio 8	29.6 ABd	3.38 ABc	38.8 ABe	7.42 ABcd	3.00 BCd	2.57 CDc	25.2 Aa	455 BCb	31.5 Bc	14.6 Bcde	79.4 Acde
	P1	27.0 Ba	3.10 Bab	33.9 Bab	5.31 Cab	2.20 Dabc	2.33 Dabc	26.0 Aa	358 Cab	31.1 Ba	14.1 Ba	38.6 Ca
45	**Pirata**	25.4 Bcd	3.54 BCab	37.3 CDab	7.60 Bab	3.34 Bab	2.97 Cbc	22.5 Aa	449 Bbcd	34.6 Babc	13.6 Babc	61.6 Bbcd
	Bamburral	30.1 Bbcd	3.83 BCa	39.4 BCabc	6.80 BCab	2.83 Bab	2.87 Cabc	27.8 Aa	413 Bbc	31.9 Bab	15.4 Bbcd	48.5 BCab
	A1	30.1 Bb	4.09 Ba	45.2 Ba	6.83 BCb	3.07 Ba	3.25 Cabc	23.2 Aa	641 Aa	35.4 Ba	14.6 Bbcd	54.4 BCab
	Clementino	43.9 Aa	5.41 Aa	45.6 Bab	8.57 ABab	4.08 Aabc	4.03 Ba	35.0 Aa	592 Aab	45.4 Aa	16.6 Ba	70.1 Bab
	Beira Rio 8	44.4 Aa	5.18 Aa	53.2 Abc	9.85 Aab	4.11 Aab	4.95 Aa	35.5 Aa	726 Aa	50.2 Aa	27.9 Aab	101 Aabc
	P1	30.7 Ba	3.16 Cab	32.1 Dab	4.78 Cab	1.91 Cbc	3.00 Ca	23.9 Aa	347 Bab	30.3 Ba	12.7 Ba	36.4 Ca
47	**Pirata**	26.3 Cbcd	3.01 Bab	33.1 Dbc	6.48 Bab	2.76 Bb	2.93 Abc	19.2 Aa	404 Dcd	30.5 Bcd	12.0 Cbc	48.2 BCcd
	Bamburral	36.8 Ba	3.15 Bab	36.2 CDbcd	6.68 Bab	2.73 Bab	2.85 Aabc	24.8 Aa	394 Dbc	32.2 Bab	14.1 BCcde	43.4 BCab
	A1	28.9 Cb	3.79 ABa	42.1 BCab	8.23 ABab	3.23 Ba	3.14 Aabc	25.6 Aa	650 ABa	39.7 Aa	19.4 ABb	54.7 Bab
	Clementino	36.1 Bbc	4.66 Aab	44.2 Babc	7.58 Babc	4.26 Aa	2.63 Ab	35.2 Aa	608 BCa	42.3 Aab	20.7 ABa	51.7 BCb
	Beira Rio 8	45.4 Aa	4.64 Aab	58.7 Aab	10.4 Aa	4.43 Aa	2.87 Abc	35.2 Aa	775 Aa	44.4 Aab	21.9 Abc	80.1 Acde
	P1	31.7 BCa	3.30 Ba	37.6 CDa	6.28 Ba	2.62 Ba	1.85 Bc	27.8 Aa	473 CDa	31.9 Ba	14.2 BCa	30.7 Ca
49	**Pirata**	28.0 Aabc	3.71 Aab	39.6 Aab	7.49 ABab	3.70 ABa	2.78 Ac	27.0 Aa	481 Bbc	35.6 ABabc	15.7 ABab	46.8 ABcd
	Bamburral	29.8 Abcd	3.18 Aab	39.9 Aab	6.37 ABab	2.94 CDab	2.55 Abc	27.9 Aa	445 Bb	29.9 Babc	22.5 Aab	29.3 Bb
	A1	30.5 Ab	3.67 Aa	40.0 Aab	7.58 ABab	3.34 BCa	2.59 Ac	25.9 Aa	625 Aa	35.4 ABa	17.2 ABbc	41.1 Bb
	Clementino	31.3 Acd	4.02 Ab	37.8 Acd	7.40 ABabc	4.09 Aabc	2.83 Ab	30.1 Aa	507 ABabc	38.0 Aabc	20.4 Aa	48.3 ABb
	Beira Rio 8	29.9 Ad	3.52 Ac	40.2 Ae	7.71 Abcd	3.34 BCcd	3.03 Abc	29.3 Aa	535 ABb	35.1 ABc	19.5 Acd	64.0 Ae
	P1	30.2 Aa	3.38 Aa	37.8 Aa	5.44 Bab	2.57 Dab	2.83 Aab	30.2 Aa	403 Bab	31.6 ABa	11.7 Bab	32.3 Ba
CV(%)		7.74	10.9	6.69	13.0	8.27	8.77	18.4	11.8	8.59	18.0	15.7

Upper-case letters compare genotype effect inside each time (WAF), whilst lower-case letters compare time effect for each genotype by Tukey's test at 5% of probability.

Discussion

The novelty of this study is associated with the quantification of macro and micronutrients in beans, husks, and berries, along with the accumulation of dry mass, from the end of the leaf/berry expansion phenophase to the stage of full maturation, This was linked to the exocarp coloration in six genotypes of *Coffea canephora*, aiming to identify the nutrient accumulation pattern in the berry and its components to refine more efficient nutrition management strategies.

The DM accumulation dynamics in the two components of the berry (bean and husk) followed distinct patterns (Table 1). In several collections was possible to observe an accumulation of DM in the beans at high rates. After reaching the maximum weight value around 45 WAF (except for late genotype P1), they slightly reduce DM, likely during the metabolic reorganization process of the grain throughout maturation. During full maturation, the slight decline in bean dry matter per fruit likely stems from the disruption of photoassimilate translocation from the fruit to the bean. Additionally, substrate consumption required for respiration during this stage could also contribute to the decrease (CARVALHO & NAKAGAWA, 1980; EIRA et al., 2006; PÉREZ et al., 2023). Respiration generates ATP, which fuels metabolic pathways involved in producing expensive secondary metabolites found in beans. These include various phenolic compounds known for their protective functions in plants. (FARAH & DONANGELO, 2006). It is worth noting that accessible metabolic analyses in coffee beans are currently conducted only at the end of fruit maturation, suggesting ideas for future research themes related to physiological functions such as photosynthesis and respiration.

The pattern of variation in husk DM contrasted with that of the bean (Table 1), remaining stable initially and reaching peak values towards the end of the experiment, coinciding with full ripeness of the berries. This delayed investment in husk DM maturation suggests a biological protective role of the husk against predators and diseases (CARRERA-CASTAÑO et al., 2020). While husks are often considered a byproduct in coffee processing by many producers, their high mineral content, especially K, N and Ca (Table 3) makes them valuable in crop management (fertilization). Utilizing husks in this way can reduce the need for mineral fertilizers in coffee plantations, contributing to increased economic and environmental sustainability of coffee cultivation (COVRE et al., 2016).

Potassium was the most accumulated nutrient by the husk and berry for all evaluated genotypes. Considering the production of 1000 kg of beans at 49 WAF, it was observed that K was the most exported nutrient in the berry, followed by N and Ca. The accumulation of K on berries demonstrated a continuous and constant increase until complete maturation (Table 7), supporting the results observed by Laviola et al. (2008) in *Coffea arabica* and by Partelli et al. (2014) and Dubberstein et al. (2016) for *C. canephora*. These studies attributed the phenomenon to potassium being necessary for the activation of various key enzymes in the synthesis of organic compounds that are produced during berry maturation, besides that, K is one of the main nutrients responsible for grain filling and subsequent grain weight (CLEMENTE et al., 2015).

The high accumulation of K in the husk (Table 8) underscores the need to return this 'byproduct' to the field as a rich organic fertilizer. Considering that the application requirement of K per hectare to produce six tons of beans (100 bags of 60 kg ha^{-1}) is approximately 300 kg (PREZOTTI et al., 2007), the husk of the Beira Rio 8 genotype could provide 140 kg, corresponding to almost 50% of the demand. This reasoning extends similarly to the macronutrients Ca and N, which are present in large quantities in the coffee husk.

Nitrogen was the most accumulated nutrient in beans (Table 8) and the second most in berries (Table 10), only behind potassium. This highlights the influence of nitrogen and its role in fruit development, emphasizing the advantages of nitrogen fertilization for coffee crops during the maturation phase (COVRE et al., 2018). As highlighted by Clemente et al. (2015), nitrogen is crucial not only to produce branches and the vegetative growth of coffee plants but also for essential functions in fruit formation. Knowledge about N accumulation is important, especially for correct manage crop fertilization, given that is a nutrient highly demanded and susceptible to various losses in soil-plant-atmosphere systems, studies must reveal their absorption and accumulation dynamics in various plant organs (SANTOS et al., 2017).

The phosphorus concentration in beans and husk did not vary significantly throughout the evaluated period, however, the accumulation showed an increasing trend, especially in beans and berries, as demonstrated by Partelli et al. (2014) when assessing the accumulation of nutrients in berries of genotypes with different maturation cycles from flowering to complete maturation. The authors reported that

the accumulation of P varied according to the maturation cycle of the genotypes, with early and medium maturing genotypes accumulating P with sigmoidal trend, while late-maturing genotypes accumulated it exponentially. This becomes evident when comparing the accumulation of the P1 genotype, with late maturation, and the early-maturing genotype Beira Rio 8, where the period of higher P accumulation was observed at the end of the evaluated period, after the peak accumulation of phosphorous on Beira Rio 8 genotypes berry.

Remobilization of Ca from leaves to berries tends to be uncommon due to its low concentration in the symplasm and phloem (TAIZ & ZAIGER, 2013), which may explain the low variation in the concentration of this nutrient in beans and husk throughout maturation (Tables 2 and 3). However, the demand for Ca during the entire reproductive phase, including maturation, is high, as Ca was the third most accumulated nutrient in the berry. When studying some agronomic attributes related to Ca nutrition, Ramirez-Builes et al. (2020) found that during the reproductive phases, the peak in Ca absorption by the plant occurred during pre-flowering and 30 weeks after flowering. However, due to the low mobility of Ca in the plant, there is a requirement for constant availability of soluble Ca in the soil solution throughout the reproductive phase.

Despite the small variation in micronutrient concentration in the bean and husk throughout berry maturation (Tables 2 and 3), there was an increase in accumulation for most micronutrients, especially for Zn in the bean (Table 4). The high demand for micronutrients during fruit maturation can cause temporary deficiency in coffee plants. Deficiency of any micronutrient limits their growth and production, even when all other essential nutrients are present in appropriate quantities (CARMO et al., 2012). Since berries are the preferential sinks during the reproductive period, it is important that nutrient supply through fertilization precedes the peaks of accumulation of elements in the berries, which occurs throughout the grain-filling and maturation period (PARTELLI et al., 2014; DUBBERSTEIN et al., 2016).

Conclusions

The accumulation of dry matter in bean, husk, and berry increases for all studied genotypes throughout berry maturation. There is a higher accumulation rate in beans initially, and after in the husk.

The concentrations of macro and micronutrients in bean, husk, and berry vary throughout the maturation cycle. In the bean, N had the highest concentration, while in the husk, K had the highest concentration.

Considering the accumulation per berry, N is the most accumulated macronutrient by the bean throughout maturation, while in the husk and berry, there is a higher accumulation of K. Among the micronutrients, Fe is the most micronutrient accumulated by the bean, husk, and berry. The Beira Rio 8 genotype accumulates more nutrients compared to others due to its high accumulation of dry matter in the berry.

The accumulation of nutrients considering the production of 1000 kg of beans at 49 WAF was increasing. The period of highest nutrient accumulation occurs with ripe berries, and the most exported nutrient through the berries is K, followed by N and Ca, what is quite important to fertilization management aiming at to restore soil adequate mineral levels to plants.

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