Dynamic of dry matter accumulation in berry, bean, and husk of six Coffea canephora genotypes during fruit maturation

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Abstract

Knowledge about the dynamics of dry matter (DM) accumulation in the berry components (bean and husk) throughout maturation process could help in the definition of the most adequate moment for the harvest of each genotype. For that, were studied the berry, bean, and husk DM accumulation dynamics during the fruit maturation process of six *Coffea canephora* genotypes, to identify the best berry harvesting stage. Berry samples were collected every two weeks at nine maturation moments/stages. The DM accumulation was initially the highest for berry and bean, while the highest increases in husk DM happened latter. Second order polynomial regressions were fitted for berry, bean, and husk DM accumulation over time. The berry, bean and husk DM accumulation increased as fruit maturation progressed, attaining the highest values in the final stages of red berries. Beira Rio 8 genotype presented the highest DM accumulation in berries, beans, and husk. Bamburral and P1 showed the lowest berry fresh mass (FM) to bean DM ratios, while A1 showed the greatest berry FM to bean DM ratio. 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.

1 Introduction

The Rubiaceae family include the genus *Coffea* and their 130 species[1]. A among them, the two species, *C. arabica* (Arabic coffee) and *C. canephora* (Robusta) that support the entire coffee trade[2]. Currently, one or both commercial coffee species are grown in about 80 tropical climate countries, with Robusta representing *ca*. 44% of world coffee production[3].

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)[4]. In *C. canephora*, branching is usually limited up to the 3rd order axes[5], unlike to what happens to *C. arabica*, which can develop 2nd to 5th order axes in three to four years after pruning[6].

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[7]. The coffee berries start to develop after a main flowering usually occurring after the in first spring rains[8]. 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[9]. Coffee tree phenology was firstly defined for *C. arabica*[10,11] and adapted for *C. canephora*[12,13], 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[14], 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 when mature due to the replacement of chlorophyll in the exocarp by red flavonoid pigments[15]. 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[16] (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[15]. In each berry of *C. canephora* usually are presented two seeds (beans), but cases of only one are also possible[17]. 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[18].

Robusta coffee, mainly in Brazil, is almost entirely subjected to dry processing, which is the cheapest form of transforming ripe berries into processed beans[19]. 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[20,21]. 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 accumulation dynamics of berry components (beans, and husk), as well as proportion of each one during the maturation phase, can be followed to predict the most adequate harvesting time, in order to ensure a high quality of yielded beans. Throughout the whole berry formation process, the accumulation of dry matter follows a sigmoidal trend, where the highest values in dry matter are found in the final stage of berry formation[22,23]. However, there is still a gap of knowledge regarding the dynamics of dry matter accumulation in the components of the berry throughout maturation process. It was hypothesized that the 1) different genotypes may show different dynamics in dry matter 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* and identify the best harvesting time to obtain the highest bean yield.

2 Results

2.1 Evolution of visual maturation of berries

The first full ripe berries appeared by the 39th WAF, while ten weeks later all genotypes had near all fully ripe berries (**Fig. 1**). The corresponding beans of each berry sample also showed visual modifications along the experimental period, with green berries usually having deformed and dark beans, while matured berries showed a lighter color and fully formed beans, the latter with commercial acceptance.

Except for Bamburral genotype, the berries usually took four weeks from the beginning of the maturation stage until reaching above 90% of mature fruits (**Fig. 1**). 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).

2.2 Berry dry matter accumulation

The studied genotypes showed similar dynamics in berry DM accumulation throughout maturation process (**Fig. 2**). The highest berry DM investment rate was observed in the period between the end of 'leaf and berry expansion' and beginning of 'maturation' phenophase (33rd to 41st WAF). Afterwards, during maturation phase, DM increase in berries was reduced, and stabilized at the end of maturation stage.

Beira Rio 8 presented the greatest berry DM along the experiment, varying between 291 to 542 mg berry^{-1} and showing a DM increase of 86% between the 33 and 45 WAF (**Fig. 2**). By contrast, P1 genotype showed the lowest berry DM in all the nine collecting dates, presenting a difference of 278 mg berry^{-1} when compared to the Beira Rio 8 by the end of the trail. Maximum berry DM values were found at fully ripe stage, which differed among the six genotypes. That value was attained at 45 WAF in Clementino and Beira Rio 8, at 47 WAF in Pirata, Bamburral and A1, and at 49 WAF in P1, reflecting maturation cycles length differences.

2.3 Bean and husk dynamics of dry matter accumulation

High bean DM per berry accumulation rate was observed 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 (**Fig. 3**). The greatest values of bean DM per berry in early/medium and medium genotypes occurred when berries were fully ripe, between 43 and 47 WAF, after that, the beans lost weight until the end of experimental period. Late genotype P1 had a different dynamic, and its bean DM per berry accumulation was prolonged until the last collection period.

Evolution of DM accumulation in beans (**Fig. 3**) was very similar to DM accumulation in berries (**Fig. 2**). As for berry DM accumulation, the Beira Rio 8 also had the greatest DM bean accumulation among all studied genotypes (**Fig. 3**), however, the difference of accumulated bean DM to the other genotypes was less expressive when compared to DM in berries (**Fig. 2**). P1 showed lower bean mass than the other genotypes until the 41st WAF, however, continued to gain weight until the last evaluated week and finished with higher bean weight than A1, positioning only behind Bamburral and Beira Rio 8 (**Fig. 3**).

During a transient period between the leaf area/berry expansion and the phases, husk had low rates of increment (**Fig. 4**), differently from DM accumulation in berries and beans (**Fig. 2** and **Fig. 3**). From the initial point of maturation (41 WAF) and onwards, Beira Rio 8 significantly increased the husk mass, up to maximal values at full maturation (45 WAF), being maintained afterwards (**Fig. 4**). Similar husk DM pattern of variation occurred in Bamburral, A1, Clementino and Pirata, although with lower values than Beira Rio 8. In contrast, P1 showed no significant husk DM variations during experimental period, presenting the lowest values among all genotypes from 41 WAF onwards.

Beira Rio 8 showed the greatest and the P1 the lowest values of husk DM, while the other genotypes showed the intermediate values that did not statistically differ most of times (**Fig. 4**). The greatest difference found between genotypes occurred at 45 WAF, when Beira Rio 8 had a husk DM berry^{-1} for 156 mg higher than P1, quantifying visible difference in the maturation stage between these genotypes (**Fig. 1**).

P1 presented high values of the berry FM to bean DM ratio at the beginning experimental time, what was reduced ratio during the berry expansion and maturation up to 45 WAF (**Fig. 5**). 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 at the last sampling time (**Fig. 1**), resulting in a low ripe berry FM. Similar dynamic to Clementino was observed in A1 genotype.

Bean and husk percentage in berry DM did not follow a same pattern over the experimental time among genotypes (**Fig. 6**). The highest values were obtained in pre-maturation period, after the end of berry expansion. Among genotypes, Bamburral and P1 had the highest percentage of beans, 69 and 66% at 39 and 45 WAF, respectively.

Pirata, Clementino and Beira Rio 8 showed maximum of about 60% of bean percentage (at 37 to 41 WAF), being at the beginning and end of the experimental period about 50% (**Fig. 6**). 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.

The yield components (berry fresh mass, berry dry mass, processed bean mass (BDM) and mass performances) were significantly different among the studied genotypes (**Table 1**). 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. The highest FM, DM, BDM and HDM were obtained in Beira Rio 8, while the lowest DM and HDM was obtained in P1 and BDM in A1. P1 and Bamburral presented the highest values for DM and BM performance, and lowest values of HDM performance.

3 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 color in six genotypes of *Coffea canephora*, to identify the best harvesting time to obtain the highest bean yield of each genotype.

The association of the DM dynamics to the berries exocarp color, brought a very practical reference to assist the farmer in deciding the ideal time to start the harvesting of the berries (**Fig. 1**), as the change in the color of the berries is the benchmark of the final maturation process. In a *Coffea arabica* genotype of early maturation cycle, a decrease of berry chlorophyll content to less than half is occured 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} of DM[24]. In fact, it is long known that the complete change in the color of the berries is the main visual criterion to identify the complete maturity of the berries, although difficulted by the absence of synchrony between the maturation of the exocarp-husk, and the endosperm - bean[15]. 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 (**Fig. 6**). 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 at 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 (**Fig. 6**). 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[8].

Although acting as strong sinks[25], the dynamics of accumulation in the two berry components (beans and husks) followed distinct patterns (**Fig. 3** and **Fig. 4**). 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 (**Fig. 3** and **Fig. 4**). 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[26,8,27]. The respiration produces ATP that can be used in metabolic processes related to expensive secondary metabolite production in beans, as are various phenolic components with protective roles in plants[28]. 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 (**Fig. 4**). This late investment in husk DM maturation would have the sense of biological protective role of the husk against predators and diseases[29]. Husks are considered a residual product of coffee processing by many coffee producers, but due to their high mineral content (P, N, Ca)[30], 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 (**Fig. 1**), which might have lower quality characteristics to coffee beverage[31]. 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 also additionally lead to physical problems in beans processing, resulting in a higher percentage of broken beans that depreciate coffee quality[27]. The defective coffee beans represent about 15-20% of coffee production on weight basis, generating 1.2 to 1.5 million tons in the world coffee industry every year, being rejected as undesirable for good beverage[32]. 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[32], 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 you run the risk of having maximum DM but not quality[33]. 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 (**Fig. 5**). The average increase in bean DM per berry was about 15% of all genotypes between 41 and 45 WAF (**Fig. 3**). The 45 WAF will be the best stage for berry harvest, with exception of Pirata (47 WAF) and P1 (49 WAF), that is tagged by black asterisk (**Fig. 3**). The proportion of beans and husk in DM of berry (**Fig. 5**) 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[34]. 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[35]. 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.

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.

4 Methods

4.1 Plant Material and Experimental Conditions

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[36,37]. The soil was classified as a Yellow Dystrophic Argisol[38].

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)[39,40] 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[41].

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.

4.2 Berry sampling and post harvesting process

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 (**Fig. 7**). 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.

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 until 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[5].

4.3 Statistical Analyses

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 software R[42] 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'[43], 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 with bean and husk percentage in dry mass of one berry, only interaction *p*-value was considered once the factors were not independently compared[44,45], 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.

Declarations

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Data Availability Statement: Publicly available datasets were analyzed in this study. The authors can provide the experimental data for all interested researchers.

Competing Interest Statement: The authors declare no competing interest.

Plant Experiment Statement: The authors declare that all plant collections and use were in accordance with relevant institutional, national, and international guidelines and legislation.

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Table

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). Estimated 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 performance	BM performance	HM performance
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	320.8 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	345.1 b	170.05c	175.0 b	59.3 b	49.3 c	20.0 bc	20.6 a
Beira Rio 8	1377.5 a	542.21a	298.0 a	244.2 a	60.6 ab	55.0 b	21.7 b	17.7 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

Figures

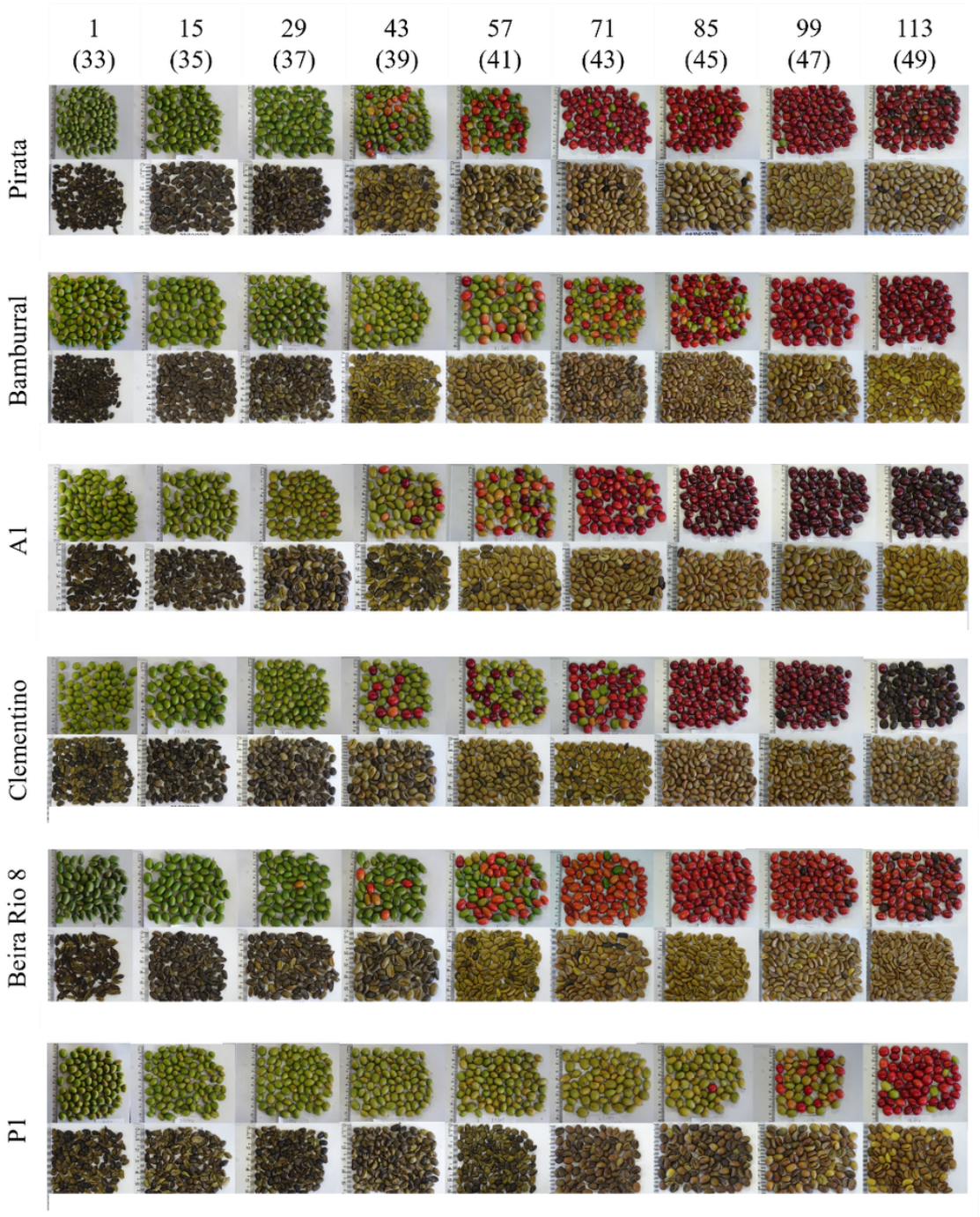

Figure 1

Evolution of visual maturation 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 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.

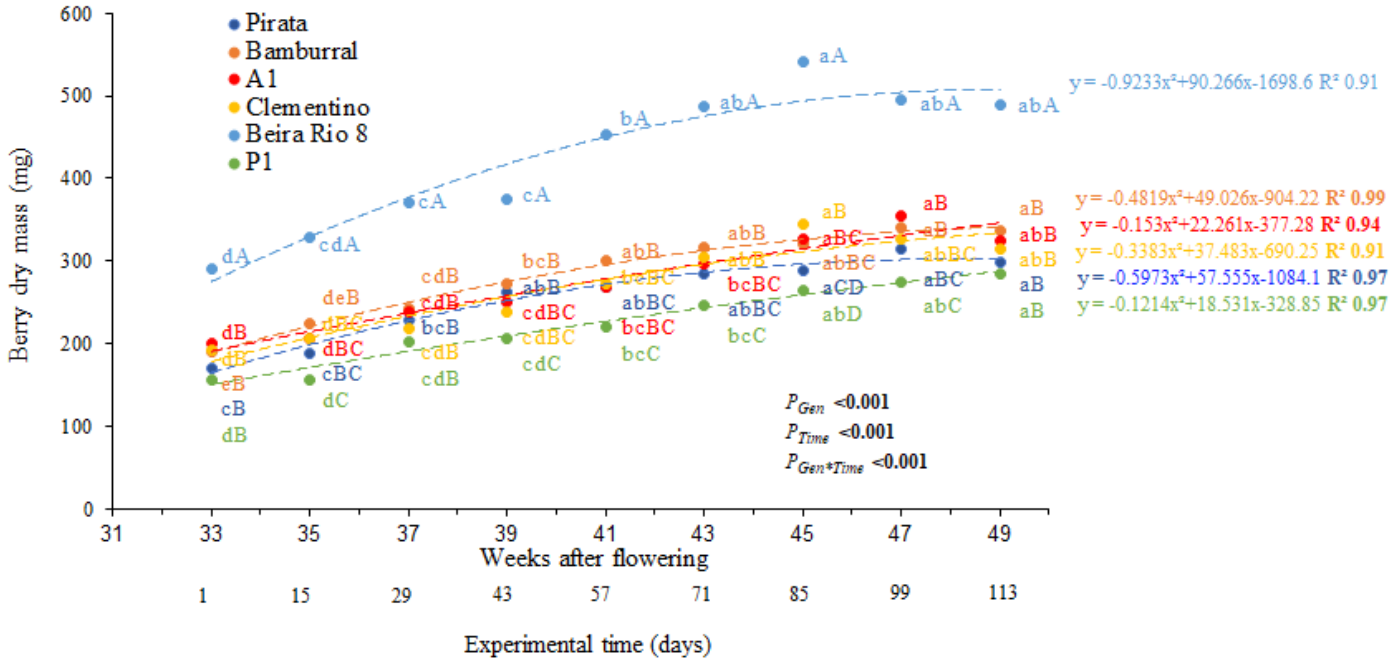

Figure 2

Berry dry mass (mg) 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). 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.

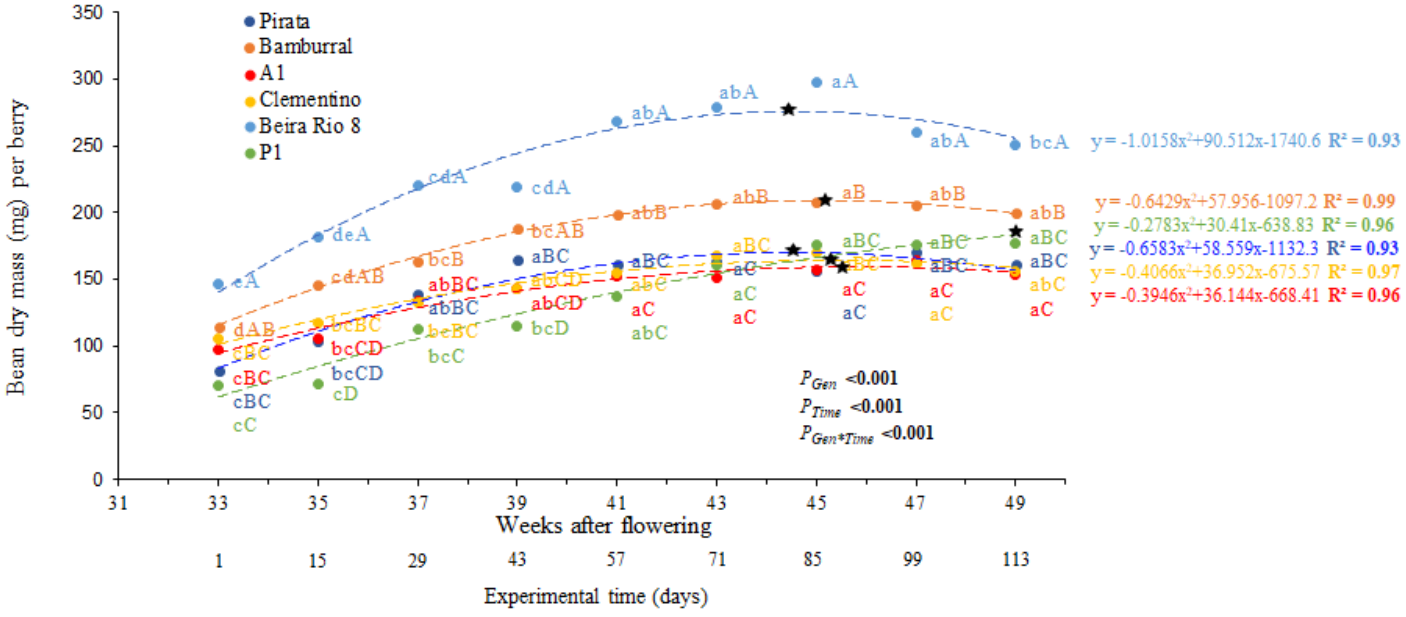

Figure 3

Bean DM in one berry (mg) 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). 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.

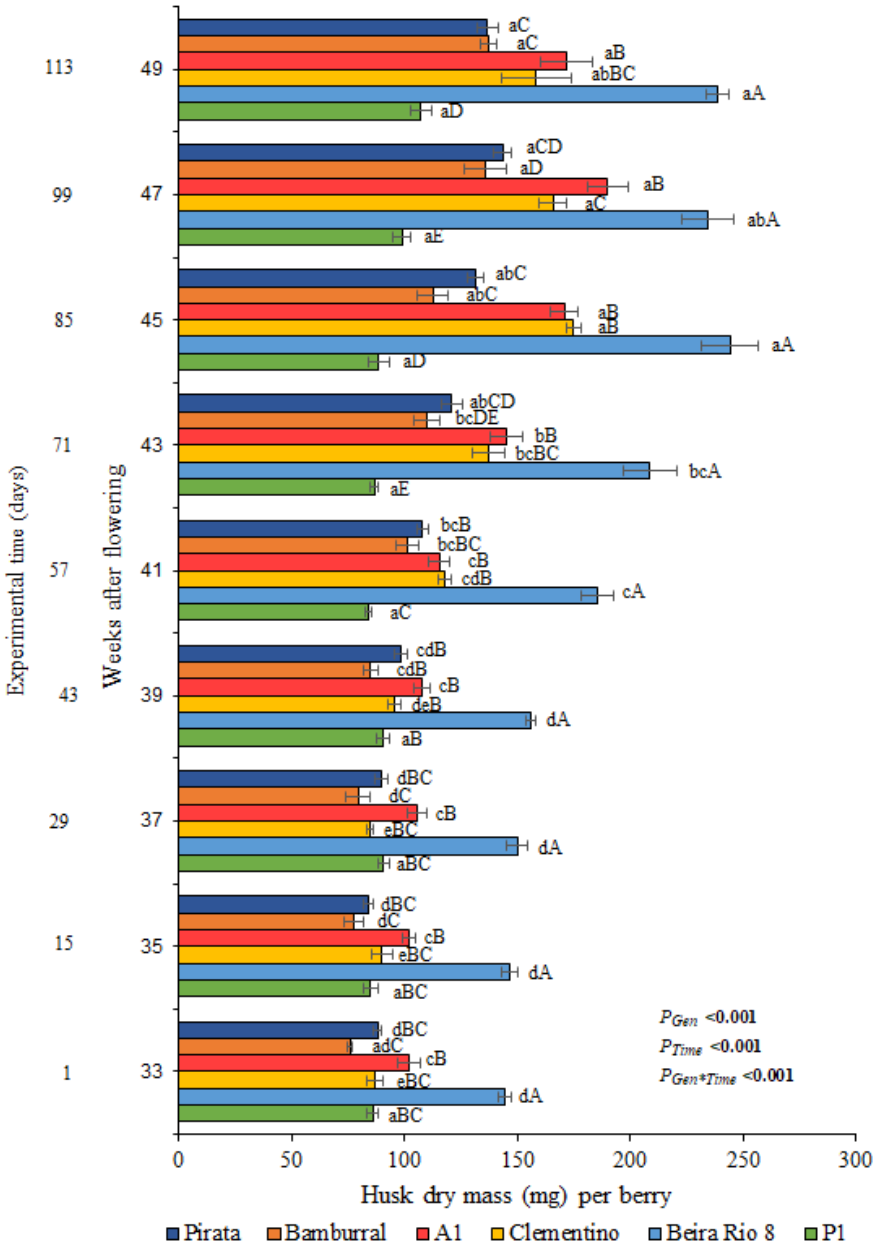

Figure 4

Husk DM (mg) per berry of six genotypes (Pirata, Bamburral, A1, Clementino, Beira Rio 8 and A1) 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. Mean ± SE and *P*-values (n=5) are 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.

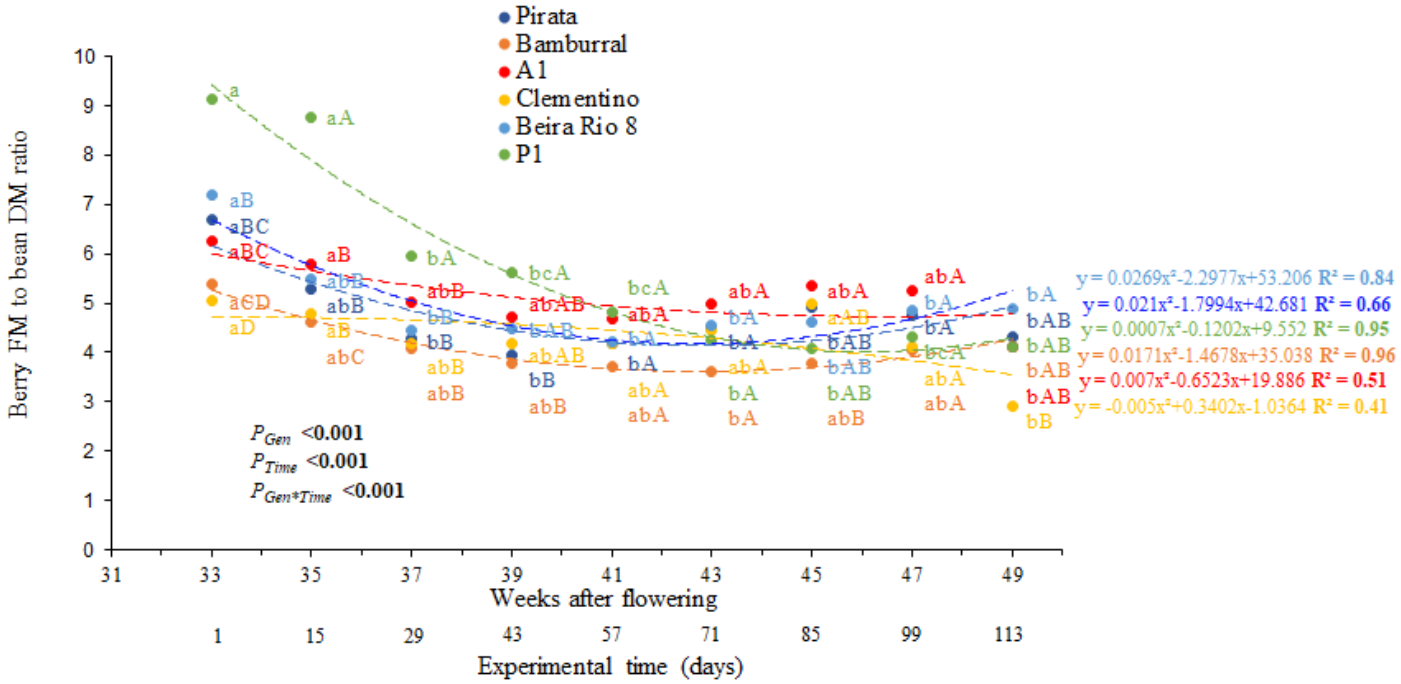

Figure 5

Second order polynomial regression for the berry FM to bean DM 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, 35, 37, 39, 41, 43, 45, 47 and 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 R^2 represent polynomial regression adjusted to each genotype, which were graphically presented in colors to facilitate genotype differentiation.

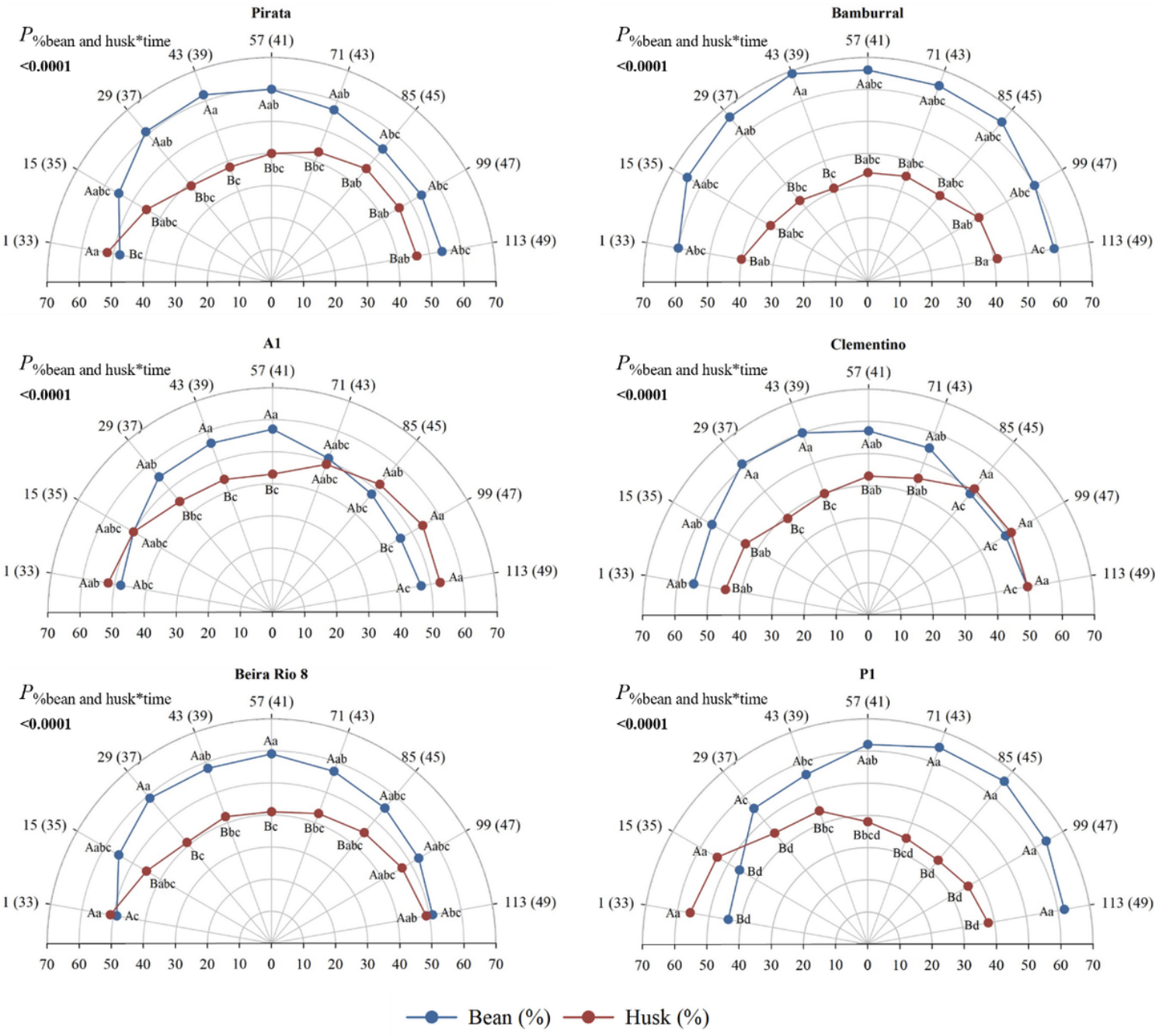

Figure 6

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).

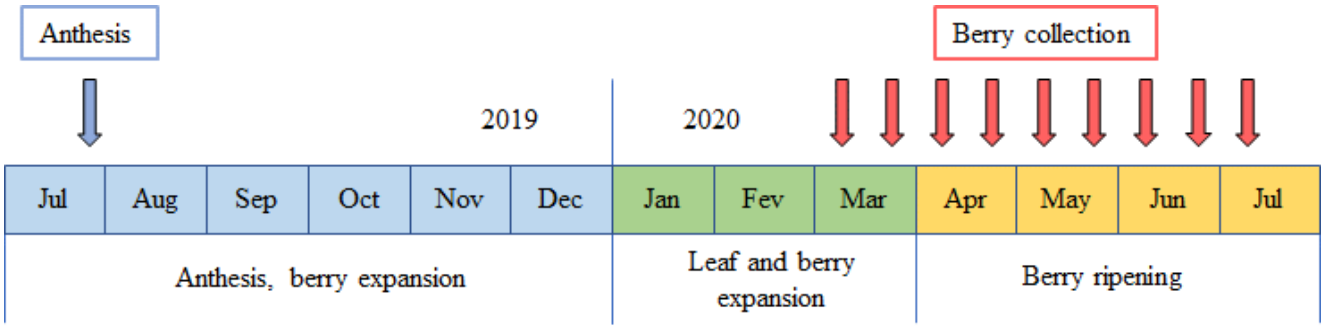

Figure 7

Phenological calendar of *Coffea canephora* during experimental period with indications of sampling / collection dates. Adapted from[16]).