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Methodologies to determine the ripening stage of coffee fruits

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Abstract

The asynchronous flowering of coffee trees results in uneven ripening, which makes harvesting ripe fruit crops difficult. To determine the ideal time for harvesting, representative sampling is required. However, existing sampling processes are labor-intensive. Therefore, this study aimed to determine the optimal number of plants and most efficient methodology to evaluate coffee fruit ripening. The experiment was conducted in Inconfidentes, state of Minas Gerais, with trials carried out on Catuaí Vermelho and Icatu Vermelho cultivars. The results of the fruit quantities were subjected to analysis of variance. An individual statistical analysis was performed and, if the homogeneity of residual variances was lower than seven, a joint analysis of variance was performed on the two crops. Each experiment had four treatments and six repetitions. We then performed a joint analysis of the data and used simulation to determine the optimal number of plants to be evaluated. The interaction between treatments and cultivars showed a significant difference in the green and cherry stages, but not in unripe, ripe, and dry fruits, and the optimal number of plants to sample varied by cultivar and treatment. It was found that the optimal number of plants to sample is 13 for the Icatu cultivar and 14 for the Catuaí cultivar using the central rosette harvesting treatment.

Keywords: Unripe fruits; coffee quality; statistical simulation.
Abbreviations: EDB _ randomized blocks; experimental units _EU; treatments _T; confidence interval _CI.

Introduction

High quality coffee has been desired by consumers, which has influenced producers to continuously refine their production processes to meet market demand. Among the stages of the production process, fruit harvesting at the stage of full ripening should be prioritized, which allows the beverage to express its maximum potential in quality.

However, the ripening of coffee fruits is not uniform due to some difficulties associated with the physiology of coffee. Because of its asynchronous flowering (Alvim, 1960), which leads to uneven ripening of fruits, harvesting of coffee plants can gather unripe fruits, which diminishes the quality of the beans and makes the beverage unpleasant (Aparecido et al., 2018).

This uneven ripening is influenced by climate components, such as temperature and rain, which can impair productivity and all phenological stages of coffee, especially flowering and fruiting (Bongase, 2017). Dutra Neto et al. (2017) emphasized that the physiology of the plant can be modified in regions with mild temperatures, which results in several blooms.

Due to its uneven ripening, sampling processes must be conducted before the harvest to determine the moment with the highest percentage of ripe fruits, prioritizing the production of specialty coffees.

In this sense, one of the stages of harvest planning is the sampling processes that need to be carried out in the crop to determine the percentage of fruit ripening (Ramos et al., 2018), and the harvest must start with the largest amount of ripe fruits.

Zhang and Ni (2021) described that the sample quality of a population affects the accuracy of the solution when the sample quantity is limited. When only a few samples are collected, the results can be biased, thus being unable to describe the phenomenon under study. To obtain reliable results, it is essential to choose a set of sub-samples that represent the population.

The definition of this optimal number of sub-samples for a population is essential to prevent costly and difficult work due to an excessive amount of samples. In the opposite direction, a scarce amount of samples is rarely able to fully represent the population, which increases the chances of wrong results that can lead to premature or late coffee harvests, impairing quality and even productivity.

Today, the coffee farmer needs a laborious methodology to be conducted for the accurate percentage of ripe fruits in a crop, which consists of randomized harvesting of plants for analysis (Martins et al., 2021; Tamayo-Monsalve et al.; 2022, Rosas et al., 2021). Consequently, this generates a huge volume of fruits, greater expenditure of time, cost, and labor, which, on certain occasions, ends up making the analysis unfeasible.

Thus, new methodologies must be developed to help the producer on deciding the best moment of harvesting and what should be the chronological order of the plots to be harvested. The scientific literature, in turn, lacks methodologies for sampling coffee fruits. Research to determine the stage of ripening of coffee tree based on computerized methodologies can be found (Ramos et al., 2017; Rodrígues et al., 2020); however, they are in

Table 1. Summary of the analysis of variance for the different cultivars for the treatments. IFSULDEMINAS – *Campus* Inconfidentes. Inconfidentes/MG, 2020.

FV	GL	F (p<0.05)			
		Green	Green-cane	Cherry	Raisin and Dry
Treatment (T)	3	0.0000*	0.3299^{ns}	0.0906^{ns}	0.0000*
Cultivars (C)	1	0.0002*	0.0000*	0.0000*	0.0000*
T × C	3	0.0144*	0.1045^{ns}	0.0051*	0.9142^{ns}
Repetition (cultivars)	10	0.0000*	0.0000*	0.0000*	0.0000*
CV%	-	18.65	15.83	10.89	8.59
>MSR/<MSR	-	1.05	1.94	3.79	3.86

MSR= Mean Square Residual. (*) Significant at 5% and (ns) not significant, according to the F test.

Table 2. Treatment means for the percentage of coffee fruits in the green and cherry ripening stages in the Catuaí and Icatu crops. IFSULDEMINAS – *Campus* Inconfidentes. Inconfidentes/MG, 2020.

	Green		Cherry	
Treatments*	Catuaí	Icatu	Catuaí	Icatu
1	13.55 a	18.54 a	23.33 a	44.06 ab
3	16.79 ab	22.22 a	24.94 a	47.24 b
4	17.99 ab	16.71 a	19.99 a	45.41 b
2	20.78 b	29.80 b	25.59 a	39.52 a

* The means followed by equal letters, in the same column showed no statistical difference by the Tukey's test at 5% significance.

experimental stage. Thus, this study aims to evaluate the optimal number of plants to determine the stage of ripening of coffee fruits and the most efficient methodology to be adopted.

Results and discussion

It was possible to perform a joint analysis between the cultivars by analyzing the quotient between the highest and the lowest residual mean squares of the treatments (Table 1) since we found that it was lower than 7 (Pimentel-Gomes and Garcia, 2002).

Using the analysis of variance, the interaction between treatments *versus* cultivars showed a significant difference in the green and cherry stages, showing that the cultivar influenced the treatments. However, in the green-cane, raisin, and dry fruit, this interaction did not show significance, that is, the methodologies can be adopted in both cultivars (Table 1).

In the treatment *versus* cultivar interaction in the green ripening stage in Catuaí crop, treatments 1 and 2 showed significant differences, and treatments 1, 3, and 4, or 2, 3, and 4 could be used to determine this stage. In the Icatu crop, treatments 1 and 3 for green fruits showed no difference when compared with the control (T4), being different only in treatment 2 (Table 2).

In the Catuaí crop, all treatments were effective in determining the cherry ripening stage since there was no significant difference when compared with the control. In the Icatu crop, for cherry fruits, treatments 4 and 3 differed from treatment 2, and treatments 1 and 2; 1, 3, and 4 showed no statistical differences (Table 2).

The results of the treatment means for the green and cherry ripening stages (Table 3) within cultivars and treatments were significantly different, which was expected considering the different harvesting time and the distinct characteristics that influence ripening. The Catuai Vermelho cultivar has smaller height, medium canopy diameter, and late ripening cycle, whereas the Icatu Vermelho has tall stature, very large canopy diameter, medium to late ripening cycle, and more uniform ripening compared to Catuai (Carvalho, 2008) The only exception was for the green fruits in the interaction between treatments and cultivars, in which treatment 4 showed similar results. The green-cane ripening stage showed no difference between treatments (Table 4), showing that the suggested methodologies were effective in determining this stage when compared with the control in all evaluated cultivars. Additionally, in the identification of the raisin and dry stages, treatments 1 and 4 differed statistically from treatments 2 and 3.

In the green-cane, raisin, and dry stages of the Catuai and Icatu cultivars, the results were different, which was expected since the cultivars have distinct ripening stages (Table 5).

Therefore, it is possible to recommend the producer to use treatment 1, central rosette collection, for the identification of any stage of ripening, as this treatment showed no difference when compared with the control.

By adopting the proposed methodology, the producer will be able to define the best harvest strategy within and between plots and, consequently, increase the quantity of ripe fruits, which is an extremely important factor in improving the quality of coffee beverage.

Besides, with this methodology, the coffee grower will be able to quantify the ripening progression more accurately in the different plots of the property, thus being able to manage the harvest labor and necessary post-harvest structure more appropriately.

The results obtained in this research present advantages over the methodology currently used by coffee growers. According to Martins et al. (2021), the methodology available for determining the stage of coffee ripening involves repeated counts of sampled fruits from some branches, followed by the evaluation of the percentage of each ripening stage by the producers. The authors also highlight that this process is laborious and subjective, present a reduced accuracy of results, as well as being excessively prolonged, which can affect harvest planning.

The methodology proposed in this research is more viable when compared with other methodologies described by Rosas et al. (2021) and Tamayo-Monsalve et al. (2022) since it reduces the volume of harvested fruits, and there is no need to harvest the plants entirely, providing greater time and labor savings since the sampling occurs only in the central rosette, reducing costs.

Some studies have been conducted to measure the accuracy

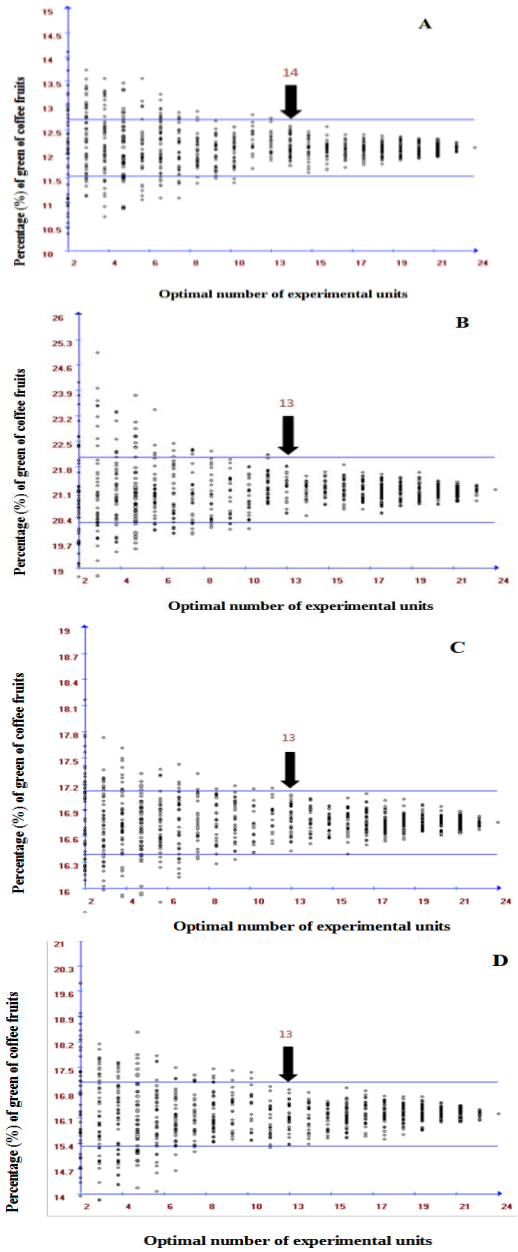

Fig 1. Number Experimental Units (EU) for fruits green coffee in the confidence interval within treatments 1, 2, 3, and 4 (Figures A, B, C, and D) to estimate the mean percentage of green fruits, in Cultivar Catuaí. IFSULDEMINAS – *Campus* Inconfidentes. Inconfidentes/MG, 2020.

of spectral images to determine the stage of coffee ripening, but limitations have been observed due to the architecture of the coffee plant and environment, making the proposal of this research applicable. Rosas et al. (2021), working with multispectral camera images to monitor coffee ripening, found that the images were able to discriminate ripening classes in most crops, but performance was greatly influenced by the pendulous load and canopy volume of the coffee plants.

In addition to defining the location for sampling, it is necessary to identify the optimal number of plants to be sampled. By analyzing only green fruits through simulation, it was observed that, to apply the treatment 1 methodology (Figure 1A) in the Catuaí cultivar, it is necessary to collect 14 experimental units (EU), indicating that this is the smallest number of EU presented no mean values out of the 95% confidence interval (CI), being sufficient to measure the ripening stage. For methodologies 2, 3, and 4, 13 EU are required (Figures 1 B, C, and D).

In the Icatu cultivar, 13 EU are required for the central rosette harvest methodology (treatment 1) (Figure 2 A). For treatment 2, 12 EU are required. For treatments 3 and 4, 11 and 15 EU, respectively (Figures 2 B, C, and D).

Therefore, the number of EU to be analyzed at the time of sampling for the Catuaí and Icatu cultivars may vary from 11 to 15 EU, depending on the methodology used. The experimental units (EU) must be evenly distributed throughout the crop to ensure an accurate quantification of fruit ripening. Plants located at the border or isolated within the plot should not be included in the evaluation. Plants that represent the population should be sampled, and plants with branches showing tip dieback cannot be sampled since the fruits will be dry, not representing the population under study.

The number of experimental units (EU) was reduced compared to the initial number of 24 EU. The studies by Silva et al. (2011) on sample size for morphological characterization of pepper fruits using the same methodology also concluded that the number of sampled peppers

Table 3. Treatment means of the Catuaí and Icatu cultivars in the green and cherry ripening. IFSULDEMINAS – *Campus* Inconfidentes. Inconfidentes/MG, 2020.

	Green		Cherry	
Treatments*	Catuaí	Icatu	Catuaí	Icatu
1	13.55 a	18.54 b	23.33 a	44.06 b
2	20.78 a	29.80 b	25.59 a	39.52 b
3	16.79 a	22.22 b	24.94 a	47.24 b
4	17.99 a	16.71 a	19.99 a	45.41 b

*The means followed by equal letters, in the same column, showed no statistical difference by the Tukey's test at 5% significance.

decreased by around 50% while maintaining the same accuracy as the standard methodology.

Costa et al. (2023) corroborated the findings of this study when evaluated the optimal number of plants required to measure the ripening stage of the Catucaí 2 SL cultivar by concluding that at least 11 EU were necessary in the analysis.

Materials and methods

Location and plant materials

The experiment was conducted at the Santa Luzia site, Córrego da Onça neighborhood in the rural area of the municipality of Inconfidentes, south of the state of Minas Gerais. Two experiments were conducted independently in a field of *Coffea arabica*, with the cultivar Catuaí Vermelho with 20 years of age (Fig 3), spacing 3.5 × 1.2 meters, and area of 1.0 hectare; and with cultivar Icatu Vermelho with 30 years of age, spacing 3.0 × 1.5 meters, and area of 0.8 hectare. Both were positioned facing east-west and the last renewal of the crop, via skeleton cut pruning, was in 2017. The site is situated at 1,100 m altitude, at 22º20'44.85'' South latitude and 46º16'54.78'' West longitude.

Experimental design and experimental procedure

The experimental design was in randomized blocks (RBD), with four treatments (T), and six replicates in each crop. The blocks were randomly distributed in the crops so that the determination of ripening stage could represent the plots. No border plants were used in the evaluations. Each block consisted of 12 plants, divided into four experimental units (EU) with three plants each.

The treatments were: T1) harvest of one or two central rosettes, which occurred according to the number of rosettes per branch, even number for harvest of two rosettes, odd number for harvest of one rosette, taken from a plagiotropic branch per quadrant, in the upper, middle, and lower thirds; T2) harvest of the first and last rosettes of a plagiotropic branch per quadrant, in the upper, middle, and lower thirds; T3) harvest of all fruits from a plagiotropic branch per quadrant, in the upper, middle, and lower thirds; T4) control, harvest of all fruits from the plant.

Traits measured

After the harvest, the fruits from the three plants (EU) in each treatment were manually homogenized and then a 1 L sample was taken. Green fruits, green cherries, ripe cherries, overripe fruits, and dry fruits were counted and the percentage of fruits in each ripening stage were determined.

Harvests always occurred in the same branches for all treatments. The harvest followed the sequence: T1, T2, T3, and T4, with replacement of the fruits harvested in treatments 1 and 2 to compose treatments 3 and 4. This procedure was performed for the four EU, from which the average was obtained for each treatment.

The harvesting was conducted from June 1 to July 12, 2019. The first cultivar harvested was the Icatu Vermelho and then

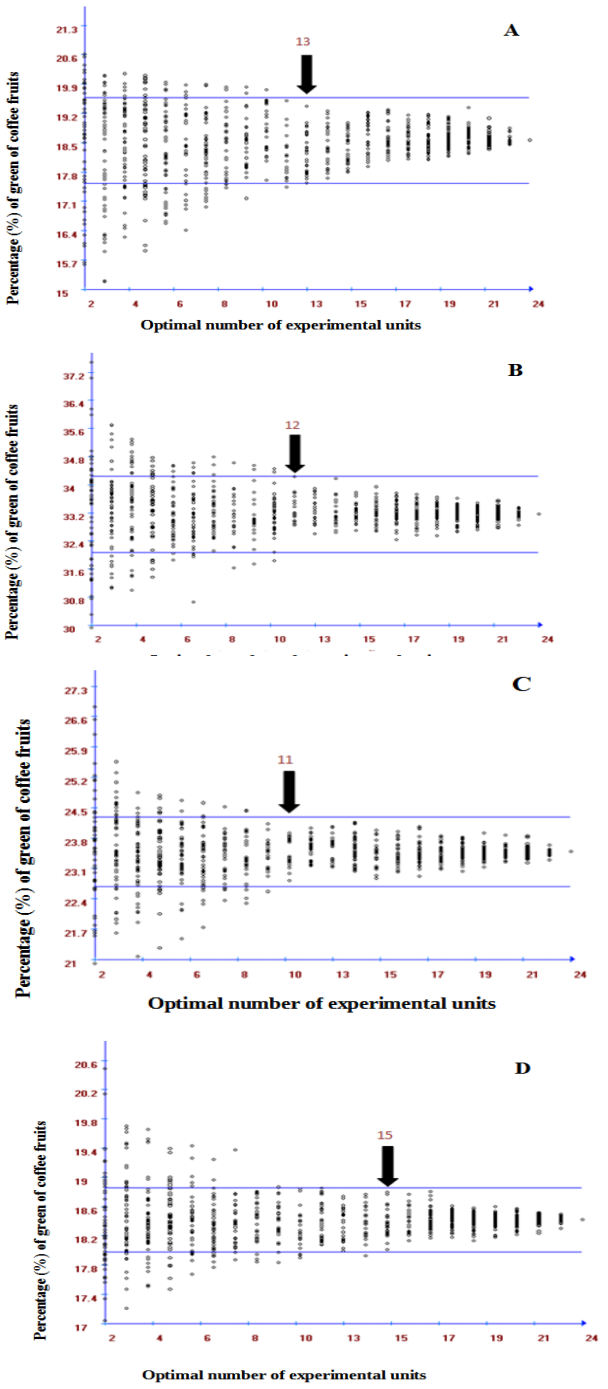

Fig 2. Number Experimental Units (EU) for fruits green coffee in the confidence interval within treatments 1, 2, 3, and 4 (Figures A, B, C, and D) to estimate the mean percentage of green fruits, in Cultivar Icatu. IFSULDEMINAS – *Campus* Inconfidentes. Inconfidentes/MG, 2020.

Table 4. Treatment means for the percentage of coffee fruits at green, raisin, and dry ripening stages for the two cultivars IFSULDEMINAS – *Campus* Inconfidentes. Inconfidentes/MG, 2020.

Treatments*	Green-cane	Raisin and Dry
2	10.67 a	31.50 a
3	10.51 a	33.89 a
1	10.12 a	40.14 b
4	9.52 a	40.42 b

*The means followed by equal letters, in the same column, showed no statistical difference by the Tukey's test at 5% significance.

Table 5. Mean percentage of ripening stages for Catuaí and Icatu cultivars in the green-cane, raisin, and dry ripening stages. IFSULDEMINAS – *Campus* Inconfidentes. Inconfidentes/MG, 2020.

*	Catuaí	Icatu
Green-cane	4.85 a	15.57 b
Raisin and Dry	54.41 b	18.56 a

*The means followed by equal letters, in the same column, showed no statistical difference by the Tukey's test at 5% significance.

Fig 3. Separation of coffee fruits in the ripening stages: green (A), cane green (B), ripe (C) and dry (D).

the Catuaí Vermelho, and each block was harvested in a maximum of two days. For the collection of all treatments, the soil under the plants was kept covered with a common harvesting cloth to prevent the loss of any fruits that might have fallen. Treatments T1, T2, and T3 were collected with the aid of a sieve to make the subsequent separation of the fruits faster. Treatment T4 was harvested directly onto the cloth, as it involved a larger volume of fruits that made the use of a sieve unfeasible at the moment of harvesting.

The fruits collected in treatments T1, T2, and T3 were not cleaned, with the leaves being removed by hand. In treatment T4, however, the fruits were cleaned with the help of a sieve.

Statistical analysis

The results of the quantities of unripe fruits, partially ripe fruits, ripe cherries, overripe cherries, and dry fruits were subjected to analysis of variance, and the means were compared using the Tukey's test at a 5% level of significance. An individual statistical analysis was performed and, if the homogeneity of residual variances was lower than seven (Pimentel-Gomes and Garcia, 2002), a joint analysis of variance was performed on the two crops. The homogeneity of residual variances was determined by the quotient between the highest and lowest residual mean square.

The simulation method, consisting of sub-sample resampling described by Silva et al. (2011), was used to quantify the optimal number of plants, for which the arithmetic means of the estimated percentage of unripe fruits were analyzed based on 2 to 24 EU.

Sample sizes were analyzed ranging from 2 to 24 EU, with 50 draws for each size, simulating a sampling process with data replenishment. For example, to obtain the sample mean estimate for a sample of 4 EU, the software used performed 50 consecutive draws of 4 EU from the original sample of 24 EU and estimated the percentage of unripe fruits from the 50 values obtained.

The mean estimates for each size of the analyzed samples were plotted on a graph for analysis and visualization of the stabilization according to the number of experimental units (EU) of each simulated sub-sample for each treatment. This occurred when the size of the sub-samples adequately represented the reference sample. It was considered that the small sample size represented the reference sample when there were no simulated values out of the confidence interval (95% CI) for this sample, with a probability of 95%. For the estimation of the minimum number of EU, sub-samples started from two EU, with an increase of one EU from one analysis to the next. The number of EU has increased successively until reaching a total of 24. The simulations and analysis of variance were performed using the GENES program, version 2006.4.1 (Cruz, 2013).

Conclusion

The optimal number of plants to sample to represent the crop was 13 EU for the Icatu cultivar and 14 EU for the Catuaí cultivar using central rosette harvesting.

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References

Alvim PT (1960) Estresse de umidade como requisito para o florescimento do cafeeiro. Ciência. 132: 354.

Aparecido LEO, Rolim GS, Moraes JRSC, Valeriano TTB, Lense GHE (2018) Maturation periods for *Coffea arabica* cultivars and their implications for yield and quality in Brazil. Journal of the Science of Food and Agriculture. 98(10): 3880–3891. DOI 10.1002/jsfa.8905

Bongase ED (2017) Impacts of climate change on global coffee production industry: Review. African Journal of Agricultural Research. 12(19):1607-1611.

Carvalho CHS (2008) Cultivares de café: origem, características e recomendações. Brasília/DF: Embrapa Café. 334 p.

Costa WH, Melo BMR, Ferreira S, Castro DG, Marcílio MH, Alexandre A (2023) Metodologias alternativas na quantificação do percentual de frutos verdes do cafeeiro. Magistra. 33.

Cruz, CD (2013). GENES - a software package for analysis in experimental statistics and quantitative genetics. Acta Scientiarum. 35(3): 271-276.

Dutra Neto C, Uetanaboro APT, Oliveira E, Silva GR, Oliveira D P A, Souza EQ (2017) Indicação geográfica do planalto de Vitória da Conquista, denominação de origem para o café. Revista Extensão & Cidadania. 4(7):103- 114.

Martins RN, Pinto FAC, Queiroz DM, Valente DSM, Rosas JTF (2021) A novel vegetation index for coffee ripening monitoring using aerial imagery. Remote Sensing. 13(2): 263. DOI: 10.3390/rs13020263.

Pimentel-Gomes F, Garcia CH (2002) Estatística aplicada a experimentos agronômicos e florestais: exposição com exemplos e orientações para uso de aplicativos. 14ª ed. Editora FEALQ: Piracicaba/SP. 309 p.

Ramos PJ, Avendaño J, Prieto FA (2018) Measurement of the ripening rate on coffee branches by using 3D images in outdoor environments. Computers in Industry. 99:83-95. DOI: 10.1016/j.compind.2018.03.024

Ramos PJ, Prieto FA, Montoya EC, Oliveros CE (2017) Automatic fruit count on coffee branches using computer vision. Computers and Electronics in Agriculture. 137: 9-22. DOI: 10.1016/j.compag.2017.03.010.

Rodríguez JP, Corrales DC, Aubertot J-N, Corrales JC (2020) A computer vision system for automatic cherry beans detection on coffee trees. Pattern Recognition Letters. 136: 142-153. DOI: 10.1016/j.patrec.2020.05.034.

Rosas JTF, Pinto FAC, Queiroz DM, Villar FMM, Valente DSM, Martins RN (2021) Coffee ripening monitoring using a UAV-mounted low-cost multispectral camera. Precision Agriculture. 23: 300-318.

Silva AR, Rêgo ER, Cecon PR (2011) Tamanho de amostra para caracterização morfológica de frutos de pimenteira. Horticultura Brasileira. 29:125-129. DOI: 10.1590/S0102-05362011000100022

Tamayo-Monsalve MA, Mercado-Ruiz E, Villa-Pulgarin JP, Bravo-Ortíz MA, Arteaga-Arteaga HB, Mora-Rubio A, Alzare-Grisales JA, Arias-Garzon D, Romero-Cano V, Orozco-Arias S, Gustavo-Osorio G, Tabares-Soto R (2022) Coffee maturity classification using convolutional neural networks and transfer learning. Ieee Acess. 10: 42971-42982. DOI: 10.1109/ACCESS.2022.3166515

Zhang BY, Ni YQ (2021) A hybrid sequential sampling strategy for sparse polynomial chaos expansion based on compressive sampling and bayesian experimental design. Computer Methods in Applied Mechanics and Engineering. 386: 114130. DOI: 10.1016/j.cma.2021.114130.