https://doi.org/10.18406/2316-1817v14n120221707 e-ISSN 2316-1817

Evaluation of harvest yield and beverage quality of coffee under ethylene application

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Received in: 22/03/2022
Accepted in: 23/08/2022

Abstract

The coffee plant is characterized by the irregular ripening of its fruits. This uneven ripening often makes it impossible to optimize its harvest, since green fruits are more adhered to the plant than those in the ripe and overripe stages. In addition, it can influence the final product's beverage quality. The use of ethylene is an alternative to optimize and increase the harvest yield of coffee, besides reducing expenditures on labor and post-harvest ground picking. This study was carried out to examine the harvest yield of coffee variety Mundo Novo IAC 379/19 under different ethylene rates as well as to analyze beverage quality in the different treatments. The experiment was laid out in a randomized-block design with four treatments (ethylene rates: 0, 300, 500, or 700 mL ha^{-1}). The plots consisted of nine plants and three replications, but only the three central plants were evaluated. Results were analyzed by Tukey's test at a significance level of 5%. The rates of 700 and 300 mL ha^{-1} provided the lowest amount of green fruits, whereas the percentage of ripe fruits was equivalent between treatments. The treatment with 700 mL ha^{-1} resulted in the highest percentage of fruits in the overripe stage, among the evaluated rates. Ethylene use did not increase harvest efficiency. Control treatment provided a significantly higher number of green fruits. Additionally, the use of ethylene-induced changes in the chemical composition of the bean and beverage quality.

Keywords: *Coffea arabica*. Fruit ripening. Plant hormone.

Introduction

Harvesting is the most expensive operation in the entire coffee production chain, representing 50% of the labor required in the fields and accounting for 25 to 35% of the direct annual production cost (MATIELLO *et al*., 2005).

Coffee fruits do not ripen evenly, so the same plant can have beans in different maturity stages. This phenomenon can be a problem, as it interferes with the choice of the ideal period to start the harvest, besides influencing the final product's beverage quality (SILVA *et al*., 2009).

To achieve good harvest yields, ripe beans must present in greater amounts than green beans, since the latter hinders strip-picking by hand and incur a higher cost at the end of the process.

An alternative to facilitate the harvesting process is the use of the plant hormone ethylene, which is present in most plant cells and produced mostly by injured organs, dormant buds, and in the period of tissue senescence and abscission. The phytohormone is applied to coffee fruits to ensure uniformity and accelerate the grain ripening period. The commercial product has a contact action and needs specific regulation so that the spraying reaches the fruits correctly. It is important to apply it to fruits in an already-developed stage to ensure the expected ripening (SCUDELER *et al*., 2004).).

This study was carried out to examine the harvest yield of coffee variety Mundo Novo IAC 379/19 under different ethylene rates as well as to analyze beverage quality in the different treatments.

Material and methods

The study was developed on the Santa Rita farm, owned by coffee grower José Laurício Gois and located in the municipality of Ouro Fino, the southern region of Minas Gerais, Brazil. The experiment took place in a 10-year-old coffee crop planted at a spacing of 2.7 m between rows and 1.2 m between plants, using variety Mundo Novo IAC 379/19. The experiment was laid out in a randomized-blocks design, with the plots consisting of nine plants with three replications. Only the three central plants of each plot were evaluated.

The treatments, which involved ethylene application, were as follows: T1 = 0 mL ha^{-1} (control), T2 = 300 mL ha^{-1}, T3 = 500 mL ha^{-1}; and T4 = 700 mL ha^{-1}, with the treated area corresponding to 0.039 ha^{-1}. The commercial product used was Ethrel, from Bayer S.A., whose toxicity is classified as highly toxic by contact action. The rate recommended by the manufacturer corresponds to that used in treatment T4, and the others were defined to determine whether lower rates of the product could also ensure satisfactory results, aiming at product economy.

The application was carried out with a motorized backpack sprayer (Yamaho LS-937) in the middle third of the plant, in the morning, through a jet directed at the fruits. The procedure took place on May 14, 2016, a period in which 90% of the fruits were physiologically mature. According to the descriptions of the product given in the package insert, it is possible to identify whether the fruits are mature by cutting them with a sharp material: a hard interior with the seed formed indicates that the fruit is physiologically mature.

Due to the high incidence of rainfall in the region, the harvest had to be performed 30 days after the application of the Ethrel product, that is, on June 13, 2016. Table 1 shows the total precipitation on the Santa Rita farm in the period from May to June 2016 (index obtained from a rain gauge situated at the experiment site).

The beans were harvested with a manual strip-picking tool, so coffee fruits at different stages of maturation were harvested. The time spent by the operator in all repetitions of the treatments was counted. Once harvested, the fruits of each treatment were packed in jute bags and sent to the cement yard, where they were dried to 11 to 12% moisture. During this period, care was taken in turning the coffee in the yard during the day, which was performed every 45 min. The coffee was stacked in the afternoon, with the aid of an implement, to avoid wetting with dew.

Physicochemical analyses of the coffee samples at different stages of maturation were carried out at the laboratory of the "Dr. Alcides Carvalho" Agricultural Research Corporation of Minas Gerais (Epamig), in Lavras/MG. Moisture was determined in a ventilated oven at 105 ºC (± 1 ºC), for one day, following Brasil (1992). The beans of each sample were ground in a mill (model TE 631/2, Tecnal) for 1 min. After grinding, they were packed in plastic packaging and stored in a freezer at −18 ºC until all analyses were carried out. Electrical conductivity was measured with a sample soaking time of 5 h, following the method of Loeffler, Tekrony, and Egli (1988). Potassium ion leaching was determined also with a soaking time of 5 h, as proposed by Prete (1992); whole beans were used for this analysis. Titratable acidity was determined as per the Association

Table 1. Total precipitation in the months of May and June 2016, on Santa Rita farm, in the municipality of Ouro Fino - MG. IFSULDEMINAS, Inconfidentes Campus, Inconfidentes - MG, 2022.

Month	Total precipitation (mm)
May	62 mm
June	107 mm
Mean	84.5 mm

Source: authors' work.

of Official Analytical Chemists (AOAC, 1990). Sugar extraction was performed in accordance with the method of Lane and Enyon, cited by AOAC (1990,) and determined by Somogy's method, adapted by Nelson (1994). Polyphenols were hot-extracted by the method of Goldstein and Swain (1963), using 50% methanol as the extractor identified by the Folin Denis method, as described by the AOAC (1990).

Sensory analysis of the treatments was also carried out by a private company that works with the purchase and sale of coffee located in the municipality of Ouro Fino/MG, on June 30, 2016. Through the cup test, the taster was able to assign scores to representative samples of each treatment, in addition to evaluating 17#-sieve-up percentage and bean moisture. Before the roasting process, intrinsic and extrinsic defects were removed. The samples were roasted for 24 h before the tasting began. The coffee beans were medium-roasted, meaning the colors of the beans varied between shades of brown to reddish brown, after a process that can last from 9 to 11 min.

Sensory analysis protocol provided by the Specialty Coffee Association (SCA) was adopted, and the final results of the sensory evaluation were obtained using the SCA classification scale (2016) (Table 2).

Results were analyzed by Tukey's test with a nominal significance level of 5%. Statistical analyses were performed using Sisvar computer software (FERREIRA, 2011).

Results and discussion

Table 3 shows the data on the percentage of green, ripe, and overripe coffee beans between the tested treatments.

Ethylene application at the rates of 700 and 300 mL ha^{-1} provided a significantly lower number of unripe fruits at harvest than the control treatment, which did not involve the application of the product. This result corroborates those published by Ferrari *et al*. (2009), who observed that at any ethylene application flow rate used in cultivar Mundo Novo, the presence of unripe fruits was significantly lower compared with the control.

There was no significant difference between treatments for ripe fruits. The percentage of fruits in the overripe stage, however, was highest in the treatment that involved 700 mL of ethylene, which can be explained by the longer time the fruits remained on the plant. Nonetheless, this result is contrary to that found by Carvalho *et al*. (2003), who tested the efficiency of Ethephon on

Table 2. Classification for sensory analysis of specialty coffees, according to the SCA (2016) protocol. IFSULDEMINAS, Inconfidentes Campus, Inconfidentes - MG, 2022.

Total score	Specialty description	Classification
95-100	Outstanding	Super premium specialty
90-94	Exceptional	Premium specialty
85-89	Excellent	Specialty
80-84	Very good	Special
75-79	Good	Good/normal quality
70-74	Weak	Medium quality
60-70		Exchange grade
50-60		Commercial
40-50		Low grade
< 40		No grade

Source: authors' work.

Table 3. Mean values of percentage of green, ripe, and overripe coffee beans harvested in the different treatments. IFSULDEMINAS, Inconfidentes Campus, Inconfidentes - MG, 2022.

Treatment	Green (%)	Ripe (%)	Overripe (%)
0 mL	36.52 a*	13.42 a	50.05 b
300 mL	22.73 bc	11.54 a	65.72 ab
500 mL	29.11 ab	19.37 a	51.51 b
700 mL	15.22 c	10.97 a	73.80 a

*Values followed by the same letters do not differ from each other by Tukey's test at the 5% probability level.

Source: developed by the authors.

ripening and earliness of harvest and observed that the control treatment led to the highest percentage of overripe fruits in cultivars Acaiá Cerrado and Catuaí Vermelho IAC-15.

Table 4 displays the variables of harvesting time, liters harvested, and liters harvested per minute.

Harvesting time, liters harvested, and liters harvested per minute did not differ statistically between treatments. Although we did not find differences, it is worth mentioning that Oliveira *et al*. (2007) evaluated the operational costs of mechanized harvesting of Arabica coffee and found that strip-picking by hand took approximately 376 h ha^{-1}, whereas mechanized harvesting time only 3.14 h ha^{-1} at a speed of 0.72 m s^{-1}, with a cost reduction that reached up to 62.36% compared with picking by hand.

Table 4. Mean values of harvesting time (in minutes), liters harvested, and liters harvested per minute in the different treatments. IFSULDEMINAS, Inconfidentes Campus, Inconfidentes - MG, 2022.

Treatment	Time	Liters	L/min
0 mL	6.92 a*	89.75 a	13.01 a
300 mL	5.28 a	77.75 a	14.18 a
500 mL	5.97 a	88.50 a	15.38 a
700 mL	5.95 a	80.25 a	13.43 a
CV (%)	12.36	18.15	12.61

*Values followed by the same letters do not differ from each other by Tukey's test at the 5% probability level.

Source: developed by the authors.

The samples were analyzed for beverage score, 17#-sieve up percentage, and income percentage by the company (Table 5).

As demonstrated and according to the grading scale used, the beverage score for the control treatment fit the medium quality category. The other treatments resulted in a beverage of good/normal quality, and it can be stated that the greater presence of green fruits in the control treatment was what led it to a lower score.

This finding shows that the plant hormone did not negatively influence beverage quality, corroborating the results found by Carvalho *et al*. (2003), who evaluated the use of Ethephon on the beverage quality of three coffee cultivars and found that the use of the plant hormone did not interfere with the final quality of the beverage. This result was also similar to those observed by Ferrari *et al*. (2009), who examined the use of Ethephon in cultivar Mundo Novo and described that the beverage quality of plants subjected to the application of the product was similar to that of plants that did not receive it. In this experiment,

Table 5. Beverage score, 17#-sieve up percentage, and income percentage. IFSULDEMINAS, Inconfidentes Campus, Inconfidentes - MG, 2022.

Treatment	Score	17# sieve up	Income
0 mL	74 points	30%	61%
300 mL	75 points	32%	60%
500 mL	78 points	33%	58%
700 mL	78 points	36%	60%

Source: developed by the authors.

the treatments with Ethephon application involving 1.0 L ha^{-1} of the commercial product were as follows: 1 – no application (control); 2 – application at a flow rate of 490 L ha^{-1}; 3 – application of 580 L ha^{-1}; 4 – application of 630 L ha^{-1} 20 days after all treatments; and 5 – application of 730 L ha^{-1}.

The 700 mL ethylene rate provided the highest percentage of 17#-sieve-up beans. This result is in disagreement with the reports of Borges *et al*. (2002), who also used the phytohormone and observed that the maturity stage of the fruits at the time of harvest did not influence the classification of the beans by size.

Table 6 describes the total soluble solids content, total titratable acidity, polyphenols, potassium leaching, and electrical conductivity of samples in the different treatments.

According to Costa *et al*. (2004), total soluble solids (TSS) play an important role when it comes to fruit quality since they influence the biological, chemical, and thermophysical properties of the fruit. A greater amount of TSS is desired from both the standpoints of industrial performance and contribution to ensuring the body of the beverage (RODRIGUES *et al*., 2019). There was a significant difference in TSS levels between treatments (Table 6). The 300 mL treatment stood out, providing the highest TSS content, whereas the 0-mL treatment (characterized by the absence of ethylene application) resulted in the lowest content, in significant quantity. The TSS value obtained in the 300 mL treatment was above the reference values for Arabica coffee, which are 20.3 to 34.4% for processed raw coffee beans, with a moisture content of 11 to 13% (wb) (MENDONÇA *et al*., 2007; ABRAHÃO *et al*., 2009; SANTOS; CHALFOUN; PIMENTA, 2009). Pimenta *et al*. (2005) found TSS values of 31.25% at the green, cherry, and overripe stages and 33.93% at the cane-green stage, which are within the reference range (21 to 34% TSS). These results are similar to those found in this study (except for the 300-mL rate, which resulted in a significantly higher value).

There was a significant difference in total titratable acidity (TTA) concentration between treatments (Table 6). As stated by Siqueira and Abreu (2006), TTA is a relevant property for the sensory analysis of coffee beverages. This attribute varies during the different stages of fruit ripening and is influenced by the region where the crop is located, the harvest method, processing, the type of drying, as well as the climatic conditions during harvest and drying. Carvalho *et al*. (1989) found that the higher the TTA value of the coffee fruit, the worse is the beverage quality and that fermented beans tend to have higher acidity levels. The values found in this study are within the range of 211.20 (for better-quality coffees) to 284.50 mL NaOH 0.1 N 100 g^{-1} (for worse-quality coffees), according to Carvalho *et al*. (1994), who observed that

Table 6. Total soluble solids content (TSS, %), total titratable acidity (TTA, mm NaOH 0.1 N 100 g^{-1}), polyphenols (POLI, %), potassium leaching (KL, ppm g^{-1}), and electrical conductivity (EC, μ S cm^{-1} g^{-1}) of samples in the different treatments. IFSULDEMINAS, Inconfidentes Campus, Inconfidentes-MG, 2022.

Treatment	TSS	TTA	POLI	KL	EC
0 mL	28.60 c*	228.78 a	7.76 b	61.77 b	125.18 b
300 mL	37.23 a	210.03 c	7.97 a	68.69 a	132.98 a
500 mL	34.25 b	216.89 b	7.70 b	60.96 b	133.73 a
700 mL	34.97 ab	196.57 d	6.85 c	35.42 c	68.56 c
CV (%)	2.43	0.89	0.75	1.63	0.86

*Values followed by the same letters do not differ from each other by Tukey's test at the 5% probability level.

Source: developed by the authors.

higher TTA values indicate a higher degree of fermentation in worse-quality coffees. The 700 mL treatment provided the lowest acidity concentration, making it the best for this trait.

Polyphenols differed significantly between treatments (Table 6). Pinto *et al*. (2001) observed that Rio beverage coffee had a higher number of polyphenols when compared with the Soft, Hard, and Riada beverages. Polyphenols ensure astringency in the drink and are related to the stage of maturity of the fruit. A lower percentage of polyphenols indicates that the fruit is closer to ripeness. The 700 mL treatment provided the lowest level of polyphenols, whereas the 0 mL (control) and 500 mL treatments exhibited no significant difference. The 300 mL treatment led to the highest percentage of polyphenols.

Prete (1992) described that there is a significant difference between the potassium leaching (KL) and electrical conductivity (EC) values in defective beans: the more deteriorated the membrane, the higher the KL and EC. Additionally, the author found that at the temperature of 30 ºC, coffees harvested when ripe, that is, in the 'cherry' and 'overripe' stages, showed lower KL and EC values compared with green beans. This fact confirmed the influence of the green defect on these values and showed that higher KL and EC values tend to lead to lower beverage quality. High KL and EC values can be related to the coffee deterioration process and loss of its quality, and have been considered important indicators of damage to the cell membrane of the bean (PRETE; ABRAHÃO, 1995; PIMENTA *et al*., 2008). The lowest KL value was found in the 700 mL treatment (Table 6), indicating better beverage quality. On the other hand, the 300 mL treatment exhibited the KL highest value, whereas the 0-mL (control) and 500 mL treatments did not differ statistically from each other, but were inferior to the 700 mL treatment and superior to the 300 mL treatment for this variable. The results of this study are in line with those reported by Malta, Pereira, and Chagas (2005), who found that normal beans had the lowest EC and KL values, differing statistically from defective beans.

According to Pereira (2008), the EC test aims to assess how damaged the cell membranes are, where membranes with a higher degree of injuries exhibit higher EC values. Malta, Pereira, and Chagas (2005) observed that solutes are leached more as the incidence of injuries increases, and EC also increases. The 700 mL treatment showed the lowest EC (Table 6), so it can be stated that it was the treatment with the least damaged beans. The 0 mL treatment (control) was inferior to the 700 mL treatment, but superior to the 300 and 500 mL treatments, since the latter obtained higher EC values and did not result in a significant difference between them. In view of the results, it can be affirmed that the treatment with the highest amount of ethylene contributes to the uniform ripening of the fruits and less damage to the cell membranes of the beans.

Table 7 shows the results of total sugars, proteins, caffeine, polyphenoloxidase enzyme activity, lipids, and the potential of hydrogen obtained with the different treatments.

According to the International Coffee Organization (ICO, 1991), the components that most influence the formation of flavor and aroma of coffee are total sugars, with the sweetness being a characteristic required in specialty coffees. It can be said that the higher the percentage of TS, the greater the potential for beverage quality and the more caramel-like flavor the coffee may acquire. Pinto *et al*. (2002) found different TS values in different types of coffee beverages. For Strictly Soft coffee, they found a value of 8.37%; for the Soft beverage, a value of 8.62%; and for the Just Soft beverage, a value of 8.34%. The 700 mL treatment proved to be statistically different from the others (Table 7), resulting in a potential for excellent-quality beverage,

Table 7. Total sugars (TS, %), proteins (PROT, %), caffeine (CAF, %), polyphenoloxidase enzyme activity (PPO, u min^{-1} g^{-1} of sample), lipids (L, %), and potential of hydrogen (pH) obtained with the different treatments. IFSULDEMINAS, Inconfidentes Campus, Inconfidentes - MG, 2022.

Treatment	TS	PROT	CAF	PPO	L	pH
0 mL	7.19 b*	12.50 a	1.11 a	45.23 b	13.19 a	5.59 a
300 mL	7.35 b	12.50 a	1.02b	45.81 ab	13.17 a	5.60 a
500 mL	7.50 b	12.17 ab	1.03 b	46.16 ab	13.39 a	5.62 a
700 mL	8.38 a	12.00 b	1.03 b	48.12 a	13.61 a	5.62 a
CV (%)	4.07	1.10	1.22	1.82	2.00	0.21

*Values followed by the same letters do not differ from each other by Tukey's test at the 5% probability level.
Source: developed by the authors.

since it was within the range reported by Pinto *et al*. (2002). Borem *et al*. (2008) found TS levels between 5 and 10%, which the current findings corroborate.

In terms of protein, two treatments exhibited higher percentage means, namely, 0 mL (control) and 300 mL, whereas the 700 mL treatment showed the lowest protein content (Table 7). Borém (2008) found an average protein content of 9.2% in raw Arabica coffee, a percentage below the result found in this study.

Control treatment (0 mL), characterized by the absence of ethylene application, showed the highest caffeine content (Table 7). Borém (2008) mentioned that, in *Coffea arabica* seeds, caffeine is found at concentrations varying from 0.53 to 1.45%, which was the same range found in our experiment.

The highest polyphenoloxidase enzyme activity values were observed in the coffees under the 700 mL treatment (Table 7), which corroborates the results observed in sensory analysis. However, this treatment did not differ statistically from the 300 and 500 mL treatments. Many studies demonstrate a relationship between polyphenoloxidase activity and coffee quality (AMORIM, 1978; LEITE, 1991). Oliveira (1972) studied different beverage classes and found significant differences in polyphenoloxidase activity only between the Soft and Rio beverage coffees, describing no variations in the other classes. Carvalho *et al*. (2003) obtained superior beverage quality in cultivar Catuaí Vermelho IAC-15 compared with the others; however, this was regardless of the use of Ethephon, since there was no significant difference between treatments for any of the evaluated traits.

The lipid content did not differ significantly between treatments (Table 7). Changes in lipid levels may be related to the various metabolic processes that occur in the bean in response to some stress suffered (RODRIGUES, 2015). The lipid values found in this study are within the range of 8 to 17% in raw coffee beans (*Coffea arabica* L.), as cited by Ravindranath *et al*. (1972) and Clifford (1985). Barbosa *et al*. (2002) reported that there was no direct relationship between bean quality and different levels of ether extract. The present results corroborate this statement since the oscillations observed in the lipid values did not lead to sensory alterations.

As for the potential of hydrogen (pH), the treatments showed no significant difference (Table 7). Siqueira and Abreu (2006) reported the importance of pH in sensory analysis, as this factor allows understanding of certain fermentation processes and helps to determine which management strategy is more appropriate in the post-harvest period, positively influencing beverage quality. The pH values found are within the range of 5.30 to 5.90 for processed coffee beans as reported by Siqueira and Abreu (2006).

Conclusions

The use of ethylene did not induce an increase in coffee harvest efficiency, in this experiment. The presence of green fruits was significantly higher in the control treatment, indicating the efficiency of the product. Under the presented experimental conditions, the use of ethylene caused alterations in the chemical composition of the bean and in the beverage quality of coffee by providing uniform ripening.

Acknowledgements

To the Federal Institute of Education, Science, and Technology of South of Minas Gerais – IFSULDEMINAS.

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