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RESEARCH ARTICLE

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Technical-economic viability of mechanized picking coffee (*Coffea arabica* L.) in up to three annual operations

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Abstract

Aim of study: Unavailability, coupled with the burden of labor for agricultural services nowadays, has made the mechanization process of harvesting of fallen coffee (*Coffea arabica L.*) essential. Although this operation has essential importance, it is often not monitored and executed in search of extreme quality. Considering the search for higher profits, this study aimed to analyze the performance of a coffee picker in three passes in an area in order to collect and process all the material and its economic viability.

Area of study: The experiment was carried out in July 2017 in the Brazilian Cerrado, in the municipality of Presidente Olegário, Minas Gerais, Brazil, at Fazenda Gaúcha/Café.

Material and methods: The amount of gathered coffee was equivalent to 600 kg ha^{-1} of processed coffee. The data from 2017 were used to analyze the economic viability of the picking operation. Treatments were distributed in split-blocks with three passes of the picking machine. The analyzed variables were picking and cleaning efficiency, picking losses, and percentage of vegetal and mineral impurities.

Main results: Coffee losses reached the minimum level in the third pass. However, the harvesting operation could be carried out at most twice in the same area from the economic point of view under the evaluated conditions.

Research highlights: Mechanized picking of coffee can be performed at most twice in the same area, providing a positive economic return.

Additional key words: agricultural mechanization; picking viability; machine efficiency; coffee losses; economic analysis.

Abbreviations used: AD (Anderson-Darling normality test); AFWD (auxiliary front wheel drive); Ck (coefficient of kurtosis); Cs (coefficient of skewness); CV (coefficient of variation); LCL (lower control limit); SPC (statistical process control); SQC (statistical quality control); UCL (upper control limit).

Authors' contributions: Conception, design, and execution of experiments: BRO, TOT, and LPO. Analysis of data: BRO, RPS, and LCGC. Contribution with reagents/materials/analysis tools: TOT. Drafting of the manuscript: BRO. All authors have read and approved the final manuscript. The four co-authors participated in all stages of the work, including the conception and design of the research, revision of the intellectual content, and drafting of the paper.

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Introduction

Coffee (*Coffea arabica* L.) is one of the most important crops in the world, growing in more than 60 countries (Läderach *et al.*, 2017). It is also considered one of the most valuable and marketed crops in the world, providing an important source of income and employment. Coffee plants present biennial production (Pereira *et al.*, 2011), which influences especially the difference in production between growing seasons. However, Brazil manages to leverage good productions and is the world's largest producer of coffee (Conab, 2019).

Harvesting is the main cultivation time, being the stage that most influences production costs (Lanna & Reis, 2012). Harvest losses can reach up to 20% (Tavares *et al.*, 2018) and, for this reason, picking the coffee fallen on the soil become the best option for coffee growers to increase production profitability and contribute to the management of one of its main pests, the coffee berry borer (*Hypothenemus hampei*) (Escobar-Ramírez *et al*., 2019). However, picking coffee is considered unfeasible when performed manually due to its low efficiency and high operating costs (Tavares *et al*., 2015). Mechanized picking is a great way to reduce operating costs when compared to the manual collection, but machines that perform this operation often have a low capacity for collecting and cleaning the coffee (Tavares *et al*., 2015).

The need for controlling and analyzing the performance and quality of operations arose along with the development of mechanization in the sector. Statistical quality control (SQC) has been an important tool for process evaluation. The statistical process control (SPC) allows expressing the results sequentially and in graphs aiming to classify the variability and stability of the evaluated process (Voltarelli *et al*., 2013) and its use has been increasingly expanding in agriculture, such as in coffee harvesting (Tavares, 2016), peanut sowing and digging operations (Zerbato *et al*., 2019), and bean harvesting (Silva *et al*., 2013).

Thus, in order to contribute to the improvement of the mechanical picking performance of sweeping coffee, this study aimed to analyze the efficiency of the operation carried out up to three times in the same area and its economic viability.

Material and methods

The experiment was conducted in July 2017 at Fazenda Gaúcha/Café, located in the municipality of Presidente Olegário, Minas Gerais, Brazil, close to the geographic coordinates 18°05′ S and 46°28′ W, with an average altitude of 968 m and an average slope of 3%. The soil of the experimental area is classified as a medium textured dystroferric Red Latosol (Oxisol), with a wavy relief (Embrapa, 2013). The climate is type Aw, according to Köppen classification (Alvares *et al*., 2013). Variety Catuaí Vermelho IAC, 144 with 11–12 years of age, was planted at a spacing of 4.0 × 0.5 m, totaling 5,000 plants ha^{-1} with a drip irrigation system.

Initially, the area was characterized by quantifying the total mass of the fallen material (vegetal impurities, coffee, and mineral impurities) present in the area (Table 1). The average level of coffee present on the soil was low (low-productivity year), with a value of 205.7 kg ha^{-1} (3.42 bags of processed coffee ha^{-1}), which represents 1.28% of the total amount of material to be picked. Thus, an adjustment was carried out to obtain the desired quantities of coffee under the plants. Coffee is a biannual crop, with a year of low production in which plants vegetate to show a full production in the subsequent year.

Table 1. Characterization of 30 m^2 in the interrow of five sample points.

Sample	Total mass (kg)	Coffee mass (kg)
1	60.50	1.252
2	73.25	0.216
3	57.25	0.884
4	67.50	0.368
5	35.50	0.366
Mean	58.80	0.617
Equivalence per hectare	19,600.0 kg	205.7 kg (3.42 bags)

This adjustment was carried out to adequate the amount of coffee to the conditions that would require more picking operations, according to the objective of this study. For this, an amount equivalent to 394.8 kg coffee ha^{-1} was distributed under the plants, which, in addition to the coffee already in the area, would reach an amount equivalent to 600 kg ha^{-1} (10 bags of processed coffee ha^{-1}). It represents the amount commonly found in high crops, which, in most cases, can reach up to 20% of losses (Alvarenga *et al*., 2018).

The experiment was carried out using four crop rows with a length of 170 m each, and each treated plot had 28 m. Five characterizations were performed in the experimental area, each of them in an area of 30 m^2 (7.5 × 4.0 m), with samples collected at random. All the material present on the soil surface was collected in this evaluation to measure the total mass and the coffee bean mass.

The experiment was carried out in a split-block design, with three passes of the picking machine and eight replications. The amount of coffee adjusted for picking was equivalent to 600 kg ha^{-1} (10 bags of processed coffee ha^{-1}).

Sweeping of the material on the soil surface was carried out using a Mogiana mounted sweeper-blower (Fig. 1a) and a 4×2 auxiliary front-wheel drive (AFWD) John Deere coffee tractor with a maximum power of 55.2 kW (75 hp), working at speeds of up to 2 km h^{-1} and 178 rad s^{-1}. This operation performs the cleaning in the interrow of the crop using sweeping mechanisms and airflow. Thus, the materials present on the soil surface are joined at the center of the interrow (Fig. 1b) to allow the mechanized picking.

The mechanized picking operation of the fallen coffee was performed using a MIAC Master Café II machine (Fig. 1c) pulled by a 4×2 AFWD Massey Ferguson coffee tractor with 55.2 kW (75 hp) power. The picking operation was performed with a power take-off rotation of 199 rad s^{-1} in the engine. The mechanized

Figure 1. Mogiana mounted sweeper-blower (a); coffee and impurities joined at the center of the interrow, ready for the picking operation (b); MIAC Master Café II picker machine for mechanized picking (c).

assembly operated in 3rd A gear and 199 rad s^{-1} to reach a speed of 1.57 km h^{-1}. This operation collects all the material previously windrowed by the mounted sweeper-blower machine, separates coffee from impurities, stores the collected coffee beans, and expels impurities by a fan mechanism at the rear of the machine.

Samples of 2 L were collected from the inside the pickup bulk tank during the operation, being later separated into coffee beans and impurities, allowing calculating the percentages of vegetal and mineral impurities and the machine cleaning efficiency using Equations 1, 2, and 3. After this operation, a rectangular frame of 4 m^2 (4 × 1 m) was used to evaluate coffee losses by collecting and quantifying all the beans present inside the frame. The data obtained from losses were also used to calculate the machine picking efficiency using Equation 4.

$$VI = \frac{MVI}{TSM} \times 100 \quad [1]$$

$$MI = \frac{MMI}{TSM} \times 100 \quad [2]$$

$$CE = \frac{CC}{TSM} \times 100 \quad [3]$$

$$PE = \frac{MC - L}{MC} \times 100 \quad [4]$$

where *VI* is the vegetal impurity (%), *MVI* is the mass of vegetal impurity (g), *TSM* is the total sample mass (g), *MI* is the mineral impurity (%), *MMI* is the mass of mineral impurity (g), *CE* is the cleaning efficiency (%), *CC* is the collected coffee (g), *PE* is the picking efficiency (%), *MC* is the mass of coffee in the area (g), and *L* is the loss (g).

The results were analyzed and discussed using analysis of variance, tools of statistical quality control, and test of means (Tukey). In addition to the statistical analysis, the detection of variability was carried out to verify the stability, average behavior, and quality of a process over time achieved through the SPC (Voltarelli *et al*., 2013). In this case, the results are shown using sequential graphs, such as control charts of individual values and moving ranges. Control charts allow easy understanding of the operation, assisting in the detection of failures or outliers that can negatively affect the quality of the process. Finally, the economic analysis of the operation was carried out in order to verify the economic viability of the number of passes necessary for picking.

Results and discussion

The quality indicators picking losses and cleaning efficiency showed very high and high coefficients of variation (CV), respectively (Table 2). High values of coefficient of variation and standard deviation are commonly found in studies focused on mechanization due to the high variation of situations imposed by the field, as found by Toledo *et al*. (2008) and Noronha *et al*. (2011) in mechanized soybean and sugarcane harvest, respectively. The other indicators showed parameters that ranged from low to medium, with high values only in the first machine pass for impurities.

The coefficient of skewness (Cs) presented high values on the right only for the quality indicator picking losses. The variables cleaning efficiency and vegetal and mineral impurities had the data more concentrated on the right, with a small to moderate curve, with distribution on the left for cleaning efficiency and mineral impurities in the second pass and vegetal impurities in the third pass. According to the methodology, the values of skewness found for the variables picking losses and picking efficiency are classified as high, indicating a high distance from the variable in relation to the central value (Tavares *et al*., 2015). The highest values were found mainly in the first machine pass, when the operation has a high variability of the material to be picked due to size, weight, and texture.

The coefficient of kurtosis (Ck) shows the dispersion of the data distribution in relation to a standard. The distribution is classified as symmetric when the coefficient has a dispersion equal to zero (Ck = 0), which was not observed for the treatments. A leptokurtic behavior (Ck > 0) was observed in the first pass for the indicators picking losses, picking efficiency, and vegetal impurities, and for picking losses, picking efficiency, and mineral impurities in the third pass. The other quality indicators and passes presented a platykurtic distribution (Ck < 0). Regarding the normality of the data (AD), non-normal values were found only in the first and third passes for the variables picking losses and picking efficiency. However, non-normal values do not limit the application of control charts (Silva *et al*., 2015).

The control chart of individual values for the quality indicator losses in the mechanized picking of coffee (Fig. 2) showed a gradual decrease in the average losses as the passes of the picking machine were carried out. The first pass of the picking machine presented the highest variability in the process, with discrepant points in relation to the mean, in addition to an out-of-control

Table 2. Descriptive statistics for quality indicators of the mechanized picking of coffee.

QI	Treatment	Mean	σ	CV (%)	Cs	Ck	AD
Picking losses (g m^{-1})	1st pass	38.10	34.10	89.38	2.42	6.10	1.288 A
	2nd pass	10.75	7.48	69.57	1.07	-0.20	0.561 N
	3rd pass	2.50	0.75	30.24	1.32	0.88	1.059 A
Picking efficiency (%)	1st pass	84.12	14.20	16.88	-2.42	6.10	1.288 A
	2nd pass	95.62	3.12	3.26	-1.07	-0.20	0.561 N
	3rd pass	98.87	0.31	0.32	-1.32	0.87	1.059 A
Cleaning efficiency (%)	1st pass	46.45	11.05	23.79	0.03	-1.59	0.398 N
	2nd pass	33.57	8.12	24.19	-0.17	-2.24	0.571 N
	3rd pass	25.10	5.45	21.70	0.27	-1.33	0.260 N
Vegetal impurities (%)	1st pass	20.92	7.18	34.33	1.69	2.77	0.696 N
	2nd pass	29.96	5.31	17.72	0.83	-0.46	0.458 N
	3rd pass	35.41	3.95	11.15	-0.33	-0.93	0.284 N
Mineral impurities (%)	1st pass	32.63	9.73	29.82	0.77	-0.82	0.468 N
	2nd pass	36.47	5.06	13.87	-0.07	-1.13	0.272 N
	3rd pass	39.49	6.88	17.41	0.83	0.87	0.244 N

QI: quality indicator. σ: standard deviation. CV: coefficient of variation. Cs: coefficient of skewness. Ck: coefficient of kurtosis. AD: Anderson-Darling normality test (N: normal distribution, A: non-normal distribution).

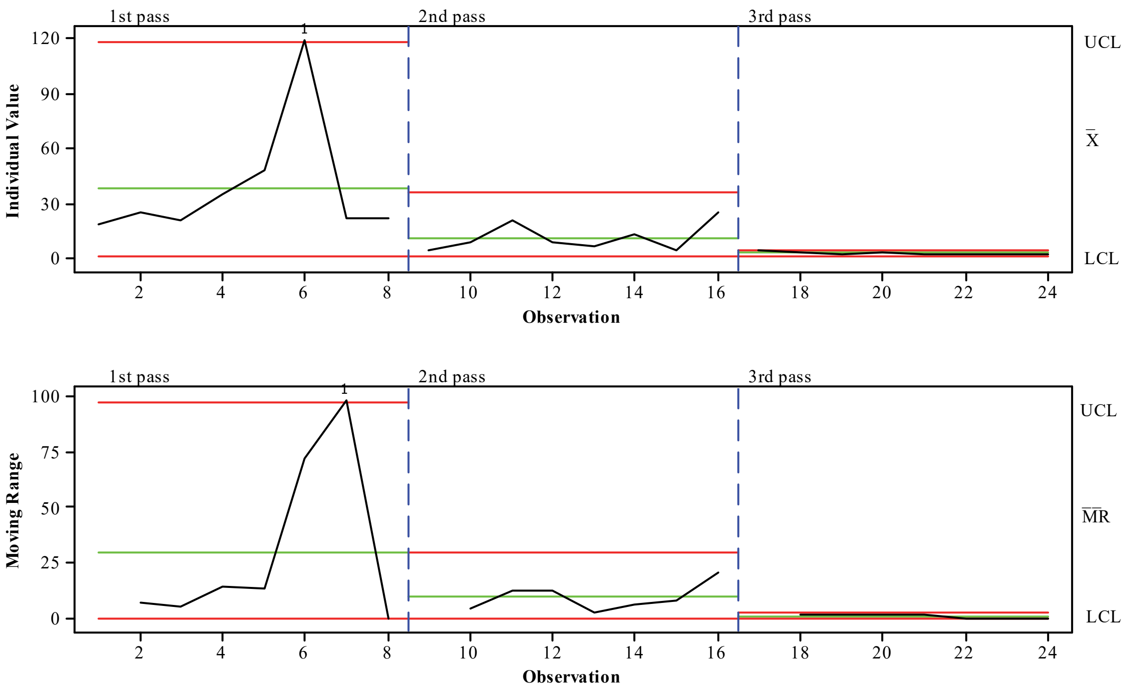

Figure 2. Control chart of individual values of coffee picking losses (g m^{-1}).

point above the upper control limit (UCL). Out-of-control points are uncommon points distanced from other evaluations and/or average, considered values that do not represent the real behavior of the data but can be explained by factors such as machine, method, labor, raw material, measurement, and environment (Zerbato *et al*., 2013). In this case, the machine is the factor that suits to this failure, as the picking machine could not process all the coffee due to the high amount of vegetal material to be picked in the area compared to the others. The control chart of moving ranges showed an outlier in the first machine pass, which could be explained by the out-of-control point in the control chart of individual values. It occurs because the moving ranges express the variation of the point-to-point process.

The third pass had the lowest variability of the process among the three passes regarding the in the quality indicator losses (Fig. 2), with the evaluated points and control limits closer to the mean. The reduction in variability improves quality and can be analyzed by the statistical process control (Noronha *et al*., 2011). Thus, the highest quality in the process can be explained by the third machine pass, which presented the lowest amount of coffee to be picked, as it has been managed since the first pass.

The control chart of individual values for the variable picking efficiency (Fig. 3) had one point below the lower control limit (LCL). This point is associated with the high loss rate evaluated at the same location and observed in Figure 2, and can be explained by the calculation of the picking efficiency (Equation 1), in which loss values are used to obtain it. The same point showed an outlier above the UCL on the control chart of moving range, as moving range values are represented by the difference between the analyzed point and the previous one, resulting in the outlier due to the high discrepancy between the analyzed points.

The third machine pass presented the best quality of process execution, with points close to the mean and within the control limits. It occurred because picking losses and picking efficiency are dependent variables. In this case, the efficiency had a high level of quality, as the amount of coffee to be picked in the third pass was considerably lower than the amount present on the soil in the previous passes. In similar studies, but picking efficiency had means from 80 to 91% with a single passes (Silva *et al*., 2007; Tavares *et al*., 2015).

Figure 4, represented by the control chart of cleaning efficiency of the picking operation, shows average values below the level considered acceptable for this variable from the first pass. Similarly, Tavares *et al*. (2015) verified an average of approximately 83%. Also, the machine passes negatively affected operation quality.

A reduction in the cleaning efficiency according to the passes occurred, as the picking machine had collected the coffee from the soil since the first pass, and the size of materials in the area (vegetal and mineral impurities) decreased due to its cleaning mechanism. Thus, material separation is strongly affected because part of the impurities not removed by the extractor eas-

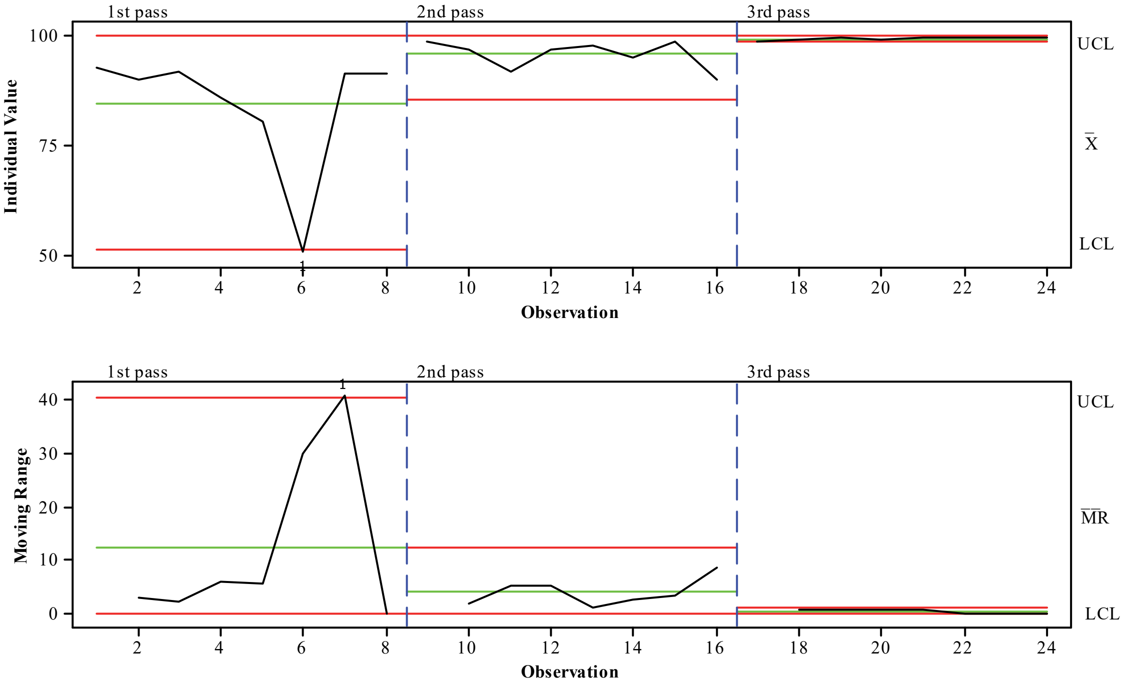

Figure 3. Control chart of individual values of picking efficiency (%).

ily go through the cleaning sieve each time their size decrease, contributing to reduce the cleaning efficiency of the picking machine.

The control chart of vegetal impurities (Fig. 5) shows that the values gradually increased as the picking machine passed. Statistically, the best-studied treatment was the third pass, as it presented less variability of the collected data. However, because it is an inversely proportional variable, it is convenient that the data present lower values to be considered better.

Figure 5 shows that according to the real field requirements, in which low impurity rates are set as

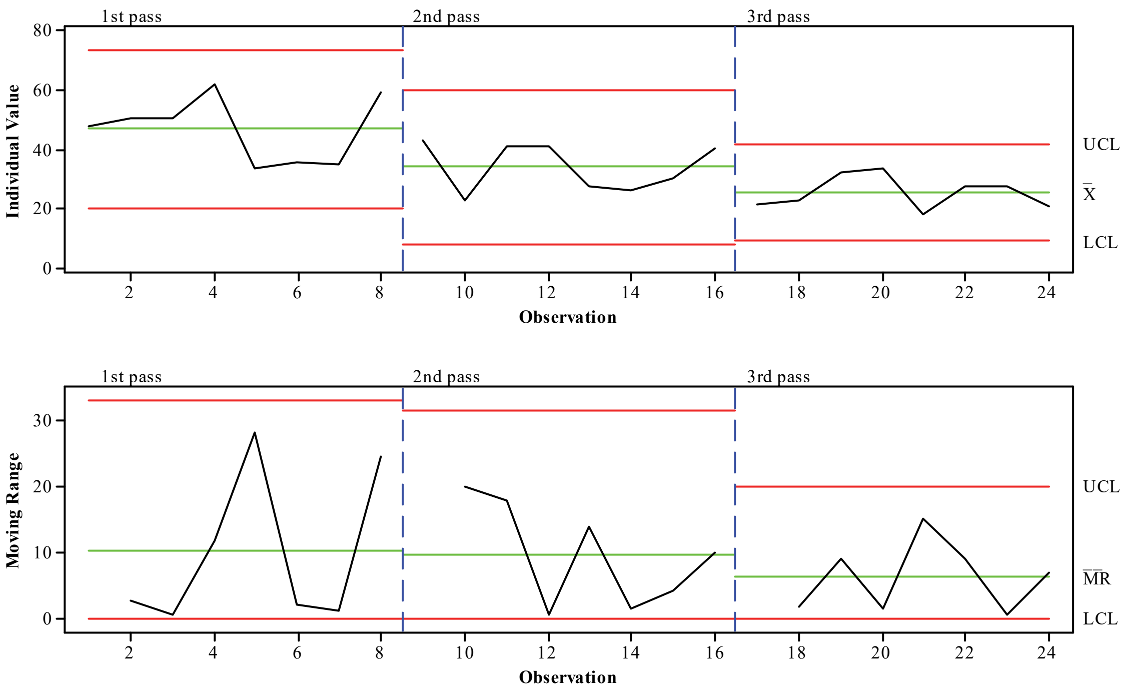

Figure 4. Control chart of individual values of cleaning efficiency (%).

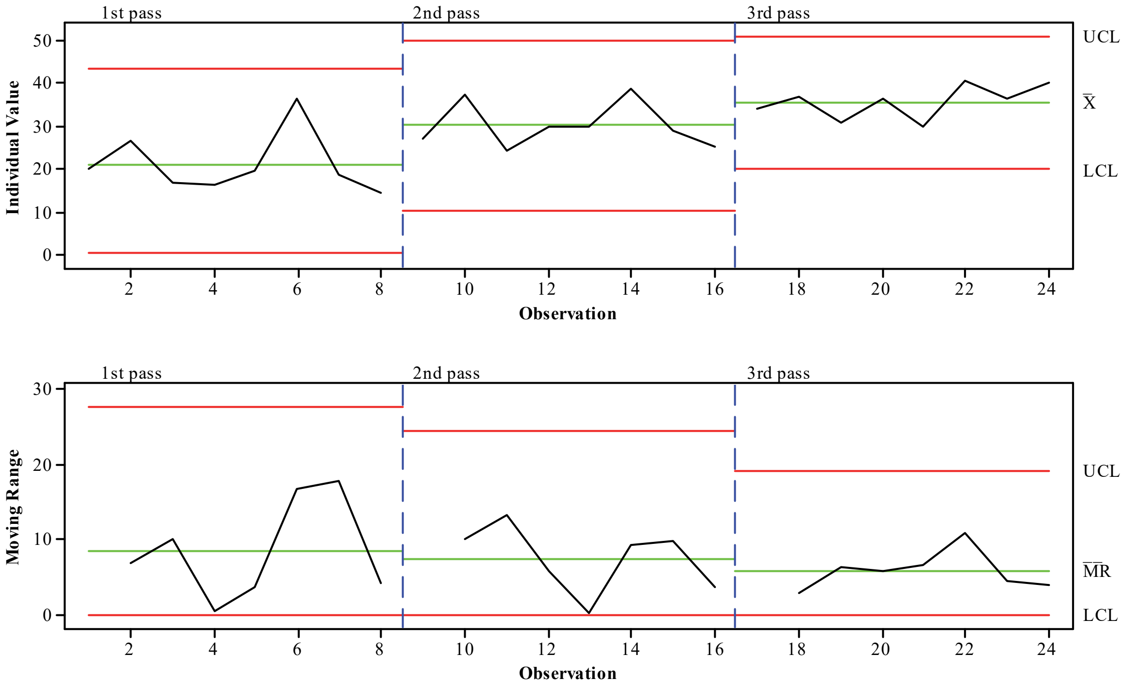

Figure 5. Control chart of individual values of vegetal impurities (%).

necessary, the results are different from those found following the guidelines of the statistical process control. The first pass of the picking machine became the best treatment when compared to the third pass when considering the amount of vegetal impurities collected. In this case, the first pass presented the lowest average of undesirable materials collected, which was preponderant in this operation. However, these values are low when compared to those found by Tavares (2016) in a similar evaluation, in which vegetal impurities accounted, on average, for 4%, that is, about 25 percentage points lower than that found in the present study.

As for vegetal impurities, the control chart of mineral impurities (Fig. 6) showed that despite the high variability of the process in the first machine pass, it still provided a good result compared to the other passes, with the lowest means between treatments. Statistically, the best pass was the second one, as it presented the highest stability of the data. The index of collected mineral impurities shows that the machine performed a good material separation, as the residues from the coffee washer were distributed in the study area the coffee washer was distributed in the interrows of the crop, increasing the amount of mineral impurities mixed with the fallen coffee to be picked for separation.

The test of means used to characterize the quality of the coffee picking operation showed a statistical difference between the second and third passes, demonstrating the feasibility of performing up to two picking operations in the area (Table 3). The same result was found for the variables picking efficiency and cleaning efficiency, which also had no statistical difference between the second and third passes. Santinato *et al.* (2015) observed the need for repassing when working with the coffee harvesting operation and concluded that three passes would be the best option for growing seasons with high productivities.

The quality indicator vegetal impurities presented a difference between all treatments, in which impurity levels increased as the picking operation was repeated. In this case, the amount of coffee together with impurities was lower in the second and third passes, which makes the separation process difficult, as shown in the control chart of vegetal impurities (Fig. 5). The same result was observed for the variable mineral impurities, but with no statistical difference between treatments.

A simple economic analysis was carried out considering the real market values of the coffee crop and operating costs. According to the Center for Advanced Studies on Applied Economics (CEPEA/ESALQ), coffee (60-kg bags) was traded in the 2017 growing season with an average value of US$ 141.75 from June to September, that is, the months of the coffee harvest. In this sense, there was initially on the soil surface of the experimental area an amount of coffee to be picked equivalent to US$ 1417.51 ha^{-1}, which is also equivalent to 10 bags ha^{-1}. It is a high amount commonly found in commercial coffee fields.

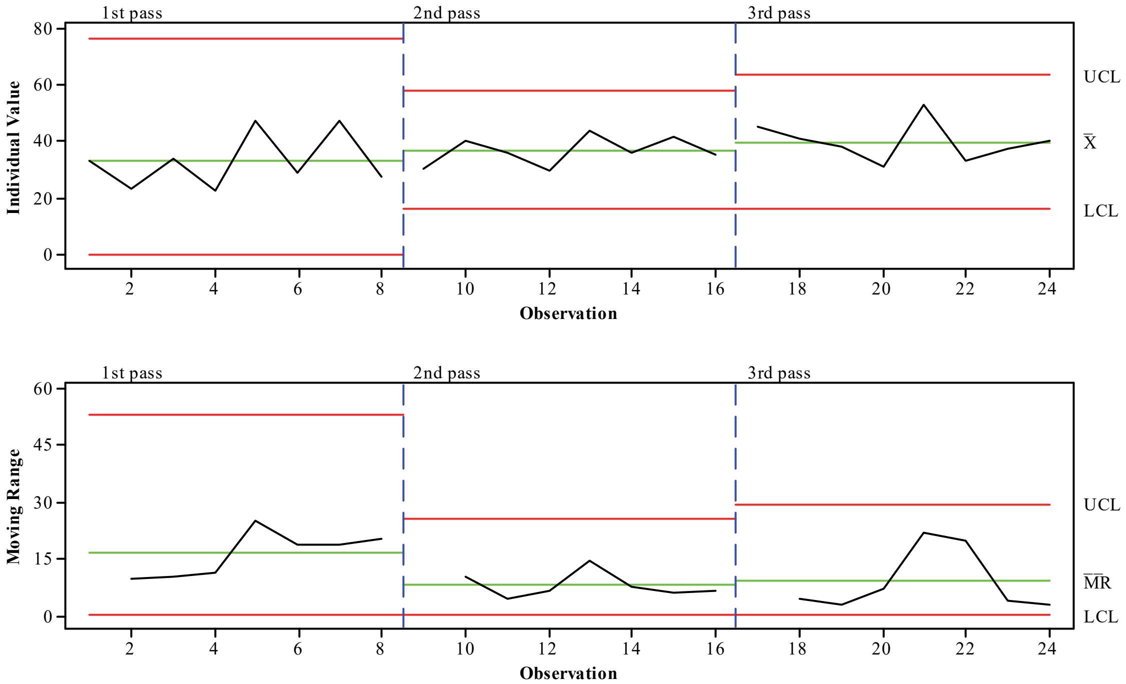

Figure 6. Control chart of individual values of mineral impurities (%).

Table 3. Test of means for quality indicators of the mechanized picking of coffee.

Treatment	Picking losses ($g\ m^{-1}$)	Picking efficiency (%)	Cleaning efficiency (%)	Vegetal impurities (%)	Mineral impurities (%)
1^{st} pass	38.13 a	84.12 a	46.45 a	20.92 a	32.63 a
2^{nd} pass	10.75 b	95.62 b	33.56 b	29.96 b	36.47 a
3^{rd} pass	2.50 b	98.87 b	25.10 b	35.41 c	39.49 a
F-test1	6.76**	6.55**	21.29**	32.43**	3.42^{ns}
CV (%)[2]	118.43	9.22	18.80	12.63	14.52

[1] F-test: nsnot significant; **significant at 1% probability. [2] CV: coefficient of variation. Means followed by the same letter in the column do not differ from each other by the Tukey test at 5% probability.

The mechanized operations of sweeping and picking represented a cost of US$ 29.20 and 57.53 ha^{-1} $pass^{-1}$, respectively, totaling US$ 86.73 ha^{-1} $pass^{-1}$. These costs are real from the farm and consider labor, fuel, and maintenance of machines in the 2017 agricultural year. The profit obtained from the different machine passes can be obtained considering these values (Table 4). Thus, using the values of operating efficiency, we reached gains of US$ 1192.40, 215.24, 9.75 ha^{-1} in the first, second, and, third passes, respectively, with results (profit or loss) of US$ 1105.67, 128.51, and −76.99 ha^{-1}, indicating that the operation is economically viable when performed up to two passes.

The first, second, and third passes presented losses of US$ 225.10, 9.86, 0.11 ha^{-1} (coffee not picked by the machine) (Table 4), respectively. These values are in agreement with the economic viability of performing a second picking operation because from the first to the second passes, losses were reduced by US$ 215.24, and the operating cost was US$ 86.73, generating a profit of around US$ 1234.17 with two passes.

As conclusions, loss values reached the minimum level in the third pass of the picking machine in the experimental area but with low cleaning efficiency and high amount of vegetal impurities. The percentage of mineral impurities in the bulk tank was not affected by machine passes, but it negatively affected the percentage of vegetal impurities. The economic viability of the picking operation under the studied conditions is up to two machine passes.

Table 4. Economic analysis of the viability of the mechanized picking of coffee up to three annual operations.

Pass	Picking efficiency (%)	Cost (US$)	Gain (US$)	Loss (US$)	Profit (US$)
1st pass	84.12	86.73	1192.40	225.10	1105.67
2nd pass	95.62	86.73	215.24	9.86	128.51
3rd pass	98.87	86.73	9.75	0.11	−76.99

References

Alvarenga CB, Val-Júnior NA, Val VLP, Zampiroli R, Rinaldi PCN, 2018. Losses during the arabica coffee mechanical harvesting and gathering operations in the Cerrado region of Minas Gerais State. Acta Iguazu 7 (4): 35-46.

Alvares CA, Stape JL, Sentelhas PC, Moraes G, Leonardo J, Sparovek G, 2013. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift 22 (6): 711-728. https://doi.org/10.1127/0941-2948/2013/0507

Conab, 2019. Acompanhamento da safra brasileira: café. SAFRA 5 (3): 48 pp. Companhia Nacional de Abastecimento, Brasília. https://www.conab.gov.br/component/k2/item/download/28519_1451c80af85a09013032c62c38317623

Embrapa, 2013. Sistema brasileiro de classificação de solos [Brasilian soil classification]. Embrapa-Solos, Rio de Janeiro.

Escobar-Ramírez S, Grass I, Armbrecht I, Tscharntke T, 2019. Biological control of the coffee berry borer: main natural enemies, control success, and landscape influence. Biol Control 136 (1): 103992. https://doi.org/10.1016/j.biocontrol.2019.05.011

Läderach P, Ramirez-Villegas J, Navarro-Racines C, Zelaya C, Martinez-Valle A, Jarvis A, 2017. Climate change adaptation of coffee production in space and time. Climatic Change 141 (1): 47-62. https://doi.org/10.1007/s10584-016-1788-9

Lanna GBM, Reis PR, 2012. Influência da mecanização da colheita na viabilidade econômico-financeira da cafeicultura no sul de Minas Gerais. Coffee Sci 7 (2): 110-121.

Noronha RHF, Silva RP, Chioderoli CA, Santos EP, Cassia MT, 2011. Controle estatístico aplicado ao processo de colheita mecanizada diurna e noturna de cana-de-açúcar. Bragantia 70: 931-938. https://doi.org/10.1590/S0006-87052011000400028

Pereira SP, Bartholo GF, Baliza DP, Sobreira FM, Guimarães RJ, 2011. Crescimento, produtividade e bienalidade do cafeeiro em função do espaçamento de cultivo. Pesqu Agropec Bras 46 (2): 152-160. https://doi.org/10.1590/S0100-204X2011000200006

Santinato F, Ruas RAA, Silva RP, Carvalho Filho A, Santinato R, 2015. Número de operações mecanizadas na colheita do café. Ciência Rural, Santa Maria 45 (10): 1809-1814. https://doi.org/10.1590/0103-8478cr20140801

Silva FD, Alves MC, Silva FC, Silva JCS, Barros MM, 2007. Desempenho operacional da recolhedora de café Dragão Eco. 33 Congr Bras de Pesquisas Cafeeiras, Lavras. Anais. Embrapa Café, Brasilia. 2 p.

Silva RP, Cassia MT, Voltarelli MA, Compagnon AM, Furlani CEA, 2013. Qualidade da colheita mecanizada de feijão (Phaseolus vulgaris) em dois sistemas de preparo do solo. Rev Ciênc Agron 44 (1): 61-69. https://doi.org/10.1590/S1806-66902013000100008

Silva RP, Votlarelli MA, Cassia MT, 2015. Controle de qualidade em operações agrícolas mecanizadas. Jaboticabal, SBEA, 244 pp.

Tavares TO, 2016. Recolhimento mecanizado do café em função do manejo do solo e da declividade do terreno. UNESP, Faculdade de Ciências Agrárias e Veterinárias, Dissertação de Mestrado em Agronomia. Jaboticabal, 58 pp.

Tavares TO, Santinato F, Silva RP, Voltarelli MA, Paixão CSS, Santinato R, 2015. Qualidade do recolhimento mecanizado do café. Coffee Sci, Lavras 10 (4): 455-463.

Tavares TO, Borba MAP, Oliveira BR, Silva RP, Voltarelli MA, Ormond ATS, 2018. Effect of soil management practices on the sweeping operation during coffee harvest. Agron J 110 (5): 1689-1696. https://doi.org/10.2134/agronj2017.10.0598

Toledo AD, Tabile RA, Silva RP, Furlani CE, Magalhães SC, Costa BO, 2008. Caracterização das perdas e distribuição de cobertura vegetal em colheita mecanizada de soja. Engenh Agríc 28 (4): 710-719. https://doi.org/10.1590/S0100-69162008000400011

Voltarelli MA, Silva RP, Rosalen DL, Zerbato C, Cassia MT, 2013. Quality of performance of the operation of sugarcane mechanized planting in day and night shifts. Aust J Crop Sci 7: 1396-1406. http://www.cropj.com/voltareli_7_9_2013_1396_1406.pdf

Zerbato C, Cavichioli FA, Raveli MB, Marrafon M, Silva RP, 2013. Controle estatístico de processo aplicado à colheita mecanizada de milho. Eng Agr 21 (3): 261-270. https://doi.org/10.13083/1414-3984.v21n03a05

Zerbato C, Furlani CEA, Oliveira MFD, Voltarelli MA, Tavares TO, Carneiro FM, 2019. Quality of mechanical peanut sowing and digging using autopilot. Rev Bras Eng Agr Amb 23 (8): 630-637. https://doi.org/10.1590/1807-1929/agriambi.v23n8p630-637