SPEED AND ROTATION VARIATIONS IN GATHERING COFFEE MACHINE

VARIAÇÕES DE VELOCIDADES E ROTAÇÕES NO RECOLHIMENTO MECANIZADO DO CAFÉ

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ABSTRACT: The mechanized harvesting operation of coffee sweep from ground have a great importance, due the value of the coffee that was lost by the harvest process, as well as the breakdown of the cycle of pests that can damage the coffee. To change work settings can influence significantly the capacity of the gathering system. Due, the objective of this study was to evaluate the influence the speed of displacement and rotations of the components of gathering coffee machine in its performance. The experiment was carried out in the municipality of Presidente Olegário-MG on coffee plantations aged 10 to 11 years. The field, presenting an average of 990 kg ha^{-1} of coffee present in the soil after the machine harvest. The engine rotations of the tractor evaluated were 146.6, 162.3, 178.0, 193.7, and 209.4 rad.s^{-1} combined with the 1stA and 2ndA gears, resulting in different working speeds. The treatments were distributed in randomized blocks with five replicates. The variables analyzed were the gathering efficiency, cleaning efficiency, coffee losses, and percentage of mineral and vegetal impurities. It was concluded that the gathering efficiency was higher when working with 178.0 rad.s^{-1} at 1.26 km h^{-1}, resulting in lower coffee losses in the operation, a preponderant factor in the study. On the other hand, the best cleaning efficiency of the machine was found when using 193.7 rad.s^{-1} and 1.37 km h^{-1}.

KEYWORDS: Agricultural mechanization. Gathering coffee. *Coffea arábica*.

INTRODUCTION

The evolution of technology, coupled with the unavailability and burden of labor in the field, strongly implied the replacement of man by the machine in the field, especially with regard to coffee crops, where mechanization is present in all productive phases. This is especially true for the harvest, which represents the highest costs of production (LANNA; REIS, 2012). In Brazil, the mechanization of the coffee harvesting process has been optimized since the end of the 1970s with the launch of the first coffee harvester, a machine that

efficiency of operation and reducing costs (SILVA et al., 2007).

However, even though they are often improved by new technologies, mechanized agricultural operations, especially harvesting, almost never present maximum efficiency, since even after improvements in the machines they still have deficiencies in the execution of the process (SANTINATO et al., 2014). In addition to the damage caused to the plants by the operation (CASSIA et al., 2013) owing mainly to the high vibration of the rods (TAVARES et al., 2015), the collector system of the gathering coffee machine when working with large amounts of coffee increases the values of losses (OLIVEIRA et al., 2018). This is because the coffee can fall on the leaves shed as a result of the harvest, causing a possible difficulty in the separation process. The lack of separation of the material present on the conveyor belt causes the coffee to fall under the skirt of the coffee tree along with the leaves, resulting in a larger amount of coffee falling onto the ground (SILVA et al., 2010).

Fallen coffee should be collected because and often the amount of coffee that is on the ground can represent a productivity gain. Another factor that reinforces the need to perform the harvesting operation is the phytosanitary factor because the fruits that remain from one harvest to another can become hosts for the coffee fruit borer (*Hypothenemus hampei*). The borer is an important pest that attacks the coffee crop (ESCOBAR-RAMÍREZ et al., 2019). It is a beetle that perforates the fruits and oviposites, in addition, the larvae feed on the coffee seeds (VEGA et al., 2015). For this reason, the gathering presents

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economic and phytosanitary importance in the management of coffee cultivation.

Gathering coffee machines arose from machine adaptations used in bean harvesting and have changed little since then, so there are many possibilities for studies to improve the harvesting process (TAVARES, 2016), such as the interaction between rotations and speeds of the machine. In addition to the harvesting of other crops, it can be seen that the displacement velocity is an important factor when studying harvest losses, as in mechanized soybean harvests, where Campos et al. (2005) observed that grain losses are directly proportional to the velocity of displacement, a fact also found by Carvalho Filho et al. (2010), who reported an increase in loss of around 120%. Therefore, the travel speed is strongly linked to the volume of operation losses. When increasing the work speed, it is important to consider the tolerable levels of losses and not only the capacity to work (EMBRAPA, 2011). However, Loureiro et al. (2012) observed that in a mechanized harvest of maize, the greatest losses were found at lower speeds, since with the vibration of the machine the spikes could detach from the plant in advance.

In this sense, assuming that the adequacy of gears, rotations, and speed can affect the performance of a mechanized coffee harvesting operation, the objective of this study was to evaluate the efficiency of the gathering coffee machine in different combinations of gears and rotations.

MATERIAL AND METHODS

The experiment was carried out in the municipality of Presidente Olegário - MG, close to the geographical coordinates of latitude 18º02’01” S and longitude 46º27’05” W, with average altitude and slope of 839 m and 3%, respectively. The soil of the area is classified as RED LATOSOIL dystroferric, and has a medium texture (EMBRAPA, 2013). The climate is classified as Cwa according to Köppen (ALVARES et al., 2013). The coffee plants age was between 10 and 11 years. This field was planted with Catuaí Vermelho (IAC 144), with spacing 4.0 x 0.5 m between rows and plants. The amount of plants is 5000 plants ha^{-1}.

The efficiency of the mechanized gathering coffee operation was evaluated according to five-speed combinations of the engine in two working gears, with rotations of 146.6, 162.3, 178.0, 193.7, and 209.4 rad.s^{-1} and the 1stA and 2ndA gear. The combinations between the rotations and the 1stA gear gave speeds of 1.06, 1.15, 1.26, 1.37, and 1.51 km h^{-1}, respectively. When combined with the 2nd gear, they gave speeds of 1.50, 1.65, 1.83, 1.98, and 2.15 km h^{-1}. These combinations of rotations were chosen because they cover different working conditions of gathering coffee machine, and the gears are the most used for this operation (MATIELLO et al., 2013). The treatments were in split-blocks with subdivided plot scheme, in five coffee lines. Each line has 300 m and representing one block, totaling five replications.

Prior to the gathering, a sweeping operation was carried out in order to enclose to the between the lines all material present in the soil, including coffee, leaving it in favorable conditions for the gathering to take place. The sweeping was done by a mechanized assembly composed of a 2 x 1 (two rows x 1 line) rotor-blower of the brand VARRE TUDO coupled to a tractor of 4 x 2 Auxiliary Front Wheel Drive (AFWD) with a nominal power of 55.2 kW (75 hp) and average speed of 2 ,5 km h^{-1} with 56.5 rad.s^{-1} in the Power Take Off (PTO).

Afterward, was conducted five points of characterization area to evaluate the amounts of vegetal, mineral impurities and coffee fruits present in the soil for gathering. Each evaluation had a sample area of 30 m² (7.5 x 4.0 m) including 15 plants, where all material present in the soil was collected and was separated and quantified for characterization. The area obtained an average equivalent to 990 kg ha^{-1} of coffee. The mechanized gathering was carried out with a Master Café II of MIAC brand, driven by a 4 x 2 Auxiliary Front Wheel Drive (AFWD) with nominal power of 55.2 kW (75 hp), working with gears and rotations varying according to established treatments.

Changing tractor engine speeds resulted in different rotations in the pickup components. The rotation of the components was measured with the aid of an electronic tachometer with both work rotations analyzed. The resulting data is listed in Table 1.

As evaluation parameters, the variable losses in the gathering, gathering efficiency, mineral impurity, vegetal impurity, and cleaning efficiency were used. The gathering efficiency was determined by means of the characterization of the coffee losses according to Equation 1. The losses in the gathering were measured with the aid of a frame of the equivalent area of 1.8 m^2, which covers the working width of the collection platform, collecting all coffee present inside the frame for further quantification.

Table 1. Rotation in $rad.s^{-1}$ of components of gathering machine as function of rotation of tractor motor.

Motor	PTO[1]	C.R.M.[2]	C.R.[3]	T.R.[4]	Eli.[5]	Sv.[6]	Ex.[7]	Ele.[8]
146,61	46,50	6,28	22,10	18,33	37,18	31,73	113,31	12,25
162,32	51,63	6,91	24,71	20,11	41,47	35,29	125,45	12,99
178,02	56,34	7,33	26,49	20,63	45,24	38,43	137,18	13,61
193,73	61,16	7,96	29,01	25,55	48,90	42,10	149,02	14,24
230,38	72,78	9,63	31,73	26,39	52,36	45,76	160,33	14,66

[1]PTO: Power Take-off; [2]C.R.M.: Collection running machine; [3]C.R.: Collection Roller; [4]T.R.: Tangential rotor; [5]Eli.: Elicoid; [6]Sv: Sieves; [7]Ex.: Exaustor; [8]Ele.: Elevator.

During the operation, samples equivalent to 1 liter were collected at the exit of the elevator, inside the bulk tank, and in the treatments in order to evaluate the amounts of mineral and vegetal impurities and the cleaning efficiency, as expressed by Equation 2. The mineral and vegetal impurities were separated with the assistance of sieves and were then quantified according to the treatments. These are expressed by Equations 3 and 4, respectively.

$$GE = \frac{MC - L}{MC} \times 100 \quad \text{Equation 1}$$

$$CE = \frac{CC}{TSM} \times 100 \quad \text{Equation 2}$$

$$MI = \frac{MIM}{TSM} \times 100 \quad \text{Equation 3}$$

$$VI = \frac{VIM}{TSM} \times 100 \quad \text{Equation 4}$$

where

$GE = Gathering\ Efficiency\ (\%)$

$MC = Mass\ of\ coffee\ present\ in\ the\ area\ (g)$

$L = Losses$ (g)

$CE = Cleaning\ Efficiency\ (\%)$

$CC = Collected\ Coffee\ (g)$

$TSM = Total\ Sample\ Mass\ (g)$

$MI = Mineral\ Impurities\ (\%)$

$MIM = Mineral\ Impurities\ Mass\ (g)$

$VI = Vegetal\ impurities\ (\%)$

$VIM = Vegetable\ Impurities\ Mass$ (g)

The data were submitted to an F test to analyze the variance. When significant differences occurred, the rotation factors were studied by regression analysis, selecting models based on the significance of their terms, the value of the coefficient of determination, and the meaning agronomic behavior. The precision of the models was determined according to R^2 and the Mean Absolute Percentage Error (MAPE) determined the accuracy, according to Equation 5.

$$MAPE = \frac{\sum_{i=1}^{N}\left(\left|\frac{Yest_i - Yobs_i}{Yobs_i}\right| * 100\right)}{N} \quad \text{Equação 5}$$

Where

$Yest = estimated\ value$

$Yobs = observed\ value$

$N = total\ number\ of\ values$

RESULTS AND DISCUSSION

The losses and gathering efficiency did not significantly affect by the factors tested, or by the interaction between the gear and rotation factors (Table 2).

High values were obtained for the gathering efficiency at above 88%. According to the literature, the values presented were higher than those found by Tavares et al. (2015) in same machine conditions, who obtained values of 79.2 to 81.2% in a crop with a large amount of coffee to be harvested (18 bags ha^{-1}). A possible explain is the difference in composition of the material to be gathered, as well as the mass of impurities.

Although the engine rotation does not significantly influence the gathering efficiency, as seen by the same author, it can be observed that when the operation is performed at 146.6 $rad.s^{-1}$, the efficiency obtained exceeded 91%, this is a good efficiency value, Balastreire, (2004) indicates good efficiency values as 70% to 90%. The mechanized sets used in these evaluations presented good conditions of use and low age machine, which may be preponderant for the values found. The high efficiency occurs because according to the characteristic curve of the tractor's engine, a rotation of 146.6 $rad.s^{-1}$ is indicated for carrying out operations by using 9 $rad.s^{-1}$ at the power take-off (PTO), which according to the norms of techniques for agricultural machinery, is an adequate rotation for the accomplishment of operations, this presents a proximity to the point of the minimum specific consumption of fuel (FEREZIN, 2015).

Table 2. Analysis of variance for quality indicators: gathering losses, gathering efficiency, cleaning efficiency, mineral impurity, and vegetal impurity.

QI[1]	Losses (Kg ha^{-1})	Gathering Efficiency	Cleaning Efficiency	Mineral Impurities	Vegetal Impurities
		(%)			
Gear					
G1[2]	98.90	89.30	75.50	19.40	5.00
G2[3]	94.20	89.80	76.60	17.60	5.60
Rotation					
R1[4]	105.35a	88.60a	73.30a	16.40a	10.20a
R2[5]	111.45a	82.90a	76.90a	16.30a	6.70b
R3[6]	76.15a	91.70a	73.50a	22.20a	4.20c
R4[7]	87.55a	90.50a	79.00a	17.30a	3.50c
R5[8]	102.25a	88.90a	77.40a	20.30a	2.10c
Test F					
M	0.15^{ns}	0.15^{ns}	3.46^{ns}	3.54^{ns}	1.53^{ns}
R	0.84^{ns}	0.85^{ns}	2.45^{ns}	2.81^{ns}	27.59^{*}
M x R	1.61^{ns}	1.62^{ns}	0.79^{ns}	0.63^{ns}	2.59^{ns}

[1]QI: Quality Indicators; [2]G1: 1ªA gear; [3]G2: 2ªA gear; [4]R1 = 146.6 rad.s^{-1}; [5]R2 = 162.3 rad.s^{-1}; [6]R3 = 178.0 rad.s^{-1}; [7]R4 = 193.7 rad.s^{-1}; [8]R5 = 209.4 rad.s^{-1}. Normality test: ^{ns} not significant; * significant at 5% probability.

According to Fernandes et al. (2012), high cleaning efficiency implies higher-quality coffee available for post-harvest processes such as washing and drying. The values found for cleaning efficiency, which were above 70%, indicate that the operation was performed in a satisfactory, demonstrating that regardless of rotation, the gathering machine has high cleaning efficiency, allowing better processing of the gathering coffee owing to its higher purity. Thus, the results obtained allow to infer that it is possible to operate at higher rotations and, consequently, with higher displacement speeds, without prejudice to the quality of the operation, which will result in greater operational capacity.

When at high rotations, the cleaning efficiency is strongly affected by the mineral impurities because the conditions of high rotation favor the removal only of the vegetal impurities of the system. In addition, an increase of the flow of material inside the machine hinders the separation of the mineral impurities.

At low rotations, there was an increase in vegetal impurities owing to the low number of fan rotations affecting the removal quality of impurities in the cleaning system machine. However, when the rotation was increased, the number of rotations of the fan consequently increased (Table 1), contributing with the system machine efficiency.

The high percentages of mineral impurities obtained in the present study can be explained by the lack of ability of the collector to separate and eliminate clods of a size similar to or less than that of a coffee bean, as also found by Tavares et al. (2015). This reduces the cleaning efficiency of the machine. These authors, while working with coffee pickup in three PTO rotations, concluded that the amount of coffee present in this material presents high variability, which interferes with the capacity of gathering and cleaning the machine. An increased PTO rotation does not alter the efficiency of separation of coffee from vegetal impurities by the machine in the Table 2 shows. This is owing to an increase in the number of rotations of the components of the cleaning system, which is composed of an axial cylinder, sieve, and exhaust fan.

It was observed by means of Figure 1 that the percentage of vegetal impurity decreases with an increase in the rotation of the motor, and consequently with an increase of rotation of the cleaning components (Table 1). This can be explained by the low mass of the vegetal impurities, which allows for better separation of these impurities from the collected coffee since most of the separation of the impurities is carried out through the sieves with the aid of the exhaust mechanism.

The reduction in the percentage of impurities influenced the cleaning efficiency of the operation, ranging from 73.3% to 79%. These results were similar to those obtained by Tavares (2016) in flatlands (with a declivity of up to 10%). The same authors mention that greater declivities can reduce the gathering efficiency.

On the other hand, for gear 2, it was observed that a reduction in the impurities occurred when the motor rotation increased from 146.6 to

193.7 rad.s^{-1} (Table 2), when the increase in rotation started to increase the amount of impurities. This increase from the rotation of 193.7 rad.s^{-1} can be explained by the consequent increase in the speed of the displacement of the machined assembly, which also increases the mass flow inside the machine. This makes it impossible to carry out the separation of the impurities with full efficiency.

In relation to the MAPE the models obtained for both gears were precise, with R^2 of 0.71 and 0.72 for 1st and 2nd gear, respectively. Their accuracy obtained higher MAPE values of 39 and 40%. However, between the two marches, the behavior was the same, differing by only 1%. The standard deviation of the percentage of vegetal impurity was 0.85 and 1.12 for 1st and 2nd gear respectively (Figure 1).

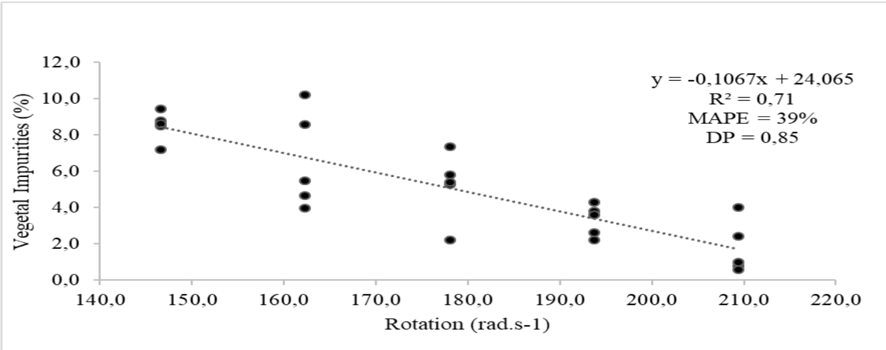

Figure 1. Regression analysis of vegetal impurity for 1st gear.

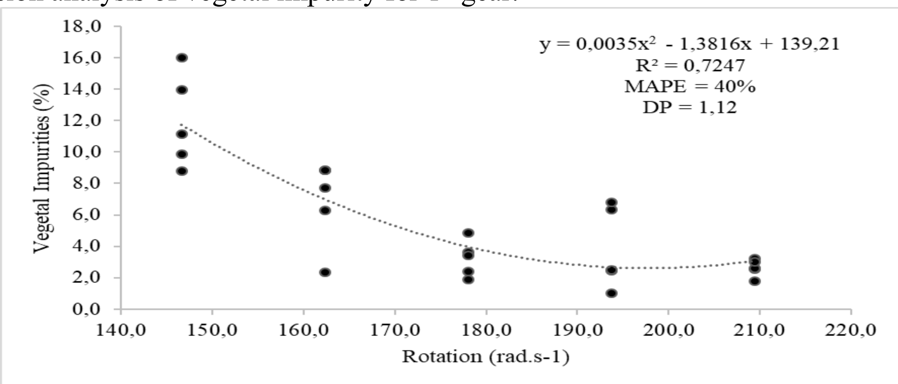

Figure 2. Regression analysis of vegetal impurity for 2nd gear.

CONCLUSIONS

The efficiency of the gathering coffee machine was not affected by varying speeds and rotations.

Only the vegetal impurity indicator responded positively to the increased of rotations, providing lower levels of vegetal impurities in mechanized gathering coffee.

Owing to the low sensitivity of the gathering coffee machine to changes in gears and rotations, it is concluded that the optimal rotation is 178.0 rad.s^{-1} for providing 56.4 rad.s^{-1} at the power take-off. This is the ideal point of operation of the tractor engine.

RESUMO: A operação de recolhimento mecanizado do café de varreção apresenta grande importância, devido ao valor do café que é perdido pelo processo de colheita, como também pela quebra do ciclo de pragas que podem prejudicar o cafeeiro. A alteração de regulagens de trabalho da recolhedora pode influenciar significantemente na capacidade do sistema de recolhimento. Portanto, objetivou-se neste trabalho avaliar a influência da velocidade de deslocamento e das rotações dos componentes da recolhedora no seu desempenho. O experimento foi realizado no município de Presidente Olegário-MG em lavoura de café com idade de 10 a 11 anos. A área estudada foi caracterizada, apresentando média de 990 kg ha^{-1} de café presentes no solo para recolhimento. As rotações do motor do trator avaliadas foram de 146.6, 162.3, 178.0, 193.7, e

209.4 rad.s^{-1} combinadas com as marchas 1ªA e 2ªA, resultando em diferentes velocidades de trabalho. Os tratamentos foram distribuídos em blocos casualizados com cinco repetições. As variáveis analisadas foram a eficiência de recolhimento, eficiência de limpeza, perdas de café e porcentagem de impurezas minerais e vegetais. Concluiu-se que a eficiência de recolhimento foi maior quando se trabalhou com 178.0 rad.s^{-1} à 1,26 km h^{-1}, originando assim menores perdas de café na operação, fator preponderante no estudo. Por outro lado, a melhor eficiência de limpeza da máquina foi encontrada quando se utilizou 193.7 rad.s^{-1} e 1,37 km h^{-1}.

PALAVRAS-CHAVE: Mecanização agrícola. Café de varreção. *Coffea arabica*.

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