

Doi: <http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v41n1p98-106/2021>

## DOES MOISTURE IN PODS INTERFERE WITH MECHANIZED HARVESTING OF PEANUTS?

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### KEYWORDS

Harvest losses,  
harvest impurities,  
peanut gathering,  
adjustment of  
machines.

### ABSTRACT

Although peanut harvesting results in significant losses, it has rarely been investigated. Thus, this study aimed to analyze the interference of different pod moisture contents on peanut harvesting and their influence on the process quality based on losses and impurities. An experiment was performed in a peanut seed producing area, in Luzitânia, district of Jaboticabal - SP, using average moisture contents of 15% and 20% in the pods; 16 and 14 data points were collected for the 20% and 15% treatments, respectively. The experimental design used statistical process control (SPC) to analyze the collected variables. The results indicated higher losses in the platform than in the machine. In addition, the harvest quality was not affected by the pod moisture content. However, the correct adjustment of machines can restrict total losses to approximately 1% of the yield. Pods with moisture contents of 15% and 20% can be used for peanut harvesting. However, although a pod moisture content of 15% reduced the amount of mineral and vegetal impurities inside the bulk tank, the number of open pods increased, whereas a pod moisture content of 20% provided a greater number of whole pods.

### INTRODUCTION

Harvest losses occur for several factors, regardless of the crop. Improvement in peanut harvesting techniques can provide higher operational efficiency, but the determination of harvest losses is necessary to achieve this (Butts et al., 2009). In crops such as soybean and corn, the loss ratio is practically defined by monitoring and adjusting internal mechanisms as well as the harvester's displacement speed, which can reduce losses and increase the quality process (Menezes et al., 2018, Ormond et al., 2016; Paixão et al., 2017a).

The harvester adjustments are made throughout the working day according to the characteristics of the plants, such as plant stand and height, and grain moisture as well as workforce and crop management, to reduce losses (Tedesco-Oliveira et al. 2020). However, in the case of peanuts, the growers also need to consider pod humidity and width and height of the windrow as these can affect the harvesting quality. The grain moisture can change with temperature and humidity. In modern harvesters, this

change is monitored and displayed on the harvester display, which allows the operator to make necessary adjustments to maintain process quality (Voltarelli et al., 2017).

However, knowledge about the machine-plant interaction in peanut cultivation is still incipient (Colvin et al., 2018), particularly in harvesting. The pods, immediately after dug, have a humidity between 40% and 50% (Cavichioli et al., 2014), which is considered high for the threshing and separation capacity of harvesters. In this case, regardless of the system (axial or tangential), the pods require time to reduce the moisture before being harvested; this period is called the curing period.

The curing period is essential for peanut harvesting as it enables the reduction of the moisture content of pods and plant mass (Ormond et al. 2018) providing more efficiency to the harvester's internal mechanisms, which can reduce the amount of mineral and vegetable impurities. Furthermore, less water in the pods results in reduced drying cost and improved quality.

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Area Editor: Fabio Henrique Rojo Baio

Received in: 5-21-2020

Accepted in: 10-22-2020



As peanut harvesters do not have the function of monitoring the quality of the operation in real-time (monitor screen), an alternative used by several authors to evaluate and monitor the operation is Statistical Process Control (SPC) (Kazama et al., 2018; Santos et al., 2016; Tavares et al., 2018). However, studies regarding SPC are focused on monitoring digging losses under different conditions (Santos et al., 2019; Zerbato et al., 2019; Ormond et al., 2018; Zerbato et al., 2017), requiring studies on applying SPC to peanut gathering. The SPC expresses the results graphically and sequentially, allowing monitoring of the average levels of behavior, stability, and variability throughout the operation (Samohyl, 2009).

Thus, considering that the moisture content of the pods interferes with the peanut harvesting, we hypothesized that lower moisture content would improve the quality of the operations, with lower loss rates and higher number of whole pods with fewer impurities. The objective of this study was to analyze the interference of pod water content on peanut harvesting under different pods water content and its influence on the process quality based on losses and impurities using SPC tools.

## MATERIAL AND METHODS

### Experimental site

The experiment was conducted in a peanut seed producing area in Luzitânia district, São Paulo, Brazil, located near the geographic coordinates 21°06' S and 48°14' W, in the WGS84 reference geodetic system, with altitude and average declivity of 540 m and 3%, respectively. The predominant soil type was of loamy clay texture (EMBRAPA, 2013), and the climate type was Aw according to the Köppen classification. The granoleic 886 variety of peanuts was used. It was sowed with a separation of 0.90 m between rows, with a population density of 18 plants m<sup>-1</sup>.

Before the harvesting operation, a mechanized dig was performed using an MF 7390 Dyna-6 tractor with a 140 kW (190 hp) engine. The digger-shake-inverter used was a KBM-AIA2 (two lines and one windrow). This operation was performed 120 days after sowing, when the pods displayed 75% maturity.

The mechanized gathering operation (pod harvesting) was performed three days after the plants were dug. The set machines used were a MIAC Double Master III, powered by a 6110J tractor, with 81 kW (110 hp) engine power, with an average displacement speed of 5.30 km h<sup>-1</sup>. This harvester machine has a working width of 1.60 m, is driven by power take-off (PTO), and has a platform collector to collect the peanut windrows that enter the inside of the machine. An internal mechanism (low-impact axial flow) is responsible for separating the pods from vines in the threshing cylinder. The concave area provides considerable time and space for threshing and separation. After that, the pods fall in a set of sieves that move them to a continuum bucket until bulk. The vines are thrown up to the outside by the turbine air.

To ensure homogeneity, the threshing cylinder pins were held at the -45° position relative to the helicoid in both treatments. This direction of material movement provides a longer threshing time as the material passes more slowly through the system, avoiding loss of pods along with the

straw, which is discarded at the end. This is suitable for high-yield peanut crops with high mass or pod moisture content.

### Treatments

The treatments used were moisture content of two pods (15% and 20%), with 16 and 14 data points collected in the moisture content treatment of the pods with 20% and 15%, respectively. The 20% and 15% moisture content treatments were harvested before 12 a.m. and after 4 p.m., respectively. The moisture content was determined using the method described by Martins & Lago (2008). The method of collection of variables followed SPC design and was performed using mechanized set displacement.

The harvest losses and average yield were estimated in a sample area of 2 m<sup>2</sup>, 5 m ahead of the point where the variables for each treatment were measured. The average was 28 points, and the values were extrapolated to kg ha<sup>-1</sup>. All the pods that developed inside the frame were considered for the analysis.

### Variables analyzed

The quality of the operation was evaluated by monitoring the following indicators: harvesting platform losses (PPR), machine losses (PMR), and total harvesting losses (PTR), which were determined based on the average yield of 5,500 kg ha<sup>-1</sup>.

Four 0.33 m<sup>2</sup> hoops were thrown between the pickup platform and the tracker wheel axle to collect the pods being lost from the process. Thus, all pods found below the hoops after the harvester's pass were considered as losses. This was in addition to the visible losses in the preceding operation (digging). The pods above the hoops were considered as machine losses, that is, pods that the machine was not able to process, and the sum of these two losses was considered as total losses on pickup. The methodology for loss determination was adapted from Ferreira et al. (2007).

Samples to analyze the quality of the harvested material were collected using a recipient with a known volume (1 L) from inside the bulk tank while the harvester was gathering the windrows. In the laboratory, the mass was determined and standardized to 400 g for each sample. Thus, values were established as percentage of each analyzed variable, which were separated and classified according to Table 1.

TABLE 1. Variables used to characterize the quality of the material harvested in the peanut harvesting operation and respective definitions.

Variable	Variable characteristics
Whole pods (WP)	Fully developed pods that showed no sign of mechanical damage
Open pods (VA)	Pods that were open or split in half, or those with signs of apparent mechanical damage
Vegetal impurity (IV)	Dried twigs and/or leaves of the plant or weeds, gynophore, crop residues
Mineral impurity (IM)	Soil, stone, and other materials

### Statistical analysis

The data were subjected to the Anderson-Darling (AD) normality test at 5% probability with the normal distribution, and control charts were constructed to analyze the quality of the peanut harvesting operation. In addition, a descriptive analysis was performed.

Process variability was analyzed using SPC using the Minitab® 17 program ([www.minitab.com](http://www.minitab.com)). Control charts were applied to the variables and the mobile amplitude individual (I-MR) model, which contains two graphs: an upper one, corresponding to the individual values sampled at each point, and a lower one, obtained by calculating the amplitude between two successive observations, was used.

The control limits were established considering the variation of data owing to uncontrolled (special) causes in the process and were calculated based on the standard deviation ( $\sigma$ ) of the variables, as shown in eqs (1) and (2) with  $\alpha = 0.01$  (Montgomery, 2009). However, in this study, the lower control limit values (LCL) were taken to be zero because there were no negative losses value.

$$UCL = \bar{x} + 3\sigma \quad (1)$$

$$LCL = \bar{x} - 3\sigma \quad (2)$$

In addition, to compare and estimate loss percentages during peanut harvesting, we used the

stipulated value for soybean, for which total losses of around 1% are considered acceptable (Embrapa, 2002), as a value for peanut is not available yet. Then, the upper control limit (UCL) was adapted to the total peanut losses chart in this study.

Moreover, a simple analysis was performed to estimate possible increments in profit due to reduction in harvest losses for each condition (15% and 20% pod moisture). It assumed that the peanut costs \$9.76 per 25 kg and used the total losses. This analysis was performed to evaluate if growers need to consider the peanut pod's moisture condition to maintain harvest losses at around 1% as well as necessary adjustments during the day.

### RESULTS AND DISCUSSION

Table 2 shows a descriptive analysis and the AD normality test results, indicating that the data distribution was normal only for the variables PPR, PTR, WP (with 20% water content in the pods), and VA and IM (with 15% water content in the pods). However, although data with normal distribution is desirable, it is not fundamental to the application of control charts (Samohyl, 2009). Furthermore, the whole pods variable (WP) presented low coefficients of variation (CVs): 9.45 and 4.83 for 20% and 15% of water content in the pods, respectively. These results indicate that the smaller the variation in the pods, the better the operation quality.

TABLE 2. Descriptive analysis for treatments with 20% and 15% water content of the pods.

	20% water content of the pods						
		kg ha <sup>-1</sup>			%		
	PMR	PPR	PTR	WP	VA	IM	IV
Max.	32.61	103.26	125.00	85.80	6.64	16.88	3.77
Min.	0.00	10.87	10.87	62.22	0.00	1.42	1.70
Average	0.00	43.48	54.95	73.82	3.09	10.76	2.92
$\sigma$	14.44	27.61	32.92	6.89	1.75	4.68	0.67
CV	123.95	59.26	56.53	9.45	47.89	48.2	23.30
AD	<0.005 <sup>A</sup>	0.58 <sup>N</sup>	0.73 <sup>N</sup>	0.60 <sup>N</sup>	0.15 <sup>A</sup>	0.44 <sup>A</sup>	0.46 <sup>A</sup>
	15% water content of the pods						
Max.	43.48	92.39	97.83	76.83	6.29	20.67	5.45
Min.	0.00	0.00	0.00	66.92	0.00	1.09	2.03
Average	0.00	40.76	57.93	71.72	3.60	10.11	2.99
$\sigma$	13.68	26.02	28.57	3.47	1.78	5.14	0.99
CV	143.81	56.75	51.60	4.83	53.83	48.58	30.51
AD	<0.005 <sup>A</sup>	0.40 <sup>A</sup>	0.16 <sup>A</sup>	0.34 <sup>A</sup>	0.69 <sup>N</sup>	0.92 <sup>N</sup>	0.31 <sup>A</sup>

PMR: Machine Losses; PPR: Platform Losses; PTR: Total Losses; WP: Whole pods; VA: Open pods; IM: Mineral impurity; IV: Vegetal impurity; AD: Anderson-Darling Normality test, N: Normal distribution, A: Non-normal distribution ( $p > 0.05$ ).

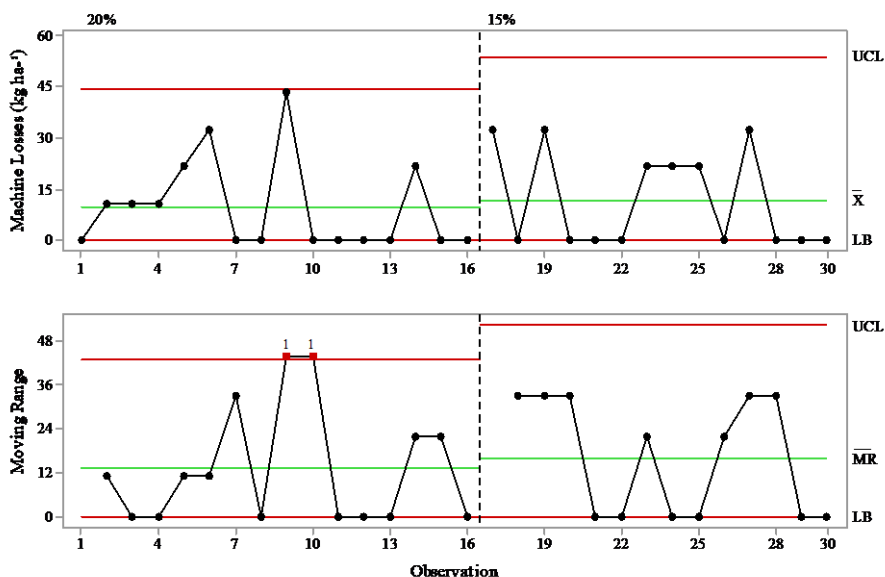
For the variables PMR, PPR, and PTR, the CV and  $\sigma$  values are high (Pimentel-Gomes & Garcia, 2002), which indicates high data dispersion and heterogeneity of the samples. However, in experiments to evaluate harvest losses, CV values are often high or very high (Ormond et al., 2018) mainly because losses occur in larger or smaller

scales between the points, which restricts the use of this classification. Thus, it is suggested that each variable should have a classification range of specific CVs (Fritsche-Neto et al., 2012).

The high variabilities between points can make a process unstable or uncontrolled when assessing losses

using SPC. Thus, the control charts are useful for monitoring variability and maintaining process quality (Ormond et al., 2018) as they show all the data points in the graphic. Thus, under SPC optics, all the loss types measured were controlled (machine, platform, and total losses). However, on average, the machine losses (Figure 1) are higher when the moisture content is 15% (64% above average). The low water content causes an increase in

harvest losses because it is easier for the pods to detach from the branches (Colvin et al., 2018). In contrast, high moisture content in pods can lead to an increase in losses due to the difficulty of detachment, particularly when the dig is performed, and it rain during the drying period of pods in the field. In other crops, such as beans, the pod's moisture has been highlighted as a factor that affects internal mechanism of harvesters (Souza et al., 2001).



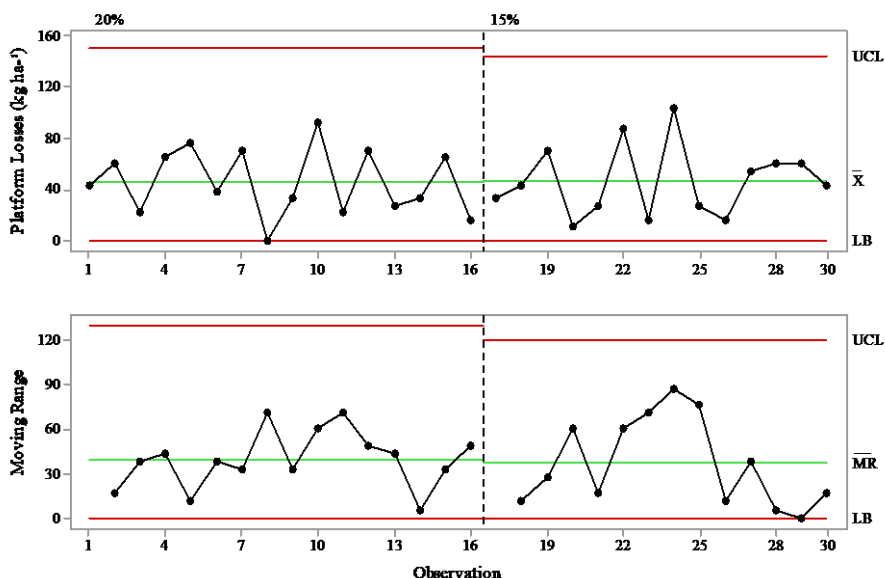
UCL: Upper Control Limit; LB: Inferior Control Limit,  $\bar{x}$ : media; MR: Moving Range.

FIGURE 1. I-MR control charts for peanut harvesting machine losses with 20% and 15% moisture content.

The highest above-average losses in this condition are due to the harvester's track roller adjustment, which was in the  $-45^\circ$  position to ensure homogeneity in the treatments. However, this behavior indicates that the management of harvester adjustments must be constantly monitored and that they must be changed according to crop conditions to maximize the efficiency of the harvester (Purfürst & Erler, 2011). However, the lack of embedded technology in peanut harvesters makes it challenging to adjust and manage the settings in real time, unlike harvesters for other crops that already have embedded loss sensors (Ni et al., 2011).

Losses on the harvesting platform (Figure 2) were similar in both processes, with an average of  $46 \text{ kg ha}^{-1}$ ,

which represented most of the total losses. As peanut harvesting involves two operations, the first (digging) directly affects the yield of the second, especially platform losses during harvesting, as the pods fall on the soil, particularly at high maturity. These pods are not gathered by the harvester after the harvesting operation, thereby reducing the grower's profit. Thus, in any situation, the platform losses are higher than machine losses, which occurs because there is no adequate conveyor belt vibrates regulation associated with low plant biomass and over maturity pods (Santos et al., 2016).



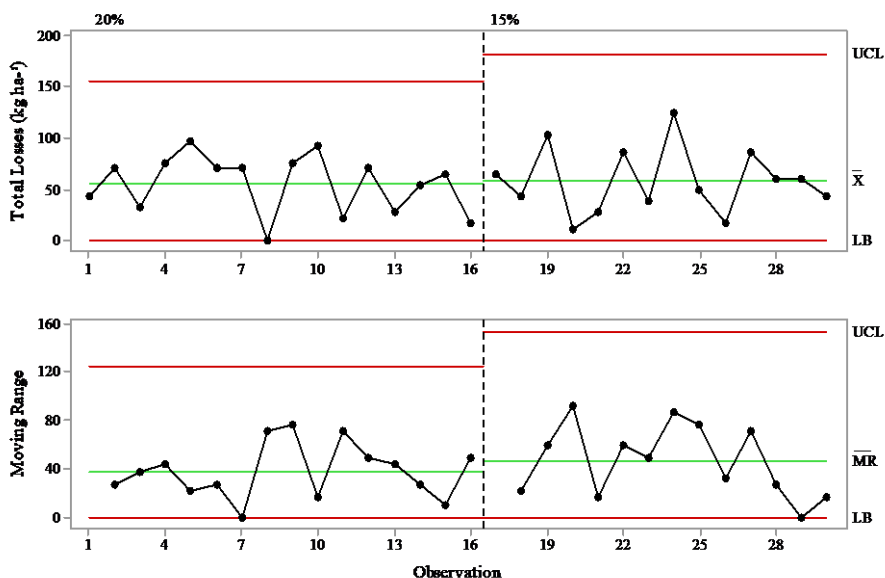
UCL: Upper Control Limit; LB: Inferior Control Limit,  $\bar{x}$ : media; MR: Moving Range.

FIGURE 2. I-MR control chart for peanut harvesting platform losses with 20% and 15% moisture content.

Similar results were also observed in semi-mechanized bean harvest, in which the platform losses were higher than losses in the track, separation, and cleaning systems of an axial flow track harvester (Souza et al., 2001). However, in the case of peanuts, in pods with lower moisture content, the gynophore is more prone to breakage when the harvester contacts the windrow, which contributes to increased losses.

When it is considered that the allowable amount of total losses in peanut harvesting is around 1% of yield in a

producing unit, it is noted from the control charts (Fig. 3) that the values are close to the limit established (LE). In each process, based on the average value, the losses can be considered acceptable, representing 1% of the average yield (5,500 kg ha<sup>-1</sup>) with pod moisture content between 15% and 20%. These values are below the acceptable levels for a track harvester, which was stipulated between 3% and 5% for bean harvesting (Souza et al., 2001).



UCL: Upper Control Limit; LB: Inferior Control Limit,  $\bar{x}$ : media; MR: Moving Range.

FIGURE 3. I-MR control chart for total peanut harvest losses with 20% and 15% moisture content.

The loss values of 55 kg ha<sup>-1</sup> and 58 kg ha<sup>-1</sup> for 20% and 15% of pod water content, respectively, found in our experiment, represent losses of \$ 21.48 and \$ 23.86 ha<sup>-1</sup>, respectively, considering that a peanut bag (25 kg) costs \$ 9.76 (Agrolink, 2017) in the Jaboticabal region, SP, Brazil. These results show the need for an effective machine adjustment system to reach total loss levels close to 1% of

yield. In addition, peanut crops respond to changes in the pod moisture content, and the useful life of the mechanized harvester can directly affect the losses and the quality of the harvesting process (Cavichioli et al., 2014), which can hinder the attainment of 1% loss levels. However, peanut growers can focus on factors that directly affect losses, such as adjustment and maintenance of the combine,

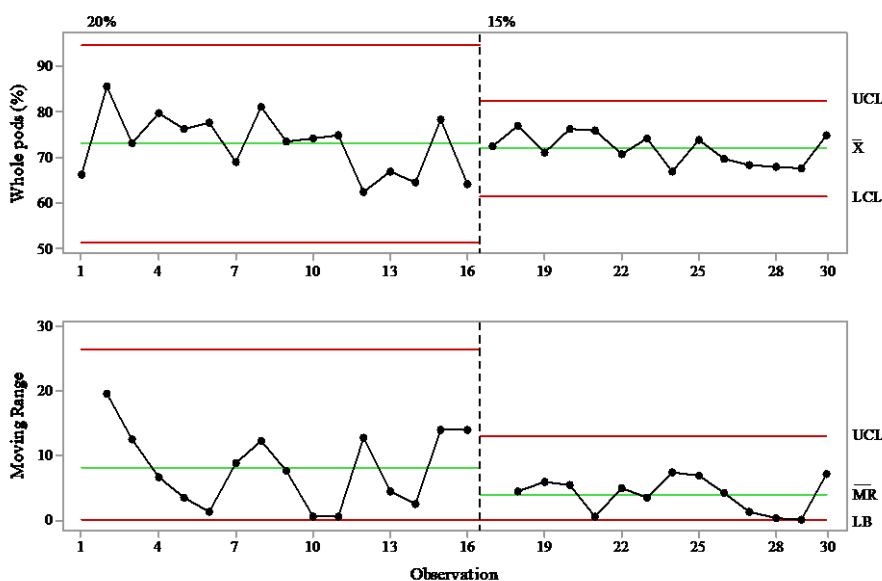
operator skill, product yield, and field conditions, instead of focusing on harvester age (Purfürst & Erler, 2011).

**Quality of harvested material**

On average, a higher number of whole pods was observed in the case moisture content close to 20%, but with considerable variability (Figure 4). However, from the perspective of CEP, variability is inversely proportional to the quality of the process. Thus, it is assumed that for moisture content closer to 15%, the process has better quality. Although low variability indicates higher process quality, in this specific case, more whole pods inside the bulk tank is advantageous to growers. In this context, we

can just say that peanut harvester machines have better process quality with 15% moisture pod content.

Another important aspect is the reduction in drying costs. In addition, the selling price of farmers probably will reduce the costs to dry the pods using a forced dryer due to the price that the farmer gets for his peanuts depends on their size, quality and moisture content (Bell et al., 2018; Cui et al., 2018; Hassan et al. 2018). In this regard, analyzing the moisture content of soybean pods and the performance of the operation, Paixão et. al (2017b) found that when the grains were drier, many of the sample points were concentrated around the average, which is reflected in the lower variability in seed data and higher quality of the harvesting process.

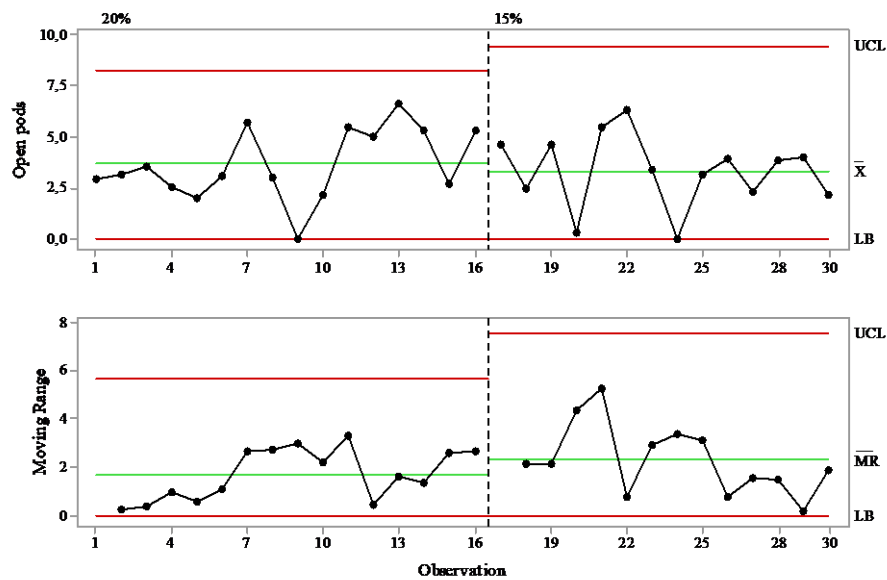


UCL: Upper Control Limit; LB: Inferior Control Limit,  $\bar{x}$ : media; MR: Moving Range

FIGURE 4. I-MR control chart for whole pods as a function of pod moisture content during harvesting.

However, in our study, the process with the lowest percentage of moisture content in the pods had more variability when evaluating the percentage of open pods (Figure 5). This is due to the lower elasticity of the pods, which makes them more sensitive to shell breakage than pods with 20% water content in the threshing and separation mechanisms. Thus, the quality of the harvest depends on the operator's knowledge of the machine's working capacity and

condition, the use of appropriate speeds regarding the state of the crop and the machine, adjustments throughout the day according to temperature and humidity conditions, and necessary maintenance. To avoid most of these problems, the operator has an important influence on quality maintenance and should be considered a key factor in the harvest process (Purfürst & Erler, 2011).

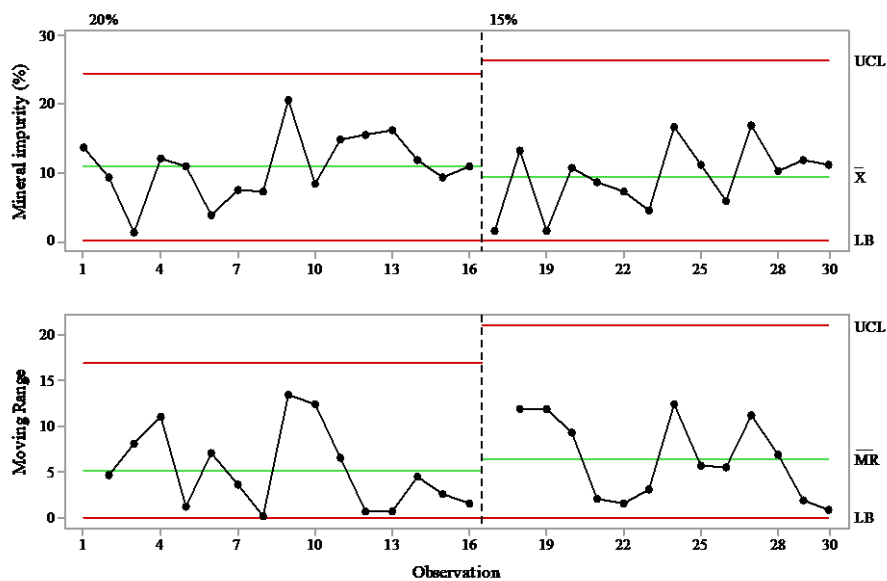


UCL: Upper Control Limit; LB: Inferior Control Limit,  $\bar{x}$ : media; MR: Moving Range.

FIGURE 5. IM-R control charts for open pods as a function of pod moisture content during harvesting.

Regarding the number of impurities (Figure 6), in the treatment with 20% moisture content of the pods, the average IM and IV were higher. This fact has an intrinsic relationship with peanut physiology, as the pods develop under the ground. Clayey soils have a characteristically high

apparent cohesion due to the surface tension of the water in the soil capillaries (Fredlund & Rahardjo, 1993), which increases the adhesion strength of the soil particles to the pods, decreasing the IM cleaning abilities, caused by the internal mechanisms of the peanut harvester.



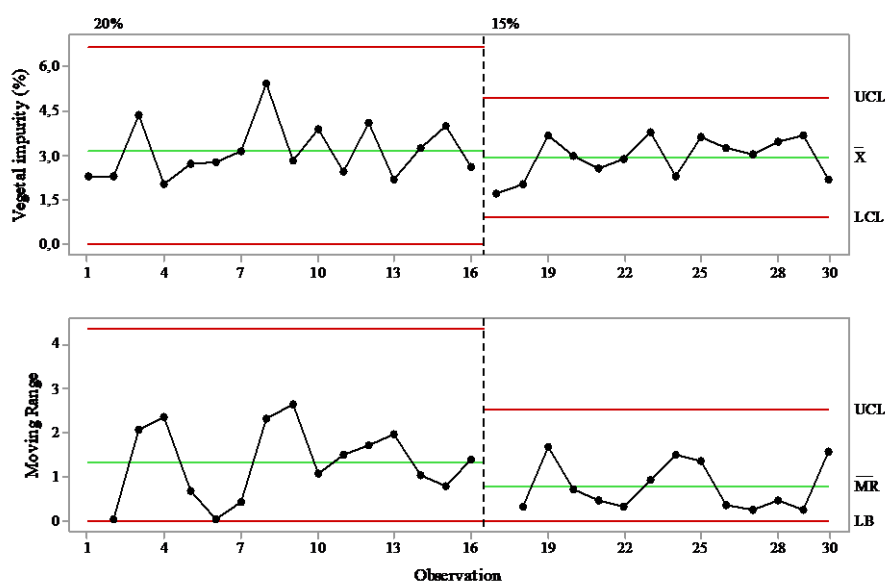
UCL: Upper Control Limit; LB: Inferior Control Limit,  $\bar{x}$ : media; MR: Moving Range.

FIGURE 6. I-MR control charts for the percentage of IM as a function of pod moisture content during harvesting.

The lower amount of IV (Figure 7) is due to the efficiency of the internal cleaning mechanisms of the axial systems in this type of peanut harvester. After separation of the pods and vines, the internal systems use a fan to eliminate less dense material. Thus, the capacity of the cleaning section is a limiting factor because the fan needs to

generate a strong and uniform airflow (Gebrehiwot et al., 2010). In mechanized sugarcane harvesting, a positive correlation was found between the fan speed, wind speed, and pressure in the extractor chamber (Wang et al., 2018); although the feed rate had no effect on the impurity rate, it directly influenced sugarcane losses.





UCL: Upper Control Limit; LB: Inferior Control Limit,  $\bar{x}$ : media; MR: Moving Range.

FIGURE 7. I-MR control charts for the percentage of IV as a function of pod moisture content during harvesting.

A lower variability in IVs was also observed in a study of the quality of mechanized outsourced cane harvesting operations compared to the semi-mechanized and mechanized fronts using more technologically advanced machinery (Alcântara et al., 2017). From a technical perspective, the similarity in the harvest quality between sugarcane and peanut in terms of reducing IVs inside the bulk tank indicates the advantage of peanut harvesters, as sugarcane harvesters have more advanced embedded technology compared to current peanut harvesters.

## CONCLUSIONS

A moisture content of peanut pods between 15% and 20% did not interfere with harvest losses; they presented close average values with small variability. However, a moisture content of 15% provided a reduction in the number of whole pods in the bulk tank and an increased open pod variability, whereas a moisture content of 20% provided higher whole pod variability and lower number of open pods.

The threshing and separation mechanisms were more efficient with a pod moisture content of 15%, which provided reductions in the amounts of IMs and IVs, probably because such pods are drier and lighter.

Despite necessitating complex adjustment peanut harvesters throughout the day, the pod's moisture content may be improving the quality of the process and maintain the losses at around 1% of the yield.

## ACKNOWLEDGEMENTS

The authors are grateful to the São Paulo State University (UNESP), Jaboticabal Campus, for the academic support and availability of laboratories, and the National Council for Scientific and Technological Development (CNPq) for the first author's scholarship during his Ph.D.

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