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LOSS SAMPLING METHODS FOR SOYBEAN MECHANICAL HARVEST

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Abstract

Harvesting is one of the most important stages of the agricultural production process. However, the lack of monitoring during this operation and the absence of efficient methodologies to quantify losses have contributed to the decline in the quality of the operation. The objective of this study was to monitor mechanized soybean harvest by quantifying losses through two methodologies using statistical process control. The study was conducted in March 2016 in an agricultural area in the municipality of Ribeirão Preto, SP, using a John Deere harvester model 1470 with a tangential-type track system and separation by a straw-blower. The experimental design followed the standards established by statistical process control, and every 8 min of harvest, the total losses by the circular framework and rectangular framework methodologies were simultaneously quantified, totaling 40 points. Data were analyzed using descriptive statistics and statistical process control. The averages of the circular methodology framework were values above those found in the rectangular methodology framework, presenting greater representativeness of losses. The process was considered unable to maintain losses of soybeans at acceptable levels during mechanical harvest throughout the operation of the two frameworks. The circular framework for collecting samples at different locations resulted in higher reliability of data.

Keywords: Control Charts. Grain Harvester. *Glycine max L.* Loss Methodology. Statistical Process Control.

1. Introduction

Within the world agribusiness, soybean production is among the economic activities that have presented expressive growth in the last few decades. According to Conab (2020), in the 2019/2020 harvest, the cultivated soybean area reached approximately 36,820.8 thousand hectares, with an increase of 2.6% in relation to the 2018/2019 harvest. Thus, representing total production in the order of 123,249,9 million tons.

Because it is one of the main stages of the production process, harvest has become a very important operation, requiring good execution to reduce losses such that the producer has a return on their investment (Câmara 2015). According to Mesquita et al. (2018), it is estimated that Brazil loses approximately 2.4 million tons during soybean harvest. Losses in mechanized soybean harvesting can be caused by factors, such as the use of non-adapted cultivars, grain water content, machine settings (cylinder rotation, harvester speed, hollow opening, and cutting height), and often are caused by the lack of trained operators for this function (Cassia et al. 2015).

In this regard, there are many questions about the size of the frame used to collect losses during mechanized soybean harvesting. There are several variations in the methodology used for the evaluation; however, the main changes are related to the area and format of the frame used. Cortez et al. (2019), when evaluating various formats of frames used to determine losses in mechanized harvesting, observed that these interfered with quantifying total losses in the soybean culture.

According to the methodology of Costa and Tavares (1995), the frame area is variable with the size of the harvester's cutting platform, which is delimited by two 0.50 m pieces of wood, joined by string threads at both ends, with length equal to the width for the cutting deck. However, the methodology suggested by Mesquita et al. (1998) consists of defining the frame area at 2 m² for corn and soybeans, with a frame length equal to the length of the harvester's cutting platform (nylon threads) and sides (pieces of wood) of variable size, determined by the quotient of the frame area (2 m^2) and the length of the harvester's cutting platform. Portella (2000) stated that the area of the frame must be established using a rectangle of string and wood, with one side of a width equal to the cutting platform and the other side lengths that result in a rectangular area of 1 m^2. However, studies have shown that variations in the rectangular frame do not cause differences in quantification (Loureiro Júnior et al. 2014; Cortez et al. 2019).

However, several studies have adapted the methodology described by Augsburger (1992), in which four rings of 0.56 m in diameter should be used, totaling an area of 1 m^2, positioned after the platform has passed and before the straw crusher of the grain harvester. Thus, it has not yet been identified which of the different frames has the highest accuracy in representing soybean harvesting losses.

With regard to modernity and the future of agriculture, concepts that aim to efficiently manage crops become indispensable because they provide producers with information that allows them to identify better strategies in search of quality in agricultural operations (Menezes et al. 2018). Statistical process control (CEP) allows monitoring and decision-making to be assisted in the various stages of production, identifying any flaws within the processes such that they can be eliminated later to ensure greater quality and stability of mechanized operations (Silva et al. 2015). Thus, based on the assumption that the shape of the frame influences the practicality of the methodology and the variability and representativeness of the data, the objective of this work was to determine the best methodology to measure the losses in mechanized soybean harvesting, considering the variability, stability, and capacity of the process through CEP.

2. Material and Methods

The experiment was conducted in an agricultural area in the municipality of Ribeirão Preto - SP, located close to the geodesic coordinates 21°10’39”S, 47°48’37”W, with an average altitude of 546 m. Sowing was conducted to plant the soybean crop in October 2015, using the NS 7000 IPRO variety developed by NIDERA. The spacing was 0.50 m between rows and 18 seeds m^{-1}, totaling a sowing density of approximately 360,000 plants ha^{-1}.

Harvesting started in March 2016 using a John Deere combine, model 1470, year 2013, with approximately 711 engine hours. The harvester had a John Deere 6.8 L engine, whose nominal power was 142 kW (193 hp). It was equipped with a 6.60 m wide cutting platform, tangential-type trail system, and separation by straw bag and bulk tank with a capacity of 5500 L. Throughout data collection, the same operator was maintained to reduce experimental error related to differences in operators.

The experimental design followed the standards established by the statistical process control, in which the sampling points were collected over time (Montgomery 2009). Every 8 min of harvest, losses were quantified simultaneously using the methodologies of Augsburger (1992), who called it the circular frame methodology, and Mesquita (1998), who called it the rectangular frame methodology, totaling 40 points by the end of the harvest operation for each methodology.

To determine losses using the circular frame methodology, circular frames were used, made with 0.25 m² frames, sealed with a sunshade screen resembling sieves, using four frames of the same size, which together totaled an area of 1 m². The hoops were launched at predetermined points such that two hoops were arranged outside the layout of the front wheels of the harvester (left and right), and two were launched between the wheels (middle). All grains and pods present in the rim region were collected after the harvester passed. The losses from the internal mechanisms were represented by the grains and pods found on the sieves, and the grains and pods found below the sieve were considered losses from the platform (added to natural losses); thus, total losses were calculated as the sum of the losses on the platform and the internal mechanisms. In contrast, in the rectangular frame methodology, it was positioned transversely to the sowing lines, with an area of 2 m^2 after the passage of the harvester.

This frame had a length (nylon threads) equal to the width of the harvester cutting platform (6.60 m) and the sides (wooden battens) with values determined by the quotient between the area of the frame (2 m^2) and the width of the harvester cutting platform, resulting in a frame width of 0.305 m. All grains loose on the ground, pods with grains, and plants with pods found inside the frame were collected and packed in paper bags and properly identified to quantify total losses.

After collecting all the points of the two frames, the samples were weighed on a scale with a resolution of 0.01 g and then stored in an oven for 24 h at a temperature of 105 °C to be weighed again to determine the mass of dry grain. After collecting all the points of the two frames, the samples were weighed on a scale with a resolution of 0.01 g and, soon after, stored in an oven for 24 h, at a temperature of 105 ° C to be weighed again to determine the mass of dry grain.

Subsequently, statistical process control was used with the following tools: run charts, control charts of individual values, mobile range, and process capacity analysis. To determine the randomness or non-randomness of the process, run charts were used, which allowed the identification of the possible presence of special causes of variation by examining the existence of patterns of grouping, mixing, trends, or oscillation.

Verification of the possible randomness of the data was conducted through a 5% probability test, and if the p-value for the standards was less than 0.05, the null hypothesis of non-randomness was rejected in favor of the alternative to the tested standard (Montgomery 2009). Thus, the occurrence of these standards may indicate that the process is close to exceeding the control limits, that is, becoming unstable, or even that the process is already "unstable" and potentially does not meet established quality standards. However, this type of analysis must be complemented by checking the control charts, thereby obtaining greater precision in analyzing the behavior of the variables (Voltarelli et al. 2015).

To increase the rigor of the analysis in detecting the presence of special causes in the control charts because of variability not common to the process, the following analysis methodology proposed by Montgomery (2009) was used. Test 1: one or more points outside the limits of the upper or lower control; Test 2: a sequence of nine points on the same side of the midline; and Test 3: a sequence of five increasing or decreasing points intercepting the midline.

The control charts of individual values and the mobile range were used to detect existing variability in the process. The upper limit, average, and lower limit of control allow the inference of whether there is variation in the data caused by non-random causes in the process (special causes) and are calculated based on the standard deviation of the quality indicators, as shown in Eq. 1, 2, and 3, respectively, for the individual values chart (Montgomery 2009):

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

$$\bar{X} = \frac{(X_1 + X_2 + X_3 + \ldots X_N)}{N} \quad 2)$$

$$LCL = \bar{X} - 3\sigma \quad 3)$$

Where
UCL: Upper control limit;
LCL: Lower control limit;
$\bar{X}$: General average;
N: Total number of the sample;

σ: standard deviation.
3: multiple constant of the standard deviation

For the mobile range chart, the upper limit, average mobile range, and the lower control limit are calculated as shown in Equations 4, 5, and 6, respectively:

$$UCL = D_4\,\bar{A}\bar{M} \tag{4}$$

$$\bar{A}\bar{M} = \frac{|X_i - X_{i-1}|}{N} \tag{5}$$

$$LCL = D_3\bar{A}\bar{M} \tag{6}$$

Where
UCL: Upper control limit;
LCL: Lower control limit;
$\bar{A}\bar{M}$: Average of the general mobile amplitude;
N: Total number of the sample;
i: Number referring to the individual value;
D3 and D4 = tabulated values according to individual values. In this case, for individual values, D3 was zero, and D4 was approximately 3,267 ± 0.01 (Montgomery 2009).

When the individual values or mobile amplitude exceeded at least one point of the control limits, special causes were detected, and the point was highlighted on the control chart with the number of the respective tests. This point indicates there is non-random variation in the data because of causes extrinsic to the process and that such variation must be investigated, detected, and subsequently corrected. Conversely, when no point is highlighted in the control chart, there is no evident observation of failure in the process; that is, there are no special causes of variation, and consequently, the process is under statistical control, with only random causes.

The analysis of the capacity of the process was conducted to more adequately determine the function of predicting whether the values of the variables of the agricultural operations meet the specifications designated by the specific control limits, determined by the production unit such that the desired quality goal for the process is managed to relate the variability inherent to the process with its specifications. Associated with this, the capacity of the process was analyzed according to the methodology proposed by Montgomery (2009), defined together with the production unit, through brainstorming, a goal of up to 60 kg ha^{-1} of losses during the mechanized soybean harvest.

After defining the specific limits and goals, the Pp and Ppk processes (minimum and maximum) were obtained using the standard deviation of all measurements (general σ), indicating the general variation of the process Equations 7, 8, and 9.

$$Pp = \frac{(SUL - SLL)}{6\sigma_{general}} \tag{7}$$

Ppk minimum (PPL, PPU)

$$PPL = \frac{(\bar{X} - SLL)}{3\sigma_{general}} \tag{8}$$

$$PPU = \frac{(\bar{X} - SUL)}{3\sigma_{general}} \tag{9}$$

Where:
Pp = general capacity index;
Ppk = general minimum capacity index;

PPL = general capacity index in relation to the specified lower limit;
PPU = general capacity index in relation to the specified upper limit;
SUL = specified upper limit;
SLL = specified lower limit;
Dp or σgeneral = estimate of the general standard deviation using the entire distribution of the dataset.
$\overline{X}$ = mean of the variable.

3. Results and Discussion

The total loss quality indicator showed a non-normal distribution of the dataset in the rectangular and circular frames, which were verified by the Ryan-Joiner test values far from zero and the p-value (Table 2). The non-normality can be explained by the high values of the asymmetry and kurtosis coefficients that were positive and far from zero. Additionally, the kurtosis coefficients show elongated distribution curves, with high values for losses during harvest for both types of frames. This fact demonstrates, in practice, that there was no uniformity in the evaluated losses, with values occurring at some points close to the average, and in the vast majority, extremely high values above the average.

Table 1. Descriptive statistics for total losses in mechanized soybean harvest according to the shape of the frames.

Sampling methodology	Total losses (kg ha^{-1})						
	$\overline{X}$	Σ	CV	Cs	Ck	RJ	p-Valor
Rectangular frame	44,06	42,21	95,82	1,25	0,56	0,916	<0,01^{A}
Circular frame	102,5	120,10	117,13	2,61	8,16	0,823	<0,01^{A}

$\overline{X}$ - general average; σ - standard deviation; CV (%) - Coefficient of variation; Cs - Asymmetry coefficient; Ck - Kurtosis coefficient; RJ - Ryan-Joiner normality test; p-Value (> 0.01), N - normal probability distribution; A - Non-normal distribution of probability.

Based on the descriptive behavior of the data, it appears that the average of the circular methodology framework presents values well above those found in the rectangular methodology framework, which can be explained by the greater number of sample points for circular methodology, in which four were used; thus, resulting in greater representativeness of losses. The variability of an attribute can be classified according to the magnitude of its variation coefficient (Freddi et al. 2006). For the total losses, there are high values for the coefficients of variation (Pimentel-Gomes and Garcia 2002) and the standard deviation, which explains the high dispersion of the dataset in both methodologies. Other authors assessed losses in mechanized soybean harvest and found high values of the coefficient of variation, among which can be cited Mesquita et al. (1999, 2001, 2002) (69.2, 71.7, and 64.8%, respectively) and Câmara et al. (2007) (88.26% and 32.85%, for frames of 2 and 3 m², respectively).

According to Silva et al. (2013), the high values found for the variation coefficient are justified by the high variability of the sample. It should also be noted that Toledo et al. (2008) found a variation coefficient value of approximately 170%, portraying the existing variability and that inherent in the quantification of losses in mechanized soybean harvest. It is noteworthy that in all these studies, rectangular frames of 2 m² were used. Paixão et al. (2017) evaluated the losses in mechanized harvesting and soybean according to the shape of the plots. They found a coefficient of variation for the total losses between 19.80% and 37.02% using circular frames, a result lower than that found in the present study. In both frames evaluated, no patterns of non-random origin were found (Table 2).

Table 2. Values of probability patterns in the sequential graphs for total losses in mechanized soybean harvest according to the shape of the frames.

Quality Indicators	Loss Methodology	Standards			
		A*	M	T	O
Total losses	Rectangular frame	0.168^{ns}	0.832^{ns}	0.601^{ns}	0.399^{ns}
	Circular frame	0.261^{ns}	0.739^{ns}	0.304^{ns}	0.696^{ns}

* A - Grouping; M - Mixture; T - Trend; O - Oscillation; *standard values of non-randomness detected by the probability test at $p < 0.05$; ns, standard values of randomness detected by the probability test at $p > 0.05$.

The absence of standards may indicate that the data have a homogeneous distribution of their values around the average, regardless of the situation found (stability) for the control charts, causing no damage to the process. For example, Compagnon et al. (2012) studied losses in mechanized soybean harvesting caused by day and night periods of work and found high variability in the total loss values. This situation is similar to the present study because the variability of the process is associated with random and non-random origin factors, and those of random origin are more difficult to determine and eliminate from the process because they occur at random.

Costa et al. (2002) stated that the high variability found in studies of mechanized soybean harvest shows that the causes are related to the presence of non-random patterns, related to factors, such as poor maintenance and inadequate adjustments of the harvesters, as well as the occurrence of rain during the harvest period. For the total losses quantified in the rectangular frame (Figure 1), it was noted that during mechanized soybean harvesting. The process can be considered unstable because there are sample points that exceed the upper limit of the control for the individual value and amplitude charts (Test 1) (Figure 1a and 1b) and the presence of Test 2 in the individual value charts (Figure 1a), presenting a sequence of points below the average values of losses in the harvest. This situation is favorable to this operation.

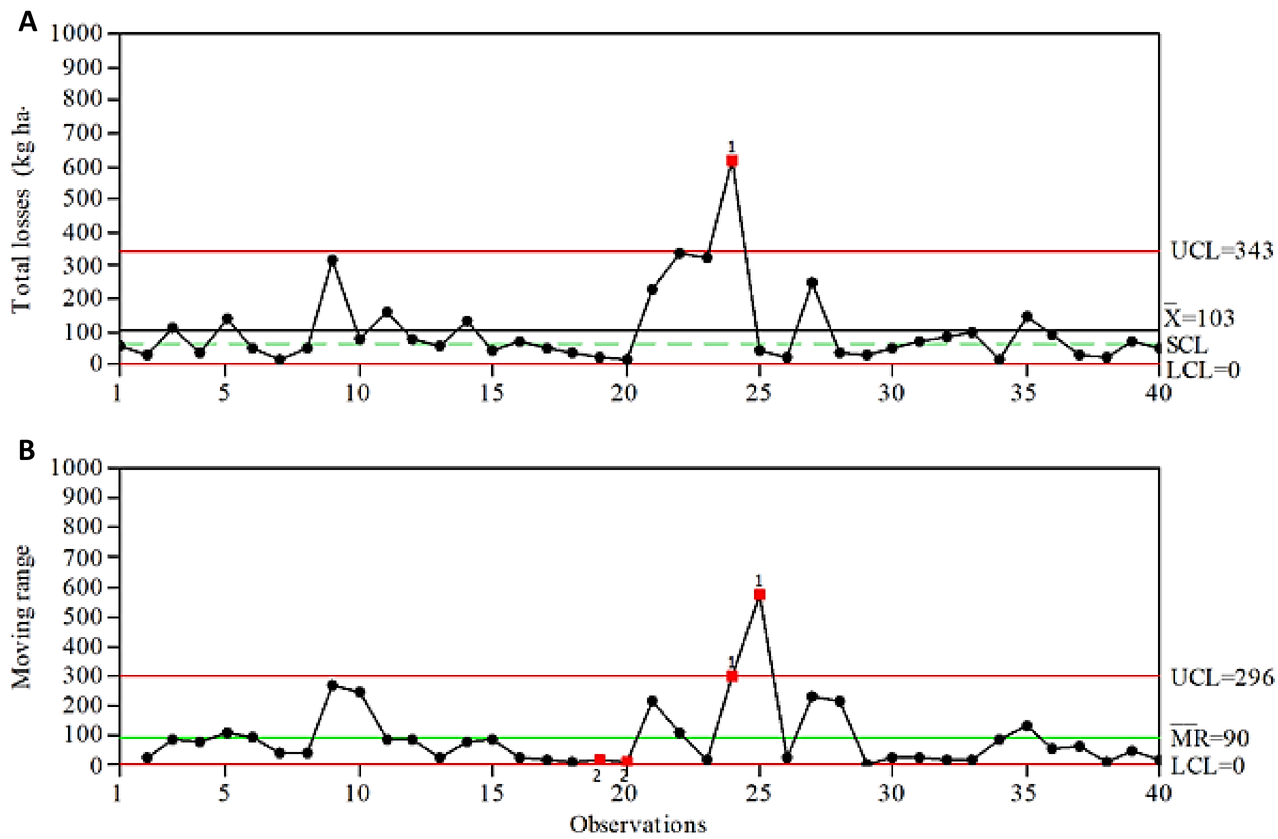

Figure 1. A - Control charts of individual values and B - mobile range for total losses using the rectangular frame methodology during mechanized soybean harvest. LSC: Upper control limit; LIC: Lower control limit; $\bar{\bar{x}}$: Average of the sample values; $\overline{AM}$: average of the general mobile amplitude.

However, the average of total losses in the harvest was below the acceptable limit because surveys conducted at the level of properties have demonstrated high rates of losses in the soybean harvest, with an acceptable loss of up to 60 kg ha^{-1} (Embrapa 2011). In this sense, it can be said that despite the high points of losses resulting from the variability of the operation, the harvest is performed acceptably within the quality standards of the production unit. It was also verified that 10 and 25% of the sample points were unstable during the process and above the goal established by the production unit, respectively, for the individual value control charts. For the total losses collected with the circular frame during mechanized soybean harvesting, the process can be considered unstable because there was at least one sample point outside the upper control limits for the individual value charts (Test 1) (Figure 2a).

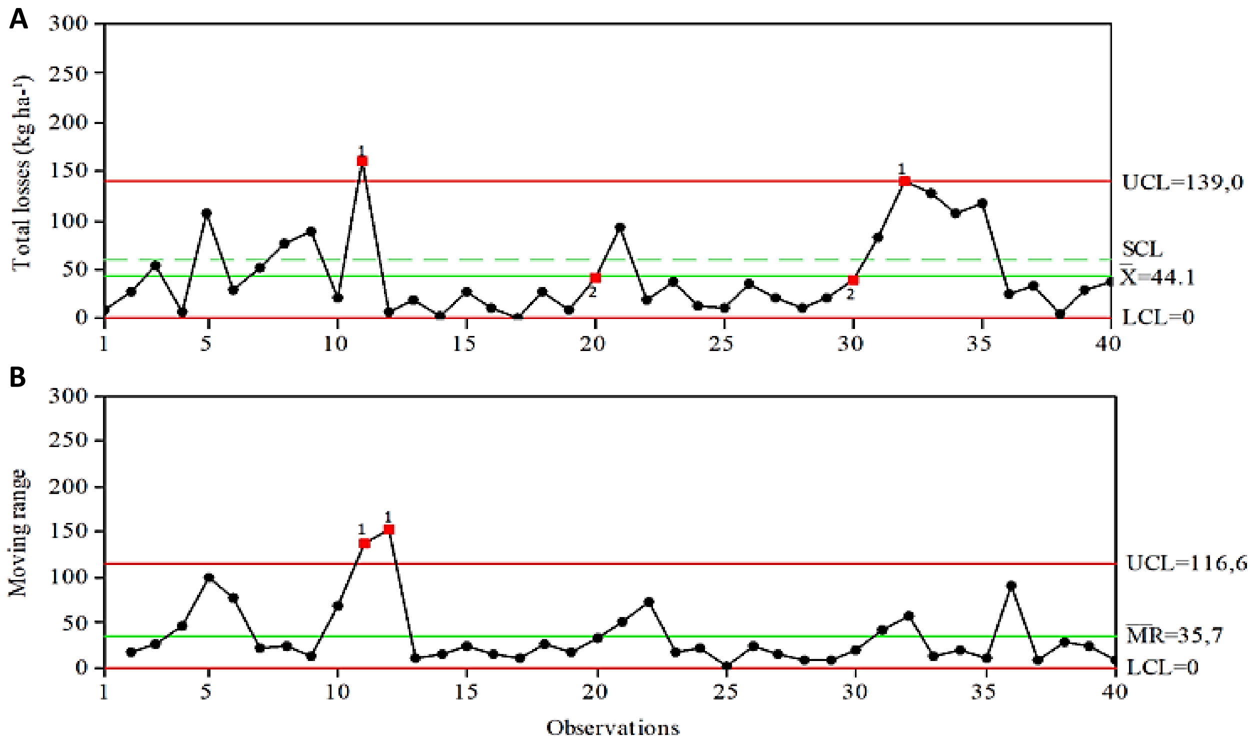

Figure 2. A - Control charts of individual values and B - mobile range for total losses using the circular frame methodology during mechanized soybean harvest. LSC: Upper control limit; LIC: Lower control limit; $\bar{\bar{x}}$: Average of the sample values; $\bar{A}\bar{M}$: average of the general mobile amplitude.

In the moving range chart, the process was unstable because of Tests 1 and 2 (Figure 2b). It is noteworthy that, in this case, the determination of the process instability determined by Test 2, presenting nine points below the average, shows less variability in losses during the mechanized soybean harvest, a situation that is favorable to mechanized soybean harvest when it is intended to reduce its variation and the total amount of losses.

It was also observed that the average total losses in the harvest were above 60 kg na^{-1}. From this point of view, Emater (2005) surveyed 440 properties in the state of Paraná and found that most of the machines lost more than 60 kg na^{-1} (approximately 60 to 180 kg na^{-1}), which is similar to the situation in the present study. It is also noted that 2.5 and 32.5% of the sample points were unstable during the process and above the established goal, respectively.

The determination of losses with the use of circular frames presents na additional advantage in that it does not affect the operational performance of mechanized soybean harvesting, as the harvester does not need to stop to quantify losses on the platform, as during the loss's methodology, total losses on the platform/natural and losses of internal mechanisms are measured simultaneously. However, the rectangular methodology requires a large amount of time to measure these losses, and each type of loss must be evaluated separately, requiring more time for its execution.

According to Slc (1998), it is necessary to know na efficient method for measuring grain loss to identify where and in what quantities it occurs. Another relevant factor is the number of sampling points, and in this work, at 40 points, 160 samples were collected (four sieves per point), whereas for the rectangular frame, only 40, influencing the increase in the coefficient of variation of the set of Dice. In this sense, the representativeness of the harvested area and the losses with the circular frame are monitored to be better represented because of the greater number of samples. By analyzing the general capacity of the process determined by the values of Pp < 1.33, the process is considered unable to maintain losses from mechanized soybean harvesting at acceptable levels, established by specific control limits, using the rectangular frame along with the operation (Figure 3).

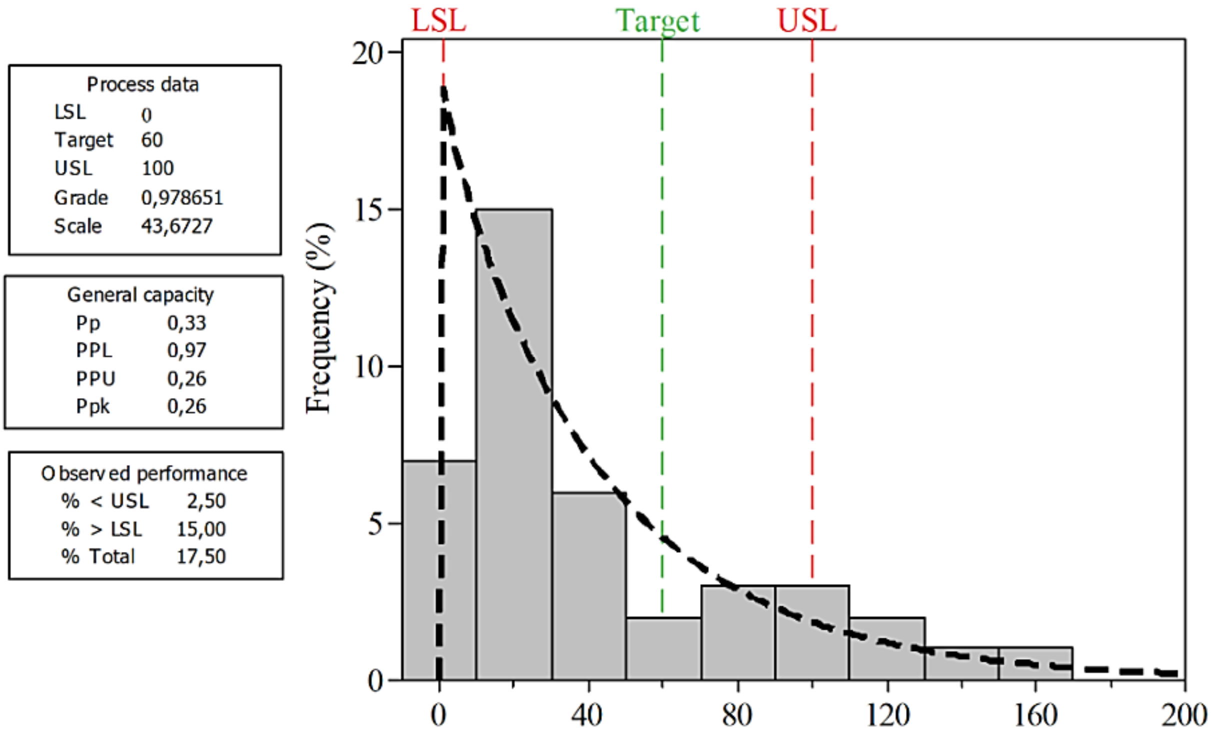

Figure 3. Process capacity analysis for the rectangular frame methodology using the Weibull distribution.

It was observed that the Weibull distribution form score has a value close to one (0.978), which results in a decreasing exponential curve, indicating that the level of losses tends to decrease over the mechanized soybean harvest. Furthermore, the decrease in the level of losses can be associated with the exponential curve with its scale value (43.67), which indicates that the lower this value, the longer the variable will reach the quality standards established by the producing unit.

However, the Pp index is next to Ppk, showing possible proximity of the distribution curve to the established target. It should also be noted that the performance of the process presented 17.5% of the sample values of losses outside the specified lower and upper limits. The same behavior was observed for the circular frame, in which the process was also considered unable to maintain losses from mechanized soybean harvesting at acceptable levels throughout the operation (Figure 4).

However, the values found were higher than those of the rectangular frame for both the Weibull distribution shape (1.031) and the exponential curve value (scale) 104.08, which indicates that the process has the potential to reach the quality levels stipulated by the production unit in a shorter period, in relation to the circular frame methodology. Furthermore, the higher value when using the circular frame can be associated with the fact that this methodology better represents the harvested area for collecting samples in different locations, which results in greater data reliability and, consequently, better representation of the total loss indexes.

According to Triola (1999), we cannot avoid the occurrence of the sampling error, but we can limit its value by choosing a sample of adequate size and number. However, the sampling error and the number of samples follow opposite directions; therefore, the author still states that the greater the number of samples, the smaller the error made and vice versa.

It should also be noted that the performance of the process presented 27.5% of the sample values of losses outside the specified upper limit. When comparing the exponential distribution curves for the methodologies of the rectangular and circular frames, it was found that the highest probability of occurrence of total losses in the soybean harvest was 18% and 27%, respectively.

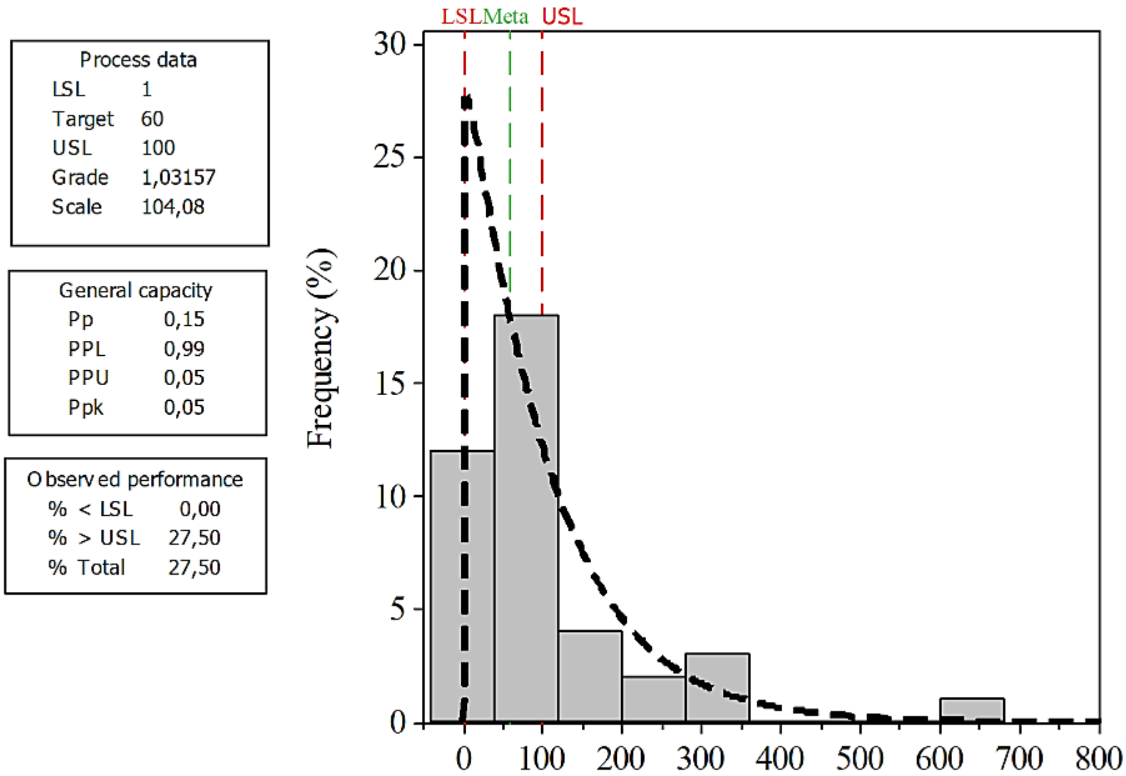

Figure 4. Process capacity analysis for the circular frame methodology using the Weibull distribution

4. Conclusions

The mean of the circular methodology framework presents values well above those found in the rectangular methodology framework, presenting greater representativeness of losses. In both frames evaluated, no patterns of non-random origin were found or showed instability during the process. The process was considered incapable of maintaining losses from mechanized soybean harvesting at acceptable levels throughout the operation for both frames. The scale factor for the circular frame methodology had a value of 104.08, which was higher than the others, which indicated that the loss levels have a greater potential to reach the quality standards established in a shorter time interval. The circular frame for collecting samples from different locations resulted in greater representativeness and reliability of the data.

Authors' Contributions: PAIXÃO, C.S.S.: Conception, design, data collection, Analysis, statistical analysis and interpretation of data, drafting of the manuscript and critical revision of the manuscript for important intellectual content. VOLTARELLI, M.A.: Conception, design, data collection, Analysis, statistical analysis and interpretation of data, drafting of the manuscript and critical revision of the manuscript for important intellectual content. SILVA, R.P.: Conception, design, data collection, Analysis, statistical analysis and interpretation of data, and supervising the work. SOUZA, J.B.C.: Drafting of the manuscript and critical revision of the manuscript for important intellectual content. BRITO FILHO, A.L.: Drafting of the manuscript and critical revision of the manuscript for important intellectual content.

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