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Physical and physiological quality of soybean seeds at three speeds of the harvester

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mechanical damage
vigor
control charts

ABSTRACT
The mechanized harvesting of soybean is a fundamental tool in the production process of this crop and, if not performed properly, it can result in severe mechanical damage to the seeds, causing significant losses at harvest, particularly due to reduced quality. Thus, this study aimed to evaluate the physical and physiological quality of soybean seeds at three speeds of the harvester, using statistical process control. The experiment was carried out in the municipality of Conceição das Alagoas-MG, Brazil, with three travel speeds: 4.5, 5.0 and 5.5 km h^{-1}. The seed samples were collected at 20 min intervals for 3 h of operation, with a total of 9 samples for each speed. The evaluations were performed based on the following parameters: grain temperature, water content, concave opening, cylinder rotation, mechanical damage and electrical conductivity. The physical and physiological quality of the seeds was dependent on the displacement speed of machine. The highest speed led to lower mechanical damage and higher vigor of soybean seeds.

Palavras-chave:
Glycine max (L.) Merrill
dano mecânico
vigor
cartas de controle

Qualidade física e fisiológica das sementes de soja em três velocidades da colhedora

RESUMO
A colheita mecanizada de soja é fundamental no processo produtivo desta cultura e, caso não seja realizada adequadamente, poderá resultar em danos mecânicos severos às sementes, acarretando prejuízos significativos na colheita, particularmente devido à redução da qualidade. Neste sentido se objetivou, neste trabalho, avaliar a qualidade física e fisiológica das sementes de soja em três velocidades da colhedora, por meio do controle estatístico de processo. O experimento foi realizado em área agrícola, no município de Conceição das Alagoas, MG, com três velocidades de deslocamento da colhedora (4,5; 5,0 e 5,5 km h^{-1}). As amostras de sementes foram coletadas em intervalos de 20 min durante 3 h de operação, totalizando nove amostras para cada velocidade. As avaliações foram realizadas a partir dos seguintes parâmetros: temperatura das sementes, teor de água, abertura do côncavo, rotação do cilindro, danos mecânicos e condutividade elétrica. A qualidade física e fisiológica das sementes foi influenciada pela velocidade de deslocamento da máquina. A maior velocidade apresentou menor valor de dano mecânico e maior vigor das sementes de soja.

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Introduction

Using high-quality soybean seeds is essential to obtain high yield (Barbosa et al., 2012). However, during the productive process, various factors can influence seed quality and harvest is considered as the most critical phase of the entire process (Carvalho & Novembre, 2012).

When harvest is performed in the inadequate maturation stage, associated with improper operation of the harvesters, it may lead to considerable losses, decreasing the profitability (Ferreira et al., 2007).

During harvest, the impacts and friction caused by the threshing system are the main responsible for cracks and breaks in the seeds (Cunha et al., 2009), which considerably reduces their vigor.

It is essential that regulations, such as harvester speed, cylinder rotation and concave opening, be adequate in order to reduce mechanical damages and losses in seed quality during harvest (França Neto et al., 2007).

Another important aspect to be considered during harvest is the moisture level of the seeds. To reduce damages, it is recommended that harvest be performed in seeds with moisture of 12-14% (Daltro et al., 2010).

The utilization of statistical methods in the control of seed production processes is a logical and organized way to identify and solve existing problems, promoting continuous improvement in the quality of the process and decrease in the variability (Silva et al., 2008; Noronha et al., 2011). In this context, statistical process control is a tool that can bring advantages to the agricultural production system. However, there are no studies on the monitoring of seed quality during the harvesting process.

Therefore, based on the assumption that the quality of soybean seeds is influenced by the travel speed of the harvester, this study aimed to evaluate the physical and physiological quality of soybean seeds as a function of three travel speeds of the harvester, through statistical process control.

Material and Methods

The experiment was conducted in March 2014 in an agricultural area of the municipality of Conceição das Alagoas-MG, Brazil, and in an area of the São Sebastião Farm located close to the geographic coordinates of 19º 44' 54" S and 47º 55' 55" W, at mean altitude of 801 m.

Soybean was sown in November 2013, at spacing of 0.50 m between rows and 21 to 22 seeds m^{-1}, totaling a sowing density of approximately 430,000 seeds ha^{-1}. A Tatu Marchesan seeder was used, with 9 lines, useful width of 4500 mm and regulated for the depth of seed placement in the soil of 30 mm, using the variety BMX Turbo RR developed by BRASMAX (BMX), which showed germination above 80% in all lots.

The mechanized harvest of soybean used a Massey Ferguson harvester, model MF 5650 Advanced, year 2010, with approximately 700 h of operation. The harvester has 6-cylinder AGCO Sisu Power engine, with nominal power of 130 kW (175 hp), equipped with 5.0-m-wide cutting platform; tangential threshing system; separation by straw walkers and grain tank with capacity for 5500 L.

The statistical design was completely randomized, based on the assumptions of the statistical process control, and the soybean seed samples were collected at 20-min intervals during 3 h of operation, totaling 9 samples of soybean seeds for each harvester speed in this time interval. In the same area, three speeds of the harvester were evaluated: 4.5, 5.0 and 5.5 km h^{-1}. Harvest started and ended as follows: 8 h and 30 min - 11 h and 30 min, 14 - 17 h and 8 - 11 h for the speeds of 4.5, 5.0 and 5.5 km h^{-1}, respectively.

The evaluations were performed based on the following parameters: seed temperature, seed water content, concave opening, cylinder rotation, mechanical damages and electrical conductivity of the seeds. The concave opening and cylinder rotation were determined through data collected by sensors, quantified on the digital monitor of the front column, located inside the cabin of the harvester, and written down on a paper by a person in charge, along the entire evaluation period.

The samples of soybean seed were collected at the outlet of the endless screw elevator that supplies the grain tank, packed in plastic bags and then subjected to the determination of water content and temperature of the seeds, using a portable meter (Model G600). Three readings were taken using the meter, in the same selected sample, to obtain mean values of water content and temperature of the seeds.

After water content determination, the seeds were transferred to multiwall paper bags and taken to the laboratory for the quantification of qualitative losses. The seed samples were classified by size using those retained in the 5.5 and 6.0-mm-mesh sieves and, for some tests, the seeds were treated with carbendazim + thiram (2 mL kg^{-1} of seeds). Then, the seeds were subjected to the analyses of mechanical damage through the test of sodium hypochlorite (Krzyzanowski et al., 2004), performed with four replicates of 50 seeds per sample, which were immersed in 0.13% sodium hypochlorite solution and maintained for 10 min. After this period, the seeds were dried in paper towel and evaluated, counting the number of soaked seeds, with results expressed in percentage.

The analysis of electrical conductivity used four replicates of 50 seeds per sample, weighed on analytical scale with resolution of 0.01 g and immersed in 75 mL of deionized water in plastic cups (200 mL). The seeds were maintained at constant temperature of 25 ºC for 24 h in BOD germination chambers. After this period, the electrical conductivity of the seed soaking solution was determined using a conductivity meter (MCA 150) and the results were expressed in μS cm^{-1} g^{-1} (Marcos Filho & Vieira, 2009).

The results were statistically analyzed by the program Minitab® 16, through the statistical control using, as tools, the control charts for variables, and the previously described variables were used as quality indicators.

The model of control chart used in the evaluation was "Individual", which contains a sequential graph corresponding to the individual values sampled point by point. The control limits were established considering the variation of the results due to uncontrolled causes in the process (special causes), calculated based on the standard deviation of the variables. When the calculation of the lower control limit resulted in negative values, it was considered with null value (LCL =

0), because, for the studied variables, negative values do not represent any physical meaning.

The occurrence of special causes was tested using the "Automotive Industry Action Group (AIAG)" test, considering in the execution of the test only Type I error, which considers, as out of the control limits, any point higher or lower than the mean, plus or minus three times the standard deviation.

When one observation has failure in the test for special causes, the point is highlighted in the control chart, indicating non-random variation in the results that must be investigated. In this case, the process is called "unstable" or "out of control". If no point is highlighted in the control chart, it is considered that there are no special causes of variation and, consequently, the process will be considered as "stable" or "under statistical control". Voltarelli et al. (2015) report that, regardless of the assumption of data normality, the use of control charts of individual values is adequate for the monitoring and analysis of the process, provided that the analyst has deep knowledge on the analyzed quality indicators.

Results and Discussion

Seed temperature is associated with the period in which soybean harvest was performed, which is the reason why this quality indicator exhibited unstable behavior for the first two speeds during the operation. Only the speed of 5.5 km h^{-1} is within the lower and upper control limits, showing stable behavior and the lowest variability of data, in which most are found around the mean (Figure 1).

For the speed of 4.5 km h^{-1}, harvest was performed at the beginning of the day and ended at noon; thus, the temperature increased along the process. It is noted that the highest temperatures were observed in the harvest at speed of 5.0 km h^{-1}. This is related to the harvest, which started in the after noon and ended at the end of the day. This fact explains the lower temperatures found at the end of the harvest for this speed.

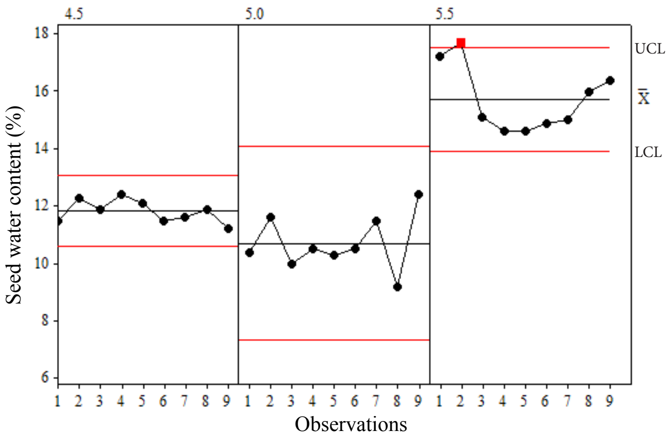
The speed of 5.5 km h^{-1} showed stability of the process because harvest was performed in the morning, i.e., the temperature was mild, in relation to the treatment of 5.0 km h^{-1}. Reis (2013) observed that there is alteration in the level of damage to the seeds during the mechanized harvest of soybean under the influence of seed temperature, which is also associated with the water content in the grain. The higher the temperature of the seeds, the higher the probability of occurring mechanical damages to the seeds, either in the mechanism of cut and supply or in the threshing system.

Figure 2 shows the water content of soybean seeds, which exhibited a stable behavior for the first two speeds during the harvest (4.5 and 5.0 km h^{-1}), being within the lower and upper limits. However, the speed of 5.5 km h^{-1} indicated instability of the process, in which only one point exceeded the limits. This event was observed because of the occurrence of rainfall in the night before the harvest at this speed, which caused increase in the water content.

For soybean seeds, it is recommended to harvest the grains with water content between 12 and 15% (EMBRAPA, 2006), because in this range there is lower occurrence of mechanical injuries and damages by moisture, as observed in the present study for the speeds of 4 and 5 km h^{-1}.

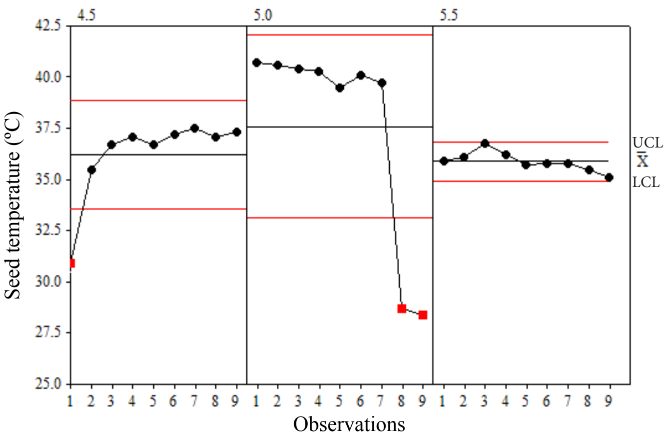
The mechanized harvest of soybean for seed production can be performed with higher water content (18%), provided that the producer adequately regulates the threshing systems and has sufficient structure for artificial drying (França Neto et al., 2007). Hence, all water contents found in the present study are within the acceptable limit.

Cylinder rotation showed stable behavior for all speeds evaluated (Figure 3).



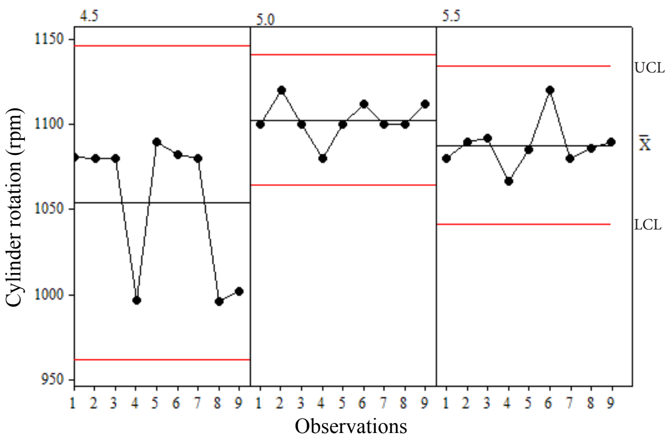
UCL - Upper control limit; LCL - Lower control limit; $\bar{X}$ - Overall mean

Figure 2. Control charts for seed water content during the mechanized harvest of soybean at different speeds



UCL - Upper control limit; LCL - Lower control limit; $\bar{X}$ - Overall mean

Figure 1. Control charts for seed temperatures during the mechanized harvest soybean at different speeds



UCL - Upper control limit; LCL - Lower control limit; $\bar{X}$ - Overall mean

Figure 3. Control charts for cylinder rotation during the mechanized harvest of soybean at different speeds

Higher cylinder rotations were adopted at the speed of 5.5 km h^{-1}, because, with the increment of speed, greater amount of material is harvested in the harvester and, therefore, an increment in cylinder rotation was required.

The water content of the seeds also directly influences cylinder rotation. According to Ruffato et al. (2001), the drier the grain, the lower the elasticity, making it vulnerable to damages by the action of the cylinder. This fact was observed in the present study, in which at the speed of 5.5 km h^{-1} the seeds showed higher water content and, consequently, higher speed of the threshing cylinder.

For the mechanical damages, there was a stable behavior at all speeds and all points were within the lower and upper control limits (Figure 4). On the other hand, higher values of mechanical damage were observed at the speeds of 4.5 and 5.0 km h^{-1}, at which the seeds showed lower water content (Figure 2). Hence, the highest value of mechanical damage of the seed during the harvest occurred at the lowest water content of the seeds, which can be explained by the lower flexibility of the tegument at the moment of the impact by the threshing rotor associated with the concave.

Costa et al. (1979), evaluating the effect of mechanical harvest on soybean seed quality, observed that the mechanical damage was significantly higher when the soybean seed showed moisture levels lower than 11.5%, in comparison to the harvest of seeds with moisture levels of 11.5 to 14%, as observed in the present study, in which there were some points with water contents lower than 11.5% at the speed of 5.0 km h^{-1}.

There was a reduction in the level of mechanical damages with the increment in travel speed from 5.0 and 5.5 km h^{-1}. This fact can be related to the greater filling of the space between cylinder and concave with straw, because the increment in travel speed increases the supply rate, decreasing the direct impact of seeds on the metal parts of the threshing system. This increment of mechanical damage could influence the germination rate, making unviable the use of the grain as seed, as well as decrease the time of storage due to injuries in the tegument.

According to Moore (1974), these injuries can not be totally avoided, but their extension and severity can be attenuated by the handling during the harvest and pre-harvest operation. Each mechanical damage that affects the seed, however small it is, is cumulative and is an integral part of the total damage to the seed, being able to reduce its germination power, initial vigor and yields in the total production (Jijon & Barros, 1983).

For the control charts of electrical conductivity, which represent seed vigor, there was a stable behavior for all evaluated speeds, being within the lower and upper control limits (Figure 5).

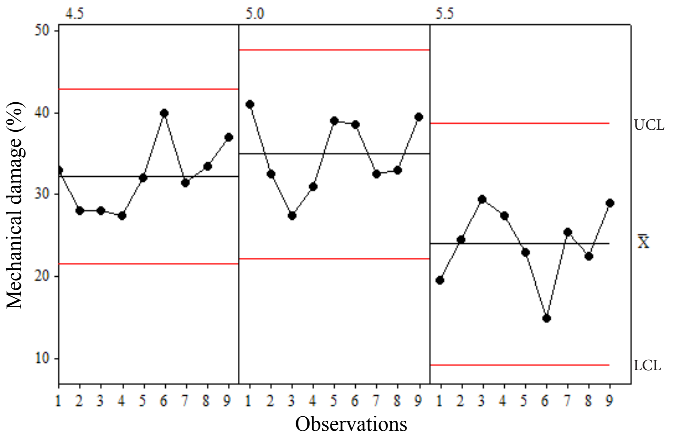
According to Vieira & Carvalho (1994), the electrical conductivity, for being a parameter to indicate the integrity of the seeds, is affected when they suffer any type of injury. It is noted that, for the speed of 5.5 km h^{-1}, a lower electrical conductivity was observed; consequently, higher vigor in the seeds. In contrast, at the other evaluated speeds (4.5 and 5.0 km h^{-1}), the electrical conductivity was higher; thus, lower vigor in the seeds.

Andrade et al. (1999), evaluating the electrical conductivity of soybean seeds, concluded that, with the increase in the level of mechanical damages, there is an increment of its values. As in the present study, the lowest value of electrical conductivity of the soaking solution of soybean seeds was obtained with the lowest mechanical damage at the speed of 5.5 km h^{-1}.

The concave opening showed unstable behavior during the operation, for the three speeds evaluated, with all points outside the lower and upper control limits (Figure 6). This situation can be explained by the fact that the calculated limits have values very close to each other, indicating the lowest variability during the harvest.

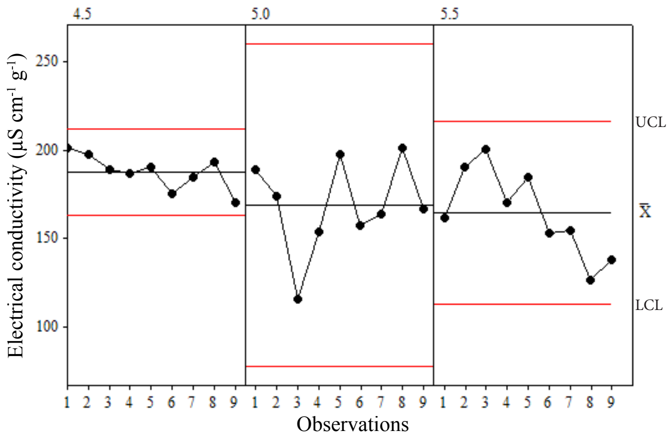
The regulation of the concave opening is directly linked to the water content of the seeds, and values of 29 or 39 mm were established by decision of the operator together with the producing unit, depending on the water content of the seeds.

Based on the water contents at speeds of 4.5 and 5.5 km h^{-1}, the seeds showed higher water contents at the beginning of the harvest (Figure 4). Thus, the concave opening remained in the highest regulation (39 mm), because all the harvested material (plant, pod and seeds) was wetter, different from the regulation of the concave at the beginning of the afternoon (5.0 km h^{-1}, around 14 h), when the material showed lower moisture content (28 mm).



UCL - Upper control limit; LCL - Lower control limit; $\bar{X}$ - Overall mean

Figure 4. Control charts for mechanical damage during the mechanized harvest of soybean at different speeds



UCL- Upper control limit; LCL - Lower control limit; $\bar{X}$ - Overall mean

Figure 5. Control charts for electrical conductivity during the mechanized harvest of soybean at different speeds

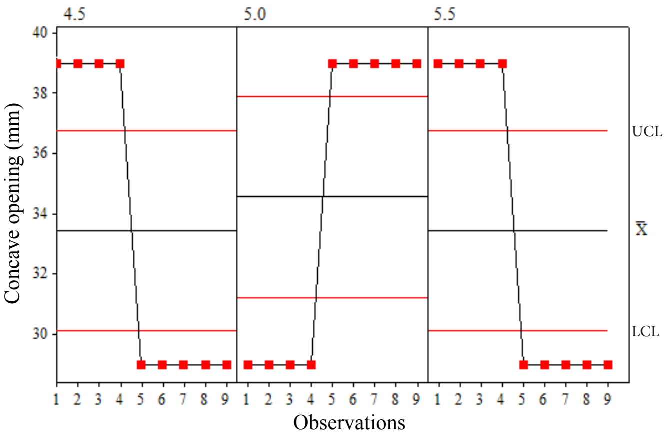


Figure 6. Control charts for concave opening during the mechanized harvest of soybean at different speeds

Conclusions

1. Seed physical and physiological quality was influenced by the displacement speed of the machine.

2. The highest speed (5.5 km h^{-1}) led to lower values of mechanical damage and higher vigor of soybean seeds.

3. Cylinder rotation and concave opening showed stable and unstable processes, respectively, influenced by the speed of the harvester.

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